IP1

Approximation of Transport Processes Using Eulerian-Lagrangian Techniques

Transport processes are common in geoscience applications, and find their way into models of, e.g., the atmosphere, oceans, shallow water, subsurface, seismic inversion, and deep earth. Our objective is to simulate transport processes over very long time periods, as needed in, e.g., the simulation of geologic carbon sequestration. A good numerical method would be locally mass conservative, produce no or minimal over/under-shoots, produce minimal numerical diffusion, and require no CFL time-step limit for stability. The latter would allow better use of parallel computers, since time-stepping is essentially a serial process. Moreover, it would be good for the methods to be of high order accuracy. Our approach is to develop locally conservative Eulerian-Lagrangian (or semi-Lagrangian) methods combined with ideas from Eulerian WENO schemes, since they have the potential to attain the desired properties.

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IP2

The Spatiotemporal Dynamics of Waterborne Diseases

Dynamics of waterborne diseases in space and time is studied via multi-layer network models, consisting of coupled ODEs. They account for the interplay between epidemiological dynamics, hydrological transport and long-distance dissemination of pathogens due to human mobility, described by gravity models. Conditions for the outbreak of an epidemic are given in terms of the dominant eigenvalue of an appropriate reproduction matrix, while the initial disease distribution is linked to the dominant eigenvector. The theory is tested against epidemiological data of the extensive cholera outbreaks occurred in KwaZulu-Natal (South Africa) during 2000-2001 and in Haiti during 2010-2012.

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IP3

Career Award Lecture: Some Successes and Challenges in Coastal Ocean Modeling

The coastal ocean is rich with physical and biological processes, often occurring at vastly different scales. In this talk, we will outline some of these processes and their mathematical description. We will then discuss the current state of numerical methods for coastal ocean modeling and recent research into improvements to these models, focusing on accuracy and efficiency for high performance computing. We will also highlight some of the successes of these models in simulating complex events, such as hurricane storm surges. Finally, we will outline several interesting challenges which are ripe for future research.

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IP4

Junior Scientist Award Lecture: Interpreting Geological Observations Through the Analysis of Nonlinear Waves

Geological and environmental systems are rich in examples of self-organization and pattern formation. These patterns contain information about processes as diverse as seawater intrusion into coastal aquifers, the long-term safety of geological CO2 storage, and the formation of the oceanic crust. I will discuss how important observations in these three areas can be explained by non-linear waves. This illustrates the potential of the mathematical analysis of non-linear waves to contribute to our understanding of fundamental geological phenomena and applied environmental problems.

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IP5

An Unstructured Grid Model Suitable for Flooding Studies with Applications to Mega-tsunamis

Mega-thrust earthquakes and tsunamis cause untold destruction. In this talk a new finite volume unstructured grid tsunami model is presented. The model is a finite volume analogue of the P1nc-P1 finite element, in which mass conservation is guaranteed not only in a global sense, but within each cell. The model conserves momentum, and accurately handles flooding and drying problems. Results from the Indian Ocean and Japanese Tsunami compare well with flooding and run-up data.

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IP6

Data Assimilation in Global Mantle Flow Models:Theory, Modelling and Uncertainties to Reconstruct Earth Structure Back in Time

The ability to extract the history of motion associated with large-scale geologic structures that are now imaged seismically in the Earth's interior, such as plumes and subducting slabs, is crucial to constrain the fundamental deformation processes of mantle convection. Here we show how fluid dynamic inverse theory, based on a variational approach, can be applied in a global circulation model of the mantle to project Earth structure back in time. We present the basic theory of the forward and inverse problem, review geologic constraints, provide computational considerations relevant to the global flow problem with about 1 billion finite elements, and discuss uncertainties. The latter restrict the problem in practice, as our knowledge of deep Earth structure and its interpretation in terms of dynamically relevant buoyancy anomalies is necessarily limited.

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IP7

Data Assimilation and Inverse Modeling in Earth System Sciences

Physical theories in the Earth System sciences are designed to explain and possibly predict natural phenomena. Both, the explanation and prediction necessarily include a quantitative representation of the natural system state. Quantitative assessment of the actual, true, state is fundamentally achievable only by measurements. The theories and models based on them are consequently designed to explain and predict the measurements. A synergy of the models and measurements is necessary for achieving such goal. Methodology of data assimilation and inverse modeling provides objective means for that purpose. An overview of the currently used methodology will be presented, including examples of application in atmospheric sciences in domain of cloud analysis and modeling and tropical cyclone modeling and prediction.

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IP8

Efficient Numerical Numerical Computation of Multi-Phase Flow in Porous Media

Appropriate models, accurate discretization schemes and efficient solvers for the arising linear systems are the basis for any numerical simulation. In this talk I will address these aspects by first considering a model for compositional two-phase flow with equilibrium phase exchange that is able to handle phase appearance/disapperance properly. Then a new fully-coupled discontinuous Galerkin scheme for two-phase flow with heterogeneous capillary pressure will be presented. The third part of the talk is devoted to the efficient solution of the arising linear systems by means of algebraic multigrid methods. All numerical schemes have been implemented in the Distributed and Unified Numerics Environment and have been scaled up to 300000 cores. This is joint work with Olaf Ippisch and Rebecca Neumann.

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CP1

A Mixed and Galerkin Finite Element Formulation for Coupled Poroelasticity

The numerical treatment of coupled poroelasticity is a demanding task because of the instabilities affecting the pore pressure solution. A combination of Mixed and Galerkin Finite Element methods is employed to obtain stable numerical solutions at the interface between different materials. A comparison of the performance of monolithic and sequential schemes in solving the algebraic systems arising from the balance equations is presented. Some results relative to real field large scale simulations are finally discussed.

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CP1

Coupled Geomechanics and Flow for Unstructured Naturally Fractured Reservoir Models

We consider unstructured reservoir models composed of a deformable saturated matrix and a network of natural fractures. A finite-volume method is used for the flow. Galerkin finite elements are used to discretize the poro-elasto-plasticity equations. We account for normal and shear stresses on the fracture surfaces. The corresponding nonlinear coupled equations are solved using either the sequential-implicit fixed-stress approach, or the fully-implicit method. The framework is demonstrated using several test cases with discrete fracture models.

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CP1

Mechanics of Fluid Injection into Deformable Porous Materials

Poroelasticity, where the mechanical deformation of a porous solid is coupled to internal fluid flow, has been studied intensely in geophysics in the context of pressure buildup during fluid injection, such as in carbon sequestration or enhanced oil recovery. Here, we develop a novel experimental system that allows us to visualize and quantify the dynamic, flow-driven deformation of a quasi-two-dimensional poroelastic material. We use it to study the coupling between fluid injection and mechanical deformation patterns.

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CP1

A Finite Volume Method for the Solution of Fluid Flows Coupled with the Geomechanics of Compacting Porous Media

A numerical approach in which a coupled geomechanical/fluid flow problem in porous media is solved in a single grid using a Finite Volume Method is advanced. The possibility of using a unique grid and the same conservative method for both problems renders to the scheme robustness and generality. Details of the coupling strategy are also addressed. The novel developments offer an interesting route for solving coupled problems in a unified approach using full conservative schemes.

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CP1

Solution Strategies for Coupled Geomechanical and Flow Problems Recent Experiences

Many geoscience problems involve coupled THM (thermal-hydrodynamic-mechanical) processes. The strength of coupling has varying degrees, ranging from problems that can be solved sequentially to those requiring full nonlinear coupling. The selection of the method and the degree of coupling are highly problem-dependent. The best strategy for THM processes depends critically on the physics of the problem. We will give a survey of the methods (used in coupled reservoir geomechanics) and discuss examples of our experience with their stability and implementation.

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CP1

A Fully Coupled Multiphase Flow and Geomechanics Solver for Highly Heterogeneous Porous Media

This paper introduces a fully coupled multiphase flow and geomechanics solver that can be applied to modeling highly heterogeneous porous media. In this work, we developed a coupled multiphase flow and geomechanics solver that solves fully coupled governing equations, namely pressure, velocity, saturation, and displacement equations. The solver can deal with full tensor permeability and elastic moduli for modeling a highly heterogeneous reservoir system.

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CP2

A Domain Decomposition-Based Parallel Software for Data Assimilation in the Mediterranean Sea

OceanVar is a data assimilation (DA) software which is being used in Italy within the Mediterranean Forecasting System (MFS) to combine observational data (SLA, SST, Argo-floats profiles) with backgrounds produced by computational models of ocean currents of the Mediterranean Sea (namely, the NEMO framework). OceanVAR implements a three-dimensional variational scheme. We discuss the design of a fully parallel version of OceanVar, based on domain decomposition approach, which is able to face to the ever greater multi-level parallelism and scalability of the current and the next generation of leadership computing facility systems (multi processors, many core and GPUs), while fulfilling the specific requirements of OceanVar within the MFS.

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CP2

Scalable Reservoir Simulation on Massively Parallel Computers

We investigate parallel performance for reservoir simulation on multiple massively parallel computing architectures. A deliberate strategy of performance-based development of the major types of computations encountered in reservoir simulation programs is employed. Even though most operations are memory-bandwidth bound, it is possible with careful implementation, to get excellent parallel efficiency to several 1000s of cores. We discuss numerical issues, scalability and parallel efficiency of reservoir simulator on several very large and geologically challenging examples.

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CP2

Scalable Multi-Level Preconditioning Techniques for Variable Viscosity Stokes Flow Problems Arising from Geodynamic Applications

Over long million year time scales, many geological processes can be described as incompressible, variable viscosity Stokes flow. Such descriptions of rock deformation are challenging to handle as the viscosity structure is inherently heterogeneous and may possess both continuous and discontinuous local variations on the order of 10^9. Here we explore the performance of a parallel matrix-free geometric multi-grid preconditioner combined with several exotic coarse grid solvers to study high resolution 3D geodynamic processes.

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CP2

Sam$(oa)^2$, a Parallel Cache-Efficient Simulation Environment

We present an integrated approach for parallel adaptive grid refinement and respective solution of PDEs. Using a stack-and-stream system and an element order defined by the Sierpinski space filling-curve to store and process the grid and simulation data, we obtain an inherently memory- and cache-efficient simulation algorithm. The locality properties introduced by the Sierpinski curve are retained even throughout adaptive refinement and coarsening of the grid, and are exploited for efficient parallelisation and load balancing. We will focus on parallelisation and discuss a run-length encoding to deal with the data exchange on the shared inter-process edges. These data include the numerical unknowns, refinement flags on the edges, and load balancing information. We present two test case scenarios: A Discontinuous Galerkin solver for the Shallow Water Equations and a coupled problem for porous media flow using FEM for the pressure equation and finite volumes for the advection term.

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CP2

A Parallel Server for Adaptive Geoinformation

In this talk we present ASAGI, a library that provides a simple and efficient interface to large input data sets with multiple resolutions in a high performance computing context. The key feature of ASAGI is to decouple the data management from the actual simulation by introducing caching strategies on node level. Thus, for dynamically adaptive simulations with parallel partitions that may change their spatial position and extent, ASAGI provides the parameter information (material properties, topography or bathymetry data, etc.) required for adaptive refinement and coarsening.

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CP3

Some Strategies of Linear and Nonlinear Preconditioning for Reactive Transport Model

We investigate block preconditioning for accelerating a Newton-Krylov method applied to a reactive transport model. Work by Kern and Taakili (2011) for a single species with sorption is extended to the multi-species case, with complex chemistry. The block structure of the model is exploited both at the nonlinear level, by eliminating one unknown, and at the linear level by using block Gauss-Seidel preconditioning. A link is made between physics based preconditioning and the algebraic methods.

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CP3

High Performance Computing Using Local Time-Stepping Methods for Elastodynamics

The simulation of seismic wave propagation in heterogeneous media requires local mesh refinements that prevent the use of finite difference schemes widely used in the oil industry. In this talk, we will present a mesh refinement strategy combining local time stepping and a discontinuous Galerkin discretization using quad elements enabling the use of embedded Cartesian grids. We will also discuss how this regular structure can be exploited in a parallel implementation to tackle large 3D examples.

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CP3

Geosounding Inversion with Bregman Iterative Methods

In this contribution, several novel algorithms for nonlinear inversion of electrical, electromagnetic and resistivity soundings based on Bregman iterations are presented. Results are reported of algorithm implementation for several geosounding methods applying Bregman distance to minimize the TV functional. Implemented algorithms consist of a Taylor linearization for the forward functional, Bregman distance applied to the regularization functional and stop criteria. The resulting algorithms are easy to implement and do not require any optimization package. Positivity constrained version of the algorithms are also presented by applying projected Barzilai-Borwein method with box-constrains. A comparison of developed models for Bregman based algorithms with those obtained with a linear programming package is also presented for synthetic and field data.

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CP3

Algebraic Multigrid Preconditioner for Numerical Finite-Element Solutions of Electromagnetic Induction Problems

We present a parallel nodal finite-element solver for the three-dimensional electromagnetic modelling in anisotropic media. The method can be used for modelling different controlled-source and magnetotelluric problems. To improve efficiency of the method, we have developed an algebraic multigrid preconditioner for Krylov subspace solvers. Tests for various problems show that, compared to other preconditioners, our preconditioner improves the convergence of different solvers and reduces the execution time by up to an order of magnitude.

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CP3

Unconditionally Stable Transport Solvers for Two Phases Flow with Polymer.

We present a nonlinear Gauss-Seidel algorithm for solving implicitly discretized saturation equations. NGS relies on the well-posedness of single-cell problems (residual equation for one cell with all other saturations known). Unconditional stability of the single-cell problem guarantees that a global solution exists for any time step. We give necessary and sufficient conditions on discretized flux for unconditional stability of the single-cell problem and present such flux discretizations for two-phase flow with polymer and gravitation splitting.

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CP3

Precisely, How Fast Is Your Fully Implicit Newton-Like Solver?

This work characterizes the convergence rate of Newton-like methods that are applied to solve nonlinear residual systems arising in implicit numerical simulations. The analysis exploits the Asymptotic Mesh Independence Principle relating the convergence rate of discrete Newton methods to their infinite-dimensional counterparts. By characterizing the precise evolution of the nonzero spatiotemporal support of the infinite-dimensional iterations, the analysis reveals the asymptotic scaling relations between nonlinear convergence rate and time-step and mesh sizes.

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CP4

A Computational Method for Simulating Immiscible Incompressible Three Phase Flow Model in Heterogeneous Porous Media

We describe a computational method for simulating three-phase immiscible incompressible flow problem in inhomogeneous media taking the form of a nonlinear transport system with spatially varying flux functions under combined convective, capillary and gravity effects. Our new method is an operator splitting procedure for decoupling the nonlinear three-phase flow system with mixed and conservative discretization methods leading to purely hyperbolic, parabolic and elliptic subproblems. Preliminary numerical experiments will be also presented and discussed.

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CP4

Co2 Storage Simulations Using Low Complex Model Geometries

Complex 3D models are a potential way to precisely describe the heteroeneous flow paths in a reservoir, but the uncertainties of material parameters are quite large. Due to long simulation times, 3D approaches only allow a small number of realizations. Thus, we perform Monte-Carlo simulations using simplified model grids of lower complexity to describe the fate of CO2 at the Ketzin test site located in Germany.

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CP4

A Conservative Numerical Methodology for Multiphase Flow in Heterogenous Porous Media Allowing Changes in Porosity

In this work we present a conservative numerical methodology for simulating multiphase-flow in highly heterogenous porous media, which allows changes of the porosity field in time and space. This methodology combines stabilized mixed-hybrid finite elements for the flow subsystem (velocity and pressure) with a semi-discrete central scheme for the transport problem, based on a generalization of the Kurganov and Tadmor (KT) scheme. This methodology is proposed to be used as a block for coupling multiphase flows with geomechanics.

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CP4

Using Coupled Implicit and P-Adaptive Discontinuous Galerkin Method to Model Miscible Displacement with Adverse Mobility Ratio

Many EOR or stimulation processes require an accurate estimation of the distribution of the injected fluid. Traditional reservoir simulators based on low order finite volume method suffers grid orientation effects when modeling miscible displacement with adverse mobility ratio. In this talk, we propose a fully coupled and implicit discontinuous Galerkin (DG) formulation which can accurately compute the flux direction and effectively remove the grid orientation effects. P-adaptive DG scheme will also be proposed so that high order DG is used only at locations where high gradients of concentration are present. Numerical results show that the time spent for p-adaptive scheme is comparable to the low order methods.

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CP4

Co2 Vertical Migration Through a Piecewise Homogeneous Porous Medium

We consider the migration of a CO2 plume through a vertical column filled with a piecewise homogeneous porous medium. The impact of capillary pressure and flux continuities at the interface on the CO2 migration is studied numerically and mathematically. We analyze how saturations and saturation gradients on either side of the interface evolve with time and if a local steady state is reached. Different cases are considered : capillary dominant, gravity dominant and intermediate case. The influence of this micro-scale dynamics on upscaled migration is discussed.

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CP4

Reservoir Modelling Based on Transmissibility Upscaling

Prediction of reservoir performances requires coarse models coherent with fine scale geology. In Eni methodology effective coarse transmissibility (T*) is used in place of permeability. This is motivated by the results achieved whenever T* has been implemented on field models where geological and simulation grids are aligned. The issue is to deal with geometries where coarse and fine grids are misaligned. In this work real field applications will show T* benefit on aligned 3D grids, while the effectiveness on misaligned is proved on 2D synthetic cases.

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CP5

On the Impact of Anisotropic Mesh Adaptation on Solute Transport Modeling in Porous Media

We propose an anisotropic mesh adaptation technique for modeling solute transport in porous media. The method relies on a recovery-based error estimator and is coupled with a finite element code solving the Advection Dispersion Equation. The proposed methodology is assessed against experimental breakthrough curves collected in homogeneous and heterogeneous media. We compare results obtained by adapting the mesh according to various indicators. We analyze the impact of mesh adaptation on optimal parameter estimation for the experiments considered.

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CP5

Simulating Non-Dilute Transport in Porous Media Using a Tcat-Based Model

Predicting the transport of non-dilute species in fluids of variable density in porous media is a challenging problem for which existing models are unable to represent accurately the experimental data collected to date. We consider the displacement of an aqueous phase with dense brine solutions. Displacement experiments were conducted in vertically oriented 1D columns. Simulation of a non-dilute system based upon the thermodynamically constrained averaging theory (TCAT) using an entity-based momentum equation was compared to data. The model accounts for the effects of non-dilute, non-ideal systems and consists of a nonlinear set of equations including a flow equation, a species transport equation, and closure relations. We rewrite the entity-based model as a system of two coupled partial differential-algebraic equations with relevant closure relations. We use a stiff temporal integrator to create 1D simulations of the model. We will discuss both results and numerical difficulties.

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CP5

Structure of Reaction Fronts in Porous Media

Multicomponent reactive flow and transport in permeable media gives rise to reaction fronts with complex morphology. The first-order structure of these patterns can be analyzed in the hyperbolic limit of the governing equations. Comparisons between analytic solutions, numerical simulations and field as well as experimental data for ion-exchange reactions shows good agreement. New theoretical results for reactive transport with pH-dependent surface complexation reactions show a more complex morphology of the reaction front and provide the first semi-analytic benchmarks for numerical simulations of this phenomenon.

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CP5

A Comparison of Closures for Stochastic Transport

Perturbation-based moment equations for randomly advected solute produce unrealistic multimodality, contrary to macrodispersion theory despite strong similarities between the two. A study of basic macrodispersion approximations reveals higher-order terms that are effectively added to conventional moment-equation approximations at second and fourth order. We propose a closed-form approximation to two-point (auto)covariance in a manner consistent with macrodispersion theory and illustrate its improvement upon moment-equation approximations for an example of transport in stratified random media.

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CP5

Large - Time Behavior of the Solution for Nonlinear Random Boussinesq - Glover Equation Driven by Colored Noise

We study the nonlinear random Boussinesq Glover equation in Banach spaces, driven by a colored noise and with random initial condition. The noise process is defined as stationary solution of a stochastic differential equation in finite dimensional (or Hilbert) spaces. Under suitable assumptions, we prove the existence of stationary solution and the path wise global attractor. The attractor is P a. s. independent of probabilitary variable. Similar results arise in nonlinear random reaction diffusion equations.

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CP5

Multilevel Monte Carlo (MLMC) for Two Phase

Flow and Transport in Random Heterogeneous Porous Media

Monte Carlo (MC) is an established method for quantifying uncertainty arising in subsurface flow problems. Extending MC by means of multigrid techniques yields the MLMC method. In this study, MLMC is applied to assess uncertain two phase flow and transport in random heterogeneous porous media. It was found that the computational costs of MLMC are substantially lower compared to MC.

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CP6

From Nonlinear Adsorption at Microscale to Nonlinear Diffusion at Macroscale.

We have considered the coupled convection-diffusion equations for the bulk and surface concentrations at the microscale of a periodic porous medium. The coupling is through a reaction term expressing nonlinear adsorption phenomena at the solid-fluid interface. Two-scale asymptotic expansion with drift helps to pass from microscale to macroscale description. Upscaled equation is a nonlinear diffusion equation. Numerical simulations are done to approximate the solution for the microscale problem using correctors.

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CP6

A Multi-Scale Numerical Simulation of Carbonate Rocks Properties Using 3D Micro-Tomography Images

We have estimated the porosity, the permeability and the elastic moduli of fifteen samples from a carbonate reservoir using numerical simulations on 3D micro-tomography images. Core plugs were scanned at a coarse scale and a few millimeters subsets were extracted and digitalized at a finer scale to take into account rock heterogeneity. The comparison between simulated and experimental laboratory properties showed a relative good agreement. Advantages and limitations of the proposed methodology will be discussed.

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CP6

A Multi-Scale Method to Include Analytical Solutions for Multi-Phase Leakage Through Faults in a Numerical Model

A computationally efficient approach to multi-phase flow modeling of geologic basins containing faults is developed based on embedding analytical solutions within coarse-scale numerical models. The analytical solutions are used to determine the fluxes in and around the fault and the pressure corrections that relate pressure at a given fault to the coarse-scale pressure in the numerical grid blocks. This method accounts for both vertical and lateral flow within the fault.

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CP6

A Multiscale Finite Element Method for Transport Modeling

Simulating flows in porous media often requires the resolution of convection-diffusion problems where diffusion coefficient and velocity exhibit strong variations at a much smaller scale than the domain of resolution. This work proposes a new multiscale finite element method to first solve this kind of problems on coarse grids and then reconstruct the variations of the solution on a finer grid. An a priori error estimate is established and numerical results are presented.

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CP6

A Multi-Scale Approach to Assessing the Hydro-

logical Connectivity of Road and Stream Networks

We study a forested, upland landscape in northeastern USA to understand the downstream effects of roads on streams. Previously, only simple metrics have characterized road-stream connectivity; few studies have examined scale or quantified effects on channel morphology. Using newly-derived proximity and orientation metrics, statistical analyses show proximity to be successful at distinguishing among categories of stream geomorphic condition at the reach scale. These proximity metrics are even more revealing when reanalyzed at the tributary scale.

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CP6

Adaptative Multi-Scale Parameterization in Fractured Porous Media

Flow in fractured porous media is very complex. An inverse model using a double porosity approach is developed solving the direct problem with a Quasi-Newton algorithm coupled with the adjoint-state method to calculate the objective function gradient (OFG). The inverse problem is solved on a reduced number of parameters using an Adaptative Multi-scale Parameterization with successive mesh refinement depending on the OFG value. The model is validated on the Hydrogeological Experimental Site of Poitiers.

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CP7

Applications of Level Set Methods in Numerical Modelling of Flow and Transport Problems

An introductory overview of level set methods and their applicability to solve flow and transport problems with interfaces will be given. Finite volume discretization of all involved partial differential equations will be described that is very natural for modelling the flow and transport processes in porous media. Some particular examples will be presented that shall illustrate a potential of level set methods in general. P. F.: *Application of level set method for groundwater flow with moving boundary.* Adv. Wat. Res., 47:56–66, 2012.

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CP7

A Locally Conservative Eulerian-Lagrangian Finite Volume Weno Scheme for Hyperbolic Conservation

The object of this talk is to define a locally conservative Eulerian-Lagrangian finite volume scheme with the weighted essentially non-oscillatory property (EL-WENO) for hyperbolic conservation law. This locally conservative method has the advantages of both WENO and Eulerian-Lagrangian schemes. It is formally high-order accurate in space (we present the fifth order version) and essentially non-oscillatory. Moreover, it is free of a CFL time step restriction for linear advection equations, with a relaxed CFL time step restriction for nonlinear hyperbolic equations and has small time truncation error. A subcell WENO reconstruction procedure is defined, and this procedure makes it possible for this Eulerian-Lagrangian schemes. Flux corrections are carried out over the approximated characteristic lines using the Runge-Kutta method with natural continuous extension scheme. Numerical results are provided to illustrate the performance of the scheme.

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CP7

A Locking-Free Lowest-Order Discretization of Biot's Consolidation Model on General Meshes

We present an original Euler-Gradient Scheme discretization (i.e. implicit Euler in time and Gradient Scheme in space) of Biot's consolidation model on general meshes. Gradient Schemes are a generic framework which encompasses a large class of nonconforming methods such as the Hybrid Finite Volumes. Under sufficient conditions on the space discretization, and under minimal regularity assumptions on the solution, we prove the convergence of this generic scheme on general meshes. The discretization is also proved to be locking-free, in the sense that a discrete inf-sup condition guarantees the absence of spurious spatial oscillations on the pore pressure in the first time steps in poorly permeable regions.

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CP7

Space-Time Hybridizable Discontinuous Galerkin Methods for Incompressible Flows

I will discuss a new Discontinuous Galerkin (DG) method, namely the Hybridizable DG (HDG) method. We recently extended the HDG method to a space-time formulation allowing efficient and accurate computations on deforming grids/domains. I will introduce the method for the Incompressible Navier-Stokes (INS) equations. A comparison of results and efficiency will then be made between the space-time HDG and DG method for the INS equations on deforming domains.

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CP7

A Cell-Centered Scheme for the Heterogeneous and Anisotropic Diffusion Equations on Distorted Meshes

In this paper, we derive a finite volume scheme for the heterogeneous and anisotropic diffusion equations on general, possibly nonconforming meshes. This scheme has both cell-centered unknowns and vertex unknowns. The vertex unknowns are treated as intermediate ones and are expressed as a linear combination of the neighboring cell-centered unknowns, which reduces the scheme to a completely cell-centered one. The coefficients in the linear combination are known as the weights and two types of new explicit weights are proposed, which allow arbitrary diffusion tensors, and are neither discontinuity dependent nor mesh topology dependent. These new weights can reduce to the one-dimensional harmonic-average weights on the nonuniform rectangular meshes, and moreover, are easily extended to the unstructured polygonal meshes and non-matching meshes. Both the derivation of the nine-point scheme and that of new weights satisfy the linearity preserving criterion which requires that a discretization scheme should be exact on linear solutions. Numerical experiments show that, with these new weights, the resulting new scheme and its simple extension maintain optimal convergence rates for the solution and flux on general polygonal distorted meshes in case that the diffusion tensor is taken to be anisotropic, at times heterogeneous, and/or discontinuous.

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CP8

In Search for a Robust Representation of Cloud Microphysics for Aerosol-Cloud-Aerosol Interactions

Representation of such processes as cloud drops formation on aerosol particles and further processing of the aerosol physicochemical properties by precipitation-forming clouds represents a challenge for classical bulk, multi-moment and bin models of cloud microphysics. Several alternative approaches have been recently proposed such as Lagrangian particle-tracking simulations or multi-dimensional bin approaches. In this study we intercompare these novel schemes using a 2-dimensional prescribed-flow simulations of drizzling marine stratocumulus to systematically analyze the mechanisms by which the physiochemical properties of aerosols change in warm clouds.

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CP8

Asymptotic Modeling of Non-Hydrostatic/Hydrostatic Dynamical Coupling in the Ocean Surface Boundary Layer

A primary challenge in physical oceanography is the systematic representation of non-hydrostatic boundary-layer (BL) turbulence in numerical models and stability analyses of hydrostatic flows. Here, we use asymptotic analysis to derive a multiscale PDE model that captures the coupling between wind-driven Langmuir turbulence and O(10)-km submesoscale flows in the ocean surface BL. Numerical simulations and nonlinear WKBJ analysis confirm that non-hydrostatic/hydrostatic coupling gives rise to a variety of novel upper ocean phenomena.

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CP8

Weather Models of Anomalous Diffusion

The numerical simulation of fractional diffusion equations in three dimensions is considered, to describe fluid flow through porous media. A fractional version of the Alternating Direction Implicit (ADI) scheme is proposed. A strategy improving the speed of convergence by an extrapolation method is also presented. Numerical results are given to support our theoretical analysis.
Keywords: anomalous diffusion; fractional diffusion, fractional partial derivatives; Alternating Direction Implicit (ADI) scheme; extrapolation techniques.

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CP8

Water in the Subducting Oceanic Plate: a Trilogy

In this presentation we summarize the results of a project focused on geological processes related to water in the slab at different stages of subduction. We discuss numerical modeling results of fluid flow during slab hydration and dehydration, potential geophysical implications of an hydrated slab at intermediate-depths and deep subduction of fluids.

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CP8

A Non-Hydrostatic Spectral-Element Model of the Atmosphere

To perform climate simulations at resolutions greater than 1/8th of a degree, the hydrostatic primitive-equations must be replaced with non-hydrostatic Euler equations valid in this regime. To this end, we are working to develop a non-hydrostatic version of CAM-SE, the spectral-element Community Atmosphere Model used at NCAR. We will discuss the design choices made in the new non-hydrostatic dynamical core and present some preliminary results.

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CP9

Perfectly Matched Layers for the Wave Equation in Discontinuous Media

Applications arising in geophysics and electromagnetic problems can be composed of layers of rock, water and possibly oil. The ultimate goal of this project is to investigate the efficiency of the PML in a layered media. We consider a computational set-up consisting of smaller structured domains that are patched together to a global domain, using high order difference operators for approximating spatial derivatives and weak enforcements of interface conditions. Numerical simulations will be presented demonstrating the stability and high order accuracy of our schemes.

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CP9

Numerical Approximation for a Model of Methane Hydrates

We consider a simplied model for evolution of methane hydrates in the hydrate zone, which includes a parameter-dependent maximum solubility constraint represented as a nonlinear complementarity constraint (for solubility). Our model consists of a single PDE and two unknowns (solubility and saturation) which are bound by a parameter dependent family of graphs. We analyze solvability and other properties of the fully discrete scheme for the model, and discuss current extensions.

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CP9

Fast Uncertainty Quantification of Subsurface Flow and Transport with Markovian Velocity Processes

Contaminant transport predictions in large subsurface systems involve high uncertainties due to sparse conductivity measurements. To quantify these uncertainties, we propose a simulation method that is about three orders of magnitude faster than conventional Monte Carlo simulation. The new method is based on parameterized Markov processes for the velocity of fluid particles, which allow for the presence of an arbitrary number of conductivity measurements.

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CP9

A Bioventing Mathematical Model Based on Pure Oxygen Injection

A mathematical model and the simulation of subsoil decontamination by bioventing will be presented. The bases for the model construction are the following: (1) the pollutant is considered as immobile and confined in the unsaturated zone; (2) only oxygen is injected in the subsoil by wells; (3) the bacteria acting the pollutant removal are immobile and their growth depends on oxygen and pollutant concentration.

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CP9

Torsional Wave Dispersion Relation in a Self-Reinforced Layer over a Gravitating Viscoelastic Half Space

The present paper constitute the study of torsional surface wave propagation in a self-reinforced layer resting over a gravitating viscoelastic half space. The layer has an inhomogeneity of linear type associated with the rigidity and density of the medium. Dispersion equation has been obtained in the terms of HypergeometricU and LaugurreL function. The dispersion equation reduces to a classical form as a particular case. The influence of various parameters has been depicted by means of graphs for both reinforced and reinforcement free medium.

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CP10

A Fourier Finite Element Method for the Simulation of 3D Csem Measurements

We present a novel numerical method to simulate 3D geophysical controlled source electromagnetic (CSEM) measurements. The method combines a 2D finite element method (FEM) in two spatial dimensions with a hybrid discretization based on a Fourier-FEM along the third spatial dimension. The method delivers high accuracy simulations of marine CSEM problems with arbitrary 3D geometries while it considerably reduces the computational complexity of traditional 3D simulators, since Fourier basis functions are mutually orthogonal within the background layers.

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CP10

Expected Value Estimators in Nuclear Well-Logging Simulations

Simulation of nuclear well-logging tools and their responses is a long-standing problem, usually solved in the framework of transport theory by Monte-Carlo methods. Widely used conventional Monte Carlo algorithms are often unacceptable, and variance reduction techniques are required. In this talk, the algorithms with expected value estimators are considered. These algorithms showed their efficiency when applied to different types of nuclear well-logging problems. The description and analysis of the results are the subjects of the presentation.

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CP10

Seismic Stratigraphic Modelling Through Comput-

ing in Bengal Basin at Higher Depths

Stratigraphic seismic modelling through software package STICHA between two wells of Bengal Basin at different depths between 2000ft to 4400 ft,the zone of interest for crude oil bearing, has been made and analysis has been made geologically for potential oil-bearing.The Depth models and respective synthetic seismic setion models at different interesting layers have been developed. The results match comfortably .The drilling data agrees with seismic models made.This is economic in oil exploration.

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CP10

Inexact Interior Point Algorithms for Seismic Imaging

An inexact interior-point algorithm is devised and its performance is compared against the exact one on several linear and nonlinear PDE-constrained optimization problems. Schur-complement preconditioners for the resulting KKT systems are constructed and their robustness is investigated for every benchmark problem considered. Application areas include parameter estimation in diffusion problems, super-conductivity and seismic imaging both in the frequency and time domains.

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CP10

Mathematical Techniques for Very Large Scale Tomographic Inversion

We present an approach to find regularized solutions to very large linear systems arising from a tomographic inverse problem that are difficult to handle directly even with large computational resources. We present a system using matrices that reach terabytes in size. We use a multi-step approach to work with such systems, consisting of wavelet compression and randomized low rank SVD approximations. We obtain significant reductions in size and speed-up in computation time.

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CP11

Gradient-Based Techniques for Data Assimilation in Reservoir Simulation

A computational framework that combines a full-featured compositional reservoir simulator with adjoint-based inverse modeling is presented. Automatic differentiation is applied to facilitate construction of the required derivatives. The spatial correlation structure of the geological model is captured using a PCA-based regularization, with the PCA basis determined from geostatistical modeling. A new zonation procedure based on sensitivity magnitude is introduced. History matching results using the new framework are presented for challenging problems.

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CP11

Polymer Injection Optimization Using the Ensemble Kalman Filter

Eni is currently studying the applicability of polymer-based EOR to brown fields. A workflow hinged on the Ensemble Kalman filter (EnKF) has been developed to assimilate production data, evaluate the efficiency of the polymer, quantify process-relevant uncertainties and maximize the economical revenue. In this work, EnKF is used to generate an ensemble of history matched models for a field sector, with careful estimation of the boundary condition. Then, the ensemble logic is used for a robust optimisation of the economic return of the EOR project.

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CP11

Dual States Estimation Using Ensemble Kalman Filtering for Subsurface Flow-Transport Coupled Models

Modeling contaminant evolution in geologic aquifers requires coupling a groundwater flow model with a contaminant transport model. Assuming perfect flow, an ensemble Kalman filter can be directly applied on the transport model but this is very crude assumption as flow models can be subject to many sources of uncertainties. If the flow is not accurately simulated, contaminant predictions will likely be inaccurate even after successive Kalman updates of the contaminant with the data. In this study, we propose a dual strategy for this one way coupled system by treating the flow and the contaminant models separately while intertwining a pair of distinct Kalman filters; one on each model. Preliminary results suggest that on top of simplifying the implementation of the filtering system, the dual approach provide time consistent updating scheme and more stable and accurate solutions than the standard joint approach.

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CP11

Geodetical Data Assimilation with Ensemble Kalman Filter

Geomechanical phenomena are fundamental in explaining the dynamic behaviour of the reservoir: surface displacements measurements can provide additional insight into the nature of the reservoir rock and help constrain the reservoir model. In this study, an integrated workflow for the assimilation of dynamic flow measure data and surface displacements observations has been developed through the Ensemble Kalman Filter approach, in order to estimate reservoir flow and material properties and to identify compartments not yet drained.

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CP11

Impact of Model Order Reduction to Hydrological Data Assimilation.

Sophisticated data assimilation (DA) techniques, e.g. particle filters with MCMC, have been recently developed to address inverse problems. These methods are difficult to apply to high-dimensional models, since they require many system solutions. Reduced order models (RM) reduce the computational burden required to solve transient PDEs. Here we investigate the application of DA schemes with a large number of realizations computed with the RM. Our preliminary results show that DA techniques correct the RM errors.

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CP11

Improved Estimation of the Stochastic Gradient with Quasi-Monte Carlo Methods

Stochastic approximation of the gradient, although not as efficient as adjoints, has recently received significant attention for solution of optimization problems where adjoints are not available or difficult to implement. These methods are generally much easier to implement as they are non-intrusive and treat the simulator as a black box. In this work, we propose the application of quasi-Monte Carlo methods for improving the efficiency and accuracy of the stochastic gradient compared to current methods. While the existing approaches rely on Monte Carlo sampling, quasi-Monte Carlo sampling has a better convergence rate leading to more accurate and efficient gradient approximation. In particular, we apply the Sobol sequence for sampling, which demonstrates better convergence compared to other quasi-Monte Carlo sampling techniques. More than 30% improvement was obtained in the accuracy of the stochastic gradient calculated with Sobol sampling over standard Monte Carlo sampling.

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CP12

Subglacial Water Flow Beneath Ice Streams

Ice streams, characterised by high basal sliding velocities, play a dominant role in ice sheet drainage. Subglacial hydrology is believed to be one of the main controlling factors in their spatial and temporal evolution: how the water drains beneath an ice sheet has important implications for the ice-bed boundary condition. We pose a model to describe subglacial stream flow through the underlying sediment, and consider the coupled behaviour of the ice and meltwater systems.

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CP12

Towards a New Marine Ice-Sheet Model

We present a unified model in order to model an ice flow. The grounded part (ice sheet and ice shelf) leads to a unique lubrication-type model. A new model for the floating ice mass is developed. We consider the ice shelf as a two free surface problem with a lateral sea pressure force at calving front. We obtain an integro-differential evolution equation of the ice shelf thickness.

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CP12

Control Method Inversions for Ice Stream Bed Conditions Using a Higher-Order Glacier Model

Ice streams undergo drag from sliding over their beds, but this stress is not measurable remotely. However, one can use observed ice velocities to invert a glacier model for the

spatially-varying bed friction. In this talk, I will compare the results of inverting two different models from observations at Pine Island Glacier: the shelfy stream equations and the more complex L1L2 equations. These models are depth-averaged perturbations of the 3D Stokes equations.

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CP12

A Conceptual Model for Permafrost-Climate Feedback.

The permafrost methane emission problem is the focus of attention in different climate models. As a result of tundra permafrost thawing, a number of small lakes have formed and extended, and methane has entered the atmosphere. In turn, atmosphere methane can reinforce warming, and there appears to be a positive feedback loop that can lead to a climate catastrophe. Mathematically, permafrost thawing can be described by the classical Stefan approach. From this assumption we obtain a deterministic equation that serves as an extremely simplified model for lake growth. This equation are improved and transformed to a more realistic model for estimation of positive permafrost-climate feedback.

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CP13

Scale-Aware Parametrization of Eddy Transport

Mesoscale eddies are most energetic in the ocean, and are responsible for a significant portion of the tracer transport. Multi-resolution ocean models require eddy parametrization schemes that can scale across a wide range of length scales existing on the grids. This talk present results from a recent project in designing scale-aware eddy parametrization schemes, which includes a scale-aware generalization of the anticipated potential vorticity method, the Gent-McWilliams closure with spatially-varying coefficients, and some ideas for moving forward.

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CP13

Approximate Deconvolution for Large-Eddy Simulation (LES) of the Atmospheric Boundary Layer (ABL) on Adaptive Grids

Simulating the ABL in complex terrain (such as cities) could be faster and more accurate using LES and adaptive grids. However, combining these techniques generates errors. Inaccuracies in subfilter models limit LES solution reliability at the grid scale, contaminating the interpolated solution at grid interfaces. The grid interface also reflects high wavenumber solution components. We test approximate deconvolution to mitigate these errors. Results from a flat boundary layer with one grid refinement interface are presented.

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CP13

Hypothesizing and Testing Causal Relationships in Correlated Time-Series Observations

Biogeochemical archives record time progression of environmental conditions. Co-varying measurements entice cause-effect explanations, but establishing causal relationships requires rigorous epistemology. Correlation is necessary for hypothesizing causation, but insufficient for forming conclusions. Amplitude and phase response over frequency tests cause-effect scenarios: measured cause must precede proportionate effect consistent with direct forcing theory. Signal coherence offers methods for quantifying probabilistic confidence in cause-effect hypotheses. Methods are applied to ice core proxies of temperature and carbon dioxide concentration.

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CP13

Asymptotic Approaches for Rotationally Constrained Flows

Geostrophy, the dominant force balance between the Coriolis and pressure gradient forces, is often the prevailing feature observed in the convective dynamics of atmospheres and oceans and planetary interiors. The presence of fast inertial waves and thin momentum boundary layers pose significant challenges for direct numerical simulations. In this talk, I will demonstrate how multiscale asymptotic methods can be utilized to derive reduced PDEs that overcome these restrictions. Simulations reveal new flow regimes that remain inaccessible DNS of the Navier-Stokes equations.

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CP13

A Stochastic Hydrodynamic Model for Biogenic Mixing

As fish or other bodies move through a fluid, they stir their surroundings. This can be beneficial to some fish, since the plankton they eat depends on a well-stirred medium to feed on nutrients. Bacterial colonies also stir their environment, and this is even more crucial for them since at small scales there is no turbulence to help mixing. It has even been suggested that the total biomass in the ocean makes a significant contribution to large-scale vertical transport, but this is still a contentious issue. We propose a simple model of the stirring action of moving bodies through both inviscid and viscous fluids. In the dilute limit, this model can be solved using Einstein and Taylor's formula for diffusion (Brownian motion). We compare to direct numerical simulations of objects moving through a fluid. This is joint work with Jean-Luc Thiffeault (Wisconsin) and Steve Childress (NYU).

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CP13

A Thermostat Approach to Correction of Kinetic Energy Spectra

Numerical simulations of atmospheric flows typically use artificial viscosity to avoid spectral blocking. This disrupts the vorticity cascade and suppresses the growth of disturbances. We introduce a thermostat to correct the spectrum by adding a small stochastic perturbation to each mode in a spectral truncation. In Burgers' equation this approach yields the correct energy spectrum with mild perturbation of dynamics. We also discuss prospects for application to two-dimensional flow.

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CP14

Goal-Oriented Adaptive Meshing for the Shallow Water Equations

The dual-weighted residual method provides an error estimator which can be used as a mesh refinement criterion for adaptive methods. By utilization of the adjoint, the DWR method takes the discretization error of the scheme and also user specified quantities of interest into account. We tested the DWR method with a discontinuous Galerkin discretization of the shallow water equations. Our test problem is a 2D storm track simulation which is sensitive to the grid refinement.

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CP14

Central-Upwind Schemes for the System of Shallow Water Equations with Horizontal Temperature Gradients

We consider a modification of the Saint-Venant system of shallow water equations. The studied model, proposed by Ripa, takes into account temperature variations, which effect the pressure term while the temperature is transported by the fluid, which makes the model substantially more complicated than the classical Saint-Venant system. We introduce a central-upwind scheme for the Ripa system. The scheme is well-balanced, positivity preserving and does not develop spurious pressure oscillations across temperature jumps. Such oscillations would typically appear when conventional Godunov-type methods are applied to the Ripa system, and the nature of the oscillation is similar to the ones appearing at material interfaces in compressible multifluid computations. The resulting scheme is highly accurate, preserves two types of lake at rest steady states, and is oscillation free across the temperature jumps, as it is illustrated in a number of numerical experiments.

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CP14

Robust Code-to-Code Validation by Means of Parameter Uncertainty Propagation and Anova

We consider the issue of robust code-to-code validation for long wave run-up on complex bathymetries. The objective is the assessment of the output sensitivity w.r.t. model parameters affecting the properties of the schemes. We will compare the behavior of two shallow water codes using the second order scheme of Nikolos and Delis (*CMAME* 198 2009) and of Ricchiuto (*AIP Proc.* 1389 2011). Robust validation is achieved by using uncertainty propagation and analysis of variance to compare the codes single parameter sensitivities.

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CP14

Shallow Water Simulations with the Source Term by the Depth Gradient and Weighted Average Flux

Methods

A finite volume scheme based on depth gradient method (DGM) and weighted average flux (WAF) method with source term has been formulated to solve the two-dimensional shallow water equations. Approximated solutions are updated in time using predictor-corrector types of methods. The predictor step is calculated by the DGM with piecewise-linear reconstructions in each cell volume. Computations at the corrector step are performed using a total variation diminishing (TVD) variant of the WAF method. The accuracy of numerical solutions is demonstrated by applying it to variety of benchmark problems. It is shown that the method is accurate and robust. Also, it can be used to solve problems involving shock-capturing.

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CP14

Central-Upwind Schemes for Shallow Water Models

The talk will be focused on recent applications of the finite-volume central-upwind schemes to several shallow water models including the two-layer shallow water equations, the Savage-Hutter type model of submarine landslides and generated tsunami waves, and the non-hydrostatic Saint-Venant system. The main advantages of the central-upwind schemes are their simplicity and robustness, their ability to preserve a delicate balance between the fluxes, (possibly singular) geometric source term and friction terms as well as to preserve positivity of the computed water depth.

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CP14

Total Least-Squares Adjustment for Various Forms of Coordinate Transformations: A Comparison

In recent years, the Total Least-Squares adjustment within Errors-In-Variables models has been used frequently when estimating parameters of certain coordinate transformations from empirical data. While the affine-transformation parameters could be solved efficiently in a multivariate setting, the similarity transformation required algorithms for general weight matrices to reflect its special structure. Here, an attempt will be made to develop a unifying framework that also will allow the treatment of intermediate forms, such as the prototypical “orthogonal coordinate transformation.’

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CP15

A Numerical Approach to Fluid Induced Sediment Processes

Fluvial bedforms like dunes, ripples or scour marks are formed by current driven sediment transport processes. This includes the interaction of entrainment and deposition of sediment particles. In this study we use a numerical simulation of the three dimensional fluid flow and the simultaneous transport to reproduce these processes. To solve the incompressible two-phase Navier-Stokes equations we use NaSt3D as three dimensional fluid solver for incompressible flow problems. High order schemes are applied for spatial as well as for temporal discretization. The main variants of sediment transport are modelled by applying na advection-diffusion equation for suspension load and Exner equation to bed load transport. The rearrangement of sediment leads to a new sediment surface height which results in new bedforms. To test our model we simulate the evolution of a scour mark around an obstacle and the erosion of sediment from a dune crest.

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CP15

Numerical Modeling of Flow Over Flexible Vegetation

The existence of vegetation in a region can greatly increase the resistance to flow. The vegetation is often highly flexible and moves as the flow field changes which complicates quantifying the resistance and incorporating it into a flow model. We present a method to model resistance due to bending vegetation using the immersed boundary method for fluid-structure interaction. Comparisons to several experimental benchmark problems are shown.

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CP15

A Residual Based Approach for the Madsen and Sorensen Boussinesq Model

We consider the discretization of the Boussinesq model of Madsen and Sorensen using a residual based approach. Following previous work of Ricchiuto and Bollerman (*J.Comput.Phys* 228, 2009), we write discrete nodal equations as weighted averages cell residuals obtained by integrating the time-discretized Madsen and Sorensen equations over a cell. We will discuss the influence of various discretization choices (weights, time discretization etc.) on dispersion and accuracy properties of the resulting scheme, and show results on relevant nonlinear wave propagation and transformation tests.

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CP15

Pebble Shape Evolution Along the Williams River, Australia: a Numerical Abrasion Model

Modeling sediment transport and abrasion in various environments is a long-standing problem in sedimentology. We present a new numerical abrasion model describing the collective evolution of size and shape in large pebble collections as a Markov process, due to mutual abrasion and friction. We apply the model to the Williams River in order to reconstruct the downstream variation in grain size and shape.

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CP15

Interval Output of a SISO Linear System with Known Impulse Response for Incompletely Described Input

In hydrology convolutions are used in the context of hydrographs and tracer hydrology. They represent the action of a linear system on an input. Usually the impulse response is a parametrized function and only a time series of averages of the input is available. For input that is non-negative and has an essential supremum we apply interval analysis to construct upper and lower bounds for the convolution.

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CP16

Incorporating Tidal Uncertainty Into Probabilistic Tsunami Hazard Assessment (ptha)

We describe two new methods for incorporating tidal uncertainty into the probabilistic analysis of tsunami hazard assessment. These methods couple inundation information from multiple GeoClaw simulations with tidal patterns from the site of interest. Performance of the methods for a recent Crescent City, California study will be illustrated, and advantages over existing methods will be given.

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CP16

Strongly Nonlinear Internal Wave Models for Two Layer Fluids

We present a generalized class of strongly nonlinear internal long wave models in a two-fluid layer system. Key steps in the derivation of models tailored for different stability properties and accuracy goals will be discussed. Nonstationary time evolution for their performance tests will be presented as well.

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CP16

Generation of Provably Correct Curvilinear Meshes

The development of high-order numerical technologies for CFD is underway for many years now. In many contributions, it is shown that the accuracy of the method strongly depends of the accuracy of the geometrical discretization. In other words, the following question is raised:we have the high order methods, but how do we get the meshes? This talk focus on the generation of highly curved ocean meshes. We propose a robust procedure that allows to build a curvilinear mesh for which every element is guaranteed to be valid. The technique builds on standard optimization method (BICG) combined with a log-barrier objective function to guarantee the positivity of the elements

Jacobian. To be valid is not the only requirement for a good-quality mesh. If the temporal discretization is explicit, even a valid element can lead to a very stringent constraint on the stable time step. The optimization of the curvilinear ocean meshes to obtain large stable time steps is also analyzed.

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CP16

Unsteady Nonlinear Gravity Waves in Water of Finite Depth

In this work, we consider two-dimensional gravity waves generated by a moving pressure distribution in water of finite depth. The fully nonlinear model in Euler equation form is solved numerically by the mixed Eulerian and Lagrangian approach. The stability of gravity waves for subcritical and supercritical flows is presented. Subcritical flow solution approaches limiting Stoke's wave for high amplitude applied pressure while a solitary wave trapped by a localized pressure is detected for supercritical flows.

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CP16

An Efficient Parallel Implementation of Multirate Schemes for Ocean Modeling

Although explicit time integration schemes require small computational efforts per time step, their efficiency is severely restricted by stability limits. In particular, unstructured meshes can lead to a very restrictive global stable time step. Multirate methods offer a way to increase the efficiency by gathering grid cells in appropriate groups. The parallelization of these schemes is challenging because grid cells have different workloads. We propose a strategy that shares the workload almost equitably between all processors at every multirate stage. Performance analyses are provided for ocean modeling applications.

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CP16

An Unstructured Approach to Ocean Wave-Generation Modeling.

Ocean surface gravity waves are an important component of the atmospheric and oceanic boundary layer and the inclusion of such in a global climate model has the potential to correct model biases and improve air-sea interactions. However, existing wave-generation models used for weather forecasting are computational expensive and ill-suited for studying polar-ice-free scenarios. Here, a comparison of an unstructured node approach (using RBF-generated finite differences) will be presented as well as an update on the the coupled wave-generation component to the NCAR Community Earth System Model.

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CP17

Synthetic Wavelet Using a Hydrographic Data: Comparing Methods to Solve It

Recently the seismic method is applied in water column in the ocean, looking for mesoescales features. For this process is necessary to use hydrographic data to fit seismic image data. Was compared the traditional method and the method that Ruddick et al. (2009) suggested, to calculate the acoustic impedance, reflectivity and wavelet. Though there are lightly differences, results show that the traditional method is more accuracy for calculation to the synthetic wavelets than other suggestion.

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CP17

Using Chaos in Groundwater Remediation

Ineffective mixing constrains groundwater remediation, limiting reactions between contaminants and treatment solutions. We address this constraint with chaos, using engineered injection and extraction to stretch and fold a plume of treatment solution. The periodic points of this flow can be elliptic (poor mixing) or hyperbolic (good mixing); the manifolds of hyperbolic periodic points reveal the asymptotic plume geometry; adjusting the magnitude of water injected generates a bifurcation structure that provides guidance for remediation system optimization.

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CP17

Uncertainty Quantification for Transport Problems in the Shallow Subsurface

We model heat transport in the shallow subsurface using a parabolic differential equation together with initial conditions and boundary conditions. The parameters in the model may be related by a mixture model, making the problem more complex. In this work we use Markov Chain Monte Carlo methods to solve the parameter calibration problem.

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CP17

Optimizing In Situ Groundwater Remediation with Engineered Injection and Extraction

Groundwater remediation requires mixing in aquifers, which can be enhanced using engineered injection and extraction (EIE), in which transient flow fields are induced using a sequence of injections and extractions of clean water at wells surrounding the contaminant plume. This presentation uses a multiobjective evolutionary algorithm to determine a set of EIE sequences that balance multiple objectives, such as maximizing the amount of reaction while minimizing the treatment solution required and the contaminant mass extracted.

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CP17

Homogenization in Case of Transient Motion of a Fluid Through a Porous Medium.

We consider transient motion of a fluid through a medium with periodic structure of pores. We use a homogenization procedure to carry out a multiple-scale asymptotic analysis. The determination of the components of effective permeability tensor is reduced to the numerical solution of periodic problems in cells. We find that the dependence of the viscosity and drag coefficient on the pressure can have a significant effect on the nature of the solution.

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CP17

Uncertainty Quantification in Subsurface Flows with Stochastic Hydrological Laws

The effects of uncertainty in hydrological laws are studied on subsurface flows modeled by Richards' equation. One-dimensional infiltration problems are treated and the influence of the variability of the input parameters on the position and the spreading of the wetting front is evaluated. A Polynomial Chaos expansion (with a non-intrusive spectral projection) is used. Test cases with different laws are presented and demonstrate that second order expansions are well-adapted to represent our quantities of interest.

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CP18

Shear Banding in a Partially Molten Mantle

We investigate the nonlinear behaviour of partially molten mantle material under shear. Numerical models of compaction and advection-diffusion of a porous matrix with a spherical inclusion are built using the automated code generation package FEniCS. The time evolution of melt distribution with increasing shear in these models is compared to laboratory experiments that show high-porosity shear banding in the medium and pressure shadows around the inclusion.

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CP18

Fracture Indicators for the Localization of Fractures in Porous Medium

We are concerned with the determination of the location and the permeability of fractures in a porous medium. We use a reduced, discrete fracture, flow model for the forward problem, and to solve the inverse problem we minimize a least squares function evaluating the misfit between given pressure measurements and the calculated pressure. The sought fractures are obtained iteratively using fracture indicators inspired by the idea of refinement indicators. The first numerical results are promising.

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CP18

Heterogeneous Material Properties and Off-Fault Plastic Response in Earthquake Cycle Simulations

We have developed a numerical method for studying how heterogeneous material properties and off-fault plasticity affect the earthquake cycle. The fault is governed by a nonlinear friction law and we discretize the medium using summation-by-parts finite difference operators and weak enforcement of boundary conditions. Our time stepping method is capable of handling multiple time scales, efficiently integrating the system through both an interseismic period and into earthquake rupture.

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CP18

Variational Methods for a Problem of Rate- and State-Dependent Friction

Rate- and state-dependent (RS) friction is a standard model in geophysics. We consider a problem of RS friction between an elastic body and a rigid foundation, the weak form of which can be written as a coupling of variational equations (VEs). This problem is discretised in time, yielding elliptic VEs. We give some answers to the question of existence and uniqueness of solutions and present a numerical algorithm based on Finite Elements and a fixed point iteration.

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CP18

Bayesian Selection of Models for the Near Real-Time Earthquake Source Inversion

We present results of quantitative Bayesianranking, under uncertainty, of kinematic earthquakerupture modelswith respect to their ability to replicate recorded seismic data. This work on rigorously quantifying uncertainties in earthquake models is part ofour research on Bayesian near real-time earthquake source inversion, withthe long term objective of helping to mitigate human and economical lossesin case of large earthquakes that possibly may generate tsunamis.

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CP18

An Immersed Interface Method for a 1D Poroelasticity Problem with Discontinuous Coefficients

We introduce an immersed interface method (IIM) based on a staggered grid for the 1D poroelasticity equations (Biot model) when the coefficients have discontinuities along material interfaces. The IIM uses standard finite difference method away from the interface and modifies the numerical schemes near or on the interface to treat the irregularities. We will derive and analyze the new method, and show some numerical results to confirm the theoretical error estimates.

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MS1

High-Order and Low-Cost Stabilized Finite Element Solvers of Primitive Equations

We present in this talk an anlisis technique for some penalty stabilized solvers for the Navier-Stokes equations. We consider low-order and high-order methods. The low-order method is a pure penalty method, while the high-order one is a projection-stabilized method. For this method the projection operator is generalized to a locally stable interpolation operator. We perform their numerical analysis (stability and convergence) for unsteady flows. In this analysis, the stability is based upon specific inf-sup conditions. No local orthogonality properties are needed for the projection-interpolation operator. The convergence is based upon the representation of the stabilizing terms by means of bubble finite element spaces. We include some numerical tests for realistic flows.

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MS1

Large Eddy Simulation of the Quasi-Geostrophic Equations

This talk surveys some recent developments in the modeling, analysis and numerical simulation of the quasi-geostrophic equations, which describe the wind-driven large scale ocean circulation. A new large eddy simulation model, which is based on approximate deconvolution, is proposed for the numerical simulation of the one-layer and two-layer quasi-geostrophic equations. A finite element discretization of the streamfunction formulation of the quasi-geostrophic equations is also proposed. This conforming discretization employs the Argyris element. Optimal error estimates are derived. To the best of our knowledge, these are the first optimal error estimates for the finite element discretization of the quasi-geostrophic equations. Numerical experiments that support the theoretical estimates are also presented.

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MS1

Assessments of Discretizations of Convection-Dominated Scalar Problems

Oceanic flow models include often convection-dominated scalar equations that model the transport of species (salinity) or temperature. It is well known that stabilized discretizations are necessary for this kind of equations. This talk presents a review about our recent experience with stabilized finite element and finite difference methods.

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MS1

High Performance Adaptive Finite Element Method for Ocean Models

We present a computational framework based on parallel adaptive FEM for ocean simulations. In order to achieve efficient representation of spatial scales we use adaptive mesh refinement based on goal oriented a posteriori error control. The framework can utilize massively parallel architecture to achieve the required model resolution. In our framework we treat the ocean as a turbulent incompressible fluid with variable density. We conclude this talk with results on the ongoing work.

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MS1

Boundary Conditions for the Inviscid Linear and Nonlinear Shallow Water Equations in Space Dimension One and Two

Motivated by problems of geophysical fluid mechanics, we derive a set of boundary conditions which are suitable for the inviscid Shallow Water equations in space dimension one and two. For the linearized two-dimensional equations, five different cases occur depending on the background flow.

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MS2

Investigation of Pore-Scale Processes with the Volume of Fluid Method

Recent advances in computational facilities enable to simulate two-phase flow with sub-pore resolution. These simulations can be used to investigate the limits of the classical continuum approach and devise alternative Darcy scale models. We present Navier-Stokes simulations of two-phase flow in complex geometry, using the Volume of Fluid method. Particular attention is paid to investigate fingering, trapping, corner and film flow and their impact on the capillary pressure-saturation relationship.

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MS2

Computation of Three-Phase Fluid Configurations at the Pore Scale by a Variational Level Set Method

We present a variational level set method to simulate capillary-controlled displacement of three fluids in 3D pore structures. The evolutionary level set equations for each fluid is derived based on constrained energy minimization in the pore space, whereas contact angle formation are enforced at the zero level sets in the solid. The method is applied to simulate equilibrium fluid configurations and the corresponding mean and principal interface curvatures in small subsets of 3D rock images.

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MS2

Kinetic Methods for Pore-Scale Simulations of Coupled Transport Problems

In our presentation we will present three-dimensional transient pore-scale simulations based on Lattice-Boltzmann models for coupled transport problems in porous media including multiple phases and components, thermal effects and interaction with electric and magnetic fields. After an introduction of the basic kinetic models we will discuss the suitability of our approach both in terms of modeling accuracy as well as numerical efficiency.

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MS2

Pore-Network Modeling of Reactive Transport under (Variably-)Saturated Conditions

A modular pore scale model is developed to study reactive and adsorptive transport under (variably-) saturated conditions, looking at various applications. The continuum porous structure is discretize into a network of pore bodies and pore throats, both with finite volumes. For each pore element, transport of solute is calculated by solving the governing mass balance equations, while chemical reaction of the fluid phase with reactive solid components may change the pore geometries.

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MS2

Pore Scale Modeling of Two and Three Phase Flow and Transport Through Porous Media: Where Are We and What Is to Be Done?

In this talk, I will review one pore scale modeling approach from rock reconstruction to network extraction and subsequent flow modeling using network modelling. Examples applying this approach in both two and three phase flow are discussed. In particular, the role of wettability of the porous medium on multiphase flow physics will be studied. Future research directions in this area will be considered and the prospect for true prediction of macroscopic flow parameters is assessed.

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MS3

An Efficient Finite Volume Discretization to Simulate Flows on 3D Discrete Fracture Network for Transient Flow Analysis and Equivalent Permeability Upscaling

The organization of natural fracture networks induces flow paths that control fluid flows in reservoirs. Taking into account all heterogeneities is computationally very costly, therefore, equivalent multi-porosity and multi-permeability models have to be used. We present an innovating discretization procedure allowing to simulate flow on 3D Discrete Fracture Networks involving over 100.000 fractures. We then demonstrate how to improve the computation of an equivalent permeability tensor by combining analytical and clever-meshed numerical solutions.

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MS3

An Interface Fault Model for Sedimentary Basin Simulation

We present an interface fault model which is compatible with basin modeling. It considers that the fault zone is represented by two interfaces, one for each side of the fault that is meshed conformal with its neighboring block and that can move relatively to the other side. Combined with a Finite Volume discretisation, this approach leads to fault-fault fluxes across fault faces that do not match. Results for one-phase and two phase flow are shown.

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MS3

Flow Modeling Techniques for Fractured Reservoirs - Gridding, Discretization, and Upscaling

Detailed procedures for constructing upscaled fracture models are presented. Fine-scale models are formed by combining sets of triangulated surfaces, and discretization is accomplished using discrete fracture modeling techniques. Coarse cells are formed by agglomerating fine-grid cells, and new flow-based upscaling techniques provide coarse-grid transmissibilities. The local pressure fields needed for upscaling are constructed using linear combinations of (pre-computed) large-scale pressure solutions. Simulations of flow through 3D fractured reservoirs demonstrate the accuracy of the proposed techniques.

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MS3

Is Discrete-Fracture Modeling Helpful for Reservoir Engineer?

Discrete fracture and matrix modelling and flow simulation of detailed small-scale representation of heterogeneities are not routinely used for fractured reservoirs studies, even for upscaling purposes, to field-scale simulation with dual porosity approach. However new techniques and tools are now available. Could such DFM models be of any use for the reservoir engineer? If so, in which situation, and how it impacts our workflow today and in the future? Practical examples will illustrate our works in this domain.

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MS3

Discretizing Fractured Porous Media for Multiphase Flow Simulation

Adaptive discretization is key for physically realistic and efficient simulation of multiphase fluid flow through porous rock with discrete fractures. For goal-based simulation, where space-time accuracy is predefined by the user, spatial discretization errors need to be dealt with using an error metric. In the discretization of time, stepping needs to adapt to the wide range of flow velocities. Here we present models of fractured rock where discretization is adapted to fracture geometry, fluid-pressure-error and flow speed.

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MS4

Multiphase Flow, Deformation and Wave Propagation in Porous Media

Single and multiphase flows are determined by Lattice Boltzmann Models and elastic deformations of the solid matrix by Lattice Spring Models. These two codes are coupled by using a momentum exchange. Then, wave propagation is addressed either by direct simulations or homogeneization. A few comparisons with analytical solutions or results obtained by different numerical methods are given. Some applications to real porous media, possibilities and extensions of these codes are discussed.

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MS4

Mixed Mortar Methods for Flow in Heterogeneous Porous Media

With the equation in mixed form, we use a nonoverlapping mortar domain decomposition method, which is efficient in parallel if the mortar space is small. We define formally first and second order multiscale mortar spaces using homogenization. For locally periodic permeability, the method achieves optimal order error estimates in the mesh spacing and heterogeneity period. Otherwise, numerical results show the method works well. It can be adapted as a two-level solver for the fine-scale system.

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MS4

Theoretical and Computational Perspectives on Chemical Enhanced Oil Recovery Processes

In this talk, I will give a brief overview of some of the fundamental theoretical and computational problems in EOR technology that are of interest to the speaker. Then I will give some recent results on some of these problems obtained by the speaker and his collaborators. The research to be presented has been made possible by a grant (NPRP 08-777-1-141) from the Qatar National Research Fund (a member of The Qatar Foundation).

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MS4
The Riemann Problem for Three-Phase Flow

We focus on a particular system of two conservation laws which models immiscible flow in porous media relevant for petroleum engineering. The Riemann solutions are found for a range of initial conditions important in applications, representing the injection of two fluids (water, gas) into a horizontal reservoir containing a third fluid (oil) to be displaced. Despite loss of strict hyperbolicity, the solutions for each data exists and is unique. Also, it depends L_1 continuously on the Riemann data. Such solutions always display a lead shock involving one of the injected fluids and the fluid already present. There is a threshold solution separating solutions according to which of the injected fluids is present in the lead shock.

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MS4
Modelling and Computation of Thermohaline Groundwater Flows

We study salinity- and thermohaline-flow in fractured porous media. We adopt two approaches: (i) the fractures are treated as thin flow subregions having the same dimension as medium in which they are embedded; (ii) the fractures are regarded as manifolds of reduced dimension. We discuss the validity of both approaches and, in the case of salinity-driven flow, investigate the deviations of the results determined by employing the Forchheimer correction with those predicted by Darcy's law.

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MS5
A Unified Fe Approach for Wave Propagation in Elastic Media - from Near Incompressibility to Acoustics

The CMU Quake group has been working on large-scale earthquake simulations using Hercules –an octree-based finite-element wave propagation simulator. This code is based on trilinear displacement elements. One limitation is its inability to provide reliable results for low S- to P-wave velocity ratios. Here, we assess the performance of a quadratic displacement-based formulation versus that of a mixed displacement-pressure formulation for nearly incompressible and acoustic wave-propagation applications, and explore their applicability to gravity waves.

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MS5
High Order One-Step Pnpm Schemes on Unstructured Meshes for Hyperbolic Balance Laws

In this talk we present a new unified approach of general $P_N P_M$ schemes on unstructured meshes in two and three space dimensions for the solution of time–dependent partial differential equations, in particular hyperbolic conservation laws. The new $P_N P_M$ approach uses piecewise polynomials u_h of degree N to represent the data in each cell. For the computation of fluxes and source terms, another set of piecewise polynomials w_h of degree $M \geq N$ is used, which is computed from the underlying polynomials u_h using a reconstruction or recovery operator. The $P_N P_M$ method contains classical high order finite volume schemes ($N = 0$) and high order discontinuous Galerkin (DG) finite element methods ($N = M$) just as two particular special cases of a more general class of numerical schemes. Our method also uses a novel high order accurate one–step time discretization, based on a local space–time discontinuous Galerkin predictor, which is also able to solve PDE with stiff source terms.

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MS5
Large-Scale Bayesian Seismic Inversion

We present a computational framework for solution of discretized infinite-dimensional Bayesian inverse problems. We address several computational issues related to the appropriate choice of prior, consistent discretizations, tractable treatment of the Hessian of log posterior, and scalable parallel MCMC algorithms for sampling the posterior. We apply the framework to the problem of global seismic inversion, for which we demonstrate scalability to 1M earth parameters, 630M wave propagation unknowns, and 100K cores on the Jaguar supercomputer.

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MS5

High-Order Explicit Local Time-Stepping Methods for Wave Propagation

We propose high-order explicit local time-stepping (LTS) schemes based either on classical or low-storage Runge-Kutta schemes for the simulation of wave phenomena. By using smaller time steps precisely where smaller elements in the mesh are located, these methods overcome the bottleneck caused by local mesh refinement in explicit time integrators. In (J. Diaz and M.J. Grote, Energy conserving explicit local time-stepping for second-order wave equations, SIAM J. Sci. Comput., 31 (2009), pp. 1985–2014.), explicit second-order LTS integrators for transient wave motion were developed, which are based on the standard leap-frog scheme. In the absence of damping, these time-stepping schemes, when combined with the modified equation approach, yield methods of arbitrarily high (even) order. To achieve arbitrarily high accuracy in the presence of damping, while remaining fully explicit, explicit LTS methods for the scalar damped wave equation based on Adams-Bashforth multi-step schemes were derived in (M. J. Grote and T. Mitkova, High-order explicit local time-stepping methods for damped wave equations, J. Comput. Appl. Math., 239 (2013), pp. 270–289). Here we propose explicit LTS methods of high accuracy based either on explicit classical or low-storage Runge-Kutta (RK) schemes. In contrast to Adams-Bashforth methods, RK methods are one-step methods; hence, they do not require a starting procedure and easily accommodate adaptive time-step selection. Although RK methods do require several further evaluations per time-step, that additional work is compensated by a less stringent CFL stability condition.

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MS5

High-Performance 3D Numerical Simulations for Seismic Scenarios: An Engineering Perspective

In spite of the progress in computational tools for seismic wave propagation, the vast majority of engineering studies are still routinely performed using 1D approaches, relying on the assumption of vertical plane wave propagation in a horizontally layered soil. Although this is a rational approach for many engineering applications, it may provide unrealistic results when applied to earthquake ground motion prediction and to the generation of ground shaking maps in the vicinity of a seismic fault. Relying on a non-conforming strategy, the SPEED high performance computing code (SPectral elements in elastodynamics with Discontinous Galerkin) has been developed to study complex 3D models and provide the capability to simulate seismic wave propagation from the source to the structure. This may open new perspectives to solve earthquake engineering problems.

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MS6

Hybrid Multiscale Finite-Volume Galerkin Method for Elliptic and Parabolic Problems

The iterative multiscale finite-volume method can be regarded as a domain decomposition method with the particular advantage that conservative fluxes are obtained at any iteration level. This is of great advantage e.g. for transport in heterogeneous porous media. Recently, enriched multiscale methods have been proposed to improve robustness and along this line, here a hybrid multiscale finite-volume Galerkin (MSFVG) method is introduced.

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MS6
Generalized Multiscale Finite Element Methods.

In this talk, we present a general approach called Generalized Multiscale Finite Element Method (GMsFEM) for performing multiscale simulations for problems without scale separation over a complex input space. In the proposed approach, we present a general procedure to construct the offline space that is used for a systematic enrichment of the coarse solution space in the online stage. In the online stage, for any input parameter, a multiscale space is constructed to solve the global problem on a coarse grid. We present various examples in the paper and some numerical results to demonstrate the effectiveness of our method.

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MS6
Dynamic Upscaling/downscaling for Multi-Phase Flow in a Multiscale Finite Volume Framework

We propose an upscaling/downscaling method that is based on dynamic simulation of a model in which the accuracy of the upscaled model is continuously monitored via indirect error-measures. If the error measure is bigger than a specified tolerance, the upscaled model is updated with approximate fine scale information that is reconstructed from a multiscale finite volume method. We apply adaptive prolongation and restriction operators for flow and transport equations in constructing an approximate fine scale solution.

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MS6
Convergent Non-Linear Upscaling for Multiphase Flow and Transport in Porous Media

Upscaling of nonlinear multiphase flow and transport problems in porous media is challenging, but often necessary to lower computational cost. We propose a method that automatically upscales in the appropriate limiting flow regimes and acts as a preconditioner to the fine scale nonlinear system otherwise. Communication between the numerical scales is handled by physically based compression and reconstruction operators. Further, fine scale computations are automatically localized to the more demanding regions of the domain.

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MS6
Multiscale Mortar Methods for Multiphysics Applications

We discuss a multiscale framework for multiphysics problems based on mortar domain decomposition methods. The domain is decomposed into a series of subdomains (coarse grid) with different physical processes, mathematical models, and numerical methods. The equations are discretized locally on a fine scale, while interface conditions are imposed weakly on a coarse scale using mortar finite elements. By eliminating the subdomain unknowns, the global problem is reduced to a coarse scale interface problem that is solved efficiently using a multiscale flux basis. Applications to Stokes - Darcy and porous media flow - geomechanics couplings are presented.

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MS7
Applications of Shaping Regularization in Geophysical Inverse Problems

Shaping regularization is a general framework for solving inverse problems. Instead of specifying an objective function for optimization, shaping requires a forward operator, a backward (approximate inverse) operator, and a model shaping operator, which can be a projection of the estimated model into the space of acceptable models. I will show several examples of using shaping regularization in geophysical inverse problems: data regularization, simultaneous source separation, and seismic velocity estimation.

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MS7

Inversion of Large Scale Electromagnetic Data

Abstract not available at time of publication.

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MS7

Full Waveform Inversion of Blended Data: Analysis of Multi-frequency Inversion Strategies

One way to reduce the overall cost of waveform inversion is via the adoption of blended or simultaneous sources, where multiple sources are simultaneously fired with random time delays. This can be achieved by assembling multiple sources into super-shots. In the present study, we examine the effect of different multi-frequency selection strategies on the inversion of complex velocity models with data that simulate a simultaneous source acquisition.

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MS8

Coupling Two-Phase Compositional Porous-Medium and Free Flow

The numerical simulation of flow and transport phenomena in porous media is quite often based on Darcy's law, whereas in free flow regions the Navier-Stokes model has to be used. Of special interest are structures composed of a porous part and an adjacent free flowing fluid. So far, the coupling of free flow with porous medium flow has been considered only for a single-phase system. We extend this classical concept to two-component non-isothermal flow with two phases inside the porous medium and a single phase inside the free flow region. Our coupling concept also takes into account evaporation and condensation processes at the interface. We discuss our new model and introduce different coupling conditions. Moreover, some numerical examples illustrate the coupling between the two model domains.

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MS8

Space-Time Domain Decomposition for Porous Media Flow and Transport

We present two non-overlapping domain decomposition methods for solving heterogeneous time-dependent advection-diffusion problems in a mixed formulation: a time-dependent Steklov-Poincaré operator with a Neumann-Neumann preconditioner and a Schwarz waveform relaxation method with optimized transmission conditions. Thus, different time steps can be used in different subdomains adapted to their physical properties. We derive the formulations using a splitting approach. We show numerical results in 2D on a simplified test case suggested by the nuclear waste disposal problems.

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MS8

"Heterogeneous Domain Decomposition Methods for Surface and Saturated/unsaturated Ground Water Flow"

Our approach to the mathematical modelling of coupled surface and ground water flow is based on Richards equation and a clogging-type coupling to the shallow water equations or simple compartement models for surface water. The seepage along river beds and lakes is described by Signorini-type boundary conditions. We will present Poincare-Steklov formulations of this heterogeneous problem and an iterative solver of Robin-Neumann-type taking the multiple time scales of ground and surface water flow into account. We present numerical experiments with model problems illustrating the basic properties of our approach, such as mass conservation, as well as the performance of our iterative scheme.

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MS8

Multidimensional Coupling for Shallow Water Flows

The motion of water in a complex hydrodynamic configuration is characterized by a wide spectrum of space and time scales. Consequently, the numerical simulation of a hydrodynamic system of this type is characterized by a large computational cost. In the last years a lot of work has been done concerning 1D-2D coupling. In this talk 3D-1D and 3D-2D coupling strategies will be introduced.

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MS9
A Multiscale Formulation Based on CVD-MPFA Schemes on Structured and Unstructured Grids

Families of Darcy-flux approximations have been developed for consistent approximation of the general tensor pressure equation arising from Darcy's law together with mass conservation. The schemes are control-volume distributed (CVD) with flow variables and rock properties sharing the same location in a given control-volume and are comprised of a multipoint flux family formulation (CVD-MPFA). The schemes are used to develop a CVD-MPFA based multiscale formulation applicable to both structured and unstructured grids in two-dimensions.

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MS9
Mimetic Finite Difference Methods and Virtual Element Discretizations for Porous Media Applications

We present the family of mimetic finite difference methods and of virtual element discretizations and discuss how these approaches can be used to design efficient schemes to approximate flow and transport models in porous media. The permeability tensor in the diffusive terms may be heterogeneous, full and anisotropic. These numerical techniques can be applied to computational meshes of polygonal or polyhedral cells with very general shape, also nonconforming as the ones of the Adaptive Mesh Refinement (AMR) method and non-convex, and used to approximate linear and non-linear models like the Richards equation.

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MS9
Nonlinear Monotone Finite Volume Method for Richards Equation

The Richards equation is often used to model subsurface flow in unsaturated media. We present a new nonlinear finite volume method which guarantees the discrete maximum principle in every subdomain with homogeneous permeability. In state-of-the-art methods the monotonicity is achieved by using the first order upwind of the relative permeability which decreases the accuracy of a method. Our approach provides the second order of accuracy for the pressure which is confirmed by numerical tests.

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MS9
Coupling of Stokes and Darcy Flows using Discontinuous Galerkin and Mimetic Finite Difference Method

We present a numerical method for coupling Stokes and Darcy flows based on discontinuous Galerkin (DG) elements for Stokes and mimetic finite difference (MFD) methods for Darcy. Both methods are locally mass conservative and can handle irregular grids. The MFD methods are especially suited for flow in heterogeneous porous media, as they provide accurate approximation for both pressure and velocity and can handle discontinuous coefficients as well as degenerate and non-convex polygonal elements. We develop DG polygonal elements for Stokes, allowing for coupled discretizations on polygonal grids. Optimal convergence is obtained for the coupled numerical method and confirmed computationally.

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MS9
Nonlinear Discretizations for Multi-Phase Flows in Porous Media

We consider approaches to the design of a monotone cell-centered finite volume discretization of convection-diffusion equations describing multiphase flows. The permeability tensor may be heterogeneous, full and essentially anisotropic. The conformal computational mesh is assumed to consist of convex polygonal or polyhedral cells. The schemes possess the minimal stencil containing the closest neighboring cells only. The cornerstone of the approaches is the nonlinear discretization of fluxes derived on faces of mesh cells, see Rus. J. Numer. Anal. Math. Modelling 27(4) 2012 and references therein.

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MS10
Equal-order Finite Elements for Hydrostatic Flow Equations of the Ocean

Simulation of flow phenomena in the ocean and in other large but relatively flat basins are typically based on the primitive equations, which result from application of the hydrostatic approximation. We analyze such ”2.5-

dimensional" systems and formulate stabilized finite element schemes with equal-order interpolation. We show stability and give an a priori error estimate for several established stabilized equal-order schemes, as pressure-stabilized Petrov-Galerkin (PSPG), Galerkin least squares (GLS) and local projection schemes (LPS) which are extended here to the hydrostatic approximation.

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MS10

Recent Results on Inviscid Limits for the Stochastic Navier-Stokes Equations and Related Systems

One of the original motivations for the development of stochastic partial differential equations traces it's origins to the study of turbulence. In particular, invariant measures provide a canonical mathematical object connecting the basic equations of fluid dynamics to the statistical properties of turbulent flows. In this talk we discuss some recent results concerning inviscid limits in this class of measures for the stochastic Navier-Stokes equations and other related systems arising in geophysical and numerical settings.

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MS10

Velocity-Pressure Proper Orthogonal Decomposition Methods For Flow Problems

Proper Orthogonal Decomposition is one of the most successful tools in the context of reduced-order modeling for flow problems modeled by incompressible Navier-Stokes equations. The standard approach in combination with very common assumptions leads to a reduced-order model (ROM) only for velocity. However, the need for computation of pressure is a given. In this talk, the numerical studies of some already existing pressure ROMs and of a new one will be presented.

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MS10

An Ergodic Theory and Harmonic Analysis Based Method for Analyzing Ocean Flows

We consider an approach, called the ergodicity defect, for analyzing ocean flows. The ergodicity defect distinguishes individual trajectories via their complexity, which in turn allows for the identification of Lagrangian coherent structures. The approach combines the mathematical areas of ergodic theory and harmonic analysis/wavelet theory. The advantages, practical uses, and disadvantages of the method are discussed and several examples are presented.

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MS11

Energy Stable Scheme for Shallow Water Equations

The subject of the talk is the numerical solution of shallow water equations with bathymetry. It is known that in some cases spurious oscillations in the numerical solution may arise. This is due to the conservation properties of the adopted numerical scheme. In this talks we are going to revise energy stable and energy preserving finite volume scheme in order to end up with an oscillation free method. Some preliminary numerical results are also presented.

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MS11

Modelling Solute Transport in Meandering Channels using a High-order DG Method

A third-order accurate numerical method for the 2D shallow water equations, inclusive of the convection-diffusion terms due to the streamlines curvature, is discussed. The hydrodynamics and the behaviour of a passive contaminant are analyzed, using recent advances in river mechanics and novel findings in RKDG methods. The comparison with selected laboratory data shows that good results can be obtained using relatively coarse grids, supporting the use of high-order methods in engineering practice.

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MS11

Comparison Between Sph and Level Set Methods for Free Boundary Problems for Incompressible Euler and Navier-Stokes Equations

A new finite difference ghost cell level set multigrid method for the numerical solution of free boundary problems for incompressible Euler and Navier-Stokes equations is presented. The equations are discretized in primitive variable on a fixed Cartesian grid. The free surface is taken into account by a level set function, which is evolved by the normal velocity of the fluid at the surface. The Poisson equation on the pressure, obtained by the incompressibility condition, is efficiently solved by multigrid. Applications to some test problems will be presented. The numerical solutions will be compared to those obtained by a smoothed particle hydrodynamic code, in which the incompressibility is replaced by a weakly compressible equation of state, with a sound speed one order of magnitude larger than a typical flow velocity. The comparison shows a good agreement, and emphasizes the relative merits of the two approaches.

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MS11

Second-Order Finite Volume Schemes for Geophysical Shallow Water Flows with Dynamic Wet-Dry Front

We propose a revisiting of second-order finite volume schemes for 2d shallow water equations. Schemes are based on a HLLC-type solver according to [Vila86], MUSCL reconstructions and IMEX time schemes, [PaRu05]. The well-balanced property is obtained applying the method of [AuBr05]. We show the efficiency of the direct solver on real type river flows. Numerical experiments enhance differences between first and second-order schemes both for low-water flows and wet-fry front dynamics.

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MS12

Geostatistical Inversion under Transient Flow Conditions

Geostatistical inversion is a valuable tool for the assessment of aquifer permeability. In previous implementations the assumption of a stationary flow field and the solution of one adjoint problem per measurement were necessary. We present an extension of geostatistical inversion methods to instationary flow regimes. This facilitates the treatment of variable boundary conditions (e.g. nearby rivers) and large data sets. Implementation in the software framework DUNE makes high-performance-computing and full parallelization available.

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MS12

A Discontinuous Galerkin Based Quasi-Linear Geostatistical Approach

The quasi-linear geostatistical approach can be used to estimate the spatial distribution of heterogeneous hydraulic conductivity fields based on point-wise measurements of observable quantities. The accurate and efficient solution of steady-state solute transport problems is crucial for the inversion. The discontinuous Galerkin method incorporates upwinding in a natural way, yielding a robust solver even in the convection dominated case. The benefits and drawbacks as compared to the streamline diffusion method are discussed.

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MS12

Parameter Estimation by Ensemble Kalman Filters with Transformed Data: Approach and Application to Hydraulic Tomography

EnKFs have been converted to tools for parameter estimation in groundwater applications. EnKFs provide optimal parameter estimates only if all involved variables are multivariate Gaussian. To improve EnKFs, we apply nonlinear, monotonic transformations to the observed states, rendering them univariate Gaussian. The transform resembles an implicit quasi-linearization. For illustration of the improved convergence, we present a first-time application of an EnKF to parameter estimation from 3-D hydraulic tomography in multi-Gaussian log conductivity fields.

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MS12

Active and Passive Hydrogeophyscial Tomographic Surveys

This talk discusses uniqueness, scale, resolution, and uncertainty issues associated with modeling of flow through geologic media. We advocate that stochastic interpretation of non-redundant hydrological data from active and passive tomographic surveys is the key to the future hydrological characterization. In conjunction with geophysical monitoring of responses of the subsurface, hydrological tomographic surveys/stochastic joint interpretation could be the ultimate subsurface characterization methodology.

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MS13

Non-Equilibrium Capillarity Effect at Different Scales

Various studies have shown that capillary pressure is not only a function of saturation but also depends on its time rate of change. This is known as the dynamic capillarity effect. We present an overview of computational and experimental studies on dynamic coefficient and show that its value increases with the size of domain of interest. We provide an explanation for this correlation and discuss consequences of scale-dependence of dynamic coefficient for large-scale field situations.

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MS13

Phase Transitions Across Scales: Discrete and Continuum Models

It is known that phase transitions occur differently in bulk fluid than in confined porespace, and constitutive relationships at porescale differ from those at macroscale. At porescale there are discrete and continuum models, and at macroscale there are continuum models. However, there are no methods of formal upscaling for nonsmooth nonlinear processes representing phase transitions across these scales. We discuss computational models that bridge the scales for phase transitions in methane hydrate, coalbed methane, and ground freezing modeling.

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MS13

Heterogeneous Multiscale Methods for Two-Phase Flow with Rate-Dependent Extension

Abstract not available at time of publication.

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MS13

Instability Effects in Hysteresis Models for Porous Media Flow

We present various flow models for unsaturated porous media. Our main interest is the gravity driven penetration of a dry material, a situation in which fingering effects can be observed experimentally and numerically. The flow is described by either a Richards or a two-phase model. The important modelling aspect regards the capillary pressure relation which can include static hysteresis and dynamic corrections. We report on analytical existence and instability results for the corresponding models and present numerical calculations. We show that fingering effects can be observed in various models and discuss the importance of the static hysteresis term.

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MS14

Convection Driven by Internal Heating

Two-dimensional direct numerical simulations are conducted for convection sustained by uniform internal heating in a horizontal fluid layer. Top and bottom boundary temperatures are fixed and equal. Prandtl numbers range from 0.01 to 100, and Rayleigh numbers (R) are up to $5 \cdot 10^5$ times the critical R at the onset of convection. The asymmetry between upward and downward heat fluxes is a quantity without analog in classical Rayleigh-Bénard convection and is found to be non-monotonic in R. Scaling arguments previously applied to the Rayleigh-Bénard Nusselt number are applied to the mean temperature.

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MS14

Effects of Velocity and Temperature Boundary Conditions in Turbulent Thermal Convection

We report on results of high resolution direct numerical simulations of two-dimensional Rayleigh-Bénard convection for Rayleigh numbers up to $Ra = 10^{10}$ in order to study the influence of both temperature and velocity boundary conditions on turbulent heat transport. In the first scenario, while imposing the no-slip velocity bound-

ary condition, we consider the extreme cases of fixed heat flux and fixed temperature Both cases display identical heat transport at high Rayleigh numbers fitting a power law $Nu \approx 0.138 \times Ra^{.285}$ above $Ra = 10^7$. The findings are compared and contrasted with results of recent three-dimensional simulations and experiments. In the second scenario we consider the setup originally considered by Rayleigh for calculating conditions for the onset of thermal convection, fixed temperature boundary condition with free-slip velocity boundary conditions. Surprisingly, at high Rayleigh numbers a strong shear flow develops with periodic 'bursting' of the thermal boundary layers. We'll discuss this phenomena and its impact on the heat transport.

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MS14

Large Scale Patterns in Convection: from Rayleigh-Benard, through Prandtl problem, to moist atmospheric convection

Large scale patterns formation in dry and moist convection scenarios are addressed in this paper. The first part of the talk will be devoted to the case of clustering of plumes in Rayleigh-Benard convection: through a two-scale process, kinetic energy is transferred mainly to low horizontal wave numbers while the sizes of individual plumes remain on the scale of the boundary layer thickness. Again in a direct numerical simulation framework, the study of the Prandtl problem is addressed as a simplified model of dry atmospheric convection, kept in statistically stationary radiativeconvective equilibrium. Finally the emergence and temporal evolution of large-scale spatial-temporal oscillating modes in deep moist convection, for an atmosphere in radiative-convective equilibrium. To this end, we use cloud-resolving numerical simulations of the convective atmosphere at very high resolution and on a very large domain, using WRF model in LES mode.

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MS14

High Rayleigh Number 2D Rayleigh-Benard Convection

Although there is a significant understanding of the ultimate regime of Rayleigh-Benard convection, there are still some open questions regarding the transition towards it and the logarithmic boundary layers associated with it. We report the results of our 2D DNS that have contributed to understanding the transition to the ultimate regime as well as the encountered difficulties pushing our code towards high Ra.

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MS15

Scalable Coupling of Surface-Subsurface Water Flows

Recent advances in computing architectures push towards the development of computational codes with an optimal scaling. We have developed a coupled surface-subsurface water flow model that solves the governing equations with discontinuous Galerkin and control volume finite element methods. Our model uses an explicit time discretisation for the 3D Richards equation and hence achieves optimal scaling both weakly and strongly. A wide range of test problems have been solved to highlight the model properties.

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MS15

Evaporation from Porous Media Influenced by Atmospheric Processes

Evaporation from porous media into the ambient air involves varios interacting processes and depends on a multitude of properties of the fluids, of the porous medium and of the flow regime. The evaporation rate can be limited from the porous-medium side, e.g. due to limited water supply by capillary forces or by diffusion through the tortuous porous medium, or from the free-flow side involving the transfer through a boundary layer. Modeling such complex system on the scale of representative elementary volumes (REVs) is a challenging task. We have developed a model for the coupled simulation of a two-phase porous medium flow (Darcy) and a laminar free flow (Stokes) under non-isothermal conditions. Possible extensions and simplifications to the developed laminar coupled

model are discussed.

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MS15

Transition Region Model for Coupling Free Flow and Porous Medium Systems

A transition region model for coupling single-phase two-component free flow and two-phase two-component porous medium systems is developed by means of the thermodynamically constrained averaging theory (TCAT) approach. The model is averaged in the direction normal to the boundaries of the free flow and porous medium domains being joined. Unlike sharp interface approximations, the TCAT transition region model resolves the storage and transport of mass, momentum and energy.

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MS15

Numerical Assessment of Different Discretizations for Stokes-Darcy Coupling

There are a number of options in the numerical simulation of the Stokes-Darcy problem. This talk presents studies of different approaches for applying interface conditions and the use of inf-sup stable and stabilized finite elements for the mixed (dual) Darcy problem.

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MS16

Solution of transient CSEM problems in model reduction framework

We suggest general model reduction framework for the solution of large scale multidimensional transient inverse problems. Rational Krylov subspace model reduction accelerates the solution of the forward problem and efficiently compresses the data in time and space. A nonlinear transform of the compressed data (based on the Stieltjes-Krein-Marchenko-Gelfant-Levitan method) speeds up Gauss-Newton iterations and improves quality of inversion. We illustrate our approach using synthetic 2.5D CSEM examples of hydrocarbon reservoirs in the marine environment.

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MS16

Regularization for Nonlinear Inverse Problems

Ill-posed nonlinear inverse problems require regularized solutions, and typically this is done iteratively with Gauss-Newton or Levenburg-Marguart methods. The discrepancy principle determines regularization parameters by applying a χ^2 test, and here we will extend that idea to show that a χ^2 test can be applied at each iterate of these nonlinear methods. This test is used to estimate regularization parameters for nonlinear problems, and results will be shown on benchmark problems in Geophysics.

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MS16

3D Forward and Inverse Modeling of Geo-Electromagnetic Fields

The inversion of geo-electromagnetic data is a nonlinear and ill-posed problem. In large-scale settings it is generally solved iteratively using regularized Newton, Quasi-Newton, Gauss-Newton or all-at-once approaches. The forward problem is demanding because of complex geometries imposed by natural environments, the different physical behaviors of the fields, a multitude of source configurations and many right-hand sides. We formulate the problem in the time and frequency domains using Nédélec finite elements on unstructured grids and apply Krylov subspace techniques to reduce the numerical costs.

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MS16
Joint Inversion in Poroelasticty

Remote sensing and geodetic measurements are providing a wealth of new, spatially-distributed, time-series data that promise to improve the characterization of the subsurface and the monitoring of pressure transients due to fluid injection and production. We formulate a Bayesian inverse problem to infer the permeability distribution in a quasi-static poroelastic model from the joint inversion of time-series surface deformation and well pressure measurements, and compare different methods to characterize the posterior probability density of the permeability.

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MS17
Coupling Navier-Stokes and Darcy Equations: Modeling and Numerical Methods

We present two possible methods to compute the finite-elements approximation of a Navier-Stokes/Darcy problem to model filtration processes through porous media. First, using suitable continuity conditions, we transform the coupled problem into an equivalent one on the interface separating the fluid from the porous medium. Then, adopting an optimal-control approach, we couple the two sub-problems avoiding relying on any interface conditions. We compare these approaches theoretically and on some test cases of physical relevance.

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MS17
Mathematical and Numerical Delicacies in Coupled Ocean-atmosphere Simulations

Atmospheric and oceanic simulation models are widely used for weather, general circulation, and climate. In this context, the simulated flows are spectrally broad band across global to micro scales. A full representation in different scales is uncomputable and numerical models contain parameterizations to account for unresolved processes. The mathematical formulation of parameterization schemes is devised empirically, and often impairs the regularity of the solutions. This problem is even more acute when considering coupled ocean-atmosphere models. In this talk, it is showed that this complexity has to be taken into account to devise mathematically consistent and efficient coupling algorithms. This problem is here addressed from the point of view of Schwarz-like domain decomposition methods. Using a hierarchy of examples, from highly simplified to fully-realistic cases, the delicacies associated with ocean-atmosphere coupling are illustrated both theoretically and numerically.

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MS17
An Overview of Coupling Strategies between Ocean and Atmosphere in Earth System Models

Earth system models are used to study climate variability from decades to millennium. Historically, they have been built from several components : ocean, atmosphere, sea-ice, etc. Each component comes from a scientific community. It is validated with fixed boundary conditions. Coupling consists in exchanging boundary conditions. To-benefit from the communities expertise, initial methods minimize scientific and technical modifications in the components. This review considers existing coupling strategies under the constraints brought by the physics, numerics and informatics.

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MS17
Domain Decomposition for Poroelasticity and Elasticity with DG Jumps and Mortars

We couple a time-dependent poroelastic model in a region with an elastic model in adjacent regions. We discretize each model independently on non-matching grids and we realize a domain decomposition on the interface between the regions by introducing DG jumps and mortars. The unknowns are condensed on the interface, so that at each time step, the computation in each subdomain can be performed in parallel. In addition, by extrapolating the dis-

placement, we present an algorithm where the computations of the pressure and displacement are decoupled. We show that the matrix of the interface problem is positive definite and establish error estimates for this scheme.

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MS18

Comparison of DDFV and DG Methods for Flow in Anisotropic Heterogeneous Porous Media

We consider unsteady single-phase flows modeled by the Richards' equation. We compare Discrete Duality Finite Volume and Discontinuous Galerkin schemes applied to discretize the diffusive term. Backward Differentiation Formula of second order is used for the time stepping method. Accuracy and robustness of these two types of schemes are tested and compared on various test cases, especially in anisotropic heterogeneous media.

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MS18

Non Linear Finite Volume Schemes For the Heat Equation in 1D

Many solutions exist for the numerical approximation of diffusive equations on general unstrutured grids. But if one needs high order and the preservation of the maximum it becomes quite challenging. In particular the non linear techniques used for hyperbolic equations cannot be used without strong modifications. I will review recent advances in the understanding of the mathematical and numerical structure of this problem: in particular I will detail a 1D example (based on multiD Le Potier's Finite Volume schemes) where high order (third order in practice in 1D) and preservation of the maximum principle are obtained together.

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MS18

Soil Moisture Dynamics and Rain Interarrival Times

Soil moisture data taken down to two meters has been used for assessing the relations between the vertical discretization and rain interarrival times. A one dimensional Richards equation solution provided the tool for also evaluating the effects of hysteresis in the soil water retention curve. A statistics of soil moisture time variations can be related to the pdf of interarrival times.

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MS18

A Non Linear Correction and Maximum Principle for Diffusion Operators with Hybrid Schemes and Discrete Dual Finite Volume Schemes

In the framework of nuclear waste disposal simulation, we are interested in a transport model in porous media which can be described by a convection-diffusion equation. Recently, nonlinear finite volume schemes have been proposed to discretize diffusion operators. For these methods, discrete maximum principle has been obtained for distorted meshes or highly anisotropic diffusion tensors. In the present work, we extend this technique to the class of hybrid schemes and to the discrete dual finite volume methods. We show that this correction is equivalent to the original scheme with a modified flux which is consistent. We give a few words about the coercivity of the modified algorithm. Finally, we show that the new method is nonoscillating. Using an analytical solution, we show the robustness and the accuracy of this algorithm in comparison with results obtained by linear schemes which do not satisfy the minimum principles on this test.

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MS19

Numerical Analysis of a Smagorinsky LES Model for Primitive Equations

This work deals with the development of efficient numerical solvers for the Primitive Equations of the ocean in turbulent regime. We derive the numerical approximation of a reduced model by the Smagorinsky turbulence model that includes stabilization of the pressure discretization by a penalty technique. We perform the numerical analysis of this discretization (stability, convergence, error estimates), obtaining error estimates of at most first order in natural norms, due to the penalty structure of the Smagorinsky eddy viscosity. We finally perform some numerical tests for the Primitive and Navier-Stokes equations, that confirm the theoretical convergence expectations.

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MS19

Lagrangian Tools and the Assessment of the Predictive Capacity of Geophysical Data Sets

We examine, with recently developed Lagrangian tools, altimeter data and numerical simulations obtained from the HYCOM model in the Gulf of Mexico. Our data correspond to the months just after the Deepwater Horizon oil spill in the year 2010. Our Lagrangian analysis provides a skeleton that allows the interpretation of transport routes over the ocean surface. The transport routes are further verified by the simultaneous study of the evolution of several drifters launched during those months in the Gulf of Mexico. We find that there exist Lagrangian structures that justify the dynamics of the drifters, although the agreement depends on the quality of the data. We discuss the impact of the Lagrangian tools on the assessment of the predictive capacity of these data sets.

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MS19

Grand LAgrangian Deployment (GLAD): Optimal Launch Strategies for Dispersion Near the Deepwater Horizon Oil Spill Site

Initial dispersion, residence time, and advective pathway results obtained from the nearly simultaneous deployment of some 300 surface drifters in the vicinity of the DwH oil spill in the DeSoto Canyon are reported. The goal of the GLAD experiment was to characterize, with unprecedented statistical significance, multi-point and multi-scale dispersion properties of the flow in the region of the DwH spill site including demarcation of the advective pathways between the Canyon and larger-scale flow features in the Gulf. GLAD was designed and executed to consist of optimal launch templates needed for dispersion calculations. For the initial time period considered, drifter motion was characterized by large amplitude inertial motions, overall strong topographic control, and significant indications of interior control by frontal dynamics on 1-5 km scales. Very limited exchange, either across-shelf or with nearby mesoscale features, was observed and residence times in the Canyon typically exceeded one week with many drifters remaining there for more than 21 days.

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MS19

Multi-Phase Air-Sea Interface Model

We have implemented a model of the air-sea and air-oil interface with surface tension using a VOF multi-phase CFD model. Under hurricane conditions, the interface was disrupted by Kelvin-Helmholtz instability, forming two-phase transition layer. Experiments with imposed short wavelets revealed streamwise coherent structures and tearing of wave crests, formation of water sheets and spume. The numerical simulation provided an estimate for the gas phase hydrocarbons flux from the ocean to the atmosphere under hurricane conditions.

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MS19

The Search for Lagrangian Coherent Structures in Coastal Areas: Results from the Gelato 2012 Experiment in the Gulf of Naples

Abstract not available at time of publication.

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MS20

Absolute and Relative Permeability for Water-wet Systems Calculated in the Presence of Micro- (un-

resolved) Porosity

Abstract not available at time of publication.

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MS20
Pore Geometry: Film Menisci Motion and Throats

We discuss two related problems in the motion of fluids through porous media. The first is the motion of the arc-menisci governing wetting films in channel cross sections. In the second we address the question "what is a throat" and demonstrate the importance of this question once porosity rises above 20%.

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MS20
Pore Scale Coupling of Fluid and Solid Mechanics for Simulation of Infiltration of Fines in Porous Media

Due to heterogeneity, standard constitutive relationships and models yield poor predictions for flow and rock properties of the porous media infiltrated by fines. We couple computational fluid dynamics and discrete element modeling to simulate the particulate flow through porous media. Pore scale simulations allow for visualization and understanding of clogging processes while varying particle/grain size ratio, fluid viscosity, flow rate and porosity. Further, velocity fields are integrated into a distinctly non-monotonic permeability-porosity/(depth of penetration) relationship.

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MS20
Hybrid Multiscale Finite Volume Method for Two-Phase Flow trough Porous Media

We present a hybrid multiscale algorithm that couples Darcy- and pore-scale descriptions of two-phase flow trough porous media. The Darcy-scale problem is formulated using the Multiscale Finite Volume method, which allows adaptive reconstruction of fine-scale details. At pore scale we solve the Navier-Stokes equations in combination with Volume Of Fluid method. The results of the hybrid simulations are compared with direct pore-scale solutions for several flow regimes and the limits of Darcy's law are discussed.

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MS20
Volume of Fluid Direct Numerical Simulations of Invasion of 3D porous media

We shall present the Volume of Fluid method with the height function method for surface tension, and discuss contact angle implementations in the Gerris Flow Solver code. Then we show some example direct numerical simulations solving the Navier-Stokes equations in 3D porous media on a parallel architecture. We discuss accuracy and scalability issues.

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MS21
A Finite Element Optimization Method for Simulating Discrete Fracture Network Flows

We investigate a new numerical approach for the computation of 3D flows in a discrete fracture network that does not require conforming discretization of PDEs on complex 3D systems of planar fractures. The discretization within each fracture is performed independently of the discretization of the other fractures and of their intersections. Independent meshing process within each fracture is a very important issue for large scale simulations, making easier mesh generation. Simulations will be shown to prove the viability of the method. The resulting approach can be naturally parallelized for dealing with systems with a huge number of fractures.

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MS21
Coupled Flow Model and Simulation in 3D Porous-fractured Media

Taking into account water and solute exchanges between porous and fractured media is of great interest in geological applications. The coupled porous-fractured flow equations and their discretization by a Mixed Hybrid Finite Element Method are presented as well as the derived linear system. An appropriate mesh generation is proposed to deal with the complexity involved by randomly generated fracture networks. Numerical experiments are shown, that provide flow fields for forthcoming transport simulations.

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MS21
Reduced Models for Flow in Networks of Fractures

Subsurface flow is influenced by the presence of faults and large fractures which act as preferential paths or barriers. Several models have been proposed to handle fractures in a porous medium as objects of co-dimension 1. In this work we consider the case of a network of intersecting fractures, with the aim of deriving physically consistent and effective coupling conditions at the intersection between fractures. This new model accounts for the angle between fractures at the intersections and allows for jumps of pressure across the intersection. This permits to describe the flow more accurately than models that impose pressure continuity when fractures have different properties. The main mathematical properties of the model are analysed. We consider a numerical discretisation where fractures may be non-matching at the intersection to increase the flexibility of the method in the case of complex geometries characterized by a high number of fractures.

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MS21
DFM Modelling for Non-Matching Fracture and Matrix Grids: Pressure Continuity and Boundary Conditions

Fractured porous-media systems are simulated, where the characteristic flow behavior depends on both the fractures and the matrix. A structured rock-matrix grid is coupled with an independent, arbitrarily orientated fracture-network grid of codimension one that leads to discontinuous solutions across the fractures which are handled by an XFEM approach. Discontinuities also occur at fracture crossings. A consistency condition which can handle arbitrary crossings is presented as well as consistent boundary conditions for fractured boundaries.

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MS21
A Multiscale Model for Network Flow Embedded in Porous Media

In this talk, we consider the coupling between two diffusion-reaction problems and two transport equations, one defined in a three-dimensional domain $\Omega \subset R^3$, the other in a one-dimensional subdomain $\Lambda \subset \Omega$, respectively. The mathematical analysis of such problems must be handled with care, because the coupling between Λ and Ω is established by measure terms. Finally we describe, how this model can provide the basis for a multiscale analysis of processes occuring in the context with natural gas production by hydraulic fracturing.

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MS22
An Efficient Numerical Method for ASP Flooding in Tertiary Oil Recovery

In this talk, we present a new efficient, high order accurate high performance numerical method for solving a coupled highly nonlinear system of partial differential equations arising in the context of the fractional flow model of Alkali-Surfactant-Polymer flooding of oil reservoirs. The method is based on the use of an extended FEM elliptic solver, an implicit-time linearized FDM, and level set formulation. We will present numerical results using this method. The

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MS22

A Mixed Approach "Pore-Network Model/Direct Numerical Simulation" to Simulate Multiphase Flow Processes

Many petroleum or chemical engineering processes involve multiphase flows in porous media with interface dynamics preventing the use of classical quasi-static network models. We develop mixed models involving two distinct modelizations : a classical pore-network approach, coupled locally, whenever this is required by the flow dynamics, to a multiphase solver (VOF). The continuous dialog between both modelizations required the introduction of an innovative penalization method for solving two-phase flows over complex geometries on simple Cartesian meshes.

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MS22

Scale Analysis of Miscible Density-Driven Convection in Porous Media

Scale analysis of unstable density-driven miscible convection in porous media reveals that both concentration variance production and dissipation rates are independent of the Rayleigh number (beyond a critical limit). As a conclusion, ensemble averaged Darcy modeling and the large-mode simulation approach are proposed to compute the behavior after a short onset time. The former method targets ensemble averaged solutions and the latter coarse scale finger dynamics; in both cases a dramatic reduction of computational cost is achieved.

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MS22

Optimal Flux Allocation and Control of Volume Errors in Streamline-Based Flow Simulation

Advection dominated porous media flow can be solved efficiently by transporting components along a time-varying streamline grid and accounting for non-advective transport on the underlying Eulerian grid using operator splitting. In this work, we investigate the flux allocation to individual streamlines and the resulting volume errors between the streamline and Eulerian grids. We present a framework for balancing these errors using optimization strategies involving the number of streamlines and distribution of well fluxes to streamlines.

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MS22

Finite Elements for Reactive Flow in a Fracture and Reaction-induced Boundary Movement

We study the reactive flow in a thin strip where the geometry changes take place due to reactions. Specifically, we consider precipitation dissolution processes taking place at the lateral boundaries of the strip. The geometry changes depend on the concentration of the solute in the bulk (trace of the concentration) which makes the problem a free-moving boundary problem. The numerical computations are challenging in view of the nonlinearities in the description of the reaction rates. In addition to this, the movement of the boundary depends on the unknown concentration (and hence part of the solution) and the computation of the coupled model remains a delicate issue. Our aim is to develop appropriate numerical techniques for the computation of the solutions of the coupled convection-diffusion equation and equation describing the geometry changes. The performance is demonstrated with the help of numerical tests.

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MS23

Dispersion Analysis by Rayleigh Quotients: An Efficient Tool for High Order Finite Element Analysis in Wave Modeling

Dispersion analysis is a very important tool for assessing the accuracy range of numerical methods for wave propagation simulations. For high order schemes, as in the case of spectral elements, the standard dispersion analysis can be difficult and computationally very intensive, hence a more efficient approach would be desirable. In this work we review the Rayleigh quotient approximation of the eigenvalue problem that characterizes the numerical dispersion of spectral element methods for wave propagation problems in homogeneous media and extend this analysis to one-dimensional, periodic layered media in the particular case where the ratio between the wavelength and the layer thickness is high. This regime is relevant for interpreting stratigraphic data. In addition to spectral element methods, we study the numerical dispersion of a poly-grid spectral element method in which the velocity field is written in terms of Haar wavelet functions within each element.

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MS23

Seismic Wave Propagation and Earthquake Simulations Based on a 3D Fourier Pseudo-spectral Method

We have recently implemented the Fourier pseudo-spectral method (FPSM) into a numerical code for effective large scale 3D modelling of seismic wave propagation and earthquake simulation on highly parallel computers. In particular, the new code uses vertically stretched staggered grids, and it includes features such as general intrinsic attenuation of the medium, anisotropy, irregular surface topography and extended earthquake sources, with kinematic rupture description. We present the main code features and some recent application results.

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MS23

Lessons Learnt from Recent Earthquakes: the Importance of 3D Physical Modeling in Insurance and Reinsurace Market

The recent earthquake sequences that hit New Zealand (Sep. 2010-Dec. 2011, Canterbury plain) and Northern Italy (May 2012, Emilia-Romagna), proved once more that a detailed description of the seismic scenario is required. We will present a challenging case study, aiming at simulating the seismic response of the central business district (CBD) of Christchurch, located in the alluvial plain of Canterbury in New Zealand. The Canterbury sequence caused 181 casualties and devastated the entire region. We decided to focus on the Lyttleton event event, modeling the kinematic rupture along the fault and studying the wave propagation through the complex deep soft-soil sediments up to the high and middle rise buildings located inside the CBD of Christchurch.

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MS23

Modeling Biot Systems in Porous Media

In this paper we consider modeling complex processes in porous media taking into account fluid motion and accompanying solid deformations. Important applications in environmental engineering and petroleum engineering include carbon sequestration, surface subsidence, pore collapse, cavity generation, hydraulic fracturing, thermal fracturing, wellbore collapse, sand production, fault activation, and waste disposal. Here we employ a multipoint flux mixed finite element method for modeling Darcy flow and a continuous Galerkin method for elasticity. This Biot system is decoupled using a fixed stress iterative coupling scheme. We present both theoretical and computational results demonstrating convergence of this approach as well as efficiency in parallel implementation. Specific treatment of discrete fractures, effects of stress dependent permeability, and multiphase flow are discussed.

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MS23

A Comparison of Explicit Continuous and Discontinuous Galerkin Methods and Finite Differences for Wave Propagation in 3D Heterogeneous Media

Traditionally, the wave equation is solved in the time domain with the finite-difference method because of the relative ease of coding and parallelization, the use of high-order spatial discretization schemes and its computational speed. However, finite elements on tetrahedral meshes are more flexible and accurate, if the mesh follows the geometry of the impedance contrasts and of the surface topography. We compare the DG symmetric interior penalty and continuous mass-lumped finite elements with finite differences. The results show that for simple models the finite differences outperform finite element method by at least an order of magnitude. For a model with interior complexity and topography, the finite elements are about two orders of magnitude faster than finite differences. As applications we consider seismic modeling and migration.

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MS24

An Adaptive Multiscale Finite Element Method

We discuss and introduce an adaptive multiscale finite element method (MsFEM) for solving elliptic problems with rapidly oscillating coefficients. Starting from a general version of the MsFEM with oversampling, we present an a posteriori estimate for the H^1-error between the exact solution of the problem and a corresponding MsFEM approximation. Our estimate holds without any assumptions on scale separation or on the type of the heterogeneity. The estimator splits into different contributions which account for the coarse grid error, the fine grid error and even the oversampling error. Based on the error estimate we construct an adaptive algorithm that is validated in numerical experiments.

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MS24

TOF-based two-phase Upscaling of Flow and Transport in Subsurface Formations

Flow and transport in subsurface formations are affected by geological variability over multiple length scales. In this talk, we present a TOF-based two-phase upscaling approach to generate upscaled two-phase flow functions. This approach uses more accurate local saturation boundary conditions, which are found to have a dominant impact (in comparison to the pressure boundary conditions) on the upscaled two-phase flow models. It incorporates single-phase flow and transport information into local upscaling calculations, effectively account for the global flow effects, as well as the local variations due to subgrid heterogeneity. The method was applied to permeability fields with different correlation lengths and various fluid-mobility ratios. It was shown that the new method consistently outperforms existing local two-phase upscaling techniques and provides accurate coarse-scale models for both flow and transport.

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MS24

Multiscale Finite Volume Method As a Framework for Physically Motivated Model Reduction.

In subsurface flow simulations, multiscale methods have been developed as tools to improve computational efficiency. Some of them, however, offer an excellent framework to combine several physical descriptions at different scales and in different regions. By using the Multiscale Finite Volume method, we discuss the possibility of choosing adaptive coarsening criteria based on physical considerations. We show application to flow through porous media, with special attention to applications involving interface dynamics at the pore scale.

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MS24

Reduced Modeling by Global Transmissibility Upscaling for Optimzation

Reservoir models are often too detailed for optimization

purposes. We present a framework for automatic model reduction using global information that consists of three components: algorithms to coarsen the grid, transmissibility upscaling methods, and a robust fully implicit solver. Through a combination of these methods, one can incorporate the most important reservoir responses for use in optimization. In particular, we discuss different ways of using global information to partition the grid and upscale transmissibilities.

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MS24

An Approximate Method for Multiphase Scale-Up

Coarsening and upscaling are common practices in reservoir simulation for reducing model size to improve computational efficiency. As part of the standard simulation workflow, engineers upscale geological models to simulation models to speed up the run and at the same time reduce the requirement on resources, e.g., memory. Coarsening is also an attractive approach for reduced order modeling. In that case, aggressive coarsening is carried out to drastically reduce the size of the simulation model, and hence simulation time. Reduced order modeling plays a crucial role in uncertainty quantification, history match, and other applications where a large number of simulation runs are required. This presentation describes a new method for upscaling relative permeability for the purpose of multiphase flow simulation. This method is simple, efficient, and treats physics factors important to recovery processes. With this approach, approximations are introduced to eliminate the need for local or global multiphase flow simulations for the purpose of building coarse-scale displacement tables (pseudos). Instead, the technique is based on global pressure solutions and velocity fields for incompressible single phase flow. Using the velocity fields, time-of-flight (TOF) and saturation distributions are obtained by solving finite difference equations using a sequential procedure. For testing, coarse-scale relative permeability tables are used to simulate flow on fields with challenging horizontal and vertical permeability properties. Test results show that the use of the proposed multiphase upscaling method preserves accuracy of simulation on the coarse scale, while speeding up the run by more than 100 times.

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MS25

Dynamic Simulation of Tsunamigenic Earthquake Rupture

Earthquakes might generate disproportionately large tsunamis due to particular characteristics that include slow rupture speed, rupture up to the trench and slip on splay faults. I will summarize current results from models of subduction earthquake cycle and dynamic rupture aimed at understanding which physical properties of the subduction megathrust can lead to such tsunamigenic earthquakes. In particular, I will examine the conditions that control the occurrence of large slip and slow rupture at shallow depth.

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MS25

A 3D Dynamic Rupture and See Floor Displacement Simulations of the 2011 Mw9 Tohoku Earthquake

We perform earthquakes dynamic rupture simulations of 2011 Mw9 Tohoku event governed by the slip weakening friction. Based on these simulations, we investigate the spatio-temporal evolution of the ground motion displacement of the see floor. Moreover, we investigate the role of the non-planar fault of the subduction interface and its effect on the ground motion displacement of the see floor, that in turn provide important insights on tsunamis generations.

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MS25

Broadband Ground-Motion Simulations from Rupture Dynamics

Broadband ground-motion calculations for earthquake engineering applications are a key challenge in seismology. In this talk, I present physics-based earthquake shaking simulations based on dynamic rupture computations combined with seismic scattering in heterogeneous Earth. I discuss our rupture-dynamics modeling strategy, using correlated-random initial stress that generates realistic space-time rupture evolutions. We combine the resulting band-limited synthetic seismograms with multiply S-to-S scattered high-frequency seismic waves. I also introduce simplified rupture-modeling strategies for tsunami prediction.

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MS25

Recent Advances in Numerical Simulation of Earthquake Rupture Dynamics: Application to the 2011 Tohoku-Ori Earthquake

Recent advances in numerical simulation of earthquake rupture dynamics using non-smooth Spectral Element Method are discussed here in the light of canonical problems and of the recent 2011 Tohoku-ori earthquake. High-order Spectral Element approximation, combined with explicit second-order time stepping, allows to simulate very accurately the rupture radiation in complex geological media. Dynamic earthquake rupture along preexisting faults of complex geometry is modeled as a frictional instability using extension of a Barenblat-type surface energy formulated in terms of a slip-weakening friction law. The frictional contact is implemented using an implicit non-smooth contact formalism and solved locally using Moreau's sweeping process. The frictional contact is regularized to take into account bi-material interfaces. Simulations of the interaction between rupture propagation and free surface will be in particular discussed in the light of the implications for tsunami source generation.

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MS26

On the Regularity of Non-Negative Solutions to a Logarithmically Singular Equation

The local behaviour of solutions to a logarithmically singular diffusion equation is investigated in some open space-time domain $E \times (0,T]$. It is shown that if at some time level $t_o \in (0,T]$ and some point $x_o \in E$ the solution $u(\cdot,t_o)$ is not identically zero in a neighborhood of x_o, in a measure-theoretical sense, then it is strictly positive in a proper cylindrical neighborhood of (x_o,t_o). As a consequence, solutions are analytic in the space variables and at least Lipschitz continuous in the time variable.

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MS26

Structural Stability Problems for Nonlinear PDEs of Porous Media

The problems of structural stability and continuous dependence on initial data for Brinkman Forchheimer Equations and related systems of equations of porous media will be discussed

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MS26

On the Development and Generalizations of Cahn–Hilliard Equations within a Thermodynamic Framework

We provide a thermodynamic basis for the development of models that are usually referred to as phase-field models for compressible, incompressible, and quasi-incompressible fluids. Using the theory of mixtures as a starting point, we develop a framework within which we can derive phase-field models both for mixtures of two constituents and for mixtures of arbitrarily many fluids. In order to obtain the constitutive equations, we appeal to the requirement that among all admissible constitutive relations that which is appropriate maximizes the rate of entropy production (see Rajagopal and Srinivasa in Proc R Soc Lond A 460:631–651, 2004). The procedure has the advantage that the theory is based on prescribing the constitutive equations for only two scalars: the entropy and the entropy production. Unlike the assumption made in the case of the Navier-Stokes-Fourier fluids, we suppose that the entropy is not only a function of the internal energy and the density but also of gradients of the partial densities or the concentration gradients. The form for the rate of entropy production is the same as that for the Navier-Stokes-Fourier fluid. As observed earlier in Heida and Malek (Int J Eng Sci 48(11):1313–1324, 2010), it turns out that the dependence of the rate of entropy production on the thermodynamical fluxes is crucial. The resulting equations are of the Cahn-Hilliard-Navier-Stokes type and can be expressed both in terms of density gradients or concentration gradients. As particular cases, we will obtain the Cahn-Hilliard-Navier-Stokes system as well as the Korteweg equation. Compared to earlier approaches, our methodology has the advantage that it directly takes into account the rate of entropy production and can take into consideration any constitutive assumption for the internal energy (or entropy).

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MS26

Combined Finite Volume-Finite Element Scheme for Compressible Two Phase Flow in Porous Media

We present an industrial scheme, to simulate the two compressible phase flow in porous media. For homogeneous and isotropic diffusion tensor, this scheme consists in an implicit finite volume method together with a phase-by-phase upstream scheme which satisfies industrial constraints of robustness. We show that the proposed scheme satisfy the maximum principle for the saturation and a discrete energy estimate on the velocity of each phase. For inhomogeneous and anisotropic diffusion tensor, we discretize the diffusion term over an unstructured mesh of the space domain by means of the piecewise linear nonconforming finite element method combined with an upwind scheme for the mobility of each phase. We prove the convergence of the scheme, only supposing the shape regularity condition for the original mesh.We use a priori estimates and the Kolmogorov compactness theorem for this purpose. In addition, we present some numerical tests in 2D on an unstructured mesh for water-gas flows in porous media.

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MS27

Towards Large-Scale Compositional Simulation of CO2 Enhanced Oil Recovery (EOR)

This talk will focus on the simulation of CO2 EOR, and discuss simulation performance (accuracy and efficiency) for various techniques. The impact of model complexity (e.g., reservoir heterogeneity, relative permeability, and miscible vs. near-miscible displacements) is illustrated, and we discuss the use of upscaling to speed up the simulation. It is shown that the combined use of parallel simulation, Adaptive Implicit (AIM) models, and upscaling makes it possible for large-scale simulation of CO2 EOR.

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MS27

A Multi-Physics Approach to Model Compositional Flow on Adaptive Grids.

A multi-physics approach is presented that reduces the numerical model complexity locally in an adaptive manner to lower the computational efforts per cell. This approach is combined with adaptive refinement of the grid that uses a multi-point flux approximation in combination with the standard two- point flux stencil. The combination of both approaches allows for an efficient simulation of compositional multi-phase flow, such as a large-scale scenario of CO2 storage.

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MS27

Application of Saturation Functions and Implication of Representing Complex Dynamical Systems in Up-Scaled Models

Compositional reservoir simulations of gas displacement processes incorporating complex phase behavior and dynamic movements of phases will be presented. Based on consistent handling of two-phase saturation functions to three-phase conditions, examples of Water-Alternating-Gas (WAG) injection will be illustrated in 1D and 2D models. Saturation history development for immiscible and miscible WAG injection processes in a 2D trough cross stratified sandstone model at mesoscopic scale heterogeneities will be demonstrated. Important issues for up-scaling will be addressed.

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MS27

Accurate and Efficient Modeling of Near-Miscible Gas Injection at Reservoir Scale

In this presentation I will focus on important aspects of a near-miscible gas injection simulation. That will include efficiency of thermodynamic computations, accurate phase state identification, important details of nonlinear formulations and nonlinear solvers. Development of miscibility and its accurate treatment in a compositional simulation as well as possible scaling strategies for gas injection processes will be also discussed.

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MS28

Combing Models of Ice Dynamics and Subglacial Hydrology

I will present recent attempts to model hydrologically controlled acceleration and deceleration of ice-sheets. In particular, I will described a coupled model in which ice deformation is described with a vertically integrated model incorporating large amounts of basal slip, and the subglacial drainage system is described by a water sheet of variable thickness. The model will be forced by a prescribed rate of melting of the ice surface, the meltwater being routed through the drainage system and causing variation in basal slip as a result. I will explore and discuss different ways of describing the evolution of the drainage system and of coupling the drainage system to ice flow.

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MS28

Discretization and Solvers for the Stokes Equations of Ice Sheet Dynamics at Continental Scale

Ice sheets exhibit incompressible creeping flow with shear-thinning rheology. On a continental scale, the flow is characterized by localized regions of fast flow that are separated from vast slow regions by thin transition zones. We use a parallel, adaptive mesh, higher-order finite element discretization to model in 3D the equations for ice sheet dynamics on a continental scale. We will address issues related to the scalable solution of the resulting equations, with emphasis on the nonlinear rheology and addressing the effects of a highly anisotropic discretization.

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MS28

Advances in Ice-Sheets Simulations, Models Comparison and Parameters Estimation

Several models of different complexity and accuracy have been proposed for describing ice-sheet dynamics. We introduce a parallel, finite element framework for implementing these models, which range from the ”shallow ice approximation” up through nonlinear Stokes flow. These models make up the land ice dynamical core of FELIX, which is being developed under the Community Ice Sheet Model. We present results from large-scale simulations of the Greenland ice-sheet, compare models of differing complexity and accuracy, and explore different solution methods for the resulting linear and nonlinear systems. We also address the problem of finding an optimal initial state for Greenland ice-sheet via estimating the spatially varying linear-friction coefficient at the ice-bedrock interface. The problem, which consists of minimizing the mismatch between a specified and computed surface mass balance and/or the mismatch between observed and modeled surface velocities, is solved as an optimal control problem constrained by the governing model equations.

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MS28

Modeling the Response of Pine Island Glacier, West Antarctica, for the next 50 years

Pine Island Glacier experienced spectacular changes over the past decades, which are attributed to warmer ocean waters in the Amundsen Sea affecting the floating part of Pine Island. We use ISSM and a three-dimensional higher-order model to simulate the evolution of the glacier for the next fifty years and assess the effect of changes in several climate forcings and model parameters, namely basal melting under the floating part, ice front position, atmospheric conditions and grounding line retreat, on ice dynamics.

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MS29

A Mixed Order Scheme for the Shallow Water Equations

Learn how to use mixed order schemes for faster simulation of the shallow water equations. This session will explain how the use of different order schemes within the same simulation can give higher numerical performance with a minimal impact on accuracy. We present the implementation of our numerical scheme on the GPU, discuss the accuracy of the approach, and benchmark how well it maps to the underlying computational hardware.

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MS29

Lateral Coupling of 1D-2D Shallow-Water Equations

There are numerous situations in hydraulic engineering (dam breaks, flooding events...) that require numerical simulation. Since large domains are often considered, yielding significant computational cost, it is still remaining a challenging domain.1D and 2D tools developed by Electricité De France, respectively called Mascaret and Telemac2D , are widely used to solve this kind of free surface flow problems. They are based on solution of the shallow water equations. In this study, we aim at coupling these two codes in order to benefit from their different assets in the same computation.. To this end, a lateral coupling technique without overlapping has been developed.. This coupling based on transversal local Riemann solver is described and validated on academic test cases.

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MS29

Coupling 1-D and 2-D Shallow Water Equations for Flood Modelling

Rubar 3 and Rubar 20 developed by Irstea solved respectively 1-D and 2-D shallow water equations using similar finite volume Godunov type second order schemes. Their coupling is built on a calculation of the exchange terms using the 2-D method. Two examples are shown: an experiment in which a pipe is connected with one street simulating the calculation unit for urban flood and the annual flood in the Inner delta of the Niger River.

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MS29

Computational Methods for Coupling 1D channels in Complex Shallow Water Networks

We present two methods for coupling 1D channels in complex shallow water networks. In the first method, 1D channels are connected through local 2D unstructured mesh patches. The second technique replaces the 2D patch by a single, specially chosen 2D element. Both methods work well for all flow regimes, including bores, with CPU-time savings of two orders of magnitude relative to a full 2D treatment.

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MS30

En-Route Data Assimilation

Assimilation of data collected by Lagrangian or pseudo-Lagrangian instruments such as drifters, gliders, or floats, and in particular subsurface data, is of great interest, but difficult because the subsurface paths are unknown. Our recent work introduces an observation operator which allows us to express these en-route observations as a function of the state vector of the model at the measurement time. We show the efficacy of this en-route data assimilation scheme.

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MS30

Towards Improvement of Climate Models Using Data Assimilation

The data assimilation problem is traditionally a state estimation problem, combing observational data with a numerical model to create an improved estimate of the current state from which to make forecasts. We will look at the inverse problem of using observational data coupled with state-of-the-art data assimilation techniques to incrementally improve the forecast model. This will include estimation of non-global parameters as well as stochastic parameterization of unseen dynamics.

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MS30

Assimilation and Model Error for a 3D Ocean Process Model

A simple kinematic model of a wind-forced three dimensional ocean eddy can illuminate complex dynamics of the fluid flow. However, a kinematic model alone cannot hope to perfectly describe reality or the data one may collect. As such we propose modeling the difference between the kinematic model and data as a random function which we refer to as a bias. Once the random function is fit, we use the now bias-corrected kinematic model to explore the eddy dynamics.

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MS30

Pseudo-Orbit Gradient Descent for Lagrangian Data Assimilation

A nonlinear approach to data assimilation, known as pseudo-orbit gradient descent, is presented and illustrated in the context of assimilating Lagrangian tracer trajectories in two-dimensional flows of point-vortex systems. The approach centers on minimizing a cost function in sequence space, initialized with the noisy observations. The tracer advection equations augment the point vortex model equations, allowing the observed tracer positions to update the state information about unobserved vortex positions. Pseudo-orbit gradient descent has been successfully demonstrated for the case of both full and partial observations.

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MS31

Modeling Coupled Hydro-Mechanical Phenomena in the Near Field of a High-Level Radioactive Waste Repository in Clay Formations

Clay/shale formations are being investigated as potential host rock for geological disposal of high-level radioactive waste throughout the world. This presentation discusses advanced computational methods for modeling the coupled hydro-mechanical processes occurring near repository tunnels as a result of tunnel excavation, ventilation, waste emplacement, and gas production. We also touch on how these methods are being tested against in situ experimental data from underground research laboratories.

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MS31

Can CCS Find Synergies with Geothermal Energy and Shale Gas Production?

Currently, the only realistic path forward for implementation of large-scale Geological Carbon Storage is through synergistic activities that can provide positive economic drivers for CO2 storage. Two such possibilities are CO2 injection as part of a geothermal production strategy, and injection of CO2 into depleted shale gas formations. Comparison of simulation approaches for these two systems with simulation approaches for CO2 injection into deep saline aquifers highlights the challenges associated with these alternate strategies.

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MS31

Coupled Thermal Models with Vertical Equilibrium

Coupled thermal and fluid flow processes should be considered when modeling CO_2 injection and storage. Often, CO_2 is injected at a different temperature than geothermal conditions, leading to significant density differences within the plume. This impact is particularly important for injection sites near the critical point. We couple heat transfer within the vertical equilibrium framework for fluid flow, which requires an upscaled representation of thermal processes. Simulations are performed for realistic geological storage sites.

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MS31

Lifetime of Carbon Capture and Storage as a Climate Change Mitigation Technology

In carbon capture and storage (CCS), CO2 is captured at power plants and then injected underground into reservoirs like deep saline aquifers for long-term storage. While CCS may be critical for the continued use of fossil fuels in a carbon-constrained world, the deployment of CCS has been hindered by uncertainty in geologic storage capacities and sustainable injection rates, which has contributed to the absence of concerted government policy. Here, we clarify the potential of CCS to mitigate emissions in the United States by developing a storage-capacity supply curve that, unlike current large-scale capacity estimates, is derived from the fluid mechanics of CO2 injection and trapping and incorporates injection-rate constraints. We show that storage supply is a dynamic quantity that grows with the duration of CCS, and we interpret the lifetime of CCS as the time for which the storage supply curve exceeds the storage demand curve from CO2 production. We show that in the United States, if CO2 production from power generation continues to rise at recent rates, then CCS can store enough CO2 to stabilize emissions at current levels for at least 100 years. This result suggests that the large-scale implementation of CCS is a geologically viable climate-change mitigation option in the United States over the next century.

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MS32

Multicore Aware Parallel Simulations of Co2 Geological Storage

We enhance the parallel scalability of the general-purpose Tough2-MP code to consider complex modeling. This talk will focus and the required adaptations of the assembly and the solve phases considering the impact of the mapping of the processes on the physical cores. We will also comment on the extra-costs inferred by the memory hierarchy and the bandwidth limitation. Some illustrative examples of long-term fate of CO2 stored in reservoirs will also be detailed.

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MS32

Assessment of An Hpc Two-Phase Flow Solver in Porous Media for Realistic Cases

In this presentation we address the developments and performance of a two-phase flow solver for porous media. The software library implements the IMplicit Pressure/Explicit Saturation (IMPES) algorithm. To address realistic cases, with millions of degrees of freedom and physical properties with strong variations, a parallel implementation is needed, along with a suitable choice of preconditioners. We present here some tools and techniques that can be used to achieve good performance on modern supercomputers.

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MS32

Improving the Scalability of Reservoir Simulation on Multicore Architecture

Today, reservoir simulators have difficulties to fully harness the power of modern supercomputers: a simulation of several million of active cells barely scales over a few hundred cores when large supercomputers count hundreds of thousands of cores. In this presentation, we discuss our research to improve the scalability of a reservoir simulator by using a fine grain parallelization in an MPI/thread framework. We will focus on the linear solver part which is the bottle-neck of such an approach.

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MS32

Compositional Two-Phase Flow with Disappearing Nonwetting Phase - Modeling and Numerical Simulation of CO2 Sequestration

Carbon Capture and storage is simulated with a two-phase two-component flow model employing a special set of primary variables (capillary pressure / phase pressure) to deal with the (dis-)appearance of the nonwetting phase. The implementation is based on DUNE PDELab. Numerical results of massive parallel simulations for test cases with millions of unknowns on hundreds of cores on the super computer HERMIT (Cray X6) are presented and discussed.

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MS33

Discontinuous Galerkin Multiscale Methods for Elliptic Problems

A discontinuous Galerkin multiscale method for flow in porous media is proposed. Convergence results are presented both for diffusion and convection dominated problems, with heterogeneous data without any assumption on scale separation or periodicity. The multiscale method uses a corrected basis that is computed on patches/subdomains. Linear convergence in energy norm is obtained independently of the data. Numerical experiments confirms the theoretical rates of convergence.

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MS33

Discontinuous Galerkin Multiscale Methods for Advection-Diffusion Problems with Highly Heterogeneous Data

In this talk, we introduce a discontinuous Galerkin heterogeneous multiscale method (DG-HMM) for advection-diffusion problems with highly heterogeneous data. We discuss the stability of the method for both advection and diffusion dominated problems and for general data. Further, we present fully discrete a priori error estimates for locally periodic data. Moreover, we show that under scale separation assumption (e.g., local periodicity) the computational work is independent of the smallest scale in the medium.

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MS33
On Oversampling for the Multiscale Finite Element Method

In this talk, we review several oversampling strategies as performed in the Multiscale Finite Element Method (MsFEM). Common to those approaches is that the oversampling is typically performed in the full fine scale space restricted to a patch. We suggest, by contrast, to perform local computations with additional constraints. The new setting gives rise to a general fully discrete error analysis for the proposed multiscale method with oversampling without suffering from resonance effects.

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MS34
Probabilistic Models of Earthquake Slip for Tsunami Hazard Assessment

Probabilistic Tsunami Hazard Assessment (PTHA) for a community requires sampling the earthquake parameter space of possible seismic events that may cause tsunamis. The distribution of slip on a given fault geometry can greatly affect the resulting inundation, particularly in the nearfield. Recent work will be presented on the use of Karhunen-Loeve expansions to represent slip on the Cascadia Subduction Zone, and use of these models together with GeoClaw for PTHA on the coast of California and the Pacific Northwest.

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MS34
Effect of Heterogeneous Earthquake Slip on Tsunami Run-Up Uncertainty

We first review investigations of tsunami propagation due to heterogeneous slip, with emphasis on uncertainty and predictability. A systematic study of plane wave propagation and uncertainty propagation due to heterogeneous slip from earthquake slip scaling laws all the way to run-up is then presented. Non-hydrostatic hydrodynamic effects are given particular attention. Finally, the effect of heterogeneous slip from real cases such as the 2011 Tohoku tsunami is briefly discussed.

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MS34
Modelling Tsunamis and Problems Constraining the Slip in Mega-Thrust Earthquakes

Mega-thrust earthquakes and tsunamis cause untold destruction. In this talk a new finite volume unstructured grid tsunami model is presented. The model is a finite volume analogue of the P_1^{nc} - P_1 finite element, in which mass conservation is guaranteed not only in a global sense, but within each cell. The model conserves momentum, and accurately handles flooding and drying problems. Results from the Indian Ocean and Japanese Tsunami compare well with flooding and run-up data.

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MS34
Modeling Dynamic Rupture with Implications for An Alaskan-Aleutian Megathrust Earthquake and Resulting Tsunami

We investigate the effects of rate-strengthening-like friction (e.g., Dieterich, 1992) and heterogeneous fault prestress on rupture propagation, slip, free surface deformation, and the resultant tsunami in time (Shuto, 1991; Satake, 2002). Using time-weakening friction as a proxy for rate-strengthening friction, and given fault data along the Alaska-Aleutian megathrust assembled from the Science Application for Risk Reduction team (SAFRR), we are able to dynamically model a Mw9 earthquake and resultant tsunami on a similar megathrust.

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MS35

A Multilevel Domain Decomposition Algorithm for Fluid-structure Interaction in Porous Media

In this talk we consider multilevel domain decomposition algorithms for the numerical solution of fluid structure interaction problems for flows in porous media. From the physical point of view, the use of this class of algorithms is motivated by the need to solve fluid filtration problems in porous media which are characterized by a high heterogeneity in terms of length scale, as it occurs for instance in the case of fractured porous media with complicated geometries. From the numerical point of view, multilevel domain decomposition algorithms are defined with the purpose of combining the advantageous features of both geometric multigrid and domain decomposition methods, such as optimal computational complexity and parallelizable implementation. We investigate the performances of the algorithm in terms of accuracy and computational efficiency by considering the results of some numerical tests for fluid-structure problems naturally arising in the study of porous media fluid flows.

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MS35

Realistic Scale Simulations of Sedimentary Basins

A parallel implementation for the development and evolution of sedimentary basins is proposed. Rocks are modeled as highly viscous fluids in creeping flow regime. When dealing with realistic scales, the number of degrees of freedom becomes huge, and the solution of the discretized problem becomes challenging, especially in the presence of high variations in the physical parameters. In particular, preconditioners that scale well with respect to parallel processes, viscosity ratios and dofs are analyzed.

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MS35

Modeling Mulitscale and Multiphase Flow in Porous Media

We consider multiphase flow, e.g. water and air, in porous media, using an upscaling approach to recently derived phase field models. To this aim, we combine rational thermodynamics, i.e. the assumption of maximum rate of entropy production by Rajagopal and Srinivasa, with formal asymptotic expansion. The result will be a family of twoscale models for several types of microscopic regimes.

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MS35

Water Transport in Partially-molten Ice - A Multiphase Theory Approach

We present a two-phase model for thermo-mechanical evolution of partially molten ice and gravity-driven water extraction. We perform scale analysis and associated model reduction in a physical setting relevant for conditions in the ice layers of moons of outer planets in the solar system (Europa, Enceladus). We revisit the traditional zero compaction length approximation, obtained by omission of the coupling effects between melt flow and ice deformation. We numerically investigate the relation between the shock-like solutions of the zero compaction length model and the wave-train solutions of the full model and examine the effects of the zero compaction length approximation on the character of the water transport.

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MS36

Using the Gibbs-Helmholtz Constrained Eos in Reservoir Simulation

This talk will provide an overview of a general framework for multi-component, multi-phase equilibrium flash calculations, which uses the multi-scale Gibbs Helmholtz Constrained (GHC) equation, and discuss the reliability and efficiency of the flash algorithm, how they are measured, and their relationship to reservoir simulator performance. The multi-scale GHC equation flash algorithm, GFLASH, has been coupled to the Stanford University reservoir simulator, AD-GPRS. Reservoir simulation examples and geometric illustrations are presented to elucidate key concepts.

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MS36

Calculation of Phase Equilibrium: Status and Perspectives

The talk presents an overview of selected computational methods for calculation of phase equilibrium. Topics are equilibrium calculations of relevance for compositional simulation with the classical cubic equation of state. In addition the computational aspects of implementing complex equations of state like SAFT are discussed. For such equations, formulation in terms of volume rather than pressure may be preferable.

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MS36

Gibbs Free Energy Minimization for Reactive Flow in Porous Media

The modeling of CO_2 injection for enhanced oil recovery in carbonate reservoirs entails complex interplay of flow, geochemical reactions and hydrocarbon phase behavior. A new framework for compositional simulation is introduced that integrates reactions and phase behavior using local equilibrium assumption. The equilibrium composition is solution to the constrained nonlinear optimization of the Gibbs free energy function for the system. Two applications are discussed – acid gas solubility and hydrocarbon phase changes in presence of reactions.

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MS36

Multi-Linear Representation of Phase Behavior for Large Scale Gas Injection Simulation

We describe an Adaptive Compositional Space Parametrization (ACSP) method for compositional flow simulation. The method is based on casting the nonlinear governing equations in terms of the tie-simplex. The tie-simplex space is directly discretized using a limited number of tie-simplexes. The coefficients in the governing system of equations, including the composition, density, and mobility of the phases, are computed using multilinear interpolation in the discretized space. The ACSP completely replaces all the standard EOS computations

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MS37

Block-Structured Adaptive Mesh Refinement in the Bisicles Ice Sheet Model

The BISICLES ice sheet model employs a block-structured mesh of rectangular cells to obtain high resolution at the grounding line. In some ways that is restrictive compared to (say) an unstructured mesh of triangles, but it has three points in its favor. First, it is straightforward to use new meshes as a simulation progresses. Second, it is natural to construct a geometric multigrid solver for the stress-balance equations. Thirdly, domain decomposition is easy.

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MS37

Grounding Line Migration in a Full-Stokes Model: from Processes to Applications

We examine here the possibility of modeling Antarctic outlet glaciers using the full-Stokes finite-element model Elmer/Ice. Process studies of the grounding line dynamics on synthetic regular bedrocks are first discussed and compared with analytical results. Further simulations showing the evolution of actual systems are presented and compared with obserbations.

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MS37

Mesh-adaptive Approaches to Numerical Grounding Line Migration

Central to the evolution of marine ice sheets that could potentially make large contributions to sea level rise in coming centuries is the evolution of grounding lines, a process difficult to represent numerically, largely due to issues of resolution. I will show numerical results of several mesh-adaptive approaches that attempt to deal with these issues. I will discuss the strengths of weaknesses of each approach, and compare with an existing quasi-analytical approach.

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MS37

Review of Adaptive Methods for Marine Ice Sheet Models

Adaptive mesh refinement methods are required to account

for the sharp changes of the dynamical regime of ice in the transition zones between ice sheets and ice shelves. The empirical criterion, which consists of strongly refining close to the grounding line, is easy to implement but not optimal. In contrast, a new family of methods based on error estimates has appeared in recent years. This talk aims to give a comparative overview of such methods.

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MS38

One-Dimensional Finite-Volume Modelling of the Flow and Morphological Processes During the 1996 Lake Ha!Ha! Dyke Break Event

The Lake Ha!Ha event is chosen as an example of extreme flow to highlight two key issues in numerical simulations of real events: the discretisation of topographical source terms in very irregular and evolving cross-sections, and the representation of morphological processes when erosion affects the river banks as well as the river bed. A finite-volume modelling framework is used to conduct the analysis first from a pure hydrodynamical point of view, and secondly by including morphological processes.

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MS38

2D Depth Integrated Modeling of Morphodynamical Processes: A New Algorithm for Unstructured Grids

In recent years many complex multi-phase or multi-layer models were proposed for modeling water and sediment flows in unsteady conditions. Moreover representation of complex geometries can be achieved using a unstructured mesh. In the present paper an ad-hoc algorithm for unstructured triangular cells is proposed. It is demonstrated that the algorithm is globally mass-preserving. Effectiveness of the proposed approach is demonstrated by the numerical integration of the morphodynamic model proposed by Greco et Al. (2012).

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MS38

Local Adaptive Mesh Refinement on the GPU

We present the implementation of adaptive mesh refinement (AMR) for shallow water simulation on the GPU. AMR significantly increases accuracy, with little impact on computational cost compared to increasing grid resolution for the entire domain. Mapping the AMR algorithm to the GPU, however, is non-trivial. Our implementation targets the second-order accurate Kurganov-Petrova central scheme. We present implementation details, difficulties, key insights, and performance benchmarks.

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MS38

A GPU Implementation of High-Order PVM Finite Volume Schemes for Shallow Flows on Triangular Meshes

In this work we present a CUDA implementation of the high-order WENO reconstruction operator proposed by M. Dumbser and M. Käser for triangular meshes. We use this reconstruction operator in combination with the PVM-IFCP sheme in order to simulate one an two-layer shallow water flows achieving second and third order accuracy. Finally, we perform an analysis of the obtained precision and efficiency with respect to CUDA implementations of the first order PVM-IFCP scheme for one and two-layer shallow water systems.

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MS39

Targeting Observations and Parameter Estimation Techniques Within Ensemble Data Assimilation

We explore novel data assimilation techniques for two model problems of potential meteorological interest. Using the local ensemble transform Kalman Filter (LETKF), our main result demonstrates LETKF with targeted observations based on largest ensemble variance is skillful by outperforming LETKF with randomly located observations. We implement the parameter estimation method SPEEK to further improve state estimation. We also determine the effect that number of observations, ensemble size, and localization radius have on state estimation.

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MS39

The Onset of Desertification: the Dynamics of Vegetation Patterns under Slowly Varying Conditions

In this talk we introduce a conceptual model for vegetation patterns in semi-arid ecosystems on sloped terrains. We consider the onset of pattern formation through a Turing/Turing-Hopf bifurcation by varying the parameter (A) that measures yearly rainfall. We numerically construct Busse balloons to follow the family of stable spatially periodic (vegetation) patterns into the realistic area of localized vegetation patterns. Next, we assume that A is a slowly decreasing function and study the trajectory of the patterns through the Busse balloon. We find that the vegetation patterns undergo 'mini-catastrophes' as the trajectory approaches the boundary of the Busse balloon before they reach the final catastrophe of desertification.

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MS39

Pseudo-Orbit Data Assimilation for Atmospheric Gcms

Data assimilation for nonlinear models such as weather forecasting models is a challenging task. A promising alternative approach is proposed to produce more consistent estimates of the model state, and to estimate the (state dependent) model error simultaneously, using the Pseudo-orbit Data Assimilation method with a stopping criteria. This method is shown to be more efficient and more coherent than the variational method and outperform the Ensemble Kalman Filter in nowcast on large scale models.

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MS39

Automatic Identification of Oceanic and Atmospheric Coherent Structures As Minimal Flux Regions Using Transfer Operators

Optimally coherent sets are the most efficient transporters of geophysical flow mass (eg. water mass or air mass). We describe a recent numerical method that uses Lagrangian information to detect and track optimally coherent sets in time-dependent geophysical flows. We illustrate the new approach by tracking Agulhas rings, and accurately determining the locations of the Antarctic polar vortex. The method works naturally in two- and three-dimensions, and can handle both advective and advective/diffusive dynamics.

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MS40

Experimental Investigation of Shale Gas Production Impairment Due to Spontaneous Imbibition of Fracturing Fluid Following Wellbore Stimulation.

A series of laboratory experiments were conducted to mimic spontaneous imbibition of water-based fracturing fluid into fractured shale formations and investigate its impact on gas production impairment. The imbibing front was monitored using X-ray computed tomography, which allowed us to map saturation at controlled time intervals. Results are compared against similar experiments in tight sand and Berea sandstone samples in terms of regained permeability and evolution of saturation profiles.

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MS40

Competitive Usage of Sub-Surface Systems: How Can Modeling Help to Quantifiy Potential Impacts and Risks?

Global climate change, shortage of resources and the growing usage of renewable energy sources has lead to a growing demand for the utilization of subsurface systems. Among these competing uses are Carbon Capture and Storage (CCS), geothermal energy, nuclear waste disposal, "renewable" methane or hydrogen storage as well as the ongoing production of fossil resources like oil, gas and coal. Additionally, these technologies may also create conflicts with essential public interests such as water supply. For example, the injection of CO2 into the subsurface causes an increase in pressure reaching far beyond the actual radius of influence of the CO2 plume, potentially leading to large amounts of displaced salt water. In order to be able to asses the large scale impacts of different technologies it is necessary not only to consider the reservoir itself but also the regional hydrogeology. This is especially important for the vertical migration of displaced formation fluids or contaminants. Structures such as fault zones or salt domes are

considered as potential pathways for displaced fluids into shallow systems and their influence has to be taken into account.

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MS40

Simulation of Coupled Flow and Reactive Transport in Porous Media by MFEM with Application to Concrete Carbonation

We discuss a prototypical reaction-diffusion-flow scenario in saturated/unsaturated porous media. The special features of our scenario are: the reaction produces water and therefore the flow and transport are coupled in both directions and moreover, the reaction may alter the microstructure. This means we have a variable porosity in our model. For the spatial discretization we propose a mass conservative scheme based on the mixed finite element method. The scheme is semi-implicit in time. Error estimates are obtained for some particular cases. We apply our finite element methodology for the case of concrete carbonation – one of the most important physico-chemical processes affecting the durability of concrete.

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MS41

Gampack (gpu Algebraic Multigrid Package)

Algebraic multigrid (AMG) has become the preconditioner of choice for solving the pressure subblock of multiphase flow matrices. The serial and irregular nature of traditional AMG algorithms has made accelerating them on massively parallel processors difficult. We discuss the approaches we have used to successfully accelerate AMG on multiple GPUs by employing algorithms with sufficient fine-grained parallelism. We then compare the performance of our GAMPACK solver with CPU-based AMG solvers for matrices arising from reservoir simulation.

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MS41

Arcfvdsl, a Dsl in C++ to Develop Diffusive Problems in Geoscience for New Hybrid Architecture

Industrial simulation software have to manage: *(i)* the complexity of the underlying physical models, *(ii)* the complexity of numerical methods used to solve the PDE systems, and finally *(iii)* the complexity of the low level computer science services required to have efficient software on modern hardware. Nowadays, some frameworks offer a number of advanced tools to deal with the complexity related to parallelism in a transparent way. However, high level complexity related to discretization methods and physical models lack of tools to help physicists to develop complex applications. Generative programming and domain-specific languages (DSL) are key technologies allowing to write code with a high level expressive language and take advantage of the efficiency of generated code for low level services. In our paper, we present a C++ Domain Specific Embeded Language (DSEL) to implement multiscale methods for elliptic problems in porous media with a high level of abstraction allowing to separate the low level layer necessary to have performance on new hybrid heterogeneous mutiprocessors architecture with data-parallel accelerators. We focus on the capability of the language to design complex multi-scale methods and we present the abstract object oriented runtime system model allowing to adress heterogeneous architecture. We present some performance results on various hybrid platforms.

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MS41

Scalability of a Multi-Phase Code for Performance Assessment of a Radioactive Waste Disposal in Porous Media

The French National Radioactive Waste Management Agency (Andra) runs numerical simulations to assess performance of radioactive waste disposal in geological media. Parallel mpi based code TOUGH2-MP has been used for years to perform multi-phase simulations on this topic.According to grid of millions cells and long time simulated, scalability of TOUGH2-MP has been studied on Linux clusters (Intel and AMD) up to 2048 cores for various physical situations and results are presented here.

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MS41

Multi-GPU Parallelization of Nested Factorization Linear Solver

We describe a massively parallel Nested Factorization (NF) linear solver. The key features are: 1) a special ordering of the matrix elements that maximizes coalesced memory access, 2) application of twisted factorization, which doubles concurrent threads at no additional cost, and 3) extension to multiple GPUs by overlapping memory transfer between GPUs with solution of the interior regions. The 6-GPU solution of a 26.9M-cell model is more than five times faster than the single-GPU solution.

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MS42

The Localized Reduced Basis Multiscale Method

We present the *Localized Reduced Basis Multiscale* (LRBMS) method for parameter dependent heterogeneous elliptic multiscale problems [F. Albrecht, B. Haasdonk, S. Kaulmann, and M. Ohlberger. The Localized Reduced Basis Multiscale Method. *In A. Handlovičová and Z. Minarechová and D. Ševčovič (editor(s)): ALGORITMY* ***2012*** *- Proceedings of contributed papers and posters (2012), 393–403*]. This method brings together ideas from both Reduced Basis methods to efficiently solve parametrized problems and from multiscale methods in order to deal with complex heterogeneities and large domains. We present recent developments of the method and applications in the two-phase flow context.

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MS42

Analysis of a Control Volume Hmm for Multi-Physics Problems in Porous Media

We discuss conservative methods based on the heterogeneous multiscale methodology. The key ingredients are locally conservative control volume methods on the coarse scale, coupled with local solvers for the fine scale problems, thus providing proper effective relationships among coarse scale parameters. We place particular emphasis on proper handling of coarse-scale heterogeneities.

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MS42

Coupled Local-Global Model Reduction for Compressible Flows in Highly Heterogeneous Porous Media

The governing equations for porous media problems consist of coupled processes that can vary over multiple scales. Because of disparity of scales, the direct numerical simulations of these processes are prohibitively expensive. This presents the need to develop simplified models to significantly reduce the number of degrees of freedom while neglecting irrelevant details of the involved physics. In this work, we apply dynamic mode decomposition (DMD) and proper orthogonal decomposition (POD) on compressible flows in highly heterogeneous porous media to extract the dominant coherent structures and derive a reduced-order model. Different permeability fields are considered to investigate the capability of these techniques to capture the main flow characteristics and reconstruct the flow field within a certain accuracy. In most of the cases, DMD-based approach showed a better predictive capability.

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MS42

Computation of Eigenvalues by Numerical Upscaling

We present a numerical upscaling technique for computing eigenvalues of selfadjoint elliptic operators with multiscale coefficients. We compute a low-dimensional generalized finite element space that preserves small eigenvalues in a superconvergent way. The approximate eigenpairs are then obtained by solving the corresponding low-dimensional algebraic eigenvalue problem. The rigorous error bounds are provided.

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MS43

Discontinuous Galerkin Unsteady Discrete Adjoint Method for Real-Time Efficient Tsunami Simulations

An unsteady discrete adjoint implementation for a discontinuous Galerkin model solving the shallow water equations on the sphere is presented. Its use for tsunami simulations is introduced to reconstruct the initial condition automatically from buoy measurements. Based on this feature, a real-time tsunami model is developed, using several numerical tools such as a high-order discretization, hp-refinement, parallel dynamic load balancing and adjoint-based data assimilation. The model is able to reconstruct the tsunami source and accurately forecast its far-field propagation in a computational time 20 times faster than the physical propagation time. The work presented constitutes a step towards an efficient nonlinear tsunami warning model. Additional features could be added for more complete realistic forecasts.

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MS43

Quadrilateral-Based Discontinuous Galerkin Methods with Adaptive Mesh Refinement for the Oceanic Shallow Water Equations

In recent years, we have been working on a triangle-based discontinuous Galerkin shallow water model for simulating tsunamis. This model, DGCOM, is a semi-automated system that allows a user to build a grid along any coastal region and then run the problem. However, DGCOM never included any type of adaptive mesh refinement (AMR). Recently, we have developed a quadrilateral-based discontinuous Galerkin AMR code for various applications including the 1) nonhydrostatic atmosphere and 2) shallow water on the sphere, and more recently 3) shallow water on the plane. In this talk I will describe this new model which we call NUMACOM and will show some benchmark test cases and discuss the addition of inundation algorithms for this high-order quadrilateral-based DG AMR model.

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MS43

Modeling of Tsunami Generation by An Underwater Landslide

A high-resolution model solving for dynamics of a stack of shallow layers in curvilinear co-ordinates has been developed for simulating landslides that can serve as source of tsunami waves. The model relies on the reduced-gravity approximation and solves nonlinear, hydrostatic or non-hydrostatic equations for horizontally inhomogeneous, viscous fluid layers on an f-plane. The dynamical equations are discretized by the finite-difference method and integrated on a rectangular grid, which is the map of the curvilinear grid generated by the elliptic method. Verification and validation of numerical model is performed against the laboratory experiment by Heller (2007) and megatsunami Lituya Bay event.

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MS43

Implementation of Triangular Galerkin Type Adaptive Tsunami Propagation and Inundation Schemes

A tsunami simulation framework is presented, which is based on adaptive triangular meshes with finite element Galerkin type discretizations. This approach allows for high local resolution and geometric accuracy, while maintaining the opportunity to simulate large spatial domains. Within this framework, different discretizations are implemented and compared concerning efficiency and accuracy. Furthermore, the whole evolution of a tsunami event is investigated, from the excitation to the inundation event at the coast.

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MS44

The Multidimensional Muskat Inial Boundary Value Problem

We consider the Muskat Problem for a generalized formulation to Darcy's law equation (Darcy-Brinkman's law). We follow our original idea established in previous work, which is to perturb the Darcy law equation with a positive (small as needed) viscosity term. The mathematical model is formulated as

$$\partial_t \rho + \mathbf{v} \cdot \nabla_{\mathbf{x}}\, \rho = \mathbf{0}, \qquad \partial_{\mathbf{t}} \nu + \mathbf{v} \cdot \nabla_{\mathbf{x}}\, \nu = \mathbf{0},$$

$$h(t, \mathbf{x}, \mu)\, \mathbf{v} - \mathrm{div}_{\mathbf{x}}\big(\mu\, \mathbf{D}\mathbf{v}\big) = -\nabla_{\mathbf{x}}\mathbf{p} + \rho \mathbf{f}, \qquad \mathrm{div}_{\mathbf{x}}\mathbf{v} = \mathbf{0},$$

where $\mathbf{v}$ is the velocity field, $\rho-$the density, $\nu-$the effective viscosity and $\mu = \rho\nu-$the dynamic viscosity. The generalized Muskat Problem is posed in a bounded domain of R^N for two-phase flow (oil-water), that seems more realistic from the physical point of view. We show the solvability of the initial boundary value problem for the system. This is primarily joint work with Wladimir Neves (Institute of Mathematics, Federal University of Rio de Janeiro).

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MS44

Blow-up and Vanishing Properties for a Class of Doubly Degenerate Parabolic Equations with Variable Nonlinearity

Anisotropy and variable nonlinearity lead to certain properties intrinsic for the solutions of doubly degenerate parabolic equations of this type. We discuss the influence of anisotropy on the blow-up and vanishing of solutions and show that for equations with variable nonlinearity the effects of finite time vanishing and blow-up may happen even if the equation becomes linear at time infinity.

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MS44

Regularity of Solutions to Weighted Equations of Porous Medium Type

We establish the Harnack inequality and continuity for nonnegative solutions of nonlinear parabolic equations of porous medium type in the presence of weight. This work incorporates the recent improvements brought to regularity theory by Di Benedetto, Gianazza and Vespri and greatly simplifies the proofs obtained by Ivanov in 80s.

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MS44

Geometric PDE Models for Secondary Structure in Proteins

This report represents a small part of an extensive research project regarding elastic membranes which occur in molecular structures. It applies to the mathematical study of the beta-sheet models which appear in the protein folding. The β sheet (sometimes called β-pleated sheet) is a form of regular secondary structure in proteins (as the most well-known form is the alpha helicoidal sheet). The existing literature approximates the β sheet models by minimal surfaces (catenoidal surfaces). We will prove that the existing model is neither mathematically nor chemically appropriate, and we will propose a different model based on surfaces whose mean curvatures lie in intervals of the form $(h-\epsilon, h+\epsilon)$. Mathematical tools involved are based on differential geometry, calculus of variations, numerical methods and special functions.

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MS45

Modeling Coupled Gas Compositional Flow, Geochemical, and Thermal in Porous Media

Abstract not available at time of publication.

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MS45

Simplified Mineralization Dynamics in Long-Term CO2 Storage

Geological CO2 storage relies upon long-term trapping of CO2 within the storage formation. Knowledge of the efficiency of trapping mechanisms, of which the most permanent is carbon mineralization, is essential for risk analysis. Timescales of mineralization may be comparable to the timescales of dissolution trapping due to convective mixing. We present results regarding the interaction between dissolution trapping and mineralization trapping. We use simplified mineralization dynamics to efficiently explore sensitivity regarding the rate of mineralization.

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MS45

A New Flow-Reactive-Transport Numerical Modeling Framework and Application to Co_2 Mineral Carbonation

Surveys of carbon reservoirs suggest that mineral carbonation is a stable long-term storage mechanism for CO_2 in geologic formations. Simulation of carbonation entails modeling the coupled phase equilibrium, multiphase flow, species transport, and reaction processes. This presentation describes a fully-coupled procedure for general flow and reactive-transport problems in a compositional simulation framework, based on element conservations. The procedure, accomplished within Stanford General Purpose Research Simulator, enables field-scale simulation of CO_2 carbonation in deep saline aquifers.

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MS46

On the Transport of Particles in Oceanic Flows: Modeling, Theory, and Experiments

We study reduced models for transport of particle pollutants in the ocean. The particles transported by the fluid are modeled by another continuum phase, with models resembling dusty-gas or Eulerian ones adapted to the incompressible setting. Theoretical results and some numerical experiments will be shown.

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MS46
Progresses and Challenges in Spectral Multidomain Simulations of Small-Scale Oceanic Stratified Flow Processes

Following an overview of spectral multidomain penalty method (SMPM) fundamentals, we discuss the physical insights enabled by application of a singly non-periodic version of SMPM to the simulation of select small-scale oceanic stratified flow processes. We then present a recent modification of SMPM for quadrilateral subdomains. Emphasis is placed on the challenges, in terms of consistency and preconditioning, resulting from the non-symmetric matrix in the iterative solution of the discretized pressure Poisson equation.

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MS46
Central-Upwind Schemes for 2D Shallow Water Equations

In this talk we will discuss central-upwind schemes for the shallow water equations. These equations are widely used in many scientific applications related to modeling of water flows in rivers, lakes and coastal areas. Furthermore, many real world engineering applications require the use of triangular meshes due to the complicated structure of the computational domains of the problems being investigated. Therefore the development of robust and accurate numerical methods for the simulation of shallow water models in complex domains is an active challenging problem. In our talk we will discuss the recently developed central-upwind schemes for such models. We will demonstrate the performance of the proposed methods in a number of numerical examples. This is joint work with J. Albright, S. Bryson, A. Kurganov and G. Petrova.

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MS46
Reconstruction of the Pressure in Long-Wave Models with Constant Vorticity

The effect of constant background vorticity on the pressure beneath steady long gravity waves at the surface of a fluid is investigated. Using an asymptotic expansion for the streamfunction, we derive a model equation given in terms of the vorticity, the volume flux, total head and momentum flux. It is shown that for strong vorticity, the maximum pressure is not located under the wave crest, and the fluid pressure near the surface can be below atmospheric pressure.

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MS46
Numerical Modeling of Oceanic Turbulent Mixing-Layers

We introduce elements for the mathematical and numerical analysis of turbulence models for oceanic surface mixing layers. Turbulent mixing-layer models are usually vertical first-order closure models, depending on the gradient Richardson number. We propose a model that allows to manage mixing layer flows with horizontal perturbations of the initial conditions. We perform a theoretical and numerical analysis of the model, and a comparison with a general model, based on the Primitive Equations.

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MS47
Multiscale Simulation of Reactive Flow and Transport in Porous Media

In this work we model single, multiphase, reactive, and non-Newtonian flow at the pore and sub pore scales but develop multiscale techniques to bridge the pore and macroscales. A more efficient, novel domain decomposition method is used for upscaling. The medium is decomposed into hundreds of smaller networks (sub-domains) and then coupled with the surrounding models to determine accurate boundary conditions. Finite element mortars are used as a mathematical tool to ensure interfacial pressures and fluxes are matched at the interfaces of the networks boundaries. The results compare favorably to the more computationally intensive (and impractical) approach of upscaling the media as a single model.

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MS47
Adaptive Hybrid Models of Reactive Transport in Porous Media

Continuum-scale models of flow and transport in porous media rely on sets of assumptions and simplifications, and fail to describe experimentally observed phenomena whenever such conditions are not satisfied. This is particularly true for highly localized phenomena, e.g. (bio-) geochemical reactive processes, in which poor mixing at the pore-scale often leads to a localized breakdown of macroscopic equations. In such systems the use of hybrid models, which solve pore-scale equations in a small portion of the computational domain and use their continuum counterparts everywhere else, become imperative. A desirable feature of hybrid models is their ability to track where and when in space and time to use pore-scale simulations, i.e. their adaptability to time- and space-dependent phenomena. In this work, we construct criteria for adaptive hybridization, based on macroscopic dimensionless numbers. This approach allows one to dynamically establish whether or not hybridization is needed at any instances in space and time, by evaluating continuum-scale quantities only. Finally, we implement the proposed adaptive hybridization scheme to reactive flow through a chemically heterogeneous planar fracture.

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MS47

On the Origin of Non-Fickian Transport in Porous Media

The exact relationship between structure, velocity field and non-Fickian transport in heterogeneous media has not been fully understood. A novel methodology is developed that predicts transport on micro-CT images by using probability density functions (PDFs) of displacement and transit times between image voxels, and relates it to PDF of local velocity. A key determinant for non-Fickian transport is the spread in velocity distribution, as demonstrated on beadpack, sandstone and a range of complex carbonate rock.

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MS47

Pore-Network Modeling of Electrokinetic Flow and Transport in Microcapillaries

Electrokinetic transport porous media is a complex coupled phenomenon, which is highly influenced by surface chemistry as well as transport of the ions in the microcapillaries. After derivation of analytical relations for flow and transport in a micro-capillary that include gradients of concentration, pressure and electric potential, these relations are solved numerically in a complex network. Effects of heterogeneity of pore geometry and zeta potential on flow and transport have been studied.

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MS47

Simulation of Film and Droplet Flow on Smooth and Rough Wide Aperture Fractures using Smoothed Particle Hydrodynamics

Gravity-driven flow in fractured porous media exhibits highly dynamical interfaces and a wide range of intermittent flow processes ranging from adsorbed films to droplets, rivulets and wavy surface films. We present a free-surface Smoothed Particle Hydrodynamics model to simulate capillary forces dominated droplet and film flow on dry and prewetted wide aperture fracture surfaces. We demonstrate the various effects of wettability on the flow dynamics and show the influence of surface roughness on maximum Reynolds numbers.

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MS48

Multiscale Simulation of Flow and Heat Transport in Fractured Geothermal Reservoirs with Improved Transport Upscaling

We present a framework for modeling and simulation of flow and heat-transport in fractured geothermal reservoirs, where fractures impact flow and transport at multiple scales. Flow in large-scale fractures are simulated explicitly in the computational model, while flow in small-scale fractures and the porous media is upscaled. The link to the fine-scale solution is kept to enable computation of approximate fine-scale solutions. Based on the approximate fine-scale solutions, upscaling of the transport is improved.

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MS48

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MS48

Space-Time Domain Decomposition For Transport In Porous Media With Fractures

We consider nonoverlapping domain decomposition methods for transport problems in porous media with fractures. The first approach uses the time dependent Steklov-Poincaré operator and the second uses the optimized Schwarz waveform relaxation. Each method enables different time steps in the subdomains. Both d-dimensional and $(d-1)$-dimensional fractures (for a d-dimensional domain) are considered. Numerical results in 2D will be presented.

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MS48

Modeling Subsurface Fractures Using Enriched Finite Element Method

Enriched finite element method (EFEM) allows us to accurately model fractures without having to construct mesh to honor geometries of fractures. In this talk, we will present two applications of EFEM with improved formulations. The first one concerns rapid evaluation of well productivity with fractured completions. Examples will be given on how to use the new method to quantify the impact of non-Darcy effect for different configurations of fractured stimulation. The second application concerns predicting natural fracture patterns under geological loading. The method to model fracture interaction in EFEM will be discussed.

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MS48

A Numerical Method for Two-Phase Flow in Fractured Porous Media with Non-Matching Grids

Two-phase flows in porous media are influenced by the presence of fractures in many relevant applications. Instead of refining the grid to capture the fractures, we represent them as immersed interfaces, using a reduced model for the flow and suitable coupling conditions. We allow for non matching grids between the porous matrix and the fractures to obtain a flexible method for realistic configurations. Numerical fluxes that yield an entropic and conservative scheme are discussed.

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MS49

Compressibility of Porous Materials with Compressible Fluids Using Thermodynamics

There are a variety of compressibilities for porous materials: jacketed, unjacketed, and pseudo-bulk are a few examples. The relationship between these compressibilities traditionally do not account for the volume fraction. Here we present how thermodynamics can be used to determine the relationship between these compressibilities, the volume fraction, and the compressibility of each phase.

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MS49

Modeling Transport of Charged Colloids Including Electrochemically Induced Adhesive Interactions

In this talk, we present a pore scale model describing the transport of charged colloids in a porous medium. Despite diffusion, convection and electrophoretic transport mechanisms, the considered model includes electrochemically induced adhesive interactions. The talk focuses on how to model these additional adhesive interactions which play an important role in many applications.

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MS49

Multiscale Modeling of Colloid and Fluid Dynamics in Porous Media including an Evolving Microstructure

We describe colloidal dynamics and fluid flow within a porous medium at the pore scale. The model consists of the NernstPlanck and Stokes equations including a forcing term. Surface reactions result in an evolution of the microstructure which is captured by a level set function. Applying an averaging procedure in this framework, we obtain Darcys law and a convectiondiffusion equation with time- and space-dependent coefficients. The results are complemented by simulations of a heterogeneous multiscale scenario.

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MS49

Multiscale Adaptive Simulations of Concrete Carbonation Taking into Account the Evolution of the

Microstructure

Concrete carbonation is a chemical degradation mechanism compromising the service life of reinforced concrete structures. Using a homogenization approach to upscale the associated reaction–diffusion system given in a porous medium, whose microstructure undergoes an evolution in time, an effective macroscopic limit model is obtained. To lower the complexity of numerical simulations further, an efficient adaptive finite element scheme for the limit problem is presented. The approach is generally applicable to reaction–diffusion problems in porous media.

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MS49

Conceptual Multiscale Models for Flows in Layered Deforming Media

We present sveral approaches to reduce computational complexity of flow and deformation simulations in double porous media featured by local periodicity which is assumed in the "horizontal directions' for each layer. Homogenized models are obtained which result in the 3D-to-2D dimensional reduction of the associated PDEs, while the microstructure is fully 3D. We develop coupling conditions which enable us to combine models for several homogenized layers to approximate a 3D structure. Applications in tissue perfusion are discussed.

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MS50

Modelling Chemical Reactions in Porous Media with Particle Based Methods

We use a particle-tracking method to simulate several one-dimensional bi-molecular reactive transport experiments. In our numerical scheme, the reactants are represented by particles: advection and dispersion dominate the flow, and molecular diffusion dictates, in large part, the reactions. When compared to the solution of the advection-dispersion-reaction equation (ADRE) with the well-mixed reaction experiments and the particle-tracking simulations agreed well showing 20% to 40% less overall product, which is attributed to poor mixing. The poor mixing also leads to higher product concentrations on the edges of the mixing zones, which the particle model simulates more accurately than the ADRE.

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MS50

Mixing Entropy and Reactive Solute Transport

Mixing processes affect reactive solute transport in fluids. In this work the transport equation for the entropy of a reactive compound is derived and we show that the exponential of the Shannon entropy is an appropriate metric to quantify the interplay between mixing and reactive processes. The degree of uniformity of the solute distribution for a reactive species and its rate of change are informative measures of physical and (bio)chemical processes and their complex interaction.

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MS50

Characterization and Modeling Non-Fickian Dispersion Triggered by Matrix-Diffusion in Porous Media

Mobile-immobile mass transfer model implicitly states that large scale non-Fickian dispersion is controlled by the microscale properties of the media. This model has been applied successfully to interpret tracer tests at many scales using a memory function (MF) as a sink/source term in the ADE equation for describing the transient diffusive mechanisms in the immobile domain. The MF is an intrinsic characteristic of the medium that can be calculated using high-resolution 3D representation of the pore structure.

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MS50

Diffusion and Reaction in Heterogeneous Media: A Continuous Time Random Walk Approach

Reaction kinetics in heterogeneous systems are different from the ones observed in well-mixed reactors. We present an approach to model reactive transport in complex media based on a transport representation in terms of continuous time random walks. In this framework, linear kinetic sorption-desorption reactions are modeled as compound Poisson processes. More general chemical reactions are quantified using a kinetic Monte-Carlo approach. This method allows studying the impact of heterogeneity on anomalous diffusion and reaction behavior.

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MS50
The Architecture of Random Mixtures

The principles of scalar mixing in randomly stirred media, aiming at describing the overall concentration distribution of the mixture, its shape, and rate of deformation as the mixture evolves towards uniformity are reviewed. Then we consider the fine structure of a scalar mixture advected in a random, interconnected, frozen network of paths, i.e. a porous medium. We describe in particular the relevant scales of the mixture, the kinetics of their evolution, the nature of their interaction, and the scaling laws describing the coarsening process of the concentration field as it progresses through the medium, including its concentration distribution.

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MS51
Modeling Arterial Walls As Multi-Layered Poroelastic Structure and Their Interaction with Pulsatile Blood Flow

We present a new model and two novel loosely coupled schemes modeling fluid-structure interaction between an incompressible, viscous fluid and a multi-layered structure, consisting of a thin elastic shell and a poroelastic medium. Elastodynamics of the thin shell is described by the linearly elastic Koiter shell model, while the poroelastic medium is modeled as a Biot system. We present the analysis and comparison of the two methods, and numerical results.

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MS51
A Rigorous Derivation of the Equations for the Biot-Kirchhoff-Love Poroelastic plate

We rigorously study limit behavior of the solution to quasi-static Biots equations in thin poroelastic plates as the thickness in x3 direction tends to zero. At Terzaghis time scale we obtain the norm convergence. The bending and the pressure equations are coupled. Bending equation contains Laplacian of the pressure bending moment. The pressure equation has derivatives only in t and x3 and contains the time derivative of the in-plane Laplacian of the vertical deflection.

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MS51
Geomechanical Coupling Between Poroelastic Reservoirs and Viscoelastic Cap Rocks: Application to Pre-Salt Geological Formations

We construct locally conservative numerical methods for two-phase immiscible flow in a strongly heterogeneous poroelastic rock underneath a saline formation composed of halite and anydrite displaying creep behavior with the viscous strain ruled by a nonlinear constitutive law of power-law type. Numerical simulations are presented of a water-flooding problem in a strongly heterogeneous carbonated rock overlain by a salt dome lying between a two-well vertical arrangement showing the effects of viscoelasicity upon breakthrough curves.

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MS51
Multiscale Modelling and Analysis of Flow, Chemical Reactions and Mechanical Processes in Elastic Porous Media

Microscopic descriptions (at the pore scale) of flow, transport and reactions of substances, and their interaction with mechanics of the solid phase in porous media, lead to coupled systems of partial differential equations in complex geometric structures. We derive an effective description given by the quasi-static Biot system, coupled with the upscaled reactive flow. Effective Biot's coefficients depend on the reactant concentration. Additionally to the weak two-scale convergence results, convergence of the energies is proved.

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MS51

A High-order, Fully-coupled, Upwind, Compact Discontinuous Galerkin Method for Modeling of Viscous Fingering in Compressible Porous Media

We present a new approach for high-fidelity porous media flow simulation, based on a fully coupled, upwind, high-order discontinuous Galerkin formulation of miscible (compressible) displacement transport. The proposed method is flexible on complex subsurface geometries and captures the strong interaction between pressure and transported concentrations in highly compressible media. It also shows very low sensitivity to mesh orientation and its robustness and accuracy are demonstrated in a number of compressible and incompressible multiphase flow problems.

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MS52

Hardware-aware optimization of SeisSol, an unstructured ADER-DG code.

In this talk we give an insight into advanced hardware-aware optimizations applied to SeisSol, a package for simulation of seismic wave phenomena on unstructured grids, based on the discontinuous Galerkin method combined with ADER time discretization. We show how a rigorous enriched pre-compile phase leads to significant speedups. Especially code generation for small sparse matrix kernels, typical for discontinuous Galerkin schemes, is a key point enabling usage of advanced features on state-of-the-art hardware, such as the AVX-instruction set. We also discuss memory access patterns for unstructured grids used in SeisSol, such as element orders or grid-dependent access frequencies to a small number of flux matrices. Finally we give an outlook to optimizations introducing hardware requirements already in the numerical method, which is crucial to prepare SeisSol for next-generation supercomputers.

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MS52

Large-Scale Dynamic Earthquake Rupture Simulations with the Ader-Dg Method: Towards Simulation Based Seismic Hazard Assessment

We aim to understand ground-motion generation from large-scale dynamic earthquake scenarios in 3D Earth structure using the ADER-DG scheme. The method solves the spontaneous rupture problem with high-order space-time accuracy on unstructured tetrahedral meshes. To this end, geometrically complex faults can be accurately discretized and a high frequency content may be generated. The physical problem is challenging for current numerical methods with respect to both algorithmic and computational complexity, and thus requires advanced optimization strategies.

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MS52

Tsunami Alert and Forecast Using a Massive Par-

allel Multiscale Model over French Polynesia

Over the last four years, one widespread tsunami occurred each year in Pacific Ocean which were observed on tide gages and coasts of polynesian islands. The French Polynesia Tsunami Warning Center (CPPT), located on Tahiti, used these last events to improve the accuracy of the tsunami height estimation. In this context, the last tsunamis have been modelled over Pacific ocean to test the accuracy and validate our new local forecast system of tsunami height based on our model using a parallel implementation and our new computational capabilities (2.5 Tflops). The water surface initialization has been computed from Okada's formulation, using seismic parameters evaluated by CPPT. Tsunami propagation has been modelled by a finite-difference numerical model solving shallow water equations. The model is implemented using the domain decomposition technique in conjunction with message passing interface (MPI). The values of tsunami amplitudes, flow velocities and arrival times are compared to the observed data in French Polynesia.

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MS52

The SeisSol Software Package for Tsunamigenic Earthquake Simulations

We will present the SeisSol software package for the simulation of tsunamigenic earthquakes. The dynamic earthquake faulting and the subsequent seismic wave propagation is solved simultaneously by a high order ADER-DG method implemented on unstructured tetrahedral meshes. The package provides a workflow with a concept for mesh generation, pre- and postprocessing tools and solutions for visualization. To demonstrate the advantages of the scheme we will present a subduction earthquake scenario.

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MS53

Comparison of Open Source Porous Media Simulators for Reservoir Engineering Applications

Open-source code provides a chance for sustainable software development in the geosciences, being attractive for academic institutions and industry. Recently, several open-source simulators have been developed for flow in porous media. This talk presents a detailed comparison of some of these simulators for reservoir engineering applications. By means of realistic field-scale scenarios, robustness, efficiency and accuracy are compared by means of various measures. All participating simulators are part of the Open Porous Media Initiative, opm-project.org.

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MS53

Fully Implicit Solvers for Matlab Reservoir Simulation Toolbox (MRST)

We present a framework for development of fully implicit solvers based on automatic differentiation (AD) in the open-source toolbox MRST. With an AD-class for automatically generating Jacobians, solver prototyping basically boils down to writing down the residual equations. It also facilitates easy manipulation of Jacobians, essential for preconditioning. As example we use the code for adjoint-based optimization of net-present-value for a realistic case using the black-oil model.

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MS53

Ensemble Kalman Filter Toolbox in Mrst

An open source Ensemble Kalman Filter (EnKF) module was developed for use with the Matlab-based reservoir toolbox MRST. The module can be used for rapid testing and prototyping of new algorithms and workflows for history matching reservoir models to production or seismic data. This presentation will discuss the functionality included in the module and show examples on both synthetic grids and Eclipse corner point grids.

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MS53

Flow Diagnostics on Stratigraphic Grids

We present a set of simple flow diagnostic tools that can be used to assess the quality of upscaling and quantify uncertainty in reservoir characterization. The tools are based on the computation of time-of-flight and stationary tracer distribution using an Eulerian rather than a streamline formulation. The tools are available as a module in the open-source Matlab Reservoir Simulation Toolbox.

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MS54

Upscaling of Fine Scale Geological Models for Non-Linear Flow Simulations

In this work some classical upscaling methods are extended to the non-linear Forchheimer law. We consider the incompressible and slightly compressible single phase steady state filtration in anisotropic heterogeneous porous media. Our approach is local: the fine grid problem is solved independently on each subregion covering the coarse cell with suitable boundary conditions. The fine solution is then used to determine the coarse cell parameters locally on a single coarse cell.

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MS54

Multiscale Finite Volume Method For High-Contrast Heterogeneous Media

We study the mathematical properties of the MSFV method and detect the cause of its failure in presence of highly heterogeneous transmissibility fields. Local grid- and stencil-based treatments are proposed to resolve this limitation in a general way. For several problems we show that the results of our conservative MSFV are accurate and monotone with no nonphysical peaks.

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MS54

Theory and Software Concepts

Based on a mathematical abstraction layer for multiscale methods such as the heterogenous multiscale method, multiscale finite element methods and the localized reduced basis multiscale (lrbms) method [Albrecht, F. et al., 2012. The Localized Reduced Basis Multiscale Method. In A. Handlovicová, Z. Minarechová, & D. Ševcovic, eds. Algoritmy 2012. Publishing House of STU, pp. 393–403.] we introduce an interface-based software framework enabling exascale computing for multiscale methods. Additionally we present recent results for the lrbms method.

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MS54

Conditional Numerical Simulations of Flow and Transport in Porous Media

In this talk we compare the solutions of flow and transport models obtained by conditional simulations with Monte Carlo and stochastic collocation methods. We show that for both methods the conditioning helps to reduce the uncertainty of the solutions. We discuss a method of simulating the conditional random fields based on the unconditional representation and provide the error estimates associated with the simulation of conditional random fields.

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MS54

Multiscale Parameterization of Geologic Uncertainty

Abstract not available at time of publication.

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MS55

A Finite-volume Approach for Coupled Simula-

tions of Ice, Sediment, and Melt-water Transport

We present a finite-volume approach for simulating coupled ice-related flow processes. The method employs explicit time marching and discrete cell interactions. Ice flow is computed using a second-order shallow-ice approximation (iSOSIA). The inherent benefit of the method relates primarily to the ease with which several types of earth surface processes may be simulated simultaneously. We illustrate the potentials of the approach by simple model scenarios related to the long-term dynamics of alpine glaciers.

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MS55

Inverse Modeling of the Greenland Ice Sheet Flow Dynamics: from Local Sensitivity to Large-Scale Model Initialisation

Over the last two decades, the Greenland Ice Sheet has been losing mass at an increasing rate, with an important contribution coming from acceleration and thinning of numerous outlet glaciers. Representing these changes in flow models is a challenge requiring the development of (i) grid refinement strategies to capture individually the narrow outlet glaciers, (ii) efficient numerical schemes to solve the appropriate flow equations and (iii) inverse methods to constrain poorly known parameters. Here, we will present details and applications of these recent developments from local sensitivity analysis to large-scale model initialisation

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MS55

Estimating the Ice Thickness of Mountain Glaciers with An Inverse Approach Using Surface Topography and Mass-Balance

We present an inverse approach to estimate the ice thickness distribution within a mountain glacier, given transient surface geometry and mass-balance. It is based on the minimization of the surface topography misfit in the shallow ice approximation. Neither filtering of the surface topography nor interpolation of the basal shear stress is involved. Novelty of the method is the use of surface topography and mass-balance only within a time-dependent Lagrangian approach for moving-boundary glaciers.

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MS56

Dynamic Effects and Hysteresis in Two-Phase Flow in Porous Media

We consider a model describing two-phase flow in porous media, where dynamic effects are taken into account in the difference of the phase pressures('tau term').We investigate the existence and uniqueness of weak solutions, starting with the non-degenerate case and then extending to the degenerate case . Then we study the convergence of numerical approximation schemes and the error estimates in the two cases.

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MS56

Hysteresis and Trapping in Two-Phase Flow in Porous Media

The parameters and parameter functions of classical formulations of two-phase flow in porous media - the relative permeability saturation relationship, the capillary pressure - saturation relationship, and the associated residual saturations - show path dependence, i.e. their values depend not only on the state variables but also on their drainage and imbibition history. In my talk I will focus on hysteresis of the standard model and illustrate mathematical implications, modeling challenges and possible applications.

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MS56

A Componnt-Based Eulerian-Lagrangian Formulation for Multiphase Multicomponent Flow in Porous Media

Abstract not available at time of publication.

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MS57

Estimation of Discrete Geologic Facies Distributions from Production Data Using Probability Maps

Conditioning complex geologic facies models to nonlinear flow data leads to a discrete parameter estimation problem. We introduce a probability conditioning method (PCM) that, instead of directly estimating facies distribution, uses the flow data to infer spatial facies probability maps. The probability maps are then used to guide facies simulation. We extend the proposed PCM approach to a Bayesian mixture model formulation for conditional simulation under multiple plausible prior facies connectivity models.

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MS57

Updating Large-Scale Geological Structures and Application to Shallow-Marine Environments

Accurate description of dominant large-scale geological structures in petroleum reservoirs are essential for improved hydrocarbon recovery. In this talk we discuss challenges related to updating of these features. Further, we show an application where the ensemble Kalman filter is used to update facies boundaries and petrohpysical parameters in a field with shallow-marine environment characteristics. The methodology is based on a parameter transformation that ensures better agreement with the necessary Gaussian assumptions.

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MS57

Channelized Reservoir Estimation using EnKF. A Probabilistic Approach

In this study we estimate the locations of facies types that occur in the reservoir domain. We introduce a new object named "signed probabilities field", and probabilities are used as distances from two instances represented by 1 and 0. Then, the ensemble Kalman filter is applied for the objects of this space and with an inverse function we rebuild the facies distribution. We present two examples with different types of complexity, both channelized reservoirs.

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MS57

Multi-Level Estimation of a Layered Subsurface from Sea Floor Electromagnetic Data

We aim to identify large-scale geological structures with different electric conductivities using seafloor electromagnetic data. An implicit representation of the parameter structure related to level-set parameterization is applied to reduce the number of parameters while maintaining structural flexibility. To quantify the model uncertainties we use ensemble-based estimation methods. We balance data fit and stability using a multi-level regularization, while a new technique called shape priors is applied to incorporate geological realism.

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MS58

Vanishing Capillarity Solutions of Buckley-Leverett Equation in Multi-Layer Porous Medium and Their Approximation by a Convergent Phase-by-phase Upstream Scheme.

We present mathematical and numerical tools for approximating two-phase flow models in porous media that consist of different rock types. We study situations where the capillary effects can be neglected within each rock; but at the junctions between rocks, capillarity effects should be carefully taken into account. From the mathematical viewpoint, Buckley-Leverett equation with neglected capillarity admits many different weak solutions. Following Kaasschieter (Comput. Geosci., 1999), using a theory for discontinuous-flux conservation laws we deeply investigate vanishing capillarity limits in dimension one and point out some wrong interpretations of the Kaasschieter's result that appeared in the literature. We derive a simple procedure that selects the physical solution. We use it to design efficient finite volume schemes in multiple space dimensions. In particular, we claim that the phase-by-phase upstream scheme can be adapted to the heterogeneous setting in such a way that it does converge to the physically relevant vanishing capillarity solution.

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MS58

Multi-Phase Multi-Component Flow in Heterogeneous Porous Media

Natural porous media often show a pronounced heterogeneity, which not only influences the permeability but also relative permeability and capillary pressure saturation curves. This is of particular importance for applications like soil physics. We present an approach for the numerical solution of Richards' equation and of multi-phase multi-component flow based on a capillary pressure – phase pressure formulation. Application relevant test cases are solved with a self-centred Finite-Volume scheme and the results are discussed.

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MS58

Finite Volume Discretizations of Two Phase Darcy Flows with Discontinuous Capillary Pressures

This talk deals with the extension of the finite volume vertex approximate gradient scheme to take into account discontinuous capillary pressures for two phase Darcy flows on general meshes. Our approach is based on the choice of the phase pressures as primary unknowns at the vertices which allows for discontinuous saturations at the interface between different rocktypes. The scheme is shown to converge on a simplified model and numerical tests exhibit its efficiency on general meshes.

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MS58

Discontinuous Galerkin Method for Two-phase Flows in Heterogeneous Porous Media with Capillary Barriers

We present an accurate discontinuous Galerkin method with low numerical dispersion for two-phase immiscible incompressible flows in heterogeneous porous media with a discontinuous capillary field. Implicit Euler scheme is used for the saturation equation and the total velocity is reconstructed from the discontinuous Darcy flux in a **RTN** space. The non-linear interface conditions are enforced weakly through an adequate design of the penalties on jumps of the global pressure and the saturation at interface.

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MS59

Nonlinear and Nonlocal: Combined Effects on Reactions

Many transport processes in the subsurface have been shown to be well modeled by equations that are nonlocal in space and or time. Further, many processes, including chemical reactions require a nonlinear modelling approach. In this talk we explore the influence of nonlocal phenomena in nonlinear systems as they pertain to chemical reactions in porous media.

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MS59

Multiscale Methods for Fluid-Structure Interaction with Applications to Poroelasticity

Modeling Fluid-Structure Interaction (FSI) is a complicated task in its own right, but when dealing with complicated microstructure with many scales direct numerical simulation is often impossible. To circumvent this difficulty, using a two-scale homogenization approaches, we are able to obtain a nonlinear effective poroelastic model.

Unlike in the linear poroelastic setting, the effective coefficients are nonlinearly coupled to micro-scale cell equations. We present computational techniques to deal with computing the effective coefficients off-line.

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MS59

Langevin Model for Anomalous Reactive Transport

Under certain conditions, effective transport equations fail to describe accurately reactive transport. In this presentation, a stochastic reduction model based on the Langevin approach will be presented. Numerical discretization and accuracy of the resulting stochastic equations will be discussed in the context of anomalous transport with mixing controlled bimolecular reactions.

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MS59

Quantifying Mixing of Passive Scalars in Heterogeneous Porous Media Flow using Lagrangian Statistics

The role of kinematics in increasing mixing efficiency has been topic of intense research in the past. Mixing consists of stretching and folding of material lines and surfaces, which serve to homogenize the scalar distribution. Mapping these kinematical properties onto mixing measures can help to further our understanding of the system and provide better predictions. In this talk, we quantify mixing measures as a function of the kinematical mechanisms such as straining and shearing on large-scale transport. Our work differs from previous ones in the sense that we focus on investigating the Lagrangian statistics of the spatially variable kinematical measures experienced by solute parcel in enhancing the overall mixing. We map mixing and transport patterns with the spatial structure of velocity fields in terms of its deformation counterparts. Our results illustrate the appearance of coherent structures when we map the spatially varying velocity field onto the kinematical measures. We hypothesize that analyzing the Lagrangian statistics of kinematical measures and its correlation properties can help understand their consequences in mixing of passive scalar. In particular, quantify the correlation properties (auto-correlation and cross-correlation) of the different deformation components.

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MS60

A Water-Hydrogen Gas-Liquid Flow Formulated As a Complementarity Problem

We consider a two-phase –liquid-gas– two-component –hydrogen-water– system in a porous media flow. Water is only in the liquid phase and hydrogen can be in the gas phase or dissolved following Henry's law. This problem arose from the simulation of the migration of hydrogen produced by the corrosion of metallic containers in a deep underground repository of nuclear waste. It is solved using a complementarity formulation and a Newton-min method.

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MS60

Presence of Fluid Phases as a Non-Linear Complementarity Problem

Partly because of phase transitions, miscible fluid flows in porous media tend to be numerically difficult. This talk will present an approach to explicitly deal with phase transitions in the system of equations. For this, the transition conditions are formulated as a set of local inequality problems. We will briefly discuss how this approach can be used for numerical models and flash calculations and compare it to previous approaches by means of several numerical examples.

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MS60

A General Model for Two-Phase Flow in Terms of Multiple Complementarity Conditions

We present the formulation and examine the properties of a general mathematical model for compositional two-phase flow in porous media. We discuss the proper choices of principal variables and subsequent static (flash) equations allowing for any (dis)appearance of one of the phases without the need of variable switching or unphysical quantities. The formulation in terms of complementarity conditions allows for an efficient and stable solution by the semismooth Newton's method.

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MS60

Analysis and Numerical Approximation of Methane Hydrates Model

Modeling of formation and dissociation of methane hydrates is important for energy and climate studies. The nonlinear degenerate PDE model has to account for multiple phases and solubility constraints. An appropriate formulation using monotone operator techniques leads to well-posedness results extending those for a porous-medium equation and Stefan problem. In turn, we can take advantage of complementarity constraints to get convergence results comparable to those for Stefan problem but with a superior solver performance.

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MS61

Adaptive Discontinuous Galerkin Simulations of Shallow Water Flow

Building on the work of Giraldo et al. (2002), we introduce an adaptive triangular Discontinuous Galerkin model for solving the two-dimensional shallow water equations. Accurate Riemann solvers and limiters ensure a correct handling of interfaces between wet and dry cells, while the adaptive mesh, which is created using the library amatos (Behrens et al. (2005)), reduces computational costs without effecting the precision. Several idealized testcases demonstrate the method's accuracy and efficiency.

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MS61

Comparing a DG Dynmaic Core for Local Area Weather Prediction with the Operational COSMO Model

We introduce a dynamic core based on the Discontinuous Galerkin method, implemented within the Dune software framework (www.dune-project.org/fem). Special mechanisms are included for advection dominated flow and for including local grid adaptation. We first study the efficiency, and scalability of the code. To further investigate the effectiveness and efficiency of the code, we compare it with the operational COSMO model in cooperation with the German Weather service.

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MS61

Discontinuous Galerkin Methods for Adaptive Atmospheric Flow

We present higher order discontinuous Galerkin (DG) methods for adaptive atmospheric flow problems. Adaptive DG methods will be applied to standard test cases for atmospheric flow and different adaptation indicators will be discussed. The implementation of the DG methods is based on the software package DUNE-FEM (dune.mathematik.uni-freiburg.de) which is a module of DUNE (www.dune-project.org). The numerical results will be accompanied by a short presentation of implementation details such as dynamic load balancing.

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MS61

A Semi-Implicit, Semi-Lagrangian, P-Adaptive Discontinuous Galerkin Method for the Rotating Shallow Water Equations on the Sphere

As a first step towards construction of a DG based dynamical core for high resolution atmospheric modelling, a semi-implicit and semi-Lagrangian Discontinuous Galerkin method for the SWE is proposed and analysed. The method is equipped with a simple p-adaptivity criterion, that allows to adjust dynamically the number of degrees of freedom employed. Numerical results in the framework of standard idealized test cases prove the accuracy and effectiveness of the method even at high Courant numbers.

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MS62

DuMux As a Versatile Tool for Special Core Analysis

An important problem in the interpretation of special core analysis (SCAL) laboratory data is that during relative permeability measurements a strong interference exists with the capillary forces. To unravel this interference, simulations of the experiments are necessary. The presentation highlights how DuMux has been adapted to simulate SCAL experiments, significantly improving the business impact of SCAL measurements. A web-based user interface to DuMux is made available that can be used free of charge.

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MS62

Multiscale Simulation of Flow in Fractured Porous Media using MRST

Flow and transport in fractured porous media involves processes on a continuum of scales, and a successful simulation strategy requires an adequate representation of the scales. We propose a two-level method, where dominating fractures define the coarse model. Then the long-range correlations in the problem are represented in the coarse model and, moreover, fractures give a physical interpretation of the tangential approximation often applied to determine boundary conditions for localized problems providing the basis functions.

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MS62

Opm Simulation of Polymer Injection

The Open Porous Media (OPM) Initiative provides a set of open-source GPL licensed tools centered around the simulation of flow and transport of fluids in porous media. In this talk we will give an overview of the capabilities of OPM and focus on the Enhanced Oil Recovery module. We will show simulation of polymer injection into a reservoir with heavy oil. Numerical results will be compared with output from commercial tools.

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MS62

MPFA on Adaptive Parallel Grids with Applications to Reservoir Engineering

Large scale simulation of flow through porous media with high spatial resolution of materials and processes require accurate but efficient numerical solvers. One development branch in the simulator DuMu^x addresses this problem by a bundle of sequential (IMPET) solvers which allow the use of non-conforming adaptive and/or parallel grids. Accurate flux approximation on hanging nodes is achieved by MPFA methods and efficient solution of the linear system by a parallel AMG solver.

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MS63

Intercomparison Efforts: An Overview

Abstract not available at time of publication.

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MS63

Intercomparison of Integrated Hydrologic Models

Abstract not available at time of publication.

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MS63

Intercomparison of Geochemical Reactive Transport Models

Abstract not available at time of publication.

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MS63

Intercomparison of Coupled Hydrologic Atmospheric Models

Abstract not available at time of publication.

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MS64

Weak Galerkin Methods for Darcian flow: Heterogeneity and Anisotropy

Abstract not available at time of publication.

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MS64

Connection and Differences of WGFEMs and Other Finite Element Methods

Abstract not available at time of publication.

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MS64
Title Not Available at Time of Publication

Abstract not available at time of publication.

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MS64
Weak Galerkin Finite Element Methods for Helmholtz Equations

Abstract not available at time of publication.

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MS65
Pore-Scale Modeling of Multiphase Reactive Transport with Phase Transitions and Dissolution/precipitation Reactions

We present a pore-scale model for simulating multiphase reactive transport processes including phase transitions and dissolution/precipitation reactions. The model is based on the lattice Boltzmann method (LBM) and combines the single-component multiphase Shan-Chen LB model, the mass transport LBM, and the dissolution/precipitation model. Additional schemes are developed to handle reactive and moving boundaries with complex geometries, to account for liquid/vapor phase transition, and to guarantee mass and momentum conservation in a closed system.

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MS65
Pore Scale and Multiscale Modeling Using LBM

We use GeoDict to generate geometries for representative elementary volumes of real porous medias. The pore-scale flows inside those geometries are simulated by the efficient LBM based on the N-S equation and macroscopic properties are calculated. An efficient upscaling strategy is employed to reduce the CPU time of micro- and macro-scale computations.

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MS65
Hybrid Multiscale Methods in Porous Media

One of the most significant challenges facing hydrogeologic modelers is the disparity between those spatial and temporal scales at which fundamental processes can best be understood and quantified (e.g., microscopic to pore scales, seconds to days) and those at which practical model predictions are needed (e.g., plume to aquifer scales, years to centuries). We review a range of approaches to this challenge, focusing on methods that directly integrate models defined at multiple distinct scales.

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MS65
Accounting for Saturation History in Image-Based Pore-Scale Modeling of Two-Phase Flow

Multiphase flow behavior depends on saturation history in many situations, which poses problems for traditional Darcy-scale models (which treat the parameters as state functions of saturation) and also for pore-scale models that employ periodic boundary conditions (saturation cannot evolve naturally from the physics). In this paper we present a pore-scale algorithm for dynamic two-phase flow that operates on non-periodic domains using pressure gradient and inlet fractional flow as boundary conditions. This enables the model to be used to study a wider variety of multiphase flow conditions and to couple the algorithm to continuum models.

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MS65
Large-Scale Computations of Flows with Inertia and Anisotropy Based on Micro-Imaging Data

Based on computational solutions of Navier-Stokes equations in geometries representing porous media at a pore scale, we study flows for a wide range of velocities. Our main focus is on performing simulations on voxel-based micro imaging real 3D data sets. Compared to synthetic geometries, this brings challenges due to size, data resolution, and complexity of structures. We propose a practical power-based fully anisotropic non-Darcy model at corescale with parameters computed by upscaling.

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MS66

Local Time-Stepping and High-Order Discretization for Wave Propagation

We present a local time-stepping method combined with a high-order spectral element spatial discretization, for seismic wave propagation on locally refined meshes. This space-time discretization is fully explicit. Local time-stepping methods however reduce the severe stability restriction of explicit time-stepping scheme. The coarse and fine part of the mesh is here determined by the relation among the mesh-size h and the polynomial order N. Numerical experiments illustrate the efficiency of the proposed method.

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MS66

Seismic Elastic Modeling for Seismic Imaging

We shall discuss the pros and cons for forward modeling of elastic waves considering volumetric methods, boundary integral approaches and asymptotic formulations. Finite difference methods are efficient. However, they suffer from limitations not met by finite element methods. Boundary integral approaches are quite efficient especially using fast moment methods although simple heterogeneities should be considered between boundaries. Asymptotic methods have not met too much attention when considering full waveform inversion. We may see why.

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MS66

High-Order High-Throughput Numerical Methods for High-Contrast Seismic Imaging

We will discuss numerical and computational issues driving research into high-resolution methods for accurately resolving wave propagation in high-contrast media. In particular we will compare accuracy and efficiency of mass lumped finite elements, spectral elements, and discontinuous Galerkin based solvers for acoustic and elastic wave scattering problems. We will discuss the structure of the methods and how this relates to their parallel scalability on modern hardware accelerators.

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MS67

Modeling Biofilm Formation Within Microfluidic Channels

Despite multiple diseases causing widespread damage to the citrus, wine, and other fruit industries, there has been little attention paid to modeling biofilm development and progression of many plantal bacterial infections. A multiphase modeling framework will be used to examine the dynamic behavior and fluid/structure interactions of biofilm colonization within microfluidic channels. Linear stability analysis will be used to determine potential causes and tendencies of a robust, regular spatial patterning visualized in a laboratory setting.

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MS67
Modeling of Bacterial Growth, Adhesion and Transport in Porous Media

We introduce a numerical simulator for multiphase multicomponent reactive flow in porous media, which is able to consider simultaneously multiphase flow, component transport, phase exchange and microbiological processes. The observed behaviour of *Escherichia coli* like growth, adhesion and biofilm formation onto sand grains was added to the simulator. The results of numerical simulations of *E. coli* growth and transport in the capillary fringe, with nutrient supply under steady-state and transient flow conditions are finally compared to the experimental data.

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MS67
Upscaling of Thin Layer Flows Involving Reactions at Moving Solid-Fluid Interfaces

We consider pore scale models for reactive porous media flows, with particular focus on the case when the reaction product deposits in layers having non-negligible thickness when compared to the pore size. This leads to models involving moving interfaces between the fluid and the deposited layer. After addressing some modeling details, we consider a simplified geometry for which we derive upscaled models. These results are further extended to transport dominating diffusion, and to biofilm growth.

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MS67
Remediation in Porous Media by Bacterial Chemotaxis and Bioclogging

We model the degradation of pollutants in porous media by chemotactically moving bacteria that react with the contaminants. Chemotaxis describes the influence of the locomotion of organisms toward or away from the concentration gradient of a chemical species. A second species of bacteria can form strong biofilms which can be used as biobarriers to restrict the flow of the pollutants. Concerning the corresponding system of PDEs we discuss some analytical results and numerical simulations.

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MS67
Interaction of Reactive Flow with Solid Phase, Leading to Changes in Volume and Mechanical Properties - Mathematical Modelling and Simulation

The interaction of reactive flow with solid phase is an important aspect in various applications, e.g. plaque formation in blood vessels. In this talk, we formulate a model to describe this process. This includes the interaction between flow and solid, and the penetration of chemical species in the solid phase. Numerical simulations illustrate changes in volume of the solid phase, and increase stress values.

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MS68
Miscemetry in Reactive Transport

Simulation of groundwater flow and transport relies on upscaling fluid dynamics and linked reactive processes specified at pore- or column-scales. Upscaling failure has led many to refocus on ”mixing measures” as proxies for reactions. I review this approach as one of calculating the exposure-time of one solute to another, and develop (eulerian) equations governing the evolution of a solute over space, time, and mixing extent. Limitations associated with transition state theory are introduced.

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MS68
Scaling of Convective Mixing in Porous Media

Convective mixing in porous media results from a Rayleigh–Bénard-type instability resulting from a higher density fluid mixture overlaying a light fluid. Here we study the scaling of dissolution fluxes by means of the variance of concentration and the scalar dissipation rate. The fundamental relations among these three quantities allow us to show that the classical model of convective mixing in porous media exhibits, in the regime of high Rayleigh number, a dissolution flux that is constant and independent of the Rayleigh number. Our findings point to the need for alternative explanations of recent nonlinear scalings of dissolution flux observed experimentally.

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MS68
Probability Density Function of Concentration in Porous Media

We study the mixing of a scalar line transported in a two-dimensional porous media under heterogeneous advection and diffusion. We propose a theoretical framework to quantify the overall concentration distribution, predicting its shape and rate of deformation as it progresses towards uniformity. Analytical expression for the temporal scaling of the concentration moments and the scalar dissipation rate are derived for all times. High resolution numerical simulations of flow and transport in heterogeneous permeability fields provide a detailed quantification of concentration distribution, which validates the theory.

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MS68
Magnetic Resonance Measurement of Transport Dynamics and Mixing in Biogeochemical Precipitation

Geoengineering the subsurface to sequester carbon dioxide is a current topic of societal and technological interest. Significant theoretical advances in modeling and simulation of reactive transport processes in porous media have occurred recently. Noninvasive magnetic resonance (MR) measurement of the water phase molecular displacement length and time scale dependent dynamics due to hydrodynamic dispersion in porous media characterize transport and mixing. The use of MR data in testing and analyzing reactive transport models is considered.

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MS68
Anomalous Kinetics of Reactive Fronts in Porous Media

The dynamics of reactive transport phenomena in porous media derive from the interaction of microscopic mass transfer and reaction processes. The understanding of observed reaction behavior requires the quantification of these microscale processes and their impact on the large scale reaction and transport behavior. Here we study the mixing limited (fast) reaction A + B -¿ C at the pore-scale, and its effective behavior on the mesoscale, as a paradigmatic case that allow us to provide a connection between local mixing properties and global reaction kinetics

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MS69
Domain Decomposition for Poroelasticity-Elasticity Systems

A domain decomposition framework is discussed, which is applicable for large systems that dynamically couple poroelasticity and elasticity. Mortar finite elements are used to impose physically meaningful interface conditions.

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MS69
Darcy vs Brinkman

Different laws for describing filtration of a fluid through a porous medium can be found in the literature. We focus on Darcy's law and Brinkman's law. They have different mathematical structure, but they can both be derived from the Navier-Stokes system using homogenization in periodic model of porous medium, depending on the magnitude of permeability.

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MS69
Full Finite Volume Discretization for Poroelasticity

The standard approach to discretization of coupled flow and mechanics in geological porous media is to apply finite volume methods to the Darcy flow equation and finite element methods to the deformation equations. We propose an alternative approach where both flow and deformation are discretized using finite volume methods. We construct a novel finite volume discretization for linear elasticity, and highlight the coupling between the flow and deformation discretizations. Convergence is established for homogeneous cases.

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MS69
Coupling Biot and Navier-Stokes Equations for Modelling Fluid-Poroelastic Media Interaction

We focus on a fluid-poroelastic structure interaction problem arising in hemodynamics. The finite element approximation of such a problem is involved because both subproblems are indefinite. Thanks to stabilization techniques, we use the same finite element spaces for all the variables, sim-

plifying the discretization and the enforcement of the coupling conditions. To solve the associated linear system we propose both a monolithic approach and partitioned procedures. We compare all the methods on a test problem.

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MS69

Hierarchical Multiscale Method for Elastic Mechanical Deformation of Naturally Fractured Rocks

A multiscale finite-element method (MSFEM) is developed for solving the elliptic mechanics equation for heterogeneous porous media. Heterogeneity and anisotropy in the elastic properties may be due to the presence of fractures, as well as, geometric complexity of the reservoir architecture. The basis functions, coarse-scale operator, and reconstruction kernels are described in detail. We show that relatively small-scale features can affect the global deformation and stress fields quite significantly, e.g., fault activation and large-scale formation instabilities. We analyze the MSFEM method for naturally fractured systems, both in terms of the quality of the coarse-scale (upscaled) operator and overall computational efficiency.

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MS70

Hybrid Tree-based Approach to Block-structured AMR for Finite Volume Methods

Block-structured adaptive meshes have a long tradition in the numerical solution of hyperbolic PDEs. In contrast, the development of non-overlapping, strictly tree-based AMR methods has been motivated predominantly by low- and high-order finite element discretizations. We present an approach that uses the `p4est` octree algorithms to drive the parallelization of Clawpack-based numerics for conservation laws. We will outline differences and similarities to structured AMR methods and close with presenting preliminary numerical studies.

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MS70

Hybrid Tree-Based Approach to Block-Structured AMR for Finite Volume Methods on the Sphere

Skepticism persists as to whether the use of adaptive mesh refinement (AMR) can improve atmospheric flow simulations. Model developers are reluctant to engage in AMR code development amid concerns that multi-resolution grids are ineffective in the absence of precise error estimators or can damage numerical solutions. We propose a highly scalable, spatially adaptive code to test modern finite volume discretizations on Cartesian grids, and establish their effectiveness on several benchmarks in atmospheric flows.

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MS70

Wavelet-Based Dynamic Adaptivity for the Shallow-Water Equations on Staggered Meshes

This talk presents a dynamically adaptive wavelet method for the shallow water equations on a staggered hexagonal C-grid, designed so it can be extended easily to the icosahedral subdivision of the sphere. Distinct biorthogonal second generation wavelet transforms are developed for the pressure and the velocity, together with compatible restriction operators ensuring mass conservation and no numerical generation of vorticity. The conservation and error control properties of the method are verified by applying it to a propagating inertia-gravity wave packet and to rotating shallow water turbulence. Even in the latter case significant savings in the number of degrees of freedom are achieved.

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MS70

Imex Methods for Continuous and Discontinuous Galerkin Methods for the Compressible Euler Equations: Applications to Nonhydrostatic Atmospheric Modeling

We have been developing 3D fully parallel compressible Euler solvers using high-order continuous (CG) and discontinuous Galerkin (DG)methods. The focus of this model is towards numerical weather prediction at both the limited-area and global scale. In order to improve the efficiency of these models, we construct Implicit-Explicit time-integrators whereby the slow modes (advection) are treated nonlinearly and explicitly while the fast modes (acoustics) are treated linearly and implicitly. In this talk, I will describe the challenges we have faced in constructing IMEX methods for both CG and DG methods. For example, in order to increase the efficiency of the methods requires extracting the Schur Complement of the IMEX system which is non-trivial for DG methods. I will report on the ideas that have proven successful and those that have not for both CG and DG.

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MS71
A Discontinuous Galerkin Scheme for a 2-Equation Vertical Eddy Viscosity Parameterization

Vertical eddy viscosity parametrizations are one of the key components of ocean models affecting the model skill and its performance. Here we discuss our implementation of the 2-equation generic turbulence length scale parametrization (Umlauf, Burchard, 2003) within UTBEST3D – a 3D discontinuous Galerkin simulator. A specialty of our approach is the discretization of the turbulence unknowns with the help of a 1D discontinuous Galerkin method on vertical segments.

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MS71
Adaptive Galerkin Type Methods for Inundation Computations

Tsunami as well as storm surge simulation requires accurate and robust simulation techniques capable of resolving the large scale features (in deep ocean) and the small scale phenomena (usually near the shore). This is achieved by using Galerkin-type (finite element and discontinuous Galerkin) numerical approximations on adaptively refined meshes. In this presentation we focus our attention to efficiency and accuracy of the numerical schemes in inundation applications.

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MS71
Green-Naghdi solutions to the Pressure Poisson equation with Boussinesq-type scaling

One of the most challenging aspects of numerically modeling near shore wave dynamics is balancing computational cost and accuracy. One approach to reducing cost is through Boussinesq–type scaling, however the irrotationality assumption is often invalid for near–shore physics. A Boussinesq–type scaling without the assumption of irrotationality is presented. Solutions to the Pressure Poisson equation using a Green-Naghdi approach are shown to be advantageous in terms of cost and order of the solution.

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MS72
From a Geological to a Numerical Model for Earthquake Generation (and fluids reaction)

We model the state of stress and the circulation of fluids in faults cross-cutting the brittle-ductile transition (BDT). The fault is assumed have stickslip behavior in the brittle crust and to deform by steady-state shear in the ductile crust. These contrasting behaviors determine a stress and strain gradient at the BDT that is dissipated during the earthquake. Changes in porosity and permeability at the BDT from interseismic to coseismic stages control fluid discharge.

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MS72
Surface Water Enables Subduction on Earth: Predictions from Self-Consistent Models

Fully coupled solid-fluid numerical models demonstrate that the presence of surface water controls both initiation and style of subduction via local brittle/plastic rock strength reduction. Although subduction fails to initiate under fluid-absent conditions, it can naturally start and become self-sustaining when porous water is present inside oceanic crust and along the plate boundaries. Fluid percolation localizes along spontaneously forming fractures where high fluid pressure compensates lithostatic pressure, thus dramatically decreasing friction along the subduction zone.

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MS72
Consequences of Viscous Anisotropy in Partially

Molten Rocks

In partially molten regions of Earth, rock and magma coexist as a two-phase aggregate in which the solid grains of rock form a viscously deformable matrix. Liquid magma resides within the permeable network of pores between grains. Deviatoric stress causes the distribution of contact area between solid grains to become anisotropic; this causes anisotropy of the matrix viscosity. The anisotropic viscosity tensor couples shear and volumetric components of stress/strain rate. This coupling, acting over a gradient in shear stress, causes segregation of liquid and solid. Liquid typically migrates toward higher shear stress, but under specific conditions, the opposite can occur. Furthermore, in a two-phase aggregate with a porosity-weakening viscosity, matrix shear causes porosity perturbations to grow into a banded structure. We show that viscous anisotropy reduces the angle between these emergent high-porosity features and the shear plane. This is consistent with lab experiments.

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MS72

Improved Rheological Models for the Description of Rift Dynamics

Oceanic rift processes are due to diverget plate tectonics, these zones represent the fundamental areas where to investigate lithosphere/mantle interactions. The development of a mathematical model is required in order to exploit modern numerical tools to give a detailed description of the structures developed in rift areas. In this talk a set of novel mathematical models (in accordance with modern geological observations) to describe the rift processes is presented.

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MS73

Wgfem for Elliptic Interface Problems

Abstract not available at time of publication.

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MS73

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MS73

Weak Galerkin Finite Element Methods for Elliptic Problems

Abstract not available at time of publication.

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MS73

Wgfem for Biharmonic Problems

Abstract not available at time of publication.

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MS74

Bayesian Uncertainty Quantification of Subsurface Flow Models Using Nested Sampling and Sparse Polynomial Chaos Surrogate

An accelerated Bayesian uncertainty quantification method based on the nested sampling (NS) algorithm and non-intrusive stochastic collocation method is presented. Nested sampling is an efficient Bayesian sampling algorithm that builds a discrete representation of the posterior distributions by iteratively re-focusing a set of samples to high likelihood regions. The main difficulty of the nested sampling algorithm is in a constrained sampling step which is commonly performed using a random walk Markov chain Monte-Carlo (MCMC) algorithm. In the current work, we utilize a two-stage MCMC sampling using a polynomial chaos response surface to filter out rejected samples in the Markov chain Monte-Carlo method. The combined use of the nested sampling algorithm and the two-stage MCMC provides significate computational gains in terms of the number of simulation runs. The proposed algorithm is applied for calibration and model selection of subsurface flow models.

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MS74

Toward An Expectation-Maximization Method for Parameter Estimation and Its Application to Rate Estimation in Oil Wells

Information of flow rates in individual wells is crucial for production optimization and reservoir management. To obtain this information, a framework has been developed consisting of a transient wellflow model, a stochastic flowrate model, and estimation methods. The stochastic flowrate model used in the framework needs to specify the variances of the driving noise terms. In this talk, an Expectation-Maximization (EM) based method is adopted to automatically estimate these parameters in an online fashion.

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MS74

Multiple Criteria Optimization of CO2 Sequestration Strategy Under Geological Uncertainty Using Adaptive Sparse Grid Surrogates

The key to successful CO_2 sequestration depends on economic efficiency, capacity and long-term security of CO_2 storage. Making decisions in injection strategies under multiple objectives become a challenging task due to geological uncertainty and conflicting objectives. In the current work, we used Non-dominated Sorting Genetic Algorithm (NSGA-II) based on Adaptive Sparse Grid Interpolation (ASPI) to maximize sweep efficiency, economic criteria, and simultaneously minimize risks associated to CO_2 injection. Numerical results showed that a Pareto-optimal front of the injection strategies is essential to making a decision in CO_2 sequestration projects.

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MS74

Multilevel Monte Carlo for Groundwater Flow Problems in Random Media

Partial differential equations (PDEs) with random coefficients are used in computer simulations of physical processes in science, engineering and industry applications with uncertain data. The goal is to obtain quantitative statements on the effect of input data uncertainties for a comprehensive evaluation of simulation results. However, these equations are formulated in a physical domain coupled with a sample space generated by random parameters and are thus very computing-intensive. We outline the key computational challenges by discussing a model elliptic PDE of single phase subsurface flow in random media described by correlated lognormal distributions. In this application the coefficients are often rough, highly variable and require a large number of random parameters which puts a limit on all existing discretisation methods. To overcome these limits we employ multilevel Monte Carlo (MLMC), a novel variance reduction technique which uses samples computed on a hierarchy of physical grids. A rigorous convergence and complexity analysis of MLMC requires the estimation of the error introduced by the finite element discretisation. We extend recent works on the analysis of standard nodal finite elements to mass-conservative lowest order Raviart-Thomas mixed finite elements. This is very important since the use of mass-conservative discretisation schemes is highly desirable in realistic groundwater flow problems. As in the standard case, the analysis is non-trivial due to the limited spatial regularity and the unboundedness of the employed lognormal random fields. This is joint work with Andrew Cliffe (Uni Nottingham), Mike Giles (Uni Oxford), Ivan Graham (Uni Bath), Minho Park (Uni Nottingham), Robert Scheichl (Uni Bath) and Aretha Teckentrup (Uni Bath).

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MS75

An Adaptive Fast Multipole Accelerated Boundary Element Method for 3D Elastodynamics

The Boundary Element Method is well suited to the computation of elastic wave propagation as only the domain boundaries are discretized. This advantage is offset by the fully-populated matrix. Considerable speedup of solution time and decrease of memory requirements are achieved with the Fast Multipole Method. This speeds up the matrix-vector product computation at each iteration. Then, additional gains in CPU time and accuracy are reached by using a dedicated mesh adaptation procedure.

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MS75

Up-scaling 3D Complex Geological Media for the Elastic Wave Equation

Seismic waves propagating in the Earth are affected by different sizes of heterogeneities. When modelling these waves, taking into account small heterogeneities is a challenge because it often requires important meshing efforts and leads to high numerical costs. In the recent years, this problem has been overcome by applying the homogenization technique (originally developed in solid mechanics for periodic media) to the elastic wave equation in non-periodic media (Capdeville et al 2010a,b; Guillot et al 2010). This technique allows to upscale the small heterogeneities and yields a smooth effective medium and effective equations. In this presentation we first recall the theory of the homogenization, then we describe its implementation in the 3D case, and we finally show applications which validate our code.

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MS75

Forward and Inverse Problems in Acoustics and Seismic Modeling: An Optimized-Spectral Element Approach

Spectral-element methods for adjoint/inverse problems have evolved significantly in recent years. We will discuss recent improvements that have been implemented in the SPECFEM3D package, namely coupling with a regional quasi-analytical solution, wavelet compression, and source encoding. We will also show a real application to seismological data obtained in the Pyrenees region in Southern France in the context of the ANR PYROPE / TOPOIBERIA transportable recording array experiment that has been carried out in recent years.

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MS75

Dicontinuous Galerkin Approximation of Seismic Wave Propagation Problems

In this talk we present SPEED-SPectral Elements in Elastodynamics with Discontinuous Galerkin- a high performance open-source numerical code for seismic wave propagation problems. Based on the Discontinuous Galerkin paradigm, allows the treatment of non-uniform polynomial degree distribution as well as a locally varying mesh size. We show validation benchmarks that demonstrate the accuracy, stability, and performance of the parallel kernel as well as applications of SPEED for simulating realistic multiscale wave propagation phenomena.

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MS76

An Efficient Numerical Approach for Reactive Multiphase Multicomponent Flow in Porous Media

We present an efficient numerical model for the simulation of partially miscible two-phase multicomponent flow with chemical reactions. The choice of primary variables is suitable to deal with phase transitions which are handled by a complementarity approach. A model-preserving reformulation technique is applied to eliminate unknowns and the remaining system is solved by a global-implicit approach using Newton's method.

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MS76

Efficient Numerical Simulation of 2D and 3D Multicomponent Reactive Transport

We present complex scenarios of multicomponent reactive transport in 2-D and in 3-D. These scenarios are further developments of the setting given by the MoMaS benchmark. We show how to solve the equations using a global implicit approach in an efficient way, and we present the derived computational results.

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MS76

Importance of Non-Negative Numerical Solution for Mixing-Controlled Reactive Transport

Conventional numerical methods for reactive transport can produce non-physical values, particularly for heterogeneous flow fields, irregular grids and full tensor dispersion. Negative concentrations cannot be tolerated for nonlinear reactions. We present several computational strategies to address these issues for mixing-controlled reactions. The flux corrected transport framework is a flexible method that can be used with existing simulators. We also present a FEM formulation that uses optimization to strictly enforce maximum principles and the non-negative constraint.

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MS76

Isotopic Management in the Reactive Transport Code Hytec : Isotopic Fractionation and Radioactive Decay

HYTEC is a coupled reactive transport code used for a wide variety of applications in geosciences. This work presents a new functionality : the isotopic management. This new option allows to take into account any even complex radioactive decay chains and chemical isotopic fractionation at equilibrium. The effective implementation of the new option is presented as well as two illustrative examples with comparison to analytical solutions: one for the radioactive decay, and the other for isotopic fractionation.

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MS77

Autofocusing of Internal Multiples and Application to Multidimensional Deconvolution

We describe a method that reconstructs the wavefield from a virtual source inside a medium without needing a receiver at the virtual-source location. An estimate of the direct arriving wavefront is required in addition to reflection data. This method allows us to decompose the reconstructed wavefield in up- and down-going components. We illustrate the method with numerical examples in lossless acoustic media. This method is a basis for techniques relying on Multi Dimensional Deconvolution.

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MS77

Wavefield Tomography Based on Local Image Correlations

A smooth model of the subsurface is necessary to map waves recorded at the surface where contrasts in physical parameters exist. The model is unknown and must be estimated from the data. Contrast interfaces are described by position and orientation. If the model is accurate, the reflector positions are invariant with respect to an extension parameter (e.g., shot index). Our inversion procedure is based on similarity of the reflector orientations and requires fewer images.

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MS77

Renormalization of Scattering Series and the Improvement of Convergence Property

It is well known that the forward or inverse Born scattering series is of the Fredholm type and its convergence is limited to a region of weak scattering regime. The current status in application of the higher order Born series is to calculate only a few terms and see the improvement compared with the first order term. In this work, we apply the De Wolf series method (De Wolf transform) to reorder and renormalize the Born series, and hence transform the Fredholm type into a Volterra-type series which has a guaranteed convergence. Numerical examples are given to demonstrate the convergence and efficiency of the De Wolf approximation for multiple forward-scattering.

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MS77

Interferometric Imaging of the Leading-order Internal Multiples

We develop a three step imaging procedure, which would image the first order internal scattering. This approach mainly utilizes the background Green's function from the surface to each image point. We first back propagate of the recorded surface data using the background Green's function down to the image point. Next, we cross-correlate the back-propagated data with the recorded surface data. Finally, we cross-correlate the result of second step with the background Green's function form surface to image point. This would give us the image of the point from which single scattering has not been recorded. Note that this internal multiple imaging procedure will image only the points which has taken part in a single order internal scattering and single scattering points will be suppressed. We add this image to those obtained from any of the many single scattering based imaging procedure, for example, Kirchhoff migration, to give the total image. Application to synthetic data with reflectors illuminated by multiple scattering only demonstrates the effectiveness of the approach. We shall also show that the first order internal scattering is imaged by the conventional Reverse Time Migration (RTM), but is very weak compared to single scattering image and cause possible crosstalk. In our method, by cross-correlating the back propagated field with the data we manage to separate the second order term in the Born scattering series (first order internal scattering), which enhances the image corresponding to that term.

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MS78

A Numerical Study of Splitting Schemes and Implicit Solution Methods for Biot's Equation

The stability of splitting schemes for Biot's equation has recently been studied by Mikelič and Wheeler [1], and others. We will investigate the performance of these stable splittings, and compare them with a fully implicit solution method on two cases which are numerically difficult. We will also look at a reformulation of the most promising splitting scheme as a block preconditioner for a fully implicit solver. [1] A. Mikelič, M. F. Wheeler: Convergence of iterative coupling for coupled flow and geomechanics, Computational Geosciences, 2012. DOI: 10.1007/s10596-012-9318-y

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MS78

Inexact Linear Solvers for Control Volume Discretizations

We discuss the construction of inexact linear solvers for control volume discretizations of elliptic problems. The methods are formulated as multi-level discretizations which preserve the conservation structure of the continuous problem, and conservative flux fields are produced even for inexact pressure solutions. Thus the linear solver allows for significant computational savings while still producing physically meaningful solutions. The iterations are controlled by error estimates. Numerical experiments verify the viability of our approach.

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MS78

Multiscale Methods: Tools to Balance Accuracy and Efficiency

In the description of flow through porous media, approximate solution based on upscaling procedures have been widely employed. Recent advances in adaptive multiscale techniques offer a general framework that enables great flexibility in balancing accuracy and efficiency. However, an optimal choice is possible only if the objectives are clearly defined and the particular application specified. We discuss this topics in relation to the MsFV method.

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MS78

A Posteriori Error Estimates, Stopping Criteria, and Adaptivity for Two-Phase Flows

We show how computable a posteriori error estimates can be obtained for the two-phase porous media flow problem. Iterative linearizations by, e.g., the Newton method and iterative solutions of the arising linear systems are typically involved in the numerical approximation procedure. We show how the corresponding error components can be distinguished and estimated separately. A fully adaptive solution procedure, with adaptive choices of the number of nonlinear and linear solver steps, the time step size, and the computational mesh, is presented.

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MS79

A Multilevel Time Integrator for Large-scale Atmospheric Flows

We present a numerical scheme aimed at simulating multiscale atmospheric flows in the low Mach number regime. Compressible flow equations are discretized with a second-order accurate projection method. Results obtained with the advection of a vortex, an acoustic wave and a rising warm air bubble showcase the method's performance. With a multilevel time integration approach based on multigrid ideas, the scheme can handle multiscale features around balanced regimes in a controlled fashion.

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MS79

Exponential Integrators for Applications to Environmental Fluid Dynamics

The accuracy and performance of some kinds of exponential time integrators are assessed for the time discretization of hyperbolic problems. In particular, their potential for applications to environmental fluid dynamics problems is assessed by comparison with more common time discretization techniques. Possible extensions of the standard exponential methods discussed in the ODE literature will also be discussed.

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MS79

Comparison of Adaptive and Uniform DG Simulations

Adaptive mesh refinement generally serves to increase computational efficiency without compromising the accuracy of the numerical solution significantly. However it is an open question in which regions the spatial resolution can actually be coarsened without affecting the accuracy of the result significantly. This question is investigated for the simulation of warm air bubble test cases. For this purpose a novel numerical model is developed that is tailored towards this specific meteorological problem. A method is introduced which allows one to compare the accuracy between different choices of refinement regions. For a rising warm air bubble the additional error by using adaptivity is smaller than 1% of the total numerical error if the average number of elements used for the adaptive simulation is about 50% smaller than the number used for the simulation with the uniform fine-resolution grid.

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MS80

Multiresolution Ocean Simulations with Fesom

Unstructured meshes offer geometric flexibility. In the context of large-scale ocean modeling they enable simulations with a regional focus in an otherwise global setup. The Finite-Element Sea ice-Ocean circulation Model (FESOM) offers such functionality. A brief review of current FESOM-assisted research will be given, to illustrate the utility of the approach. New developments include a global cell-vertex finite-volume setup which is compared to FESOM in global ocean simulations.

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MS80

Local Timestepping in the Discontinuous Galerkin Method for Shallow Water Systems

Coastal models discretized explicitly in time on unstructured meshes can give rise to severe global CFL timestep constraints. This constraint is in fact local, depending on the local eigenvalues of the system and the element mesh size. By allowing the timesteps to vary spatially, one can significantly improve computational efficiency. In this talk, we describe a parallel local timestepping approach which conserves mass and has been observed to be second order accurate. Applications to storm surge modeling will be presented.

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MS80

Pressure Forcing and Dispersion Analysis for Discontinuous Galerkin Approximations to Oceanic Fluid Flows

This work is part of an effort to study the potential application of DG methods to the numerical modeling of the general circulation of the ocean. One step performed here is to develop an integral weak formulation of the pressure forcing that is suitable for usage with a DG method and with a generalized vertical coordinate that includes level, terrain-fitted, and isopycnic coordinates as examples. This formulation is then tested, in special cases, with some computational experiments and with analyses of well-balancing, dispersion relations, and numerical stability.

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MS80

Adaptive Vertical Coordinates for Modeling Stratified, Coastal Seas

An adaptive strategy for the vertical gridding in terrain-following 3D ocean models is presented here, which is designed for reducing discretisation errors in ocean models. With this, internal flow structures such as pycnoclines can be well resolved and followed by the grid. A set of examples is presented, which show that the adaptive grid strategy reduces pressure gradient errors and numerical mixing significantly and improves the representation of physical processes, nutrient fluxes and plankton growth.

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MS81

Aspect: An Advanced Solver for Problems in Earth Convection

Simulating convection in Earth's mantle is challenging for many reasons: the vastly varying scales, nonlinear material behavior, advection dominated transport, and long time spans of interest. We present an overview of the open source code ASPECT that uses modern numerical methods for adaptive mesh refinement, solvers and stabilization to solve convection problems in Earth. It is written with a particular focus on extensibility and scales to very large computations.

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MS81
Flexible Finite Element Methods for Geodynamics

The FEniCS Project is an open source solution for the automated solution of differential equations and is largely developed at Simula. Recently, we have applied FEniCS to mantle convection problems and tested it against published benchmarks. FEniCS as a generic solver can complement existing purpose built software for rapid deployment, complex and adaptive meshes and adjoint problems.

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MS81
Improved Thermo-Tectonic Basin Reconstruction with P-T Dependent Gravimetric Calibration

Source rock maturity depends on the thermal evolution of sedimentary basins. Modeling this requires a tectonic model that resolves the basin and the lithospheric scale. Unfortunately, no unique solution exists. This can be improved by including datasets usually not considered in the basin-modeling context. Here we show that calibration with the gravity signal leads to better-constrained thermo-tectonic basin models. This approach also improves gravity modeling, as the thermal state of the lithosphere can be included.

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MS81
Simulating Mantle Convection, Plate Tectonics and the Thermo-Chemical Evolution of Planetary Interiors in a 3-D Spherical Shell on High-Performance Computers

It is now possible to perform global 3D spherical models of solid Earth evolution that span 4.5 billion years, include self- consistently generated plate tectonics and magmatism that produces crust and chemically differentiates the mantle. Such calculations make predictions that can be compared to observations from seismology, geochemistry, paleomagnetism and geology. We are also applying such models to other planets, both in our own solar system and around other stars (super-Earths).

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MS82
Methods to Determine the Effective Resolution of Dynamical Cores

The effective resolution of a model is the smallest scale that is fully resolved. We present theoretical methods and idealized test cases to determine the effective resolution of dynamical cores. Investigating the dissipative and dispersive properties of a scheme determines which wavenumbers are resolved for linear systems. Using baroclinic wave tests, we can numerically determine which scales are resolved for the nonlinear system. We present results for NCAR's Community Atmosphere Model finite-volume core.

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MS82
Adaptive Mesh Refinement for the Non-Hydrostatic Unified Model of the Atmosphere (NUMA)

The Adaptive Mesh Refinement algorithm was designed for the Discontinuous Galerkin (DG) method in frame of a 2D mesoscale version of the Non-hydrostatic Unified Model of the Atmosphere. An investigation of the algorithm and its interaction with IMEX time-stepping was performed. The implementation was extended to include the Continuous Galerkin (CG) method formulation. We present the behavior of both DG and CG methods for non-conforming adaptive simulations on a suite of test cases employing both statically and dynamically refined grids.

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MS82
The Endgame Dynamical Core: Test Results Using a Switchable Discretisation

ENDGame is the next dynamical core for the Met Office's Unified Model to be used for weather and climate prediction across a range of time and space scales. ENDGame employs a flexible discretisation of the deep atmosphere nonhydrostatic equations allowing a number of simplifications to be made. The effects of a number of these formulation switches in ENDGame are investigated using a variety of idealised tests - results and the lessons learnt will be discussed.

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MS82

Potential Vorticity Anomalies: Dynamic Or Numerical Artifact?

Conservation breaking anomalies in the dynamic potential vorticity (PV) field have been observed in simulations for models as simple as the Eady model. These anomalies occur when isentropic (constant potential temperature) surfaces intersect the surface (in the case of the atmosphere). We make use of a dry baroclinic wave test case to investigate this phenomenon, and consider whether it is desirable for a dynamical core to capture these anomalies, and the consequences of these features on the other pertinent dynamical fields.

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MS83

Well Placement Optimization Using Stochastic Approximated-Gradient Methods

Stochastic approximated-gradient methods combine the advantages of both gradient-based and stochastic optimization algorithms without the corresponding computation effort. Two algorithms, EnOpt and FSP, are investigated and compared for well placement optimization in this work. They do not require access to simulator code and generally, the gradient approximation is independent of the problem dimensions. The results indicate that FSP tends to show improved convergence characteristics and requires a lesser computational effort in comparison to EnOpt.

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MS83

Dual Ensemble Filtering for States Estimation of Coupled Subsurface Transport Models

Modeling contaminant evolution in geologic aquifers requires coupling a groundwater flow model with a contaminant transport model. This coupling may provide accurate future estimates of the subsurface hydrologic state if assisted with essential flow and contaminant data through data assimilation. Assuming perfect flow, an ensemble Kalman filter (EnKF) can be directly used for data assimilation into the transport model. This is; however, a crude assumption as flow models can be subject to many sources of uncertainties. If the flow is not accurately simulated, contaminant predictions will likely be inaccurate even after successive Kalman updates of the contaminant with the data. The problem is usually better handled when both flow and contaminant states are concurrently estimated using the traditional joint state augmentation approach. We introduce, here, an efficient dual strategy for data assimilation into this one-way coupled system by treating the flow and the contaminant models separately while intertwining a pair of distinct EnKFs; one on each model.

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MS83

Iterative Smoothers for Subsurface Reservoir Flow History Matching

On Iterative Smoothers for Bayesian Estimation By: Andreas S. Stordal Abstract: Approximate solutions for Bayesian estimation in large scale models is a topic under inves- tigation in many scientific communities with tha main focus being on ensemble based methods such as the ensemble Kalman filter or Gaussian mixture filters. We define an iterative smoother version of the adaptive Gaussian mixture filter as a robust alternative to adaptive importance sampling. The filter is compared to other iterative smoothers from a practical and theoretical point of view. Asymptotic properties of the new smoother are computed and compared with a theoretical result on randomized maximum likelihood. We show that we have asymptotic optimality under certain conditions, contrary to other smoothers where the sample distribution depend on the nonlinearity and scaling of the model. The new smoother is also shown to outperform existing methods on simple problems as well as a one dimensional highly nonlinear reservoir problem.

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MS83

Combining Multidimensional Scaling (MDS) with Ensemble-Based Algorithms for Automatic History Matching

The ensemble Kalman filtering fails to preserve non-Gaussian features of geological facies where there is a strong contrast in permeability values of channels and non-channels locations. We develop a methodology to combine multidimensional scaling and the ensemble Kalman filter for updating models for a channelized reservoir. A dissimilarity matrix is computed using the dynamic responses of ensemble members. This dissimilarity matrix is transformed to a lower dimensional space using multidimensional scaling. The responses mapped in the lower dimension space are clustered and based on distances between the models in a cluster and the actual observed response, the closest models to the observed response are retrieved. Updating of models within the closest cluster are performed using EnKF equations. The results of the update are used to re-sample new models for the next step.

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MS84

The Interior-Penalty Discontinuous Galerkin Method for Elastic Wave Propagation in Fractured Media

Abstract not available at time of publication.

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MS84

Higher Order Summation-by-parts Methods for Seismic Wave Propagation

A fourth order accurate finite difference method for the elastic wave equation in second order formulation is presented. The numerical method satisfies the principle of summation-by-parts (SBP), which guarantees energy stability for arbitrary heterogeneous materials in bounded domains, with free surface or Dirichlet boundary conditions. Our approach generalizes to realistic topography by transforming the elastic wave equation to curvilinear coordinates before it is discretized by the SBP technique.

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MS84

Exact Boundary Conditions for Modelling and Inversion of Elastic Wave Propagation

Many applications of modelling elastic wave propagation require the ability to recompute the wavefield after local model alterations. By using so-called exact boundary conditions, the computational domain in for instance a finite-difference solution can be arbitrarily truncated and the wavefield recomputed around the region of change. The updated wavefield will fully include all high-order long-range interactions between the truncated part and the full model. Applications include full waveform inversion and seismic multiple elimination.

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MS84

Geological Complexity, Topography and Seismic Wave Modelling: Are Finite-Differences Up to the Challenge?

The finite-difference (FD) method is still the most widely used method for modelling seismic waves in geophysics. However, it is not well-suited for modelling the effect of the free-surface, especially in the presence of topography. Although it is commonly inferred that high-order finite-elements (FE) are the only affordable alternative in such scenarios, we want to show that certain modified FD schemes can satisfy most needs for seismic modelling, including challenging topographies and geologically complex models.

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MS85

Effective Upscaling of Kinetics in Simulation of in-Situ Combustion Processes

Sustained high oil prices and growing demand have unlocked heavy oil resources. Production of such unconventional oils typically requires thermal stimulation. In-situ combustion is an attractive stimulation method as heat is generated in the subsurface and the oil can often be upgraded. Performance prediction and optimization of ISC projects require effective upscaling of reservoir rock properties, fluid properties and kinetics. We propose an effective upscaling technique that is competitive in accuracy with traditional approaches and many times faster.

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MS85

Formulation for Multiphase Multicomponent Flows and Stopping Criteria for Two-phase Flows

The petroleum industry needs to model multiphase multicomponent flows in large porous domains. These computations are very expensive and thus one is interested in optimizing them. The talk will first discuss a new formulation for multiphase multicomponent flow, its finite volume discretization, and efficient computer implementation. In a second part, we restrict ourselves to the two-phase setting and present some adaptive stopping criteria for nonlinear and algebraic solvers based on a posteriori error estimates.

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MS85

Analysis of Mixed Finite Element Discretization for Crystal Precipitation and Dissolution Model

We deal with the numerical analysis of an upscaled model describing the reactive flow in a porous medium. The solutes are transported by advection and diffusion and undergo precipitation and dissolution. The reaction term, in particular, the dissolution term has a particular, multivalued character. We consider the mixed finite element discretization and prove the convergence to the continuous formulation. Additionally, this also yields an existence proof for the model in mixed variational formulation.

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MS85

Locally Mass Conservative Methods with Discontinuous Galerkin in Time for Miscible Displacement in Porous Media

The miscible displacement problem of a solvent fluid into a resident fluid in porous media is characterized by a system of coupled partial differential equations. The flow of the fluid mixture is modeled by Darcy's law, and the concentration of the solvent fluid satisfies a transport equation. We propose a high order method in time and space, that combines discontinuous Galerkin in time with locally mass conservative methods such as mixed finite element methods and interior penalty discontinuous Galerkin methods. Convergence of the numerical solution is obtained under mild regularity assumptions on the data. Boundedness of the dispersion-diffusion matrix is not required. The analysis utilizes a generalized Lions-Aubin theorem, that can be applied to broken Sobolev spaces. Numerical examples show that optimal rates of convergence are reached for smooth solutions. Robustness of the method is tested for heterogeneous porous media.

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MS86

Regularization in Banach Spaces for Microwave Borehole Subsurface Prospection

In electromagnetic prospection of buried targets, the electromagnetic scattered field is collected in a set of measurement points located above the air-ground interface or in a borehole arrangement . The relationship between such field and the dielectric properties of the targets can be modeled by using a nonlinear integral operator involving the Green function for half-space configurations. In the present work, an algorithm based on regularization in Banach spaces is considered to solve the associated inverse scattering equation. With respect to previous algorithms, usually based on classical Hilbert spaces, the present method in Banach spaces is able to give a substantial reduction of the oversmoothing and ringing effects in the restored buried object.

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MS86

Lp-Penalized Methods for Spatial Resolution Enhancement of Microwave Radiometer Data

Microwave radiometer data are characterized by a spatial resolution that, although adequate for large-scale phenomena, is a severe limitation to observe small-scale features. An effective technique is first proposed to enhance the spatial resolution of two-dimensional radiometer data. It is based on the iterative regularization in Banach Spaces. It allows reducing the over-smoothing effects and the oscillations that are present in standard Hilbert procedures. Experiments undertaken on actual data confirm the effectiveness of the approach.

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MS86

The Cylindrical Wave Approach and the Electromagnetic Scattering by Buried Objects

The Cylindrical-Wave Approach (CWA) is a spectral-domain method for the full-wave solution of the electromagnetic forward-scattering problem by subsurface two-

dimensional objects. The scattered field is represented in terms of a superposition of cylindrical waves. Use is made of the plane-wave spectrum to take into account the interaction of such waves with the interface between air and soil, and between different ground layers. The ground losses and all multiple-reflection and diffraction phenomena are taken into account.

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MS86

Regularized Solution of Linear and Nonlinear Problems in Electromagnetic Sounding

Electromagnetic induction techniques are often used for non-destructive investigation of soil properties, since they allow to ascertain the presence in the ground of metals, liquid pollutants, or saline water. Maxwell equations lead to a nonlinear model for this problem, which is sometimes transformed into an approximated linear model. In both cases, the inverse problem is severely ill-conditioned. We will introduce the models and present the results of numerical experiments on both synthetic and real data.

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MS87

Lava Flow Simulation with Smoothed Particle Hydrodynamics on GPU

We present a GPU implementation of the Smoothed Particles Hydrodynamics (SPH) numerical method to solve the dynamic and thermal equations involved in the simulation of lava flows. Our model implements multiple rheologies (newtonian, Bingham, power-law, Hershel-Bulkely), with both fixed and thermal-dependent parameters, to allow different physical models of liquid lava to be tested; simulations can be run on natural topographies, obtained for example from an Digital Elevation Model of the location of the simulated event.

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MS87

A Discontinuous Galerkin Method for the Simulation of Multiphase Pyroclastic Flows

The mixture of gas and solid particles in non-equilibrium conditions that compose a pyroclastic flows is described with a set of coupled partial differential equations for the mass, momentum and enthalpy of each species. Following the methods of lines, a Discontinuous Galerkin space discretization is introduced first, then different explicit time discretization schemes are adopted. Finally, several examples and comparisons between different numerical schemes are presented.

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MS87

A Second Order Finite-Difference Ghost-Cell Method for Volcano Deformation Modelling

We propose a novel strategy based on a second order Finite Difference (FD) ghost-cell method for solving the elasto-static equations in an arbitrary domain described by a level-set function to compute rock deformation caused by the pressurization of magma sources. The elasto-static equations are solved on a regular Cartesian grid and the domain is defined implicitely by the level-set function. We consider two-dimensional cases to validate the method versus analytical solutions and Finite Element results.

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MS87

Analysis of Non Equilibrium Effects in the Decompression Structure of Multiphase Underexpanded Volcanic Jets

We have developed a semi-implicit, second-order accurate finite volume numerical scheme to simulate underexpanded volcanic jets by means of a N-particle Eulerian multiphase flow model. We discuss the influence of the grain-size distribution and particle load on the shock wave pattern of supersonic jets issuing from a narrow conduit. The problem of the influence of non-equilibrium phenomena, associated to the polydisperse nature of the mixture, on the stability of the volcanic column is finally addressed.

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MS88

Simulation of Tropical-Cyclone-Like Vortices in Shallow-Water ICON-Hex Using Goal-Oriented R-Adaptivity

We build r-adapted grids to predict the tracks of two interacting tropical-cyclone-like vortices. A linear sensitivity analysis using a finite element model delivers goal-oriented error estimates that indicate each grid cells' contribution to the error in the cyclone tracks. These estimates are used to optimize the grid of the hexagonal C-grid shallow-water model ICON-hex. Compared to uniform meshes, our approach reduces the required degrees of freedom by a factor of four.

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MS88

Mimetic Finite Element Methods for Ocean/atmosphere Modelling

We present a finite element framework for the rotating shallow water equations on the sphere, which could be considered to be an extension of the mimetic C-grid approach of (Ringler, Thuburn, Klemp and Skamarock, 2010) to finite element methods. The finite element framework maintains conservation of potential vorticity and mass, absence of spurious pressure modes, the capability to preserve energy (although dissipation is required to control oscillations near to fronts) and stationarity of geostrophic linear modes on the f-plane, but makes three extensions, namely: 1) the possibility of higher-order accuracy, 2) no restriction to orthogonal meshes, and 3) additional flexibility which can be used to alter the balance between velocity and pressure degrees of freedom to remove spurious mode branches. We discuss extensions to three dimensional modelling and illustrate the approach with numerical tests.

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MS88

An Edge-Based Model for Mesoscale Atmospheric Dynamics

A three-dimensional semi-implicit edge-based unstructured-mesh model is developed that integrates nonhydrostatic anelastic equations, suitable for simulation of small-to-mesoscale atmospheric flows. The model builds on nonoscillatory forward-in-time MPDATA approach using finite-volume discretization and admitting unstructured meshes with arbitrarily shaped cells. Technical considerations are supported with canonical simulations of convective planetary boundary layer, and stably stratified orographic flows. The unstructured-mesh solutions are compared to equivalent results generated with an established structured-grid model, theory and observation.

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MS89

SLIM, A Baroclinic Discontinuous Galerkin Finite Element Model for Marine Flows: Validation on Academic and Real Applications

Unstructured grids models for marine flow modelling are used for many years now. These models have proved their efficiency for coastal applications. A 3D baroclinic discontinuous Galerkin finite element model with split-explicit time stepping, SLIM 3D, have recently been developed and applied to ideal coastal flows. This model still suffers problems of stability. The simulation blows up easily on the boundaries and non-physical behaviour can be observed where there is a high horizontal pressure gradient. In order to fix it without changing the physics beyond the model, a stabilized version has been developed and applied to large-scale ocean circulation test-case, where the problems of stability are crucial. This model has been compared to other models to assess the quality of the results. This talk presents the SLIM model explaining its spatial and temporal discretization characteristics. Then a large-scale application in which we assess the robustness of our model is presented. This application, a baroclinic instability in a zonally re-entrant channel, gives a comparison between the SLIM model and other references. Eventually, some results of different coastal academic and real applications on which the model has been assessed are given.

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MS89

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MS89

Modeling Three-Dimensional Processes in Coastal Engineering Applications

Irreducibly three-dimensional (and time-dependent) processes arise often enough in real-world coastal engineering applications that effective tools for their solution are needed. These processes include interaction of waves and currents with coastal and hydraulic structures and subsurface air/water dynamics in heterogeneous materials. In this talk I will discuss examples of fully three-dimensional engineering problems and methods for solving them directly in three dimensions, particularly finite element and level set methods on unstructured meshes.

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MS89

Efficient and Elegant Numerical Tools for Ocean Flows

Numerical modelling of coastal flows is a challenging topic due to complex topography, complex flow dynamics and large density variations. Such phenomena are best simulated with unstructured grid models due to their highly exible spatial discretisation. A three-dimensional discontinuous Galerkin finite element marine model is presented. The spatial discretisation and explicit mode splitting time integration scheme are described. Free surface movement is accounted for by means of an arbitrary Lagrangian Eulerian (ALE) moving mesh method. Mass and volume are conserved. The conservation properties and baroclinic adjustment under gravity are tested with numerical benchmarks. The approach exploits the topology of the 3D mesh, that is formed by stacking layers of prisms in the vertical direction. A robust mapping between the finite difference grid and the finite element function space is designed, taking into account the discontinuities in the latter.

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MS90

Mantle Convection Modelling

Mantle convection is central to understanding the large scale geologic evolution of our planet. In this contribution I will review recent progress in mantle convection modeling in my group at Munich University.

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MS90

Simulations of Thermal Convection in Rotating Spherical Shells

Di?erent implementations of several time integrators based on our own codes and public libraries are presented to study their e?ciency when are applied to a three-dimensional thermal convection problem in rotating spherical geometry. The equations are discretized with pseudo-spectral techniques. Many geophysical and astrophysical phenomena such as the generation of the magnetic ?elds, or the di?erential rotation observed in the atmospheres of the major planets can be studied in this framework.

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MS90

Inverse Retrospective Problems in Geodynamics

Present geophysical and geodetic observations provide a clue to understanding the dynamics of the Earth interior in the geological past. Data assimilation allows to constrain the mantle flow and temperature in the past using dynamic models and present observations. Quantitative tools are required to solve inverse retrospective problems of geodynamics. The basic inversion methods (data assimilation methods) and their applicability to restore the

evolution of the Earth interior will be discussed.

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MS90

Multipole Boundary Element Method in Geodynamics

We illustrate advantages and difficulties associated to the use of Multipole-Boundary Element Method (MP-BEM) in geodynamics. MP-BEM complements Finite Element, Volume and Differences in an original way, offering solutions to geophysical fluid-dynamic problems such as multiphase, porous media and bubbly flow, exploiting its lagrangian formulation. Applications to regional and global geodynamics are finally also shown. Mathematical and computational issues are clarified in detail showing how MP-BEM is particularly suitable for parallelization on massive parallel computers.

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PP1

A Reduced Fracture Model for Two-Phase Flow with Different Rock Types

In this work we are concerned with a reduced, discrete-fracture model for two-phase flow in porous medium. We take capillary pressure into account, and use the global pressure formulation. We consider the case that the fracture and the surrounding matrix are of different rock type, that is they have different capillary pressure and relative permeability curves. Numerical results will be presented.

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PP1

Optimizing a Cartesian Shallow Water Code on Hybrid Architectures

SWE is an education-oriented code to solve the shallow water equations on Cartesian meshes, having tsunami simulation in mind as application. It is designed to support hybrid parallelisation with multiple GPUs or co-processors such as Intel Xeon Phi. We will demonstrate optimisation techniques (vectorisation, e.g.) required to achieve decent performance, and present results on recent parallel architectures.

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PP1

Polymer Flooding Techniques in Enhanced Oil Recovery

Enhanced Oil(petroleum) Recovery in petroleum reservoirs is very important now due to depleting oil reserves.This paper elaborates at length different method of EOR.Polymer flooding methods in depleted oil reservoirs have been enunciated.The mathematical equations have been developed and analysed.The analytical solutions are found.It is seen that an increase in production upto 30% is anticipated in this method.The bypassing of water over oil is arrested and drag reduction enhances production.

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PP1

Numerical Modeling of Stress Fields in the Earth's Mantle with Non-Newtonian Viscosity

The spatial fields of overlithostatic pressure, the vertical and horizontal stresses in the mantle are studied in 2D numerical model of mantle convection. The model viscosity is temperature-, pressure-, and strain-dependent. The typical overlithostatic stresses in the main part of the mantle are in the range of (7 - 9) MPa, with strong concentration in the areas of descending slabs (up to 50 MPa). We find significant differences between the three studied fields.

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PP1

Render the Interpolation Library SCRIPP Conservative

Abstract not available at time of publication.

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PP1

Inversion for Hydraulic Conductivity Using the

Unsaturated Flow Equations

Hydraulic conductivity (K) is a property of the soil media and is the main regulator of groundwater flow. However, in many hydrogeologic studies K is only known as a bulk average. An accurate estimate of K that is spatially consistent with the media is highly valuable. Here we present an inverse problem that calculates K from time-varying saturation (or pressure head) data; the saturation data can come from geophysical imaging and is spatially extensive.

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PP1

Transport Upscaling Using Coupled and Correlated Continuous Time Random Walks

We present a continuous time random walk (CTRW) framework for the upscaling of transport in heterogeneous media. The CTRW approach describes particle motions in terms of a random walk in space and time. The challenge consists in the determination of the map of the quenched disorder that represents spatial heterogeneity, into the stochastic processes describing the space and time transitions. Based on stochastic models for the spatial disorder, we present two upscaling approaches: (i) for transport in a correlated random medium, which leads to a fully coupled CTRW, and (ii) transport in correlated divergence-free random velocity fields, which leads to a CTRW characterized by correlated random time increments. The transport behavior is discussed in terms of first-passage time distributions, spatial particle distributions, and mean squared displacement, using random walk particle tracking simulations. Both sub- and superdiffusive behavior is observed. Finally, we derive the related (non-local) partial differential equations for the particle densities that describe the large scale transport dynamics.

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PP1

Scale Dependent Coupling of Hysteretic Capillary Pressure, Trapping and Fluid Mobilities

We study the impact of capillary-pressure hysteresis and CO2-trapping on vertically integrated constitutive parameter functions. Trapping is the dominant contributor to hysteresis in integrated models for the initial drainage and a following imbibition. The hysteretic nature of the capillary fringe is of secondary importance for advective processes. The hysteretic capillary fringe plays an important role for redistributive processess.

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PP1

Compressional Seismic Velocity Fields Parameterized by Haar Wavelet

Two-dimensional seismic compressional velocity fields, extracted from geological models, are parameterized by means of Haar wavelet. The coefficients of the Haar series are calculated using integral formulas. The primary objective of this work is to be assured that such parameterization can represent the seismic velocity field in a satisfactory way (reasonable accuracy and few coefficients) and, then, as secondary objective, to create appropriated conditions to estimate wavelet coefficients by some inversion procedure using seismic data.

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PP1

Improvement of Convergence of Multigrid Method in Multiphase Flow Problems.

Multigrid methods often become inefficient for solution of multiphase flow problems because the construction of coarse grid operators does not take into account inhomogeneous saturation distribution. This leads to inefficient residual smoothing and significantly reduces convergence rate. Here we examine the convergence behavior of geometric multigrid method in case when the upscaling methods (incl. multiphase) are employed in construction of coarse grid operators. The application for nonlinear multigrid method is also discussed.

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PP1

Numerical and Geometric Optimization Techniques for Environmental Prediction Systems

Abstract not available at time of publication.

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PP1

Polynomial Interpolation and Quadrature on Subregions of the Sphere

Using some recent results on trigonometric interpolation and quadrature on subintervals of the period, we present a rule for numerical integration over some regions of the sphere, that include spherical caps and zones. The rule has positive weights and is exact for all spherical polynomials of degree less or equal than n. We also construct Weakly Admissible Meshes and approximate Fekete points for polynomial interpolation on such regions of the sphere. All the algorithms have been implemented in Matlab.

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PP1

Space-Time Wavelet Techniques in the Reverse-Time Depth Migration

A method based on the well-known reverse–time depth migration and new Poincaré space-time wavelets is presented for a smooth layered medium. We represent the forward and back-propagated fields in terms of localized solutions centered along rays in the medium. Initial amplitudes of these localized solutions on the surface are calculated by means of the continuous space-time wavelet analysis for the seismic data. An example with seismograms calculated by the finite differences method is presented.

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PP1

Statistical Characteristics, Circulation Regimes and Unstable Periodic Orbits of Simple Atmospheric Model

The theory of chaotic dynamical systems gives a lot of tools that can be used in climate studies (Lyaunov exponents, attractor dimension etc). Another potentially useful one that could be used for the local analysis of the system PDF involves an expansion in terms of unstable periodic orbits (UPOs). According to it, the system statistical characteristics are approximated as a weighted sum over the orbits. The weights are inversely proportional to the orbit instability characteristics so that the least unstable orbits make larger contributions to the PDF. In our study we will try to apply the idea of UPO expansion to the simple atmospheric system based on the barotropic vorticity equation on the sphere. We will check how well orbits approximate the system attractor, its statistical characteristics and PDF. The connection of the most probable states of the system with the UPOs will also be analyzed.

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PP1

Capillary Fracturing in Granular Media

We study the displacement of immiscible fluids in deformable, non-cohesive granular media. Experimentally, we inject air into a thin bed of water-saturated glass beads and observe the invasion morphology. The control parameters are the injection rate, the bead size, and the confining stress. We identify three invasion regimes: capillary fingering, viscous fingering, and capillary fracturing, where capillary forces overcome frictional resistance and induce the opening of conduits. We derive two dimensionless numbers that govern the transition among the different regimes: a modified capillary number and a fracturing number. The experiments and analysis predict the emergence of fracturing in fine-grained media under low confining stress, a phenomenon that likely plays a fundamental role in many natural processes such as primary oil migration, methane venting from lake sediments, and the formation of desiccation cracks.

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PP1

Comparison Study of Spurious Wave Reflection Response with Staggered Finite-Volume and Unstaggered Element-Based Galerkin Schemes under Mesh-Refinement

Spurious wave reflections caused by different grid sizes are examined using both 1D linear shallow water equations models based on staggered finite-volume and unstaggered continuous/ discontinuous Galerkin (CG/DG) discretization. We test spurious wave reflection response caused by mesh refinement with both low and high wavenumber wave packets. Results indicate that unstaggered CG/DG scheme produce less spurious wave reflection compared to staggered finite-volume scheme. In particular, DG with Lax-Friedrich numerical flux is completely free from spurious wave reflections.

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PP1

A Statistical Subgrid Model for Large Eddy Simulations

Cinlar velocity field has been shown to represent the submesoscale eddies up to 5 km in radius by an analysis of high-frequency radar observations. As a result, it is proposed as a subgrid model for Large Eddy Simulation (LES). We consider a velocity field composed of eddies in two dimensions using Gamma distribution for their radius. In LES, the subgrid stress is modeled based on the covariance structure of the random velocity field.

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PP1

Application of a Fast Algorithm to Solving the Pressure Equation Efficiently

In this talk, we will present several fast methods for solving a non-separable elliptic pressure equation arising in porous media flow modeling using Darcy's law. All of these methods use a fast algorithm for solving the elliptic equation by Green's function method. We will present numerical results and compare the performance of this methods. This work is currently under progress. The research to be presented has been made possible by a grant (NPRP 08-777-1-141) from the Qatar National Research Fund (a member of The Qatar Foundation).

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PP1

Statistical Simlulation of Fault Zone Structures

The study demonstrates the potential use of statistical simulation for describing some observed structural features of complex faults zones. Deformation bands are sampled according to probability distribution based on their link to distance from the fault and fault displacement. Stochastic modelling of fault core lens properties takes into account their links to known physical constraints (i.e. host rock stratigraphy and strain distribution). Particular attention is given to the statistical validation procedure of sampled realizations.

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PP1

New Efficient Numerical Method for Integral Equations in EM Sounding of Inhomogeneous Media

The new iterative numerical method for 3d integral equations of electrodynamics was devised. The main challenge of using this equations in forward problems of EM sounding is a need to solve a high-order system of linear equations with a dense matrix. The main distinctive feature of the proposed method is a double integration of the electric Green's tensor in the process of algebraization of the original equation to decrease the order of the matrix.

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PP1

Upscaling of Density-Driven Instabilities Using Countercurrent Flow

In two-phase flow models opposite flow directions are allowed for the two phases in presence of density-driven flow. This countercurrent flow can be seen as macroscopic description of unresolved microscopic velocities. We aim at extending the concept of countercurrent flow to upscale instability observed in density-driven single-phase flow models that are originally described at the Darcy scale. The results are included in the Multiscale Finite Volume method to improve approximation of density-driven instabilities.

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PP1

Upscaling of Reactive Flows in Domains Having Rough Boundaries

We consider the flow and transport of chemically reactive substances in a channel over substrates having complex geometry (rough boundaries). At the boundaries, the precursors undergo precipitation as well as dissolution. To overcome the computational complexity, we replace the rough boundary by a flat one and provide an upscaled boundary condition. We do this for both situations: when the geometry is assumed fixed (rigorous) and when the geometry varies due to reactions (formal asymptotics).

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PP1

Modeling a Stochastic Convective Preciptation Process

A simple stochastic model is used to simulate a strong convective precipitation process. The model includes three stochastic components: a stochastic trigger for precipitation state on and off (a two-state Markov jump process based on a Poisson distribution), a stochastic mass flux at cloud base for a turbulence closer equation, and another stochastic closure for neighborhood domain's influence, such as moisture convergence/divergence. These three stochastic processes are tested for a single column model of climate.

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PP1

Up-scaling Reaction Rates from Pore to Core Scale

We focus on the network flow simulation of up-scaling, from pore to core scale, of rates of anorthite and kaolinite reaction under acidic conditions commensurate with CO2 sequestration. The simulations allow investigation of uncertainties in our knowledge of micro-scale reaction rates under flow regime as well as the flow dependence of bulk reaction rates. The results reveal the susceptibility to prediction errors in the case of reactions close to equilibrium.

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PP1

Systems of Conservation Laws for Thermodynamically Consistent Adsorption with Subscale Diffusion and Memory Terms

Multicomponent adsorption is typically described by a system of conservation laws in which the nonlinear flux terms come from explicit functional relationships called isotherms. The most popular extended Langmuir isotherm is thermodynamically inconsistent. We discuss analysis and numerical approximation of multicomponent adsorption system where the thermodynamically consistent isotherms are given only implicitly, or from a coupled microscopic model. We include memory terms in our model and new examples.

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PP1

A Benchmark for Thermo-Hydrological Codes on Cold Regions Hydrology

Recent numerical studies proved the importance of coupled thermo-hydrological processes to study the evolution of water bodies in permafrost environments under climate change. Such coupled systems of non-linear equations (including phase change) are hard to solve and lack validation exercises. We present a benchmark of codes (numerical and experimental test cases). It is further intended as a forum to improve the simulation performances in view of intensive 3D simulations including the complexity of natural systems.

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PP1

Geometric Characterization of Strata By Inverse Scattering and Active Contours

For simplicity, traditional subsurface characterization methods assume flat geological layers. Our approach seeks the actual, arbitrary layer shapes that best match given surface measurements of seismic waves. Through the minimization of an energy functional, active contours modeling layer geometry evolve to the desired shape. The gradient descent direction is derived semi-analytically for increased computational speed. Together with the method of fundamental solutions for numerical elastodynamic wave solutions, we obtain a meshfree inversion algorithm.

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PP1

Identification of Seismic Quiescence Anomalies in the Seismic Region of the Mexican Pacific Coast

We used the region-time-length (RTL) and the Schreider algorithms to characterize seismic quiescence anomalies in the Mexican Pacific coast. We investigated the spatiotemporal variations of seismic quiescence prior to the past Mexican earthquakes of magnitude greater than 7.5 since 1970. We used an improved RTL algorithm with optimal parameters. To better understand these seismic quiescence anomalies we also studied synthetic catalogues obtained with a two dimensional spring-block model that mimics the seismic faults dynamics.

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PP1

A Three-Scale Model of Charged Solute Transport in Swelling Clays Including Ion Size Correlations

A three-scale model is developed to describe the mixing of two ionic contaminants in swelling clays. The nanoscopic problem arises from the Statistical Mechanics and is governed by an integral Fredholm equation for the ion/nanopore correlation function coupled with Poisson problem for the electric potential. Swelling of the clusters is coupled microscopically with the diffusion of the species in the micro-pores and the homogenization procedure is applied to up-scale the microscopic model to the macroscale.

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PP1

Continuum Darcy Approach for Coupling Surface-Subsurface Flows: Application to Heterogeneous and 3D Configurations

A fully integrated coupling between surface and subsurface flows has been implemented recently (Weill et al., 2009). This model unifies the Richards and the diffusive wave equations into a single generalized Richards equation defined in a single domain composed of surface and subsurface subdomains. This model has been applied successfully to 2D configurations. We will show some improvements of the scheme to simulate the runon-runoff process on a heterogeneous soil and 3D configurations.

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PP1

Large Scale Patterns in Convection: from Rayleigh-Benard, Through Prandtl Problem, to Moist Atmospheric Convection

Large scale patterns formation in dry and moist convection scenarios are addressed in this paper. The first part of the talk will be devoted to the case of clustering of plumes in Rayleigh-Benard convection: through a two-scale process, kinetic energy is transferred mainly to low horizontal wave numbers while the sizes of individual plumes remain on the scale of the boundary layer thickness. Again in a direct numerical simulation framework, the study of the Prandtl problem is addressed as a simpli?ed model of dry atmospheric convection, kept in statistically stationary radiativeconvective equilibrium. Finally the emergence and temporal evolution of large-scale spatial-temporal oscillating modes in deep moist convection, for an atmosphere in radiative-convective equilibrium. To this end, we use cloud-resolving numerical simulations of the convective atmosphere at very high resolution and on a very large domain, using WRF model in LES mode.

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PP1

Multiphysics, Multiscale Network Modeling of Gas Transport in Mudrocks

Despite recent research activity, shale petrophysics remains elusive due to the difficulties in experimental and numerical analysis of length scales below 100nm. We implement a network model with both micron and nanometer scale pores that includes effects of convection, diffusion as well as sorption of gas on pore walls. Diffusion and sorption have a significant impact on ultimate gas permeability, and the magnitude of the effect depends on pore connectivity, network geometry and size distribution.

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PP1
Explicit Modeling of Fault Damage Zone Properties

This work aims to capture realistic damage zone features explicitly in reservoir models. A separate fault zone grid is generated from a conventional reservoir model and subsequently populated with damage zone properties using an extensive dataset of deformation band densities and permeability collected from outcrops. The resulting fault zone grid populated is subsequently merged with the original conventional model, and comparison of flow behavior of this merged model and the conventional model is conducted.

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PP1
Applied Precipitation Nowcast

We present a reliable precipitation nowcasting system which operates on radar data. The computational method is an extension of the McGill Algorithm for Precipitation Nowcasting by Lagrangian Extrapolation (MAPLE), which provides a fast and accurate forecast by semi-Lagrangian advection and near-optimal wavelet filtering. Our implementation provides near real-time computation and we extend MAPLE by using level sets for the computation of precipitation areas and optical flow methods for the computation of advection vector fields.

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PP1
Meshless Techniques for Anisotropic Diffusion Problems

Solving anisotropic diffusion equations is an important task for many problems in Geosciences. We compare the efficiency of two meshless techniques based upon the Mesless Local Petrov–Galerkin (MLPG) framework. The fist technique is an MLPG method with suitable test and trial functions; the latter is based on the Generalized Moving Least Squares method. By numerical experiments we show that both methods can solve highly anisotropic problems.

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PP1
Numerical Approximation of Reactive Flow in Porous Media with Discontinuous Reaction.

We present a numerical method for the simulation of reactive flows in porous media characterized by a discontinuity in the reaction term. The strategy is based on an operator splitting that decouples the reaction from advection and diffusion, so that it can be approximated with tailored time integration schemes that guarantee accuracy even in the case of discontinuous right hand sides.

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PP1
A Fully Implicit Solver for Geochemical Processes in Compacting Basins.

Geochemical processes such as quartz precipitation and illite-smectite transformation play a major role in determining porosity and permeability in compacting basins. We present a fully implicit method for the simulation of temperature, pressure and porosity evolution in the presence of mechanical and geochemical compaction. The implicit approach is compared with an iterative decoupling of the equations to assess the better performances of the first strategy in cases characterized by strong overpressures.

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PP1
Semi Lagrangian Methods in Variable Density Flow

We present a 3D model for transient groundwater flow in a confined aquifer based on discretized flow and solute mass balance equations. To overcome the difficulty of coupled nonlinear governing equations a Semi - Lagrangian method is implemented for the solute transport equation. This enables to choose arbitrarily large time step without losing stability, reduce numerical diffusion and also keep the system mass conservative.

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PP1
Investigation of Instability of Displacement Front in Flow Problems

The problem of two-phase immiscible fluid flow is considered, including sources and dependence of viscosity on temperature. Numerical calculations were achieved for different values of temperature and with increasing temperature, oil viscosity decreases exponentially and the stable state is possible. Additionally to the front stability there is an increase in the rate of displacement oil and increasing of production rate. Selecting optimal temperatures of injected fluid is a way for intensification of the field development.

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PP1
Pore-Scale Modeling and Experimental Investigations of Mixing-Controlled Geochemical and Biological Reactions

Many important applications in geosciences and groundwater pollution require understanding of mixing-controlled geochemical and microbiological reactions that affect porosity through mineral precipitation/dissolution and biofilm growth. We study these coupled processes using pore-scale simulation and micro-fluidics laboratory experiments. We use the lattice Boltzmann method to solve for single-phase fluid flow, the finite volume method to solve for multi-species reactive transport, and a cellular automaton method for porosity evolution. Direct numerical simulations are compared with laboratory experiments.

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PP1
A Multiscale Time Integrator for Computing Long-wave Shallow Water Flows at Low Froude Numbers

A new multilevel semi-implicit scheme for the computation of low Froude number shallow water flows is presented. Motivated by the needs of atmospheric flow applications, it aims to minimize dispersion and amplitude errors in the computation of long wave gravity waves. While it correctly balances "slaved" dynamics of short-wave solution components induced by slow forcing, the method eliminates freely propagating compressible short-wave modes, which are under- resolved in time.

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PP1
Efficient Solver for Transversely Isotropic Eikonal Equation Using Perturbation Theory

Numerical solutions of the eikonal (Hamilton-Jacobi) equation for transversely isotropic (TI) media are essential for imaging and tomography applications. Such solutions, however, suffer from the inherent higher-order nonlinearity of the TI eikonal equation, which requires solving a quartic polynomial at each computational step. Using perturbation theory, we approximate the first-order discretized form of the TI eikonal with a series of simpler equations for the coefficients of a polynomial expansion of the eikonal solution in terms of the anellipticity anisotropy parameter η. In addition to achieving very high accuracy, the formulation allows tremendous cost reduction compared to the exact TI eikonal solver. We demonstrate these assertions through tests on a homogeneous TI model, the VTI Marmousi model, and the BP TTI model.

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PP1
Adaptive Multi-Scale/physics Modeling of Two-Phase Flow Including Capillary Pressure

Important applications in porous media require large-scale simulation. To capture important effects high spatial resolution can be necessary leading to enormous computational costs. One solution strategy are multi-scale methods, which decrease the global degrees of freedom while preserving important features. We present an approach, which is applicable in a wide range of flow regimes, also if capillary pressure effects are significant. It combines adaptive grid methods based on MPFA with local upscaling techniques.

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