IP1

The Seismic Inverse Problem Towards Wave Equation Based Velocity Estimation

This talk will be on the inverse problem of exploration seismology, which aims at recovering earth parameters from controlled source seismic data measured at the surface of the earth. I will focus on retrieving the velocity function of seismic waves and discuss two approaches towards solving this problem, namely reflection tomography and Full Waveform Inversion.

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IP2

Numerical Simulation of Fractured Reservoirs: Old Challenges and New Ideas

Fractures are ubiquitous in geological formations and often control the successful exploitation of valuable resources such as hydrocarbons, water, and heat. Geoscientists, engineers, and mathematicians have struggled for decades to model and quantify the relevant physical and chemical processes accurately. This presentation will review some of the key challenges and approaches, and introduce new model concepts and numerical techniques that could led to a step-change when simulating heat and mass transfer in fractured geological formations.

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IP3

Grimmond CANCELLED

Talk is cancelled.

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IP4

A Multi-Scale Approach to Global Ocean Climate Modeling

Two advances in the field of applied mathematics have enabled a new approach to global ocean climate modeling. First, the creation of optimal, smoothly-varying Voronoi meshes has enabled the specification of different resolutions in different parts of the ocean. Second, a mimetic discretization of the rotating shallow-water equations insures that important conservation principles, such as energy and potential vorticity, are maintained on these multi-scale meshes. This talk will highlight how the combination of these advances might transform how we think about and use global ocean climate models.

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IP5

Mathematical Modeling of Sedimentary Basins

There is a fundamental asymmetry in the continental crust between high topography which tends to erode and low topography where sediments accumulate. As a result of this asymmetry, sedimentary basins contain much of the history of the Earths topography both high and low. Unravelling that signal means understanding the processes in the basement which form the basins themselves and the erosion, transportation and deposition of the sediments which find themselves in the basin. I will review some of the challenges in modelling a basin through its formation and filling and also touch on how this knowledge impacts our ability to use basins wisely.

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IP6

Locally Conservative Methods in Large Scale Simulation

Efficient approximation methods for Stokes-type systems are a crucial ingredient for many coupled multi-physics applications, e.g., in mantle-convection. The co-design of discretization concepts and solvers that satisfy local mass conservation, scale up to current peta-scale architectures and result in a small time-to-solution is of special interest. Here we discuss locally defined a posteriori flux corrections and a massively scalable hybrid matrix-free simulation framework. This work is part of the DFG funded priority program SPPEXA.

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SP1

SIAG/GS Career Prize Lecture: Title Not Available at Time of Publication

Abstract not available at time of publication.

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CP1

Dynamics of a Compositional Flow on Porous Media

The compositional flow in porous media involves phase creation and subsequent fluid transport coupled with phase equilibrium. A great challenge in this work is that gas phase appeared and vanished periodically. We present a 2×2 dynamic system on a single pore to study these behaviors. Several tests were run with different injected flow rate to investigate the condition that the system goes to steady state or the gas phase appeared and vanished periodically.

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CP1

Nonlocal Continuum Description of Flow in Porous Media with Long Bypassing Connections

In porous media multiple pathways exist between different locations, and flow at a given position has contributions from paths of different length. Considering pore network representations of such media, there exist pores which get bypassed by long tubes. To capture the nonlocal effects due to long bypassing connections, a nonlocal continuum model is proposed. The model is applied to different porous media and the results are compared with Darcy and pore network simulations.

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CP1

Numerical Methods in Secondary Oil Recovery

In this talk we present a large time step overlapping grids numerical method for hyperbolic conservation laws. The method is based on a finite volume method and has advantages that is relatively inexpensive and easy to implement. We consider two systems of conservation laws used in secondary oil recovery modeling multiphase flow of oil, gas and water, and we present numerical results using the above numerical method.

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CP1

Calibration of a Tcat Model for Salt Water Intrusion

In this talk we present a novel TCAT model for salt water intrusion. The model is a partial differential algebraic equation (PDAE). We discuss the numerical solution of the equations and the calibration of the model against experimental data. This is joint work with Deena Giffen, Casey Miller, Bill Gray, and Pam Birak.

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CP1

Mathematical Modeling for Geothermal System Via Sub-Systems and Applications to Secure Hydrocarbons Waste Disposal

In this presentation we consider a geothermal system and present a new mathematical model for the geothermal system. We view the system in terms of its sub-systems. Local and asymptotic stability of the model is discussed and applications to secure hydrocarbons waste disposal. The interesting case of propane is explored.

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CP1

Modeling the Influence of Biosurfactant Adsorption on Rock Wettability in a Meor Process

A very general model is presented in the companion work in this congress (Daz-Viera, M., Ortiz-Tapia, A., Hernndez-Prez, J., (2015). A flow and transport model in porous media for microbial enhanced oil recovery studies. SIAM GS15). Here, is studied the effect of changed biosurfactant concentration through adsorption in a rock core, on the residual oil saturation, modeled as a linear function of the trapping number, which is in turn an empirical function of biosurfactant concentration.

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CP2

Duality Based Error Estimator for a Discontinuous Galerkin Discretization of Advection Problems

We show that the dual weighted residual method provides an error estimator for a regularized 1D advection equation which converges to the error estimator of the purely advective problem under the condition that the primal solution in the weak formulation can be tested with the dual solution. Our counter example shows that the weak formulation is not defined if the primal and dual solution have coinciding discontinuities.

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CP2

A High-Resolution Scheme for Advective-Diffusive Transport Modeling on Arbitrary Polyhedral Grids

A high-resolution finite volume scheme for the discretization of advection operatorator on arbitrary 3D polyhedral grids is presented. The scheme features local linear reconstruction of concentration on mesh elements, which provides second order accuracy in smooth regions and front capturing. This reconstruction is accomplished using optimization methods, adapted to the problem. The scheme is compared to conventional methods within the existing groundwater flow and transport modeling software. It's applications to complex problems are shown, namely density-driven flow and reactive transport modeling.

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CP2

Large-Scale 3D Geo-Electromagnetic Modeling with Parallel Adaptive High-Order Finite Elements

Electromagnetic methods of geophysics aim at studying the subsurface electrical conductivity distribution, and typically require the solution of a large number of problems derived from Maxwell's equations. In this contribution, we investigate the use of adaptive high-order finite elements (FEs) to discretize these problems in large-scale parallel settings. We present a new scalable algorithm for solving the resulting linear systems, based on block-diagonal and auxiliary-space preconditioning. A particular advantage of our solver is that it can handle arbitrarily high-order FEs on unstructured and non-conforming locally refined meshes. The meshes are refined by using highly efficient goal-oriented error estimator. The solver is also algebraic in nature, so it is efficient for a wide range of frequencies, boundary conditions, physical sources, and large conductivity contrasts. We use 3D magnetotelluric modeling to demonstrate that the adaptive high-order FE discretization with the new solver is beneficial for many relevant problems.

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CP2

A Multiscale Discontinuous Galerkin Method for Transport Modeling

We study in this work a multiscale method designed for convection-difusion problems and based on a Discontinuous Galerkin discretization. Using results of homogenization, we prove an a priori error estimate in the case where all parameters of the problem are assumed to be periodic. We also present numerical results where the Darcy equation is first solved and the multiscale method is then applied to simulate the transport of a tracer within the porous medium.

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CP2

Radial Basis Based Spectral Collocation Method for Orr-Sommerfeld Eigenvalue Problem in Fluid Dynamics

The Orr-Sommerfeld eigenvalue problem decides hydrodynamic stability in the analysis of parallel fluid flow in an idealized infinitely long domain. Spectral methods are reported to be viable tools for numerical solution of a differential equation involving simple domain and smoothly defined problems. In this work, we present a spectral collocation method on chebyshev grids using multiquadratic radial basis function to obtain derivative approximation for the numerical solution of Orr-Sommerfeld eigenvalue problems.

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CP2

A High Order Finite Difference Method to Simulate Wave Propagation in Fluid-Filled Fractures

Interface waves along fluid-filled fractures can carry information about fracture geometry, which is of interest to oil and gas industry, and volcanologists. To simulate these waves we use summation by parts finite differences on curvilinear, multiblock grids solving the linear elastic wave equation and a linearized approximation of the compressible Navier-Stokes equations. We enforce coupling conditions weakly and investigate accuracy and stiffness using eigenspectra calculations. Coupling to quasi-one-dimensional conduits using transfer functions is also discussed.

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CP3

Identification of Conductivity by Minimising a Gradient Co-Linearity Mismatch Norm

Behold, Let $\Omega \subset I\!R^2$ be bounded by two heteroclinic orbits, Γ_1, Γ_2 of the ∇u-flow. Then $\nabla \cdot (c\nabla u) = 0$ in Ω implies $c \equiv 0$ in $\bar{\Omega}$ [Chicone and Gerlach, 1987]. Let $u \in \mathcal{C}^2(\Omega) \cap \mathcal{C}^0(\bar{\Omega})$ be known. The (unique) conductivity $\hat{a}$, which complies with $\nabla \cdot (\hat{a}\nabla u) = f$, can be identified by minimising with respect to b the norm of $\nabla \tilde{a}[b] \times \nabla u - \nabla b \times \nabla p$ under constraints, where $\nabla \cdot (b\nabla p) = f$ and $\tilde{a}[b]\partial_j u := b\partial_j p$, $j = 1$ **or** 2. This is an attempt at justifying the “comparison model’ algorithm [Scarascia and Ponzini, 1972], which has seen successful practical applications to inverse hydrogeology ever since.

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CP3

Bayesian Inversion for Hydraulic Conductivity at Wipp

We cast the problem of inferring hydraulic conductivity from measurements of hydraulic head and transmissivity as a Bayesian inverse problem. Using a Metropolis-Hastings MCMC method to sample from the posterior distribution, we construct the CDF of a quantity of interest, the travel time of a particle released in the flow. We give numerical results for data from the Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM.

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CP3

Multi-Model Ensemble Assimilation for Enhance Model Prediction: Specification of Ionosphere-Thermosphere Environment

The simulation of complex physical phenomena is commonplace in many areas of science. A concern is that model errors and bias, resulting from uncertain parameters and unaccounted physical processes, have a significant influence on model forecast accuracy. In this talk we present a multi-model ensemble system coupled with an assimilation algorithm to improve the forecast of the ionosphere-thermosphere environment. The main advantage of our approach is that combining a number of models can help mitigate model errors suffered by any one model. A number of numerical experiments are presented which compare the forecast performance of assimilation with single-model and multi-model techniques.

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CP3

Bayesian Emulators in Spatial Inverse Problems

We consider a Bayesian approach to nonlinear inverse problems in which the unknown quantity (input) is a random spatial field. The Bayesian approach casts the inverse solution as a posterior probability distribution. The likelihood term in the posterior distribution contains the forward simulator, which is complex and non-linear, therefore computationally expensive. We develop an emulator based approach where the Bayesian multivariate adaptive splines (BMARS) has been used to model unknown functions of the model inputs. The emulators run almost instantaneously hence they are much computationally efficient as compared to the forward simulators. Data from different sources and scales are also integrated using a Bayesian hierarchical model. The estimation is carried out using trans-dimensional Markov chain Monte Carlo method. Numerical results are presented by analyzing simulated as well as real data from reservoir characterization.

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CP3

Data Reduction Techniques Applied in Inverse Modeling

The Bayesian inverse modeling techniques uses the likelihood function as an engine for parameter estimation. This likelihood function is affected by the data dimensionality of the inversion problem. We use a combination of different dimensionality reduction methods such as principal components analysis (PCA), Fast Fourier Transformation and geometric methods for determining the intrinsic dimension for better characterization of spatial random fields applied in groundwater problems.

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CP3

Constructing the Dynamic Tortuosity Functions from Dynamic Permeability Data at Distinct Frequencies

Dynamic tortuosity quantifies the effective interaction between solid and viscous fluid in poroelastic materials. It plays an important role in dissipation/dispersion in the poroelastic wave equations, which have been used to model waves in fluid saturated rocks. However, it is difficult to measure. The recent results on using the dynamic permeability, which is easier to measure, at different frequencies to reconstruct the dynamic tortuosity function for materials with arbitrary pore space geometry will be presented.

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CP4

Evaluate and Analysis of Experimental Data in Associated with a Sand Packed Model Using a Numerical Method at Polymer Flooding Process to Enhanced Oil Recovery

Polymer Flooding as one of the Chemical Enhanced Oil Recovery (EOR) plays an important role during EOR process. Polymer solution with controlling mobility ratio of injected water can recover further percent of Original Oil In Place (OOIP).This study concerns a numerical method to evaluate obtained results of a sand packed model. Injection rate and concentration as two major parameters are fund and better analysis of them can lead to the desired results. A numerical method in order to evaluate such parameters was selected and utilized . Based on experimental data, related equation from numerical method are constructed and after creating equations, resulted for reach to further oil recovery polymer solution should be firstly injected at high rate and then be flooded with low rate of injection. As well as, polymer solution should be injected with low concentration and then high concentration respectively.

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CP4

Weak Solutions to a Nonlinear Degenerate Equation Arising in Chemotaxis Or Porous Media

We are interested in the mathematical analysis of a general degenerate nonlinear parabolic equation modeling the saturation of one phase in a multiphase ow in porous media. The equation presents degenerate terms of order 0 and of order 1 to handle with the pressure term. The degeneracy of the dissipative term occurs in the region where one of the phases is missing and the dissipative fonction vanishes at two points, we obtain solutions in a weaker sense compared to the classical formulation. Therefore, a degenerate weighted formulation is introduced taking into account the degeneracy of the dissipative term.

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CP4

Analysis and Numerical Approximation for Adsorption Models

We focus on the structure of an adsorption model as systems of conservation laws (multicomponent case for adsorption), with equilibrium and non-equilibrium type nonlinearities, where the latter are associated with microscale diffusion. We also work with an unusual type isotherm called Ideal Adsorbate Solution, which is defined implicitly. For the IAS adsorption system, we show sufficient conditions that render the system hyperbolic. We also construct numerical approximations for equilibrium and nonequilibrium models.

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CP4

Reactive Transport at the Pore-Scale: the Impact of Flow Field Heterogeneity

We present a Lagrangian pore-scale method to simulate carbonate dissolution on 3D micro-CT images of rocks. Particle advection employs a new semi-analytical streamline tracing algorithm. Dissolution is controlled by the flux of particles through the pore-solid interface. Validation is done using dynamic imaging data. Using rocks of various degrees of heterogeneity, we show that dissolution is controlled by the relative importance of advection, diffusion and reaction, and also by the flow field heterogeneity (e.g hydraulic tortuosity).

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CP4

Numerical Aspects of Equilibrium Calculations in Tight Oil Formations

Despite the large potential of unconventional resources, many unknowns still exist regarding the physics of multiphase flow in these settings. These include accurate representation of phase equilibrium in tight formations and effective implementation of these models in simulation tools. In this work, we analyze the numerical aspects of including capillarity phenomena in VLE calculations in an effort to

arrive at a robust and efficient algorithm for compositional simulation of unconventional reservoirs.

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CP4

High-Dimensional Visualization of Flow Response from Ensemble of Exhaustively Sampled Reservoir Models

Ensemble-based reservoir simulation has become increasingly feasible in recent years due to the computational advancement. One of the criticisms is: how can we interpret such numerous simulation results? Big data analytics is the key to solving the problem. We propose a new high-dimensional visualization method to rapidly interpret flow response from large ensemble of reservoir models, which consists of more than thousands, exhaustively sampled from high-dimensional space spanned by geological uncertainty parameters.

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CP5

Upscaling Interpretation of Nonlocal Fields, Gradients and Divergences

In this talk, the interrelation between weight-function upscaling (measurement) and the definition of various nonlocal operators will be explored. Let $\langle f \rangle = f * g$ where $f * g$ is the convolution product which represents the effect of upscaling via an instrument (defined by g) on a field variable f and its localized counterpart. Nonlocal field variables are defined and employed for upscaling. It will be shown via Fourier transform, for judicious choice of the arbitrary function ρ, that $\mathcal{G}_\rho f(\mathbf{x}) = \langle \nabla f \rangle(\mathbf{x})$ where $\mathcal{G}_\rho f(\mathbf{x})$ is the nonlocal gradient of f and ∇f is the classical gradient. Upscaled representations for the adjoint of $\mathcal{G}_\rho$ and the nonlocal divergence are also obtained. A nonlocal self-diffusion equation is upscaled and written in terms of nonlocal operators.

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CP5

A General Framework for Hierarchical Hybrid Multiscale Simulation

We consider multiscale methods in which microscale and macroscale models are explicitly coupled in a single hybrid multiscale simulation. A limited number of hybrid multiscale simulations of biogeochemical earth systems exist based on customized approaches for model coupling. We describe a generalized approach to hierarchical model coupling designed for high-performance computational systems and an example implementation based on coupling two models with different representations of physics and biogeochemistry at two distinct scales.

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CP5

Model-Order Reduction for Subsurface Flow Using a Trajectory Piecewise Quadratic Approach

A trajectory piecewise quadratic (TPWQ) representation of nonlinear effects is combined with proper orthogonal decomposition to provide a reduced-order subsurface flow model. The method enables the fast computation of approximate pressure and saturation states for new well settings in oil-water problems. Results demonstrate that TPWQ can be used as an error indicator for trajectory piecewise linear (TPWL) models. The incorporation of TPWQ into an efficient production optimization procedure is also illustrated.

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CP5

Upscaling Barrier Systems and Calculating Five-Spot and Line Drive Well Rates Using Theta Functions and Elliptic Integrals

Using theta functions and elliptic integrals we derive a novel practical formula for the effective vertical absolute permeability for a general class of generic barrier systems. The results can also be applied for deriving explicit formulas for single phase production rates in wells in five spot patterns and for line drive patterns. The analysis also involves the so-called nome which is related to modular functions and the monster group.

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CP6

Optimal Compressive-Sampling Measurement Matrices for Seismic Acquisition

We discuss and compare various applications of compressive sampling in seismic data acquisition. The sampling scheme directly impacts the mutual coherence of the resulting dictionary, which is in turn crucial to a successful recovery of sparse signals. Based on a Fourier signal representation, we show that the maximum mutual coherency of the dictionary can be minimized by a smart design of the sampling scheme. This can be physically interpreted as minimizing the maximum aliasing power.

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CP6

Estimation of Spatial Uncertainties of Geophysical Tomographic Models

Models derived from geophysical inversion (e.g., seismic tomography) often lack a clear indication of the associated spatial uncertainties, which are as important for the interpretation as the models themselves. This study investigates how quantitative estimates of spatial uncertainties (e.g., in meters) can be obtained by analysis of equivalent models using a posteriori covariance analysis. We focus on efficiency and flexibility for deriving structure related uncertainties that also account for the directionality of the spatial uncertainties.

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CP6

Optimal Experimental Design for Geophysical Imaging of Flow in Porous Media

Designing experiments for imaging fluid flow requires both the integration of the dynamical system describing the flow and the geophysical imaging technique. In this talk we explore optimal experimental design methods for such problems, and demonstrate the applicability of the techniques for the problem of imaging subsurface flow using seismic methods.

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CP6

Optimal Space-Time-Frequency Design of Microphone Networks

We use an array of microphones to extract a single source out of a multi-source, multi-path environment. Our convex optimization technique not only chooses D microphones out of N possible choices but also designs the taps of the multirate filterbanks that process each of the D outputs. We model our sources as random wide sense stationary processes and show how to convert the continuous frequency problem to a discrete frequency approximation that is computationally tractable.

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CP6

Constrained Optimization Framework for 1D Seismic Wave Propagation Problems

We create a unified algorithmic framework that accommodates several constrained optimization schemes for solving one-dimensional seismic wave propagation problems. We use a PDE-constrained optimization formulation where we introduce inequality constraints over the inversion parameter, e.g. the material properties. Our goals are to provide a unified affine invariant approach, to improve a line-search step computation, and ultimately to identify robust schemes that incorporate inequality constraints for solving the inverse problem with interior-point, and active set methods.

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CP6

Study of Torsional Wave in the Crustal Layer with Varying Inhomogeneity

The study deals with the propagation of torsional surface waves in a homogeneous crustal layer over a transversely isotropic layer over a gravitating dry sandy Gibson half space under the influence of initial stress. In the isotropic layer the directional rigidity as well as the density varies exponentially. In the homogeneous crustal layer rigidity and density remains constant. The dispersion equation has been obtained in the closed form and the results have been shown graphically.

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CP7

The Impact of Correlated Observational Errors in High-Resolution Atmospheric Data Assimilation

The fast-growing volume of high-resolution atmospheric measurements has prompted the need for modeling correlated observational errors in atmospheric data assimila-

tion systems. An adjoint-based error covariance sensitivity approach is formulated to identify high-impact error correlation structures and provide a priori estimates to forecast error reduction. Mathematical and computational aspects are presented in four-dimensional variational data assimilation. The forecast impact of spatial and inter-channel error correlations is analyzed for hyperspectral satellite instruments assimilated in Navy's NAVDAS-AR/NAVGEM.

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CP7

Improving Numerical Stability of the Non-Hydrostatic Global Environmental Multiscale Atmospheric Model for High Resolution Forecasting

Improving numerical stability of atmospheric models for high resolution forecasting applications, particularly over complex orography, may necessitate a combination of adjustments to the existing models. Several modifications within the non-hydrostatic Global Environmental Multiscale model, ranging from adjustments in spatiotemporal discretizations to changes in the hybrid vertical coordinate system, are currently being investigated at Environment Canada to ascertain their implications on the overall numerical stability of the model. Pertinent results will be presented at the conference.

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CP7

Advancing the All-Scale Eulag Model Towards Energy-Efficient Exa-Scale Simulation of Atmospheric Flows.

We investigate complementary role and the relative computational performance on classical and modern supercomputer architectures of the consistent semi-implicit soundproof/compressible model formulation applied to the archetype weather problems using the all-scale non-oscillatory forward-in-time EULAG model. The consistent semi-implicit integrators of the compressible and soundproof PDEs share the two algorithmic engines: the non-oscillatory MPDATA advection schemes and the preconditioned non-symmetric Generalized Conjugate Residual solver with newly developed parallel alternate direction implicit preconditioners.

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CP7

A Semi-Implicit, Semi-Lagrangian Dg Framework for Adaptive Numerical Weather Prediction

We present an adaptive discretization approach for NWP model equations, which combines the semi-Lagrangian technique with a TR-BDF2 semi-implicit time discretization and with a DG spatial discretization with (arbitrarily high) variable and dynamically adaptive element degree. The resulting method has full second order accuracy in time, is unconditionally stable and can effectively adapt at runtime the number of dof employed in each element, in order to balance accuracy and computational cost.

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CP8

Towards Improved Characterization of Geochemical Hot Moments: A Combined Wavelet-Entropy Approach

A novel wavelet-entropy technique is used to investigate hot moments of geochemical activity in groundwater and seeps in the Rifle field site, CO. Wavelet analysis was conducted along three different transects within the Rifle floodplain and entropy analysis was based on site characteristics. Hot moments were associated with seasonal and annual hydrologic variations along the contaminated and seep transects, respectively. In contrast, a different frequency (3 months) constituted hot moments in a naturally reduced zone.

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CP8

An Eulerian Strategy for Disperse Phase Flows

A new method is introduced for the transport of a disperse phase (aerosol, particle-laden flow and/or spray). It is robust and accurate and allows adaptive use of the many descriptions available for disperse phases (population balance, Monte-Carlo sampling, moments, and sectional discretization) as well as their full coupling together. A case is computed with agglomeration, as handled by a high-order-in-size sectional approach.

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CP8

Unidirectional Flow with Temperature-Dependent, Shear Thinning Viscosity and Biases in Estimation

of Lower Crustal Viscosity

Crustal deformation is routinely used to infer the viscosity of the lower crust. Inferences using cumulative deformation over million year time scales are typically lower than those estimated from decadal scale deformation. Models of lower crustal flow most often assume Newtonian viscosity in a homogeneous lower crustal channel. Using a solution for Poiseuille flow with temperature-dependent, non-linear viscosity, appropriate for the the lower crust, we explore the biases in viscosity estimates using simplified models.

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CP8

Prediction of Water Flow in Irrigation Network by Using Numerical Techniques

Prediction of water flow in rivers and canals and sediment movement can be carried out with sufficient accuracy using numerical models. In this work, we will use approximate techniques for water flow calculations and sediment transportation for a full network of natural and constructed channels of Pakistan.

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CP8

On Various Kriging Predictors for Geoid Densification: a Comparison

For geoid densification, traditionally the method of Least-Squares Collocation (LSC) has been heavily used which requires the knowledge of a suitable covariance function. Interestingly, it could be shown that equivalent results can be achieved by means of Kriging, a method that is usually based on the semi-variogram or, perhaps, the homeogram. This equivalence, however, turns out to be perfect only as long as the spatial "coherency functions" are not estimated separately. In this study, the influence of such estimates on a variety of empirical Kriging predictors (Simple Kriging, Ordinary Kriging, Optimal Biased Kriging) is analyzed, and some conclusions will be drawn.

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CP9

A Parallel Cpr-Like Preconditioner Based on Non-Smoothed Aggregation Amg

For flow in porous media non-smoothed algebraic multigrid (AMG) based on aggregation has turned out to be one of the most efficient and scalable preconditioners. This is achieved by either subtle aggregation heuristics that honor the physical properties of the problem or specialized multigrid cycles, called either Krylov- or AMLI-cycle. In this talk we will present a CPR-like preconditioner using the former AMG method for the pressure system, and show its scalability for reservoir simulations.

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CP9

Analysis of the Hybrid Upwinding for Fully-Implicit Simulation of Multiphase Flow with Gravity

Accurate description of the dynamics in the subsurface requires solving the PDEs that represent the conservation laws of multiphase flow in porous media. In these PDEs, the flow is coupled to the highly nonlinear transport of species. We present a numerical scheme honoring this coupling that combines the Fully-Implicit Method with a hybrid upwinding of the flux across an interface between two control volumes. We obtain a monotone and differentiable numerical flux resulting in fast convergence of Newton-based nonlinear solvers, which reduces the computational cost of a simulation.
Reference: Lee, S. H., Efendiev, Y., Tchelepi, H. A., [2015], Hybrid Upwind Discretization of Nonlinear Multiphase Flow with Gravity, submitted to *Advances in Water Resources*.

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CP9

Componentwise Time-Stepping for Radially Symmetric Pde

Time-dependent PDE with radially symmetric solutions are of particular interest in reservoir simulation, where the center of the domain represents a well. This talk presents a new approach to such PDE, in which stiffness is overcome through individualized approximation of each component of the solution, in a basis of orthogonal polynomials. The proposed method represents an extension of Krylov subspace spectral (KSS) methods, which overcome stiffness for PDE on rectangular domains, to circular domains.

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CP9

Modified Sequential Fully Implicit Scheme for Compositional Flow Simulation

The Fully Implicit Method (FIM) is widely employed for

reservoir simulation. However, in the Multi-Scale Finite-Volume approach, sequential strategies are used to couple flow and transport. For problems with tightly coupled nonlinear interactions between flow and transport, these approaches may require many more Newton iterations, and/or smaller time steps compared with FIM. We analyzed the nonlinear coupling between flow and transport for multiphase, multi-component systems that involve significant compressibility effects and interphase mass transfer and we propose a modified scheme. We show across a wide parameter range that this new algorithm has convergence properties consistently better than usual ones. Black-oil and compositional systems in depletion and compression settings are presented and discussed.

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CP9

Time Stepping for Advection Dominated Methane Hydrate Models with Significant Salinity Dependence

Comprehensive methane hydrate models account for methane and salt concentration as well as for variable pressure and temperature, and their most difficult part is a robust phase behavior solver coupled to transport. If temperature is assumed known, one can consider several variants of time-stepping for the resulting reduced phase behavior model. In the talk we discuss convergence and accuracy of the numerical scheme for the case when advection is dominant; this is assessed using recently derived analytical solution as well as experimental data from Ulleung basin.

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CP9

Subduction Zone Simulations with Rate-and-State Friction

Section: 4. Lithosphere and pedosphere modeling Subsection: d. Plate tectonics and earth dynamics We present here a novel algorithm for elastodynamic problems of rate-and-state friction, along with first results on existence and uniqueness of solutions as well as convergence of the scheme. At its center lies a rate-and-state decoupling fixed-point iteration, the stability of which is demonstrated by the example of a two-dimensional laboratory-scale subduction zone simulation, which is shown to be in good agreement with laboratory measurements. As an outlook, we present preliminary three-dimensional results.

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CP10

Multiple Steady Solutions of a Model Subpolar Ocean Forced by Localized Wind

A simple model of the subpolar North Atlantic can produce closed, recirculating cells in the Irminger and Labrador Seas, consistent with float data. But it can also produce an inertial solution with swift, open currents that do no recirculate. We explore this transition in a periodic channel to isolate the dynamics at work. Weak forcing leads to the classic beta plume, while strong forcing causes the circulation to strengthen and elongate.

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CP10

Offshore and Coastal Wind Resource Characterisation for Mexican Waters

Preliminary results for an offshore and coastal wind energy atlas for Mexico are presented, based on statistical wind energy computations using upscale climate data, and meteorological station wind data from coastal locations, both extrapolated to a height of 90m above ground level. Some study case scenarios, at particular locations in the Gulf of California and the Mexican North-Eastern Pacific, will also be discussed.

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CP10

A New Well-Posed Vorticity Divergence Formulation of the Shallow Water Equations

A completely new vorticity-divergence formulation of the two-dimensional shallow water equations including boundary conditions is derived. The new formulation is necessary since the conventional one does not lead to a well-posed initial boundary value problem for limited area modelling. The new vorticity-divergence formulation include four dependent variables instead of three, and require more equations and boundary conditions than the conventional formulation. On the other hand, it forms a symmetrizable hyperbolic set of equations with well defined boundary conditions that leads to a well-posed problem with a bounded energy.

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CP10

Simulation of Multiscale and Multiphysics Coastal Ocean Flows by Integration of Geophysical Fluid Dynamics and Fully 3D Fluid Dynamics Models

Integration of geophysical fluid dynamics and fully 3D fluid dynamics models is proposed to predict multiscale/multiphysics coastal ocean flows. This integration is able to simulate distinct flow phenomena at spatial scales O (1) m – O (10,000) km with high fidelity. The methodology is discussed, and its unprecedented capabilities are illustrated by applications to emerging problems such as impact of storm surge on coastal infrastructure that are beyond the reach of other existing models.

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MS1

Variational Space-Time Approximation of Transport Processes and Iterative Solver

Numerical simulation of time dependent transport is desirable in several fields of technology. While the discretization in space involves significant challenges, temporal approximations have received little interest and have often been limited to low order methods. We present two families of continuous and discontinuous variational time discretization schemes that are combined with mixed finite element approximations in space. Error estimates and numerical studies are presented. The solver technology for the arising systems is addressed further.

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MS1

A Multipoint Flux Mixed Finite Element Method with Non-Matching Hexahedral Grids

We propose and analyze several methods for extending the multipoint flux mixed finite element method to allow efficient simulations on multiblock domains with nonmatching distorted hexahedral grids. Numerical techniques are developed based on the enhanced velocity finite element method and the local flux mimetic finite difference method. We develop a reasonable assumption on geometry, discuss implementation issues, and give several interesting numerical results.

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MS1

Solving the Nonlinear and Nonstationary Richards Equation with Adaptive Domain Decomposition and Subcycling

Modeling the transport processes in a vadose zone plays an important role for a wide range of environmental issues. Water flow is governed by Richards equation. Certain materials with dominantly uniform pore sizes (e.g. coarse-grained materials) can exhibit steep gradients of constitutive functions. Numerical approximation of the Richards equation requires sequential solutions of systems of linear equations arising from discretization and linearization of the problem. Typically, one has to solve huge systems of linear equations to obtain only a few updates of solution. Then the local updates typically represent local disturbances (e.g. moving wetting front). A method for adaptive subdomain split, that enables sequential solutions of subdomains covering the local disturbances only is currently under an intense development. The method was already labeled as *dd*-adaptivity. Our recent presentation will focus on multi-time-step improvement of our *dd*-adaptivity algorithm.

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MS1

Fully-Implicit Nonlinear Flux Approximation for Two-Phase Flow in Porous Media

Classical linear Finite Volume methods do not fulfill properties like monotonicity or extremum principles for general meshes or anisotropic behavior. Therefore, during the last decade different authors developed nonlinear Finite Volume methods satisfying discrete extremum principles. We will give a detailed comparison between linear and nonlinear methods combined with different solution strategies, such as the fully-implicit or the adaptive-implicit. A special focus is set to the applicability for complex flow processes in porous media.

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MS1

Adaptive Multistep Time Discretization and Linearization Based on a Posteriori Estimates for the Richards Equation.

We derive a posteriori error estimates based on the dual norm of the residual of the Richards equation. The error is decomposed into space, time, and linearization terms. Error estimators are computed with reconstructions especially designed for a multistep Discrete Duality Finite Volume scheme. We stop the fixed-point iterations when the linearization error becomes negligible, and we choose the time step to balance the time and space errors. Results are presented to several test cases.

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MS1

An Adaptive Inexact Uzawa Algorithm Based on Polynomial-Degree-Robust a Posteriori Estimates for the Stokes Problem

We are interested in designing an adaptive inexact Uzawa algorithm applied to the linear Stokes problem solved by all standard conforming and conforming stabilized finite element method. We present an a posteriori error estimate based on the equilibrated flux reconstruction which can distinguish the different error components. Our estimate gives a guaranteed upper bound on the overall error as well as a polynomial-degree-robust local efficiency. Some numerical examples showcase the performance of our adaptive strategy.

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MS2

Full Waveform Inversion Without Source Estimation

Full waveform inversion attempts to estimate elastic parameters of the subsurface by fitting synthetic data to real seismic data. Usually the source time signature is unknown and is estimated by the inversion scheme. We use a simple finite-difference modeling scheme to compute the downgoing source wavefield directly from two-component streamer data and employ this wavefield in the full waveform forward modeling. This removes the need for simultaneous estimation of elastic parameters and source signature.

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MS2

Block-Diagonal Approximation of the Hessian for Multi-Parameter FWI

In multi-parameter waveform the trade-off between parameters is sub-surface point dependent due to the limited acquisition aperture. The estimation of the radiation patterns of each model parameter is challenging in wave-equation approach because it requires the knowledge of the diffraction angles. We propose to extend the diagonal approximation of the Hessian of the least-square misfit by a block-diagonal approximation. We shall discuss an efficient implementation with random pulse excitations to compute simultaneously the receiver wavefields.

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MS2

Multi-Scale Inversion of Subsurface Velocity Models Using Cartoon-Texture Decomposition

We propose a multiscale formulation of full-waveform inversion (FWI) that is similar to image decomposition into a cartoon and texture used in Image Processing. The inversion problem is formulated as unconstrained multi-norm optimization and solved using Bregman iterations and gradient-projection methods. We demonstrate the proposed model decomposition approach by recovering low and high-wavenumber subsurface velocity model components from noisy data, and discuss the effect of noise on the feasibility and accuracy of multiscale inversion.

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MS2

Land Elastic Waveform Inversion for Seismic Velocity Model Building

Surface waves in land seismic data complicate the retrieval of the (compressional) velocity long-wavelengths. With acoustic waveform tomography we remove them in the inverse problem. With large elastic parameters, the low-frequency first event is not always a pure acoustic one due to tuning effects. In this waveform tomography context, we then propose an elastic waveform inversion with a modified surface boundary condition to avoid generating surface waves in the modeling. In this presentation, we will discuss the relevance and limitations of this approach.

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MS2

Waveform Inversion of Seismic Data

The earth physics of seismic waves is modeled with acoustic and elastic equations. A new method is called IDWI, for iterative direct waveform inversion is proposed. The current full wave form methods have limitations; in the use low frequency data, the non-linearity of the objective functions, and computational expense. Demonstrations of synthetic velocity models data results and real field data examples are presented illustrating the usefulness of this new method.

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MS2

Data Conditioning and Model Conditioning to Address Factors of 10x with FWI

Although data conditioning and model conditioning are conceptually mundane aspects of inversion, they can influence inversion efficiency and effectiveness by a factor of 10x. They are hard to do well, they often involve craft and experience, and they often need to be customized to each individual data application. It is probably appropriate to consider this conditioning on the experimental side of geophysics. There is industry need for academia to investigate this mundane, experimental side of applied geophysics.

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MS3

Consider Parsimony in Fault and Fissure Modeling for Land Subsidence Investigations

Parsimony should be a key consideration when developing numerical models to simulate fault behavior in coupled poroelastic and fluid flow aquifer systems. Parsimony is dictated by three important factors: (1) objective, (2) scale, and (3) observations. In the investigation we consider a fault-zone case in which both parsimony is used (traditional continuum poromechanics) along with more complex cohesive zone fault modeling and compare three-dimensional surface displacements and water levels in both modeling approaches.

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MS3

Accuracy and Robustness of the Lagrangian Approach for the Numerical Simulation of Faults

Stress variations induced by gas/oil production may activate pre-existing regional faults. To predict seismicity consequences, it is important to simulate fault mechanics in the actual geological setting. Faults yield discontinuity in the displacement field that finite elements cannot address. Interface finite elements are used to simulate the fault behaviour. A Lagrangian approach has been developed to enforce contact condition. It is proved that the Lagrangian approach is more robust than the Penalty approach.

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MS3

Computational Framework for Unstructured Discrete Fracture Models with Application to Oil Recovery

This work focuses on a numerical method for solving the coupled flow and geomechanics for large scale fractured subsurface formations. We present a formulation that extends the Discrete Fracture Model typically used for flow and transport problems. A mixed formulation combining continuous Galerkin Finite Elements and Finite Volumes is developed. The set of coupled nonlinear equations is solved by a fully coupled method. The framework is fully integrated within the multi-phase flow simulator AD-GPRS.

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MS3

Computational Modeling of Coupled Multiphase Flow and Geomechanics to Study Fault Slip and Induced Seismicity

The coupling between subsurface flow and geomechanical deformation is critical in the assessment of the environmental impacts of groundwater use, underground liquid waste disposal, geologic storage of carbon dioxide, and exploitation of shale gas reserves. In particular, seismicity induced by fluid injection and withdrawal has emerged as a central element of the scientific discussion around subsurface technologies that tap into water and energy resources. Here we present a new computational approach to model coupled multiphase flow and geomechanics of faulted reservoirs. We represent faults as surfaces embedded in a three-dimensional medium by using zero-thickness interface elements to accurately model fault slip under dynamically evolving fluid pressure and fault strength. We incorporate the effect of fluid pressures from multiphase flow in the mechanical stability of faults and employ a rigorous formulation of nonlinear multiphase geomechanics that is capable of handling strong capillary effects. We develop a numerical simulation tool by coupling a multiphase flow simulator with a mechanics simulator, using the unconditionally stable fixed-stress scheme for the sequential solution of two-way coupling between flow and geomechanics. We validate our modeling approach using several synthetic, but realistic, test cases that illustrate the onset and evolution of earthquakes from fluid injection and withdrawal. We also present the application of the coupled flow-geomechanics simulation technology to the post mortem analysis of two earthquake sequences: (1) the Mw=5.1, May 2011 Lorca earthquake in south-east Spain, to investigate the possibility that the earthquake was induced by groundwater extraction; and (2) the Mw=5.8, May 2012 earthquake in the Cavone oilfield in northern Italy, to assess the potential for induced seismicity from reservoir fluid injection and production.

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MS3

A 3-Dimensional Model for the Simulation of Hydraulic Fracturing

Optimizing the hydraulic fracturing process requires understanding on the fracture process in relation with the poromechanical properties of the rock formation. In this contribution we will present a 3 dimensional partition-of-unity based model for hydraulic fracturing in saturated porous rocks. The position of the fracture surface is represented by two evolving level set functions. The performance of the model will be demonstrated by the analysis of the propagation of hydraulic fracture planes.

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MS3

Coupled Reservoir and Geomechanical Numerical Modeling of Water Injection into a Fractured Formation

Optimization of fracturing operations in well completion for oil and gas, geothermal and other operations requires modeling of the complex mechanics of the dynamic shear-induced fracture network and the resulting enhanced permeability region. We discuss and contrast several approaches to model the problem. Rigorous methods, based on theory of joints and equivalent media are described for both static and dynamic fracture systems, and compared with a simple approach using empirical functions for modifying both mechanical and flow properties of the failed media.

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MS4

General Curvilinear Ocean Model Application: Completely Three-Dimensional Modeling of San Diego Bay Hydrodynamics

The General Curvilinear Ocean Model (GCOM) is unique in its ability to solve non-hydrostatic momentum equations utilizing completely three-dimensional curvilinear grids. GCOM is designed to work at super-high resolutions (tens of meters) on problems resolving strong current forces acting on complex bathymetry near the coastline. These problems include turbulence from flow through channels and curved boundaries, river and estuary flows, and how bottom surface rugosity affects current flow. The model has shown successful results in idealized simulations, this presentation details model application in studying the hydrodynamics of San Diego Bay, California. The entrance channel to San Diego Bay is unique in its use as a conduit for naval submarines, this lends itself well to application for the GCOM fully three-dimensional curvilinear approach. Specifically, estimates of tidal flow, temperature, salinity, and current velocity at small scales within the bay are nested with Regional Ocean Model System output.

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MS4

Nesting Nonhydrostatic UCOAM within Hydrostatic ROMS

The Regional Ocean Modeling System (ROMS) is a hydrostatic free-surface ocean model ideally suited to simulate mesoscale to basin-scale ocean processes. The Unified Curvilinear Ocean Atmosphere Model (UCOAM) is a nonhydrostatic large eddy simulation (LES) model designed specifically for high-resolution simulations. In this research, a hybrid model is developed that nests a fine-grid UCOAM model within a coarser-grid ROMS. The hybrid model is tested in idealized flow over a seamount.

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MS4

Ensemble Filters to Reduce Uncertainties in San Quintin Bay Hydrodynamic Forecast System

Uncertainties in the hydrodynamics model parameters have been accurately estimated though automated calibration and validation process in previous studies. However, uncertainties propagated over time are still largely unknown, and have yet to be tested in San Quintin Bay. For our research, we implemented a Delft3D Model to study the hydrodynamics of San Quintin Bay, in which Data Assimilation (DA) techniques have played an important role. The mathematical methods of DA describe algorithms for combining the observations of a dynamical system (a computational model that describes its evolution), with other relevant information. The aim of this study is to find the optimal ensemble size for the EnsKF to evaluate the long-term predictive capability of the Delft3D Model by using water level, current, and temperature measurements from different locations within the bay. OpenDA is considered an effective tool for delivering real-time forecasting via the introduction of the Ensemble Kalman Filter algorithm; therefore, the automatic procedure is expected to result in an improved model forecast.

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MS4

Merging Tsunamis and Resulting Impact on Coastal Regions

Tsunamis often severely devastate some coastal areas while leaving others with little damage. This unpredictable situation has been a major challenge for accurate and timely tsunami forecasting for evacuating coastal communities. Here we show evidence from satellite observations of the 2011 Tohoku-Oki earthquake-induced tsunami that sheds light on this issue. Three satellites observed the same tsunami front, and for the first time, one of them recorded a tsunami height about twice as high as that of the other two. Model simulations confirm that the amplified tsunami is one of several jets formed through topographic refraction when tsunamis travel across ocean ridges and seamount chains. This process causes the tsunami front to merge as it propagates, resulting in doubling its wave height and destructive potential in certain directions before reaching shore. We conclude that the potential of tsunami merging jets should be taken into consideration for designing coastal tsunami hazard maps and assessing risk levels at coastal oil refineries and nuclear power facilities.

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MS4

Parallelization of a 3D Curvilinear Non-hydrostatic Coastal Ocean Model

DRAFT: The UCOAM model, developed by Abouali and Castillo, is a high-resolution (sub-km) Large Eddie Simulation (LES) CFD model capable of running ocean and atmospheric simulations. It is the only environmental model in existence today that uses a full, 3D curvilinear coordinate system, which results in increased accuracy, resolution, and reduced times to solution. UCOAM is a petascale model: it requires significant memory (10^2 arrays with 10^{10} elements) ; communication along all 3 dimensions; and simulations generate TBytes of data. To facilitate simulations, we have developed a computational environment (CE) that includes a parallel, MPI framework for the model, and cyberinfrastructure-based services. For the parallel model, we have designed a modular, parallel framework (PFW), written in F95, that supports staggered grid, CFD applications. The framework includes modules that allow each processing element (PE) to track the execution environment including: communicator groups; local and global scope data decomposition; ghost and halo communication cells; the location and distribution of the staggered grid variables; and utility tools (file I/O, timing, plotting, analysis). In this talk we discuss our experiences in developing and testing the parallel framework. The parallel framework has been used to develop several applications, including nesting the model within the global Regional Ocean Model System. We also present results that demonstrate scaling of the parallel and application frameworks to nearly 2000 nodes, and show that the applications scale similarly to other comparable coastal ocean models.

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MS4

The Impact of Vegetation and Culverts on Sediment Transport in a San Francisco Bay Salt Marsh

We study sediment transport pathways in a San Francisco Bay salt marsh using observations and the three-dimensional, unstructured-grid SUNTANS model. Two field deployments were conducted to measure currents, water levels, salinity, and suspended sediment for three weeks during a rainy winter period and a dry summer period in 2014. These data are used to obtain a general understanding of the hydrodynamics and sediment transport in the marsh, paying particular attention to the differences between the dynamics of the wet- and dry-period deployments. A majority of the marsh is covered by dense vegetation that is submerged only during spring tides, and hence most of the sediment transport dynamics are governed by flow through the marsh channels with intermittent transport to and from the marshes. The observations are used to validate the three-dimensional model that is used to compute sediment fluxes throughout the marsh. Results show that tidal flows consistently drive landward fluxes of sediment from San Francisco Bay into the marsh, while intermittent river inflow events induce seaward sediment fluxes, flux patterns that are expected in shallow estuarine systems composed of mudflats and vegetation. By running the model with and without marsh drag effects, we demonstrate that, as expected, the vegetation acts to prevent erosion in the shallow mudflats. However, a more important effect of the vegetation is to channelize the flows in the main channels and induce erosion of sediments that are transported landward and onto the vegetated mudflats. We also study the impact of culverts in the system on sediment transport pathways. Running the model with and without the culverts shows that they act to limit seaward sediment transport.

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MS5

Arcos: a Coupling Framework for Managing Complexity and Enabling Rapid Development in Ecosystem Hydrology.

The growing role of simulation in Earth systems science has led to a significant increase in the number and complexity of processes in modern simulators. This increase has created a need for multiphysics simulation frameworks that facilitate dynamic selection of processes, component testing, and numerical experimentation with model representation and coupling strategies. We present the ideas behind Arcos, a strategy built on a dependency graph and process tree, and its use for managing this complexity.

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MS5

Three-Dimensional Estuarine Model Based on Hardware-Agnostic Finite Element Solver

Modeling of coastal and estuarine flows poses several numerical challenges. Key features of coastal models are variable mesh resolution, strict mass conservation, low numerical diffusion, and computational efficiency. We present first results of a 3D baroclinic model, implemented on a flexible finite element solver framework that utilizes automatic code generation. The flexible solver framework allows rapid model development, generation of adjoint models, and produces code optimized for current and emerging HPC architectures.

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MS5

Pushing Integrated Hydrologic Modeling Towards the Exascale: Case Studies in Residence Time and Scaling Using Hyperresolution Simulations over the Continental Us and the Colorado Headwaters

Regional or watershed, scale simulations have been effective tools in understanding hydrologic processes. However, there are still many questions, such as the adaptation of water resources to anthropogenic stressors and climate variability, that need to be answered across large spatial extents at high resolution. Understanding and simulating the residence time distributions of water from land surface to stream outlet is a fundamental open question in hydrology often considered a grand-challenge. The residence time of water plays a critical role in understanding important topics including weathering and land formation, and anthropogenic impacts on water quality such as nitrate from agricultural sources. In response to these grand challenges in hydrology, we present the results of a parallel, integrated hydrologic model simulating surface and subsurface flow at high spatial resolution (1 km) over much of continental North America (6.3 million square km). These simulations provide predictions of hydrologic states and fluxes, namely water table depth and streamflow, at unprecedented scale and resolution. The physically-based modeling approach used here requires limited parameterizations and relies only on more fundamental inputs, such as topography, hydrogeologic properties and climate forcing. Such large scale simulations necessitate massively parallel recourses and good computational efficiency. We further demonstrate complex residence time distributions derived from these first-principles flow and transport simulation over this same flow domain. Results show that while major North American river basins have median ages from 2-20 years, all stream waters may be composed of a wide range of residence timesfrom 0.1 to 10,000 yearsindicating a strong memory filter on streamwater chemistry.

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MS5

Interfacing the Geochemical Code CrunchFlow with HPC Transport Codes at Different Spatial Scales: Lessons and Outlook.

Implementation of new geochemical capabilities into flow and transport codes is often circumvented by coupling them to existing reaction codes. We used this approach to make CrunchFlow's geochemistry available to HPC flow and transport codes applicable across a range of spatial scales, from the pore scale (Chombo) to the watershed (ParFlow). Recently, a new generic, interoperable coupling approach through Alquimia, a biogeochemistry API and wrapper library, has been used to couple CrunchFlow to Amanzi.

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MS5

Interoperable Design of Extreme-Scale Application Software (ideas): A Community Approach to Software Productivity

The IDEAS project is leveraging an interdisciplinary community to address the productivity challenges that scientists face on extreme-scale architectures. We will discuss the potential of this approach to enhance productivity through a combination of modern development workflows and design abstractions that support a collection of interoperable components from new and existing codes, within a lightweight open framework. This approach is motivated and tested through process-rich Use Cases in hydrologic and biogeochemical modeling of terrestrial systems.

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MS5

Experience and Lessons on Modular Ecosystem Model Development

As environmental models became more complicated, we need new tools to analyze and validate models and facilitate collaboration. Modular design and function test have gained attention recently. In this talk, we present our methods and software tools to analyze environmental software and to generate scientific function testing models for the Community Land Model using three typical scenarios: 1) individual function testing, 2) compiler-assisted module generation, and 3) a virtual tree model generation for root research.

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MS6

Stochastic Optimization of Enhanced Oil Recovery Implementation Using Approximate Dynamic Programming

Successful field implementation of enhanced oil recovery processes is dependent on finding the optimal policy in the presence of numerous uncertainties, both reservoir related and economic. This presentation will focus on the use of a stochastic approximate dynamic programming approach in producing optimal implementation policy for enhanced oil recovery. The method used was inspired by real options theory and was enhanced by incorporating the probabilistic collocation method. This was applied to a number of examples.

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MS6

A New Dual Ensemble Kalman Filter for State Parameter Estimation in Subsurface Hydrology

The ensemble Kalman filter (EnKF) is a popular method for estimating the state and parameters in large scale applications. The usual filtering procedure for state-parameters estimation is based on either joint or dual strategies, in which, at each assimilation cycle, a forecast step by the model is followed by an update step with incoming observations. The joint approach directly updates the state and parameters as one single vector, while the dual approach makes use of two separate filters; one to estimate the parameters and the other to estimate the state based on the updated parameters. In this work, we propose a new dual EnKF algorithm in which we reverse the order of the forecast-update steps following the one-step-ahead (OSA) smoothing formulation of the Bayesian filtering problem. Compared to the standard dual EnKF, this introduces a new update step to the state in a fully consistent Bayesian framework, which is shown to enhance the performance of the dual filtering approach without significant increase in the computational cost. Numerical results comparing the performance and robustness of the proposed scheme with the standard joint and dual EnKFs will be presented.

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MS6

Gradient Quality in Ensemble Optimization

With an increase in the number of applications of ensemble optimization (EnOpt) for production optimization, the theoretical understanding of the gradient quality has received little attention. An important factor that influences the quality of the gradient estimate is the number of samples. In this study we use principles from statistical hypothesis testing to quantify the number of samples needed to estimate an ensemble gradient that is comparable in quality to an accurate adjoint gradient. We develop a methodology to estimate the necessary ensemble size to obtain an approximate gradient that is within a predefined angle compared to the adjoint gradient, with a predefined statistical confidence. Our results provide insight into the necessary number of samples required for EnOpt, in particular for robust optimization, to achieve a gradient comparable to an adjoint gradient.

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MS6

Bayesian Nonlinear Smoothing

New schemes are presented for optimal Bayesian nonlinear state estimation of nonlinear fluid and ocean dynamical systems, both forward and backward in time. The Bayesian nonlinear smoothing combines reduced-order Dynamically-Orthogonal (DO) equations with Gaussian Mixture Models (GMMs), extending linearized backward pass updates to a Bayesian nonlinear setting. Examples are provided for fluid and ocean flows. This is joint work with our MSEAS group at MIT.

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MS6

Optimization Under Uncertainty: A Unified Framework for a Class of Ensemble Data Assimilation Algorithms

We present an expectation-maximization type framework that can be employed to describe a class of ensemble data assimilation algorithms which may be iterative or non-iterative, and are derived from either a Bayesian or non-Bayesian perspective. Example algorithms include the conventional ensemble Kalman filter with perturbed observations, the ensemble smoother and the ensemble Kalman smoother that are suitable for linear or weakly nonlinear systems, and their iterative counterparts that are implemented in situations with stronger nonlinearity. Some implications of the proposed framework are explained, and potential future algorithm developments are discussed.

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MS6

Adaptive Spectral High-Dimensional Model Representation Techniques for Optimisation of Injection Strategy of CO2 Sequestration

Successful operation of CO2 storage sites relies on designing optimal control strategies of the injection wells under operational constrains. Solving this high-dimensional optimisation problems is computationally demanding. We propose an efficient surrogate assisted algorithm to solve this challenging problem. The utilised surrogate has three novel aspects: (i) it relies on an ANOVA like decomposition termed High Dimensional Model Representation, (ii) component-wise interactions are approximated with adaptive sparse grid interpolation using polynomial basis functions, (iii) the surrogate is adaptively partitioned closer to the optimal solution within the optimisation iteration.

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MS7

The Reservoir Condition Imaging of Pore-Scale Flow: Trapping, Wettability and Dynamics

Recent developments in x-ray micro-CT have allowed for the imaging of multiphase flow at temperatures and pressures representative of subsurface flow. We use this technique to look at capillary trapping, contact angle measurement and the dynamics of multiphase flow. Viscous and gravitational displacement of trapped CO2 is examined by comparing pore-by-pore capillary pressure measurements to modelled pressure fields and pore parameterisations to reformulate the capillary and bond number based on the pore-scale physics of remobilization.

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MS7

Characteristic Length and Time Scales in Pore Scale Displacement Regimes

Recent advances in fast X-ray computed micro-tomography have made it possible to image pore scale displacement in multiphase flow in porous rock at time intervals of 1-40 s. That enables us to study the immiscible displacement under dynamic flow conditions, i.e. keeping the visco-capillary balance. That allows us to study pore-scale displacement processes that occur in drainage and imbibition. In drainage we find that Haines jumps often extend over more than one pore and are cooperative, non-local phenomena which are conceptually different and also have a different event size statistics than simple percolation models predict. In imbibition we find a complex interaction between film swelling and corner film flow and the breakup of clusters. When following the transition from a connected phase flow to individual clusters, at the onset of oil mobilization which occurs at relatively large oil saturation, the main mechanism is snap-off leading to a breakup of clusters. The large meniscus oscillations initiated by the snap-off, on the other hand, also leads to coalescence events, which again points to the cooperative dynamics in the ganglion dynamics regime. During forced imbibition, the visco-capillary scaling group points to the cluster length being the characteristic length scale for displacement, i.e. at which the flow regime changes from a capillary-dominated to a viscous flow regime. By inspecting the individual radiographs from the tomography experiment, which are recorded at 40 ms time intervals, we get one to two orders of magnitude better time resolution to study the detailed dynamics of displacement dynamics, finding characteristic decay times after individual events of 1-2 seconds.

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MS7
Numerical Analysis of "Real" Pore-scale Flow

The fast and continuous development of technical basis for computations and pore-scale (PS) measurement and visualization give rise to problem formulations which seemed inappropriate in the recent past. Based on pore-scale description the direct numerical simulations (DNS) approach is rapidly gaining in popularity despite the numerous technical problems in its implementation. The short critical review of the methods used currently for the DNS (diffuse interface, volume-of-fluid, level-set, DHD) is first presented in our work. The numerical methodology under consideration includes the geometrical description of flow regions (which may be based on CT imaging), the grid generation (complex problem for real, i.e. as close as possible to reality, pore volumes) and application of efficient numerical models for PS flow calculations. To test and validate the relevant DNS model of PS flow in real media under natural flow conditions the comparison to available analytical solutions, simulation and experimental results are provided. Among numerous possible oil recovery applications within the relatively simple physical framework of the single and two-phase PS flow the medium transport properties determination, the investigation of fluids entrapment and mobilization, the analysis of viscous fingering dynamics in oil-water systems and the stationary configurations of two-phase flow at different viscosity ratios, transport and capillary conditions, the imbibition and drainage flow regime are addressed. The discussion on the challenges and limits of the DNS-based PSM using diffuse interface approach is provided.

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MS7
Numerical Simulations of the Cahn-Hilliard Equation in Porous Domains

The Cahn–Hilliard equation is well-known for modeling phase reordering in binary fluid systems. Our goal is to find a suitable discontinuous Galerkin method that is computationally efficient on fine voxel-set-type grids arising from CT imaging. We give a brief overview of possible discretizations and propose a specific one. Optimal convergence against prescribed solutions is shown and robustness is demonstrated by various numerical scenarios.

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MS7
Control of Viscous Fingering Patterns in Porous Media Flow

We study numerically and experimentally the dynamics and control of viscous fingering patterns in a circular Hele-Shaw cell as a model for porous media flow. The nonlocality and nonlinearity of the system, especially interactions among developing fingers, make the emergent pattern difficult to predict and control. By controlling the injection rate of the less viscous fluid, we can precisely suppress the evolving interfacial instabilities. There exist denumerable attractive, self-similarly evolving symmetric, universal shapes. Experiments confirm the feasibility of the control strategy, which is summarized in a morphology diagram.

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MS7
Modeling Experiments and Gaining Insight by Means of Pore-scale Simulations

We discuss the ability of pore-scale modeling to contribute to advancing our understanding of the relevant pore-scale mechanisms and their impact at the Darcy scale. We focus on models that resolve the dynamics of the fluids with sub-pore resolution, such as the Volume Of Fluid method. We demonstrate the ability of the method to model experiments in micromodels and to provide insight into the role of inertial effects due to rapid, irreversible fluid reconfiguration.

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MS8
New Mixed Finite Elements on Quadrilaterals of Minimal Dimension

We present two new families of mixed finite elements on quadrilaterals. The new families are inf-sup stable, and they approximate optimally the velocity, pressure, and divergence of the velocity. The spaces are of minimal dimension subject to the approximation properties and finite element conformity (i.e., they lie in H(div) and are constructed locally). The two families gives full and reduced H(div) approximation, like Raviart-Thomas and BDM spaces.

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MS8

Mimetic Finite Difference Method for the Richards Equation

Nonlinear diffusion equations (such as the Richards equation) are used to model geophysical flows in variably saturated media. They require numerical schemes that remain robust and accurate under extreme conditions where the diffusion coefficient is not only discontinuous but may also become very small or even degenerate. We present a new family of mimetic finite difference schemes for these equations. These schemes incorporate upwind algorithms into the conventional mimetic framework.

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MS8

Discretizations of the Diffusion Equation with Multi-material Cells

Multi-material (MM) cells appear when base mesh does not conforms to material interfaces. The interfaces are reconstructed inside this MM cell and materials are represented by pure material polygons, which form cell mini-mesh. To solve diffusion equation we construct homogenized material properties for MM cells; then solve equations on base mesh; and finally, to obtain solution in each material in the MM cell, we solve equations on mini-mesh, using boundary conditions obtained from global solve.

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MS8

Locally Conservative Eulerian-Lagrangian Localized Adjoint Methods for Multiphase Flow

The Eulerian-Lagrangian localized adjoint method (ELLAM), when formulated with indicator (piecewise constant, finite volume) space-time test functions, conserves mass locally in a Lagrangian sense (on subdomains that move with the flow). Recent developments in applying these concepts to multiphase flows will be summarized.

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MS8

Enhanced Coarsening Strategy for the Multiscale Finite Volume Method

The MultiScale Finite Volume (MSFV) leads to non-monotone solutions if the fine-scale operator has high contrast in the coefficients. We enhance the MSFV coarse grid by adapting the grid geometry to the heterogeneity and anisotropy in the fine-scale system in order to improve monotonicity and accuracy of the solution. In addition, we investigate the effects of the enhanced coarsening strategy on the convergence rate when MSFV is used as a preconditioner in an iterative process.

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MS8

Multipoint Flux and Stress Mixed Finite Element Methods for Flow and Mechanics on Quadrilaterals

We discuss a new multipoint stress mixed finite element method for elasticity on quadrilaterals. It is based on the lowest order mixed elasticity space introduced by Arnold, Awanou, and Qiu. A trapezoidal-type quadrature rule allows for local stress elimination and reduces the method to a cell-centered scheme for displacements and rotations. The method is combined with the multipoint flux mixed finite element method for flow to obtain a cell-centered scheme for the Biot system of poroelasticity.

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MS9

Beating Fwi Convergence Problems by Tomographic Fwi

Convergence of full waveform inversion (FWI) can be improved by extending the velocity model along the time-lag axis. This extension enables us to linearly model large time shifts caused by velocity perturbations. This linear modeling is based on a new linearization of the scalar wave equation. The resulting tomographic FWI method achieves convergence even when the starting model is far from being accurate.

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MS9

Stereo-wave Tomography: A New Strategy for Seismic Imaging

Seismic shot gathers usually exhibit local coherency at least over a few records corresponding to adjacent stations. Full waveform inversion (FWI) is a generic method to determine the Earth's properties from seismic measurements but does not explicitly exploit this local coherency. We design a new method called stereo-wave tomography to precisely fill this gap. It consists of computing local radon transforms of the signal and of extracting information from these panels.

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MS9

Relaxation Methods for Inverse Wave Scattering

Inversion of kinematic parameters from scattered waves can lead to hard optimization problems, e.g., when the measurements are interferometric, or when a background velocity needs to be estimated. I will explain how and when the semidefinite relaxation framework can be used to mitigate some of the nonconvexity inherent in these problems. Joint work with Augustin Cosse and Laurent Seppecher.

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MS9

Pros and Cons of Full- and Reduced-space Methods for Wavefield Reconstruction Inversion

By insisting on fitting observed data, Wavefield Reconstruction Inversion (WRI) is no longer cycle skipped and therefore less reliant on the accuracy of starting models. While extending the search space mitigates local minima, there are challenges scaling to 3D seismic when using reduced-space methods that require accurate solves. Conversely, full-space methods allow for inaccurate solves but require storage of all wavefields. We weigh pros and cons of these two approaches in the seismic context.

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MS9

Analysis of Extended Waveform Inversion

Extended modeling permits a reformulation of waveform inversion, in some cases avoiding multiple physically-irrelevant local solutions that plague the standard formulation. Addition of (non-physical) degrees of freedom to the model-data relation permits precise fit to data even in the absence of precise model information, thus avoiding the "cycle-skipping" phenomenon that leads to multiple local solutions. We review several extended modeling approaches, both recently suggested an more mature, and describe their relation to travel-time tomography.

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MS9

Robust Adaptive Waveform Inversion

Full-waveform seismic inversion suffers from the effects of cycle skipping, leading it to become trapped at a local minimum in the objective function, if the starting model is not accurate. Adaptive waveform inversion overcomes this problem by designing a suite of filters that match the predicted data to the observed data; it formulates the inversion problem to find the earth model that turns these matching filters into trivial filters that do nothing to input data.

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MS10

Element-Based Algebraic Multigrid Upscaling for Reservoir Simulation

We present a dimension reduction approach for reservoir simulations exploiting a finite element based algebraic multigrid (or AMGe) technique which provides coarse models with guaranteed accuracy. Coarse basis functions are determined by solving local eigenvalue problems, which ensures that high contrast coefficients can be represented on a coarse grid. Our reservoir simulation exploits a conservative finite volume formulation of the Darcy equations of porous media flow.

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MS10

Element-Based Algebraic Multigrid Leads to Ac-

curate Numerical Reservoir Simulation

We will present scalable multilevel solution techniques for a Mixed Finite Element discretization of the two-phase porous medium flow equations. The results will be presented for a numerical upscaling scheme based on an operator-dependent element-based Algebraic Multigrid (AMGe) method recently developed at LLNL. To simulate at different spatial resolutions, with optimal computational cost and high accuracy, benefits applications such as uncertainty quantification (Multilevel Monte Carlo) and optimization which is also investigated.

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MS10

Effective Solvers for Reservoir Simulation

The most time-consuming part of modern reservoir simulation, which uses computational tools to predict the multiphase flow in porous media, is solving a sequence of large-scale and ill-conditioned Jacobian systems. In this work, we develop new effective preconditioners which are based on the algebraic multigrid methods. Proper subspace splittings are developed according to some important properties of the underlying physical systems and used to design the preconditioners. Field-scale reservoir simulation validates the effectiveness and robustness of the solvers.

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MS10

Experience with AMG Solvers in Production Reservoir Simulation

AMG (Algebraic Multi-Grid) is one of the most efficient solvers for linear systems from discretization of the pressure equation in IMPES or Sequential Implicit formulations. Classical AMG (Ruge-Stuben) works very well for monotone matrices from finite volume discretizations, but cannot solve efficiently linear systems with the facility unknowns included because of the different nature of these equations. We share our experience how this problem can be overcome and discuss further extensions.

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MS10

An Algebraic Multigrid Solver for Fully-Implicit Solution Methods in Reservoir Simulation

The linearized equations of oil reservoir simulations often yield a complex Jacobian linear system that is challenging to solve by iterative methods. We present our efforts to develop an AMG-preconditioned Krylov method for directly solving the original discretized system. The preconditioner is designed to represent the coupling between the physical variables and account for the underlying physics of the system. We present performance results for the solver on challenging applications emerging from reservoir simulations.

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MS10

Unified Framework for Block-Partitioned Solution Methods for Coupled Poromechanics

This work focuses on solution strategies for coupled poromechanical problems. Recently, several fully implicit and sequential implicit schemes have been proposed that exhibit stable and rapid convergence to the coupled solution. While superficially different, these schemes can be interpreted as subtle variations of a block-preconditioned iterative method. Rapid convergence results from the choice of sparse Schur complement approximation. Further, these partitioned approaches lead to sub-problems that are well addressed by algebraic multigrid methods.

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MS11

Pushing an Estuarine Circulation Model to the Brink: Lessons Learned and Next Steps

SELFE, a low-order unstructured-grid circulation code, has both succeeded and been severely challenged in modeling the dynamics of a river-dominated multi-regime estuary. The modeling process, which is informed by a comprehensive set of long-term and high-resolution observations, is described. Results for SELFE are used to reflect on the limitations of this and other leading-edge contemporary estuarine models. In addition, the modeling process is used to envision the requirements for a next-generation estuarine and coastal model.

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MS11

A Revival of Semi-Lagrangian Advection Methods for Adaptively Refined Meshes?

Semi-Lagrangian methods have long been used as advection schemes due to their unconditional stability property. Their lack of formal conservation, and the somewhat obscure parallelization potential has lead many researchers to abandon this type of methods. Reviewing the method in light of its seamless integration into a posteriori adaptive mesh methods yields a new perspective. Recently developed efficient (quasi-) conservative semi-Lagrangian schemes with flux formulation of the governing equations yields an elegant ocean modeling method.

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MS11

Simulating and Optimizing the Extraction of Tidal Energy Using Multi-Scale Numerical Methods

The acceleration of tidal current in coastal regions represents an attractive source of renewable energy. However, economic and environmental barriers must be overcome to allow the exploitation of this resource. This necessitates the development of numerical models that are able to predict impacts and returns of tidal turbine arrays, and crucially that are also able to reliably contribute to their optimal design. This presentation will describe the approaches we have taken to achieve these goals.

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MS11

Challenges in Three-Dimensional Hydrodynamic Modelling of the Shallow Bays and Estuaries Along the Gulf of Mexico Coast

The Gulf of Mexico coast is characterized by wide, shallow (< 3 m deep) bays and estuaries with narrow openings to the Gulf and geometrically complex shorelines. Tidal forcing is small (< 0.5 m range) yet strong tidal currents (>1.0 m s^{-1}) with large spatial variability exist at narrow constrictions and shipping channels. We present hydrodynamic modeling results from Galveston Bay, Texas, using the three-dimensional, finite-volume SUNTANS model. We demonstrate the effectiveness of employing hybrid quadrilateral/triangular grids in which the main channels are resolved with quadrilateral grids. Using results from the hybrid grid, we show that accurately predicting the low-frequency circulation and salinity distributions requires resolving the small-scale topographic features, implementing a host of different processes into the boundary conditions, and correctly parameterizing the sub-grid scale mixing.

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MS11

Aspects of Higher Order Discontinuous Galerkin Solutions to the Shallow Water Equations

Second order accurate Finite Volume and Continuous Galerkin Finite Element solutions to the shallow water equations are widely used in coastal ocean hydrodynamics. However existing models are quite expensive to implement for unstructured meshes. We examine aspects of using p=1 through p=3 order Discontinuous Galerkin solutions to the shallow water equations including cost efficiency for triangular and quadrilateral elements as well as flow through channels. The later problem requires special handling of the boundary conditions.

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MS12

Uncertain Prediction of Marine Ice Sheet Dynamics and Volume Loss

Marine ice streams, most notably those in West Antarctica, may have begun rapidly retreating due to the marine ice instability. However, uncertain ice dynamics and expensive computational models make predicting retreat rate and volume loss difficult. Ice stream/shelf models that relate retreat rate and rate of volume loss to grounding line thickness and ice shelf buttressing are used within Bayesian inference methods to predict ice stream/shelf behavior.

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MS12

Scalable Parameterized Surrogates Based on Low Rank Tensor Approximations for Large-scale

Bayesian Inverse Problems

Hessian operators (of the negative log posterior) have played an important role in high-(infinite-) dimensional Bayesian geophysical inverse problems, from characterizing the (inverse of the) posterior covariance under the Gaussian approximation, to accelerating MCMC sampling methods by providing information on the local curvature in parameter space. The key to making computations with them tractable is a low rank approximation of the (prior-preconditioned) data misfit component of the Hessian. Here we consider the role of higher derivative operators in Bayesian inverse problems and whether scalable low rank approximations can be constructed.

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MS12

Dealing with Uncertainties in Decadal Global Ocean State Estimation

Over the last 1.5 decades the consortium "Estimating the Circulation and Climate of the Ocean" (ECCO) has developed a framework for fitting a state-of-the-art global ocean (and sea ice) general circulation model (GCM) to much of the available diverse streams of satellite and in situ observations via a deterministic least-squares approach. A key ingredient is the availability of an adjoint model of the time-evolving GCM to invert for uncertain initial and surface boundary conditions, as well as internal model parameters. With increasing maturity of the framework and the decadal global state estimates so produced, increased attention is warranted to assess the fidelity of prior errors assigned to the observations and the inversion (control) variables, as well as a rigorous assessments of posterior uncertainties. The latter is a key open question, both for the provision of realistic uncertainties in climate reconstructions, as well as implications for forecasting. Ongoing work to tackle these problems in the context of ECCO will be described.

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MS12

Fast Large-Scale and Joint Subsurface Inversion Using Principal Component Geostatistical Approach

Geostatistical approaches, widely used for inverse problems in geosciences, require the computation of the Jacobian matrix from min(m,n) forward runs for m unknowns and n observations. Jacobian computation can be prohibitive when m and n become large. The Principal Component Geostatistical Approach (PCGA) using low-rank approximation of the prior covariance is an efficient implementation with controlled accuracy. Our PCGA method is illustrated with large-scale Hydraulic Tomography and joint inversion using MRI imaging data.

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MS12

From Data-to-Predictions under Uncertainty for Antarctic Ice Sheet Flow

We present efficient and scalable algorithms for a data-to-prediction process under the Gaussian approximation and in the context of modeling the flow of the Antarctic ice sheet and its effect on sea level. The ice is modeled as a viscous, incompressible, creeping, shear-thinning fluid. The observational data come from InSAR satellite measurements of surface ice flow velocity, and the uncertain parameter field to be inferred is the basal sliding parameter. We show that the work required for executing this data-to-prediction process is independent of the state dimension, parameter dimension, and data dimension.

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MS12

Inference of Parameters in Mantle Flow Stokes Models

The flow in earth's mantle and the associated tectonic plate motion is often modeled using nonlinear Stokes equations with temperature- and strain rate-dependent viscosity. To describe poorly known/understood phenomena such as the plate coupling strength or the relation between strain rate and stress, parameters are introduced in the constitutive relation. Using a Bayesian inference approach, we study the prospects and limitations of inverting these parameters from surface observations.

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MS13

Preserving Geological Realism of Channelized Facies in Complex Reservoir

Ensemble-based data assimilation methods have been successfully applied for parameter estimation in reservoir models. However, when complex reservoir geology exists, certain reservoir structures may lose the plausibility during data assimilation. This work will address these issues on a real field with a newly extended facies parameterization approach coupled with Iterative Adaptive Gaussian Mixture (IAGM) Filter. We investigate the interaction between facies and nonfacies layers and the preservation of geological channel continuity during data assimilation.

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MS13

Seismic History Matching Combining Ensemble Kalman Filter and Model Order Reduction Techniques

We present a methodology to update the reservoir model of porosity and permeability by simultaneously matching production and seismic data. The inversion scheme is based on the Ensemble Kalman Filter method, combined with model order reduction techniques such as Proper Orthogonal Decomposition. In the proposed workflow, seismic data are matched by introducing a reduced parameterization of time-lapse seismic-inverted results. The methodology is illustrated using a 2D synthetic example. Reduced and full parameterization results are compared.

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MS13

Nonlinear Flow Data Assimilation into Training-Image-Based Facies Models

Assimilating nonlinear flow data into complex geologic facies models that are simulated from a training image (a conceptual geologic model) has proven to be challenging. In particular, the categorical and non-Gaussian nature of these facies models pose significant difficulty in using classical inverse modeling techniques, which are typically designed for continuous, linear, and multi-Gaussian systems. In this talk, two alternative methods are presented for preserving the geologic complexity of the facies models during data assimilation.

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MS13

Adaptive ES-MDA for Data Assimilation

The ensemble smoother with multiple data assimilation has proved to be a robust ensemble-based data assimilation method provided inflation factors are chosen correctly. We provide a procedure based on the theory of regularizing Levenberg-Marquardt to choose the inflation factors adaptively during the data assimilation process. Examples indicate the adaptive procedure further improves the reliability of the original ES-MDA algorithm.

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MS13

Sequential Assimilation, Multiple Assimilation and Iteration

Four non-iterative parameter estimation methods, applying four different ways to assimilate data, are compared to an iterative method on problems with weakly non-linear, simplistic forward models. Asymptotic calculations in an idealized setting reveal interesting relations between the methods. Numerical calculations with randomized model settings are performed to verify the asymptotic results. Numerical results where random effects are averaged out strongly support the asymptotic results, while numerical results for a single model setting are significantly blurred.

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MS13

Ensemble Based Reservoir Characterization Using Seismic and Production Data

During the last decade ensemble based methods has shown great success in history matching using production data. Applying repeated seismic data has shown to be more challenging. Part of the challenge is the error quantification of the seismic data. By including the seismic inversion in the workflow, we can have a better error quantification of the inverted seismic data (acoustic velocities). The workflow is illustrated on a synthetic 2-D case.

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MS14

Convective and Elliptic CVD-MPFA Darcy Fluxes

Convective and elliptic CVD-MPFA (control-volume distributed multi-point) Darcy flux approximations will be presented. A range of aspects including grid effects and gravity flux approximation will be discussed. [Lamine S. and Edwards M. G., Multidimensional Upwind Schemes and Higher Resolution Methods for Three-component Two-phase Systems Including Gravity Driven Flow in Porous Media on Unstructured Grids to appear Comp. Meth. App. Mech Eng.] [Edwards M G, Zheng H., Quasi M-Matrix Multi-Family Continuous Darcy-Flux Approximations with Full Pressure Support on Structured and Unstructured Grids in 3-D SIAM J. Sci. Comput 33 (2) pp. 455-487 2011] [Edwards M G., Global and Local Central Non-Upwind Finite Volume Schemes for Hyperbolic Conservation Laws in Porous Media Int. J. Numer Meth, Fluids Vol 64, Issue 7, 10 November 2010, Pages: 793811]

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MS14

A High Resolution Finite Volume Method for the Simulation of Oil-Water Displacements in Anisotropic and Heterogeneous Petroleum Reservoirs Using a Multidimensional Limiting Process

In the present work, we use a robust Multidimensional Limiting Process (MLP) together with a high order finite volume method to discretize the saturation equation for the oil-water displacement problem producing accurate and monotone solutions. For the solution of the pressure equation, we use a non-orthodox Multipoint Flux Approximation Method based on a Diamond type stencil (MPFA-D). In order to assess the accuracy of the proposed methodology, we solve some benchmark problems found in literature.

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MS14

Virtual Element Methods for Flows and Transport in Porous Media

We present a family of schemes for solving elliptic partial differential equations on unstructured polygonal and polyhedral meshes. These discretizations can be interpreted in the framework of mimetic finite difference methods and virtual element methods. These methods satisfy local consistency and stability conditions. The consistency condition, which ensures the well-posedness, is an exactness property, i.e., all the schemes of the family are exact when the solution is a polynomial of an assigned degree. The degrees of freedom are the solution moments on mesh faces and inside mesh cells, thus resulting in a non-conforming discretization. Higher order schemes are built using higher order moments. The developed schemes are verified numerically on convection-diffusion-reaction problems with constant and spatially variable (possibly, discontinuous) tensorial coefficients for the diffusive term.

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MS14

Hybrid Finite Element - Finite Volume Scheme for Multiphase Flow in Geologic Media with Full Tensor Flow Properties

Today, most reservoir simulators only handle grid-aligned permeability components. This serious limitation can be overcome with hybrid simulation methods: We combine finite element- with finite volume- discretization methods using operator splitting: the pressure equation is solved accumulating full tensor finite-element mobility integrals; the transport equation is solved, reconstructing the required multidimensional finite-volume facet flux, using projections of the permeability tensor and the saturation functions that can also be of tensorial nature.

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MS14

High Order Moving Mesh Finite Volume for Two Phase Flow Problems.

We present here a High order moving mesh finite volume method for the simulation of two phase flow in porous media. The method consist of transforming the equation of the flow stated on a fixed domain into a problem on a moving domain. Then one combine an optimization mesh procedure, an O-method finite volume strategy and a constraint minimization strategy to build a finite-volume where the user choose the order of convergence in advance. The algorithm is highly parallelisable and resolve steep fronts properly.

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MS14

Nonlinear Finite Volume Discretization Methods for Anisotropic Diffusion Equation

In this work several nonlinear finite volume methods for anisotropic diffusion equation are being derived. These methods either preserve nonnegativity of the solution or discrete maximum principle. Methods are compared with well-known classical multipoint flux approximations on benchmark problems and problems of practical interest.

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MS15

What Makes Full Waveform Inversion Difficult?

The earth computer generates the recorded seismic data. The digital computer generates the model data from human generated parameter fields: density, P-wave and Shear-wave velocities, attenuation, anisotropy, topography, numerical approximations, partial differential equations, and other questionable activities. To the first order we try to estimate the uncertainty of each phenomenon, and illustrate the effects on the FWI objective functions.

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MS15

Recent Advances in Optimal Experimental Design for Imaging

Given geophysical observed data, full waveform inversion aims at quantitatively characterizing the subsurface model parameters. These data are collected, given a design, using a set of control parameters including acquisition geometries and tool settings. However, a successful data acquisition, processing and inversion also depends on many uncertain variables. In this talk, I will review recent advances in experimental design for obtaining cost-effective acquisition surveys while enhancing full waveform inversion results.

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MS15

Optimal Compressive Sampling Measurement Matrices for Seismic Acquisition

Abstract not available at time of publication.

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MS15

A Linear Sampling Method for Reconstructing Fluctuations in an Elastic Wave Field

A method for reconstructing fluctuations of an elastic wave field based on observed scattered waves is presented in this paper. The concept of the solvability index is for the inversion equation is newly developed here in order to have the spatial distribution of the solvability index describe the spatial spreads of the fluctuations of the wave field. Several numerical results are shown to verify the accuracy of the present method.

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MS15

A Stable Data-Constrained Formulation of Full-Waveform Inversion with Wavefield Reconstruction for Few Principle Sources

We avoid local minima related to cycle skipping by considering a modified data-constrained FWI formulation where observed data is fitted exactly. This formulation is a well-conditioned limit of the Lagrangian dual of Wavefield Reconstruction Inversion. To mitigate instabilities, we use a source encoding strategy based on singular vectors of the wavefields. In addition, we propose a frugal SVD that efficiently computes the principle components of the wavefields directly from the data.

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MS16

A Physics-Based Block-Triangular Preconditioner

for Coupled Flow and Geomechanics

We present a block-triangular preconditioner for the solution of Biot's equations of coupled consolidation obtained by mixed displacement/pressure formulations based on finite element and finite volume discretization schemes. The preconditioner is constructed from a block LU decomposition of the coefficient matrix. Crucial for the competitive performance of the preconditioner is the sparse approximation of the Schur complement by a scaled pressure mass matrix, that depends element-wise on the inverse of a suitable bulk modulus.

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MS16

Stabilized Mixed Finite Elements for Twofold Saddle Point Problems in Deformable Double Porosity Media

High-fidelity descriptions of double porosity media such as fissured rocks require an explicit treatment of two-scale pore pressures. Three-field mixed finite elements for coupled deformation and flow in double porosity media encounter a so-called twofold saddle point problem in the limit of undrained deformation/incompressible flow. We present an extension of the pressure projection stabilization technique, which has proven to be robust for various single saddle point problems, to circumvent the twofold saddle point problems arising in deformable double porosity media.

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MS16

Numerical Modeling of Flow-Mechanics Coupling in Fractured Reservoirs with Porous Matrix

A finite volume solver for flow induced slip failure was developed. For the stress-strain relations, linear poroelasticity approximations are used. A semi-implicit method is employed to couple stress and pressure calculations. Shear failure along prescribed fractures depend on both local stress and pressure solutions. To obtain the displacements, a new equilibrium based on the dynamic friction law relating fluid pressure, shear and compressive traction forces along the fracture manifold, is solved.

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MS16

Numerical Issues in the Simulation of Coupled Poromechanics by Mixed Finite Elements

The numerical solution to coupled poromechanics is still a challenging task because of several issues: (1) pore pressure instability, (2) large number of unknowns, and (3) ill-conditioning of the discretized system. The use of Mixed Finite Elements can alleviate the numerical oscillations in the pressure solution, but give rise to very large and ill-conditioned systems of algebraic equations. The use of efficient block preconditioners is presented and discussed to accelerate convergence in complex real-world applications.

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MS16

Stable Discretizations for the Biot Equations

We consider three important limits for stable discretizations of Biot's equations: Incompressible fluid, incompressible solid, and small timesteps. Robust discretizations should be able to handle any combination of these limits, however, due to the saddle-point structure of Biot's equations, this can be elusive. As a novel result, we show that the hybridized variational finite volume framework (which includes the multi-point flux (MPFA) and multi-point stress (MPSA) approximations) allows the construction of a naturally stable cell-centered finite volume discretization for Biot's equations. We give an overview of the proof, including explicit bounds on the stability constants, and numerical examples.

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MS16

Coupled Flow and Geomechanics for Fractured Poroelastic Reservoirs

An accurate hydrocarbon recovery prediction from fractured (hydraulic and discrete) shale reservoirs requires adequate modeling of underlying physical processes and robust solution schemes. A coupled reservoir-fracture flow model is presented which accounts for complex reservoir geometry including non-planar fractures. Different flow models for fractures and reservoir are used to capture flow physics accurately. The geomechanical effects are included using multiphase Biot's equations. A solution scheme is presented followed by numerical results to demonstrate model capabilities.

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MS17

Wetting/Drying in the 3D Discontinuous Galerkin Model

We present anisotropic slope limiting algorithm for a 3D coastal ocean model based on the discontinuous Galerkin method. The method works by separating vertical and horizontal limiting post-processors. The purpose of this separation is to reduce numerical diffusion caused by the limiting procedure. Several academic and realistic test cases demonstrate the performance of the scheme.

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MS17

Well-Balanced Schemes for the Shallow Water Equations with Coriolis Forces

In this talk, we consider shallow water equations with the bottom topography and Coriolis forces. These equations play an important role in modeling large scale phenomena in geophysical flows, in which oceanic and atmospheric circulations are often perturbations of the geostrophic equilibrium. For oceanographic applications, it is essential to develop a well-balanced numerical method – the method, which exactly preserves a discrete version of the geostrophic equilibrium states. Otherwise if numerical spurious waves are created, they may quickly become higher than the physical ones. We design a special piecewise linear reconstruction, which is combined with the well-balanced update in time and implement it in the context of the finite-volume framework. Theoretical proofs and numerical experiments clearly demonstrate that the resulting numerical scheme preserves geostrophic equilibria exactly. Our construction is general and can be used for a variety of numerical method.

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MS17

Adaptive Measure-Theoretic Parameter Estimation for Coastal Ocean Modeling

High-resolution computational meshes for coastal ocean modeling often require high-resolution parameter fields. Unfortunately, using field measurements to determine these parameters can be prohibitively expensive. Regardless, complex hydrological models require some representation of parameters fields such as those used to represent momentum loss due to a combination of bottom friction, vegetation, and other structures. We explore the application of adaptive measure-theoretic parameter estimation to estimate spatially varying bottom friction parameters for coastal ocean models.

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MS17

Stabilization in Runge-Kutta Methods for Nonlinear Geophysics

Stabilizing explicit-in-time solvers is important when trying to recovering accurate and robust solutions. Even so, much of the present work in the area has been aimed at linear test problems, that ignore the delicate interplay between the different subsystems that naturally couple in the more common nonlinear systems setting. In this talk we discuss some of the nuances of these systems, present a method for stabilizing nonlinear systems, and discuss the virtues of different types of Runge-Kutta methods in these contexts.

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MS17

Local 3D Ocean Waves Model for Aquatories with Complex Boundaries

We present an approach for the multi-model coupling of global ocean and local 3D flows in aquatories with complex boundaries. The examples of such flows are wetting of a shore line, waves approaching a pier or flow around an offshore platform. The local model is based on the solution of the 3D Navier-Stokes equations with free surface and boundary conditions from the global ocean.

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MS17

An Ocean Oil Spill Model

Challenges of and recent progress in the development of an oil model for the fate of surface and subsurface oil spills will be summarized. We are building a computational platform for ocean/oil dynamics by tackling modeling and computation together. The goal is to produce a model with variable resolution and concomitant physics. For specificity we will summarize how this plays out in the context of modeling oil spills near the shore.

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MS18

A Flow And Transport Model In Porous Media For Microbial Enhanced Oil Recovery Studies

In this work, a flow and transport model which was implemented using a finite element method to simulate, analyze and interpret MEOR processes at core scale under laboratory conditions is presented. The flow model is based on the oil phase pressure and total velocity formulation, in which the capillary pressure, relative permeabilities, the effects of gravity and the dynamic porosity and permeability modification due to the clogging-declogging phenomena are taken in account.

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MS18

Fast Solvers for Coupled Problems and Applications to Geomechanics

Many problems in geophysics comprise interactions of processes, and are typically formulated as a system of coupled PDEs. In most cases this systems are transient and often also non-linear. Hence, developing efficient solvers is often a delicate task and must include combining suitable schemes for (i) time integration, (ii) linearization, and (iii) geometric and algebraic multigrid solvers. In this presentation, we take an application oriented approach, and focus on the problem classes of poroelasticity problems and density-driven-flow. For these two examples, we comment on similarities and differences, and then provide details on the solution strategy.

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MS18

Modeling of Chemical Enhanced Oil Recovery on General Hexahedral Grids

Accurate numerical simulations are required for design and evaluation of enhanced oil recovery strategies such as ASP (Alkaline Surfactant Polymer) and foam flooding. We discuss the significance of accurate fluxes for non-Newtonian viscosity calculations. A multipoint flux mixed finite element method is used for discretization. This improves concentration and saturation front predictions owing to better calculation of advection, diffusion and dispersion terms. The numerical results show the effect of accurate fluxes on recovery predictions.

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MS18

Robust Mass-Conservative Schemes for Two-Phase Flow in Porous Media

We will present a robust, mass conservative numerical scheme for two-phase flow in porous media. The fluids are assumed immiscible and incompressible. The solid matrix is also assumed non-deformable. The formulation adopted here uses the global pressure and a complementary pressure (obtained by using the Kirchhoff transformation) as primary unknowns. The system to be solved includes two coupled nonlinear partial differential equations, one degenerate elliptic - parabolic and one elliptic. The discretization in space is based on mixed finite element method (lowest order Raviart-Thomas elements) and in time on backward Euler. A robust iterative method is proposed for linearization. The convergence of the scheme is rigorously shown, order of convergence estimates being obtained. The convergence of the linearization scheme does not depend on the mesh diameter or on the number of spatial dimensions. Finally, relevant numerical examples will be presented.

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MS18

Non-Physical Oscillations in Foam Enhanced Oil Recovery

If hydrocarbon recovery methods fail because of viscous fingering and gravity override one can turn to enhanced oil recovery methods, like foam injection. Foam generation can be described by a set of strongly nonlinear PDEs. Forward simulation methods lead to temporal oscillations, due to discretization artifacts. The heat equation with discontinuous thermal diffusivity shows similar oscillations. By applying a new discretization scheme we solve this problem. We propose a similar technique for the foam model.

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MS18

Simulating CO2 Foam Sequestration in Porous Media

CO_2 sequestration in saline aquifers usually suffers from low volumetric sweep efficiency. CO_2 foam injection can lower gas mobility and therefore suppresses the channeling caused by heterogenous permeability and the overriding caused by gravity and thus increases the storage volume. We simulate the problem using the reservoir simulator IPARS. The foam model we use considers the change of the gas mobility based on the factors of surfactant concentration, gas velocity and limiting water saturation.

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MS19

Frequency Scalable Hessian Preconditioners for Seismic Full Waveform Inversion

Hessian solves are the primary computational bottleneck in Newton's method for frequency domain full waveform inversion. Using traditional preconditioners, the number of Krylov iterations per solve scales poorly with frequency. Moreover, each Krylov iteration is expensive, requiring one forward and one adjoint wave solve per frequency per source. We present a new Hessian preconditioner for frequency domain seismic full waveform inversion that exhibits better scalability with respect to increasing wave frequency.

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MS19

Universal Optimization Framework for Robust, Regularized and Constrained Full Waveform Inversion

In this talk, we shall describe a scalable universal optimization framework that allows for seamless incorporation of a broad range of noise models, forward models, regularizers and reparametrization transforms. The formulation covers robust noise models (as Huber and students t), as well as sparse regularizers, projected constraints, and Total Variation regularization. The framework is also expandable - we explain the adjustments that are required for any new formulation to be included.

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MS20

The Peclet Number of Poroelasticity and Its Role in the Convergence of Multigrid Solvers

In several geomechanical applications (e.g. simulation of soils), the finite element discretization of poroelasticity systems may present unstable solutions. For these situations we define a novel Peclet number. It allows to introduce a lower bound on the time step-size that guarantees accuracy of the solution in the n-dimensional case. We discuss the importance of this bound for the convergence of a multigrid solver in a biomechanical application, i.e. the simulation of the periodontal ligament.

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MS20

Application of an Advanced Fracture Flow Model to Field-scale Problems

The code d3f (distributed density-driven flow) for simulations in highly complex ground-water flow systems has been advanced by a sophisticated discretization scheme to cope with fracture flow. A short sketch of this scheme will be presented as well as simulations of the underground flow system in the granitic rock around the Hard Rock Laboratory at sp, Sweden. The models include tunnels, boreholes, fractures and an inhomogeneous rock matrix in the vicinity of the geotechnical openings.

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MS20

Fault Leakage Analysis for Geological Co2 Sequestration Using a Coupled Multiphase Flow / Geomechanics Model with Embedded Discontinuities

CO2 injection into saline aquifers bears the risk of fault leakage or even reactivation. The injected volume that can be contained by a sealing fault is estimated with a coupled multiphase flow- and geomechanics model where the fault is represented as a frictional interface that becomes leaky upon failure. The model is discretized with an extended hybrid finite element - finite volume method with split-node discontinuity. Results are contrasted with similar studies from the literature.

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MS20

Grid Generation for Simulations of Groundwater Flow in Fractured Porous Media

In the presented approach we consider the full dimensional bulk medium and contained fracture networks that we approximate by low dimensional manifolds. In order to resolve arising jumps in the flow variables, those manifolds are surrounded by a zero-thickness layer of so called 'degenerated elements' which help to associate additional unknowns with the different fracture sides during discretization. We describe the required meshing steps and necessary adjustments in the involved discretization techniques.

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MS20

Massively Parallel Solvers for Density Driven Flow

Multigrid methods for the solution of large sparse matrices arising from grid-based discretizations of partial differential equations are well known for their optimal complexity, i.e., the computation effort only increases linearly with the problem size. This makes them a promising algorithm when focusing on the weak scaling properties of such a matrix solver. However, while reducing the problem size within a multigrid algorithm on coarser grid levels is its strength, this gives rise to a potential performance bottleneck when parallelization is taken into account. Indeed, on coarser grid levels the inner to boundary ratio of the grid parts assigned to a process become unpleasant and a parallel smoother on those coarse levels will suffer from the fact that mostly communication at the boundary takes place and only little computation on the inner part is performed. In order to overcome this bottleneck we present an algorithm that avoids this situation by gathering coarser levels to fewer processors leaving the remaining processors idle. To this end we introduce vertical interface connections that allow this gathering process and adapt the transfer operators of the multigrid algorithm to respect these interfaces. Arriving at a single process on the coarsest level a serial base solver, e.g., LU factorization, can be used. We show that this approach leads to nice weak scaling behavior for an exemplary application: Discretizing a pde system for density driven flow using a vertex-centered finite volume scheme and implicit Euler time stepping we analyze the efficiency of the geometric multigrid solver in the first Newton linearization of the first time step. It turns out that up to 130,000 processors the weak scaling efficiency is still above 80%.

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MS20

Modelling and Computation of Thermohaline Groundwater Flows in Fractured Porous Media

Density driven and thermohaline flows can show convection rolls, i.e. a kind of simplified vortex formation. This plays a role in the computation of these flows in fractured porous media. We simulate the flows using an adaptive finite volume algorithm. For the representation of fractures, two approaches are used, a full-dimensional and one with reduced dimension. We derive a criterion for the validity of the simplified representation and present an algorithm using adaptive dimensional representation.

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MS21

Representation of the Arctic Ocean in Ocean/sea-Ice Components of Current Climate Models

The representation of Arctic Ocean hydrography and circulation in 15 coupled global ocean/sea-ice models has been investigated. All models used the CORE-II atmospheric and runoff forcing as specified by the CLIVAR Ocean Model Development Panel. Most models are components of climate models with a resolution similar to what used in CMIP5. An effort will be made to group model biases based on resolution and choice of vertical coordinate, horizontal discretization, and parameterizations.

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MS21

Adaptive Refinement Strategies and a Lagrangian Particle Method for Geophysical Flow

A Lagrangian Particle Method (LPM) for geophysical flow on the sphere is introduced for applications related to weather and climate modeling. LPM is characterized by the Lagrangian formulation of the equations of motion, the use of singular Green's functions to solve PDEs, and an adaptively refined remeshing procedure that minimizes error due to Lagrangian mesh distortion. Standardized test cases for the tracer transport equation and the barotropic vorticity equation are used to demonstrate the convergence properties of the scheme and to compare its error to methods employed by current dynamical cores. Several adaptive refinement strategies are discussed to improve both the efficiency and accuracy of the method as flows evolve in time. Ongoing work to extend the method to the shallow water equations is discussed.

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MS21

Cloud Simulations with the Nonhydrostatic Unified Model of the Atmosphere (NUMA)

This talk will describe our recent work on cloud simulations using the Nonhydrostatic Unified Model of the Atmosphere (NUMA). NUMA is a scalable 3D compressible Navier-Stokes solver designed for weather prediction. NUMA is unified in using both continuous and discontinuous element-based Galerkin methods. We will present results for 3D thunderstorm simulations and will describe all of the necessary algorithms required for such simulations including the scalability of the model, stabilization, and visualization.

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MS21

Multiple Time Scales and Pressure Forcing in Discontinuous Galerkin Approximations to Layered Ocean Models

Barotropic-baroclinic time splitting is widely used in ocean circulation modeling to separate the fast and slow motions into distinct subsystems. This talk addresses two aspects of this usage in the context of DG methods. (1) For purposes of computing pressure at cell edges, a splitting of variables makes it possible to reduce the associated Riemann problem to a much simpler system of lower dimension. (2) The numerical solutions of the layer equations and the fast vertically-integrated barotropic equations must continually be made consistent. The method discussed here has the unexpected effect of introducing a type of time filtering into the forcing for the layer equations, so that those equations can be solved stably with a long time step.

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MS21

A Global Ocean Circulation Model Based on a Mimetic Discretization Approach

A new global ocean general circulation model, ICON-O, is introduced. ICON-O solves the ocean primitive equations on a triangular icosahedral grid. The models dynamical core and its subgridscale closures coherently uses a novel mimetic discretization approach. The discretization is described and numerical experiments are shown to demonstrate the models capabilities. ICON-O is the ocean component of the new coupled atmosphere-ocean model ICON that the Max Planck Institute for Meteorology and the German Weather Service jointly develop.

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MS21

Towards Robust Multi-Scale Global Atmospheric Models

As atmospheric models are pushed towards higher and higher resolutions, there is an increasing need to reevaluate the numerical methods that have traditionally been used for simulating atmospheric flows. This talk will discuss some of the outstanding issues that still remain for global atmospheric modeling at high resolutions, and current efforts to address these issues in next-generation modeling systems.

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MS22

Interactive Processing of Geophysical Data

Almost all geophysical software is written as a series of batch processing steps, sometimes with a GUI tacked on. To process a dataset the user sets some parameters, runs the data through a single step, evaluates the results, then reruns or moves to the next processing step. The approach can be thought of pushing data through a processing pipeline, storing intermediate datasets on disk. Twenty years ago this was an optimal approach given the relative speed of compute vs. IO and limited RAM. Today, relatively, IO is much more expensive than compute and RAM is several orders of magnitude larger. An alternate approach is to think of processing as an interactive process. When you view a given portion of your dataset, data is pulled from disk, or some intermediate memory level, run through the various processing steps and displayed. When you move to a new location the process is repeated. As you add additional processing steps to your chain, you get instant feedback.

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MS22

Madagascar Opens-source Software Package: Interface to Reproducible Research

Madagascar is an active open-source project, which provides tools for large-scale multidimensional data analysis of geophysical data, as well as reproducible documents with workflow examples. Since its public release in 2006, more than 80 people have contributed to the project. The main data object in Madagascar is a multidimensional array stored as a file on disk. Following the Unix philosophy, Madagascar programs are filters that process files and can be combined with Unix pipes or scripts. This allows for a great flexibility in mixing languages and programming interfaces. While the majority of Madagascar programs are written in C, there are programming interfaces to other languages: Fortran-77, Fortran-90, C++, Java, Matlab, and Python. I will discuss the importance of reproducible research (as pioneered by Jon Claerbout and his students at Stanford) and will describe examples of designing parallel computational algorithms by taking advantage of Madagascar's Unix-style encapsulation.

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MS22

Pysit: Seismic Imaging Toolbox for Python

The Python Seismic Imaging Toolbox (PySIT) is research-scale platform for prototyping numerical algorithms for full waveform inversion (FWI). PySIT is a common platform which implements standard methods from the literature and from which researchers can quickly develop and reproducibly compare or benchmark new methods against the state-of-the-art. This talk will outline PySIT's structure in the context of the mathematical framework for FWI, with an emphasis on the accessibility enabled by the Python programming language.

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MS22

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Abstract not available at time of publication.

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MS22

The MRST Open-source Toolbox for Reservoir Simulation

The MATLAB Reservoir Simulation Toolbox (MRST) is a free, open-source framework for rapid prototyping of new computational methods and workflow tools for reservoir engineering. In the talk, we outline how MRST to can be used to quickly implement simulators that are efficient and robust, easy to extend with new models and functionality, and applicable to models of industry-standard complexity. In particular, we discuss two of the key numerical technologies implemented in the software:

- discrete differentiation and averaging operators, which enable you to write codes in a compact and readable form that is close to the mathematical formulation of the discretized flow equations,
- automatic differentiation, which enables you to evaluate the values of gradients, Jacobians, and adjoint-based sensitivities to machine-precision accuracy without having to analytically compute the necessary partial derivatives.

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MS22

Coupling High-Performance Modeling with Optimization: a Library Approach to Building Inversion

Inversion via data-fitting combines modeling (of wave phenomena, for the seismic incarnation) with optimization. Modeling algorithms involve physical fields, the laws coupling them, and numerical realizations (grids, finite element meshes); optimization algorithms are built on mathematical abstractions such as vectors, linear operators, and differentiable functions. Bridging these disparate levels of abstraction to construct inversion applications poses a software design problem. The author will review the strengths and weaknesses of a libary-based solution.

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MS23

A Global-Local Optimization Template for Multiple History-Matched Reservoir Parameters

Parameterization of petroleum reservoirs is an important component of reservoir management. However, the process of reservoir parameterization is fraught with nonuniqueness of estimated parameters. Such nonuniqueness leads to large uncertainty and risks in reservoir management. One way to reduce and quantify the uncertainty in parameter estimation is to generate multiple equiprobable realizations of the parameters. We introduce an algorithm called GLOCAL that generates multiple realizations of reservoir parameters by performing global optimization at a coarse-scale and local optimization at a finer scale.

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MS23

Multi-Scale Assimilation with Scale Dependent Discrepancy in Model and Observation

We present a method of using classical wavelet based multi-resolution analysis to separate scales in model and observations during the application of an ensemble Kalman filter. When forecasts are performed using modern data assimilation methods observation and model error can be scale dependent. The dependence on scale in observational error can be caused by properties of the observation mechanism. Scale dependent model error can be due to biases in the model when poorly understood physical processes are excluded. During data assimilation the blending of error across scales can result in model divergence since large errors at one scale can be propagated across scales during the analysis step. Applying the multi-scale decomposition causes little computational increase over standard ensemble Kalman filtering. Our methods are demonstrated on a one dimensional Kuramoto-Sivashinsky (K-S) model and an application involving the forecasting of solar photospheric flux.

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MS23

Identifiability of Location and Magnitude of Model

Anomalies from Production Data

Classic identifiability analysis of flow barriers in incompressible flow reveals that it is not possible to identify the location and permeability of low-permeable barriers from production data, and that only averaged reservoir properties in-between wells can be identified. We extended the classic analysis by including compressibility effects. Numerical and semi-analytical results show that it is possible to identify the location and the magnitude of the permeability in the barrier from noise-free data. By introducing increasingly higher noise levels the identifiability gradually deteriorates, but the location of the barrier remains identifiable for much higher noise levels than the permeability.

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MS23

Probabilistic Particle Swarm Optimization (Pro-Pso) for Using Prior Information and Hierachichal Parameters

In this research, the equations in general Particle Swarm Optimization (PSO) are reformulated from a probabilistic point of view. The mathematics of PSO algorithm is converted from the behavior of stochastic particle motion to the equivalent sampling from the distribution (PDF) of particle positions. The equations for the probability distribution function of the particles position are derived. By doing so, this probabilistic PSO (Pro-PSO) provides the means of incorporating any probabilistic form of prior information into PSO framework and utilizing parameters hierarchically to improve computational performance.

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MS23

Calibration and Prediction with a Data-Driven Model

We derive and implement an interwell reservoir simulation model (INSIM) for model calibration and future performance prediction. After defining a connection list between nodes in a network model, pressures are solved as in IMPES and saturations are calculated by a front tracking procedure. Parameters along connections are estimated by assimilation of production data. Computational examples show that using these estimates in INSIM results in reasonable future performance predictions.

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MS23

Data Assimilation for Complex Geological Models Using Optimization-Based Pca Parameterizations

A parameterization procedure based on principal component analysis (PCA), referred to as optimization-based PCA or O-PCA, is described. The method enables the representation of non-Gaussian geological models in terms of relatively few uncorrelated parameters. The O-PCA representation is incorporated into a randomized maximum likelihood (RML) method, which entails gradient-based minimization, to enable data assimilation and uncertainty assessment. Results demonstrate the efficacy of the subspace RML method for history matching two-, three-facies, and bimodal geomodels.

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MS24

Multiscale Modeling of Spatially Heterogeneous Cellular Processes Including Metabolic Channeling

We make a rigorous derivation of an upscaled model of a system of microscopic non-linear reaction diffusion equations in a porous medium consisting of three components separated by interfaces. The differential equations in the different domains are coupled by non-linear flux-transmission conditions. Additionally we consider a reaction-diffusion process on the microscopic surface. These models can be applied e.g. to metabolic processes in (plant) cells, especially under consideration of metabolic channeling at mitochondrial membranes.

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MS24

Multiscale Modelling and Simulation of Processes

in Membranes and Tissues

We are concerned with processes in membranes and tissue. Using multi-scale homogenization methods it is possible to derive reduced systems. In many applications processes have to be modelled on the molecular scale. We consider a population of ions penetrating a membrane through channels. A stochastic model for the dynamics is developed and simulated in case of nano- and micro-channels. This report is based on joint research with Neuss-Radu (Erlangen) and Capasso, Morale and Zanella (Milano).

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MS24

A Multi-Scale Approach to Modeling of Gas Transport in Shales

We consider gas transport in shales, consisting of nanoporous organic material, microporous inorganic matrix, and a system of secondary fractions. The model incorporates free gas diffusion and filtration as well as the effect of gas adsorption and diffusion of desorbed gas. Macroscopic equations for free gas amount in-place are obtained through two successive steps: homogenization over nanoporous level leads to a microscopic description which is further homogenized to lead to description of macroscopic flow.

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MS24

Analysis of Hemodynamic Factors in the Simulations of Atherosclerotic Plaque Growth

Atherosclerosis, the major cause of cardiovascular disease, is a chronic inflammation that starts when LDL cholesterol enter the intima of the blood vessel to be oxidized. This complex process leads to the formation of an atherosclerotic plaque and possibly to its rupture. This talk is devoted to the study of simplified mathematical models capturing essential features of the early stage of atherosclerosis and to the influence of hemodynamic factors in the simulations of atherosclerotic plaque growth.

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MS24

Methane Transport in the Hydrate Zone

A two-phase two-component model is formulated for the advective-diffusive transport of methane in liquid phase through sediment with the accompanying formation and dissolution of methane hydrate. This free-boundary problem has a unique generalized solution in L^1 ; the proof combines analysis of the stationary semilinear elliptic Dirichlet problem with the nonlinear semigroup theory in Banach space for an m-accretive multi-valued operator.

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MS24

Numerical Simulation of Plaque Formation in Vessels

In this talk, we formulate a model to describe plaque formation. This model includes the interaction between blood flow and vessel wall, and the penetration of chemical species in vessels. Numerical simulations are performed to investigate the mechanisms, that lead to the formation and growth of plaques. We verify the numerical approach by convergence analysis of numerical solutions and describe effective methods to maintain the mesh quality under a large deformation.

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MS25

Almost Parallel Flows in Porous Media

We consider a reduced two-phase flow model for mostly unidirectional porous media flows. It is a nonlinear transport equation, in which velocity depends nonlocally on saturation [Yortsos, 1995]. However, solutions of this model cannot be defined in the distributional sense, as a direct consequence of the reduced regularity of the two-phase flow model. Therefore, we consider a Brinkman two-phase flow model, where existence of weak solutions is proved [Coclite et al., 2014]. Following [Yortsos, 1995], we derive an extended model similar to the model proposed by Hassanizadeh and Gray [Hassanizadeh and Gray, 1993], but in a completely different context. Assuming a medium of layers, the extended model is a system of 1D equations coupled due to vertical mixing. We study the effect of the higher-order terms in the extended model and the medium′s number of layers on the fluids spreading speed, which is usually overestimated [Menon and Otto, 2006,Yortsos and Salin, 2006].

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MS25

A Numerical Model for Reactive Twophase Multicomponent Flow

We present a numerical framework for efficiently simulating partially miscible two-phase flow with multicomponent reactive transport in porous media. The system of coupled PDEs, ODEs and AEs is treated by a model preserving reformulation technique and the use of a nonlinear, implicitly defined resolution function. By choosing persistent primary variables and using a complementarity approach, interphase mass exchange and the local appearance and disappearance of the gas phase can be handled.

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MS25

A Mathematical Formulation for Reactive Transport in Porous Media Adapted to Co2 Sequestration

Carbon capture and storage (CCS) is currently one of the major options to reduce greenhouse gas emissions from power plants. However, the implementation of CCS has been slowed down by uncertainties about the long term evolution of injected carbon into deep saline aquifers. Reactive transport numerical models [Steefel, C. I. et al., Reactive transport modeling: An essential tool and a new research approach for the Earth sciences, Earth and Planetary Science Letters, 240, 53955, 2005] are used to predict temperature and pressure variations, brine and gas phases displacement, and chemical effects of gas-water-rock interactions. One of the main challenges of these models is to accurately represent the coupling between transport phenomena and mass transfer occurring in sub-surface porous media.
In this work, we present a new mathematical formulation for reactive transport in porous media. This fully implicit multi-component, multi-phase flow formulation is able to deal with phase appearance and disappearance combined with stoichiometric mass transfer. The novelty of our work consists in the extension of concepts used so far to deal only with phase equilibrium [Coats, K. H., An Equation of State Compositional Model, SPE-8284-PA, 1980] [Eymard, R. et al, Vertex-centred discretization of multiphase compositional Darcy flows on general meshes, Computational Geosciences, 16, 987-1005, 2012] to both homogeneous and heterogeneous equilibrium reactions.
We implement our mathematical formulation in a three-dimensional multi-phase flow code using the HPC numerical framework Arcane. We first show results obtained with this code applied to numerically challenging test cases in reactive transport modelling such as precipitation and dissolution of minerals or gas-water equilibrium. We then test the code for validation against more realistic benchmark studies and discuss the results.

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MS25

Volume Averaging for Dispersion and Heterogeneous Nonlinear Reaction in Porous Media

In this study we conduct upscaling for mass transport in porous medium with heterogeneous nonlinear reaction at the fluid-solid interface in a multi-scale dissolution problem, using the method of volume averaging. We investigate the impact of flow properties, chemical features and nonlinear reaction orders on the effective parameters in the macro-scale model, which can be obtained by solving the corresponding closure problems. The importance of two non-traditional effective parameters is studied in an application.

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MS25

Numerical Simulation of Two-Phase Multi-Component Flow with Reactive Transport in Porous Media

Two-phase multicomponent flow with chemical reactions play a significant role for the long term simulation of CO2 geological storage. We propose a decoupling algorithm based on the separation of the system between water and gas components (with the most influence on the flow subsystem), and the dissolved components (undergoing reactive transport). We show numerically that the mass conservation error introduced is negligible. The method is validated on test cases from the literature, using a code based on DuMuX.

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MS25

High Order Discretization for Simulating Miscible Displacement Process in Porous Media

We present a high order method for miscible displacement simulation in porous media. The method is based on discontinuous Galerkin discretization with weighted average stabilization technique and flux reconstruction post-processing. The mathematical model is decoupled and solved sequentially. We apply domain decomposition and algebraic multigrid preconditioner for the linear system resulting from the high order discretization. The accuracy and robustness of the method are demonstrated in the convergence study with analytical solutions and heterogeneous porous media respectively. We also investigate the effect of grid orientation and anisotropic permeability using high order discontinuous Galerkin method in contrast with cell-centered finite volume method. The study of the parallel implementation shows the scalability and efficiency of the method on parallel architecture. We also verify the simulation result on highly heterogeneous permeability field from the SPE10 model.

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MS26

Microseismicity, Seismic Velocity, and Observations That Reveal Crustal Response to Dynamic Stress

Stress state and elastic properties of the Earths crust are important to seismic hazards, earthquake physics, and resource extraction and can be observed indirectly through seismicity, seismic velocities, and strain. Dynamic stresses produced by the 2012 M8.6 Indian Ocean earthquake triggered bursts of shallow normal faulting events offshore Japan which are associated with an increase in seismic velocities onshore. Increased seismic velocities are associated with changes in the strain field produced by normal faulting earthquakes.

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MS26

On Modeling Wave-Induced Sea Ice Motion and Break-Up at the Large Scale

Granular properties of sea ice in the marginal ice zone (MIZ) are strongly affected by surface gravity waves. They cause floes to break, move back and forth, drift and collide, which in turn influence the large-scale behavior of the ice cover. In this perspective, the floe size distribution is central for modeling MIZ dynamics. This talk will discuss ways to model wave-ice interactions and their effects in large-scale numerical models.

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MS26

Ocean Waves Drive a Turbulent Ocean

The oceans are the major reservoir of heat and carbon on short timescales, and the circulation of the oceans results from the wind and buoyancy changes that flow through the surface. All of this action for the climate system must pass through the ocean surface layer and its dynamics, which are interesting in their own right. I will discuss some of the most important processes in the surface layer, relate new results involving the roles of surface waves and submesoscale fronts and instabilities, and quantify the significance of these phenomena in the functioning and sensitivity of the climate system.

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MS26

Propagation of Torsional Surface Wave in An Anisotropic Porous Layer over a Non-Homogeneous Substance

The present paper studies the propagation of torsional surface waves in an anisotropic porous medium over a non-homogeneous substance. Two types of inhomogeneity namely quadratic and hyperbolic have been considered in the lower substance. The dispersion equation has been obtained for each case in a closed form by means of variable separable method. In a particular case, when upper layer is isotropic with non porous and lower half-space is homogeneous the dispersion equation coincides with classical result of Love wave. Dispersion curves are plotted for different variation in poroelastic constant and inhomogeneity parameters. The effects of the medium characteristics on the propagation of torsional surface waves are discussed.

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MS26

Use of the Effective Wavefield in the Prediction of Ocean-Wave Interactions with Rough Extended Obstacles

Ocean waves attenuate with distance travelled into the sea-ice covered ocean. This is reminiscent of the wave localisation phenomenon. In certain situations, the effective wavefield, which is amenable to multiple-scale methods, can be used to predict attenuation, but in others it is highly inaccurate, e.g. attenuation due to a rough seabed in intermediate water depth. We report recent progress on this phenomenon, with a focus on attenuation due to sea ice.

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MS26

Wave-Mean Flow Interactions in the Ocean

Inertia-gravity waves and mean flows associated with lateral density gradients are ubiquitous in the ocean. Classical theory predicts that the interaction between the fast waves and the slow mean flows should be weak. New theories suggest, however, that this interaction can be strong at ocean fronts, regions where lateral density gradients are especially intense. An overview of these theories will be presented and the implications for the energetics of the ocean circulation will be discussed.

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MS27

Imaging Multiphase Dynamics with Fast Micro-Tomography

We present recent work using dynamic synchrotron based microtomography to image dynamic drainage and imbibition at a resolution of 4 microns. Three drainage events were analysed, showing equilibrium capillary pressure changes and both local and distal snap-off. Capillary pressure measurements of disconnected and connected ganglia show that snap-off must be caused by dynamic (rather than quasi-static) forces. Snap-off during imbibition, however, appears to be an equilibrium process where quasi-static assumptions apply.

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MS27

Dynamic X-ray Microtomography: Displacement Processes and Relaxation Dynamics in Multiphase Flow

With recent advances at X-ray micro-computed tomography synchrotron beam lines, it is now possible to study pore-scale flow in porous rock under dynamic flow conditions. The collection of 4 dimensional data allows for the direct 3D visualization of fluid-fluid displacement in porous rock as a function of time. With this data we are able to identify individual imbibition and drainage events, predict oil blob mobilization, measure interfacial curvature, and monitor relaxation dynamics during multiphase flow.

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MS27

Kinematics of Multiphase Flow in Porous Media: Insights from Micro-Models

Microfluidic experiments are used to validate a two-fluid-phase flow model for porous medium systems that includes components based upon both conservation equations and kinematics. Laboratory experiments were performed in which the external fluid pressures were varied and the system was observed as it dynamically relaxed to an equilibrium state. Experimental observations showed varying time scales for changes in boundary pressures, fluid saturations, and interfacial curvatures, corresponding with the mechanisms formulated in the theoretical model.

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MS27

Physics-based Models of Multiphase Flow in Porous Media

Formulation of models of multiphase flow in porous media is complicated by the need to formulate equations at the macroscale, to account for processes occurring at interfaces between phases, and to ensure that smaller scale processes are properly accounted for. These complications have caused some ill-posed models to be proposed and implemented. Here, we point out some inconsistencies, propose a proper model, and demonstrate some of the existent processes that impact system behavior.

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MS27

Digital Rocks Portal for Fast Storage and Retrieval of Porous Microstructure Images

The recent imaging advances (such as X-ray microtomography) have provided datasets that reveal the pore-space microstructure (nanometer to centimeter scale) and allow investigation of flow and mechanical phenomena from first principles using numerical approaches. However, images are large, from diverse sources and not easily accessible. We are developing an open repository that organizes images and related measurements of different porous materials, jumpstarts productivity and enables scientific inquiry and engineering decisions founded on data-driven basis (https://pep.tacc.utexas.edu/).

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MS27

Modeling Coupled Porous Medium and Free Flow Systems using TCAT Approach

Thermodynamically constrained averaging theory (TCAT) is applied to formulate a solvable closed model for the transition region between porous medium and free flow systems. Free flow and porous medium models are coupled with the transition region model via appropriate interface conditions. The transition region model is an alternative to the sharp interface model. The two modeling approaches will be compared for single-phase and two-fluid-phase systems, and numerical simulation results will be presented.

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MS28

Issues with Coupling Macrophysics and Microphysics in the ACME Climate Model

Because the equations governing cloud parameterizations are uncertain, relatively little effort has been put into their numerical implementation. We show here, however, that numerics errors in the implementation of and coupling between macrophysics and microphysics parameterizations in the ACME model have a first-order impact on global climate. Substepping or using more sophisticated numerical schemes for macrophysics and microphysics are shown to reduce this error.

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MS28

Numerical Errors in Coupling Micro and Macrophysics in the Community Atmosphere Model

We investigate numerical errors in version 2 of the Morrison-Gettelman microphysics scheme and its coupling to a development version of the macrophysics scheme in version 5 of the Community Atmosphere Model (CAM5). Our analysis utilizes the Kinematic Driver framework, which combines CAM5 macro- and microphysics schemes with idealizations of all other model components making it easier to diagnose problems. Initial results suggest that numerical convergence requires time steps much shorter than those typically used in CAM5.

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MS28

A Finite-Difference Algorithm with Characteristic-

Based Semi-Implicit Time-Integration for the Euler Equations with Gravitational Forcing

We propose a high-order finite-difference algorithm for atmospheric flows with semi-implicit time-integration. A characteristic-based flux-splitting is introduced to separate the slow (convective) and fast (acoustic) modes. Additive Runge-Kutta methods are used to integrate in time; the fast modes are solved implicitly while the slow modes are solved explicitly. We verify our approach for benchmark atmospheric flow problems, and show that the semi-implicit approach allows significantly higher time-step sizes without compromising accuracy and resolution.

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MS28

Physics Dynamics Coupling in Atmospheric Models: Review and Outlook

Physics dynamics coupling (PDC) in atmospheric models is a multidisciplinary problem. It has recently found a platform in the PDC workshop series. Summarizing the results of the first workshop in this series, held recently in Ensenada, Mexico, this talk will outline the core problem and current and future issues. Following a review of the literature the impact of physics dynamics coupling on model performance, analysis to support design strategies and idealized testing will be discussed.

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MS28

Numerical Simulations of the Humid Atmosphere above Mountain

We aim to study a finite volume scheme to solve the two dimensional inviscid primitive equations of the atmosphere with humidity and saturation, in presence of topography and subject to physically plausible boundary conditions. In that respect, a version of a projection method is introduced to enforce the compatibility condition on the horizontal velocity field, which comes from the boundary conditions. The resulting scheme allows for a significant reduction of the errors near the topography when compared to more standard finite volume schemes. We then report on numerical experiments using re- alistic parameters. Finally, the effects of a random small-scale forcing on the velocity equation is numerically investigated. The numerical results show that such a forcing is responsible for recurrent large-scale patterns to emerge in the temperature and velocity fields.

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MS28

A Simple But Effective Method for Quantifying and Attributing Time-Stepping Errors in Climate Models

We present a test strategy that evaluates the time-step convergence properties of atmospheric general circulation models, with special attention to the representation of subgrid scale processes. The method provides a quantitative assessment of the overall time-stepping error in a model. It can also help identify which processes and assumptions are responsible for poor numerical convergence.

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MS29

On the Role of Constrained Linear Optimization to Construct Higher-order Mimetic Divergence Operators

We develop a general algorithm implementing a variant of the Castillo-Grone Method (CGM) called the Castillo-Runyan Method (CRM) to construct k-th order mimetic divergence operators (k even). This algorithm is then modified to study the restrictions of the CRM, when it comes to the construction of uniformly eight-order accurate mimetic divergence operators. This modification consists of reposing the problem of constructing an eight-order divergence as a constrained linear optimization (CLO) problem, thus yielding a new variant of the CGM implemented by means of a CLO-based algorithm.

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MS29

Mimetic Discretization Operators

Mimetic discretizations or compatible discretizations have been a recurrent search in the history of numerical methods for solving partial differential equations with variable degree of success. There are many researches currently active in this area pursuing different approaches to achieve this goal and many algorithms have been developed along these lines. Loosely speaking, "mimetic" or "compatible" algebraic methods have discrete structures that mimic vector calculus identities and theorems. Specific approaches to discretization have achieved this compatibility following different paths, and with diverse degree of generality in relation to the problems solved and the order of accuracy obtainable. Here, we present theoretical aspects a mimetic method based on the extended Gauss Divergence Theorem as well as examples using this methods to solve partial differential equations using the Mimetic Library Toolkit (MTK).

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MS29

Roofline-based Optimization of Elastic Wave Propagation with Mimetic Free Surface

Elastic full wave propagation is an expensive process in terms of both computational resources and development of the software needed to perform it. Therefore, it is desirable to optimize the performance of the code while minimizing the development costs. We present the roofline-directed methodology to determine the impact of the optimization process and as a guideline to know when to stop it. An isotropic problem with mimetic free surface is shown as example.

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MS29

Mimetic Finite Differerence Methods for 2D Reverse Time Migration

We introduce the use of mimetic methods for Reverse Time Migration (RTM) subsurface imaging. In this paper, both the forward and reverse seismic waves are modeled with mimetic differential operators over the standard staggered grid. These discrete differential operators, constructed using the Castillo-Grone method, satisfy the conservation laws of their continuous counterparts. To demonstrate the efficacy of the mimetic discretization scheme, different variations of the RTM algorithm are solved and compared.

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MS29

Well-Posed Boundary Conditions for the Incompressible Vorticity Equation Using a New High Order Mimetic Arakawa-Like Jacobian Differential Operator

Mimetic schemes are widely used in long-time computations of geophysical flows. A high order mimetic expression for the celebrated Arakawas Jacobian for the two-dimensional incompressible vorticity equation is developed. Mimetic properties such as skew-symmetry, energy and enstrophy conservation for the semi-discretization are proved using summation-by-parts operators. A new form of well-posed boundary conditions is derived on a general two-dimensional domain. The discrete version of the boundary conditions are weakly imposed. Numerical experiments corroborate the results.

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MS29

Numerical Methods in Geophysical Exploration: An HPC Approach

The field of geophysical exploration is aiming at closing the gaps between physics, algorithmics and supercomputing. We show current development, compromises and breakthroughs in both forward and inverse modelling of large 3D datasets. We will put a particular focus on highly efficient and versatile numerical schemes for wave propagation, resilient workflows and architecture-aware optimizations.

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MS30

Closed-Loop Approaches for Real-Time Mining and Petroleum Extraction A Comparison

Advanced data acquisition and process modelling technology provides online data about different aspects of the resource extraction process. Closed-loop approaches have recently been applied to utilize the value of this information for improved production control in mineral resource extraction. Similar techniques have been developed in the petroleum industry combining computer-assisted model updating with model-based production optimization. This contribution reviews methods applied, highlights differences and assesses the potential value added for both application domains.

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MS30

Uncertainty-Based Mine Development and Production Optimization with a Hybrid Genetic - Pattern Search Algorithm: Example from An Iron Ore Mine

A hybrid method using genetic algorithms (GAs) and pattern search (PS) is proposed for solving large-scale mine production optimization under geological uncertainty from an Indian iron mine. The solution of the production optimization problem is obtained by solving a sequence of sub-problems and each sub-problem is solved using the proposed method. In this hybrid method, GAs help to identify approximate areas of the search space and PS helps to improve approximations to the maxima.

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MS30

On Applications of Global Sensitivity Analysis to Performance Optimization and Monitoring of Reservoirs under Uncertainty

We present an overview of various applications of Global Sensitivity Analysis (GSA) to relevant oilfield challenges including well test design and interpretation, reservoir performance evaluation and design of monitoring programs under reservoir uncertainty. We also discuss an adaptive optimization workflow combining mean-variance approach with GSA. Illustrative examples will include optimization of enhanced oil recovery, characterization of fractured reservoirs, and uncertainty analysis for performance and monitoring of CO_2 sequestration projects.

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MS30

Simultaneous Optimization of Mining Complexes and Mineral Value Chains with Uncertain Metal Supply and Market Demand

A mining complex and related mineral value chain is an integrated business extracting materials from mines, treating extracted materials through connected processing facilities and generating mineral products sold to customers or spot market. Materials extracted (supply) and commodity prices (demand) are uncertain. Simultaneous optimization of a mining complex is approached through stochastic integer programming; metaheuristics are developed to provide efficient solutions to applications entailing millions of variables. Examples show major improvement in production and net-present-value.

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MS30

Multiobjective Optimization with Nonlinear Constraints with Application to Optimal Well Control under Geological Uncertainty

We develop methodology based on the normalized boundary intersection method for the solution of multiobjective optimization problems with nonlinear constraints where the solution is represented by the Pareto front. Each optimization sub-problem is solved by an augmented-Lagrange algorithm. The overall procedure is applied for optimization of water flooding under geological uncertainty where the objectives include maximization of net-present value, minimization of risk and minimization of variance.

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MS30

An Efficient Robust Production Optimization Method for Closed-loop Reservoir Management

A methodology for production optimization under geological uncertainty is presented. Efficiency is achieved by performing the optimization over a reduced set of representative realizations, where the number of representative realizations is determined through a systematic multi-level optimization-with-validation procedure. An efficient gradient-based method is used as the core optimizer. This treatment, together with gradient-based history matching, is incorporated into a closed-loop reservoir management workflow, which is then applied to challenging problems.

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MS31

Pore Scale Model for Non-Isothermal Flow with Mineral Precipitation and Dissolution

Motivated by rock-fluid interactions occurring in a geothermal reservoir, we consider a pore scale model describing fluid flow and solute transport through the void space and mineral precipitation and dissolution at the interface between fluid and grains. The precipitation and dissolution affect the porosity. We also include heat transport through both fluid and grains and take into account thermal effects on fluid properties and chemical reactions. We apply formal homogenization to derive upscaled effective models.

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MS31

Hydrodynamics of the Rhizosphere: How Roots Modulate Flow and Transport Properties in their Immediate Environment

Plants roots inhabit in the soil environment, where their mobility is severely restricted and resources such as water, nutrients and air, are frequently scarce and patchy. To survive in this restrictive environment plants modify their immediate environment to their benefit, particularly the rhizospherea small volume of soil that surrounds each individual root. One mechanism that plants use for this purpose is exudation of complex organic molecules and thereby modify the soil characteristics. Here, we present a mathematical model of alteration of soil hydrodynamic properties. In particular, we focus on the water retention potential of the hydrogels formed when the exudates are hydrated. Here we will present results from two related simulation studies. First, we demonstrate that exudates play important role in facilitating water flow by providing built-in water potential gradient within the rhizosphere. This results in fairly wet environment near the roots, which is important for nutrient diffusion, microbial activity, and nutrient cycling. Secondly, we show that exudates facilitate the release of water from roots to the rhizosphere at night, when transpiration is shut down. This is a widely documented phenomenon, known as hydraulic lift, in many dry regions. In most dry areas, the hydraulic lift water is likely to be the only source of moisture to drive microbial activity and nutrient diffusion. The results of this modeling study suggest that hydraulic lift is an actively controlled adaptation mechanism that allows plants to remain active during long dry spells by acquiring nutrients from the dry near surface soils while relying on deep soil moisture reserves for transpiration.

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MS31

Homogenization of Freezing and Thawing Processes in Porous Media

We show well-posedness of a pore-scale model for freezing and thawing processes in porous media, based on phase-field equations. We prove the existence of new extension operators for non-Dirichlet boundary conditions on periodic domains, which allow us to gain scale-independent estimates of the solutions. Using two-scale homogenization, we derive macroscopic equations which contain the microscopic effects and are effectively treatable by numerical methods. Applications of the model include the release of climate gases from thawing permafrost soil.

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MS31

Mechanistic Modeling of the Formation and Consolidation of Soil Microaggregates

We want to discuss the mathematical, mechanistic modeling and numerical treatment of processes leading to the formation, stability, and turnover of soil micro-aggregates. This includes a review of compartment models, but aims at deterministic aggregation models including detailed mechanistic pore-scale descriptions to account for the interplay of geochemistry and microbiology, or the link to soil functions. Multiscale techniques resulting in complex, coupled models including nonlinearities of the processes and spatial heterogeneity are considered.

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MS31

Flow and Transport in Evolving Porous Media

In recent research, upscaling flow and transport in porous

media has been undertaken for models integrating electrostatics or deformations of the porous matrix. In our talk, we first introduce a pore-scale model in terms of coupled, nonlinear partial differential equations describing these processes. To capture changes in the pore-scale geometry induced by heterogeneous reactions, we use a level-set framework. Finally, a computationally reasonable model is obtained applying two-scale asymptotics, and simulation results are presented.

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MS31

Analytical Solutions for Cation Exchange Reactions in Porous Medium

Hyperbolic theory of conservation laws are used to obtain analytical solutions for 1D flow with cation exchange reactions. Riemann solution in composition (phase) space comprises constant concentrations separated by waves. A comparison with laboratory and field data is presented for three cations. Challenges to extend for more components are highlighted.

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MS32

Causes of Sub Hydrostatic Pressure at Bravo Dome

The Bravo dome field in northeast New Mexico is one of the largest gas accumulations worldwide and the largest natural CO2 accumulation in North America. The field is only 580-900 m deep and Sathaye et al. (2014) estimated that 1.3 Gt of CO2 is stored in the reservoir. The reservoir is divided in to several compartments with near gas-static pressure. The pre-production gas pressures in the two main compartments that account for 46% and 18% of the mass of CO2 stored at bravo dome are 5.5 MPa and 4.5 MPa below hydrostatic pressure, respectively. Common explanations for sub-hydrostatic pressures include erosional unloading (Neuzil and Pollock 1983), regional groundwater circulation through low permeability beds (Senger et al. 1987), and cooling (Barker 1972). Here we introduce the dissolution of CO2 into the brine as a new process that can reduce gas pressure in a compartmentalized reservoir. This research suggests that erosional unloading, thermal effects, and dissolution of CO2 into brine can only explain $12\% \pm 3\%$, $30\% \pm 15\%$, and $20\% \pm 5\%$ of the total pressure drop, respectively. This suggests that CO2 dissolution may contribute significantly to reduce the initial pressure build-up due to injection. Our results also imply that the formation was already significantly below hydrostatic pressure before the CO2 was emplaced and that underpressured formations should be primary targets for geological CO2 storage.

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MS32

Thermal Modeling on the Bravo Dome

Thermochronological measurements suggest initial injection of hot, magmatic CO_2 into the Bravo Dome aquifer 1.2-1.5 My ago. We investigate this hypothesis by carrying out numerical simulations of the original CO_2 injection, taking into account thermal effects (density and viscosity changes, energy flow) and impact of aquifer heterogeneity. We examine the transport of heat carried by the CO_2 towards the regions for which thermochronological samples are available, to further constrain the parameters involved.

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Simulation of the Emplacement Process for a Natural CO_2 Reservoir

Due to their low solubility, noble gases can be used as reliable tracers for monitoring CO_2 dissolution at geological time scale, as it has been done in the case of the Bravo dome, a natural CO_2 reservoir, by measuring the concentration of Helium. We have implemented a compositional solver for $C0_2$, Helium, Neon and water, based on simple PVT laws. Simulating the CO_2 emplacement process then enables us to interpret in a more accurate way the spatial distribution of the components concentrations.

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MS32

Interpretation of Noble Gases in Natural CO2 Fields

Noble gas isotopes can be used to distinguish contributions of atmospheric, crustal, and mantle gases in subsurface gas accumulations. Despite being chemically unreactive, the low solubility of noble gases in brine relative to CO_2 causes these components to become enriched at the front of CO_2 migration processes. We present analytical models, combined with field and experimental data that can inform future studies of natural CO_2 migration using noble gas isotope distributions.

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MS33

Upscale and Multiscale Methods in Electromagnetics

Abstract not available at time of publication.

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MS33

Krylov Model-Order Reduction of Transient Seismic Wave Propagation in Unbounded Domains

The efficient and accurate modeling of transient acoustic wave propagation inside the subsurface of the Earth is of paramount importance in seismic exploration. In this talk, we present a new Krylov subspace reduction method that computes these wave fields in a very effective manner. The extension to infinity is modeled using an optimized complex-scaling method (a variant of the well-known Perfectly Matched Layer technique) and transient wave fields are computed by constructing Krylov subspace field approximations of a so-called stability-corrected wave function. In addition, we show that our approach allows us to directly identify which scattering poles are dominant and contribute the most to a received time-domain signal. Numerical experiments that illustrate the performance of the method are presented as well.

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MS33

An Adaptive Enriched Algebraic Multiscale Solver (AE-AMS)

We present an Adaptive Enriched Algebraic Multiscale Solver (AE-AMS) within the AMS framework of Wang et al. [JPC, 2014]. Our enrichment strategy is efficient, because it minimizes the number of additional basis functions by accounting for both the underlying problem characteristics and the solver settings. We study several enrichment strategies through numerical test cases, and illustrate that the AE-AMS outperforms the original AMS for challenging heterogeneous problems.

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MS33

Optimization Through Multiscale Methods

Multiscale finite element (MS-FEM) methods can significantly reduce the computational costs associated with solving quasi-static Maxwells equations in electromagnetic imaging. The main idea is to project the discretized PDE onto a low-dimensional subspace whose basis depends on the, in practice unknown, electric conductivity. This dependency renders the use of MS-FEM methods for geophysical inversions very challenging. This talk presents a new optimization approach that updates the conductivity estimate as well as the multiscale basis.

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MS33

Discrete Operator Upscaling for Well Models on Polyhedral Meshes

Well modeling is a critical component of reservoir simulations because wells drive strong localized gradients in the solution while typically being under-resolved. Many state-of-the-art well-models assume that the problem is discretized on orthogonal grids. However, to capture the influence of subsurface stratigraphy it is essential to use polyhedral meshes along with advanced discretization methods. In this research we present a new methodology, which is based on model upscaling, to represent wells on general polyhedral meshes.

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MS34

Active Subspace Dimension Reduction for Subsurface Sensitivity in Hydrology

Studying sensitivity of hydrology model outputs to subsurface properties is challenging due to the high dimensionality of spatially varying subsurface fields. We apply recently developed active subspaces to reduce the dimension of the sensitivity analysis and gain insight into the relationship between permeability and model outputs.

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MS34

Quantifying Uncertainties in Gulf of Mexico Circulation Forecasts

The impacts of input uncertainties on the Gulf of Mexico circulation forecast are studied using Polynomial Chaos (PC) Expansions. Key issues are: characterizing the inputs probability density functions, their forward propagation, and the validation of the PC surrogate. We use Empirical Orthogonal Functions to constrain the dimension of the uncertain space, and an ensemble calculation to construct the surrogate. Sea Surface Height variances indicate a loss of predictability in the Loop Current region after 20 days.

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MS34

Uncertainties in Tsunami Simulations from Uncertain Bathymetry

VOLNA, a nonlinear shallow water equations solver, produces high resolution simulations of earthquake-generated tsunamis. However, the uncertainties in the bathymetry (from irregularly-spaced observations) have an impact on tsunami waves. We first employ a Gaussian field to quantify uncertainties in these boundary fields. These uncertainties are then parametrised to be used as inputs of an emulator of VOLNA. We finally propagate uncertainties in the bathymetry to obtain an improved probabilistic assessment of tsunami hazard.

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MS34

Probabilistic Parameter Estimation and Prediction for Groundwater Contamination

We compute approximate solutions to inverse problems for determining parameters in groundwater contaminant transport models with stochastic data. We utilize a measure-theoretic inverse framework to perform uncertainty quantification and estimation for these parameters. Adjoint problems, which are useful in determining a posteriori error estimates, are developed and solved numerically. The solutions are used to make predictions of future contaminant concentrations and to analyze possible remediation techniques.

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MS34

Bayesian Inference of Fault Slip Distribution During A Tsunami Event Using Polynomial Chaos

We present an efficient method to infer fault slip distribution using water surface elevation data obtained during Tohoku earthquake and tsunami. We characterize the slip distribution by six different parameters assumed constant in six fault segments. The efficiency of our approach stems from the use of polynomial chaos expansions to build an inexpensive surrogate for the numerical tsunami GeoClaw model that can be used to perform a sensitivity analysis. The surrogate also reduces the computational burden of the Markov Chain Monte-Carlo sampling needed for the Bayesian inference. Our objective is to sharpen the initial estimates of the uncertain slip distributions. We report results of the Maximum-A-Posteriori (MAP) values of the uncertain parameters.

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MS34

Towards the Prototype Probabilistic Earth-System Model for Climate Prediction

Our research is focused on making current climate model simulations more consistent with preserved scaling symmetries of the partial differential equations which govern the multi-scale nature of climate. This is achieved by moving away from the traditional deterministic approach to the closure problem in computational fluid dynamics, and towards a more novel description of physical processes near and below the truncation scale of climate models, using contemporary nonlinear stochastic-dynamic mathematics. The proposed consequences of such an approach will be to reduce biases against observations, produce estimates of uncertainty in its own predictions, and a model which can make use of emerging energy-efficient probabilistic processor hardware. We will present results from efforts in various fields of the climate model development in our group ranging from stochastic approaches in atmospheric convection parameterization, land surface process parameterization, ocean eddy-induced mixing and sea-ice parameterization to stochastic hardware simulations of simple climate models.

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MS35

Molecular Simulation of Adsorption and Transport in Shales Organic Matter

Using an atomistic description of the oil-shale organic matter and Molecular Simulations [1], we generate quasi-experimental data to study adsorption and mass transfer at the nanoscale. First, we review reservoir simulators models of dry gas adsorption [2] and extend them to light oils [3]. Second, isothermal transport is studied: non-Darcean behavior is obtained, as transport is dominated by a thermally activated diffusion process, like nanoporous carbons [4], described in the Maxwell-Stefan framework. References [1] Collell et al., Energy & Fuels 2014, 28 (12), 74577466. [2] Collell et al., Microporous Mesoporous Mater. 2014, 197, pp 194203. [3] Collell et al., J. Phys. Chem. C 2014, 118 (45), 2616226171. [4] Botan et al., Langmuir 2013, 29, 99859990.

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MS35

Assessing the Impacts of Multi-Rate Mass Transfer and Sorption in Heterogeneous Media

Direct numerical simulation of contaminant persistence in heterogeneous subsurface formations is known to be a computationally challenging problem. We describe coupled desorption and diffusive exchange between mobile and immobile zones by multiple first-order exchange terms. The link between effective first-order rates and geostatistical medium descriptions is established, using regression based on fine-scale simulations. This approach facilitates efficient assessment of reactive transport in heterogeneous domains.

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MS35

Multi-Scale Multi-Component, Multi-Phase Flash with Applications to Salt Deposition and Light Tight Oil

The Gibbs-Helmholtz Constrained (GHC) equation of state is used to predict phase properties and equilibrium behavior in two applications of current interest - CO2 sequestration and light tight oil (LTO). In CO2 sequestration, mixtures contain light gases, ions, amorphous silica and water and can exhibit three fluid phases plus solid salts. In contrast, LTO applications contain light gases, heavier hydrocarbons, and water and often exhibit different behavior in tight pores than in the bulk.

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MS35

PH Dependent Reaction Fronts in Porous Media

Multicomponent reactive transport in porous media gives rise to reaction fronts with complex morphology. The first-order structure of these fronts can be analyzed in the hyperbolic limit of the governing equations. Field and experimental data show good agreement with analytical simulations of ion-exchange reactions. New theoretical and experimental results for reactive transport with pH-dependent surface reactions show more complex front morphology and highlight the effect of nonlinear surface chemistry on transport behavior.

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MS35

Discrete-Continuum Models of Transport Phenomena

Discrete, particle-based simulations offer distinct advantages when modeling solute transport and chemical reactions. For example, Brownian motion is often used to model diffusion in complex pore networks, and Gillespie-type algorithms allow one to handle multicomponent chemical reactions with uncertain reaction pathways. Yet such models can be computationally more intensive than their continuum-scale counterparts, e.g., advection-dispersion-reaction equations. Combining the discrete and continuum models has a potential to resolve the quantity of interest with a required degree of physicochemical granularity at acceptable computational cost. We present computational examples of such hybrid models and discuss the challenges associated with coupling these two levels of description.

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MS35

Reactive Flow and Transport in Porous Media: Applications and Challenges

Thermal multiphase flow and multi-component reactive transport in porous media is an important type of simulation since it describes almost all energy- and environment-related industrial processes. Applications of practical interest include, but are not limited to, modeling conventional and unconventional petroleum reservoirs, CO2 sequestration processes and advanced geothermal applications. In my talk I will discuss a robust implementation of chemical reaction with precipitation and dissolution of a solid phase for Darcy scale and ideas of coarse scale reconstruction of fine-scale results. Several examples of practical interest will be presented.

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MS36

A Well-Conditioned Fast Multipole BEM for 3-D Elastodynamics in the Frequency Domain

The Fast Multipole accelerated boundary element method (FM-BEM) is a possible approach to solve 3D elastodynamic problems in unbounded domains. By nature the FM-BEM is used in conjunction with an iterative solver. To reduce the number of iterations, we propose a judicious integral representation of the scattered field which naturally incorporates a regularizing operator (a high-frequency approximation of the DtN). This OSRC-like preconditioner is applied efficiently to Dirichlet exterior scattering problems in 3D elastodynamics.

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MS36

Fast Frequency Domain Solvers and Seismic Microscale Inversion

Abstract not available at time of publication.

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MS36

Full Waveform Inversion for the Identifiable Subspace Using Interior Point Methods

Full-waveform inversion (FWI) optimizes subsurface model estimates to derive high-fidelity geological models. A mathematically sound method is described for selecting the part of the geological parameters that is best identifiable from the seismic acquisition geometry. This is combined with either interior-point or sequential quadratic programming methods for performing FWI for the subset of parameters that have been characterized as identifiable. Numerical results are presented on several examples of increased complexity.

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MS36

Asymptotic Preconditioning Approach for Multi-Parameter Full Waveform Inversion

Developing efficient and reliable multi-parameter approaches for Full Waveform Inversion is an increasingly important issue in seismic imaging. The main difficulty is related to potential trade-offs between different classes of parameters (P-wave velocity and density for instance). One could mitigate this issue by accounting accurately for the inverse Hessian operator within the inversion. To this end, we propose to use an asymptotic approximation of this operator as an efficient preconditioner within a truncated

Newton algorithm.

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MS36

Accelerated Discontinuous Galerkin Time-Domain Simulations for Seismic Imaging

Improving both the accuracy and computational performance of simulation tools is a major challenge for seismic imaging, and generally requires specialized algorithms to make full use of accelerator-aided clusters. We present a strategy for reverse time migration based on a high-order penalty-discontinuous Galerkin time-domain method, dealing with different wave models. Our implementation can be run on several architectures thanks to a unified multi-threading programming framework, and exhibits a good load balancing and minimum data movements.

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MS36

Signal to Noise Ratio Analysis in Virtual Source Array Imaging

We consider the problem of virtual source array imaging. Motivated by geophysical applications, we assume that the illuminating array is at the surface of the earth while the reflector to be imaged is located in a homogeneous slab at some depth. We also assume that the medium between the reflector and the illuminating array is complex and strongly scattering. In this setup traditional migration imaging fails since the echoes from the reflector are lost in the noisy backscattered echoes from the ambient medium. In virtual array imaging, noisy traces are recorded on an auxiliary receiver array that is located in the homogeneous slab above the reflector and below the strongly scattering medium. Imaging is performed by migrating the cross correlations of the recorded field. We will illustrate with numerical results the robustness of virtual array imaging and present an analysis of the signal to noise ratio of the obtained image.

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MS37

Experimental Demonstrations of Some Computational Challenges in Hydraulic Fracture Simulation

Hydraulic fracture modeling relies on a non-linear, non-local moving boundary problem with multiple nested length scales possesses a harsh numerical stability criterion for explicit time-stepping methods and a demonstrable tendency for algorithmic details to have a first order impact on predictions. Bringing together predictions from a variety of types of hydraulic fracture simulators with data from both the field and laboratory, this talk will highlight some lessons that have been learned over the past decade of research.

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MS37

Hierarchical Modeling of Networks and Solution of Nonlinear Network Models via MYNTS-NL

We present a new methodology for hierarchical modeling of networks which can be applied to pipeline systems and fractured reservoirs. The setup of the finest-level network representation heavily relies on Kirchhoffs laws and Darcy(-Weisbach) flow models. For solving the resulting system of nonlinear equations and inequalities we developed a workflow employing analytical formulations and NL. The hierarchy is based on reduced-order modeling and is used for speeding up simulations and/or comparative flow analysis.

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MS37

Efficient and Robust Compositional Numerical Modeling in Unfractured and Fractured Permeable Media Based on New Concepts

An efficient and accurate numerical model for multicomponent compressible flow in fractured media is presented. The discrete-fracture approach is used where the fracture entities are described explicitly in the computational domain. We invoke cross-flow equilibrium in fractures. This will allow large matrix elements in the neighborhood of the fractures. We use an implicit FV scheme to solve species mass balance equation in fractures. Numerical model is developed for 2D and 3D structured and unstructured meshes.

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MS37

Modeling Subsurface Fractures using Enriched Finite Element Method

Extended finite element method (XFEM) allows accurate modeling of fractures without having to construct mesh to honor geometries of fracture. In this talk, we will present two applications of XFEM with improved formulation. The first one concerns rapid evaluation of well productivity with fractured completions. Examples on using the new method to quantify the impact of non-Darcy effect will be given. The second application concerns predicting natural fracture characteristics (e.g. density, orientation, and connectivity) using a 3D geomechanical model which can simulate fracture initiation, growth, and intersection occurred in the mechanical genesis of natural fractures. Simulation studies offered new insights on the factors that control the density and connectivity of natural fractures.

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MS37

Dependence of the Equivalent Permeability of a Fractured Rock Mass on Fluid Pressure and Stress

The fracture matrix ensemble permeability / anisotropy of outcrop analog models of naturally fractured layered sedimentary rocks has been computed as a function of sample size using finite-element models. As in situ fracture aperture, influences these parameters, a sensitivity analysis was conducted with competing aperture models, also considering the influence of residual aperture. Our results indicate correlations with sample size and demonstrate the decisive role that aperture plays for fracture flow.

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MS37

Effective Transmissivity of Two and Three-Dimensional Fractured/porous Media

A method to numerically compute the full permeability tensor of a two- and three-dimensional fractured porous medium is proposed. It assumes that fluid flows through both the fractures and matrix, and calculates the full permeability tensor of the medium. The method is based on the element-wise averaging of pressure and flux. A derived formulation approximates three-dimensional flow properties in cases where only two-dimensional analysis is available, based on an alternative expression of the excluded area.

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MS38

Adaptive Mesh Refinement for Dynamic Rupture Simulations in Complex Geometries

Dynamic earthquake rupture simulations involve the coupling of wave propagation and frictional sliding fault interfaces. The friction laws used in such simulations introduce small-scale features (around the nearly singular rupture front) that would be prohibitively expensive to capture with a static mesh. Since simulations involve both wave propagation and small-scale rupture features, here we propose the use of dynamically adaptive, high-order accurate discontinuous Galerkin methods for such problems.

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MS38

A Coupled Model for Dynamic Wedge Failure, Coseismic Landslides, and Tsunami Propagation for Shallow Subduction Zone Earthquakes

We incorporate coseismic landslides and tsunami propagation in the dynamic rupture model of shallow subduction earthquakes with extensive wedge failure. An updated Lagrangian approach is used in which the equation of motion, failure criterion, and boundary conditions are evaluated at the deformed configuration. We investigate how inelastic wedge failure and landslides affect the arrival time, amplitude, and frequency content of tsunami waveforms.

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MS38

Segmented Source Structures: When Do Earthquake Ruptures Jump Between Faults?

How segmented fault systems host earthquakes is of primary importance to assessing seismic hazard. We address the potential for jumping versus continuous slip during the 1992 Landers earthquake in southern California, which ruptured segments of 5 different right-lateral, strike-slip faults. One of these faults is the 4km long Landers-Kickapoo Fault in the releasing step between the Johnson Valley Fault to the southwest, where the earthquake nucleated, and the Homestead Valley Fault to the northeast. Using boundary element method models incorporating 3D, non-planar faults, we find that slip along the Landers-Kickapoo Fault is required to transfer slip through the step. This raises the question: when do ruptures jump across a step and when are secondary faults required to transfer slip across a step? Addressing this requires the incorporation of structures present within steps into numerical models and a comparison of quasistatic model results such as these, which approximate the dynamic solution for the stress field near a slowly propagating rupture tip, with those from dynamic models, which capture slip accelerations and the seismic waves emitted from the rupture tip.

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MS38

3D FEM-based Study of the 2011 Tohoku Earthquake Tsunamigenic Rupture Process

Tohoku earthquake is investigated by using a 3D-FEM model honouring the geometrical and structural complexities of the subduction interface up to the trench zone, and performing a joint inversion of tsunami and geodetic data. Spatial correlation between slip and seismic velocity suggests structural control on the rupture. Sensitivity of retrieved slip model to elastic subduction zone parameters, inclusion of horizontal displacement and nonlinear non-hydrostatic dispersive versus linear shallow water tsunami modelling is analysed as well.

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MS38

The SeisSol Software Package for Large-Scale Tsunamigenic Earthquake Simulations

We present the peta-scale software package SeisSol 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. To demonstrate the advantages of the scheme we will present a subduction earthquake scenario. To this end, geometrically complex faults can be accurately discretized and the impact of earthquake source dynamics on tsunami initiation and propagation can be analysed.

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MS38

Seismo-Thermo-Mechanical Modeling of Subduction Zone Seismicity

Seismo-thermo-mechanical modeling aims to improve our physical understanding of spatiotemporal earthquake occurrence in subduction zones. After validating this new continuum viscoelastoplastic geodynamic model with similar on- and off-fault physics, we demonstrate the importance of off-megathrust events on the megathrust cycle. Moreover, activation of steep off-megathrust fault planes could potentially generate larger than expected tsunamis, especially for outerrise events. This additional long-term model component can provide self-consistent fault geometries, stresses and strengths to dynamic rupture models.

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MS39

Meshless Discretization of Generalized Laplace Operator For Anisotropic Heterogeneous Media

Reservoir simulations require complex discretizations due to presence of faults, fully discontinuous permeability tensors. The smoothed particle hydrodynamic (SPH) is an interpolation-based numerical technique that can be used to solve underlying partial differential equations (PDEs) describing fluid flow in porous media. The meshless multi-point flux approximation (MMPFA) for generalized Laplace operator is proposed describing fluid flow in anisotropic heterogeneous porous media. The fundamentals, potential, and computational aspects will be presented.

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MS39

Meshless Multigrid with Rough Coefficients

We introduce a meshless multigrid method for PDEs with rough coefficients (and in particular for PDEs arising in transport in porous media). The method is naturally parallelizable, has optimal complexity and we provide sharp a-priori error estimates on its accuracy.

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MS39

Partition of Unity Methods: Mass Lumping and Fast Solvers for Higher Order and Enriched Spaces

Meshless and generalized finite element methods are modern computational techniques designed to overcome some of the shortcomings of classical mesh-based approaches. The Partition of Unity Method (PUM) not only provides the fundamental framework for generalized and extended finite element methods (GFEM/XFEM) but may also be utilized to construct meshfree methods with problem-dependent approximation functions. In this talk we focus on such a meshfree PUM, its approximation properties when using higher order polynomials and problem-dependent enrichment functions, as well as its parallel implementation. Here, we are concerned not only with the efficient assembly of the stiffness matrix but also with the fast solution of the resulting linear systems (i.e. the efficient simulation of static problems or implicit dynamics). Moreover, we discuss the properties of a general mass lumping scheme which is applicable to higher order and arbitrarily enriched local approximation spaces to deal with large scale explicit dynamics problems efficiently with the proposed PUM.

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MS39

Oil and Gas Production Forecasting with Semi-Analytical Reservoir Simulation

Reservoir simulation is used by oil and gas companies to model fluid flow in the subsurface. Because of the complexity of reservoirs, forecasts and decisions regularly require the use of computationally expensive numerical simulations. However, due to the high speed in model setup and computation of results, the industry is experiencing a growth in the application of analytical reservoir simulation. This paper reviews analytical reservoir simulation technology and its applications to conventional and unconventional resources.

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MS39

Extending the Method of Fundamental Solutions to Non Homogeneous Elastic Wave Propagation

Problems

We consider the numerical solution of the Cauchy-Navier equations of elastodynamics, assuming time-harmonic variation for the displacement field in an isotropic material. In the absence of body forces, the method of fundamental solutions (MFS), a meshfree procedure for solving homogeneous elliptic PDEs, is applied. The formulation of the MFS is then modified in order to extend it to the non homogeneous case. More precisely, the unknown solution is approximated by superposition of fundamental solutions (Kupradze tensors) of the Navier operator with different source points and test frequencies. The applicability of the method is justified in terms of density results and its accuracy is illustrated trough numerical examples. The performance of the method is also tested for interior wave scattering problems and materials with non constant density.

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MS39

Large Scale Compuation of Fluid-Solid-Fracturing Using SPH with Application to Hydro-Fracturing

Conventional stimulations of strong, stiff, brittle rocks have in general been successful. However, the more ductile plays have been less successful. That is, current fracturing technology is limited to the more brittle formations. Laboratory tests with gelatin show that the fracture development is sensitive to material properties, such as anelasticity and ductility. MIT has developed an Open Source SPH code to investigate hydro-fracturing of tight formations. It is capable of handling coupled multi-phase non-Newtonian fluids, elasto-visco-plastic solids with brittle or ductile fracture. The use of SPH for fracture means that the fracture can be handled discretely without the need for special elements. The fracture geometry can be complex and nonplanar. The code is built on a parallel library capable of optimizing the execution across multi-core machines with large numbers of compute nodes.

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MS40

Machine Learning Approaches to Rare Event Sampling and Estimation

An efficient rare events sampling algorithm have been developed using machine learning classification methods to define the failure boundary (in the stochastic space) corresponding to the threshold of a rare event. The training samples for the classification algorithm are obtained using a multilevel splitting algorithm and Monte Carlo (MC) simulations. Once the training of the classifier is performed, a full MC simulation can be efficiently performed using the classifier as a reduced order model replacing the full simulator. The developed rare events sampling algorithm significantly outperforms direct MC and multi-level splitting methods in terms of efficiency and precision on a standard benchmark for CO2 leakage through a leaky abandoned well. In this test case, CO2 is injected into a deep aquifer and then spreads within the aquifer and, upon reaching an abandoned well; it rises to a shallower aquifer. The rare events sampling algorithm estimates the probability of leakage of a pre-defined amount of the injected CO2 given a heavy tailed distribution of the leaky well permeability. The proposed algorithms efficiency and reliability enables us to perform a sensitivity analysis to study the effects of the different modeling assumptions including the different prior distributions on the probability of the rare event of CO2 leakage.

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MS40

The Ensemble Kalman Filter and Beyond

The ensemble Kalman filter (EnKF) has proven to be one of the most efficient algorithms for inverse modeling of transient phenoma in a stochastic context. Its main advantage being that it does not rely on a computer-intensive optimization algorithm, but it is an assimilation algorithm that incrementally updates the inverse estimates as new state data are acquired. Its main disadvantage is that the updating is computed on the basis of the two-point auto- and cross-covariances between parameters and states, what, in the long run, yields the estimates multiGaussian. To go beyond the standard EnKF we need to get away from the multiGaussian curse.

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MS40

Model Calibration under Uncertain Geologic Scenarios Using Sparse Representation Techniques

Inverse modeling and uncertainty quantification in subsurface flow and transport systems are typically performed without accounting for the uncertainty in the conceptual geologic continuity model (e.g., variogram or training image). The geologic scenario, however, can present one of the most dominant and persistent sources of uncertainty in predicting the flow and transport behavior. We present effective formulations that are inspired by sparse representation techniques to discriminate against several proposed geologic continuity models during model calibration.

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MS40

Recent Advances and Trends in the Geostatistical Approach to Inverse Modeling and Data Assimilation

The Geostatistical Approach (GA) is a method to solve algebraically underdetermined problems including quantification of uncertainty in the context of objective empirical Bayes statistical inference. In the last few years, like other Bayesian methods, GA is revolutionized by high performance computing, particularly the introduction of fast linear algebra that uses approximate methods with controlled error. We review recent advances and trends in GA.

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MS40

Determination of Geological Scenario Using an Optimization Procedure

Uncertainty in the geological scenario or training image is often ignored in oil reservoir history matching. In this talk, a systematic procedure for the determination of the most likely geological scenario, along with model realizations within that scenario, is presented. The approach uses continuous parameterizations of uncertain training image attributes and optimization to determine attribute values. Results demonstrate that the approach can provide models that lead to uncertainty reduction and appropriately bracket future reservoir performance.

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MS40

Formal Uncertainty Quantification in Geophysics: Likelihood Free Inference Using Summary Statistics from Training Data Images

In the past decades, Bayesian methods have found widespread application and use in environmental systems modeling. Despite the progress made, hypothesis(model) refinement has proven to be very difficult in large part because of the poor diagnostic power of residual based likelihood functions. In a series of recent papers we have made the case for a diagnostic approach to model evaluation. This statistical methodology relaxes the need for an explicit likelihood function in favor of one or multiple different summary statistics rooted in environmental theory that together have a much more compelling diagnostic power to detect epistemic errors than some average measure of the size of the error residuals. In this talk, I will demonstrate the prospects of diagnostic model evaluation to improve probabilistic inversion of geophysical data. The distributions of global summary metrics (roughness, variability,etc.) from training data images are used to create an informative prior distribution, which combined with a likelihood function of the geophysical data leads to a much better representation of the subsurface than commonly used deterministic penalized least squares inversion methods. The proposed methodology reduces the ambiguity inherent in the inversion of high-dimensional parameter spaces, and accommodates a wide range of summary statistics and geophysical forward problems.

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MS41

A Floe Size Distribution in the Cice Sea Ice Model

The CICE sea ice model is a popular component of climate and forecasting models. However, it does not contain information on the size of ice floes. This is likely to inhibit its accuracy, particularly in a vicinity of the ice edge, where floe sizes are relatively small. An extended version of CICE in the Antarctic will be presented. The extended model contains a floe size distribution based on mathematical models of ice break-up.

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MS41

Free-boundary Problems in Cryosphere Models

Thin flowing layers, such as ice sheets, ice shelves, sea ice, subglacial liquid water, and supraglacial liquid water, are common components of cyrospheric climate models. These flows are characterized by interaction with other climate components (e.g. atmosphere and ocean), which adds or removes fluid. Thus there are free boundaries, in the map-plane, between where the fluid is present and not. We advocate a common approach to the construction of numerical models for these thin layer flows: semi-discretize in time, treat the nonnegativity of layer thickness as a constraint, and solve a well-posed spatial free boundary problem at each time step. Advanced numerical tools are available for solving each time step problem, namely parallel-scalable and constraint-respecting Newton solvers based on Krylov subspace methods. The approach clarifies the degree to which exact discrete conservation, a goal of climate modeling, is achievable. Non-trivial examples will be shown.

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MS41

How Climate Model Complexity Influences the Sea Ice Stability

Two types of idealized climate models find bifurcations and associated instabilities during the retreat of sea ice under global warming: (i) latitudinally-varying annual-mean diffusive energy balance models (EBMs) and (ii) seasonally- varying single-column models (SCMs). Comprehensive global climate models, however, typically find no such instabilities. To bridge this gap, we develop an idealized model that includes both latitudinal and seasonal variations. The model reduces to a standard EBM or SCM as limiting cases in the parameter regime. We find that the stability of the sea ice cover vastly increases with the inclusion of spatial communication via meridional heat transport or a seasonal cycle in solar forcing, being most stable when both are included. This implies that the sea ice cover may be substantially more stable than has been suggested in previous idealized modeling studies.

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MS41

Sea Ice, Climate, and Homogenization for Composite Materials

The polar sea ice pack is an important component of the Earths climate system undergoing rapid change. Complex physical processes in sea ice play a critical role in regulating polar climate. Understanding these processes and developing methods to monitor changes in the ice pack are thus important for making accurate predictions of the Earths future climate. Homogenization has proven to be a powerful mathematical tool for understanding the effective properties of composite media, and sea ice exhibits composite structure on multiple length scales over ten orders of magnitude. As such, homogenization techniques can be applied to understand ice properties such as fluid permeability, electrical conductivity and large-scale rheological properties.In this talk I will discuss and highlight models developed for sea ice using homogenization and how they help advance our understanding of the role of sea ice in the climate system, and improve projections of climate change

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MS41

Stochastic Dynamics and Critical Phenomena in Sea Ice Models

The evolution of melt ponds on the surface of Arctic sea ice is a complex stochastic process that is important in climate modeling. We propose two models describing the stochastic dynamics of melt pond geometry – an analogue of the Ising model from statistical mechanics, and a low-order stochastic dynamical system model of energy balance in the climate system. These models facilitate investigation of critical phenomena in Earths cryosphere, and melting sea ice in particular.

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MS41

An Anisotropic Elastic-Decohesive Constitutive Relation for Modeling Sea Ice

Satellite imagery indicates that much of the winter Arctic ice deformation is concentrated in linear features, like cracks. The aim of this research is to build on a previously formulated elastic-decohesive constitutive model that predicts the initiation, orientation and extent of cracks and tie it more closely to the thermodynamics and the distribution ice thickness. Examples are given to illustrate aspects of the model when simulating the failure of sea ice.

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MS42

Effective Properties of Realistic Oil Shale Stackings

This work aims at numerically characterizing some macroscopic properties of realistic computer-generated block stackings. The complex geometries studied represent the stacking configuration of the Ecoshale in-capsule configuration. The permeability tensor of this porous media is determined as well as the inertial correction. Concerning the thermal dispersion tensor, a classic local equilibrium volume averaging method is used.

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MS42

Towards a Coupled Thermo-mechanical and Heat and Mass Transfer Model for Source Rock Maturation and Retorting

Thermal degradation of source rock, exogenous or not, involves kerogen conversion resulting in rock structure evolution from non-permeable to permeable. Pyrolysis reactions produce oil and gas, locally increasing pressure and stress.

The rock fails and cracks propagate enhancing the permeability of the medium. This represents a new challenge for porous media research as the system to be model evolves in time and exhibits strong coupling between mass and heat transfer, and rock mechanics. A 3D numerical method is proposed to model the thermo-mechanical phenomena involved in the in-situ oil shale retorting process. The mechanical model is based on an original hybrid approach between two discrete methods. A lattice-type discretization is used to describe the underlying micro-structure of the continuum. A particulate model is used for handling the crack interfaces and their interactions. Heat conduction and thermal expansion are solved by a finite-volume algorithm. Different mechanical and thermal validation tests are presented and compared to experimental results found in the literature. They show the abilities of this framework to simulate and predict the mechanical behavior and the failure of materials undergoing significant structural changes.

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MS42

Modelling In-Situ Upgrading of Heavy Oil with Non-Equilibrium Reactions Using Operator Splitting Method

We present a mathematical model that describes the In-Situ Upgrading of bitumen and oil shale. A non-equilibrium reaction model is used to describe the transfer between the liquid and vapour phases. We use operator splitting to solve separately the transport equation and the chemical reactions describing pyrolysis and phase transfer. Dimensionless Analysis is used to study the sensitivity of the reaction parameters and identify flow regimes in a two-phase model.

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MS42

Transport in Porous Media with Surface Sources: Non-Equilibrium Models and Distribution Coefficients

We present several Darcy-scale models obtained via the method of volume averaging for a generic pore-scale problem of transport by advection and diffusion with multiple phases and sources/sinks on the interfaces. We review the different classes of approximations that can be used (eg local equilibrium, non-equilibrium, asymptotic) and discuss their limitations. We also present a multiple temperature model with a distribution coefficient that captures the partitioning between the different phases.

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MS42

Non-Newtonian Flow Through Porous Media: Micro and Macro-Scale Properties of Power-Law Fluids

In this work, we study polymer flow through porous structures in the context of Enhanced Oil Recovery methods. We consider a non-Newtonian polymer flow described by a power-law fluid and generalized incompressible Stokes equations at the pore-scale. Our strategy is based on the method of volume averaging, CFD calculations, x-ray imaging of realistic structures and statistical tools. We show that this combination of approaches provides significant insight into the complexity of the micro-scale flow, allowing us to better characterize its behavior and explicit links with macro-scale properties.

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MS42

Pore Scale Simulation of Carbonate Dissolution

We have developed a numerical tool to simulate dissolution phenomena at pore-scale. The model allows to dissolve a solid in presence of liquid acid into dissolved species. It is based on a Darcy-Brinkman framework to differentiate solid phase and void spaces. The volume fraction of solid in each cell of the computational domain varies with chemical reaction at the solid surfaces. It can, therefore, change the morphology of the solid skeleton. The model has shown promising results to capture the aperture evolution of a fracture due to dissolution and has demonstrated a good ability to simulate dissolution wormholes. First results also showed that the model can capture CO2 gas bubbles generation at the solid walls.

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MS43

High-Order Ipdg Approximations for Elasto-Acoustic Problems

We develop a solution methodology for the direct elasto-acoustic scattering problem based on Discontinuous Galerkin approximations. The method distinguishes itself by combining high-order polynomials, local stabilizations and curved element edges on the boundaries. Numerical results illustrate the salient features and highlight the performance of the solution methodology. Moreover, the designed method ensures a convergence order with a gain of two order of magnitude compared to polygonal boundaries, and a potential to address high-frequency regimes.

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MS43

Performance Assesment on Hybridizable Dg Approximations for the Elastic Wave Equation in Frequency Domain

Seismic Imaging in frequency domain represents a very challenging task when considering realistic 3D elastic media because of the huge size of the linear system to be inverted. To reduce the number of unknowns of the linear system, we propose to consider a hybridizable DG method. We analyze the performance of the method on realistic test case in a parallel programming framework and we compare it with classical Discontinuous Galekin methods.

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MS43

Dg for Large-Scale Inverse Problems in Time Domain: Opportunities and Challenges

This talk discusses various challenges of statistical inverse problem using high-order DG methods in geosciences, particularly global seismic inversion in time domain. In particular, we will talk about scalability of DG, issue with gradient/Hessian computation, discretize-then-optimize versus optimize-then-discretize, compactness of the Hessian, challenges in high dimensional parameter spaces, among many others. Numerical results for statistical inversion over 1M parameters will be presented.

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MS43

High order DG Methods on Hybrid Meshes

High order time-explicit nodal discontinuous Galerkin (DG) methods have grown in popularity over the past decade for reasons both mathematical and computational in nature. Sharp trace inequalities with explicit constants allow for explicit expressions for optimal CFL and penalty constants, and the computational structure of DG methods on simplices and hexahedra allows for efficient implementation on accelerators and graphics processing units. In this talk, we present extensions of these aspects of DG methods to high order pyramidal elements, and discuss the development of a GPU-accelerated solver for wave equations on hybrid meshes containing hexahedra, wedges, pyramids, and tetrahedra.

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MS43

A Simple and Accurate Discontinuous Galerkin Scheme for Modeling Wave Propagation in Media with Curved Interfaces

Conventional high-order discontinuous Galerkin schemes suffer from interface errors caused by the misalignment between straight-sided elements and curved material inter-

faces. We develop a novel discontinuous Galerkin scheme to reduce the errors. We modify the numerical fluxes to account for the curved interface. Our numerical modeling example demonstrate that our new discontinuous Galerkin scheme significantly suppresses the spurious diffractions seen in the results obtained using the conventional scheme. The computational cost of our scheme is similar to that of the conventional scheme. Our new discontinuous Galerkin scheme is thus particularly useful for large-scale wave modeling involving complex subsurface structures.

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MS44

Cvd-Mpfa Mixed-Dimensional Coupled Fracture Approximation

A novel cell-centred control-volume distributed multi-point flux approximation (CVD-MPFA) finite-volume formulation is presented for discrete fracture-matrix simulations. The grid is aligned with the fractures and barriers which are modelled as lower-dimensional interfaces with fracture network located between the matrix cells. The CVD-MPFA formulation naturally handles fractures with anisotropic permeabilities on unstructured grids.

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MS44

Phase Transition and Reverse Pumping During Flow Induced Slip Failure

Shear or tensile failure due to fluid injection leads to the creation of new volume, which is accessible by fluid. Depending on the ratio of mechanical to flow time scales, the pressure in such volumes temporarily decreases, which can result in a flow from the adjacent matrix into the fracture. This phenomenon is supported by simulation studies showing that this reverse pumping mechanism can be exploited to extract significant amounts of fluid from the matrix.

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MS44

New Directions and Practical Application of Finite Volume Methods for Discrete Fracture-Matrix Simulations

In recent years, application of discrete fracture-matrix (DFM) simulations to field studies has become more practical and more prevalent. As the usage has increased, new challenges have emerged, and we continue to develop new finite volume methods and workflows to meet those needs. Here, we will share recent progress on extending our methodology and applying it to study recovery mechanisms in naturally fractured reservoirs. Specifically, we will address consistent discretization, flow-based upscaling, and comparison between gridded and embedded DFM simulations.

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MS44

Reactive Transport Modeling in Fractured Porous Media: Role of Fluid-Rock Interactions on Flow and Transport

In deep geological media heat and chemical stresses can cause physical alterations, which may have a significant effect on flow and reaction rates. As a consequence it will lead to changes in permeability and porosity of the formations due to mineral precipitation and dissolution. We demonstrate the results of a numerical scheme considering material discontinuities in fractured porous media used to solve a system of nonlinear transport models.

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MS44

Generalized Multiscale Finite Element Method for Flows in Fractured Media

In this work, we present a multiscale approach for shale gas transport in fractured media. Our approach uses an upscaled model in the form of nonlinear parabolic equations to represent the matrix that consists of organic and inorganic matter. The interaction of matrix and the fracture is represented by multiscale basis functions. We follow Generalized Multiscale Finite Element Method to extract the leading order terms that represent the matrix and the fracture interaction. Numerical results are presented.

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MS44

Diffusive Zone Fracture Modeling for Porous Media Applications

We discuss modeling fractures in a poroelastic medium using a phase-field formulation. The fracture is treated as a diffuse interface in the reservoir domain. The coupled reservoir-fracture flow problem is formulated as a single, pressure diffraction equation. We provide numerical examples demonstrating the effectiveness of this approach. Additionally a comparison between two modeling approaches, fracture/matrix flow as an interface versus a diffusive zone, is also presented.

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MS45

Tsunami-Hysea Model: a Multi-Gpu Finite-Volume Solver for the Italian Tsunami Early Warning System

The INGV in collaboration with the EDANYA Group (UMA) are developing and implementing a FTRT (Faster Than Real Time) Tsunami Simulation approach for the Italian candidate Tsunami Service Provider, namely the Centro Allerta Tsunami (CAT). The numerical model used for this purpose, named Tsunami-HySEA, implements in the same code the three phases of an earthquake generated tsunami: generation, propagation and coastal inundation. The HySEA model uses nested meshes with different resolution and multi-GPU environment, which allows much FTRT simulations, computing within a few minutes wall clock time the evolution of a seismically generated tsunami in the whole Mediterranean Sea.

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MS45

Nonhydrostatic Correction for Shallow Water Equations with Quadratic Vertical Pressure Distribution: A Boussinesq-Type Equation

Two common approaches for dispersive long wave equations are compared namely the Boussinesq-type equations and the nonhydrostatic pressure correction for the shallow water equations. If the latter is derived with a quadratic vertical interpolation for the nonhydrostatic pressure, we show that both approaches are equivalent for special cases. The comparison of numerical dispersion relations is performed with a testcase implemented in a tsunami model based on an adaptive triangular mesh with finite element space discretization.

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MS45

Modeling Coastal Hazards Using the Multi-Layer Shallow Water Equations

Currently earthquake based tsunami modeling usually involves the use of a depth-averaged model of the ocean for computational efficiency and the suitability of such models to the problem. Models containing multiple layers have usually not been applied to such events as the single layer model tends to be sufficient. In this talk I will outline results looking into whether certain earthquake scenarios may warrant a multi-layer approach and what the pros and cons of the approach are.

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MS45

Managing Parallel Dynamic Adaptivity for Tsunami Simulations with Time-Dependent Source Terms

We present recent work on coupled tsunami and earthquake simulation. As tsunamis may need hours to develop and reach the shores whereas earthquakes happen within minutes, we need to tackle the problem of different time scales of those processes. On the computational side, we discuss using adaptive parallel grids for the tsunami simulation and show speedup results due to vectorizing over simultaneous tsunami simulations.

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MS45

Dynamic Models of Earthquakes and Tsunamis from Dip-Slip Faults Offshore Ventura, California

The Ventura basin in southern California is becoming increasingly recognized for seismic and tsunami hazards. Within the region is a network of coastal dip-slip faults, potentially producing earthquakes of magnitude 7 or greater. We construct a 3D dynamic rupture model of an earthquake on the Pitas Point fault to model ground motion and the resulting tsunami. Our corresponding tsunami model matches the seafloor displacement to the final seafloor displacement from the rupture model.

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MS45

Towards Operational Adaptive Tsunami Modeling - Validating Adaptive Discontinuous Galerkin Inundation Schemes

We present a tsunami simulation framework, which is based on adaptive triangular meshes and a Runge-Kutta discontinuous Galerkin (RKDG) discretization. This approach allows for high local resolution and geometric accuracy, while maintaining the opportunity to simulate large spatial domains. While the specific components of the framework have numerically been validated, in this study the applicability to realistic scenarios is considered. We compute well-known benchmark problems and compare simulation results to recent tsunami events.

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MS46

Assessment of Hydraulic Conductivity at the Local Scale via Assimilation of Travel Time Data From ERT-monitored Tracer Tests

Assessing the spatial distribution of hydraulic conductivity (K) in natural aquifers is fundamental to predict the spatiotemporal evolution of solutes, a process that is mainly controlled by the heterogeneity of K. In sedimentary aquifers at the local scale, vertical variations of K are typically larger than horizontal variations and thus exert more control on the plume evolution. The K layering can be inferred by combining the Lagrangian formulation of transport with the assimilation of tracer test data via the ensemble Kalman filter (EnKF). In this work, the data for the assimilation procedure are provided by the monitoring of tracer tests with electrical resistivity tomography (ERT). Our main objective is to show the possibility of directly using ERT resistivity data collected across a control plane by assimilating the solute travel times, instead of the concentration values, thus avoiding the need for a petrophysical law. The methodology is applied to both a synthetic and a real test case and gives a satisfactory retrieval of the K vertical distribution, as well as of the solute evolution. The performance of the method depends on the distance between the control plane and the injection source.

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MS46

A Data Assimilation Framework for Fully Coupled Hyperresolution Subsurface - Land Surface Models

Data assimilation (DA) is increasingly applied to not only update states of terrestrial system models, but also parameters. We compared different DA methodologies for joint state-parameter estimation for (1) saturated groundwater flow problems and (2) 1D land surface model columns. Experiments with 3D land surface models and large scale coupled subsurface- land surface models show the feasibility of the approach, and the current limitations and challenges.

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MS46

Recent Advancements in Data Assimilation Through EnKF Coupled with Moment Equations of Groundwater Flow

We discuss the key elements of a novel data assimilation technique we propose that is grounded on coupling the EnKF algorithm with the moment equations (MEs) of groundwater flow. Accuracy and feasibility of the approach are successfully tested and compared against its more traditional (Monte Carlo based) counterpart through a suite of synthetic studies and by way of a field-scale application

performed in an alluvial aquifer.

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MS46

Groundwater Flow Data Assimilation with a Reduced-Order Model Based on Stochastic Moment Equations

We present a computationally efficient methodology to estimate the spatial distribution of heterogeneous hydraulic conductivity fields in random geologic media using a Monte Carlo-based data assimilation (DA) approach. The computational burden associated with the forecast step of the DA scheme is reduced by projecting the groundwater flow equation into the space of few basis functions. These basis functions are obtained from the solution of the equations satisfied by the ensemble moments of groundwater flow.

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MS46

Iterative Ensemble Smoothers in the Annealed Importance Sampling Framework

Iterative ensemble techniques for solving inverse problems has recently gained a lot of interest in many geophysical communities. Although several variants exist, we focus on the ensemble smoother with multiple data assimilation (ESMDA). The first part of this study discuss the similarity between the iterative smoother and other existing techniques such as particle flow and annealed importance sampling. The second part is devoted to how we can use a sequential Monte Carlo sampler in combination with an annealing process to weight-correct the iterative sampling procedure and discuss possible approximations in large scale models.

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MS46

Estimation of a Spatially Distributed Reservoir Compressibility by Assimilation of Ground Surface Displacement Data

Fluid extraction from producing hydrocarbon reservoirs is one of the most frequent causes of anthropogenic land subsidence. A geomechanical model is used to predict the land surface displacements above a gas field where displacement observations are available. An ensemble-based data assimilation (DA) algorithm is implemented that incorporates these observations into the response of the geomechanical model. The calibration focuses on the uniaxial vertical compressibility CM which is assumed heterogeneous within the reservoir.

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MS47

A Stochastic Bulk Rate Parameterization of Cloud Microphysical Processes Driven by a Turbulent Collision Kernel

Collision and coalescence of cloud droplets to form rain droplets is a poorly understood area of cloud microphysics. Detailed models are prohibitively expensive. Various bulk models have been proposed, but require an assumed droplet distribution and rely on ad-hoc parameters. A stochastic bulk rate parametrization that avoids the use of any specific apriori distribution and includes only physically meaningful parameters is presented. A droplet distribution is assumed to exist and to have a spectral mean. Values of physically meaningful parameters are acquired from data. This new parametrization, possibly the first stochastic one, can accommodate realistic turbulent kernels. Results are presented.

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MS47

A Normal Mode Perspective of Intrinsic Ocean-climate Variability

Observations of the sea surface temperature field over more than a century indicate that there is pronounced variability in the climate system. Understanding the mechanisms of this variability is crucial to determine the role of ocean heat content variations in past and future climate changes. When a steady background state in an ocean-climate model is slightly perturbed, the long-time response is determined by the spatial patterns of the normal modes. Here, the type

and patterns of normal modes for a range of different equilibrium states in a hierarchy of ocean-climate models are presented. The rather elegant organization of these normal modes is demonstrated and prototype physical mechanisms explaining patterns of sea surface temperature variability based on these normal modes are provided.

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MS47

Carbon-weather Data Assimilation

Abstract not available at time of publication.

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MS47

Modeling and Evaluation of Hurricane Storm Surge Mitigation

Recent hurricane events in the Gulf of Mexico have demonstrated the vulnerability of coastal populations and infrastructure to hurricane storm surges. The authors have been at the forefront in the development of the Advanced Circulation (ADCIRC) storm surge model. This finite element model has been used in design/planning mode prior to the hurricane season, in predictive mode as storms approach land, and in hindcasting mode after the event. We present recent results of Hurricane Ike validation, as well as proposed structural gates and levees constructed to mitigate the effect of storm surges on significant areas such as Galveston Bay and the Houston Shipping Channel.

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MS47

Quantifying Inter-annual to Decadal Uncertainty Related to Initial Ocean Conditions

Smith et al. (2012) discuss the importance of initial conditions on long time scale forecasts and Krger et al. (2012) and Matei et al. (2012) illustrate how various reanalysis products influence decadal outcomes. In this talk we discuss the next steps that are necessary in the quantification of uncertainty: how to comprehensively quantify the downstream forecast uncertainty, as it relates to initial condition uncertainty, in a statistically rigorous manner. We present some early outcomes of the research.

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MS47

Global Warming Hiatus and AMOC Variability

Atlantic Meridional Overturning Circulation (AMOC), is also called the Great Heat Conveyor Belt. When AMOC speeds up it transports more heat and salinity from the subtropical Atlantic to the sub polar latitudes of the North Atlantic, where it sinks. The warm water melts ice in the polar latitudes; the fresh water dilutes the salty water and slows down the sinking. This negative feedback mechanism is thought to be responsible for the existence of a 60-70 year cycle in AMOC. We present underwater data of heat, salinity and AMOC overturning rate to reveal how this mechanism works in the real world, and suggest that the current hiatus in global warming is caused by this AMOC variability.

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MS48

Global-local Multiscale Model Reduction for Flows in Heterogeneous Porous Media

We combine discrete empirical interpolation techniques, global mode decomposition methods, and local multiscale methods, such as the Generalized Multiscale Finite Element Method (GMsFEM), to reduce the computational complexity associated with nonlinear flows in highly-heterogeneous porous media. To solve the nonlinear governing equations, we employ the GMsFEM to represent the solution on a coarse grid with multiscale basis functions and apply proper orthogonal decomposition on a coarse grid. Computing the GMsFEM solution involves calculating the residual and the Jacobian on the fine grid. As such, we use local and global empirical interpolation concepts to circumvent performing these computations on the fine grid. The resulting reduced-order approach enables a significant reduction in the flow problem size while accurately capturing the behavior of fully-resolved solutions. We consider several numerical examples of nonlinear multiscale partial differential equations that are numerically integrated using fully-implicit time marching schemes to demonstrate the capability of the proposed model reduction approach to speed up simulations of nonlinear flows in high-contrast porous media.

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MS48

Residual-driven Online Generalised Multiscale Finite Element Methods

The construction of local reduced-order models via multiscale basis functions has been an area of active research. In this talk, we present online multiscale basis functions which are constructed using the offline space and the current residual. Online multiscale basis functions are constructed adaptively in some selected regions based on our error indicators. We derive an error estimator which shows that one needs to have an offline space with certain properties to guarantee that additional online multiscale basis function will decrease the error. This error decrease is independent of physical parameters, such as the contrast and multiple scales in the problem. The offline spaces are constructed using Generalized Multiscale Finite Element Methods (GMsFEM). We show that if one chooses a sufficient number of offline basis functions, one can guarantee that additional online multiscale basis functions will reduce the error independent of contrast. We note that the construction of online basis functions is motivated by the fact that the offline space construction does not take into account distant effects. Using the residual information, we can incorporate the distant information provided the offline

approximation satisfies certain properties. In the talk, theoretical and numerical results are presented. Our numerical results show that if the offline space is sufficiently large (in terms of the dimension) such that the coarse space contains all multiscale spectral basis functions that correspond to small eigenvalues, then the error reduction by adding online multiscale basis function is independent of the contrast. We discuss various ways computing online multiscale basis functions which include a use of small dimensional offline spaces. The research is supported by Hong Kong RGC General Research Fund (Project 400411).

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MS48

Generalized Multiscale Finite Element Method

In this talk, I will discuss multiscale model reduction techniques for problems in heterogeneous media. I will focus on recently proposed methods that are based on Multiscale Finite Element Method (MsFEM). The main idea of this approach is to systematically incorporate the small-scale information into multiscale basis functions. These methods are intended for multiscale problems without scale separation and high contrast. I will discuss the issues related to multiscale basis construction and a number of applications. I will also discuss some applications to parameter-dependent problems.

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MS48

Algebraic Multiscale Method for Fractured Porous Media

An accurate and efficient algebraic multiscale method is developed for naturally fractured porous media, with a wide range of fracture length scales and fracture-matrix conductivity contrasts. Local basis functions for both matrix and fractures are solved to construct fracture-matrix coupled multiscale coarse system. Combined with a second stage smoother, our development leads to an iterative multiscale strategy for heterogeneous fractured media. Several numerical studies illustrate applicability of our method for real field studies.

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MS48

Fast Uncertainty Quantification of Two-phase Flow and Transport with Multi-level Monte Carlo

Multilevel Monte Carlo (MLMC) combines traditionally a multigrid technique with Monte Carlo (MC) sampling to arrive at an MC simulation framework that is substantially faster than conventional MC. Here, we apply instead of grids of different resolution a hierarchy of solution methods of different accuracy. In the context of two-phase flow and transport, we demonstrate that the resulting solver MLMC leads like traditional MLMC to significant speedups while offering greater flexibility in certain applications.

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MS48

Spatiotemporal Adaptive Methods for Multiphysics Modeling

We discuss how Multiscale methods, which have been devised to efficiently solve large reservoir models, provide an effective framework to deal with multiphysics problems. Indeed, they allow using different physical descriptions at different scales and adapting the spatiotemporal resolution to the problem of interest. We focus on the Multiscale Finite Volume method, which is based on a numerical volume-averaging paradigm and can be easily applied to different systems of conservation equations.

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MS49

Coupling Deformation and Flow in Fractured Poroelastic Materials

We introduce a coupled system of PDEs for the modeling of the fluid-fluid and fluid-solid interaction in a fractured, poroelastic material. The fluid flow in the fracture is modeled by a lower-dimensional equation, which interacts with surrounding rock matrix and the fluid it contains. To determine the mechanical and hydrological equilibrium of the system numerically, we combine an XFEM discretization for the rock matrix deformation and pore pressure with a lower-dimensional grid for the fracture. The resulting coupled discrete problem is solved using a substructuring method. Analytical aspects of the proposed procedure are discussed and illustrated with numerical examples in two and three dimensions.

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MS49

Iterative Methods for Coupled Flow and Geome-

chanics for Fractured Porous Media

Fractures play an important role in determining the flow profile and at the same time are vulnerable regions for the mechanical deformations. We consider an iterative scheme for solving a coupled mechanics and flow problem in a fractured poroelastic medium. We provide an iterative scheme to solve the coupled problem and our scheme is an adaptation due to the presence of fractures of a classical fixed stress-splitting scheme. We prove that the iterative scheme is a contraction in an appropriate norm. Moreover, the solution converges to the unique weak solution of the coupled problem. We also provide multi rate algorithms and their analysis for such problems.

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MS49

Phase Field Modeling for Fracture Propagation

In this talk, we consider phase-field-based fracture propagation in elastic and poroelastic media. The main purpose is the development of a robust and efficient numerical scheme. To enforce the entropy condition; namely, crack irreversibility, we use a robust primal-dual active set strategy. This is merged with the outer Newton iteration for the variational inequality of the fully-coupled nonlinear partial differential equation system, resulting in a single, rapidly converging nonlinear iteration. In addition, it is well known that phase-field models require fine meshes to accurately capture the propagation dynamics of the crack. Because traditional estimators based on adaptive mesh refinement schemes are not appropriate, we present a predictor-corrector scheme for local mesh adaptivity to reduce the computa- tional cost. Our proposed approach is substantiated with different numerical tests in two and three dimensions considering crack propagation in elastic media as well as multiple pressurized fractures in heterogeneous media. Collaborators: Mary F. Wheeler, Thomas Wick, Timo Heister

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MS49

Modeling of Quasi-static Hydraulic Fracture Propagation in Porous Media Using XFEM

We present a numerical model in 2D that describes hydraulically driven fracture growth. The model is based on the theory of poroelasticity and simulates the propagation of a single embedded fracture in a fully saturated, linear elastic, isotropic, porous material. Fluid flow in the open flow in the fracture is approximated by a parallel plate model. The numerical model is set up using Finite Elements and the fracture is described using the Extended Finite Element Method (XFEM). We discuss implantation of the interface conditions and show test cases.

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MS49

An Xfem Approximation of Coupled Flow and Mechanics in Fractured Rocks

XFEM are often used in the simulation of fracture mechanics. In this work we employ XFEM also to the discretization of the flow problem, so that grids can be set irrespectively of the position of fractures thanks to suitable enrichment functions. Inside the fractures, whose aperture depends dynamically on the effective normal stress, flow is computed by a suitable reduced model coupled with the flow in the surrounding porous matrix.

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MS50

Toward Stochastic Nonlinear Wave Models

The use of deterministic simulations for marine applications is a common practice in coastal and off-shore engineering. In recent years, we have proposed a i) massively parallel and ii) high-order numerical strategies for highly efficient and accurate prediction of wave propagation and wave kinematics and iii) a stochastic formulation for wave propagation. In this talk, we present our ongoing work on extending the previous works and applying it to the case of hydrodynamic loads on offshore wind turbines. We will outline the development of a new unstructured and robust spectral element method for the potential flow equations. The model is aimed at large-scale wave propagation in marine settings with complex geometric structures. The computational methods are applied to estimate the uncertainties in the hydrodynamic loads acting on the monopile of the IAE1s OC3 Phase 1 test case. Here uncertainties in the input data (e.g. bathymetry, wave spectra, geometry) are investigated using traditional and novel uncertainty quantification techniques. The objective of the study is to combine and deliver new advanced methodologies for efficient, systematic and rigorous engineering analysis.

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MS50

Harbour Modelling Via Depth Averaged and Non-Hydrostatic Models: Comparison and Validation

In this work a numerical study of the wave conditions in the old Venetian harbor in Chania, Crete in Greece, is presented using two numerical models/codes, namely the COULWAVE code and the TUCWave one. Field measurements are also used to validate the simulations. In the well-established COULWAVE code, the 2D fully nonlinear weakly dispersive Boussinesq-type equations of Wei at al. (1995) are solved. The numerical model uses a predictor-corrector scheme to march forward in time and a Finite Volume (FV) solver on structured meshes. The resulting scheme is of fourth-order of accuracy, both in space and time. In the TUCWave code the 2D weakly nonlinear weakly dispersive Boussinesq-type equations of Nwogu (1993) are solved by implementing a novel high-order accurate, in space and time, well-balanced FV numerical method on unstructured triangular meshes. A MUSCL-type reconstruction technique is implemented for enhancing the spatial accuracy while a strong stability preserving Runge-Kutta method is used for the time stepping. Here we examine the contribution of harbor resonance in the excitation of the Venetian harbor basin during typical winder storms. An extensive comparison of the two models is performed under the same conditions obtained from the field measurements.

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MS50

Integrated Coastal and Ocean Process Modeling for Management of Coastal Flooding and Morphological Changes

This paper presents applications of integrated coastal and ocean process modeling for management of coastal flooding and morphological changes induced by waves, storm surges, sediment transport, and sea level changes. It emphasizes the advancement of the integrated modeling to simulate and predict hydrodynamic and morphodynamic processes in coasts and estuaries. This paper provides engineering application examples for comprehensive impact assessment of coastal flooding and erosion due to combined hazardous storm conditions in coasts.

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MS50

Spectral Collocation Simulation of Non-Periodic Long Waves in Nonlinear Dispersive Systems

We are concerned with collocation methods based on Hermite and Laguerre functions in order to solve Cauchys problems attached to nonlinear wave equations with nonlinear (regularized long-wave) or linear dispersion (KdV, Nonlinear Schrdinger, Gordons equations, etc.) on infinite domains. We avoid the domain truncation or periodicity and use the scaling parameter hidden in these methods in order to get accurate conservation of some time invariant and to capture a large picture of the wave propagation.

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MS50

Coupling of Non-hydrostatic Models 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 this talk we will address the problem of coupling 1D, 2D and 3D non-hydrodstatic and hydrostatic models.

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MS50

Sensitivity Analysis Via Anova Decomposition for Wave Runup on Complex Bathymetries

We use uncertainty quantification tools to study the sensitivity wave runup to variations of wave amplitude, slope, and friction coefficient. Sensitivity indexes are computed from an Analysis of Variance based on a non-intrusive polynomial chaos method (Crestaux-LeMaitre-Martinez, 2009). To guarantee the repeatability of the experiments, two independent numerical codes are used, developed in (Ricchiuto, JCP 2015) and (Nikolos and Delis, 2009), respectively, and several 2D and 3D inundation bechmarks are used to investigate runup physics.

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MS51

A Multilevel Monte Carlo Method for Estimating Failure Probabilities of Two-Phase Flow Systems

This talk presents a multilevel Monte-Carlo method for computing failure probabilities of subsurface two-phase flow systems for carbon dioxide storage. We study sweep efficiency and breakthrough time as indicators for storage capacity, and denote by failure the events that these are below critical values. The flow is governed by the Buckley-Leverett equation, and the permeability field is modeled with uncertainty. We apply a multilevel Monte-Carlo method specialized for failure probabilities to reduce the computational effort.

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MS51

Distribution Functions of Water Saturation for Stochastic Nonlinear Two-Phase Problems

We give an analytical expression for the one-point cumulative distribution and probability density functions of the water saturation for the stochastic Buckley-Leverett problem with uncertainty in porosity and total Darcy flux. With the use of a streamline approach and appropriate random processes, the one-point distributions can be derived exactly, leading to any one-point statistics. We provide comparisons with Monte Carlo simulations and low order approximations to illustrate the performance of the method.

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MS51

A Stochastic Galerkin Method for Two-Phase Flow in Heterogeneous Porous Media

We consider the dynamics of two-phase flow in a two-dimensional heterogeneous porous medium with randomly located interfaces. In the deterministic case discontinuities of the flux function occur due to the change of the material parameters. Based on the capillarity-free fractional flow formulation a hybrid Stochastic Galerkin finite volume method (HSG-FV) is presented. The classical polynomial chaos expansion is extended by a multi-element discretization. This yields a weakly coupled deterministic system which allows for efficient parallelization.

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MS51

Dimension Reduction with Inverse Regression for High-dimensional Stochastic Modeling of Subsurface Flows

Stochastic modeling of subsurface flows often involves many uncertain parameters, such as permeability on each grid-block, and hence suffers the "curse of dimensionality". This difficulty is alleviated if we can represent the high-dimensional parameter vector on a lower-dimensional subspace. The inverse regression method greatly reduces model dimensionality while preserving the nonlinear uncertainty propagation from model parameters to the quantity to be predicted, and is shown to be more effective than traditional methods like K-L expansion.

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MS51

Uncertainty Quantification Using Transformed Probabilistic Collocation Method for Strongly Nonlinear Problems

In uncertainty quantification, the traditional probabilistic collocation method (PCM) may produce nonphysical oscillation and inaccurate estimation in case of strong nonlinearity/unsmoothness. To address this issue, we develop a new transformed probabilistic collocation method (TPCM), in which model response is represented by the location or arrival time of a particular response value. We show that the TPCM is more accurate than the PCM and is much more efficient than the Monte Carlo method.

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MS51

Stochastic Galerkin Methods and the Problem of High Stochastic Dimensionality in CO2 Storage

The complexity of numerical simulation of transport of CO_2 in subsurface storage formations necessitates simplified-physics models that are subject to significant uncertainty in modeling assumptions and material parameters. A stochastic Galerkin solver for stochastic CO_2 transport is presented along with numerical results and analysis of the most prominent sources of uncertainty. Special care is needed to accurately capture quantities of interest, e.g., probability of CO_2 leakage to the atmosphere and groundwater resources.

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MS52

Introduction to Terzaghi Stress Principle and a Theoretical Formulation Based on Total Differentials

Here we present results on the derivation of the Terzaghi Stress Principle theoretically using total differentials from a thermodynamic framework. We use thermodynamic definitions of the drained and unjacketed compressibilities and total differentials to theoretically determine how the total pressure relates to strain and changes in fluid pressures. We show that under simplifying assumptions we recover the varying forms of the Biot coefficient for saturated porous media and the bishop parameter for partially saturated porous media. Results are compared with other approaches such as the differential approach of Wang (2000), and the mixture theoretical approach of Coussy (1995) and Borja (2006),

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MS52

Role of Sorption in Effective Stress in Variably Saturated Soil

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MS52

A Multi-Scale Form of Terzaghi's Effective Stress Principle for Unsaturated Expansive Clays

A multi-scale approach of Terzaghis effective stress principle for unsaturated swelling clays is presented that is rigorously derived by homogenization starting from micro- and nano-mechanical analyses. The resulting macroscopic elastic stress captures coupling between electrochemical disjoining forces at the clay platelet scale and capillary effects at the clay cluster scale. Numerical simulations allow conclusions about water transfer between intra- and interparticle pores during wetting and thus about the evolution of the resulting swelling pressure.

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MS52

An Analytical Approach to Link Effective Stress, Shear Strength and Moisture at the Micro-scale

The link from water content and water tension to effective stress and shear strength is unclear. Particle contact forces and the effect of a small amount of water on them are formulated through analytical calculations of probability and geometry, for identical rigid spheres. Findings are compared to triaxial shear test results on specimens of uniform glass spheres. The effect of water is found to be different from applying an external isotropic stress to the soil.

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MS52

Effective Stress Tensor in Unsaturated Pendular-State Granular Media

The expression of a proper effective stress tensor in unsaturated granular media has been a longstanding issue essentially because of the difficulty to account for interfacial effects. While the analysis of unsaturated conditions goes beyond Terzaghi's effective stress, the commonly used Bishop's effective stress is fraught with many issues, one of them being empirical. In this connection, we derive a single effective stress tensor that encapsulates evolving liquid bridges, interfaces, particle packing, and water saturation through a micromechanical analysis of force transport in an unsaturated pendular-state granular material. Discrete Element Method (DEM) numerical simulations of triaxial compression tests of pendular-state granular samples at different matric suctions are conducted to verify the proposed effective stress equation.

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MS53

A Multi-stage Bayesian Prediction Framework for Subsurface Flows

In this talk, we discuss the development of computationally efficient procedures for subsurface flow prediction that relies on the characterization of subsurface formations given static (measured permeability and porosity at well locations) and dynamic (measured produced fluid properties at well locations) data. We describe a predictive procedure in a Bayesian framework, which uses a single-phase flow model for characterization aiming at making prediction for a two-phase flow model. The quality of the characterization of the underlying formations is accessed through the prediction of future fluid flow production.

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MS53

Efficient Numerical Methods for Simulating Surface Tension of Multi-component Mixtures with the Gradient Theory of Fluid Interfaces

Surface tension significantly impacts subsurface flow and transport, and it is the main cause of capillary effect, a major immiscible two-phase flow mechanism for systems with a strong wettability preference. We consider the numerical simulation of the surface tension of multi-component mixtures with the gradient theory of fluid interfaces. Major numerical challenges include that the system of the Euler-Lagrange equations is solved on the infinite interval and the coefficient matrix is not positive definite. We construct a linear transformation to reduce the Euler-Lagrange equations, and naturally introduce a path function, which is proven to be a monotonic function of the spatial coordinate variable. By using the linear transformation and the path function, we overcome the above difficulties and develop the efficient methods for calculating the interface and its interior compositions. Moreover, the computation of the surface tension is also simplified. The proposed methods do not need to solve the differential equation system, and they are easy to be implemented in practical applications. Numerical examples are tested to verify the efficiency of the proposed methods.

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MS53

Weak Galerkin Method for Steady Diffusion Problems with Highly Anisotropic Coefficients

In petroleum reservoir simulation, a family of control-volume methods has been developed for solving the general tensor pressure equation while satisfying flux-continuous, local mass conservative and discrete maximum principle. Weak Galerkin method is a type of finite element method which can meet all these requirements under general finite elements framework. In the talk, we will compare the finite volume method with Weak Galerkin finite element method specifically on high anisotropic diffusion problem. Second-order convergence rate and monotonicity of Weak Galerkin method are verified with numerical examples.

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MS53

Weak Galerkin Finite Element Methods for Darcy Flow on Hexahedral Meshes

For some real applications (petroleum reservoir simulations, in silico for biological and medical problems), hexahedral meshes are natural choices for spatial discretization of 3-dim irregular domains. In this talk, we present preliminary results of developing weak Galerkin finite element methods for solving the Darcy equation on hexahedral meshes. In particular, we shall discuss these issues: error estimates, algorithm implementation and integration with the visualization package VisIt, numerical experiments, and comparison with results on tetrahedral meshes. This is a joint work with Farrah Sadre-Marandi (Colorado State University) and Min Yang (Yantai University, China).

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MS53

Multi-Dimensional Eulerian-Lagrangian Advection Schemes using Quadrature

We develop an Eulerian-Lagrangian scheme to solve linear advection problems, which in theory have no CFL constraint. We integrate mass using a quadrature rule, after converting cell average masses into high order accurate values at quadrature points. We develop a new WENO reconstruction technique for the primitive function on several local stencils, weight them based on the smoothness of the solution to avoid shock-like discontinuities, and differentiate. Numerical results demonstrate the capabilities of the scheme.

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MS53

Approximate Solution to the Boussinesq Equation Near A Well

Flows near wells in unconfined aquifers are commonly modeled by the Boussinesq equation. We analyze the recharge by well of an initially dry aquifer. Using similarity variables we reduce the original problem to a boundary-value problem for a nonlinear ordinary differential equation. We construct an approximate analytical solution to this problem having a singular term, to model behavior near the wellbore, and a polynomial part, to approximate the behavior in the far field.

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MS54

The Importance of Physical and Numerical Approximations in Hydraulic Methods for Aquifer Characterization

Inversion of hydraulic data for purposes of transport modeling is a nonlinear, ill-posed Bayesian inverse problem in which the forward model may be extremely expensive due to model extent, model transience, and model nonlinearities. We will review approaches to reducing the computational burden of this problem. We will focus on useful physical and numerical approximations for reducing the expense of forward model evaluations, in addition to effective methods for data or parameter reduction.

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MS54

Parallel Preconditioner Updates in Parameterized Nonlinear Inverse Problems

We consider combinations of preconditioner updates and recycling Krylov subspace methods that yield fast convergence for parameterized systems of equations and allow efficient fine-grained parallel implementations. We consider applications in UQ for inverse problems.

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MS54

Joint Probabilistic Inference of Multi-Gaussian Conductivity Fields and Their Associated Variograms from Indirect Hydrological Data

We present a Bayesian approach for simultaneous estimation of high-dimensional conductivity fields and associated variograms. Our approach merges periodic embedding with dimensionality reduction to decouple the variogram from the random numbers, and facilitate MCMC simulation. Using the Matérn variogram allows for inference of the field smoothness. Conditioning on direct measurements is straightforward. We illustrate our method using a synthetic flow and transport experiment involving a 10,000-dimensional conductivity field, and provide comparison against other state-of-the-art approaches.

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MS54
Inversion of the Co-seismic Slip from GPS Data

Remote sensing and geodetic measurements are providing a new wealth of observational data that have the ability to improve our understanding of co-seismic rupture and slow slip events in subduction zones. We formulate a Bayesian inverse problem to infer the slip distribution on the plate interface using an elastic finite element model and GPS surface deformation measurements. We present an application to the co-seismic displacement during the 2012 earthquake on the Nicoya Peninsula in Costa Rica, which is uniquely positioned close to the Middle America Trench and directly over the seismogenic zone of the plate interface. From this study we identify a locked patch that is likely to release stress in the future.

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MS54
Model Reduction and Ensemble Kalman Filtering

Ensemble versions of Bayesian inference are convenient for estimating unobservable spatially variable properties from measurements of related state variables. Ensemble methods are especially usefu when the properties have complex spatial structures that do not conform to Gaussian descriptions. However, ensemble methods can be time consuming for high-dimensional problems. This paper describes a reduced- order approach to ensemble characterization that is particularly well suited for subsurface flow and transport problems. It uses a truncated discrete cosine transform to reduce the dimensionality of spatially variable time-invariant model parameters and a nonlinear extension of principle orthogonal decomposition to reduce the dimensionality of dynamic model states. The resulting nonlinear reduced-order model can be included in the forecast step of a reduced-order ensemble Kalman filter. We illustrate these concepts in a subsurface solute transport problem, comparing the ensembles produced by full- and reduced-order filters. The reduced-order Kalman filter does at least as well as the full-order filter in characterizing a dynamic solute plume, even though its augmented state dimension is only 2% of the dimension of the full-order state. This substantial increase in efficiency implies that 1) a reduced-order filter with the same ensemble size as its full-order counterpart can give comparable performance for orders of magnitude less computational effort or 2) it can use a much larger ensemble for the same computational effort. The possibility of substantial increases in ensemble size could lead to performance improvements through reductions in sampling error and in the rank of the ensemble null space. Also, a reduced-order model similar to the one described here could be used in ensemble real-time control applications, where it can decrease the effort required for both characterization and control.

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MS54
Statistical Tests for L_1 Regularization Parameter Selection

Choice of regularization parameter for the L_1 norm is an open question and here we view the term as the result of maximizing the probability parameters errors are from an exponential distribution. In this case the regularization term should be weighted with the mean of the error in the initial guess, which is unknown. We use a statistical test to estimate the mean, and hence find a regularization parameter. The approach will be demonstrated on an inversion of resistivity data in the near surface.

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MS55
Effective Large Scale Simulations of Discrete Fracture Network Flows with a Pde-Constrained Optimization Approach

Focusing on the Discrete Fracture Network model for fractured media, we consider a PDE-constrained optimization approach for flow simulations which allows for non-conforming grids, i.e. meshes on the fractures are required to be neither conforming each other, nor conforming to their intersections. The method is therefore well suited for dealing with large scale complex geometries, and it is well suited for parallel implementation. Effectivity of the method on rather complex networks will be shown.

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MS55
Upscaling Techniques for Highly Fractured Porous Media with Non-Matching Discretization

The aim of this contribution is to present a novel methodology for a flow-based upscaling technique applied to highly fractured reservoirs. To derive the upscaled properties we solve local problems where the numerical scheme adopted removes parts of the geometrical constraints for the grid generation. A sub-region method is considered to enhance the intra porous matrix communication. Effectiveness of the method in comparison to more classical implementations is proved through synthetic but representative problems.

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MS55

HPC Discrete Fracture Network Modeling for Subsurface Flow and Transport Applications

A workflow, dfnWorks, generates discrete fracture networks (DFN) of planar polygons, creates a high quality conforming Delaunay triangulation of the intersecting DFN polygons, assigns properties (aperture, permeability) using geostatistics, sets boundary and initial conditions, solves pressure/flow in single or multi-phase fluids (water, air, CO2) using the parallel PFLOTRAN, and solves for transport using Lagrangian particle tracking. Applications are shown for nuclear waste repository, CO2 sequestration and hydraulic fracturing and extraction of unconventional hydrocarbon resources.

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MS55

Adaptive Mesh Refinement for Modeling Flow Through Three-Dimensional Fracture Networks

Fractured formations with low matrix permeability are sometimes modeled using only a fracture network, with the matrix contributions neglected completely. In this work we present an adaptive mesh refinement (AMR) technique applicable to three-dimensional fracture networks. The method is illustrated by simulating transport in complicated fractured models. We show that our AMR procedure can effectively reduce the size of the discrete model by introducing resolution in the active parts of the network.

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MS55

An Integrated Approach To Upscaling And History Matching Of Fractured Reservoirs

Fracture statistics are commonly used to generate macroscale parameters such as permeability. The upscaled parameters are often adjusted using EnKF or similar methods, where simulator predictions are compared with field data. We show that these adjustments may be inconsistent with the underlying fracture structure, under certain conditions. We propose a new workflow to eliminate the problem, where the upscaling procedure is integrated into the history matching workflow. Synthetic field case examples are provided.

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MS55

Imposing Convergence Constraints on Multiscale Mehods for the Efficient Solution of Multiphase Flow Through Naturally Fractured Porous Media

This work investigates the possibility of using an incompletely converged pressure solution in the sequentially implicit loop, traditionally used to simulate multiphase flow through porous media. This is made possible through the Multiscale Finite Volume (MSFV) formulation, which was recently extended to include fully integrated basis functions which account for contributions from wells and fractures [Tene et al, SPE RSS 2015]. Here, we take this method one step further towards multiphase flows, by adding a conservative flux reconstruction stage and pairing it with a fine-scale transport solver. In our experiments we monitor the convergence behaviour while adaptively varying the tolerance level for the pressure solution. Finally, we conclude that only few iterations of the multiscale pressure solver are sufficient to obtain results which are meaningful for decision-making, especially given the fact that, in practice, the reservoir specification is subject to geological uncertainties.

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MS56

Dynamically Adaptive Storm Surge Simulations with a Slope-Limited Discontinuous Galerkin Model

Discontinuous Galerkin models have recently been used to produce accurate and robust storm surge simulations. The computational effort, however, is still its major weakness. In order to reduce the latter, we introduce a dynamically adaptive triangular mesh with problem-dependent refinement indicators to resolve local features. Our nodal slope-limited Bernstein approach guarantees a correct handling of wetting and drying. Near-realistic test cases demonstrate the potential of our non-uniform mesh.

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MS56

Discontinuous Galerkin Methods for Coupled Hydrologic/Hydrodynamic Flows

Tropical storms lead to rainfall runoff and storm surge which may interact during a storm event, especially in low-lying coastal areas. Overland flow, rainfall runoff into channels and streams, and storm surge occur at different spatial/temporal scales, and may be modeled using coupled 1D/2D and possibly 3D hydrodynamic models. In this talk, we will discuss a discontinuous Galerkin based framework for modeling overland flow and rainfall runoff through a network of connected channels.

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MS56

Atmospheric Simulations on the Sphere with the Nonhydrostatic Unified Model of the Atmosphere (NUMA): Advances Using Parallel Grid Generation with P4est

The Non-hydrostatic Unified Model of the Atmosphere (NUMA) developed at the Naval Postgraduate School is the dynamical core inside the Naval Research Laboratorys next-generation weather prediction system NEPTUNE. Recent advances include interfacing NUMA with the p4est library, which allowed for parallel grid generation. The results of 3D unstable jet simulations on the sphere using 2D mesh decomposition and 1D IMEX time integration will be presented, along with scalability results up to 1,555,200 million MPI ranks.

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MS56

A Trace Fem for a Coupled Transport and Diffusion over Surfaces and in a Bulk

In this talk, we consider a system of advection-diffusion equations in a bulk domain coupled to an advection-diffusion equation on an embedded surface. Such systems of coupled partial differential equations arise in, for example, the modeling of transport and diffusion of surfactants in two-phase flows. The model considered here accounts for adsorption-desorption of the surfactants at a sharp interface between two fluids and their transport and diffusion in both fluid phases and along the interface. We present a well-posedness analysis for the system of bulk-surface equations and introduces a finite element method for its numerical solution. The finite element method is unfitted, i.e., the mesh is not aligned to the interface. The method is based on taking traces of a standard finite element space both on the bulk domains and the embedded surface. The numerical approach allows an implicit definition of the surface as the zero level of a level-set function. Optimal order error estimates are proved for the finite element method both in the bulk-surface energy norm and the L^2-norm. The analysis is not restricted to linear finite elements and a piecewise planar reconstruction of the surface, but also covers the discretization with higher order elements and a higher order surface reconstruction.

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MS56

Unfitted Finite Element Methods Using Bulk Meshes for Surface Partial Differential Equations

In this talk I will introduce a family of novel finite element methods for partial differential equations posed on surfaces. The key idea is that the finite element space is based on continuous piecewise linear finite element functions on a bulk triangulation which is independent of the surface. I will introduce both a sharp interface and narrow band version of the method for stationary problems and show how these methods can be combined to solve equations on evolving surfaces. I will present robust numerical analysis for a simple model problem and provide computational examples to show the flexibility and efficiency of the methods.

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MS56

Frozen Landscapes in Transition: Improving Predictions of Ice Sheet Stability in a Warming World by Numerical Modeling

We will present the FROZEN-project that has the overall aim to develop a numerical simulation tool for ice sheet modeling. Within a Finite Element Method framework, we develop a tool that allows for high-resolution ice simulation over large areas and time intervals up to 100 000 years, and features appropriate treatment of grounding line migration at an ice sheet's marine margin. This is done by the Ice Sheet Coupled Approximation Levels (ISCAL) method, that couples the full Stokes equations and a Shallow Ice Approximation [1], and by introducing a subgrid-scale model for grounding line migration. We will present the current status of the project and discuss its continuation.

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MS57

Some Recent Developments of Level Set Methods for Flow and Transport in Porous Media

Level set methods are useful numerical tool for capturing evolving interfaces in computational modelling of processes that involve moving curves and surfaces. In this talk some applications of such methods will be discussed together with several recent developments that make such numerical methods robust enough to be applied in problems of flow and transport in porous media.

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MS57

Evolving Surfaces in Geodesy

We present evolving manifold approaches for geodetic applications, namely for building the computational grids in solving large-scale geodetic boundary value problems related to Earth gravity potential modelling, for filtering of Earth observation data given on closed surfaces as Earth topography or satellite orbits and for processing of digital terrain models.

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MS57

Evaluating Numerical Weather Prediction Data

Common numerical weather prediction models provide gridded data for various meteorological parameters in a certain temporal and spatial frame. We discuss methods to allow the comparison of different model outputs either to other model outputs for detecting general biases and consistency considerations, or to ground truth based on actual observations for quality evaluation. For the qualitative comparison of gridded data sets we focus on novel error measures based on optical flow algorithms.

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MS57

Modeling of Free Groundwater Table in a Coastal Aquifer in Northern Germany

The finite volume code d3f (distributed density driven flow), based on the UG toolbox, handles free surface groundwater flow using level set methods. The progress of application of d3f to a regional 3d model of a coastal aquifer near the German North Sea is presented, taking into account variable recharge, river discharge and the pumping wells of three waterworks. The objective is forecasting the impact of several scenarios to the seawater-freshwater interface.

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MS57

Derivation and Analysis of a Multiscale Model for Biofilm Growth in Porous Media

We consider the growth of biofilms made by bacteria within a saturated porous media and obtain in a level-set framework an upscaled model. By periodic homogenization we derive Darcy's law and modified transport equations with degenerating effective coefficients given by the evolving microstructure at the pore-scale. In case of non-degenerating coefficients, uniqueness and existence of strong solutions are shown up to possible closure of some pores.

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MS57

Fire and Ice: Evolving Interfaces in Magma and Ice Flows

Multi-phase interactions are fundamental to many questions in Earth science. Given the nonlinear nature of the governing equations, numerical methods play an important role in advancing our basic understanding and predictive capabilities of multi-phase flows. One important challenge in computational approaches for simulating geophysical flows is the accurate representation and tracking of interfaces between different phases. In this study, we focus on evolving interfaces in magmatic and ice flows to illustrate when and how interface dynamics can have profound influence on the overall behavior of the geophysical system.

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MS58

HPC Solutions for Long-Term Lithospheric Dynamics

High spatio-temporal resolution forward models of the mantle-lithosphere and crust are of industrial and societal interest. Over million year timescales, the lithosphere evolves as a highly viscous, incompressible non-linear fluid. To enable efficient 4D models, algorithmic and computationally scalable preconditioners are essential. Here I present a new FE methodology and multilevel preconditioner which exploits hardware characteristics of modern HPC facilities. Significant speedups compared to traditional methods are demonstrated through simulations of continental rifting and subduction.

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MS58

Greedy Algorithms for Regularization of Inverse Problems in the Geosciences

We present a new greedy algorithm for the regularization of ill-posed inverse problems in the geosciences. The particular features are: different kinds of basis functions (like spherical harmonics and radial basis functions) can by combined to inherit their particular advantages as the “best of both worlds”. The obtained iterative sequence of approximations is stable (also in the presence of noise) and converges to solutions with well-known theoretical justifications (Moore-Penrose inverse or Tikhonov-regularized normal equation).

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MS58

Localized Bandlimited Inversion of Planetary Magnetic-Field Data

When estimating planetary crustal magnetic fields from satellite data, the satellite altitude and noise limit the maximum achievable spatial resolution. For only locally available data, the conditioning of the crustal magnetic field inversion is exacerbated. We present a method that only solves for the well-conditioned components of the local crustal magnetic field inversion in an efficient way and estimate local magnetic field features from local high-quality satellite data for the Martian South Pole.

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MS58

The Treatment of Systematic Bias in Geomagnetic Inverse Problems

Given the excellent magnetic measurements available in the modern era from observatories and satellites, and most recently from the Swarm constellation, geomagnetic models are now striving to describe more subtle field sources. This requires a more robust treatment of noise, particularly systematic bias, which can drive estimation error more than larger variance zero-mean processes. A strategy to mitigate this bias is discussed which seeks to maximize signal-to-noise ratios of model parameter subsets within data subsets leading to improved field models.

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MS58

Inverse Modelling in Ionospheric Research

The Earth’s ionosphere is most important for radio wave propagation in space and between satellites and terrestrial observation sites. GPS observations, for instance, provide information on the slant total electron content which is the integral over the electron density along the ray path between transmitter and receiver. The estimation of the electron density is strongly underdetermined and an ill-posed inverse problem. For solving this problem we use data adaptive techniques based on B-spline series expansions.

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MS59

Fractal Analysis of Spontaneous Imbibition in Gas-water-rock Systems

Spontaneous imbibition is a ubiquitous natural and fundamental phenomenon existing in a variety of processes. Since first theoretical model for liquid moving through a horizontal capillary and then Lucas-Washburn (LW) equation were proposed, the static and dynamical problems connected with the penetration of a wetting liquid into a capillary or porous medium in contact with bulk liquid, have been investigated both analytically and experimentally. There was considerable controversy over the LW equation. For the spontaneous imbibition, some researchers modified the LW model by considering the geometrical shape of capillaries, the effect of tortuosity, and corrections relating to microstructure of rocks. But, these model predictions were not in good agreement with experimental data. It has been shown that the pore space and tortuous streamtubes/capillaries of natural porous media exhibit the fractal behavior. However, study of the spontaneous imbibition based on the fractal characters of porous media was limited. By introducing the fractal dimension for a tortuous capillary, analytical expression for time evolution of the height/weight of capillary rise is obtained. Based on the assumption that porous media are comprised of a bundle of independent different sized parallel capillaries, the spontaneous imbibition in porous media also can be analyzed. In particular, (1) The mass of imbibed liquid is expressed as a function of the fractal dimensions, the minimum and maximum hydraulic diameter of pores, and the ratio for minimum to maximum hydraulic diameters, porosity, fluid properties as well as the fluid-solid interaction. (2) the behavior of imbibed weight versus time is consistent with the LW equation, regardless of the imbibition in a single tortuous capillary and porous media. (3) An explanation from the effect of the convolutedness property of tortuous capillaries on the spontaneous imbibition is given.

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MS59

From Stokes-Cahn-Hilliard Equations to Darcy's Law for Two-Phase Flow in Porous Media Using Volume Averaging

A technique of local volume averaging is applied to a two-phase fluid mixture system and general equations are obtained which depict mass and momentum transport in porous media. Starting from the system of coupled Stokes-Cahn-Hilliard equations for incompressible two-phase fluid flow, the volume averaging is performed without significantly idealizing either the porous medium or the fluid mechanical relations. The resulting equations are generalized Darcy's law for two-phase flow with medium parameters resulted from the averaging procedure.

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MS59

Measuring and Upscaling Hydraulic Properties of Variably-Saturated Porous Media

Hydraulic properties of variably-saturated porous media are crucial for modeling multiphase flow and transport in many energy and environmental related applications. Upscaling small scale measurements to a suitable scale for numerical modeling has been a research focus for decades. Recent advances in nondestructive testing methods, such as neutron imaging, combined with new upscaling techniques have improved our capability to measure hydraulic properties and model multiphase flow and transport.

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MS59

DFN Modeling of Water Coning in Naturally Fractured Heavy Oil Reservoirs, and Comparison to Dual-Porosity Approach

We discuss a compositional Discrete Fracture Network (DFN) finite element model with capillarity and diffusion, and verify its performance by reproducing experimental data for water injection into a fractured stack at different rates. The agreement is excellent. We then simulate water coning in a densely fractured heavy oil reservoir with an underlying aquifer. The results are compared to those from a dual-porosity type representation for the fractures, which cannot capture all the relevant physics.

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MS59

Pore-Scale Modeling of Multi-Component Multi-Phase Flows

We consider the modeling and simulation of possibly compressible, partially miscible, fully compositional two-phase hydrocarbon systems using a diffuse interface model together with Peng-Robinson Equation of State (EOS). Our modeling scheme utilizes molar densities as the order parameters, and the approach is based on the coupling of the Navier-Stokes equation for flow and a Cahn-Hilliard-like equation with Peng-Robinson chemical potentials for phase behaviors of hydrocarbon fluids. Our modeling approach can be used to predict volumetric behaviors, solubility, miscibility, and interface tensions of common hydrocarbon liquid (oil) and vapor (gas) accurately. Moreover, the entire modeling approach is self-consistent and complies with the principles of non-equilibrium thermodynamics including the second law of thermodynamics, the maximum entropy production principle (MEPP) and the Onsager reciprocity principle. The continuum model is formulated mathematically in a coupled nonlinear partial differential equation (PDE) system, which usually does not have analytical solutions. We thus propose an efficient numerical solution of the modeling system, focusing on discrete energy stability, local mass conservation and numerical accuracy. For spatial discretization, we apply a finite volume-based method to turn the partial differential equations (PDE) into an ordinary differential equation (ODE) system. For temporal discretization, the resultant ODE system is decoupled by using an asymmetric splitting scheme, and then integrated in time using a semi-implicit marching scheme. In addition, targeting the specific features of each of the three terms in Peng-Robinson chemical potentials, we propose a convex splitting-based semi-implicit time scheme, which is proved to be unconditionally energy stable under certain conditions. We compare our computational results with laboratory experimental data reported in the literature, which have good agreement.

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MS59

A Probabilistic Collocation Eulerian-Lagrangian Localized Adjoint Method for Assessing CO2 Leakage Through Wells in Randomly Heterogeneous Prous Media

We develop a probabilistic collocation Eulerian-Lagrangian localized adjoint method for assessing CO2 leakage through wells in randomly heterogeneous porous media, by utilizing the intrinsic mathematical, numerical, and phys- ical properties of the mathematical model. We model the process in which CO2 is injected intbate, which depends on the pressure build-up in the aquifer due to injection and the buoyancy of CO2. The underlying Eulerian- Lagrangian framework has high potential to improve the efficiency and ac- curacy for the numerical simulation of complex flow and transport processes in CO2 sequestration. We note that the sparse grid probabilistic collocation framework, which adds computationally efficient uncertainty quantification functionality onto pre-existing Eulerian-Lagrangian methods in a nonintrusive manner and also provides a scalable framework to consider uncertainty in a straightforward parallel manner, sometimes yield nonphysical results such as negative vari- ance. We plan to conduct preliminary study on this issue and their possible remedies

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MS60

Multiscale Hybrid Models of Flow and Transport Through Complex Porous Media

Hybrid models combine pore-scale and continuum-scale representations. Desirable features of hybrid models are 1) 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, and 2) their flexibility in implementing the coupling boundary conditions. In this work, we construct criteria for adaptive hybridization and a non-intrusive non-overlapping hybridization scheme to model reactive flow through a chemically heterogeneous porous medium with complex structure.

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MS60

How to Charaterize Porosity from Image Processing

This talk aims at discussing how to characterize the porosity of media by means of image processing. We mainly focus on the problem of describing accuretaly the multi-scale information by means of geometric and/or statistical descriptors. These descriptors may be used for 3-D reconstruction and vizualisation. We will also discuss the problem of dealing with percolation properties regarding the connectedness of the poral space and how to modify this connectedness using image processing tools.

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MS60

Hybrid Reduced Models for Evolving Porescale Geometries

We consider algorithms which account how macroscale properties of porescale geometries such as permeability K change due to, e.g, biocementation, or other reactive transport and/or phase transitions. Our approach combines calculations of K for modifications of geometry generated with (i) "brute force" exhaustive search, (ii) stochastically generated representative modifications, and (iii) actual transient process simulations. We discuss the advantages and disadvantages of each approach.

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MS60

Computational and Experimental Study of Isolating Properties of Soil Mixtures at Pore and Core Scales in Environmental Applications

Computational modeling is applied to study isolating properties of mixtures of clays and sand which are used as sealing barriers of waste disposal sites. Core scale properties of 3D samples of soils are assessed by simulating flows at porescale and upscaling. Experimental measurements are used at porescale in order to provide realistic data describing geometry of mixtures, as well as to obtain core scale parameters to be compared with results of computations.

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MS60

Multiscale Reconstruction of Nano-Pore Geomaterials and Representative Sampling for Digital Rock Physics

Geomaterials containing nano-pores (shales and carbonate rocks) have become increasingly important for unconventional gas and oil resources and geological carbon storage. Accurate prediction of coupled geophysical and chemical processes in multiscale pore network systems requires realistic representation of pore structure and topology. In this work, we apply multiscale imaging techniques for characterizing pore structures at nano-to-centimeter scale and representative sampling of ensemble members for computationally efficient reconstruction of multiscale pore network for digital rock physics.

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MS61

Depth-Averaged Models for Debris Flows in Rugged Terrain

We have developed a mathematical model and software (D-Claw) for simulating landslides and debris flows, seamlessly from initiation to deposition. The depth-averaged model is a two-phase particle-fluid model incorporating principles from granular and soil mechanics. The result is a nonconservative hyperbolic system of five PDEs, similar to shallow-water models for free-surface flows in topography. The mathematical model, and the challenge of accurately incorporating topographic effects in steep and rugged terrain, will be described.

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MS61

Semi-Implicit Central-Upwind Scheme for Shallow Water Models with Friction Terms

I will introduce a new semi-implicit central-upwind scheme for the Saint-Venant system of shallow water equations with the Manning friction terms. In the case of very shallow water, for example, when the drainage of rain water is modeled, the friction terms become stiff and thus require a special treatment. We propose a new semi-implicit method, which is not only highly accurate and efficient, but also remains well-balanced and preserves positivity of the water depth.

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MS61

A Parallel, Terrain-Follow-Grid Transform for Integrated Surface and Subsurface Flow: Moving to Exascale Simulations over the Continental US

Interactions between surface and groundwater systems are well-established theoretically and observationally. While numerical models that solve both surface and subsurface flow equations in a single framework (matrix) are increasingly being applied, computational limitations have restricted their use to local and regional studies. As a step toward enabling integrated simulation over large extents and high spatial resolution, a terrain-following grid formulation (TFG) is presented for simulation of coupled variably-saturated subsurface and surface water flow. The TFG is introduced into the integrated hydrologic model, ParFlow, which uses an implicit, Newton Krylov solution technique. The analytical Jacobian is also formulated and presented and both the diagonal and non-symmetric terms are used to precondition the Krylov linear system. Using this TFG, efficient scaling to a large number of processors (16,384) and a large domain size (8.1 Billion unknowns) is shown. An integrated hydrologic simulation of surface and subsurface flow at high spatial resolution (1 km) over much of continental North America (6.3 million square km) is presented. This demonstrates the applicability of this formulation to high resolution, large spatial extent hydrology applications where topographic effects are important.

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MS61

Ice Sheet Dynamics: High-Order Approximation on the Sphere

Large ice sheets such as Antarctica play a significant role in climatology and, in particular, in sea level rise. Ice sheets behave like shear thinning fluids and can be modeled with nonlinear Stokes equations. In order to reduce the computational costs we use an high order approximation of the Stokes model that can be derived considering the ice sheet geometry as a shell. We compare results obtained using the Stokes model and its approximation.

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MS61

Modeling Shallow Water Flow on General Terrain

Shallow water equations are commonly used in many applications. Their formal derivation should account for curvatures of the terrain model. However this task is not well understood. We derive a general form of SWE accounting for terrain geometry by performing depth integration along normals to bed surface rather than to streamlines. We discuss by theoretical and numerical results the errors arising from this approximation as well as the role of curvatures in different applications.

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MS61

Bedload Sediment Transport on Gpu

In this work we propose a PVM path-conservative numerical scheme for the numerical simulation of bedload sediment transport. This first order scheme is extended by means of a MUSCL-type reconstruction operator in order to achieve second order accuracy on triangular meshes. The CUDA implementations of both numerical schemes are described, and some numerical tests with real applications are presented.

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MS62

Dynamic Earthquake Rupture Simulations on Non-planar Faults Embedded in 3D Geometrically Complex Heterogeneous Elastic Solids

Dynamic propagation of shear ruptures on a frictional interface in an elastic solid is a useful idealization of natural earthquakes. The corresponding initial boundary value problems are both numerically and computationally challenging. We present a high order accurate finite difference method for: a) enforcing nonlinear friction laws, in a consistent and provably stable manner, suitable for efficient explicit time integration; b) dynamic propagation of earthquake ruptures along non-planar faults; and c) accurate propagation of seismic waves in heterogeneous media with free surface topography.

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MS62

Goal Oriented Estimates for Interface Problems: Applications in Two Phase Transport Problems in

Heterogeneous Porous Media

In oil reservoir simulation practitioners are interested in some specific feature of the solution to the system describing the multiphase flow in heterogeneous porous media such as the oil production (goal functional). We develop an fully computable goal-oriented error estimate for discontinuous in time and space Galerkin method for interface problem for saturation equation. The error estimate is used in an adaptive strategy that allows accurate approximation of the goal functional at reduced computational cost.

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MS62

Effective Slip Law for General Viscous Flows over An Oscillating Surface

We consider the non-stationary three-dimensional viscous flow in a bounded domain with a rough boundary. Under the assumption of a smooth flow in the domain without roughness, we prove existence of a smooth solution to a problem with rough boundary. Using boundary layers and results on solenoidal vector fields, we obtain the Navier friction condition. It is valid when the size of the asprities tends to zero. Error estimates for the velocity and pressure are shown.

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MS62

A Finite Difference Framework for Porous Media Flow

We design and construct finite difference operators for applications in porous media. The new operators possess properties that facilitates boundary and interface treatments, and in many cases lead to provably robust discretisations and error estimates. The framework is in particular suitable for coupling regions with different continuity requirements using different discretisation accuracy, where the second order method is directly comparable to a finite volume discretisation. We demonstrate the applicability of the framework through numerical experiments.

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MS62

Stable Projection Operators For High-Order Finite Difference Methods

A methodology for coupling high-order finite difference methods is proposed based on projecting the finite difference solution along a coupling interface into a space of discontinuous polynomials. In this talk we show coupling to differing finite difference methods, including "hanging node' block interfaces, as well an unstructured, triangle-based discontinuous Galerkin method. Numerical examples will be provided to demonstrate the accuracy and stability of the proposed method for acoustic wave propagation.

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MS62

A New Reconstruction Algorithm for Flow and Reactive Transport Simulation in Porous Media on Cartesian Grids

Source terms in immersed boundary methods (IBMs) are determined by the difference between the interpolated values on the boundary points and the desired (physical) boundary values. In presence of subgrid discontinuity of state variables across solid boundaries, one-sided stencil reconstruction is generally employed. We propose a novel second-order reconstruction scheme based on an interpolator defined along the outward normal of the solid boundary. We demonstrate the interpolator flexibility and improved accuracy with different boundary conditions.

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MS63

SubFlow, an Open-Source Tool for Modeling Carbon Dioxide Sequestration in Geological Formations

The capture of carbon dioxide for its subsequent storage in brine saturated reservoirs or depleted oil fields has become a significant part of the US energy policy. In this work, we focus on the design and development of a novel application for modeling the time-evolution of the sequestration process. SubFlow is written in C++ and uses a relational database to store simulation data. It provides 3D real-time visualization and parallel execution. SubFlow uses either, finite volume or mimetic discretization methods to solve for the governing partial differential equations. It employs Gear's method to solve the mechanism modeling geochemical kinetics. Results are compared with those obtained by TOUGHREACT and STOMP.

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MS63

Numerical Simulation of Fluid Pressure and Fracturing in CO2 Sequestration

CO2 sequestration in underground aquifers shows significant potential in reducing greenhouse gas emissions. However, rock fractures, formed during injection, may release toxic species into the water table and release CO2 into the atmosphere. Because rock fractures develop as a result of stresses, a model to compute the internal rock stresses induced by the injection of CO2-rich water was developed. A finite element model was used to calculate the fluid pressure, stresses and strains induced by injection of CO2 into a geologic sandstone formation. The Terzaghi effective stress was determined from the calculated overburden pressure and fluid pressure. When the Terzaghi-effective stress exceeded the critical fracture gradient, simulated fractures were induced. The effect of the simulated fractures was estimated as an incremental permeability by means of Odas permeability tensor. This poroelastic pressure and fracture module was used to approximate formation pressure during injection of CO2 rich water into the Oligocene Frio Formation along the Texas Gulf Coast, with simulation parameters derived from the Frio Test Pilot Experiment. Simulation results were compared to bottom-hole pressure data obtained from an observation well 30 meters away from the injection well, during a 35-day injection phase.

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MS63

Effect of Aqueous Electrolytic Reactions on Reservoir Temperature during CO2 Injection

A well-known model for computing the thermodynamic properties of aqueous electrolytic solutions at geologic conditions of high temperature and pressure is the revised Helgeson-Kirkham-Flowers (HKF) model. The HKF model is based on computing properties of dilute aqueous species by separately considering solvation and nonsolvation contributions. The solvation contribution dominates at lower temperatures and is based on the Born model for determining the free energy of solvation, where formation water permittivity is calculated using Johnson and Norton regression coefficients. The nonsolvation contribution dominates at higher temperatures and is empirically determined. Activity coefficients of electrically charged solutes are approximated using the B-dot model, which is an extended Debye-Hckel model. The HKF derived partial molal heat capacity and enthalpy of charged aqueous species arising from the interaction of CO2-rich brine with sandstone are used in the source term of a transient heat transfer model. The heat transfer model accounts for the advective and diffusive energy transport of aqueous CO2 in a porous sandstone formation. Advective transport is modeled using Darcy's law for pressure driven-flow and solved using a finite volume method on a staggered grid. Formation pressure is computed using a poroelastic pore pressure diffusion model and solved using the finite element method. We present the effect of ion and electrolyte solute interaction on reservoir temperature as high pressure (228-372 bar) CO2-rich water is injected into a lower pressure (152-255 bar) sandstone formation.

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MS63

Mimetic Finite Differences to Simulate Carbon Dioxide Subsurface Mass Transport

We present Mimetic Finite Differences as an alternative numerical method to solve for the mass transport equation. In this work, this equation models the long-term behavior of geologically sequestered CO_2. We discuss how can we construct higher-order 1D mimetic operators, as well as how to construct their higher-dimensional counterparts. Finally, we provide simulation results within the framework of the Mimetic Methods Toolkit (MTK), an API implementing mimetic discretization and quadrature schemes.

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MS63

Pore Dynamics and Calcite Solubility in Carbonaceous Aquifers Used in Energy Storage Applications.

Geothermal energy harvesting applications use deep groundwater aquifers to store energy. The impact of this additional energy to the aquifer chemistry is crucial for long-term operation. Gaseous CO_2 is added to the injected water to compensate potential precipitates of carbonates and to prevent structural changes to the aquifer. To better understand this thermal and chemical coupling on the aquifer structure, we consider a long-wave model of this process for a single axisymmetric pore where gaseous CO_2 concentration, temperature, fluid flow and hydrochemistry modify the pore radius in space and time. Substrates are composed of calcite and dolomite, whose composition evolution is part of the full pore problem. The concentration footprint of the dissolved solid calcite concentration over many seasonal cycles of the energy harnessing system is found. The impact of these results on the efficiency of these systems, along with the chemical impact on the aquifer is discussed.

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PP1

Parallel Computation of Bayesian Model-Based Geostatistics for Improved Reservoir Characterization

Instead of spatial distribution in simple kriging, Bayesian kriging has been done to take into account the uncertainty in a form of posterior-distribution to avoid unrealistic small regions for optimal linear interpolation. Multiple equiprobable realizations have been created, statistically ranked and sampled to select P10, P50, and P90. The procedure was expedited through R parallel computing package. Rmpi allowed to create R code to run in multiple CPUs on one machine for more quick results.

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PP1

Convergence Analysis of Multirate Coupling Schemes for Coupled Flow and Geomechanics

Coupling of geomechanics and flow in poroelastic media has several environmental and petroleum engineering applications. In this work, we have rigorously formulated and analyzed multirate iterative coupling schemes for solving coupled geomechanics and flow problems in poro-elastic and fractured poro-elastic media. Multirate schemes better exploit the different time scales of mechanics and flow by allowing for multiple finer time steps for flow within one coarser geomechanics time step, reducing the overall CPU run time considerably.

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PP1

Test Condition for Obtaining the Global Optimum Value of a Function Using Discarding Algorithm

The problem of finding the global minimum of a vector function is very common in science, economics and engineering. One of the most notable approaches to find the global minimum of a function is that based on interval analysis. In this area, the exclusion algorithms (EAs) are a well-known tool for finding the global minimum of a function over a compact domain. There are several choices for the minimization condition In this paper, we introduce a new exclusion test and analyze the efficiency and computational complexity of exclusion algorithms based on this approach.We consider Lipschitz functions and give a new minimization condition for the exclusion algorithm. Then we study the convergence and complexity of the method

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PP1

A Structure-Preserving Split Finite Element Discretization of the 1D Wave Equation

We introduce a finite element (FE) discretization of the 1-dimensional wave equation that is written in split form, i.e. the equation is split into topological and metric parts. We provide a proof of concept that this FE discretization consisting of initially independent pairs of FE spaces which are then connected by a Galerkin Hodge operator is stable. We compare this discretization with a standard mixed finite element approach with respect to accuracy and efficiency.

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PP1

The Mathematics Behind Severe Thunderstorm Prediction and Alerting

The weather forecast system of the future will have to deal with massive amounts of data and still be able to produce personalized weather alerts. We present our research on generating and communicating thunderstorm forecasts, nowcasts and analyses using post-processed numerical weather prediction (NWP), radar and lightning observations and human forecaster interaction. We focus on a few specific tasks: generation of probabilistic areas from NWP forecasts, time-interpolation, tracking from radar and lightning data, and object-based verification.

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PP1

Combining Optical and Atomic Force Microscopy Measurements with Numerical Simulations Reveals Nanoscale Wetting Phenomena

We investigate nanoscale oil droplets on well-characterized glass surfaces by combining optical microscopy and atomic force microscopy. By comparing experimental results with simulations at the molecular scale of the liquid-solid interface, we reveal how the local surface properties affect wetting properties such as contact angle and surface coverage. The results will enable technology development for enhanced oil recovery and on-chip catalysis.

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PP1

Information-Theoretic Characterization of Long-Memory Gaussian Processes

We derive explicit expressions for the mutual information and conditional mutual information between states of a long-memory, Gaussian stochastic process, and specifically, ARFIMA(p,d,q). We give information-theoretic characterizations of the transition from stationary long-memory to nonstationarity, and from long-memory to anti-persistence. We also give an explicit connection between information available for prediction and the moving average representation. For comparison we derive the same quantities for the short-memory, Markovian, AR(1) process. We mention a potential application to the evaluation of predictive models.

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PP1

The Impact of Boundary Conditions and Numerical Boundary Procedures on the Stability of Perfectly Matched Layers

The perfectly matched layer (PML) has emerged as an accurate boundary closure for wave propagation problems. Unfortunately, the PML does not give us an indication about appropriate boundary conditions needed to close the edges of the PML, or how boundary conditions should be enforced in a numerical setting. We analyze initial boundary value problems for PMLs using the normal mode analysis and present a stable numerical approximations of the PML with the boundary conditions. Numerical experiments verify theoretical results.

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PP1

Relative Importance of Sorption Versus Aggregation over Soil Carbon Stocks and Dynamics

We couple BAMS1 [Riley et al., 2014] and AggModel [Segoli et al., 2013] to understand the impact of various protection mechanisms (e.g., sorption, aggregation) on SOM dynamics. BAMS1 includes microbes, multiple carbon substrate groups, and mechanistic sorption processes; AggModel includes multiple aggregate size classes. Preliminary results suggest clay mineral surface area and soil aggregates are as dominant controls of soil carbon stocks and its long residence times, respectively.

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PP1

Combining Global Optimization and Boundary Integral Methods to Robustly Estimate Seismic Velocity Models

We combine a fast Helmholtz solver using boundary integral methods with particle swarm optimization to globally estimate a seismic velocity model without an initial guess. Our forward solver constrains model space to a layered model with perturbations to achieve computational saving and allows the use of global optimization methods that require numerous evaluations and few unknowns. We apply our technique to estimate a velocity model from real teleseismic regional data and synthetic exploration scale data.

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PP1

Numerical Study of the Propagation of Acoustic Waves Around and Inside an Underground Cavity

Motivated by the need to detect an underground cavity

within the procedure of an On-Site-Inspection (OSI) of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO), which might be caused by a nuclear explosion/weapon test, we provide a basic numerical study of the wave propagation around and inside such an underground cavity. Our computations are done with the parallel finite element library Ngsolve on top of the automatic 2D/3D tetrahedral mesh generator Netgen.

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PP1

SVM with Uncertainty for Mineral Prospectivity Mapping

Over the last 20 years mineral exploration has begun adopting advanced data mining techniques to assimilate large data sets and identify prospective targets. Numerous machine learning algorithms exist, however regardless of the method all are plagued by the existence of uncertainties in both the training data and training labels (known mineralization occurrences). To address this an algorithm was developed based on support vector machines which explicitly incorporates these uncertainties into the objective function.

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PP1

Characterizing Roughness and Connectivity Properties of Aquifer Conductivity Using Bayesian Inversion

In our study, we investigate two different properties of subsurface conductivity fields that are hard to detect using classic characterization schemes; roughness and connectivity. To circumvent this difficulty we use the Method of Anchored Distributions (MAD), a fully Bayesian inversion tool. Since MAD does not assume any formal relationship between the target variable and the data, we are able to determine the ability of a wide variety of data to detect these two aforementioned properties.

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PP1

Inversion of Postseismic Deformation for Lithospheric Viscosity and Fault Slip

We present an inverse method which discerns the mechanisms driving postseismic deformation, namely, afterslip and viscous relaxation in the lithosphere. Our method is based on a linearized approximation for postseismic deformation which greatly simplifies an otherwise expensive forward problem. This approximation allows us to quickly infer fault slip over the postseismic period as well as image the lithospheres viscosity structure with unprecedented resolution. We apply our method to postseismic deformation following the 2010 El Mayor-Cucapah earthquake.

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PP1

A Posteriori Diagnosis Tools for Improved Data Assimilation System Performance

The information content of atmospheric measurements in data assimilation is closely determined by the representation of the model and observation error statistics. Evaluation of short-range forecast error sensitivities to observation error variance and innovation-weight parameters provides guidance to improve the system performance. A case study is presented for various observing instruments assimilated in NASAs GEOS-5 system. Statistical analysis of data assimilation products indicates that, in general, increasing the observation weight would improve the forecast skill.

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PP1

Local Refinement in Simulation of Wave Propagation

An algorithm for the local refinement of both time and space steps in staggered grids is introduced. It is based on a locally variable time-step scheme that matches with discontinuous grids in finite-difference method for the efficient simulation of wave propagation. The first-order velocity-stress formulations are used to obtain the spatial derivatives using finite-difference operators on a staggered grid. In principle, this algorithm may give the fast and accurate numerical solutions for any hyperbolic problem.

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PP2

Multiscale Vertically-Integrated Models with Vertical Dynamics and Heterogeneity for Co2 Migration in Geological Formations

To overcome the vertical equilibrium (VE) limitation of conventional vertically-integrated models for CO2 storage, we develop a new vertically-integrated model by casting the equations in a multiscale framework. The coarse scale is the vertically-integrated domain similar to the VE model, while the fine scale is a one-dimensional problem in the vertical direction that solves the vertical dynamics of CO2 and brine. The end result is a multiscale model that relaxes the VE assumption while maintaining most computational advantages of VE models.

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PP2

Adaptive Multi-Scale Pore Network Method for Two-Phase Flow in Porous Media

For typical two-phase flow through porous media, capillary forces are dominant at the pore scale and viscous forces at larger scales. We present a multiscale pore-network simulator which exploits this behavior. A pore-network, representing a porous medium, is subdivided into subnetworks. The fluid-fluid interface in each subnetwork is evolved using either a quasi-static or dynamic pore-network solver, depending on the local capillary number. A meso-scale equation is solved to couple the flow in the subnetworks.

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PP2

Statistical Analysis and Simulation of the Spatial Distribution of Deformation Bands in Fault Damage Zone.

Based on 106 outcrop scanlines, the distribution of deformations bands in damage zones of extensional faults in porous sandstones has been characterized as follows: logarithmic decrease of the bands away from the fault core and clustering of the bands. A statistical simulation method for deformation bands spatial distribution is presented. The proposed algorithms reproduce the observed frequency and clustering of the deformation bands. The application and validity of the developed algorithms are discussed.

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PP2

Inverse Modeling of Contaminant Transport with Implicit Sampling

Monitoring and predicting groundwater flow and contaminant transport is one of the primary concerns of the Department of Energy. Advanced Simulation Capability for Environmental Management (ASCEM) software package was developed to support efficient development of hydrological models for predictive analysis, uncertainty quantification, and decision-making. We study the use of implicit sampling, which generates sample beams toward the high probability regions of target probability density functions, in the calibration of influential model parameters. We demonstrate the efficiency of the method in accurately characterizing the uncertainty of a calibrated 3D model for the F-Area basin at Savannah River Site.

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PP2

Ensemble-Based Framework for Geosteering

Geosteering aims to steer an oil/gas well to optimize its coverage in the targeted reservoir zone. In this work, we propose an ensemble-based framework that uses logging-while-drilling (LWD) data to continuously update the geomodel, and optimize the well placement accordingly. A

2D case is investigated under the proposed framework, in which synthetic electromagnetic (EM) data generated from an advanced EM tool are assimilated. Satisfactory geosteering performance is obtained, confirming the benefits of the proposed framework.

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PP2

Determining Most Informative Measurements for Geostatistical Characterization Via Inverse Modeling

In order to use inverse modeling to infer the geostatistical parameters for a field, informative measurements are necessary. The Method of Anchored Distributions allows multiple forms of data to constrain the uncertainty in these parameters. This method is a Bayesian technique and relies on likelihood values determined from comparing measurements to stochastic realizations. This poster focuses on using Principal Component Analysis to determine which measurements have more informative distributions and the resulting impact on posteriors.

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PP2

Performance of Parallel Linear Solvers in Electromagnetic Geophysics

The size and complexity of 3D electromagnetic modelling problems present a serious challenge for computational methods. Complex linear systems arising from the finite-element or finite-difference discretizations on very large grids need to be solved multiple times during the geophysical inversion process. In this presentation we will discuss different iterative and direct solvers for large complex systems of linear equations. We will evaluate robustness, speed and parallel efficiency of these methods for large-scale electromagnetic problems, making a special focus on the reusability for similar coefficient matrices.

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PP2

Spatio-Temporal Upscaling of Reactive Transport in Porous Media for Ultra-Long Time Predictions

STRICTLY POSTER PRESENTATION In most practical applications it is satisfactory to know the macroscopic (averaged in space and/or time) values of the state variables. Predictions of subsurface transport for ultra-long times require the formulation of continuum scale models for time-averages. In the current study we perform a spatio-temporal upscaling for pore-scale advection-diffusion equations with nonlinear heterogeneous reaction using homogenization method to (i) obtain macro-time continuum-scale equations and (ii) identify their applicability regimes in terms of relevant dimensionless groups.

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PP2

Terrain Correction Considering the Isostatic Compensation of the Terrain

Terrain correction in the gravity anomaly at a point would require the Bouguer gravity anomaly values for the surrounding terrain to account for the isostatic compensation of the surrounding terrain. It is demonstrated through a two-dimensional model (i.e. two rectangular columns of rigid material separated by a horizontal distance X , having density ρ , heights H_1, H_2 , and unit width floating in a viscous fluid having density ρ_f , volume V contained in a rectangular box of width Y).

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PP2

Coupled Multiphase Flow and Reactive Transport: Effects of Compressibility and Solubility on Gas Storage Simulation

This work demonstrates an extension of the reactive transport software HYTEC – reactive two-phase flow and transport. Applying appropriate equation of state made it possible to precisely represent compressible multicomponent gas phase, its thermodynamic properties and relevant fluxes. Integrated geochemical software CHESS allowed modeling phase exchange and complex geochemical system. The developed coupling provides an analysis of gas compressibility and dissolution role in CO2 plume formation in the context of impure supercritical CO2 injection.

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PP2

On the Different Coupling Choices in Joint Hydrogeophysical Inversion

Hydrogeophysical studies combine different data types to improve the estimates of hydrological states, e.g. in solute transport studies. But solving a coupled inverse problem faces two main challenges: determining the relationship between geophysical and groundwater variables; and fitting two different sources of data. We investigate two computational approaches; first, using the alternate direction method of multipliers and second, a block coordinate descent method for minimization of the coupled objective function. Both methods provide a huge computational advantage. Geophysical and groundwater models were developed in Matlab to test the joint inversion framework for different cases, with or without knowledge of the petrophysical relationship.

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PP2

Disambiguated Characterization of Rain from Radar Measurements Using An Alternate Representation of Hydrometeor Size Distributions

We present a method to disambiguate the interpretation of radar measurements when estimating mean masses and sizes of hydrometeors. The method hinges on partial mass integrals (PMI) of arbitrary particle size distributions, without assuming gamma distribution. Optimized canonical-correlation analyses yield eigenvectors of the PMI with a maximum correlation to eigenvectors of the radar observables. The potential of this method for rain retrieval algorithms is illustrated using ground-based and airborne disdrometer measurements and simulated radar observations.

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PP2

Data-Driven Stochastic Representations of Mesoscale Ocean Eddies

We investigate how to use sample data, generated by a fully resolved quasi-geostrophic ocean model, to construct stochastic representations of unresolved processes (so-called mesoscale eddies) in a reduced ocean model. These representations are formulated as stochastic processes, conditioned on a covariate (the resolved model state). We demonstrate that the tested strategies significantly reduce the degrees of freedom of the respective model, while retaining the driving force of the unresolved processes.

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PP2

The Aurora: Electron Transport in the Upper Atmosphere

For millennia, people have been fascinated with the natural light shows of the aurora. Recently, advances in physics have been made in modeling the aurora to help us understand more about this phenomenon. There are many challenges in making predictions given an auroral model. In particular, the problem can be stated as a free boundary value problem. To date, all computational investigations have avoided the free boundary aspect of the problem. Numerical experiments are given showing that including the free boundary feature is necessary to obtaining physically meaningful solutions.

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PP2

Constrained Optimization for the Inversion of 2 and 3-Dimensional Bouguer Gravity Anomalies

We propose a constrained optimization approach applied over Bouguer gravity anomalies to improve 2- and 3-Dimensional models of Earths structures. Based on Primal-Dual Interior Point methods, we develop density constraints for transitional areas obtained from previous geological observations (e.g., borehole data). We apply the algorithm to synthetic data and gravitational datasets from a Porphyry Cu-Mo deposit formation (Cooper Flat Mine, Sierra County, NM) focusing only on those feasible models meeting the constraints.

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