IP1

Multiscale Model Reduction Techniques for Flows in High-contrast Heterogeneous Media and Applications

The development of numerical algorithms for simulations of flow processes in large-scale highly heterogeneous porous formations is challenging because properties of natural geologic porous formations (e.g., permeability) display high variability and complex spatial correlation structures which can span a hierarchy of length scales. It is usually necessary to resolve a wide range of length and time scales, which can be prohibitively expensive, in order to obtain accurate predictions of the flow, mechanical deformation, and transport processes under investigation. In practice, some types of coarsening (or upscaling) of the detailed model are usually performed before the model can be used to simulate complex processes. Many approaches have been developed and applied successfully when a scale separation adequately describes the spatial variability of the subsurface properties (e.g., permeability) that have bounded variations. The quality of these approaches deteriorates for complex heterogeneities without scale separation and high contrast. In this talk, I will describe multiscale model reduction techniques that can be used to systematically reduce the degrees of freedoms of fine-scale simulations and discuss applications to preconditioners. Numerical results will be presented that show that one can improve the accuracy of multiscale methods by systematically adding new coarse basis functions and obtain contrast-independent preconditioners for complex heterogeneities.

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IP2

The Role of Applied Computational Mathematics in the end-to-end Near-field Tsunami Early Warning System in Indonesia

In the aftermath of the 2004 Indian Ocean Tsunami, the German Federal Government funded the development of a new near-field tsunami early warning system (GITEWS) for Indonesia as a multi-national multi-institutional scientific collaboration. The system is in operation since November 2008 and is being handed over to the Indonesian Government in the days of the SIAM Geosciences Meeting. Several tsunami events have occurred since the inauguration of the system and have demonstrated the performance of this highly sophisticated and integrated tool for mitigating the effects of natural disaster. In the core of the system, several mathematical and computational techniques and procedures play a key role to interpret earth observation data and to make use of the information gained. Simulating the specific components of the earth system is just the start of the chain of mathematical processes involved. A rigorous (but simple and robust) uncertainty propagation and reduction model helps in determining the potential impact of a rupture. Statistical methods are used to develop hazard maps and define risk zones. The presentation will give an overview of the diverse technical components and societal considerations involved in the GITEWS Tsunami Early Warning System. An emphasis will be laid on the computational mathematics aspects and their core role in solving the problem of near-field tsunami detection and early warning. From this development, and the constraints of real-time robust operational service, several conclusions can be drawn for a more general geo-scientific computational perspective.

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IP3

Recent Advances in Full Waveform Global Seismic Tomography of the Earth's Mantle

Over the last 20 years, several generations of global tomographic models of the earth's mantle elastic structure have been developed, relying on simple theoretical approximations to the 3D wavefield (i.e. ray theory and first order normal mode perturbation theory). Now, it is possible to compute accurate synthetics in spherical geometry for arbitrary 3D structures using numerical approaches, such as the Spectral Element Method, which is particularly well suited for global waveform tomography. The challenge has been shifted from theoretical limitations to the length of computations involved. I will discuss and illustrate current steps towards the development of next generation, high resolution whole mantle models.

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IP4

Computational Challenges in Applications of Coupled Reservoir Geomechanics

Recent years have seen dramatic increase in the application of coupled hydro-thermo-mechanical numerical solutions to petroleum industry. In this context they are often referred to as Coupled Reservoir Geomechanics, and involve coupled solution of multiphase, thermal flow in porous media, stress and deformation, and fracture mechanics. This growing discipline encompasses diverse problems such as wellbore stability, sand production, hydraulic fracturing, compaction and subsidence, fault reactivation etc. Such applications invariably involve large, complex fields and they pose serious computational challenges. This talk will discuss some of them, including: Current state of the iterative strategies for the flow and stress coupling Grid construction, grid repair and generation of the geomechanical grid from the flow grid Creation and upscaling of the geomechanical characterization and dealing with complex media (such as naturally fractured reservoirs) Scale issues and dealing with local accuracy requirements All of these topics will be illustrated by examples of actual studies from studies of petroleum reservoirs and CO2 sequestration in aquifers.

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IP5

3-D Finite-element Simulation of Transient Electromagnetics in Complex Earth Media

The diffusion of low frequency EM fields in conductive media is the basis for controlled-source electromagnetic (CSEM) remote sensing of Earths subsurface. Over the past decade, there have been many numerical approaches developed for simulating CSEM in complex geological media, including direct implementation of the coupled Maxwells equations, the popular double-curl electric field formulation, and the coupled vector and scalar potentials formulation derived under the Coulomb gauge condition. In this talk, we present a new formulation that uses a variation of the Lorenz gauge that is well suited to finite-element (FE) modeling. Our formulation decouples the vector and scalar potentials into a separate diffusion equation for the vector potential and Poissons equation for the scalar potential. It reduces the larger FE system that results from the Coulomb gauge into two smaller decoupled systems of FE equations. Moreover, this Lorenzian-gauge formulation retains the advantages of both the double-curl electric field and the Coulomb-gauge approaches; the resulting FE system not only has the minimum number of unknowns but also can be used in the static limit using an iterative solver. We illustrate the method for large 3-D geophysical CSEM problems and compare results with the finite-element double-curl electric field approach and the finite-difference Maxwell equation approach.

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IP6

Atmospheric Convection in Weather and Climate Simulations

Convection in the atmosphere, whether driven by heating of the earth's surface or by condensational heating in clouds, is one of the most difficult processes to represent in our climate and weather models, and representing these processes is critical given the large uncertainty associated with clouds in climate assessments and weather prediction. Convective updrafts are not resolved in climate model simulations that use horizontal mesh spacings of 0(100 km), and they are severely under-resolved in weather prediction where the smallest horizontal mesh spacings are O(1 km). The issues associated with representing convection have significant implications for the design of the Navier-Stokes solvers used atmospheric models. In this talk I will briefly outline and provide examples of these issues and and discuss their implications.

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CP1

Traveltime Computation and Two-Point Seismic Ray-Tracing in Complex Velocity Models.

The problem of tracing seismic ray between two given points plays a central role in many implementations, for example in tomographic velocity analysis. Traditional ways of two-point ray-tracing, such as shooting or ray bending methods appear to be unstable and computational expensive in complex velocity anisotropic 3D models. A new approach based on eikonal finite-difference solvers is proposed. Numerical experiments using high-contrast isotropic and transversal isotropic models demonstrate the accuracy of proposed two-point ray-tracing algorithms.

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CP1

Seismic Velocity Modeling Using Genetic Algorithms, Binary Versus Real Valued Searches

From a statistical view seismograms are interpreted as random variables. The random component can be attributed to sources such as distant-dependent measurement error, human error in picking arrival phases, and random noise attributed to travel path. Stochastic modeling of such phenomenon quantifies these random processes. Genetic algorithms are iterative stochastic models that evaluate progressively improved mathematical models. We explore the benefits of using binary versus real valued based genetic algorithms in modeling seismic velocity structures.

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CP1

Appropriate Formulation of the Objective Function for a Better Integration of 4D Seismic Data to Constrain Reservoir Models.

Calibrating reservoir models to flow data involves history matching processes. Model parameters are iteratively adjusted to minimize the misfit between the real data and the corresponding simulated responses. The current formulation used to quantify the seismic data mismatch is neither representative of the difference between two images, nor of matching quality. We describe an alternative formulation, using methods rooted in image processing, to extract relevant information from seismic images and compute their dissimilarity.

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CP1

On the Stability of the Perfectly Matched Layer in Time-Dependent Elastic Wave Guides.

There are many wave propagation problems where boundary phenomenon such as surface or glancing waves are dominant. Typical examples are in seismology and earthquake engineering, which can be described by the elastic wave equation in a waveguide. It has also been reported that when an elastic waveguide is accompanied by free-surface (vanishing stresses) boundary conditions or clamped (vanishing displacements) boundary conditions, the PML becomes unstable and can not be used to truncate the computational domain. This is in part due to the existence of backward propagating modes supported by the boundary conditions. In this talk we will discuss how to avoid this instability. Analysis and numerical experiments will be presented highlighting the practicality of our technique.

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CP1

Identification of Multiple Layers in Geophysics Using Optimization and Level Set Methods

A shape reconstruction method for geophysical objects by temperature or hydraulic head measurements is presented which uses adjoint equations and a level set function approach. Temperature is measured on subdomains, e.g. representing boreholes. This information is used to reconstruct the shape of the geophysical layers. For this purpose shape optimization techniques are applied. Synthetic examples demonstrate the use of the inverse method and its behavior in different configurations.

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CP1

Estimation of Transmission Eigenvalues and the Index of Refraction Using Cauchy Data

Transmission eigenvalues have import applications in inverse scattering theory. We show that transmission eigenvalues can be computed from the near field Cauchy data. In addition, we apply an optimization method to estimate the index of refraction based on the lowest transmission eigenvalues. The numerical results validate the effectiveness of the method.

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CP2

Spectral Methods on Semi-Infinite Domains for Implementation of Open Boundary Conditions

We adopt a spectral approach to open boundary conditions [Givoli, 2008] using Generalized Laguerre functions [Wang et al. 2009], discretizing the equations in a semi-infinite domain attached to a finite region of interest. We consider 1D Shallow Water Equations, with a spectral collocation in space, semi-implicit semi-Lagrangian discretization in time. Coupling with different finite-domain discretizations shows that a reasonable number of base functions is sufficient to reach accuracy and efficiency without spurious reflections at infinity.

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CP2

Elastic Effect on the Stability of Viscoelastic Shear Flows in the Limit of Infnite Weissenberg and Reynolds Numbers

This work is concerned with the linear stability of viscoelastic shear flows of an Upper Convected Maxwell fluid under the effect of elasticity. We are focused on the stability problem of a few classes of simple parallel flows in the limit of infinite Weissenberg and Reynolds numbers. We will discuss the numerical stability results. We consider plane Couette and Poiseuille flow, the hyperbolic tangent shearlayer and the Bickley jet flows. For all these flows, we shall consider free surface boundary conditions as well as wall boundary conditions. In the inviscid case, all the flows are unstable for free surfaces. For wall bounded flows, the Couette and Poiseuille flows are stable, while stability of the shear layer and Bickley jet depends on the ratio of the channel width to the characteristic length scale of the profile. In all cases, we find that elasticity stabilizes and ultimately suppresses the instability. Our numerical approach is based on the spectral Chebyshev collocation method. We shall also show that some flows, such as plane Poiseuille flow between two parallel free surfaces, also have short wave instabilities. This is in marked contrast to the wall bounded case. In this case, no smooth velocity profiles unstables to short waves are known, and for certain classes of flows there are even results ruling out short wave instability

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CP2

A Computational Framework for Ocean and Atmosphere Modeling Based on Parallel Adaptive FEM for Unstructured Meshes

We present a computational framework based on parallel adaptive FEM for atmosphere and ocean simulations as part of the Unicorn project. In order to achieve efficient representation of spatial scales we use adaptive mesh refinement. The framework can utilize massively parallel architectures to achieve the required model resolutions. In our framework we treat the ocean/atmosphere as a turbulent incompressible fluid with variable density. We present results on the ongoing work.

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CP2

Characteristics-Based Methods for Atmospheric Simulation on Modern Hardware

Immense distributed memory parallelism requires prioritizing the lowering of communication burden in numerical methods. Focusing on atmospheric simulation, I propose herein various characteristics-based (CB) integration methods. With fully discrete explicit time stepping, CB methods reduce communication and synchronization while allowing large-CFL time steps. I will discuss the theory,

large-CFL accuracy, handling of source terms and multi-dimensionality, limiting of oscillations, and efficiency on accelerator-based computing architectures.

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CP2

Under-Resolved Les of Rayleigh-Benard Convection; Effects of Prandtl Number Anisotropy

In [Piotrowski et al., JCP 228, 2009] the effects were discussed of anisotropic numerical filtering in under-resolved large-eddy simulation (LES) on the organization of Rayleigh-Benard convection at a finite Prandtl number. This study extends the linear stability theory of that earlier work to anisotropic Prandtl numbers, to asses the role of disparate approximations to the governing equations in large-scale atmospheric codes. Asymptotic predictions of the linear theory are discussed and illustrated with computational examples.

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CP2

Finding Normal Modes of Semi-Enclosed Bays Using the Statistical Modes of a Data Set of Modeled Tsunami Wavefields

Understanding the resonant modes of bays and harbours is important for tsunami hazard assessment and monitoring. Previous methods for determining normal modes have adapted techniques developed for enclosed basins; but these generally rely on ad-hoc assumptions about the boundary between basin and ocean. We demonstrate a method for identifying the normal modes using Empirical Orthogonal Function (EOF) analysis of modeled tsunami wavefields which does not have this limitation, and show examples for Poverty Bay and Monterey Bay.

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CP3

A Joint Inversion Scheme for Contaminant Source Zone Reconstruction

A parametric level set (PaLS) method is used to characterize contaminant source zone geometry and entrapped saturation distribution from electrical resistance and hydrological (downstream concentration) data. The low order representation provided by the PaLS approach allows for tractable computation of all sensitivities based on exact physical models for resistance tomography and multiphase flow and transport and yields a geometric inversion scheme requiring no explicit regularization still capable of resolving highly detailed structure.

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CP3

Different Types of Parametrization for History-matching

One of the main goals of the reservoir characterization is to provide geologically realistic reservoir property estimates that incorporate all relevant information. Preservation of spatial structure is a crucial aspect of geologically realistic estimation. A key element in solving this issue is represented by parameterization. Different types of parameterizations are presented in combination with a history matching algorithm

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CP3

Sensitivity Analysis and Parameter Estimation in Groundwater Flows

In this work, we use Frechet derivatives of solutions of groundwater flow models with respect a hydraulic conductivity parameter and demonstrate their applicability in estimating this parameter from flow data; We will discuss the fact that the Frechet derivative operator is Hilbert-Schmidt and the implications for uncertainty quantification. We will use a power method and sensitivity equations to evaluate the most significant directions and compute reduced representations of the operator for efficient gradient calculations.

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CP3

History Matching of Production and 4D Seismic Data for a Realistic Sagd Case

We describe an assisted history matching method applied to a realistic SAGD case. The objective is to constrain a reservoir model with both production and P impedance variations, derived from the stratigraphic inversion of a 4D seismic dataset recorded over three years of production. We built a workflow with geological modeling, upscaling, flow simulation and petroelastic modeling to compute the production and seismic responses. Then, an optimization process is run to minimize the data mismatch.

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CP4

Near-Well Simulation in 3D Using Mpfa-Methods

Numerical simulation of fluid flow in a hydrocarbon reservoir has to account for the presence of wells. We investigate numerical schemes based on logarithmic grid refinement around wells. In particular, multi-point-flux approximation (MPFA) methods are investigated in three dimensions (3D) on different types of hybrid grids for the single phase pressure equation. The numerical experiments are used to provide guidelines for selection of preferred grid and discretization method for near-well simulation in 3D.

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CP4

Sensitivity for Coupled Systems of Flow and Transport

We discuss several approaches to sensitivity analysis for coupled systems modeling flow and transport in porous media. The techniques include adjoint and global sensitivity methods and the sensitivity equations. The applications include a transport model coupled to the flow with inertia and a system of diffusion equations in heterogeneous multiscale formations. Sensitivity analysis aids in the choice of a reduced model which may decrease the computational complexity.

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CP4

Adaptive Mesh Refinement Algorithm for Simulating Two-Phase Compressible Flow in Porous Media

We describe an adaptive mesh refinement (AMR) algorithm for simulating two-phase compressible flow in porous media under isothermal condition. The governing equations are decomposed based on the total velocity splitting approach to obtain a parabolic equation for the pressure and a set of hyperbolic equations for the component densities. This formulation forms the basis of a second-order sequential algorithm in which the pressure equation is solved implicitly and the component conservation equations are solved explicitly. The algorithm is then implemented within a parallel block-structured AMR framework, enabling us to perform efficient large-scale simulations. To demonstrate features in the algorithm, we will examine simulation results for an idealized model of a gas leaking from an underground LPG storage cavern.

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CP4

Mathematical and Numerical Study of a Two-Phase Two-Component Porous Media Model

We will present the mathematical existence of a degenerate parabolic system modeling two phase (liquid and gaz) two component (water and hydrogen) flow in porous media in the context of radioactive waste storage where the velocity of the mass exchange between dissolved hydrogen and hydrogen in the gaz phase is supposed finite. We will also present a numerical scheme to discretise this system and we will present some properties for this numerical scheme.

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CP4

A Coupled Large-Scale Model for Hydromechanical Simulation of Co2 Geological Storage

A coupled hydro-mechanical modeling of CO2 injection into deep aquifers is proposed. Multiphase and multicomponent fluid flow is considered in interaction with the rock geomechanical behaviour. The numerical methods used to link a flow transport code and a mechanical code, in particular fields transfer between non-coincident meshes and time coupling algorithm, are then presented. Some results of large scale simulations especially some aspects of the mechanical integrity of caprock are finally discussed.

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CP5

An Analytical Model for Transient Heat Flow in Shallow Geothermal Systems

This contribution introduces a new analytical model capable of simulating fully transient conductive-convective heat transfer processes in a shallow geothermal system consisting of a borehole heat exchanger embedded in a soil mass. The spectral analysis method is utilized. It calculates the temperature distribution in all components using the discrete Fourier transform, for the time domain, and the Fourier-Bessel series, for the spatial domain. Numerical examples will be presented. See Al-Khoury, 2010, IJFF 20, issue 7.

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CP5

Elastic Response of Granular Soils with Multiscale Substructure

Effective medium theories for elastic and/or seismic response of granular soils have typically used theories such as Hertz-Mindlin or Walton-type methods to determine overall behavior. For environmental applications, it may also be necessary to consider smaller scale granularity due to biomineralization. An important second scale of granularity arises when various forms of calcium carbonate are precipitated on the soil grains, and near the regions of contact between soils grains. The strengthening effects can be significant.

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CP5

Characteristic Thermal Profiles in Open-Loop Geothermal Energy Harvesting

In exploring deep geothermal energy ($>$ 2000 m), heat losses in the boreholes can be significant and are dependent of the pumping rates, and sharp transitions in well diameters and in geology. Temperature drops of 20-30 % between the top of the deep aquifer and ground surface are common. Quantifying these energy losses are fundamental to determining the capabilities of the technology. We formulate a mathematical model of the pipe-soil system in the limit where axial convective transport within the pipe balances radial diffusion in the surrounding medium. This results in a coupled system of boundary-value problems for steady-state solutions, and the rates of thermal losses in the axial direction are found as a function of the different pipe radii and lengths, as well as the thermal properties of the surrounding medium. Design choices for the pipe staging are suggested based on the local geology of the site.

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CP5

How Phase Transition Is Affected by Chemical Potential and Relative Concentration

When we consider the phase transition of liquid to gaseous water, relative humidity is considered the primary driving force. For adsorption/desorption, the relative concentration of the species is considered the primary driving force. Theoretical considerations via Hybrid Mixture theory indicate that it is the difference between phase chemical potentials of the species which is the fundamental driving force. In this presenation we report preliminary theory on the relationship between chemical potential and the relative concentrations.

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CP5

Numerical Solution to a Nonlinear Transport Model for Swelling Porous Materials

We demonstrate the results of a novel numerical scheme used to solve a coupled system of nonlinear transport models consisting of a Volterra partial integrodifferential equation of the second kind and a nonlinear diffusion equation. A model application is a drug delivery device consisting of a drug interlaced within a polymer matrix. Results will be shown for concentration profiles and moisture content along with an interpretation of viscoelastic effects present in the model.

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CP5

Numerical Method for Poroelasticity Based on a Coupling of Nonconforming and Mixed Finite Element Methods Using Rectangular Elements

In this talk, we present a finite element formulation to approximate the coupled fluid and mechanics in deformable porous media. The method uses a nonconforming finite element for the displacement of the solid phase, and the lowest-order Raviart-Thomas mixed finite element for the pressure and the velocity of the fluid phase. To achieve the discrete Korn's inequality, we add a penalty term to the variational formulation. We provide *a priori* error estimates.

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CP6

Existence of a Weak Solution for the Fully Coupled

Navier-Stokes/Darcy-Transport Problem

We study a surface/subsurface multiphysics problem arising from the problem of groundwater contamination through rivers. Specifically, a convection-diffusion type transport equation is coupled with the Navier-Stokes/Darcy flow via velocity field and concentration. On the interface, we accept balance of forces, continuity of the flux and the Beavers-Joseph-Saffman condition. We analyze this problem by proving the existence of a weak solution by a method based on Galerkin approach in time.

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CP6

Permeability of Fluid Flow Through Cilia

This work concentrates on finding the permeability for viscous flow though a structure of periodic cylinders as a function of cylinder density and cylinder angle. We use a full three-dimensional model of incompressible viscous fluid in combination with the Buckingham Pi Theorem to determine the relationships. Numerical results are obtained using Mixed Finite Element Method. The results are compared with Zick and Homsy (1982). Applications include modeling the flow of mucus in lung tissue

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CP6

Modelling of Tunnel Inflow with Complicated Discretisation

We solve a 3D groundwater flow problem, predicting the inflow into a deep tunnel to fit the field measurement. The main problem is a combination of a kilometer scale of the whole model and a scale of the tunnel 3.6m diameter. This is done with sophisticated set mesh parameters, changing from 1m to 100m. We show comparisons with measured data and also discuss possible solutions without explicit shape of the tunnel in the model geometry.

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CP6

Smc Methods for the Calibration of Stochastic Rainfall-Runoff Models

The rainfall-runoff model considered in this talk is a conceptual stochastic model, formulated in contiuous-discrete state space form. We use a maximum likelihood approach based on an EM algorithm. In this approach, the key ingredient is the computation of smoothed additive functionals of hidden states (Olsson et al., 2008). Sequential Monte Carlo methods (SMC), also called particle methods, are used for smoothing in the state space model.

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CP6

Solution of Time-Dependent Pde Through Component-Wise Approximation of Matrix Functions

Krylov subspace spectral (KSS) methods have been demonstrated to be effective time-stepping methods for parabolic and hyperbolic variable-coefficient PDE. Their effectiveness stems from the use of different approximations for each Fourier component of the solution, based on techniques for approximating bilinear forms developed by Golub and Meurant. In this talk, it is shown how this essential ingredient of KSS methods can be adapted to finite element methods that are applied to PDE that arise in reservoir simulation.

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CP6

Randomized Operator Fitting for Preconditioning the Wave Equation Hessian

In this seminar, we consider the problem of approximating the inverse of the wave-equation Hessian, also called normal operator, in seismic imaging. We develop an expansion scheme for the pseudodifferential symbol of the inverse Hessian, and recover the coefficients via least-squares fitting from a certain number of applications of the normal operator on adequate randomized trial functions. We show how to construct these functions properly through analytical considerations and the Curvelet transform. Once an approximate inverse Hessian is available, application to an image of the model can be done in very low complexity. We also present numerical experiments demonstrating the performance of the method.

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CP6

An Adaptive Approach for Simulation of Flow Accumulation; a Mathematical Modification of Rmmf Model

Simulation of flow accumulation with available GIS software to use in the Revised-Morgan Morgan-Finny model causes high overestimation of erosion at large scales (catchment or regional). The provided remedy was implementing harmonic and P-series in calculation of distributed runoff for simulating flow accumulation. Results showed that error in Harmonic-series approach was considerably dependent on slope length, whereas in P-series formulation remained less than 10% for various slope lengths. The accumulation of runoff along the slope was validated by measured discharge within Namchun watershed, Thailand, which was acceptable according to Morgan 2005. The study revealed that through the new modification, the RMMF model can be a useful empirical-physically-based model in erosion assessment at large scale.

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CP7

Short Wave Instabilities in Free Surface Shear Flows

In this study, We investigate the linear stability of inviscid plane Poiseuille flow between two parallel free surfaces. We show that there are short wave instabilities with eigenfunctions localized near the free surface and derive the asymptotics of these modes. The stability of wall bounded inviscid shear flows has been studied for more than a century. However, shear flows bounded by free surfaces are also a solution of the Euler equations. Although there are entire books on stability of films and jets, these studies have focussed on instabilities due to surface effects, such as surface tension and air drag, and they usually assume a uniform velocity within the jet or film. They consider an axisymmetric jet bounded by a free surface with a Hagen-Poiseuille profile of the velocity. They conclude that the nonuniform velocity in the jet has a stabilizing effect. This conclusion, however, is due to their failure to consider non-axisymmetric modes. In recent work by M. Renardy, it was shown that plane parallel shear flows bounded by two free surfaces have long wave instabilities for all velocity profiles that are not uniform. This is in marked contrast to the wall bounded case, where criteria such as those of Rayleigh and Fjortoft guarantee stability of a broad class of flows. In this work, we shall show that some flows, such as plane Poiseuille flow, also have short wave instabilities. Again, this is in marked contrast to the wall bounded case. In this case, no smooth velocity profiles unstable to short waves are known, and for certain classes of flows there are even results ruling out short wave instability.

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CP7

Analysis and Numerics of the Magnetohydrodynamic Equations for Real Gases

We present an analytical study of the wave structure of the MHD equations for real gases based on the local decomposition in characteristic wavefields. We propose a complete system of eigenvectors that guarantees continuity with respect to the conserved variables in the neighborhood of singular points. We formulate a high order characteristic-based entropy-fix upwind numerical scheme based on the analytical study. Numerical examples show good accuracy and stability under high CFL numbers.

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CP7

Constrained Optimization Schemes for 1D Inverse Wave Propagation Problems

We compare three constrained optimization schemes for solving 1D inverse wave propagation problems posed as PDE-constrained optimization programs. Our goal is to identify the best scheme that incorporates inequality constraints over the model parameter, i.e. shear modulus, to be used in conjunction with a robust algorithm that solves the inverse problem. We conduct a numerical experimentation for each method with synthetic problems, created based on velocity models derived from seismic measurements, and report their performance.

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CP8

A Sigma-Coordinate, Discontinuous Galerkin Method for the Three-Dimensional Shallow Water Equations

In this presentation, we describe the development, implementation, and application of a novel sigma–coordinate discontinuous Galerkin (DG) method for the three–dimensional shallow water equations. The h (mesh) and p (polynomial order) convergence properties of the method are demonstrated on a set of analytic test cases. The development of new efficient (in some cases optimal) cubature rules for integration over triangular prism elements is also discussed.

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CP8

Large Time Step Finite Volume Evolution Galerkin Schemes for Shallow Water Flows

We present two new large time step methods within the framework of the well-balanced finite volume evolution Galerkin (FVEG) schemes. The methodology will be illustrated for low Froude number shallow water flows with source terms modeling the bottom topography and Coriolis forces, but results can be generalized to more complex systems of balance laws. The FVEG methods couple a finite volume formulation with approximate evolution operators. The latter are constructed using the bicharacteristics of multidimensional hyperbolic systems, such that all of the infinitely many directions of wave propagation are taken into account explicitly. This is a novel feature of our FV method. As a result the FVEG schemes are typically 10 times more accurate than standard FV schemes. In order to approximate multiscale phenomena we have developed two variants of large time step FVEG method: a semi-implicit time approximation and an explicit time approximation using several evolution steps along bicharacteristic cones. Behaviour of new FVEG schemes will be illustrated on a set of numerical experiments.

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CP8

Numerical Modeling of Surface Flows Based on Multi-Dimensional Models and Variational Data Assimilation. Application to Flood Plain Flows

In geophysical flows such as surface water flows, multi-scales features and uncertainties of input parameters (eg topography, parametrization of empirical laws) invite to derive multi-dimensional models (or multi-scale models like shallow-water / ALE free surface) while comparing the numerical results to observations. We present a global algorithm based on optimal control and adjoint equations which makes fit the coupled multi-dimensional (or multi-scales) models with heterogeneous data (in-situ, remote-sensed).

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CP8

Study of Overland Flow with Uncertain Infiltration Using Stochastic Tools.

Saturated hydraulic conductivity is a key parameter in overland flow models with infiltration, but several studies have shown the difficulty to correctly measure or estimate this parameter. We therefore propose to consider this parameter as a stochastic input parameter. We use a Monte Carlo method to quantify uncertainty propagation and to study using Sobol indices the sensitivity of model results to the value and the spatial distribution of saturated hydraulic conductivity along a slope.

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CP8

Effects of Shear Flow on KdV Balance, with Applications to Tsunami

Building upon recent work on the applicability of KdV to tsunami propagation, we discuss the effects of shear flow on the KdV balance. This leads in the shallow-water limit to the Burns condition which determines propagation speeds that arise in the KdV balance. For waves propagating counter to the shear, KdV dynamics arise earlier, while they arise later for waves propagating with the shear, the magnitude of this effect depending on surface shear velocity.

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CP8

Semi-Implicit Finite Volume Schemes for Shallow Free Surface Flows

We address the derivation of FV schemes for thin film flows with low Froude number (eg surface water flows), and with potential wet-dry front. We present and analyze a new semi-implicit scheme, unconditionaly stable and robust, for unviscid shallow-water models. Numerical examples are presented in a river hydraulics context, w/wo over-flowing (flood plain).

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CP9

Stable Algorithms for a Two Domain Natural Convection Problem and Observed Model Uncertainty

Numerical algorithms are studied for a Boussinesq model of natural heat convection in two domains, motivated by the

dynamic core of climate models. One algorithm is coupled across the ?uid-?uid interface. Another is decoupled using a partitioned time stepping approach that retains unconditional stability. An empirical study of model uncertainty is presented where stochastic noise is introduced into two nonlinear coupling terms that play an important role in stability.

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CP9

Time-dependent Wellbore Index Pressure Calculations

We discuss a new post-processing technique for standard reservoir simulators to determine detailed information about the time-dependent pressure at a wellbore. This information is used in well test analysis. Standard simulators use point or line source well models and do not resolve down to the tiny scale of the well radius. Our method involves just a local solve of the time dependent pressure equation in the vicinity of the wellbore, using as boundary data information from the main reservoir simulation. We describe the connection with the Peacemann wellbore index, discuss the accuracy and show results from a number of test cases.

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CP9

On a Distribution of the Enkf Sampling Error

Ensemble Kalman filter is a state space ensemble-based formulation of the Kalman filter. It is based on a low-rank covariance approximation from a moderately sized ensemble. Sampling errors lead to artificial effects, such as spurious correlations, deteriorating the estimates and the forecasts of the system states. We derive the distribution of the sampling error for the EnKF after a single analysis step. The distribution depends on ensemble size, model dimension and observation locations.

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CP9

Modeling of Uncertainty for a Spatial Simulator Response

Complex numerical models such as oil reservoir simulator involves lots of uncertain input parameters (geological, fluid flow parameters...) and can yield spatial outputs like oil saturation maps. To compute sensitivity analysis and uncertainties studies, experimental design and metamodels are used. We propose an innovative strategy based upon the wavelet decomposition of the output, the optimal selection of wavelet coefficients and their metamodeling by the Gaussian processes. An application on an oil reservoir illustrates the methodology.

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CP9

Multiscale Wavelet-Analysis-Based Localization of Covariance Estimates in the Ensemble Kalman Filter

In the ensemble Kalman filter, a sequential Monte Carlo method for Bayesian inversion, covariances are estimated from a small ensemble. There, sampling errors manifest in spurious, long-range correlations. In this work we discuss a new method to reduce the negative impact of such correlations. It is designed for inversion problems where the forward model contains significant features on multiple scales, e.g. history matching of hydrocarbon reservoirs. Different scales are resolved by a multi-scale wavelet transform.

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CP9

Stochastic Parameterizations of Highly Heterogeneous Media

We discuss new approaches to stochastic parameterizations of flow in porous media based on Karhunen-Loeve, Haar, and other series expansions appropriate for highly heterogeneous media. Of particular interest are parameterizations for discontinuous and multiscale porous media as well as interpretations of data simulated with geostatistics packages such as GSLIB. We use these parameterizations in finite element algorithms to compute moments of variables of interest such as pressures and fluxes.

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CP10

Operator Splitting For Advection Diffusion Equations with Discontinuous Coefficients

We consider time dependent advection diffusion equations with discontinuous diffusion coefficient. Using an operator splitting methodology we develop a fictitious domain method to numerically solve the time dependent diffusion equation. For the advection part we use a dispersion optimized nonstandard finite difference method that enables following the transport and tracking sharp fronts more accurately. The problems addressed here are motivated by applications combining the transport, growth and decay of biological/chemical species in heterogeneous landscapes.

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CP10

Direct Numerical Simulation of Inertial in Pourous Media

At modest flow rates ($Re > 100$) through porous media and packed beds, fluid inertia can result in complex steady and unsteady recirculation regions, dependent on the local pore geometry. As a result of fluid intertia, flow through porous media and packed beds can develop complex steady and unsteady recirculation regions at modest flow rates ($Re > 100$). We investigate these inertial flow regimes using (i) a body-fitted unstructured grid Navier-Stokes solver [Moin and Apte, AIAA J. 2006], and (ii) a fictitious domain based finite-volume approach [Apte et al. JCP 2009], wherein non-body conforming Cartesian grids are used and the no-slip boundary conditions on the pore boundaries are enforced implicitly through a rigidity constraint force. For the body-fitted unstructured grid approach, we present methods to parameterize and simplify mesh generation for packed beds, with an eye toward obtaining efficient mesh independence for Reynolds numbers in the inertial and unsteady regimes. To handle the geometric singularity at the sphere-sphere and sphere-wall contact points, we use a *fillet bridge model*, in which every pair of contacting entities are bridged by a fillet, eliminating a small fluid region near the contact point. A second order accurate, parallel, incompressible flow solver is used to simulate flow through three different sphere packings: a periodic simple cubic packing, a wall bounded hexagonal close packing, and a randomly packed tube. Mesh independence is assessed using several measures including Ergun pressure drop coefficients, viscous and pressure components of drag force, kinetic energy, kinetic energy dissipation and interstitial velocity profiles. Direct comparisons of the body-fitted and the fictitious domain approaches are made to evaluate the accuracy of the latter approach for simulation of flow through complex configurations observed in randomly packed beds.

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CP10

Direct Numerical Simulations of Solid-Fluid Coupling in Geophysical Systems

Numerous problems in the Earth sciences involve the dynamic interaction between solid bodies and viscous flow. While modelers are well equipped to deal with the end-member cases of predominantly liquid or solid systems, the intermediary regime remains challenging. We develop a new computational methodology for simulating solid-fluid interactions based on distributed Lagrange multipliers and apply our approach to investigate the competing effects of entrainment and sedimentation of crystals during magma cooling.

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CP10

Simulation of Pore Scale Precipitation and Dissolution Using Adaptive, Finite Volume Methods

Precipitation (or dissolution) of mineral grains modifies the geometry of the pore space in subsurface sediment with continuously evolving solid-liquid boundaries. In turn, changes in the pore space alter the groundwater flow through the sediment, which ultimately affects the continuum scale reaction rates that are relevant for field applications such as carbon sequestration. Modeling provides a unique tool to understand and quantify the feedback processes between mineral precipitation (or dissolution) and flow at the pore scale. Higher-order algorithms based on adaptive mesh refinement and finite volume methods have been successfully applied to flow and reactive transport in complex microscale geometries such as microarray channels. Here, we couple a geochemical module that includes aqueous complexation and mineral reactions to a new flow and transport simulation capability based on adaptive, finite volume methods. We have also extended this framework to track moving solid-fluid interfaces as a result of mineral reactions. This approach is consistent with those used for moving fluid-fluid interfaces, providing a robust and algorithmically consistent methodology for multiphase flow. We show that these advanced methods offer a promising alternative for reactive pore scale modeling through simulations of single pore throats as well as packed beds.

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CP10

Title Not Available at Time of Publication

Multiscale methods have received significant attention in recent years. Multiscale formulations, however, have not yet reached the robustness and applicability range nec-

essary for general-purpose reservoir simulation practice. Here, we address two aspects associated with highly heterogeneous models that pose a serious challenge to existing multiscale finite-volume formulations, namely, channel-like features and strongly anisotropic transmissibility (tensor permeability, high aspect ratio). We describe a Two-stage Algebraic Multiscale Solver (TAMS) for the pressure linear system. One stage deals with a global coarse-grid problem, which is constructed using prolongation and restriction operators. The prolongation operator is assembled from the multiscale basis functions. The restriction operator is either the transpose (i.e., Galerkin coarsening), or a conservative scheme. The second stage uses a local preconditioner (e.g., Block Incomplete LU) on the fine-grid. TAMS is guaranteed to converge to the fine-grid solution with a computational cost superior to existing state-of-the-art approaches, such as Algebraic MultiGrid (AMG). Thus, TAMS can be used as linear-solver for the pressure equation. TAMS also guarantees conservation after every iteration; so, TAMS can serve as an approximate pressure solver in a conventional simulator, where the results are used to perform transport computations.

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CP11

Multilevel Simulation and a-Posteriori Estimators for Double-Porosity Models

Double porosity models are useful for modeling flow and diffusion in highly heterogeneous media of binary character. The well-known Barenblatt and Warren-Root models are actually asymptotic limits of models of tertiary structure, and the latter can be seen as a special case of the former. We present numerical solutions on multilevel meshes for these models and propose an appropriate a-posteriori error estimator which is robust in the parameters and allows to compare the models.

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CP11

Special Functions to Capture Spatial Heterogeneity for Diffusion Equation with Decay

In this talk we discuss on developing special shape functions for diffusion with decay that capture underlying heterogeneity of the medium. We show that generating shape functions using homogeneous differential equation (which is the standard way of generating special functions under the Multiscale Finite Element Method) will not satisfy the partition of unity property for the chosen equation. Herein, we consider an alternate (non-homogeneous) boundary value problem for generating shape functions that ensures Kronecker-delta and partition of unity properties. In addition, if the medium is homogeneous, we recover the standard shape functions for that particular finite element under the proposed method. Another novel feature of the proposed methodology is that the resulting solution satisfies maximum principles and the non-negative constraint on general computational grids with low-order finite elements. This is achieved by augmenting the underlying variational principle with appropriate constraints (which will be in the form of inequalities). The resulting problem belongs to convex quadratic programming, which is solved using active-set strategy. Representative numerical examples are presented to show the overall performance of these special shape functions, and their ability to resolve the heterogeneity of the medium using coarse computational grids. We also present numerical convergence studies of the proposed methodology with respect to refinement of both coarse- and fine-scale meshes. This work is in collaboration with Professor Albert Valocchi (UIUC) and M. K. Mudunuru (Texas A&M University).

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CP11

Reactive Transport Simulation with Embedded Discontinuity in Fractured Porous Media

Material discontinuities in fractured porous media strongly influence single/multiphase fluid flow. When continuum methods are used to model transport across material interfaces, they smear out jump discontinuities of concentration or saturation. To overcome this problem, we split the finite-element models with complementary node-centred finite-volumes along the material interfaces, developing a transport scheme that represents the dependent variable discontinuities arising at these interfaces. We have found that using the discontinuous scheme is crucial to capture the emerging patterns due to the interaction of heterogeneity, and reactive transport.

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CP11

Mixed Multiscale Basis Functions for Iterative Domain Decomposition Procedures

We discuss the development of a multiscale method for the solution of the heterogeneous Poisson's equation that can take advantage of state-of-the-art CPU-GPU processors. We consider non-overlapping and overlapping domain decomposition procedures for mixed finite element discretizations of the elliptic equation with discontinuous coefficients. Mixed multiscale basis functions with Robin-type boundary conditions are proposed. Computational efficiency is achieved through a careful selection of subspaces of the space spanned by these basis functions for approximating local problems.

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CP11

Effective Behavior of Flow and Transport Parameters at Different Scales in Spatially Heterogeneous Porous Media Without Scale Separation

We investigate the effective behavior of hydraulic conductivities and mixing coefficients in heterogeneous media without scale separation. The covariance function of the log hydraulic conductivity can be modeled by an algebraic function. The exponent of this power law is chosen that no finite integral length exists. Such functions can be written as a superposition of Gaussian covariance functions with finite correlation lengths. We give explicit expressions and coarse graining results for flow and transport parameters.

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CP11

On Flows Through Deformable Laminates

Fluid flows through anisotropic media are found in a wide variety of geophysical and biological systems. The macroscale behavior of these systems depend on the unknown microstructure, which depend on the local physical processes. As a first model, we consider the flow of an incompressible fluid that saturates an array of deformable laminates with gravity acting in the spanwise direction. The aspect ratio of the characteristic spacing between the laminates is much smaller than the characteristic scale of the laminate length, and we use this aspect ratio to find effective equations for the components of the stress tensor of the effective material. Compatibility conditions at leading order result in a coupled set of elliptic equations for the unknown laminate spacing and the local pore pressure. Effective stress-strain relations are derived based on the local geometry and material properties of the laminates and fluid.

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CP12

Leveraging the General-Purpose Computation on Graphics Processing Units (gpgpu) Architecture for Lidar Data Processing

Processing datasets associated with LiDAR mappings is prohibitive due to the large datasets and computational nature of the processing. This is particularly problematic when working to achieve interactive or real-time data manipulation. By leveraging GPGPUs and reevaluation of the computational algorithms used in the processing of large LiDAR datasets we are able to accelerate the datamining process. Our results reflect aspects of GPGPU environments that achieve significant speedups (and slowdowns) when ported to the GPGPU environment.

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CP12

A Comparison of Parallel Preconditioners for the Mixed Finite Element Solution of Darcy's Equation

Darcy flow in a heterogeneous medium can be accurately computed with mixed finite elements. Hybridization leads to a positive definite system, solved by an iterative method. The LifeV finite element library,developped by EPFL, MOX and INRIA, relies on Trilinos for solving the linear system. Trilinos includes parallel iterative solvers, and preconditioners based on one level Schwarz (IFPACK) and parallel multi-level methods (ML). We compare the efficiency and parallel scalability of these preconditioners for solving Darcy flow.

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CP12

Numerical Modeling of Flow Through Porous

Structures and Vegetated Regions

Due to computational constraints, when modeling incompressible flow over and around porous structures or through heavily vegetated regions one must often use upscaling techniques to find parameterizations for resistance due to form drag. We analyze and perform theoretical and computational upscaling techniques for flows ranging from those with very small Reynolds numbers to those that are turbulent through a variety of 2D and 3D domains.

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CP12

From a Coarse-Scale Flow Model to Fine-Scale Permeability Identification

We apply an inverse modeling approach to determine fine-scale permeabilities based on heads - flow rates pairs computed on the level of a coarse-scale model. This fits into a downscaling framework if we assume that coarse scale permeabilities are actually determined within an upscaling scheme. In our approach a double constraint method is used, based on finite element discrete approximations. The results obtained apply to models with anisotropy effects.

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MS1

On a LES-deconvolution Model for the Ocean with a Fixed Wind

Kolmogorov's theory predicts that simulating turbulent flows by using the Navier-Stokes Equations requires $R^{9/4}$ degrees of freedom, where R is the Reynolds number.This number is too large to perform a Direct Numerical Simulation. This is why one aims at computing mean values of the flows field. The case that we study is an oceanic basin with a fixed wind. We consider means obtained by convolutions like in usual Large Eddy Simulation models. We introduce the concept of deconvolution model that aims at reconstructing the true flow field by regenerating high frequency wave numbers when the numerical mesh has a fixed size. We summerize some mathematical results and finally show numerical simulations in an oceanic basin with a given fixed wind, using the deconvolution concept.

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MS1

Large Eddy Simulation of Mixing in Stratified Flows

Mixing is a challenging quantity to get right accurately, yet it is important for many oceanic processes and the general circulation. Performance of various eddy-viscosity and approximate deconvolution type subgrid-scale models (SGS) in LES is evaluated in the lock-exchange problem, which contains shear-driven mixing, internal waves, interactions with boundaries and convective motions, while having a simple domain, initial and boundary conditions, and forcing. The measure of the comparison taken as the background potential energy and DNS results at $10^3 \leq Re \leq 10^4$ are used as benchmarks. By relying on the best-performing SGS models, estimates of mixing at higher Re are provided.

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MS1

A New Projection Method for Separating Surface and Interior Modes in Oceanic Data

A number of recent studies have demonstrated that altimetric observations of the ocean's mesoscale eddy field reflect the combined influence of both surface buoyancy anomalies and interior potential vorticity anomalies. The former are associated with surface-trapped modes, with an exponentially-decaying vertical structure, and the latter with the standard baroclinic modes, the oscillating eigenfunctions of the quasigeostrophic potential vorticity stretching operator. In order to assess the relative importance of the two contributions to the signal, one would like to project the observed field onto a set of complete modes that separates the influence of each aspect of the dynamics in a natural way. However, because the surface-trapped solutions are dependent on horizontal wavenumber, they are not, in general, orthogonal to the (wavenumber-independent) interior baroclinic modes, thus any combined projection will contain energetic overlaps. Here we propose a generalization of potential vorticity that includes surface buoyancy anomalies (akin to Bretherton's generalized form, but without the use of numerically ill-defined delta-functions), and compute its vertical eigenfunctions for each horizontal wavenumber. These eigenfunctions provide a set of mutually-orthogonal modes that reflect surface and interior components naturally. We compute these modes for a given stratification, and demonstrate their use by projecting out the energy of a set of high-resolution, eddying simulations.

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MS1

Suitable Boundary Conditions for the Shallow Water Equations in a Limited Domain.

In this lecture we will discuss two issues of general interest in scientific computing, namely: - Numerical simulations in a limited domain when the boundary conditions are not well defined at the boundary, and, - The use of multilevel methods for solving partial differential equations. Both problems will be discussed in the context of the inviscid shallow water equations.

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MS2

An Asymptotic Description of the Interaction fo Waves on the ITCZ with Midlatitude Quasi-geostrophic Dynamics

In a ground breaking paper, Majda & Klein introduced two new dynamical regimes describing the tropical troposphere. The first regime, IPESD provides a framework for the recent multiscale models of the Madden-Julian oscillation. The second regime, the mesoscale equatorial weak temperature gradient (MEWTG), describes a circulation forced by latent heating due to moist convection. The weak temperature gradient feature of this regime implies that diabatic heating balances vertical velocity on equatorial mesoscales, O(500km), and within timescales of less than one day. Majda recognized that this new multiscale MEWTG is a closed model by going to higher order in the asymptotics. The resulting model contains the original MEWTG equations modulated by a large scale, zonally propagating gravity wave. The temperature and wind properties of the large scale wave are independent of both the zonal and meridional mesoscales and are, thereby, consistent with the weak temperature gradient nature of the tropics. The mean zonal winds described by the multiscale MEWTG equations become unbounded at large latitudes away from the equatorial belt. Unless specific restrictions are made on the mean of the diabatic heating, the theory also yields solutions with non-zero meridional velocities far from the equatorial belt; i.e. an open Hadley circulation. Furthermore, meridional geostrophic balance is not described by this theory, yet this is known to be the main balance for subtropical and midlatitude winds. We derive matching condition to the subtropics which closes the multiscale MEWTG theory and connects the equatorial flows with midlatitude dynamics.

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MS2

Stochastic Models for Tropical Convection: From Idealized Conceptual Models to GCM Simulations

Large scale models that are used for longterm weather forecast and climate prediction are based on a coarse discretization of the governing equations with a grid spacing varying from 50 km to 200 km. For a such complex system –the Earth-ocean-atmosphere system, many important processes such clouds, radiation, air sea interaction, vegetation, and boundary layer turbulence, remain unresolved; they are represented by various recipes known as parameterizations. However, most of these parametrizations such as those pertaining to clouds and atmospheric convection are based on equilibrium closures that are hardly tested and in most cases underestimate the dynamics due to very intermittent local interactions at small scales. In this talk we will discuss a hierarchy of stochastic models that represent various unresolved physical processes, and their effect on the large-scale resolved variables, ranging from convective inhibition, using an Ising-type spin flip model, to multi-state Markov chains for organized tropical convection consisting of three cloud types, congestus, deep, and stratiform. The models are first test on simple toy models where their intrinsic features are explored and their parameters calibrated then more recently implemented in the context of more comprehensive atmospheric general circulation models that are used for operational long term weather and climate predictions.

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MS2

A Potential Vorticity Dynamics for Rotating Shallow Water on the Sphere

The evolution of weather systems in the midlatitude atmosphere is well-explained by the theory of quasigeostrophy (QG), in which slow, synoptic-scale airflows are described through the advection of potential vorticity (PV). The mathematics of QG is often justified by a limit of small Rossby number. However, this assumed limit is made invalid across the equator by the vanishing of the Coriolis effects. A globally-valid analog of QG (sPV), that is based upon the dynamics of PV, is developed for rotating shallow water on the sphere. Specifically, a PV-streamfunction relationship is defined which determines the flow velocities for the entire sphere. At midlatitudes, the fluid dynamics are asymptotically equivalent to the beta-plane theory of QG, in the usual small Rossby number sense. In the equatorial regions, wave propagation at short-scales mimics the dispersion relation for equatorial beta waves. Global Rossby waves, as described in recent works by Verkley (2007) and Schubert (2008), are also included within the sPV framework. As a benchmark test of the dynamics, the propagation of waves in the sPV model are shown to be an excellent approximation to computations of the equatorial crossing of topographic waves by Grose & Hoskins (1979). Despite that this sPV model is not obtained in the usual manner of small Rossby number asymptotic analysis, the propagation of mesoscale waves across the equatorial region retains QG-like accuracy. The mathematical consistency of these sPV dynamics with the rotating shallow water primitive equations is demonstrated from the perspective of ray theory. Extensions to baroclinic instability and the possibility of PV coupling to Kelvin waves are discussed.

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MS2

A Simple Model for Atmospheric Circulations Driven by Convection

This talk proposes a mathematical theory explaining the sharp transition between tropics and extra-tropics in terms of the diurnal cycle of thermal forcing by the sun. This transition, at a latitude of 30 degrees, coincides with the outer edge of the Hadley cells, and is marked by a steep jump in the height of the troposphere, from around fifteen kilometers in the tropics to about nine in the mid and high latitudes. The tropics, equatorwards of 30 degrees, are characterized by easterly surface winds -the Trades- and a strong diurnal signal in the wind, pressure and temperature, often marked by regular daily storms in the rainy season. Polewards of 30 degrees, the winds are westerly, and the weather systems have longer spatio-temporal scales. This change of behavior can be explained in terms of diurnal waves, created by thermal forcing and trapped equatorwards of 30 degrees by the Coriolis effect [**?**]. These waves organize the convective activity, leading to more active mixing and vertical transport in the tropics. This can be illustrated in simple mathematical models, presently ranging from forced linear oscillators to nonlinear conservation laws with entraining shock waves, accounting for the entrainment into the troposphere of air from the surface boundary layer.

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MS3

Seismic Imaging of Teleseismic Waves using Gaussian Beams

The earthquake seismology community now regularly uses seismic waves from distant sources to illuminate structures beneath seismic arrays in so-called passive imaging experiments. Similarly, oil reservoirs for petroleum applications can be imaged with seismic waves incident from below using sources in boreholes. Gaussian beams can be applied for passive imaging based on an over-complete frame-based Gaussian beam representation of the seismic wavefield. Paraxial Gaussian beams are then utilized for the propagation of the seismic waves back into the medium. The approach provides stable imaging of seismic data in smoothly varying background media where caustics and triplicated arrivals can exist. Gaussian beam imaging is found to be very flexible with respect to different experimental geometries and can be configured to allow for different types of converted or reflected waves. A synthetic example is first given for a collisional zone structure with an incident P-wave from below where several different scattered wave types are used to image the structure. Seismic data from the 1993 Cascadia experiment are then used to image the subduction zone beneath the Pacific Northwest in Oregon. Finally, Gaussian beam migration of seismic data from the recent Hi-CLIMB experiment in Tibet is used to image the Tibetan lithosphere. The results from Gaussian beam imaging are found to compare favorably with imaging results obtained using ray/Born inversion.

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MS3

Gaussian Beam Methods

Gaussian beams and their superpositions are approximate high frequency solutions to linear hyperbolic PDEs. In this talk, I will give a brief review of Gaussian beams and their superpositions and discuss some of the mathematical tools that are necessary to prove that they are valid asymptotic solutions. From a simulation point of view, I will address the question of how to decompose high frequency initial and boundary data into a superposition of Gaussian beams.

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MS3

The Basics of Constructing Frames Entirely out of Complex Gaussians and Applications to the Wave Equation

We focus on the construction of a frame of complex Gaussians for the space of $L^2(R^n)$ functions. When propagated along bicharacteristics for the wave equation, the frame can be used to build a parametrix with suitable error terms. When the coefficients of the wave equation have more regularity, propagated frame functions become Gaussian beams. This work is theoretical in nature and relates to the errors in Gaussian beam solutions.

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MS3

Frozen Gaussian Approximation for High Frequency Wave Propagation

The frozen Gaussian approximation provides a highly efficient computational method for high frequency wave propagation. It makes use of fixed-width Gaussian functions on phase plane to approximate the solution. The motivation comes from Herman-Kluk propagator developed in chemistry literature. The method works in both scenario of caustics and spreading. Lagrangian and Eulerian algorithms will be introduced in this talk. Rigorous analysis result on the convergence of this method will be also presented.

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MS4

Hybrid Simulations of Reactive Transport in

Porous Media

Darcy-scale models of flow and transport in porous media often fail to describe experimentally observed phenomena, while their pore-scale counterparts are accurate but can be computationally prohibitive. Most numerical multi-scale models, which seek to combine these two descriptions, require empirical closures and/or assumptions on the behavior of pore-scale quantities at the continuum (Darcy) scale. We present a general formulation of an iterative hybrid numerical method that links these two scales without resorting to such approximations. The algorithm treats the fluxes exchanged at the internal boundaries between the pore- and continuum-scale domains as unknown, and allows for iteratively determined boundary conditions to be applied at the pore-scale in order to guarantee their continuity. While the algorithm proposed is general, we use it to model Taylor dispersion in a fracture with chemically reactive walls. Results show significant improvement upon standard continuum-scale formulations.

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MS4

Influence of THMC Couplings on Thermal Recovery from EGS Systems

We explore the evolution of thermal output from EGS reservoirs where coupled THMC effects influence the evolution of permeability structure and respond to the presence of heterogeneity at a variety of length-scales. Heterogeneity results from the presence and initial length, orientation and strength of fractures present within the reservoir and the response is exacerbated by the strong coupling between THMC processes.

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MS4

Uncertainty Quantification in Stochastic Discrete Fracture Network THMC Model

Fractures and fracture networks are the principle pathways for migration of water and heat in enhanced geothermal systems, oil and gas reservoirs migration, carbon dioxide leakage from carbon sequestration field, and radioactive and toxic industrial wastes from underground storage repositories. A stochastic discrete fracture network and a HTMC coupling will be presented. Using Monte Carlo simulations, we present the impact of parameter uncertainties of the geological characterization on the response of the HTMC model.

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MS4

Hydromechanical Simulation of Triggered Earthquakes and Mine Dewatering

Two hydromechanical simulations are presented. (1) In south Iceland two magnitude Ms 6.6 earthquakes in June 2000 were separated by an 81-hour time delay and 18-km distance. The models test the hypothesis that the pairing is the result of a two-step triggering process. (2) In the former Homestake gold mine in Lead, S.D., smulations were able to explain the co-existence of shallow and deep flow systems, which are characterized by significantly different hydromechanical properties.

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MS5

Adaptive Pattern Research for Parallel Block Approximate Inverses

An adaptive algorithm is presented to generate automatically the non-zero pattern of the Block FSAI (BFSAI) preconditioner. It is demonstrated that in SPD problems BFSAI minimizes an upper bound of the Kaporin number of the preconditioned matrix. The mathematical structure of this bound suggests an efficient parallel strategy to improve a given non-zero pattern of BFSAI, providing a novel Adaptive BFSAI (ABF) preconditioner. Numerical experiments performed on large FE matrices provide evidence of ABF effectiveness.

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MS5

Block Preconditioners for Fully Implicit Atmospheric Climate Simulations

We discuss the development of block preconditioners in an effort to reduce computational costs associated with fully implicit time integration of atmospheric climate models within CAM-HOMME. We construct a fully implicit framework based on the shallow water equations and view the subsidiary linear system as a block matrix. Formal LU decomposition is performed and block preconditioners are derived based on approximations to the upper triangular block.

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MS5

Preconditioning for Flow and for Flow Control

I will describe some solution techniques for flow computations and for optimization problems for the control of flows. In particular, I will describe preconditioned iterative solution methods for incompressible viscous flow (Stokes and Navier-Stokes problems) and for problems of PDE-constrained optimization where incompressible flow equations provide the constraints. These approaches are applicable to finite element and other discretization methods.

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MS5

An Accelerated Fixed-Point Iteration for Solution of Variably Saturated Flow

We investigate effectiveness of an acceleration method applied to the modified Picard iteration for simulations of variably saturated flow. We solve nonlinear systems using both unaccelerated and accelerated modified Picard iteration as well as Newton's method. Since Picard iterations can be slow to converge, the advantage of acceleration is to provide faster convergence while maintaining advantages of the Picard method over the Newton method. Results indicate that the accelerated method provides a robust solver with significant potential computational advantages.

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MS6

Macroscale Potentials for Charged Swelling Porous Media

In this talk we discuss the macroscopic potentials that induce bulk fluid flow or diffusive flow through swelling porous materials. Swelling porous media such as expansive soils, food stuff, biotissue, and swelling polymers have complex microstructure such as a possibly charged solid surface and a large liquid-solid interface causing the solid and liquid to be highly interactive. Here we discuss the macroscopic pressures and chemical potentials that produce flow within the framework of hybrid mixture.

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MS6

A Two-Scale Computational Model of pH-Sensitive Swelling Porous Media

In this talk we present the pore-scale modeling of a porous medium composed of electrically charged macromolecules saturated by an electrolyte solution with four ionic monovalent species (Na+,CL-,H+,OH-). Ion exchange reactions give rise to a pH-dependent surface charge which is modeled by a nonlinear Neumann boundary condition for the Poisson-Boltzmann governing the local electric potential. By coupling the governing equations in the fluid domain with the elasticity problem for the solid particles the homogenization procedure is applied to upscale the model to the macroscale. Among the homogenized results a new constituive law is derived for the disjoining pressure dependent on pH. Numerical simulations of a free swelling experiment are performed and results compared with experimental observations.

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MS6

The Impact of Pore Deformation on Sorption and Capillary Condensation in Mesoporous Solids

We report recent theoretical developments in the study of gas-liquid transitions of fluids confined to deformable mesoporous materials. Due to a synergistic coupling the phase behavior of the confined soft matter phase is significantly affected by the deformation of the confining material which in turn is deformed as a result of phase changes occurring in the confined phase. If the confined fluid is gas-like its wetting characteristics affect the deformation isotherm such that the pore may expand or contract as more gas is adsorbed prior to capillary condensation. Directly at capillary condensation the pore abruptly shrinks on account of fluid-substrate attraction. If the density of the confined liquid-like phase is then enhanced further the pore expands again. This expansion allows one to determine nanomechanical properties of the confining solid directly from the deformation isotherm. In the future it might be possible to fabricate sensors that allow one to measure mechanically changes in thermodynamic properties of confined soft matter phases.

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MS6

Food Engineering Applications of Continuum Mechanics

During fluid transport processes such as drying, sorption and frying, physical and chemical changes take place in the food biopolymers. Hybrid mixture theory based multiscale equations were developed that allow incorporating these changes into transport models. Multiscale transport and thermomechanical equations were solved to predict fluid transport (vapor, water, oil) and viscoelastic stresses in foods. Comparisons were made to the macro and microscale experiments. The optimized operating parameters resulting in improved food quality were obtained.

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MS7

Upscaling Kinetics and Geometrical Heterogeneity for Flow and Transport Models

The transport of dissolved species in porous media is a major concern for the environment, for waste storage management, agriculture or carboxyde underground storage. Anomalous diffusion is frequently observed within the context of natural porous media, especially in the underground. We aim to focus on different meanings of the word "anomalous". We revisit the classical problem of dispersion of a point discharge of tracer in laminar pipe Poiseuille flow. For Péclet numbers corresponding to Taylor's dispersion regime, we derive rigorously an effective model for the enhanced diffusion. It is justified by error estimates. We explicit the retardation and memory effects of the adsorption/desorption reactions on the dispersive characteristics and show their importance. The chemistry influences directly the characteristic diffusion width and the effective convection. Then we show how tracer dispersion can be divided into three regimes. For small times, diffusion dominates advection yielding a symmetric Gaussian dispersion cloud. At large times, the flow is in the Taylor regime. However, in an intermediate regime, the longitudinal diffusion is anomalous. We emphasize that the previous effect is completely different from the nonfickian effects often observed before the diffusive asymptotic. An example involving fractional derivatives is rigorously constructed through random walks.

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MS7

Upscaling of Reactive Flows Involving Free Boundaries

We consider the transport of solute particles in a reactive flow under dominant transport conditions for the variable geometry in the case of a thin strip. We derive the upscaled model(1-D) from the 2-D model using perturbation methods and compare the 1-D model with direct 2-D computations numerically. Further, we use rigorous homogenization techniques for a specific choice of reaction rate, namely crystal precipitation and dissolution in periodic porous medium (fixed geometry case).

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MS7

Upscaling of Adsorptive Transport Under Unsaturated Condition

In general, solute transport mechanisms under saturated conditions have been studied in detail. However, under unsaturated conditions, these mechanisms need to be understood in greater detail. In such cases, dispersion coefficient varies with Darcy velocity and saturation, and principal interactions usually occur at the solid-water interfaces (SWI) and air-water interfaces (AWI), thus greatly influenced by water content. In this study, we have investigated upscaling of adsorptive transport process under unsaturated conditions.

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MS7

Upscaling in-situ Combustion Processes for Heavy Oil Recovery When Kinetics and Phase Behavior Wreak Havoc

In-situ combustion is an attractive enhanced recovery method for heavy oil reservoirs: a small fraction of the oil is burned in-situ, which creates a steam drive and mobilizes the oil. Traditional reservoir simulators are not capable of resolving the thin reaction fronts, because these are orders of magnitude smaller than the typical reservoir scale. Instead, we propose an upscaled model that effectively represents the heat generation and combustion products at realistic grid cell sizes.

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MS8

Reduced-Order Models for Boussinesq Flows

We consider POD-Galerkin models for Boussinesq flows. Reduced-bases are computed by post-processing multiple CFD simulations computed using different boundary condition inputs. The resulting model allows for time-varying boundary conditions and seeks to accurately predict the temperature in a comfort zone in a thermally stratified room. These models are developed to model thermal transport in buildings and design the control systems (controllers as well as sensor/actuator placement).

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MS8

New Methods for Estimating Poleward Eddy Heat Transport using Satellite Altimetry

Current-generation altimetry products are too coarse to resolve most of the turbulent spectrum of the ocean and drastically underestimate eddy fluxes such as the poleward heat transport. We show that, by extracting aliased high-wavenumber information from the low-wavenumber band, one can derive "superresolved' velocity fields from sparse satellite observations. When used in combination with an adaptive stochastic model for the unresolved scales, these techniques produce significantly better estimates of poleward eddy heat transport.

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MS8

The Two-dimensional Boussinesq System - Analytical and Computational Study

Abstract not available at time of publication.

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MS8

Poisson Solvers in Thin Domains

Abstract not available at time of publication.

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MS9

Quantifying Uncertainty in Wind Power Predictions for Stochastic Unit Commitment Optimization

We discuss uncertainty quantification in wind power forecasts using numerical weather prediction (NWP) models with applications in proactive management of energy systems. Weather is one of the major drivers of energy generation and consumption, especially with the adoption of such renewable resources as wind. Our strategy consists in using numerical dynamical models to forecast ambient conditions and propagate uncertainties from initial conditions to produce accurate confidence intervals. We analyze the impact of assimilating satellite radiance in our forecasts. We present an integrative unit commitment or energy system scheduling problem that uses weather forecasts with uncertainty, and validate our results using real observations.

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MS9

Data Assimilation System Diagnosis and Tuning of Error Covariance Parameters

The specification of accurate statistical information on the errors in the prior state estimate and observational data is unanimously recognized as a major practical difficulty in geophysical data assimilation. A mathematical formalism to adjoint sensitivity analysis for diagnostics and tuning of the error covariance input parameters is provided in the context of variational data assimilation. Applications to atmospheric modeling are presented from the proof-of-concept stage to the current status of implementation at numerical weather prediction centers.

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MS9

Computational Performance of a Parallel Matrix-free Implementation of the Ensemble Kalman Filter

The Ensemble Kalman Filter (EnKF) has become an important data assimilation tool for numerical models in geosciences. For large data sets a potential bottleneck in EnKF is the computation of the Kalman gain matrix. In this talk we discuss a matrix-free parallel implementation of EnKF where the form of the matrices is exploited using a Sherman-Morrison-Woodbury inversion algorithm. This approach scales linearly with the number of observations. Performance results with a shallow-water model are presented.

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MS9

Comparison of Ensemble Data Assimilation Methods in the Presence of a Nonlinear Observation Operator

A new comparison of three frequently used sequential data assimilation methods illuminating their strengths and weaknesses in presence of linear and nonlinear observation operators is presented. The ensemble Kalman filter (EnKF), the particle filter (PF) and the Maximum Likelihood Ensemble Filter (MLEF) methods were implemented and spectral shallow water equations model in spherical geometry model was employed using Rossby-Haurwitz Wave no 4 as initial conditions. Numerical tests reveal that all three methods perform satisfactory for linear observation operator 15 days model integration, whereas EnKF, with the nonlinear observation operator failed. The particle filter and the hybrid filter (MLEF) both performed satisfactorily with highly nonlinear observation operators .

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MS10

Amplitude Calculations for 3-D Gaussian Beam Migration using Complex-valued Traveltimes

The use of Gaussian beams to represent Green's functions in 3-D Kirchhoff migration algorithms adds four additional integrals to the processing. Ross Hill reduced the four integrals to two via the method of steepest descent for integrals with complex exponents. He presented the travel time adjustment, but not the amplitude adjustment necessary for a "true amplitude' approximation in the Kirchhoff sense. We provide that adjustment here, using a recently developed iterated method of steepest descent.

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MS10

Seismic Imaging with Gaussian Wave Packets

Fast algorithm for a reverse-time migration of seismic data can be designed using a flow-out of Gaussian wave packets (GWPs). It consist of three main steps: data decomposition into GWPs; their flow-out into subsurface; imaging condition (cross-correlation of 'source' and 'receiver' fields). We achieve sparse data representation with GWPs using iterative non-linear algorithm based on l1-optimization ideas. Rigid GWP flow-out along rays is used for downward data continuation. Analytic formulas can be used for cross-correlating GWPs after their flow-out (fast implementation of the imaging condition).

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MS10

Improving Wave-equation Fidelity of Gaussian Beams by Solving the Complex Eikonal Equation

Gaussian beams are a well-known wavefield approximation. A more accurate representation can be obtained by solving the complex eikonal equation. We propose a constructive algorithm for solving the complex eikonal equation. By re-writing the complex traveltime as background real and imaginary parts and their respective perturbations, we arrive at an update scheme that aims at solving the complex eikonal equation iteratively. The initial prior may come from the Gaussian beam approximation computed by dynamic ray tracing. The result embraces complete details of the velocity model and therefore can help enhancing accuracy of Gaussian-beam migration and other applications of Gaussian beams in seismology.

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MS10

Recovery of High Frequency Wave Fields

Gaussian beams are asymptotically valid high frequency solutions to hyperbolic partial differential equations, concentrated on a single curve through the physical domain. They can also be extended to some dispersive wave equations, such as the Schroedinger equation. Superpositions of Gaussian beams provide a powerful tool to generate more general high frequency solutions that are not necessarily concentrated on a single curve. We are concerned with the accuracy of Gaussian beam superpositions in terms of the wavelength, which was thought a rather difficult problem decades ago. We present a systematic construction of Gaussian beam superpositions for all strictly hyperbolic and Schroedinger equations subject to highly oscillatory initial data, and obtain the optimal error estimates in the appropriate norm dictated by the well-posedness estimate. The obtained results are valid for any number of spatial dimensions and are unaffected by the presence of caustics. This talk presents key ideas and techniques involved in this newly developed recovery theory of high frequency wave fields, with materials drawn from recent works with J. Ralston (UCLA), and with N. Tanushev (UT-Austin) and O. Runborg (KTH).

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MS11

Multilevel Model Reduction Approaches for Flows in Multiscale Porous Media

In this talk, I will describe multilevel multiscale methods for flows in highly heterogeneous media with high contrast. In particular, I will describe multilevel construction of basis functions and how they can be used in preconditioning of flow equations.

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MS11

A Data-driven Stochastic Multiscale Method for Model Reduction and Uncertainty Quantification

We introduce a data-driven stochastic multiscale method to solve stochastic PDEs. One important feature of this methods is to construct a multiscale stochastic basis from limited samples of the stochastic solutions obtained by Monte Carlo methods. This multiscale method effectively reduces the dimensionality of the stochastic PDEs. As a consequence, we reduce the high dimensional stochastic problem to a relatively small number of coupled deterministic PDEs. Some numerical results will be presented to demonstrate the effectiveness of the method.

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MS11

Use of Reduced-order Models for Improved Data Assimilation within an EnKF Context

Reduced order modeling using trajectory piecewise linearization (TPWL) has been shown to achieve dramatic (2-3 order of magnitude) speedup for production optimization problems. In this work, we extend TPWL methodology to history matching problems. The TPWL representation is then incorporated into an Ensemble Kalman Filter (EnKF) method. TPWL and EnKF combine well, as the EnKF ensemble provides a reasonably large and varied training set for TPWL. Further, because of the sequential nature of EnKF, where forecasting is performed over short time periods, the use of linearized models is reasonable. The performance of the new methodology on 2D and 3D example cases is demonstrated.

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MS11

Toward Effective Multiscale Parameterization of Reservoir Models

A survey of emerging approaches toward reliable reservoir performance Uncertainty quantification and history matching often require a large number of reservoir simulations that is often infeasible in practice. At the core of the challenge is the curse of dimensionality. In this talk, we examine the premises of the existing modeling approach and review recent advances in reservoir characterization, geologic modeling, and understanding of impact of geologic features on fluid flow. These advances point to potential ways of effective, multiscale parametrization of reservoir models.

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MS12

Thermo-hydro-mechanical Modeling in Porous Media: A Coupled Mixed and Galerkin Finite Element Formulation

The efficient solution to the coupled system of PDEs governing the mass and the energy balance in deformable porous media requires advanced numerical algorithms. A combination of Mixed and Galerkin Finite Elements along with a staggered method are employed, addressing iteratively flow-deformation by a coupled approach and heat transport via a splitting technique, at each time step. Such formulation warrants stable numerical solutions, element-wise conservative velocity fields and accurate prediction of sharp temperature convective fronts.

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MS12

Coupled Poromechanics of Faulted Reservoirs

The coupling between pore pressure and mechanical deformation is essential to understand the initiation of fault slip and the evolution of fault hydraulic properties. This coupling is likely a critical determinant of when and where earthquakes are triggered, but the mechanisms controlling the influence of the pore pressure field on the onset of slip are currently poorly understood. Here, we present a coupled model of flow and mechanics of faulted geologic reservoirs. Faults are represented as 2D entities embedded in a 3D domain, which exhibit irreversible behavior in their friction and dilatancy poromechanical response. We employ an unconditionally-stable iteratively coupled scheme to solve the coupled flow-mechanics equations, which we implement in an open source tectonic deformation simulator.

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MS12

Coupling Geomechanics and Multiphase Flow in Porous Media

We discuss Biot models that treat the coupling of multiphase flow and elasticity in different subdomains. Extensions that include compositional flow are also considered. Here we employ locally conservative algorithms such as mixed finite element methods for flow and Galerkin for mechanics. Theoretical error estimates for certain model problems will be given as well as computational results.

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MS12

Scalable Newton-Krylov Solvers for Coupled Hy-

dromechanical Systems

In this work, we consider efficient solution methods for mixed finite element models of fluid flow through deformable porous media. In many geotechnical and geophysical applications, the behavior of a solid/fluid mixture is highly-nonlinear, introducing additional challenges for tightly-coupled solution algorithms. In our talk we focus on the implementation of implicit Newton-Krylov methods for coupled hydromechanical problems. The main difficulty is to design effective preconditioners that achieve good algorithmic scaling on today's high performance computing platforms. We highlight an approach in which preconditioners are constructed from block factorizations of the coupled systems. The resulting methodology allows one to extend single-physics preconditioners in a natural way to multiphysics applications, allowing for significant code reuse and an object-oriented framework. We test the performance of the proposed techniques on several numerical examples drawn from geotechnical and reservoir engineering applications.

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MS13

Iterative Solution Methods for Stokesian Dynamics

Stokesian dynamics is a computational technique for simulating the motions of particles suspended or dispersed in a fluid medium and interacting through hydrodynamic and non-hydrodynamic forces. Particle velocities are computed from the forces by solving with a resistance matrix which is a function of particle positions and orientations only. The resistance matrix is composed of a slowly-changing, dense, long-range component, plus a fast-changing, sparse, indefinite, short-range component. We discuss iterative solution methods for scaling up Stokesian dynamics to very-large problem sizes by exploiting this structure of the resistance matrix, as well as the design of preconditioners suitable for upcoming high-performance computing architectures. *Joint work with Tadashi Ando and Jeffrey Skolnick.*

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MS13

Constraint Preconditioners for Ill-conditioned Consolidation Problems

Block constraint preconditioners prove very efficient for the solution of the indefinite linear systems arising in FE consolidation problems. Their implementation on parallel computers, however, is not straightforward. We present a novel Parallel Inexact Constraint Preconditioner (ParICP) which is based on Block FSAI, a recent and promising development in the field of approximate inverses. ParICP is a scalable and efficient implementation of constraint preconditioning for high performance computing, proving very robust especially in ill-conditioned problems.

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MS13

Preconditioning Surface and Subsurface Flow Coupling for Arbitrary Geometries on a Structured Grid

Due to complex dynamics inherent in the physical models, numerical formulation of subsurface and overland flow coupling can be challenging to solve. ParFlow is a subsurface flow code that couples with overland flow via an overland boundary condition prescribed at the top surface. This talk will present a preconditioning approach to discrete systems arising from implicit coupling of these flow regimes in ParFlow. Numerical results will explore the effectiveness of the preconditioner and its cost.

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MS13

Quasi-Newton Preconditioner Updates for Two-phase Flow Simulations

We study Broyden-type rank-one updates of an initial preconditioner for solving the sequence of linear systems arising from Newton-like linearizations of FEM-discretized two-phase flow problems. Starting from the incomplete LU decomposition of the initial Jacobian matrix, we apply this approach to build a sequence of preconditioners. Numerical experiments show a reduction in the number of iterations needed to achieve convergence in the linear solver and in the cost of computing the preconditioner.

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MS14

Evaporative Deposition Patterns of Bacteria and Microspheres from a Sessile Drop: Potential for Characterizing Particle Adhesiveness

Evaporative deposition of colloidal particles (bacteria and microspheres) on mica from a sessile drop is investigated as a simple way to control particle deposition as well as investigate fundamental particle-surface forces. We show that it is possible to continuously vary the deposition pattern from ring deposits to cellular pattern deposits by incremental changes in surface wettability which we achieve by timed exposure of the mica surface to the atmosphere.

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MS14

Heterogeneous Reactions with Memory and Links to Multirate Mass Transfer Models of Convolution Type

The convolution form used to express mass transfer between mobile and immobile aqueous domains, and often associated with multirate mass transfer representations of matrix diffusion processes, is generalized to the case of unequal forward and reverse rates for each of the multiple rates of the multirate mass transfer, and is shown to represent also linear but non-Markovian reactions that kinetically partition mass between mobile and immobile phases with rate of return to mobile phase dependent on contiguous time spent in immobile phase. In the case where a multirate model refers to multiple sites with distributed mobilization or release rates but single-valued immobilization rate, an equivalent formulation is found using single site mobilization-immobilization with non-Markovian mobiliation rate dependent on contiguous time spent immobilized.

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MS14

Fractional Brownian Motion Run with a Non-linear Clock

We construct a family of stochastic processes with nonstationary, correlated increments which allow a priori independent selections of both fractal dimension and mean-square displacement. The family is essentially fractional Brownian motion (fBm) run with a non-linear clock (fBm-nlc). The fractal dimension of fBm-nlc is shown to be the same as that of the underlying fBm process. We also compute the p- variation and discuss the problems in using this to differentiate between diffusive processes.

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MS14

Upscaling Chaotic Dynamics in Porous Media via Central Limit Theorems

There are several upscaling (renormalization) techniques for transport in porous media. All approaches in Statistical Mechanics except the upscaling tool via central limit theorems (CLT) use second moments. When Levy motions are applied to velocity or position processes CLT plays significant roles in modeling transport in porous media. In this talk, I will present the results in the CLT approach for microbial motility in porous media.

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MS15

Homogenization of the Linearized Ionic Transport Equations in Rigid Periodic Porous Media

We undertake the rigorous homogenization of a system of PDEs describing the transport of a N-component electrolyte in a dilute solvent through a rigid porous medium. Smallness of the electric field and hydrodynamic force, allows us using O'Brien's linearized equations as the starting model. We establish convergence of the homogenization procedure and prove that Onsager's effective tensor is symmetric positive definite. (Joint work with G. Allaire (Paris) and A. Piatnitski (Narvik))

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MS15

Homogenization of a Sulfate Corrosion Problem: Modelling and Analysis

We model and then analyse a reaction-diffusion (RD) scenario describing the agressive corrosion with sulfates of the sewer pipes made of concrete. Besides being partly dissipative, our RD system includes two interface-reaction mechanisms: (1) the Henry's law and (2) a non-linear chemical reaction capturing the action of the most aggressive species – SO_4^{2-} – on the boundary of the pore walls. After discussing basic aspects of the pore-model analysis, we focus on the rigorous derivation of a set of macroscopic equations. As periodic homogenization limiting procedure, we use the two-scale convergence approach combined with the periodic unfolding. The main difficulty lies in passing to the (homogenization) limit in the nonlinear reaction terms defined on the oscillatory micro-interfaces. We derive both the weak and strong formulation of the limiting RD system. We conclude the talk by pointing out correctors, which define the quality of our averaging procedure.

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MS15

Colloid and Fluid Dynamics in Porous Media - Modelling, Analysis and Numerics

We consider a non-stationary electro-hydrodynamic system at the pore scale. After applying homogenization technique to this system of partial differential equations we discuss the resulting equivalent macroscopic model description. These theoretical results are complemented by numerical simulations. As special application we thereby focus on colloidal transport within a porous medium, which fundamentally influences contaminant transport. Extensions of the model regarding changes of the underlying microstructure due to interaction with the porous matrix will also be considered.

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MS15
Moving Boundary Problems in Porous Media

We discuss processes in porous media with moving boundaries at the pore-scale such as deposition, biofilm growth and crystal dissolution and precipitation. All these processes may change the pore geometry. We use the pore-scale free boundary problem to derive upscaled effective equations on the Darcy scale via a formal homogenization procedure. Numerical simulations show that solutions of the upscaled model match the averaged solutions of the pore-scale model very well.

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MS16
A Predictive Pore-Scale Model for Non-Darcy Flow in Porous Media

Non-Darcy flow is porous media often observed in domains where relatively high velocities occur. In these regions an empirical model, Forchheimers equation, is used. In this study, we use the method of homogenization to develop a filtration law in porous media that includes the effects of inertia at finite Reynolds numbers. A major contribution of this study is that the coefficients of the polynomial law can be derived a priori, by solving sequential Stokes problems.

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MS16
Modeling of Well Productivity Index for Nonlinear Flows and Applications in Reservoir Engineering

Motivated by the concept of the well Productivity Index (PI) we study a functional for general non-linear Forchheimer equation. The impact of the nonlinearity on the value of the PI is analyzed. Exact formula for the "skin factor' in radial case is derived. Dynamics of the PI for the class of boundary conditions is studied. Developed framework is applied to obtain non-linear analog of Peaceman formula for the well-block pressure in unstructured grid.

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MS16
On Non-Darcy Flows in the Porous Media

Non-Darcy flow is usually treated by approximate analytical and numerical techniques in petroleum engineering. Recent applications in gas reservoirs, hydraulic fractures, and naturally fractured porous media, however, require more detailed treatments. Of particular interest are the pressure- and rate-transient responses of wells under the influence of non-Darcy flow. This talk will summarize the standard treatment of non-Darcy flow in petroleum engineering and discuss the approximate application of deconvolution for non-Darcy flow.

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MS16
Modeling Flow with Inertia at Porescale and Mesoscale: Implications for Transport

We discuss computations of flow at pore-scale and mesoscale via discretizations of Navier-Stokes and non-Darcy models. We upscale from pore-scale for linear laminar and inertia regimes of Reynolds numbers and compare with experimental data. We address the issues of grid-convergence and appropriate scaling needed when REV and grain size change, as in homogenization. Most recent results concern the influence of inertia models on the parameters of transport coupled to the flow at pore-scale and mesoscale.

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MS17
UTBEST3D – A Coastal Ocean Modeling System Based on a Discontinuous Galerkin Method

We describe the application of a Local Discontinuous Galerkin method to the three-dimensional hydrostatic system in primitive variables for coastal and ocean modeling. Starting from a simple 'proof-of-concept' code UTBEST3D grew into a modular, object-oriented, highly scalable parallelized package that can be used to simulate barotropic and baroclinic turbulent flows for a wide range of physical conditions and forcings.

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MS17

Issues in Coastal Ocean Modeling

In this talk we will give an overview of current issues in coastal ocean modeling that will be discussed by various speakers in this minisymposium. We will also discuss recent research on hurricane storm surge modeling and the application of discontinuous Galerkin methods to modeling flow and transport processes in the near shore.

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MS17

A Triangular Discontinuous Galerkin Coastal Ocean Model (dgcom)

We will report on current and future developments of DGCOM which is a research code for simulating tsunamis and storm surges. In this talk we will report on the inclusion of high-order time-integrators including their implementation with boundary conditions (no-flux, non-reflecting, and wetting and drying conditions). Finally, we will describe our plans to include adaptivity into the triangular code for tracking storm-surges. Time permitting, we will describe the DG non-hydrostatic atmospheric model that is also under development that will be used to generate the wind stresses to be used in storm-surge simulations. The overlap between the two models will be discussed as well as the MPI implementation of the DG amtospheric model and strategies for coupling the two models.

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MS17

Quantifying Uncertainty in HYCOM simulation of the Gulf of Mexico

Oceanic simulations have numerous input parameters that are either unknowns, obtained from calibration, or known only approximately. These include, for example, initial and boundary conditions, as well as parameter embedded within subgrid scale parametrization. These uncertainties lead naturally to uncertainties in the output parameters; parametric studies must then be performed to explore the dependency of the solution on these parameters. Here we explore one approach to uncertainty quantification using polynomial chaos expansions, and apply the methodology to Gulf of Mexico simulations using the Hybrid Coordinate Ocean Model. Examples of uncertainty outputs will be be presented, and the potential and limitations of the methodology will be presented.

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MS18

Variational Data Assimilation for Fine-scale CO2 Source/Sink Estimation

Measurements of atmospheric CO2 concentration are becoming available at increasingly dense spatial and temporal resolution, most notably from satellites such as GOSAT, the OCO reflight mission, and other planned missions. If successful, these data could permit estimation of sources and sinks of CO2 at scales of 100-200 km or better, at subsynoptic time resolutions. While these data will initially permit only net CO2 sources to be estimated, separation of the anthropogenic and natural components may also become easier using measurements of other species, such as C14, NOx, etc. Estimating surface CO2 fluxes at atmospheric model grid resolution imposes computational demands that are being met with methods that achieve their efficiency by abandoning the calculation of the full-rank covariance of the estimate. Here we present one of these methods, variational data assimilation, as applied to the surface source/sink problem. We will discuss the physical aspects of the problem, including the linearity of atmospheric transport (no internal chemical sinks) for CO2, as well as the time scales of atmospheric mixing, and their implications for any estimation system. We will outline the the method, including a description of the control variable strategy used. We will discuss the calculation of the low-rank covariance estimate, computed here using the BFGS method. And we will give some representative results from simulation studies.

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MS18

A Geostatistical Ensemble Square-Root Filter for Estimating Surface Fluxes of CO2

In recent years, one of the important challenges that has emerged in CO2 source/sink estimation is the increase in computational cost associated with solving the atmospheric inverse problem. Solving problems in batch mode is becoming more and more computationally infeasible given the increasing spatial and temporal resolution of satellite data and ground based CO2 concentration measurements.

The alternative to these batch approaches are data assimilation (DA) techniques that efficiently solve the inverse problem by making certain numerical approximations. However, a fundamental question that has remained unanswered is the impact on estimation precision and accuracy by implementing the numerical DA tools relative to batch inversions. In this work, we will present the first results from a geostatistical ensemble square root filter that is used to estimate CO2 surface fluxes over North America using ground-based continuous measurements for 2008. The geostatistical ensemble square root filter is a novel method that is being developed to take advantage of both the versatility of a geostatistical inverse modeling framework, and of the computational efficiency of the ensemble approach. This presentation will not only focus on the methodological framework driving the geostatistical ensemble square root filter but also on comparing the results from the filter with a batch solution for the same problem. The sensitivity of both estimates and their uncertainties due to a shift from geostatistical batch inversion to a geostatistical ensemble technique will be analyzed. Further discussions will centre around the properties of the filter (for example, impact of ensemble size, representation of error covariances and their propagation, adaptive inflation etc.) and the overall framework required to reduce the computational cost associated with CO2 source/sink estimation while providing a best estimate and estimated uncertainty equivalent to traditional batch inversions.

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MS18

Quantification of Uncertainty for the Vulcan Project High Resolution Fossil Fuel CO2 Emissions Data Product

Abstract not available at time of publication.

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MS18

Ensemble Kalman Filters Applied to CO2 Source Inversion

We present a numerical study using a hybrid Ensemble Kalman Filtering (EnKF) algorithm to invert for CO2 sources. The underlying transport model is a convection-diffusion model in which the source terms are represented by the pixels of a satellite image of the US at night. The intensity of the lights represents the magnitude of the emissions. We investigate the use of this model as prior information in the EnKF based inversion.

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MS19

Mesh-independent Finite Element Methods for Earthquake Simulation

Earthquake simulation is complicated by the complex nature of faults which rupture. Faithful representation of the fault network geometry and solution robustness to variation of this geometry have proven difficult problems for standard finite element methods, which require simulation meshes to conform to the faults. Here we present a mesh-independent method, in which faults are included independently of the simulation mesh. We demonstrate the versatility of the method in earthquake and crustal deformation simulations.

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MS19

Large-scale Earthquake Simulations and the Prediction of Strong Ground Motion

Accurate, scalable numerical simulations of earthquake ruptures and the concomitant excitation and propagation of stress waves in realistic three-dimensional geologic models are important to our understanding of the physics of earthquakes and the prediction of strong ground motion. We give an overview of some insights that have accrued from recent large-scale simulations. These have revealed unexpected interactions between the source and the geologic structure that have been further illuminated by adjoint simulations.

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MS19

Adaptive Mesh Refinement for Earthquake Rupture Simulations

Strong shaking from large earthquakes extends tens to hundreds kilometers from faults of comparable size, but numerically resolving laboratory-constrained frictional processes requires millimeter to centimeter grid spacings. Constrained by current computational resources, the standard modeling approach is to use approximately constant grid spacings with artificially increased frictional length scales. We present an alternative approach that uses adaptive

mesh refinement to exploit the fact that fine-scale resolution needs are localized around the propagating rupture front.

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MS19

Simulations of Long-term Slip of Earthquake-producing Faults: Importance of Incorporating Full Inertial Effects during Seismic Slip

We study mechanics and physics of earthquakes using a unique modeling approach that reproduces both earthquakes and slow slip, with full inclusion of inertial effects during simulated earthquakes. Here, we compare this approach to a popular simplified, so-called quasi-dynamic, method, in which inertial effects are incorporated through a radiation damping approximation. We find that the two methods can produce qualitatively different earthquakes and long-term fault behavior. Our eventual goal is to determine the range of applicability for the quasi-dynamic approaches.

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MS20

An Energy-conserving Discontinuous Multiscale Finite Element Method for the Wave Equation in Heterogeneous Media

In this talk, we present a new multiscale finite element algorithm for simulating acoustic wave propagation in heterogeneous media. This method solves the wave equation on a coarse grid using multiscale basis functions and a coupling mechanism to relate information between fine and coarse grids. Our method is based on a mixed formulation of the wave equation and staggered discontinuous basis functions. Thus, our multiscale methods have the following nice properties. (1) The total wave energy is conserved, (2) Mass matrix is diagonal on a coarse grid and energy-preserving, and (3) Multiscale basis functions can accurately capture the subgrid behavior. Some numerical results will be shown. This is a joint work with Yalchin Efendiev and Richard Gibson.

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MS20

A Bayesian Uncertainty Quantification of Fractured Reservoirs using Surrogate Flow Model

The modeling of fractured reservoirs typically involves separation of the matrix and fracture parameters, and we begin by introducing a surrogate dual porosity, dual permeability model for tracer flow in this type of system. To quantify the uncertainty, the ideal situation is to integrate available static and dynamic data into this surrogate model. This is accomplished within a Bayesian framework using Markov Chain Monte Carlo methodology. A number of numerical examples are presented to illustrate the performance of the method.

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MS20

A New Problem Adapted Hierarchical Model Reduction Technique Based on Reduced Basis Methods and Dimensional Splitting

We present a new dimension reduction technique [M. Ohlberger and K. Smetana, 2010]. In comparison to the Boussinesq approach we do not neglect the dependency on the vertical direction but enhance the solution for the horizontal direction with appropriately chosen basis functions living on the vertical one. This is done by a combination of the frameworks of hierarchical model reduction [S. Perotto, A. Ern, and A. Veneziani, 2010] and the reduced basis methods [B. Haasdonk, M. Dihlmann and M. Ohlberger, 2010]. We derive a new a posteriori error estimate and demonstrate in numerical experiments that few basis functions suffice to get good approximations.

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MS21

A Practical Modeling Approach to Evaluate Long-term CO_2 Storage in Real Geological Systems

Large-scale models of CO_2 injection into geological formations must capture the relevant geological and geophysical processes that affect the migration and ultimate fate of injected CO_2. These processes span many spatial and temporal scales, and traditional numerical methods cannot solve these large, complex systems in a practical way. A new modeling approach solves coarse-scale vertically-integrated governing equations that are coupled with subgrid models to capture important small-scale processes in an efficient and accurate way.

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MS21

The Effect of Capillary Forces on Two-phase Flow

We derive a two-phase gravity current model from fractional flow theory under the assumption large aspect ratio and vertical gravity-capillary equilibrium. The saturation profile in combination with the relative permeability determines the dynamics of the two-phase current. The model significantly improves estimates of the vertical sweep, the magnitude of residual trapping, and the propagation speed of the current. This model provides physical insight and an efficient formulation for large scale geological carbon dioxide storage.

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MS21

Stochastic Inversion of Seismic and Electromagnetic Data for Co2 Saturation Prediction

Stochastic inversion of seismic (AVA) and electromagnetic (CSEM) data are used to predict CO2 saturation. A 2D synthetic model constructed for hydrocarbon exploration has been adapted to fill the reservoirs with CO2. Synthetic seismic and CSEM data are used to test the resolution of CO2 saturation predictions under a range of experimental variables. The choice of rock physics model, the proximity of wells used for rock physics, noise levels and choice of geophysical forward models all effect the quality of the CO2 saturation prediction.

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MS21

Time-lapse Wave-equation Imaging of CO2 Geosequestration

Time-lapse seismic monitoring of CO2 geosequestration is emerging as an important geophysical research field. Most 4D seismic inversions for estimating elastic property change are linearized about baseline elastic models. Large-scale CO2 injection, though, can introduce large property perturbations that lead to complex wavefield coda and a strongly non-linear inversion problem. We demonstrate that overcoming this non-linearity requires a time-lapse seismic inversion procedure that includes 4D depth velocity analysis and migration.

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MS21

The Rock Physico-chemical Basis for Time-lapse Seismic Reservoir Monitoring of CO_2 Injection

4D laboratory experiments, high-resolution imaging, and computational rock physics are used to monitor the effect of physicochemical processes occurring upon injection of CO_2 within sandstone and carbonate rocks. The goal is to understand the effect of salt precipitation and dissolution on transport and seismic properties and verify the need for extending tools currently available in rock physics to infer subsurface conditions where the coupling between pore fluids and rock matrices is not purely mechanical. Results show that the seismic response of CO_2-brine-rock systems is far from being a pure fluid-substitution problem.

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MS22

Mixed Hybrid and Linear Conforming Finite Elements for the Simulation of Reactive Multicomponent Transport in Porous Media

Mixed hybrid FE are applied to reactive transport in porous media and compared to linear conforming FE with respect to the numerical diffusion they introduce and their behavior in the case of discontinuous coefficient functions. A general discretization of the nonlinear transport-reaction equations with RT_0, BDM_1 and RT_1 elements is shown. We present numerical tests giving evidence that mixed schemes may be preferable for this application where the primary unknown is not a vector variable.

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MS22

A More Robust MHFE Scheme for Solute Transport in Porous Media

We present a new, more robust mass conservative finite element scheme for reactive solute transport in porous media. The transport is modelled by a convection-diffusion-reaction equation, including equilibrium or non-equilibrium sorption. The numerical scheme is based on mixed hybrid finite elements (MHFE) and it is more efficient for high Péclet numbers as the classical one [1]. The lowest order Raviart-Thomas elements are used. We also present an upwind variant of it, which should be considered for strong convection dominated problems. Various numerical tests, including the case of heterogeneous soil are shown.

REFERENCES

F.A. Radu, N. Suciu, J. Hoffmann, A. Vogel, O. Kolditz, C-H. Park and S. Attinger. Accuracy of numerical simulations of contaminant transport in heterogeneous aquifers: a comparative study. Advances in Water Resources, 2010, doi:10.1016/j.advwatres.2010.09.012.

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MS22

Convergence and Interpolation of Numerical Raw Field Methods on General Grids

We discuss conditions and limitations for convergence of some multi-point flux approximation (MPFA) methods on polyhedral meshes in the presence of a discontinuous permeability field. In a more general setting we look at what the difference between raw field methods (like the MPFA and mimetic FD methods) and full field methods (like the mixed finite element method) implies and the importance of interpolation. Our discussion is supplemented with some illustrative numerical examples

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MS22

Guaranteed and Robust a Posteriori Stopping Criteria for Iterative Linearizations and Linear Solvers

We present a posteriori error estimates of the linearization error in approximation of nonlinear problems and of the algebraic error in the solution of linear systems and derive stopping criteria for (non)linear iterations. Our estimates control the overall error. They are also locally efficient and thus allow to predict the error spatial distribution and to refine the mesh adaptively. We present strategies for achieving a user-specified accuracy at minimal cost and illustrative numerical experiments.

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MS23

Continuous and Discontinuous Data Assimilation Methods for Estimating a Heterogeneous Conductivity Field by Assimilating Transient Solute Transport Data

An ensemble Kalman Filter (EnKF) is developed to identify a hydraulic conductivity distribution in a heterogeneous medium by assimilating solute concentration measurements of solute transport in the field with a steady state flow. A synthetic case with the mixed Neumann/Dirichlet boundary conditions is designed to investigate the capacity and effectiveness of the proposed continuous and discontinuous data assimilation methods to identify a conductivity distribution. The developed method is demonstrated in 2-D transient solute transport. The study results indicate that the EnKF method will significantly improve the estimation of the hydraulic conductivity field by assimilating continuous or discontinuous solute concentration measurements. In comparison with the continuous data assimilation method, the discontinuous data assimilation method can better identify the heterogeneous conductivity field, especially in the downstream flow field

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MS23

Some Recent Advances in the Scaling of Earth and Environmental Variables

It has been demonstrated theoretically and numerically by the author that data sampled from fractional Gaussian/Lévy noise (fGn/fLn) exhibit apparent/spurious multifractality. Here we generalize Neuman's development in a way that (a) rigorously subordinates (truncated) fLn to (truncated) fGn, (b) extends the analysis to a wider class of subordinated self-affine processes and (c) explains why the distribution of corresponding data tends to evolve from heavy tailed at small lags (separation distances or scales) to Gaussian at larger lags.

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MS23

Uncertainty Quantification in Subsurface Modeling

We consider a a set of parabolic partial differential equations with uncertain coefficients that describe flow and transport in heterogeneous porous media. To quantify predictive uncertainty in such systems, we treat uncertain coefficients as random fields with known statistics, which renders the corresponding governing nonlinear differential equations stochastic. We derive a deterministic equation for the probability density function (PDF) of the system state. By going beyond computing system state's mean and variance, which is the standard practice in many uncertainty quantification studies, the PDF equations enable one to compute probabilities of rare events (distribution tails), which are required in modern probabilistic risk analyses.

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MS23

Iterative Coupling for Treating Compositional Flow and Geomechanics

We formulate a scheme for coupling an equation of state (EOS) compositional flow model with elasticity. We discuss iterative coupling, discretizations, solvers, and parallel scaling issues.

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MS24

Interface Conditions for Fluid Flow in Porous Media withReduced Order and Non Matching Fractures

For large scale computations of flows in porous media with complex fracture networks the conformity of the mesh can represent a severe constraint. We propose a method that allows for non-matching grids, thus very advantageous if the position of the fractures is uncertain and multiple simulations are required. We consider mixed hybridized finite elements for the discretization of the bulk flow and the reduced problem in the fractures and provide the correct interface conditions.

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MS24

Darcy-Stokes Fracture Flow

The asymptotic analysis of Darcy flow in a region coupled to Stokes flow in a very thin fracture is revisited. The appropriately scaled model leads to a limiting problem consisting of Darcy flow in the region coupled to Brinkmann flow in the fracture.

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MS24

Schur Complement Preconditioning for Flow Simulation in 3D Discrete Fracture Networks

The simulation of flow in discrete fractured media requires to solve very large linear systems. Those systems are sparse and with a specific shape due to the underlying physical problem. In order to take advantage of this specific structure, a preconditioned conjugate gradient method based on the Schur complement is used. Several preconditioning approaches are tested. We present simulations results in sequential as well as in parallel.

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MS24

Modeling Fluid Flow Along Faults

We study an approach to model fluid flow along fault compatible with the standard oil industry flow simulators where faults are represented by interfaces across which the grid does not match. The fault zone is represented by two sets of faces, each set matching its neighbouring matrix cells, and flow is modeled by a surface model. We present results ranging from academic cases to one phase flow in basin modeling where sliding along faults occurs.

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MS25

On Stability of the Fluid Structure Interaction in Porous Media fo Non-linear Potential Flows

In this work we consider the dynamical response of a non-linear plate with viscous damping interacting with a nonlinear potential flow. The system is modeled using nonlinear momentum equations for the axial and transverse displacements coupled with fluid flow subjected to Forchheimer type flow. In particular we show that for a class of boundary conditions given inlet velocity flow for liquid, dynamic of the process is stable with respect to boundary input Data.

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MS25

Multi-scale Modeling of Brinkman's Filtration in Layered Porous Media

We applied the theory of homogenization to the case of Brinkman filtration of viscous incompressible fluid through heterogeneous porous medium, whose material structure was characterized by periodicity over several length scales. We derived governing equations for all scales and obtained general relationships between the pressure and the velocity of fluid. The derivation of effective coefficients was reduced to the solution of periodic problems in cells, which were solved numerically.

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MS25

On a Power Series Solution to the Boussinesq Equation

The Boussinesq equation describes water flows in unconfined groundwater aquifers under the Dupuit assumption that the equipotential lines are vertical, making flow horizontal. It is a nonlinear diffusion equation with diffusivity depending linearly on water head. We also analyze a generalized Boussinesq equation, where the diffusivity is a power law function of water head. For certain classes of initial and boundary conditions approximate analytical solutions can be constructed using the scaling properties of the equation.

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MS25

Pore-scale Fluid Dynamical Perspective of Non-Darcy Effects in the Inertial Flows Through Realistic Porous Media: A First Principle Analysis of Forchheimer Relationship

Detailed simulations of single-phase flow in the imaged-based realistic porous media are carried out using Lattice Boltzmann Method (LBM) over a wide range of Reynolds number. Inertial effects manifest themselves as the deviation from Darcys law on the macroscopic scales. Transition from viscous forces dominated flow regime to inertia dominated flow can be systematically predicted as well as the parameters such as permeability and Forchheimer coefficient can be calculated from three-dimensional flow simulations.

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MS26

Grid Resolution Requirements and Computational Overhead in Nonhydrostatic Coastal Ocean Modeling

Computation of the nonhydrostatic pressure may be required in coastal ocean models if the relevant horizontal scales of motion are on the same order as the vertical scales. I will present a method to determine how much grid resolution is required to resolve nonhydrostatic processes. Although solution of the nonhydrostatic pressure can be expensive, I will show that weakly nonhydrostatic processes can incur minimal overhead with the use of appropriate preconditioners.

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MS26

Modeling Storm Surges with the Multilayer Shallow Water Equations

Storm surges created by tropical storms pose significant flooding risks to coastal populations. Many current models of surge use the single layer shallow water equations, which capture much of the physics while allowing rapid computation over vast regions. We are examining the potential advantages of using the multilayer shallow water equations together with adaptive mesh refinement to efficiently capture additional storm surge physics.

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MS26

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MS26

Challenges in 3D Cross-Scale Modeling

Originally developed as a 3D baroclinic circulation model for the Columbia River estuary-plume-shelf system, SELFE (Semi-implicit Eulerian-Lagrangian Finite Element) has evolved into a comprehensive, open-source community-supported modeling system. Grounded on unstructured grids, the model is designed for the effective simulation of 3D baroclinic/barotropic flows across river-to-ocean scales. It uses an efficient semi-implicit finite-element Eulerian-Lagrangian method to solve the Navier-Stokes equations (in either hydrostatic or non-hydrostatic form), written in MPI FORTRAN90 to realistically address a wide range of physical processes and of atmospheric, ocean and river forcings. The combination of unstructured grids, implicit time stepping and an Eulerian-Lagrangian Method in SELFE leads to superior flexibility, accuracy, efficiency and robustness. We present new developments of the SELFE modeling system in the areas of 3D baroclinic circulations, tsunami and storm surge inundation (including wave-current interaction). The cross-scale nature of the SELFE modeling system (from minutes to decade, and from meters to hundreds of kilometers) also presents great computational/algorithmic challenges (e.g. wetting and drying; multi-physics in a single modeling framework etc) that beckon applied mathematicians to address.

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MS27

Overview of Upscaling, Multiscale and Reduced-order Modeling Techniques for Subsurface Flow

A wide variety of upscaling (numerical homogenization), multiscale modeling, and reduced-order modeling procedures have been developed for subsurface flow simulation. We will briefly discuss these general approaches, highlighting key similarities and differences. Then, a trajectory piecewise linearization approach will be described. This technique, which entails linearization around saved states and a POD-based projection into a low-dimensional subspace, is applied for subsurface flow modeling. Some existing challenges will also be discussed.

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MS27

Parameterized Model-Order Reduction for Large-Scale Reservoir Models

In this presentation, we investigate the use of the parametric model order reduction(PMOR) techniques applied to porous media flow simulation in a system-theoretical framework. PMOR entails the generation of reduced-order models which retains the functional dependency on specific parameters of the original large-scale system. Usually, an ensemble of models is used to assess uncertainty in the reservoir simulation. In order to overcome the computational effort in this scenario, reduced-order models that take into account this entire ensemble are necessary to obtain.

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MS27

Pressure Preconditioning Using Proper Orthogonal Decomposition

We developed and implemented a new physics-based preconditioning method for solving the pressure equation in large-scale reservoir simulation as an alternative to the popular Algebraic Multi Grid (AMG) method. The new method uses a small set of pre-computed pressure solutions to transform the pressure equation into a lower-order representation using Proper Orthogonal Decomposition. In test cases we reduced the linear solver time by about 50% compared to AMG preconditioning.

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MS27

A local POD-Based Multicale Mixed FEM for Model Reduction of Multiphase Compressible Flow

We develop a local basis model-order reduction technique for approximation of flux/pressure fields based on local proper orthogonal decompositions (PODs) consistently glued together using the Multiscale Mixed FEM (MsMFEM) framework on a coarse grid. Based on snapshots from one or more simulation run, we perform SVDs for the flux distribution over coarse grid interfaces and use the singular vectors corresponding the largest singular values as boundary conditions for the multiscale flux basis functions. The span of these basis functions matches (to prescribed accuracy) the span of the snapshots over coarse grid faces. Accordingly, the complementary span (whats left) can be approximated by local PODs on each coarse block giving a second set of local/sparse basis functions. The reduced system unknowns corresponding to the second set of basis functions can be eliminated to keep the system size low. To assess the accuracy, we apply the methodology to a realistic test problem (two-phase compressible flow including gravity) with several wells and compare to results obtained from full order simulations. Both changing well configurations and changing well placements (with local update of bases) are considered. In addition, comparison to standard POD is considered.

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MS28

CO2 Geological Storage and Groundwater Resources: Model Applications

This paper provides an overview of research issues and modeling applications related to understanding potential impacts of geologic carbon sequestration on groundwater resources. Issues addressed by multi-phase modeling and reactive transport simulations include (1) the possibility of water quality changes due to leakage of CO2 (together with co-migrating contaminants) into fresh water aquifers, and (2) the potential of regional-scale hydrogeologic perturbation caused by the injection of CO2 and the subsequent displacement of native brine.

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MS28

Variations of CO2/Water Interfacial Tension and Impact on CO2 Trapping Capacity

We have implemented an empirical correlation for water/CO2 interfacial tension (IFT) in the compositional flow and reactive module of IPARS parallel reservoir simulator. The IFT correlation is a function of pressure, salinity, and temperature. The relative permeabilities are generalized to account for combined effects of viscous, buoyancy, and capillary forces. Several prototype aquifer models are studied to determine the impact of injection rates and IFT variations on CO2 migration and trapping.

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MS28

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MS28

Analysis of Capillary Structures in Heterogeneous Formations

Local capillary trapping is a potentially important mechanism for immobilization of CO_2. It occurs at small scales (compared to field scale) as CO_2 rises under gravity through heterogeneous formations. The overall objective is to analyze the structures that could form local capillary traps in typical storage formations. We generate geostatistical realizations of permeability from variogram models populated with key petrophysical properties and analyze spatial properties of them to determine the potential for local capillary trapping.

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MS28

Multiscale Numerical and Physical Modeling of Geologic Carbon Sequestration

Geologic carbon sequestration is impacted by several processes including multiphase flow with density and thermal effects, dissolution of fluid phases, and reactions with reservoir solids. These are largely controlled by pore-scale (micron to mm-scale) features of the fluid interfaces and solid material surfaces, while quantitative predictions are needed at much larger length scales. We will present a suite of numerical and physical models defined at the pore scale and their application to field-scale simulations.

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MS29

Finite Volume Approximation for Two-phase Flows with Discontinuous Capillary Pressure

We are interested in a PDE system describing an incompressible immiscible two-phase flow in a porous medium made of two different rocks. Since the capillary pressure function depends on the rock type, the capillary pressure field can be discontinuous at the interface between the rocks. We give a sense to the transmission conditions at the interface, and then, we propose a Finite Volume scheme allowing to deal with such discontinuities, and prove its convergence towards a weak solution to the problem.

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MS29

A New Corrected Operator Splitting Method Combining Streamline Approach for Two-phase Flow with Gravity

Gravity is important for dynamics which often cannot be

neglected but poses significant challenges for the numerical approximation of PDEs. Thus, this talk focuses on a new corrected operator splitting (COS) method for higher-dimensional two-phase flow problems with gravity, and the COS method is devised by handling the gravity term based on streamline tracing for a front velocity field generated from flux splitting. Different numerical examples are simulated and explained.

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MS29

The Application of Homogenization Theory to Study the Stability of Density-driven Flows in Heterogeneous Formations

Density-driven flows cut across many practical applications like normal and nuclear waste repository management, the protection of coastal groundwater aquifers from salty seawater intrusion, the harnessing of geothermal resources and the exploration of petroleum. A typical feature of such systems is that they can become unstable and exhibit the fingering phenomenon. A salient challenge to-date has been the absence of a stability criterion capable of predicting the onset of fingering. In this work we apply homogenization theory techniques developed in [Held et al. 2005] to derive the small- and large-scale transport equations [Musuuza et al., (2009)]. The small-scale equation is used to derive a stability criterion in terms of the density, dispersivities [Musuuza et al., (2010)] and heterogeneity properties. The criterion is tested on those variables and produced reasonable predictions for the onset of convection. The large-scale equation is used to study mixing behaviour by evaluating the macrodispersion tensor elements. The system stability could be inferred from the temporal evolution of the longitudinal coefficient.

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MS29

Convergence Analysis of a Vertex-centered Finite Volume Scheme for a Copper Heap Leaching Model

This work is motivated by a combined mixed finite element (MFE) - finite volume (FV) scheme of a two phase flow model for the heap leaching of copper ores modeled by a degenerate parabolic equation

$$\partial_t u - \nabla \cdot (\nabla \beta(u) + F(u)) = r(u), \quad \text{in } Q_T \equiv (0,T) \times \Omega.$$

Initially we have $u(0) = u^0$ in Ω, whereas $u = 0$ on $\partial\Omega$. In the above $0 < T < \infty$ is fixed, Ω is a bounded domain in $R^d (d \geq 1)$ with a Lipschitz continuous boundary. The function $\beta : R \to R$ is non-decreasing and differentiable. By degeneracy we mean a vanishing diffusion, namely $\beta'(u) = 0$ for some u. We prove error estimates for the finite volume discretization for this model. Then, a two-dimensional solute transport model is considered to simulate the leaching of copper ore tailing using sulfuric acid as the leaching agent. The mathematical model consists in a system of differential equations: two diffusion-convection-reaction equations with Neumann boundary conditions, and one ordinary differential equation. The numerical scheme consists in a combination of finite volume and finite element methods. Some numerical examples illustrate the effectiveness of the scheme.

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MS30

Porous Media Research at Purdue: Past and Future

My group has focused on four basic porous media problems over the years, i) swelling porous media (mixture theory and homogenization), ii) nano films (computational chemistry), iii) diffusion/dispersion in heterogeneous media (stochastic perturbation, CLTs, and statistical mechanics) and iv)nutrient transport to growing roots (non-linear moving BCs for diffusion problems). Each of these topics will be briefly discussed in the context of my students and post docs efforts. A brief look toward the future will be presented.

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MS30

Polar Field Theories: Small Scale to Large Scale Applications

Micromorphic fluids contain a particulate substructure which affects the movement of the fluid. This structure can be incorporated into the fluid flow model. This talk will present two models using these fluids including small and large scale examples. Current work initiated by Dr. Cushman and associates related to large scale continental deformation will be discussed. The continental plates are being viewed as micropolar bodies with substructures that can rotate in addition to the translational movement.

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MS30

Modeling Coupled Hydrological and Chemical Processes in Unsaturated Fractured Porous Media

Environmental remediation often leads to geochemical transformations, such as precipitation and dissolution of minerals and evolution of gases and bio-films. These transformations may in turn modify the hydraulic properties of the system. If significant changes take place in either the flow paths or the hydraulic properties, they may have an impact on the geochemical transport processes. We show how transient changes in hydrological properties caused by coupling of hydrological and chemical processes often lead to local flow channeling and saturation increases in unsaturated fractured porous media.

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MS30

Computation of Flow and Transport in Large and Sparse Fracture Networks

The discrete fracture network (DFN) approach to compute flow in large two-dimensional fracture networks is an accurate but computationally intensive methodology. Continuum based methods allow for simulation of processes not presently achievable using DFN approach but can suffer from lack of accuracy especially in prediction of transport behavior and in cases with sparse fracture networks. Techniques to improve the computational efficiency of DFN method and predictive accuracy of a continuum method are presented.

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MS31

Two-phase Flow in Porous Media with Discrete Fractures

In this talk we present a discrete fracture model for flow of a two-phase fluid in a porous medium. Fractures are represented as interfaces and fluid exchange between the fractures and surrounding medium is permitted. Thus there is a coupling of n-dimensional flow with $(n-1)$-dimensional flow. The global pressure formulation is used and the fracture domain is assumed to be of a rock type different from that of the surrounding medium; i.e. the relative permeability and capillary pressure curves for the fracture domain are different from those for the surrounding rock matrix. Thus continuity of the saturation can not be assumed in the derivation of the model. The model is implemented with a mixed finite element method being used in both the matrix and the fracture but with non matching grids. Numerical results will be shown.

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MS31

Homogenization Approach to the Quasistatic Coupling Poroelastic/ Elastic Media

In this contribution, investigations are focused on the coupling of the single phase subsurface flow with poroelasticity. Most of the multiscale approaches to Biot's equation concentrate on the dynamic case, where memory effects appear. Here we are interested in the quasistatic case and obtain rigorously the Biot consolidation theory equations. Furthermore, we find the interface conditions between two different flow regimes.

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MS31

An Efficient MPFA Approach to Discrete Fracture Matrix (DFM) Flow Models

A control volume discretization along with a Multi-Point-Flux Approximation (MPFA) is considered for a Discrete Fracture Matrix (DFM) flow model. Inspired by a recently introduced approach based on Two-Point-Flux Approximation (TPFA), elements in the intersection of fractures are eliminated by a star-delta transformation; hence, avoiding associated time-step restriction and numerical instabilities. Numerical results demonstrate the flexibility and robustness of the new approach.

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MS31

An XFEM Approach for the Simulation of Frac-

tured Porous-Media Systems

Fractured porous-media systems are simulated, where the characteristic flow behaviour depends on the fractures and the matrix. The global solution is obtained by splitting the system into a structured rock-matrix grid and an arbitrarily orientated fracture network of codimension one. No matching conditions for the two grids are required. A consistent weak coupling scheme is developed that is based on an XFEM approach.

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MS32

Performance of the Integrally-Coupled, Unstructured-Mesh SWAN+ADCIRC(DG) Model

The coupling of wave and circulation models is necessary to generate waves and surge in deep water, propagate them onto the continental shelf, and dissipate them in complex nearshore systems. In this work, the authors couple the SWAN and ADCIRC(DG) models and investigate their performance during a hindcast of Hurricane Ike (2005). The computed circulation is compared between ADCIRC(CG) and ADCIRC(DG), and its differing effects on the computed wave solution are examined.

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MS32

Response of Puget Sound to Anthropogenic Alteration Development of an Offline Water Quality Model

Puget Sound, (or Salish Sea) a fjordal estuary in Washington, has experienced water quality degradation in the form of harmful algal blooms and hypoxia in recent decades. Given climate change and sea level rise possibilities, there is considerable interest in understanding the current and future effects of anthropogenic activities such as coastal development and nutrient loading on circulation and water quality. An unstructured grid multi-scale model of Puget Sound with a grid size capable of resolving small channels near river mouths to coastal open waters and accommodating complex shoreline geometry, waterways, and islands was set up using finite volume coastal ocean model (FVCOM). To facilitate long-term water quality simulations independent of hydrodynamics, a companion offline water linkage code has been developed using FVCOM discretization of the study domain using biogeochemical kinetics from CE-QUAL-ICM model. A total of 19 state variables are considered including two species of algae, dissolved and particulate carbon, and nutrients, as part of the carbon cycle to calculate algal production and decay, and the impact on dissolved oxygen. Preliminary model application is presented in the form of a sensitivity analysis to evaluate the effect of alterations to nutrient loads, hydrologic loads, and sea level rise on circulation, and dissolved oxygen and algae growth. The effect of hydraulic modifications such as the presence of a floating bridge on flushing time and water quality are also examined. The overall objective is to identify whether human sources of nutrients in and around Puget Sound significantly impact ecosystem and if so how much nutrient reduction is necessary to improve ecological health in sensitive areas.

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MS32

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MS32

Storm Surge/Inundation Model Inter-Comparisons via a Super-Regional Test Bed on the U.S. Atlantic and Gulf of Mexico Coasts

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MS33

Designing a Top-down Inversion System Accurate Enough for Operational Use

With California law limiting greenhouse gas emissions

(AB32), policy makers will need emission estimates that are much more accurate than are usually achieved by top-down methods. One particular challenge is that the mathematical inversion techniques usually used assume that errors in the model and observations are unbiased. However, we find that biases have a major impact on retrieved emissions. We also show how observation networks can be optimized with respect to multiple constraints.

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MS33

What Can We Learn About Fossil Fuel Emissions Across North America from a Geostatistical Atmospheric CO2 Inversion Using Ground-Based Continuous Measurement Data?

Estimating anthropogenic CO2 emissions from variability in atmospheric CO2 concentrations requires separating out the anthropogenic from the strongly varying biospheric signal. Without the use of expensive C14 measurements, atmospheric CO2 inversions can still provide some insight into the quality of inventory-based emission estimates. This talk will present results from a geostatistical inversion over North America for 2004 and 2008 using continuous ground-based measurement data and a Lagrangian atmospheric transport model. This method is unique among inversion setups as it provides the opportunity to a) infer a set of total flux estimates that are completely independent of any process-based model output, while b) gaining insight into the underlying processes, e.g. by correlating individual sectors from a fossil fuel inventory database with estimated fluxes. The method can also be used to identify how consistent fossil fuel inventories are with the atmospheric measurements at larger regions such as state boundaries. Results also show how the expanding continental measurement network helps to further constrain and isolate the fossil fuel emission signal across the continent, providing hope for future inversions that will use satellite-based data for large regional anthropogenic CO2 budgeting.

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MS33

Impacts of Spatial and Temporal Correlations in Regional Atmospheric Inverse Estimates of Greenhouse Gas Fluxes

High-resolution inversions of greenhouse gas fluxes are sensitive to treatment of spatial and temporal correlations. Increasingly dense observations allow these correlations to be evaluated with more confidence. We present assessments of the spatial and temporal correlations in model-data differences in atmospheric mixing ratios and surface fluxes. We evaluate the importance of quantification of these correlations in flux estimates and uncertainty assessments, using data from North America and from the Midcontinent Intensive.

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MS33

Multiscale Spatial Models for Representing CO_2 **Emissions**

While multi-Gaussian models have been successfully used to represent biospheric CO2 emissions in inversion studies, it is less clear what models may apply for anthropogenic emissions. In this talk, we will explore various models that employ easily observed covariates like GDP, population density etc to capture spatially variable anthropogenic CO2 emission. The dimensionality of the model will be of particular interest. The models will be tested using data from fossil-fuel emissions databases for North America.

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MS34

Advances in Tsunami Wave Propagation and Inun-

dation Modeling with Adaptive Triangular Meshes

Adaptive triangular meshes have proven their suitability for representing complex bathymetry/topography features as well as multi-scale phenomena and interaction. An adaptive tsunami propagation and inundation model using Galerkin-type numerical approximations has been developed and validated. In this presentation we introduce the numerical method and show results of diverse simulations. It turns out that the adaptive mesh refinement improves computation time without sacrificing accuracy.

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MS34

An Adaptive Approach for the Propagation-Inundation Tsunami Problem

When dealing with geophysical problems we encounter multi-scale physical phenomena. A very actual example is the tsunami case where a hundred of kilometers characteristic-length waves travel trough the ocean to interact with meter-lengths scale coastal topography in the process of inundation. One possible approach to solve the full problem is to discretize the physical domain with the smaller scale resulting in a very inefficient computation due to the over-resolved tsunami waves. Another possibility is to subdivide the physical domain in several single-scale problems, solve the equations on each of them from the coarser to the finer scale and connect them using boundary conditions. The problem with this approach is that we obtain a one-way communication pattern, from coarse to fine mesh, which can lead to inaccurate local solutions. We are working on solving the complete problem following an adaptive approach. For spatial variability we adjust the mesh resolution using unstructured meshes while for time variability we use a local time step approach. We combine these techniques with an high-order accurate finite volume numerical method.

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MS34

Tsunami Simulations with DGCOM: A High-order Triangular Discontinuous Galerkin Coastal Ocean Model

We describe the development of a triangular high-order discontinuous Galerkin coastal ocean model that is being developed for modeling tsunamis. The model had previously been used to study the 2004 Indian Ocean tsunami but that version did not have wetting and drying algorithms. With wetting and drying algorithms now in place, we can study the effects of this phenomenon on the strengths of the tsunami waves and their impact on the shore lines. We will describe our wetting and drying algorithms and discuss extensions to high-order methods as well as describe other types of high-order boundary conditions (such as non-reflecting types). Finally, we will discuss the time-integration strategy being developed for this model including explicit, semi-implicit, and fully-implicit time-integrators.

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MS34

Computational Challenges in Real-time Tsunami Forecasting

The next generation tsunami forecast provides estimates of all critical tsunami parameters (amplitudes, inundation distances, current velocities etc.) based on direct tsunami observation and model predictions. There are significant challenges in meeting Tsunami Warning Centers operational requirements - speed, accuracy, and user interfaces that provide guidance that is easy to interpret. Tsunami modeling methods have matured into a robust technology that has proven to be capable of accurate simulations of past tsunamis. However, implementing this technology into real-time tsunami forecast and warning operations presents significant computational obstacles, including access to large model database, real-time data assimilation, real-time model runs etc. The methodology, tools, test results, operational implementation and computational challenges of the tsunami forecast system are discussed.

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MS34

Nonlinearity, Dispersion and Friction in Tsunami Modeling

Abstract not available at time of publication.

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MS35

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

The generalized Forchheimer law is considered for incompressible and slightly compressible flow filtration in porous media. The resulting system can be rewritten in term of non-linear equations for the pressure only, characterized by the permeability tensor depending on the pressure gradient norm. In this work we explore the possibility of extending some of the local and extended local linear Darcy upscaling models to the non-linear Forchheimer law. Coarse scale simulation results are presented.

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MS35

Uncertainty Quantification for Subsurface Flow Problems using Coarse-scale Models

Uncertainty quantification for subsurface flow often requires flow simulation on multiple geological models. We present an upscaling approach that entails statistical assignment of upscaled functions, and rapidly generates those functions for multiple models. The goal is to reproduce the ensemble statistics (e.g., P50, P10 and P90) of the fine-scale flow. This differs from most existing upscaling techniques, in which the intent is to reproduce the fine-scale solutions on a realization-by-realization basis.

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MS35

An Eulerian Joint Velocity-concentration PDF Method for Solute Dispersion in Highly Heterogeneous Porous Media

In risk analysis applications involving solute dispersion in heterogeneous formations, the knowledge of the concentration probability density function (PDF) at different spatial locations and times is crucial. A new joint velocity-concentration PDF method is proposed that is applicable for highly heterogeneous porous media. The corresponding PDF transport equation accounts for advective transport, pore-scale dispersion, molecular diffusion, and chemical reactions. It is solved numerically using an efficient particle-based approach.

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MS35

Adaptive Error Control in the Multiscale Finite Volume Method for Multiphase Flow in Porous Media

The iterative MSFV method is extended to include the sequential fully implicit simulation of time dependent problems that involves a system of pressure-saturation equations. To control numerical errors in simulation results, an error estimate, based on the residual of the MSFV approximate pressure field, is introduced. In the initial time step in simulation, iteration is employed until a specified accuracy in pressure solution is achieved. This initial solution is then utilized to improve the localization assumption of basis functions at later time steps. Additional iterations in pressure solution are employed only when the pressure residual becomes larger than a specified threshold value. A priori error estimate and control based on pressure-equation residuals are derived to guarantee the desired numerical accuracy in saturation solution. Efficiency of the adaptive iteration strategy and error control criteria are also numerically examined.

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MS36

Modelling of Biofilm Growth and its Influence on CO2 and Water (two-phase) Flow in Porous Media

With the aim of aiding experimental design and for feasibility studies, a numerical model is developed capable of simulating the precipitation of calcite in sand or rock samples due to the activity of ureolytic bacteria. The model, which is defined on the Darcy scale, accounts for the accumulation of biofilms, their influence on pH, and the subsequent changes in the properties of the porous medium.

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MS36

Gas Invasion in Soft Sediments

We investigate the displacement of one fluid by another in a deformable medium with pore-scale disorder. We develop a model that captures the dynamic pressure redistribution at the invasion front, and the feeback between fluid invasion and microstructure rearrangement. Our results suggest how to collapse the transition between invasion percolation and viscous fingering in the presence of quenched disorder. We predict the emergence of a fracturing pattern for sufficiently deformable media, in agreement with observations of drainage in granular material, and we identify a dimensionless number that appears to govern the crossover from fingering to fracturing.

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MS36

Sniffing for Leakage: Trace Gas Sensors and Carbon Sequestration

Trace gas sensors are based on optothermal detection and use a modulated laser source and a quartz tuning fork amplifier to detect small amounts of gases for disease diagnosis via breath analysis and monitoring of atmospheric pollutants and greenhouse gases. We introduce the first mathematical model of a resonant optothermoacoustic sensor. The model is solved via the finite element method and couples heat transfer and thermoelastic deformation to determine the strength of the generated signal.

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MS36

Role of Guest Molecule Exchange Kinetics on the Injectivity of Liquid CO2 into Gas Hydrate Bearing Formations

Geologic accumulations of natural gas hydrates hold vast organic carbon reserves, potentially meeting global energy needs for decades. The principal challenge for this unconventional energy resources is to develop production technologies that minimize energy costs and environmental impacts. The CO2-CH4 guest molecule exchange technology hold promise in this regard. Previous numerical simulations using an equilibrium approach predict pore plugging upon injecting of CO2. This numerical study considers the impact of exchange kinetics on formation injectivity.

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MS37

Simulation of Transport in 2D Heterogeneous Porous Media via a Random Walk Particle Tracking method

We study the transport of an inert species in a 2D heterogeneous porous medium via a Random Walk Particle Tracking (RWPT) method. The main objective is to derive the macroscopic properties of the transport by the means of Monte-Carlo simulations in large domains. Conditions to reach asymptotic macro-dispersion coefficients will be given. We will also present our on-going research about the RWPT method in presence of discontinuities within the domain.

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MS37

Flow and Mechanics in Discrete Fracture-matrix Rock Systems: Hydromechanical Behavior Utilizing an Extended Finite Element Method

This study aims to develop a fully coupled hydromechanical model which can more easily treat complex fracture geometries. Our proposed method is based on the extended finite element method (XFEM) to represent fractures as lower dimensional elements for mechanics and solve a coupled problem in a monolithic manner. It can improve feasibility for meshing and nonlinear analysis. Our numerical study shows the proposed method can produce very similar results to the interface element approach.

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MS37

PDF Methods for Uncertainty Quantification.

We obtain the probability density function (PDF) of the distribution of a passive scalar that diffuses in a random velocity field. We derive an explicit map between the velocity distribution and the scalar PDF, and determine exact solutions for the PDF of the normalized scalar. This allows for the explicit quantification of the impact of diffusion on the evolution of the scalar PDF without recurrence to a closure approximation in terms of a mixing model.

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MS37

Numerical Issues of Two-phase Flows in Heterogeneous Media with Full Permeability Tensor

We consider the water flooding stage of oil recovery when water is injected into injection wells and pushes oil toward the production wells. We discuss two numerical issues of modeling two-phase immiscible flow in heterogeneous porous media with jumping anisotropic permeability tensor. The first issue is the effect of the discrete flux approximation on the front behavior and the water breakthrough time. The second issue is the choice of the efficient solver for algebraic systems produced by the simulator.

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MS38

Tetrahedral Mesh Generation for Reservoir Simulations; Barriers and Opportunities

The challenges and opportunities of using tetrahedral meshes as reservoir simulation grids is investigated. In contrast to the current industry practices of using corner point grids, tetrahedral meshes are capable of representing multi-scale geological features efficiently in a completely automated way. The use of these grids opens many opportunities for building a reservoir simulator that uses mixed higher order numerical schemes on the tetrahedral grids and the dual control volumes.

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MS38

Impact of Geological Uncertainty and Simulation Method in CO2 Storage

Deep saline aquifers hold great capacity for CO2 geosequestration but also have great uncertainty. Streamline Simulations are ideal for fast simulation, as complex 3D systems are divided into 1D problems. We combine compressibility and a new phase behaviour algorithm in our simulator, which improves convergence without additional computational cost. Simulations on 10 geological realisations following a Huff-and-Puff injection scheme (Otway Project) are compared with an industrial simulator with results of 80% of CO2 rendered immobile.

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MS38

Microporosity Characterization and Representative 3D Modeling of Tight Gas Sandstones

Accurate representation of geometry has the first order influence on multiphase fluid flow in porous media on all relevant scales. Existing pore scale network flow models that successfully model granular materials and sandstones of porosity <= 0.1 do not capture capillary-pressure behavior characteristic of many tight gas sandstones. We present an image based characterization of microporosity, crucial for tight porous media, as well as how to incorporate it into a 3D model.

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MS38

Mortar Coupling of Pore-scale Models to Reservoir Simulators; a True Multiscale Approach

Pore-scale models are useful tools for estimating macroscopic parameters (e.g., permeability), but direct upscaling could result in misleading values, partly because employed boundary conditions ignore the impact of surrounding media. Here, we develop a novel multiscale simulator, where pore-scale models are coupled directly with continuum scale models. Continuity of pressures and fluxes are enforced at shared boundaries using finite element mortars. Moreover, we develop priori upscaling techniques that allow for fast coupling between pore-scale models.

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MS39

Multiscale Mortar Methods for Flow in Heterogeneous Porous Media

We consider a second order elliptic problem with a heterogeneous coefficient written in mixed form. We view the domain decomposition method as a multiscale method with restricted degrees of freedom on the interfaces. We devise an effective but purely local multiscale method that incorporates information from homogenization theory. We also use this decomposition method approach to devise effective preconditioners that incorporate exact coarse-scale information to iteratively solve the full fine-scale problem.

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MS39

Multiscale Mixed FEM for Compressible Flow

Multiscale methods have been shown to be a robust and accurate alternative to traditional upscaling methods for incompressible flow. We discuss the extension of a multiscale mixed method to compressible flow, using more than one basis function for each coarse face and a residual formulation with a domain-decomposition corrector.

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MS39

Mixed Multiscale Finite Volume Methods for Modeling of Fluid Flow in Porous Media

We develop a framework for constructing mixed multiscale finite volume methods for flows in porous media. Some of the methods developed using the framework are already known; others are new. New insight is gained for the known methods and extra flexibility is provided by the new methods. This method uses novel multiscale velocity basis functions that are suited for using global information, which is often needed to improve the accuracy of the multiscale simulations in the case of continuum scales with strong nonlocal features. The method efficiently captures the small effects on a coarse grid. We analyze the new mixed MsFV and apply it to solve two-phase flow equations in heterogeneous porous media. Numerical examples demonstrate the accuracy and efficiency of the proposed method for modeling the flows in porous media with non-separable and separable scales.

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MS39

Multiscale Mortar Multipoint Flux Mixed Finite Element Methods for Flow in Porous Media

We develop a multiscale mortar multipoint flux mixed finite element method for flow in porous media. The equations in the coarse elements are discretized on a fine grid scale by a multipoint flux mixed finite element method that reduces to cell-centered finite differences on irregular grids. The subdomain grids do not have to match across the interfaces. Continuity of flux between coarse elements is imposed via a mortar finite element space on a coarse grid scale. With an appropriate choice of polynomial degree of the mortar space, we derive optimal order convergence on the fine scale for both the multiscale pressure and velocity, as well as the coarse scale mortar pressure. The algebraic system is reduced via a non-overlapping domain decomposition to a coarse scale mortar interface problem that is solved using a multiscale flux basis. Numerical experiments are presented to confirm the theory and illustrate the efficiency and flexibility of the method.

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MS40

The Open Porous Media Initiative

The Open Porous Media Initiative aims to produce a wide range of simulators for porous media applications. Principal goals include the ability to model relevant industrial scenarios, easy extensibility, high performance and ease of use. The software uses the DUNE framework, yet effort is made to ensure the reusability of the code within other contexts. Initial work at SINTEF and IRIS has concentrated on simulation of petroleum reserviors. We present an initial black-oil reservoir simulator and review its capabilites.

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MS40

Our Software Commons and Where We Can Make It Lead Us

The global geoscience community is building a new, open, software toolbox. Instead of parochial, esoteric, highly-customized and under-maintained applications, we are seeing the development of user-friendly platforms, maintained by diverse and geographically widespread groups of academics and professionals. The opportunities are growing for collaborative innovation, spontaneous investigation, and just plain old fun. To realize this Arcadian dream, the community must learn to value openness, nurture the skills to contribute, and embrace new business models.

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MS40

The Distributed and Unified Numerics Environment DUNE and its Application to Porous Media with DuMuX

The first part presents DUNE, the Distributed and Unified Numerics Environment, a modular toolbox for solving partial differential equations (PDEs) with grid-based methods. The underlying idea of DUNE is to create slim interfaces allowing an efficient use of legacy and/or new libraries. The second part provides an overview of DuMu^x, a DUNE-based module for multi-{phase, component, scale, physics, ...} flow and transport in porous media.

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MS40

MATLAB Reservoir Simulation Toolbox

The MATLAB Reservoir Simulation Toolbox provides a comprehensive set of routines for developing and interactively studying simulation methods for porous media flow on unstructured grids. Emphasising flexibility and generality with respect to grid formats, particularly supporting hierarchical grids in multiscale methods, MRST promotes research and computational experiments on realistic models. Moreover, being open-source results and frameworks are accessible to anyone who wishes to reproduce or extend the existing work.

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MS41

Free Surface Flows Modeling of Real Problems: The Electricit-De-France Point of View

Modeling free surface flows is one of the most challenging areas for EDF. For its own applications, EDF develops 1D and 2D numerical tools (Telemac and Mascaret) based on the shallow-water equations (SWE). Last developments focus, on one hand, on new numerical scheme (kinetic schemes), and on the other hand, on the validity extension of the classical SWE system for the 1D model by adding specific source terms. Industrial applications will illustrate these developments.

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MS41

Immersed Boundary Method for Flood Simulation

Failure of dams and levees may lead to catastrophic floods that would cause loss-of-life and damage to urban and rural areas. In this talk we describe a two-dimensional flood model based on a first order explicit scheme in which an immersed boundary technique is used to simulate linear terrain features that cannot be captured by the resolution of the structured computational grid. The cut-cell boundary method is also used for providing coupled 1D-2D simulation capability.

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MS41

High-resolution Modeling of Urban Dam-break Flooding

Here, we present a modeling study of the Baldwin Hills dam-break flood (Los-Angeles 1963), whereby inundation is resolved at a spatial and temporal scale of ca. 3 m and 0.1 s, respectively. The ability of the model to correctly predict flood extent and streamflow is reported, model sensitivities are examined, and the potential to predict damage zones is discussed. The results of this study point to a new paradigm for urban dam-break flood impact analyses.

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MS41

Improvement of the Flood Simulation with MASCARET using Data Assimilation

A data assimilation procedure was implemented on top of the mono-dimensional hydraulics model MASCARET. The procedure is two-fold: the BLUE algorithm is used to assimilate river water level observations to correct the upstream flow forcing and also to instantaneously correct the water level and discharge. It was shown over a significant number of flood events for the Adour catchment that the two-step data-assimilation procedure improves the simulation in re-analysis and forecast modes

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MS42

Simulations of a Field of Precipitating Trade-wind Cumuli using a Particle-based and Probabilistic Microphysics Model Coupled with LES: Modeling Results and Validation against in-cloud Aircraft Observations

We present results of LES modeling of a field of shallow convective maritime clouds using the so-called RICO set-up (van Zanten et. al, submitted to J. Adv. Model. Earth Syst., 2010). We use the Super Droplet Method (Shima et al., Quart. J. Roy. Meteor. Soc., 2009) for coupling the non-hydrostatic LES CReSS (Tsuboki and Sakakibara, Quart. J. Roy. Meteor. Soc., 2006) with particle- based simulation resolving explicitly such cloud-microphysical processes as CCN activation, condensational and collisional growth growth of cloud droplets and gravitational sedimentation including drizzle and rain precipitation. Model results are compared with simulations employing bulk treatment of cloud microphysics as well as with aircraft observations of cloud-droplet size spectrum during the RICO experiment (Arabas et al., Geophys. Res. Lett., 2009).

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MS42

Multiscaling and Approximations for Coagulation Processes in High Dimension

Computing the time evolution of the multi-dimensional size distribution of atmospheric aerosol particles involves many computational subcomponents, and one of the more computationally intense of these is computing the effect of coagulations amongst particles. In this talk, we will discuss several methods of speeding up particle methods by exploiting the multiple timescales in many coagulation scenarios.

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MS42

Simulating Multivariate Particle Populations by the Quadrature Method of Moments (QMOM)

The method of moments (MOM) offers a statistically based approach that tracks only the moments of a multivariate particle population. This makes the method highly efficient. The introduction of quadrature in the QMOM gives both closure of the moment evolution equations and excellent approximation to distribution properties (physical, optical, etc.) in terms of moments. As one example of the approach we use particle-resolved simulations of Riemer et al. [JGR, 2009] to benchmark QMOM accuracy during a bi-variate simulation of the mixing states of soot and sulfate particles undergoing coagulation. This important “aging” mechanism determines aerosol optical properties and cloud condensation nuclei (CCN) concentrations in the atmosphere. Several different quadrature schemes are tested. Gauss and Gauss-Radau quadratures appear to give nested lower and upper bounds, respectively, to aerosol mixing rate. Similarities between the QMOM and Kalman filtering will also be discussed.

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MS42

Parallel Particle Methods for Aerosol Simulation

Particle-resolved stochastic models offer unprecedented levels of detail for aerosol dynamics, but at the expense of increased computational cost. To enable fast particle-resolved simulation we present several parallelization strategies, including local mixing-based algorithms and global particle-request methods, and compare their performance and scaling. All of the parallel algorithms considered are approximate, but we prove convergence to the centralized case in appropriate limits.

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MS43

A Space-Filling-Curve Approach for Parallel Adaptive Mesh Refinement in Tsunami Simulaton

Efficient parallel adaptive refinement (AMR), to capture land-ocean boundaries and to dynamically refine along propagating wave-fronts, is a performance-critical component of Tsunami simulation. We present a respective approach for parallel AMR and respective solvers for systems of PDE that is based on recursively structured adaptive triangular grids and corresponding element orders using Sierpinki space-filling curves. The approach allows for performance optimisation w.r.t multiple aspects: minimal memory requirement, inherently cache efficient processing, as well as fast load balancing. Test results are presented for a simple discontinuous Galerkin solver for the shallow water equations.

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MS43
Seismic Inversion using Discontinuous Galerkin Methods

We present a spectral-element-based Discontinuous Galerkin method to discretize full wave form seismic inverse problems. The inverse problem is formulated in a Bayesian framework, and a discretize-then-optimize approach is used to derive the gradient and Hessian-vector product. A result on the equivalence between discretize-then-optimize and optimize-then-discretize will be presented. Finally, primarily results on full wave Bayesian inversion on massive parallel computers demonstrate the capabilities of our approach.

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MS43
Tsunami Edge Waves and Complex Earthquake Rupture

Edge waves are a particular type of coastal wave trapped by refraction that propagate parallel to the coastline. In combination with scattering and resonance, edge waves create a complex waveform in which the offshore amplitude, runup, and timing of the largest wave are difficult to predict using standard numerical methods. Instead, edge waves from continental-shelf tsunamis, such as the 2010 Chile event, are examined from an analytic perspective and in relation to complex rupture models.

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MS43
Efficient Local Resorting Techniques with Space Filling Curves Applied to a Parallel Tsunami Simulation Model

The OpenMP-parallel model TsunAWI for the simulation of tsunami propagation and inundation discretizes the shallow water equations on an unstructured $P_1 - P_1^{NC}$ finite element grid. The data access to the variables on the unstructured grid is crucial for the computational performance. A reordering of the unknowns at elements, nodes, and edges along a space filling curve is presented that guarantees data locality on all levels of the memory hierarchy, thus reducing cash misses and false sharing.

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MS44
New Mathematical Models and Numerical Simulations of Multiphase Flows in Porous Media Including Phase Transitions and Chemical Reactions

Abstract not available at time of publication.

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MS44
Time-relaxation Methods for Degenerate Transport Problems

In this talk, we discuss the application of time-relaxation methods for degenerate transport problem. The work is motivated by regions in the subsurface where the governing equations change type from hyperbolic to parabolic. This occurs, for instance, when fronts move through the unsaturated zone or when material parameters change. Our findings indicate that can improve results obtained from a finite difference or continuous FEM scheme by applying a simple elliptic operator. We give theoretical and numerical evidence to support the use of these operators in legacy codes.

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MS44
A Physics-based Sparsified Solver for Reservoir Simulation

In the present work we propose a percolation-based sparsification algorithm to solve pressure-based systems arising in porous media flow applications. The main idea of this physics-based strategy is to capture the connectivity layout or solution paths describing the overall flow process on highly heterogeneous media. The proposed approach has the potential to mitigate the overhead associated with preconditioner construction and application. Results are illustrated on a wide set of field cases arising in black-oil and compositional simulations.

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MS44
A Dirichlet-to-Neumann Multigrid Algorithm for Locally Conservative Methods

Discontinuous Galerkin methods and mixed finite element methods have grown in popularity in recent years with recent work showing that both methods give rise to locally conservative fluxes. In this talk we introduce a novel, physics-based geometric multigrid framework that incorporates both mixed and DG with optimal convergence properties even in the case of multinumerics and unstructured grids. Theoretical results for symmetric operators will be presented along with numerical results for the both symmetric and nonsymmetric problems.

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MS45

Complex Evolution of Transport Properties in CO_2 Infiltrated Coal: Observations and Models

We explore the evolution of permeability in coal with swelling-induced sorption of single and multi-component gases such as CO_2, CH_4, N_2 relative to non-sorbing He. We explore important differences in the sense and timing of permeability evolution in porous coals, ubiquitously fractured coals and in coals containing a distribution of flaws. We extend these models to follow permeability evolution in coals infiltrated by binary mixtures through the application of distributed parameter models.

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MS45

Non-isothermal Flows in Porous Media for CO2 Sequestration Applications

Non-isothermal flows in porous media for CO2 sequestration applications Norbert Bttcher, Ashok Singh, Chan-Hee Park, Wenqing Wang, Joshua Taron, Uwe Grke and Olaf Kolditz Abstract: This paper deals with non-isothermal flow effects during carbon dioxide sequestration. We consider two scenarios: (i) the miscible displacement of compressible natural gases through a layer of the depleted gas reservoir by injection of carbon dioxide and (ii) CO2 sequestration in deep saline aquifers. We consider the real behavior of gaseous mixtures and immiscible fluids through using energy and distance parameters in the calculation of material parameters. In this situation dispersive mass-flux is often more significant than diffusive processes. We use the empirically extended ideal gas equation to calculate the density for mixtures. Gas injection to reservoirs can cause re-pressurization effects and reservoir temperature can fall significantly according to the Joule - Thomson cooling effect. The energy conservation equation is solved to account for heat loss due to gas expansion and viscous heat dissipation. In two-phase flow systems density dependent effects have to be considered in addition.

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MS45

Multiscale Modeling in the Context of CO2 Storage

The disparity between laboratory scales and the scale needed for CO2 storage to be meaningful, makes upscaling and simulation central research components. Here, we look at how coupled physical phenomena impact models at different scales. In particular, we emphasize how the representation of physical processes changes on different scales within a coupled model.

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MS45

Modeling the Complex Evolution of Fractured Geothermal Reservoirs

We develop models for the evolution of fractured geothermal reservoirs where mechanical and chemical responses are innately linked. The linkage between mechanics and chemistry is shown to progress at a variety of different timescales depending on diffusional control of the processes. Effective stress effects are immediate, followed by short-term thermal drawdown and the development of hydroshears. The final stage of evolution involves chemical influences and their effect of the hydraulic performance of the reservoir.

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MS46

Anomalous Transport in Heterogeneous Media: Broad Heterogeneity Distributions Versus Strong Heterogeneity Correlations

We study mechanisms that can lead to anomalous transport in quenched random media. Broad disorder point distributions and strong disorder correlations cause anomalous transport and can lead to the same anomalous scaling laws for the centered mean and mean squared particle displacements. The respective mechanisms, however, are fundamentally different. This difference is reflected in the spatial particle densities and first passage time distributions, which provide indicators for identifying the origins of anomalous transport.

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MS46

Multiscale Finite Elements Methods for High Contrast Diffusion Problems

We discuss multiscale finite element methods for elliptic problems with high contrast coefficients, arising in flow in a heterogeneous porous medium. For a restricted class of model problems our method has optimal convergence, independent of the geometry and contrast of the PDE coefficient. We also present an adaptive variant of the method which can be applied to rather general flow problems with similar convergence properties. Experiments on a wide range of model problems are presented.

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MS46

Numerical Simulation of Reactive Transport: Application to CO2 Storage in Heterogeneous Media

Coupling transport with geochemistry adds chemical heterogeneity as a new difficulty to the simulation of flow and transport in porous media. Reactive phenomena, such as precipitation or dissolution of minerals, are usually highly localized in space, and this in turn requires very accurate simulation codes, as well as an accurate coupling algorithm. The Newton-Krylov method is a globally coupled approach that is both robust and accurate. We apply the method, to a system including mineral reactions and gas dissolution, that is relevant to CO2 storage.

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MS47

An Experimental Approach using Stereo Microscope and X-ray Microtomography to Study Changes in Wettability due to Microbial Enhanced Oil Recovery at the Pore-scale

The effect of inherent wettability on recovery was studied within 2D micromodels imaged with stereomicroscopy and 3D columns imaged with x-ray microtomography. Water-wet to oil-wet surface ratios were produced in ratios: 1:5, 5:5, and 5:1 by treating a fraction of the pore space with octodecylthrichlorosilane, such that the spatial coordinates of surface wettability are defined. Interfacial curvature, oil blob morphology, and additional oil recovered are reported for each mixed-wet system, prior to and after MEOR.

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MS47

A Heterogeneous Multiscale Method (HMM) for Two-phase Flow in Porous Media

We present a formulation of heterogeneous multiscale method (HMM) for two phase flow in porous media. Standard macroscopic (Darcy's Law) equations are augmented with a network flow model on pore (micro) scale. Network flow model captures flow pathway details true to the porous medium geometry. We exemplify macro-micro iteration for two-phase flow in 1D and 2D, as well as using a conceptual model of hydraulic fracture propagation.

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MS47

Thermodynamic Equi-

librium In Multiphase Porous Media: Examining Equilibria Across Spatial Scales

Macroscopic formulations for multiphase flow in porous media rely on thermodynamics to provide a closure relationship for the capillary pressure. Obtaining a valid macroscopic formulation is contingent on specification of macroscopic thermodynamics that are defined in a way that is consistent with microscopic thermodynamics. This talk will address the challenges associated with developing a macroscopic definition for capillary pressure by considering equilibration of multiphase systems over a range of spatial scales and their relationship to more general multiphase flow processes. Simulations performed using the lattice Boltzmann method will be used to illustrate the difficulties associated with macroscopic averages of capillary pressure and to suggest an appropriate course of action.

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MS47

Dynamic Capillary Effects in Unsaturated Flow Through Deformable Porous Media

In recent years, non-equilibrium capillary effects in multiphase flow in porous media have been investigated by many authors based on experimental work or numerical simulations. However, all the previous work has been done for the flow in rigid porous media. In this work, we investigate the dynamic capillary effects in deformable porous media using numerical modeling. We consider 1D consolidation model incorporating the dynamic capillary pressure term, and we illustrate and discuss the numerical results.

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MS48

Stochastic Modeling of Complex Multi-phase Flows to Link Pore and Darcy Scale Dynamics

To simulate complex non-equilibrium multi-phase flow in porous media a Lagrangian modeling framework was devised, which employes computational particles as statistical representatives of individual fluid elements. This approach allows to describe certain phenomena in a completely new and more natural way. The main advantage, however, is its ability to represent complex joint distributions and to account for effects of unresolved features, e.g. the evolution of gravity fingers can be described without resolving them.

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MS48

Numerical Upscaling of Flows in Highly Heterogeneous Porous Media

The generalized Stokes equations (called also Brinkman equations),

$$-\mu\Delta u+\nabla p+\mu\kappa^{-1}u=f,\ \nabla\cdot u=0\ in\Omega,$$

where μ is the viscosity and κ is the permeability, are used for modeling flows in highly porous media. Motivated by industrial applications of such materials we have developed a numerical method for comupting flows in heterogeneous highly porous media with complicated internal structure of the permeability. We will present a two-scale finite element approximation of Brinkman equations. The method uses two main ingredients: (I) discontinuous Galerkin finite element method for Stokes equations, proposed and studied by J. Wang and X. Ye (2007, SINUM, v. 45) and (II) subgrid approximation developed by T. Arbogast for Darcy equations (2004, SINUM, v. 42). A number of numerical examples will be presented to demonstrate the performance of the subgrid method and an iterative method based it.

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MS48

Multilevel Multiscale Mimetic (M^3) Method for Subsurface Transport Problems in Heterogeneous Media

In our work we develop a multiscale method for modeling subsurface contaminant transport within the framework established by the Multilevel Multiscale Mimetic method. In this method a multilevel hierarchy of coarse-scale systems is constructed through a recursive coarsening procedure. The procedure involves an exact and approximate step and is locally conservative at all levels. Mimetic Finite Difference (MFD) method is a basis of this hierarchy. The presence of convection terms along with anisotropic diffusion terms introduce additional challenges for multiscale methods. Possible solutions for different regimes and unsolved issues will be presented in this talk.

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MS48

Mortar Multiscale Methods for Stokes-Darcy

Flows in Irregular Domains

We study multiscale numerical approximations for the coupled Stokes-Darcy flow system. The equations in the coarse Darcy elements (or subdomains) are discretized on a fine grid scale by a multipoint flux mixed finite element method that reduces to cell-centered finite differences on irregular grids. The Stokes subdomains can be discretized by any stable Stokes elements, including discontinuous Galerkin. The subdomain grids do not have to match across the interfaces. Continuity conditions between coarse elements are imposed via a mortar finite element space on a coarse grid scale. With an appropriate choice of polynomial degree of the mortar space, we derive optimal order convergence on the fine scale for the multiscale pressure and velocity. The algebraic system is reduced via a non-overlapping domain decomposition to a coarse scale mortar interface problem that is solved using a multiscale flux basis. Numerical experiments are presented to confirm the theory and illustrate the efficiency and flexibility of the method.

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MS49

Building a Reproducible Research Community: Experience of the Madagascar Open-source Project

Madagascar (`http://www.ahay.org`) is an open-software project, which has been in existence for nearly 5 years and has accumulated nearly 100 reproducible research publications, mostly in applied geophysics and reflection seismology. Madagascar is released under the GPL license and developed by a community of two dozen developers spread around the world between industry and academia. I will describe the main design principles and the experience of implementing and maintaining a reproducible research discipline, which implies integrating computational results, including input data and open software code, with scientific publications. Reproducible research enables higher levels of scientific scrutiny and collaboration but requires a community support to provide a continuous maintenance of reproducible results.

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MS49

The GeoClaw Software for Depth-averaged Flows with Adaptive Refinement

Many geophysical flow or wave propagation problems can be modeled with two-dimensional depth-averaged equations, such as shallow water equations. The GeoClaw software (www.clawpack.org/geoclaw) has been designed to solve problems of this nature, using high-resolution shock-capturing finite volume methods and handling flow on topography and dry states, and incorporating AMR to allow the efficient solution of large-scale geophysical problems. This open source software consists of Fortran programs together with Python tools for the user interface and flow visualization.

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MS49

DOLFWAVE: a FEniCS Application for Water Waves Simulation

In this talk, we present DOLFWAVE, i.e., an application for solving surface water waves problems. A class of improved fourth-order Boussinesq-type models to simulate the propagation and generation of dispersive waves is derived. To approximate their solutions a continuous/discontinuous Galerkin finite element method with inner penalty terms is proposed. Dissipative effects and wave generation due to a time dependent varying sea bed are included. To demonstrate the applicability of the numerical scheme, several test cases are considered.

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MS49

The Central Role of Geophysics in the Reproducible Research Movement

I will trace the history of reproducible research in geophysics and its subsequent influence in other fields, such as computational harmonic analysis. A comparison of this approach to other forms of scientific communication suggests an urgent need to restructure the current scientific publication process to encompass the reproducible research principles pioneered in geophysics.

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MS50

Multi-GPU Tsunami Simulation on TSUBAME GPU Supercomputer

One of the most destructive natural disasters on Earth is a Tsunami hence the importance of an accurate and early warning. A large-scale ocean-wide Tsunami simulation is presented utilizing the next-generation technology GPGPU to push the envelop speeding up our computing for single and multi-GPU on desktops and Tsubame Super Computer. A highly accurate and conservative numerical scheme was used with a mesh adaptation for benchmark tests and a real case scenario

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MS50

Efficient Shallow Water Simulations on GPUs

In this talk, we introduce the shallow water equations and their importance in geosciences, giving an overview of application areas and simulation approaches. The main focus is on physical phenomena; including flooding, dam breaks, tsunamis, and storm surges; and we discuss how simulations can be mapped to execution on GPUs. We further address precision aspects through validation and verification, and show that fast single precision calculations can be sufficient to capture real-world flows.

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MS50

Complex Shallow Water Simulations Through Lattice-Boltzmann-Based Mesoscopic Numerical Treatment Exploiting Hybrid Compute Nodes

The talk presents stable and efficient fluid dynamics solvers based on Lattice-Boltzmann Methods (LBM) for Shallow Water type models. The mesoscopic nature of the LBM is exploited by modifying its boundary treatment and propagation/collision operators and adapting them to the specified scenario on the particle and/or macroscopic level. With a slight focus on GPUs, the hardware-oriented design and parallelisation on all levels is addressed – from vectorisation via the multi-core-level up to full (hybrid) clusters.

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MS50

Improving PVM finite volume schemes using GPUs. Application to shallow flows

In this work, we extend the PVM finite volume numerical schemes introduced recently by Castro and Fernández for non-conservative hyperbolic systems to non-structured triangular meshes. An efficient GPU implementation using the Compute Unified Device Architecture (CUDA) framework has been performed, and applications to two-layer shallow water systems are carried out. The numerical tests show the benefits of the CUDA implementation with respect to an OpenMP CPU implementation.

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MS51

Moist Thermodynamics in Sound-proof Simulation

This presentation will discuss moist simulation applying atmospheric sound-proof equations. The key issue is that the phase changes in moist thermodynamics are affected by the temperature and pressure perturbations. In the sound-proof system, however, pressure perturbations are not readily available and only the hydrostatically-balanced environmental pressure profile is used in the moist thermodynamics. Accuracy of such an approach will be discussed and illustrated with simple numerical experiments with sound-proof and fully-compressible systems of equations.

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MS51

On the Asymptotic Range of Validity of Sound-proof Atmospheric Flow Models

Several versions of sound-proof model equations for atmospheric flows have been suggested in the past. Ogura and Phillips (1962) assumed a stratification of potential temperature of the order of the Mach numer, M, squared, which results in the characteristic times of advection and internal gravity waves to be of the same order in M. This allowed them to adopt classical single-scale asymptotics to eliminate the sound modes and to arrive at their anelastic model equations. However, with M 0.03, one has M^2 $1.0e-3$. Potential temperature variations across the pressure scale height would be restricted to less than 1 K in this regime which is in contrast with realistic values of 30–50 K. In this lecture I will summarize recent efforts at systematically justifying sound-proof models for much stronger stratifications in realistic three time scale asymptotic regimes.

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MS51

Baroclinic Instability in Sound-Proof Global Simulations

We use an anelastic model, EULAG, to simulate the growth, propagation, and breaking of planetary waves in the baroclinic instability test of Jablonowski and Williamson. Solutions yield very similar growth rates, disturbance amplitudes, and phase speeds during the linear growth regime. After ~ 8 days, wavebreaking commences, at which point EULAG results begin to depart in some details from those of JW. Nevertheless, general agreement in the global structure of the solution remains.

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MS51

Sound-proof Simulations of Atmospheric Wave Phenomena

We investigate the performance of several sound-proof models, including the anelastic Lipps-Hemler and the pseudo-incompressible Durran nonhydrostatic equations. Physics wise, our primary interests are with the dynamics of inertia-gravity waves, an important element of weather and climate. Our numerical developments are based on a class of nonoscillatory forward-in-time methods and are applicable to global and limited area models. Challenging simulations of atmospheric wave phenomena involve structured-grid and unstructured-mesh discretizations.

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MS52

Rupture Arresting due to 3D Effects in Large Earthquakes

Large events are originated in large aspect-ratio faults in which the fault length (L) is very larger than fault width (W). Previous studies (Day, 1982) shows that this kind of fault initially ruptures as a crack-like, but subsequently the rupture bifurcates into two separate pulses traveling in opposite directions. When this process occurs in the bi-material case (Dalguer and Day, 2009), it evolves interacting with the normal stress perturbation (characteristics of bimaterial fault rupture) and under very limited conditions it can lead to unilateral rupture, in which rupture is arrested in the non-preferred direction and rupture propagates indefinitely in the preferred direction. Here we continue the investigation in this direction to further understand the W effect on rupture propagation. Our numerical investigation in homogeneous fault shows that W takes an important role on rupture arresting and the generation of steady-state pulse-like rupture in strike slip as well as dipping faults due to the arrival of the stopping phases at the rupture front. Rupture velocity depends on W. This dependence leads to slowdown the rupture speed, capable to arrest the rupture for small Ws. For W/Lc less than 4 and 5.3, respectively for strike and dipping faults, rupture is arrested, in which Lc is the critical length. At large distance, the rupture propagates with a steady-state velocity pulse. In a bimaterial fault, for the same problems, rupture never stops. These results suggest that the bimaterial effects promote rupture and W effects promote rupture arresting. When combining W and bimaterial effects, both are competing, and only under some limited conditions unilateral rupture originates. In these cases, the W effects successfully arrest the rupture in the non-preferred direction, while in the preferred direction the bimaterial effect enhance rupture propagation. Such as effect can also be significant on tsunami generation, a topic currently under research.

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MS52

Tsunami Simulation and Earthquake Source Identification using GeoClaw

GeoClaw (www.clawpack.org/geoclaw) is an open source software package that solves the shallow water equations modeling tsunami propagation and inundation using adaptive mesh refinement, allowing for rapid simulation of tsunamis from known sources. Recently we have experimented with tsunami source inversion using the GeoClaw code together with data from NOAA's DART buoys, which provide real-time data on sea surface elevation as a tsunami passes by. The goal is to rapidly estimate the seafloor deformation that caused the tsunami in order to simulate the further propagation of the tsunami.

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MS52

The Discontinuous Galerkin Method for Modeling Dynamic Earthquake Rupture on Complex Faults

Modelling the dynamics of the earthquake rupture process is a key component for physics-based simulation of the slip distribution. For undersea earthquakes the resulting ocean bottom displacement is crucial for tsunami generation. We present the discontinuous Galerkin finite element method for modeling the behaviour of geometrically complicated faults in realistic subsurface conditions using unstructured tetrahedral meshes. The approach is based on the numerical solution of the elasto-dynamic waves equation using well-established friction laws as internal boundary conditions at element interfaces aligned with the fault plane.

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MS52

Earthquake Dynamics and Potential Tsunamis in the Greater Antilles Subduction Zone

Using the 3D finite element method, we model the dynamics of potential earthquakes in the Greater Antilles Subduction Zone, including the plate boundary thrust fault and the strike-slip Septentronial and Bunce faults. We find that earthquakes may propagate from the Septentronial fault to the plate boundary thrust and vice versa; thus, there may

be more routes to a tsunamigenic earthquake than have been previously assumed in this region. We will discuss implications for tsunami generation.

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MS53

Transient Non-isothermal Fully Coupled Wellbore/Reservoir Modeling

Abstract not available at time of publication.

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MS53

Enhanced Successive Substituion Algorithm for Multiphase Flash Calculations

Flash calculations are performed billions of times during a compositional flow simulation. The reliability of flash calculations greatly affects the robustness of the entire flow simulation. Consequently, reducing its CPU time, as well as improving its robustness enormously impacts compositional flow modeling. Anderson Acceleration represents an efficient and elegant approach to enhance these calculations. Anderson Acceleration is a general algorithm for enhancing convergence of fixed-point iterations. The idea of Anderson acceleration is to take advantage the information obtained from multiple previous iterations to better predict the next iterate. We do not store all of the previous iterates, nor we assign equal weights to all of them, since the early iterates may contain less predictive information. This acceleration approach has been applied to wide ranges of problems, most notably in computations of electronic structure. When applied to linear problems, Anderson Acceleration is equivalent to the well-known GMRES algorithm. We investigate the application of Anderson Acceleration as a method to enhance phase behavior flash calculations within the framework of reservoir compositional modeling. In particular, we seek to improve the convergence rate and convergence region of the common Successive Substitution algorithm for oil-gas flash. We obtain results relating to the Simple Mixing algorithm, a special case of Anderson Acceleration, with improved performance of the Successive Substitution algorithm. We utilize brute-force investigation to examine convergence behavior for various initial equilibrium ratios (K-values). We observe that the convergence regions appear to widen out for certain cases. We also compare this accelerated Successive Substitution with plain Successive Substitution and Newton-type iterations, and we discuss its inclusion into an iterative-IMPEC finite-element multiphase computational flow simulator.

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MS53

Local Velocity Postprocessing for Multipoint Flux Methods on General Hexahedra

In multiphase flow simulations, if one uses a finite volume method with a piecewise constant approximation for the saturation/concentration equation, accurate face velocities are sufficient. For higher order methods such as discontinuous Galerkin method with piecewise linears, one needs accurate velocity in the interior gridblocks. In this work, an efficient postprocessing technique is developed to get an accurate interior velocity based on an accurate face-velocity of the multipoint flux approximation method.

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MS53

A Multiscale Stochastic Framework for Coupled Subsurface and Surface Flows

We discuss a multiscale stochastic framework for uncertainty quantification in modeling flow and transport in surface-subsurface hydrological systems. The governing flow equations are the Stokes-Darcy system with Beavers-Joseph-Saffman interface conditions. The permeability in the Darcy region is stochastic and it is represented with a Karhunen-Loève (KL) expansion. The porous media can be statistically non-stationary, which is modeled by different KL expansions in different regions. Statistical moments of the solution are computed via sparse grid stochastic collocation. The spatial domain is decomposed into a series of small subdomains (coarse grid) of either Stokes or Darcy type. The flow solution is resolved locally (on each coarse element) on a fine grid, allowing for non-matching grids across subdomain interfaces. Coarse scale mortar finite elements are introduced on the interfaces to approximate the normal stress and impose weakly continuity of flux. The transport equation is discretized via a local discontinuous Galerkin method. Computational experiments are presented.

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MS54

Thermodynamical Modelling of the Hydrogen Migration in Argillite for a Deep Geological Radioactive Waste Repository - Numerical Validation

We introduce a compressible 2-phases 2-components model of flow in porous media, with vaporisation and gas solubility, based on thermodynamical principles, and consistent with the any phase state: one single phase (liquid or gaseous) or two phases. Synthetic numerical simulations are presented for validation. They include the three main problems which appeared in the ANDRA (Radioactive waste disposal French Agency) benchmark Couplex-Gas: phase appearance/disappearance - non equilibrium of the initial state - very high contrast in materials.

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MS54

3-Phase Stability in Methane Hydrates Through Capillary Inhibition and Pore Water Salinity

A common view of hydrate systems is that hydrate and water are present in the stability zone, gas and water are present below, and gas, liquid and water coexist at their interface. However, we show that the three phase region can exist over a broad zone through two approaches: 1) gas flow and hydrate solidification elevates salinity; and 2) hydrate and free gas are present in pores of different size due to capillary effects.

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MS54

Phase Transitions in Coupled Models: Equilibrium and Kinetic Models

We consider phase change in multiphase multicomponent models in carbon sequestration, hydrate evolution, or black-oil. The phase change from liquid to gas or hydrate results from a constraint of maximum solubility of a component in the prevalent liquid phase. In computations, this can be realized in equilibrium. Alternatively, a kinetic model guides the system through phase change on a local time scale via an auxiliary ODE. We discuss advantages and disadvantages of different approaches.

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MS54

Modelling Gas Transport in Coalbeds During Primary and Enhanced Methane Recovery

As both a source and a reservoir rock, coalbeds can be characterised by two distinctive porosity systems: a network of extensively-distributed natural fractures (termed cleats) and matrix blocks with a wide-range pore size distribution. Coal gas is mainly stored by adsorption, primarily in the micropores. During methane production, desorbed gas diffuses through matrix to enter cleats. This paper presents numerical approaches used for modelling gas transport in coalbeds during both primary and enhanced methane recovery.

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MS55

Numerical Simulation of Anomalous Transport in Porous Media Described by Fractional-advection Dispersion Equation

In the contribution, we present computational studies of the fractional-advection dispersion equation containing the fractional-derivative multidirectional diffusion term which can be responsible for anomalous transport effects. Known justification of this model relies on the relation with the Levy stochastic processes. The solution of the model exhibits anisotropic features and variety of interesting phenomena not observed in the Brownian diffusion. Numerical solution of the transport equation leads to the linear systems of equations with full matrices which slows down the solution process. We couple the transport equation to the single-phase saturated flow in a heterogeneous medium and study the anomalous contaminant transport in it.

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MS55

Application of Level Set Methods for Groundwater Flow with Free Surface

Level set methods are popular numerical tools for description and tracking of moving interfaces in many fields of applied mathematics. We present a level set formulation for mathematical model of groundwater flow with free water table that separates the saturated zone from unsaturated one in porous media. The advantage of our level set formulation is the possibility to use static (enlarged) computational domain with fixed computational grid for the flow equation. The zero pressure boundary conditions defined on the water table are resolved numerically by applications of immersed interface method in the framework of finite volume discretization. The movement of groundwater table and the extrapolation of physical quantities known only on the water table are given by numerical solution of related advection equations. Several numerical experiments will be presented that confirm the accuracy and the robustness of our level set methods.

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MS55

**Compact and Stable Discontinuous Galerkin Methods for
Convection-Diffusion Problems**

We present a new method, the Compact Discontinuous Galerkin 2 (CDG2) method, for solving nonlinear convection-diffusion problems. Theoretical results showing stability of CDG2 for the heat equation are given, providing explicit bound on any free parameters in the scheme. We present numerical tests for different problems, such as scalar advection-diffusion equations, two-phase flow , and for compressible Navier-Stokes. We compare SIPG, BR2, CDG, CDG2, and LDG in terms of L^2-accuracy and CPU time.

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MS55

A New Inflow-Implicit/Outflow-Explicit Finite Volume Method for Solving Variable Velocity Advection Equations

We discuss a new method for solving non-stationary advection equations. The method is based on finite volume space discretization and a semi-implicit discretization in time. Its basic idea is that outflow from a cell is treated explicitly while inflow is treated implicitly. The method is exact for constant velocity transport of quadratic functions for any length of a time step and it is second order accurate for smooth solutions in general. The matrix of the system is determined by the inflow fluxes which results in a M-matrix yielding favourable stability properties for the scheme. The method allows large time steps at a fixed spatial grid without losing stability and not deteriorating precision. This makes it attractive for practical applications. The scheme is well suited for variable velocity vector fields in higher dimensions and for nonlinear advection-diffusion problems which is documented by a series of numerical experiments.

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MS56

Numerical Homogenization for Complex Multiphase Porous Media Flow

We present a multiscale approach for multiphase porous media flow based on numerical homogenization. The multiscale method consists of a pore scale phase-field multiphase flow solver coupled to a macroscopic finite volume solver. The coupling between the solvers is done through a macroscopic pressure gradient which enters the pore-scale simulations and averaged microscopic fluxes which are used in the finite volume solver. The method is able to handle arbitrary number of flow phases and allows to include nonlinear effects such as contact angles and surface tension in a straightforward way. For single phase and simplified two-phase flow problems the approach is consistent with existing homogenization results.

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MS56

CTRW-based Methodology for Studying the Impact of Heterogeneities on Transport at Multiple Scales

The advantages offered by a methodology that unifies pore network modeling, CTRW theory and experiment in upscaling solute transport in porous media are presented. Temporal probability density functions of tracer particles explain the physical origin of the power-law scaling of dispersion coefficient vs. Peclet number. The rich Peclet-number dependence of asymptotic dispersion coefficient is predicted from first principles and compares well with experimental data for restricted diffusion, transition, power-law and mechanical dispersion regimes. However, until the velocity field is fully sampled, transport is non-Gaussian. This opens up the question on the nature of dispersion in natural systems where the heterogeneities at larger scales significantly increase the range of velocities in the reservoir, thus delaying approach to Gaussian behaviour. To describe it, the multi-scale approach is used in which transport at core, gridblock and field scale is viewed as a series of particle transitions between discrete nodes governed by probability distributions. At each scale of interest a distribution that represents transport physics (and heterogene-

ity) is used as an input to model a subsequent reservoir scale. Statistically rare events such as an encounter with a low velocity zone, have an especially large effect on the plume transport. The cause of anomalous behavior is the broad spectrum of rates or transition times engendered by the heterogeneities.

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MS56

Unstable Displacements in Multiphase Flow in Porous Media: Continuum Modeling and Simulation Challenges

Continuum modeling of wetting phenomena is important in many scientific and engineering applications, from microfluidics and multiphase flow to flow and transport in permeable media. Here we discuss the development of phase-field models of multiphase flow, with particular emphasis on viscous-unstable displacements. The proposed model is used to simulate the transport of a passive scalar through one of the fluids. We show that viscous fingering instabilities enhance mixing at low Reynolds numbers, and discuss the discretization techniques used in our simulations.

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MS56

Analysis and Parameterization of Continuum-Scale Theories using Pore-Network Models- Application for Non-equilibrium Capillarity Theories

Among different numerical and experimental methods for investigation of flow and transport in porous media, pore-scale simulators are of great importance due to their detailed physical-based structure compared to the continuum-scale models as well as their inexpensive tractability compared to the laboratorial methods. Although there are different pore-scale simulators such as Lattice Boltzmann, smoothed particle hydrodynamics, level set, etc., pore-network models are still the most extensively-used approach due to their rather inexpensive computational cost that allows simulating larger domains. We have employed dynamic pore-network modelling to analyse the non-equilibrium capillarity effects in porous media and parameterize the phenomena for continuum-scale models. This study is fulfilled in three steps: a) Pore-scale simulation of two-phase flow: using a dynamic pore-network simulator, DYPOSIT, two-phase drainage process in a conceptual porous medium is simulated under Dirichlet boundary conditions. b) Averaging the pore-scale information to obtain the Darcy-scale entities: after fulfillment of the simulations, the local information are averaged using moving window averaging to obtain the Darcy-scale entities, required for analysis of the Darcy-scale formulations. c) Defining the Darcy-scale parameters: this post-processing step involves determination of the parameters introduced in extended two-phase flow equations using the data obtained in the previous step. The relations derived in this step can be incorporated in continuum-scale simulators for two-phase flow in porous media to model large scale domains.

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MS57

Mixed Multiscale Finite Element Methods for Two-phase Flow in High-contrast Porous Media

The simulation of fluid flow in fractured rock is challenging due to the high contrast in the permeability. We present a mixed multiscale finite element method with a coarse-scale approximation space which captures fine-scale effects of flows in such high-contrast applications. The coarse space is related to a domain decomposition method designed for preconditioning the fine-scale problem. We demonstrate the effectiveness of our approach with numerical examples and discuss the use of these coarse spaces in preconditioning of mixed finite element methods.

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MS57

A Multiscale Preconditioner for Nonlinear Multiphysics Problems in Porous Media

The mortar mixed finite element method can be viewed as a multiscale method, with recent developments showing that the construction of a multiscale flux basis can greatly reduce the computational cost for the domain decomposition problem. Computing this multiscale basis can be expensive, but we show that the basis does not need to be recomputed for each time step if used as a preconditioner. This approach can also be extended to nonlinear interface problems and we provide numerical results illustrating the efficiency of this technique on fully implicit formulations for multiphase flow.

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MS57

Two-Stage Algebraic Multiscale Linear Solver for Flow in Highly Heterogeneous Formations

We address two aspects that pose a serious challenge to existing multiscale finite-volume formulations, namely, channel-like features and strongly anisotropic transmissibility. We describe a Two-stage Algebraic Multiscale Solver (TAMS) for the pressure linear system. One stage deals with a global coarse-grid problem and the second stage uses a local preconditioner on the fine-grid. TAMS converges to the fine-grid solution efficiently in those challenging cases and guarantees conservation after every iteration.

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MS58

On The Tyranny Of Corner Point Grids

The corner point grid is ubiquitous in the petroleum industry. It is used to represent reservoir structure and faults, reservoir stratigraphy and layering, and static and dynamic properties on the grid. A corner point grid has three main characteristics: geometry, topology, and transformed transport properties. Of these three characteristics, we will provide examples of the limitations of each, and describe how the topology of the grid is typically the most restrictive aspect of the description.

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MS58

Simple Grid Generation Algorithms for Fractured Porous Media

This talk describes grid generation algorithms for fractured porous media. Unlike gridding techniques designed for input geometry that is known precisely, our approach for fractures is designed to only capture details of the fracture network geometry larger than the specified grid resolution. The final grids honor fractures approximately while maintaining good cell quality. Several numerical examples are presented in two and three dimensions that demonstrate that the algorithms are robust and practical for industrial applications.

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MS58

Unstructured Hybrid Element Meshing for Reservoir Simulation

Although popular in civil engineering, fully unstructured finite-element meshing is rarely used in reservoir simulation. Critics argue that it is too complicated to apply to geologic structures. Here, we show that it is feasible and has many advantages over structured gridding. We present a workflow including indirect meshing strategies for large aspect ratio features like faults and fractures. When this discretization is permitted by the physics of interest we also use lower dimensional finite-element representations.

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MS58

On Reservoir Gridding for Assessment of Structural Uncertainty

Structural uncertainty refers to uncertainties of the structural framework; i.e. position, orientation, shape and truncations of geological faults and horizons. Structural uncertainty is in general a major uncertainty in the subsurface description, but has been cumbersome to assess explicitly. We will discuss and exemplify limitations of the industry standard for 3D gridding with respect to geometric representation the structural framework. Moreover, we will present methodology for parametric updating of the structural-framework representation in 3D grids.

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MS59

Computational Infrastructure for Geodynamics

Scientific computation has long played a key role in solid Earth geosciences; quantitative numerical models provide a critical link between observations at Earth's surface and dynamic processes in the interior. With increases in computational power and sophistication of algorithms, solid Earth geoscience has seen a proliferation of powerful and predictive models for these problems. Targets for development include models that leverage algorithmic advances to enable exploration of the fundamental interactions between the different Earth systems. Such coupled, interdisciplinary problems are becoming a target of research in solid Earth geodynamics. Examples include the interaction of the lithosphere, plate boundaries and the deeper mantle, the role of fluids in lithospheric deformation, the behavior of faults in the crust, and long-term thermal evolution of the planet. To improve our understanding of these problems using scientific computation, the Computational Infrastructure for Geodynamics (CIG) was established as a community partnership between geophysics and computational science. CIG provides advanced computational tools to the geoscience community, to enable geoscientists to more effectively explore and understand the dynamics of our planet. This talk will discuss mathematical and computational issues and directions for development in com-

putational geodynamics at CIG.

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MS59

Thermomechanics of Mid-ocean Ridge Segmentation

Abstract not available at time of publication.

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MS59

Generation and Extraction of Magma: A Multiscale, Multiphysics Geodynamics Problem

Upscaling algorithms and robust multiphysics solvers are key to model the generation and extraction of melt. Heat and chemical exchange are present from grain to plate scale. Self-organization produces channels but their interaction with large-scale structures and their time evolution are yet unknown. Can they result in magma chambers? Viscosity contrasts of 10^{20} are present. Dike intrusions occurs at much shorter time scale than mantle flow yet represent the final stage of melt delivery.

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MS59

Emerging Geodynamic Computational Techniques at the Victoria Partnership for Advanced Computing

I will survey the parallel implementation of the particle-in-cell finite element code, Underworld, and explain how the methodology was designed to attack specific geodynamics problems. I will give an overview of the relationship between this method and other particle-based approaches and show discuss the relative merits of this method (including its disadvantages). By tracking representative material points, the method is able to take account of the strong, history-dependent material non-linearities and fabric development which emerge during large-scale deformation and accompanying localisation. Underlying the method is a standard finite element engine which relies on a robust, implicit multigrid-method to solve the stress-balance equations for incompressible, Stokes' flow. The method allows for the tracking of sharp material interfaces, discontinuities and strong localisation which, in turn, creates very large variations in material properties. Careful tuning of the solvers is required to develop efficient, scalable parallel solvers that can also cope with these variations in a robust manner. Application areas for Underworld typically range from the crustal scale deformation and evolution of basins, studies of subduction zone dynamics and orogeny, to regional mantle convection simulations with many tens to hundreds of thousands of time-steps. The method is also useful for transferring geological structural models into thermal-mechanical models since it is not necessary to mesh all interfaces and structures exactly in order to consider their influence on the system.

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MS60

Optimization Techniques for Triangular Adaptive Mesh Refinement

The simulation of many geophysical problems comprises a large range of spatial and temporal scales. In computing the effect of mixing on cloud evolution, the typical cloud cluster length scale tens of kilometers, while accurate mixing is modeled with spatial resolution of approx. a meter. In order to numerically bridge this span of scales, adaptive mesh refinement (AMR) methods play an important role. This presentation introduces recent advances in optimizing these methods.

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MS60

A High-order Adaptive Global Shallow Water Model

Unstructured meshes are becoming more and more popular in geophysical flow models. We present a two-dimensional model solving the shallow water equations on unstructured meshes. The latter is dynamically adapted using the AMR technique to minimize the discretization error. The interpolation order is also adapted during the solution process. Classical test cases on the sphere are used to validate the model, as well as the global simulation of the 2010 tsunami in Chile.

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MS60

An Adaptive Discontinuous Galerkin Method for Modeling the Compressible, 2D Navier-Stokes Equations

Theoretical understanding and numerical modeling of atmospheric moist convection still pose great challenges to meteorological research. The present work addresses the following question: How important is mixing between cloudy and environmental air for the development of a cumulus cloud? A Direct Numerical Simulation of a single cloud is way beyond the capacity of today's computing power. The use of a Large Eddy Simulation in combination with semi-implicit time-integration and adaptive techniques offers a significant reduction of complexity. So far this work is restricted to two-dimensional geometry. The compressible Navier-Stokes equations are discretized using a discontinuous Galerkin method introduced by Giraldo and Warburton in 2008. Time integration is done by a semi-implicit backward difference from Restelli and

Giraldo (2008). For the first time we combine these numerical methods with an h-adaptive grid refinement. This refinement of our triangular grid is implemented with the function library AMATOS and uses a space filling curve approach (Behrens, 2005). Validation through different test cases shows very good agreement between the current results and those from the literature. For comparing different adaptivity setups we developed a new qualitative error measure for the simulation of warm air bubbles. With the help of this criterion we show that the simulation of a rising warm air bubble on a locally refined grid can be four times faster than a similar computation on a uniform mesh with the same accuracy.

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MS60

A *h-p* Adaptive Simulation Environment for Atmospheric Sciences

We present a framework aimed at problems arising in the geosciences: it can solve the non-hydrostatic equations of the atmosphere, shallow-water problems, tsunami prediction and advection tests. The DG method is employed, however, any element based discretization can be supported. A mesh database enables parallel non-conforming mesh refinements in both h-p. Modern coding techniques are employed. The latter permit the seamless optimization of compute kernels: SSE vector type are now supported but could be extended to GPUs.

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MS61

The Butterfly Algorithm for Radar Imaging and Wave Propagation

The butterfly algorithm is a robust alternative to the FFT for computing oscillatory integrals in a fast and accurate manner. At the core of the algorithm, low-rank interactions are updated in a hierarchical fashion up and down quadtrees. We review the method, its expected accuracy, and applications to synthetic aperture radar imaging and wave propagation for geophysical applications. Joint work with Matt Ferrara, Nick Maxwell, and Lexing Ying.

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MS61

Homogenization of Wave Equations with Non-separated Scales

We consider the numerical homogenization of acoustic wave equations (and elastodynamics equations) with heterogeneous coefficients, namely, when the bulk modulus (elasticity tensor) and the density of the medium are only bounded. We show that if source terms, boundary conditions and initial conditions are (integrable) regular enough then, eigenvectors associated with large frequencies are only weakly excited, and it is possible to homogenize the original problem. This homogenization is made possible, not by ergodicity assumptions, but by the observation that, if the source terms are in the unit ball of L^2 (instead of H^{-1}), then the solution space is compact in H^1, with respect to the H^1-norm. Various parts of this talk are joint work with L. Zhang, L. Berlyand, M. Desbrun, L. Kharevych and P. Mullen.

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MS61

Upscaling Finite Element Methods for Wave Propagation

Materials such as rock and disordered composites tend to exhibit heterogeneity at many (ideally, a continuum) of scales. Recently, Owhadi has expanded upon a change-of-variables interpretation of homogenization, introduced by Kozlov, to devise accurate upscaling methods for some wave propagation (and other) problems in the presence of a scale continuum. Binford has pointed out the relation between these ideas and immersed interface methods. We review these concepts and discuss extension to discontinuous Galerkin methods.

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MS61

Multiscale Aspects of Waveform Mismatch Measurements

We consider the inference of medium velocity from transmitted acoustic waves. Typically, the measurements are done in a narrow frequency band. As a result the sensitivity of the data with respect to velocity perturbations varies dramatically with the scale of the perturbation. ‘Smooth’ perturbations will cause a phase shift, whereas perturbations that vary on the wavelength-scale cause amplitude variations. We investigate how to incorporate this scale dependent behavior in the formulation of the inverse problem.

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MS62

Black-box Optimization in the Oil Industry

Many optimization problems found in oil industry applications present nonlinear cost function and constraints, both very often based on reservoir flow simulations. Because in many occasions the simulation code is not easily accessible, the use of invasive methodologies can be troublesome. In this talk we will describe a number of general black-box optimization algorithms, and we will illustrate these approaches by a number of example cases with practical relevance in the oil and gas industry.

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MS62

Modeling the Injectivity-Gap Problem in the Wellbore during CO2 Injection into Low Pressure Reservoirs

Depleted gas reservoirs are appealing targets for CO2 sequestration and EGR. Low abundant pressure is advantageous but injection process is challenging. Injecting CO2 in liquid phase may lead to dry-ice or hydrate formation. Published studies that use outflow performance tools without integration with the reservoir model may not be representative. In this work, we provide a comprehensive study to model CO2 flow in the wellbore and the reservoir taking into account the proper thermodynamics.

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MS62

Recent Advances in Closed-loop Reservoir Management

Abstract not available at time of publication.

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MS62

Demonstration of the PEGrid Environment for Uncertainty Based Optimization of Subsurface Reservoirs

The uncertainty based optimization for multiple realizations in reservoir modeling is a promising approach for efficient management of depleting hydrocarbon reserves. The application is computationally intensive, multidisciplinary and require proprietary standard data security. From the success through the TIGRE [Vadapalli et al. 2008] project in supporting these requirements, we have created the Petroleum Engineering Grid (PEGrid) for fostering industry-academia-government partnerships. The promise and scope of this effort will be presented.

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MS63

Current Research in Heavy Oil Modeling

While mathematical modeling has been successful in the recovery of conventional oil, it is still in the early stage of heavy oil modeling. As conventional oil reserves dwindle and oil prices rise, heavy oil is now the center stage. Enhanced heavy oil recovery methods are an intensive research area in the oil industry, and have recently generated a battery of recovery methods in what is the largest growing sector of this industry, such as steam assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS). However, the environmental impacts of these processes and the use of a high volume of water and natural gas suggest that extensive research is required for economic and environmentally friendly development of heavy oil reserves. This presentation will give an overview on current research in heavy oil modeling, and the presenter will also describe his current research program.

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MS63

Simulations of Commercial-scale Polymer Injection using a Parallel Computational Framework

A comprehensive polymer flow model has been implemented in the multiphase flow and reactive module of parallel reservoir simulator (IPARS). An efficient time splitting algorithm is used to solve the flow and transport equations independently. Large commercial scale polymerflood simulations are performed on multiple processors. The results of polymer flood simulations in heterogeneous reservoirs and parallel scalability will be presented. The impact of grid sizes on polymer rheology near injection wells will be discussed.

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MS63

Large Scale Reservoir Simulation

Giant reservoirs of Middle East contain substantial portion of the worlds total hydrocarbons. Accurate simulation of these reservoirs requires as many as billion cells. This is needed to obtain accurate numerical solution and also utilize the available vast amount of seismic and engineering data(measurements).A billion cell parallel reservoir simulator was presented in 2009.This paper discusses new cases as well as new methods to build and analyze large reservoir models using technologies from the other industries. Numerical examples include utilization of a fully implicit, black oil dual, porosity dual permeability billion cell reservoir simulator on worlds largest oil reservoir. Parallel performance, scalability and distribution of computational work are discussed. Numerical accuracy, effect of grid size on the results as well as parallel scalability is presented. Growth of model size in time and future computational demand, projected new computing platforms for the giant reservoir models are discussed. In addition to the numerical aspects, presentation will cover the usage of 3-D spatial computing based visualization with hand gestures to build and analyze giant models. Discussion will also cover utilization of sound in model building and analyzing.

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MS63

Domain Decomposition Approaches for Modeling Multiphysics Multiphase Flow in Porous Media

In this presentation we discuss applying algorithms based on domain decompositions for treating multiphysics, multiscale multiphase flow in porous media. Applications include contaminant transport, carbon sequestration and polymer flooding.

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MS64

Discretisation Issues Related to Tensorial Relative Permeabilities

For simulations of flow of transport in porous media, the mobility term is commonly modeled as a scalar quantity, and it is treated by upstream weighting. However, tensorial relative permeability fields (and thus tensorial mobilities) in general arise on all scales, as is seen in both laboratory and field experiments. Here, we discuss the impact of tensorial relative permeability fields on control volume schemes, and propose new discretisation approaches for the equations.

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MS64

Optimal Flux Allocation for Streamline Simulation

Streamline simulation has gained acceptance in modern reservoir flow simulation, its principal benefit being reducing the three-dimensional transport problem into a set of independent one-dimensional problems. A critical step in streamline simulation is the assignment of the cumulative well flux to individual streamlines. The current approach generally introduces mass balance errors. In this work, we explore optimizing the flux allocation so as to minimize these errors. We apply our new approach to two-dimensional multi-well examples

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MS64

Using Helmholtz Decomposition to Optimize Numerical Methods for Transport in Porous Media

We investigate the use of Helmholtz decomposition to construct a fast solver for the transport equation. Our method is based on separating the dynamics into different parts with different qualitative features. For each part we adapt the numerical method to effectively exploit specific features of this part. Then the solvers are combined to a solver for the complete system. The last part can be done for example by using our solvers as preconditioners for a traditional method or in an operator splitting framework. The aim of this work is to demonstrate the use of Helmholtz decomposition in this setting.

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MS64

Numerical Methods for Coupled Flow and Transport

Simulation of coupled phenomena in subsurface sciences is a challenge of complexity, both modeling and computational. Despite inevitable simplifying assumptions, the mathematical model should faithfully represent coupled processes, domains, phases, and components. A computational algorithm that maintains these couplings at all intermediate steps is unlikely to be practical for large-scale problems. It is crucial to construct 'smart', robust algorithms that first decouple judiciously at intermediate steps, in order to perform efficient computations on parts of the larger system, and then restore couplings upon iterative convergence. Such algorithms would attempt to find subsystems that are weakly coupled in the full system, so that neglecting these couplings in intermediate iterations would degrade convergence of the full system as little as possible. The talk will present some examples that can serve as background for later presentations in this minisymposium.

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MS65

Modeling Hydrogen-water Flow with Hydrogen Dissolution as a Problem with Complementarity Constraints

In an underground nuclear waste disposal hydrogen will be produced by the corrosion of the waste packets. This hydrogen migrates with the underground water flow and is partially dissolved. The problem is modeled as a water-gas flow nonlinear system of PDEs with complementarity constraints. A nonsmooth Newton method is applied to solve our system. This method can be regarded as an Active set strategy. Numerical examples will be presented to show the ability of our solver.

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MS65

Hyperbolic Models for Two-phase Flows with Discontinuous Capillary Pressure Fields

We consider an immiscible incompressible two-phase flow within a one dimensional porous medium made of two different rocks. The capillary pressure is supposed to be constant in each subdomain, but is not neglected at the interface between both rocks. We show that the qualitative behaviour of the corresponding hyperbolic scalar conservation law with discontinuous flux function depends strongly on the orientation of the gravity with respect to the capillarity at the interface. A convergent numerical scheme is then proposed to approximate the unique solution to the problem.

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MS65

Physical Continuity Conditions in HMFE Approximation for Compositional Two-Phase Flow in Heterogeneous Porous Media

A key point in modeling phase transition in multiphase compositional flow is the choice of main variables for solving the resulting system of PDEs. Unfortunately, in the case of heterogeneous porous media, the ideal choice of variables for describing phase transitions is not the best for ensuring physical continuity conditions. We present a modification of the generalized HMFE approximation to handle this difficulty.

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MS65

Generalized HMFE Approximation for Compositional Two-Phase Flow

Two-phase two-components flow with phase-exchange is considered. The presented model is reduced to a system of two conservation PDEs. Two main unknown fields x,y are chosen and all state variables are locally recovered from x and y by solving a double-complementarity problem. The fluxes can be eliminated explicitely and static condensation leads to a nonlinear system of equations dependent on Lagrange multipliers for x,y at each time step.

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MS66

Development of Upscaling Techniques for General-

Purpose Coarse-Scale Compositional Simulation

Upscaling of compositional simulation is challenging due to the interaction of small-scale heterogeneity and phase behavior. We present a framework to upscale two-phase multi-component flow in compositional simulation. It is shown that the oil and gas phases are not at chemical equilibrium on coarser scales. This non-equilibrium behavior is modeled by upscaled thermodynamic functions, which measure the difference between component fugacities. We also introduce upscaled flow functions to account for the effects of compressibility.

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MS66

An Efficient Multiscale Finite Volume Method for Multiphase Flow in Heterogeneous Fractured Porous Media

The i-MSFVM is extended to include multiphase flow in heterogeneous fractured porous media using a hierarchical approach. Local fracture functions are introduced to accurately capture fractures at the coarse scale. Only one degree of freedom per fracture network appears in the coarse system and independent grids are employed for matrix and fractures. Important is that neither local grid refinement nor grid alignment are needed in this approach. Convergence of the method is investigated and shown for various representative cases.

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MS66

Upscaling Technique for Modeling of Well-Reservoir Interaction

The complexity of the interaction between the well and the reservoir depends strongly on the way the well region is isolated from the reservoir region. In this work we present the concept of expanded well model, where the well region is geometrically expanded to include the relevant part of the reservoir. The effectiveness of this technique is illustrated for challenging problems such as fractured well and production from tight-gas reservoir.

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MS66

Adaptive Multiscale Finite-Volume Method for Gravity Instability

The standard Multiscale Finite Volume (MsFV) method fails to accurately reproduce finger evolution since small errors grow in time in unstable flow regimes. The iterative MsFV method overcomes this issue at the expenses of computational efficiency. Here we introduce an adaptive iMsFV technique that resolves local problems only in areas close to the unstable front. In this context, the iMsFV method can be seen as an adaptive grid-refinement technique.

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MS67

Application of Advanced Unstructured Gridding Techniques to Reservoir Simulation

Prismatic grids constructed by projection of a 2D grid can resolve stratigraphic layers and are well suited for high aspect ratios of reservoir dimensions. In this talk, we address challenges of choosing a projection technique applicable to structurally complex models with fault surfaces deviating from vertical. We use topological parametric space of a geologic model as a pre-image for prismatic grid generation, and further reduce limitations of prismatic grids in resolving 3D geometries and property distributions by utilizing a zonal gridding strategy.

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MS67

The UVT Transform: A Unified Approach to Reservoir Modeling and Uncertainty Assessment

Current reservoir modeling practices revolve around the construction of a single 3D grid that is used for both distributing reservoir properties and simulating fluid flow. The most common types of grid structure used have limitations in terms of the complexity of the reservoir structure that they can represent and often require distortions of the individual grid cells that impact both the spatial distribution of properties and numerical results of flow simulation. The UVT Transform has been introduced to enable a 3D transformation from today s space into the paleo-geochronological domain. Fit for purpose grids are constructed in the transformed space alleviating structural limitations and artificial cell deformations. This unified approach ensures consistency between seismic and geological interpretation and the various representations of the subsurface optimized for petrophysical property modeling, fluid flow simulation or geomechanical studies.

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MS67

Upgridding by Amalgamation: Flow-Adapted Grids for Multiscale Simulations

We discuss the creation of flow-adapted grids by amalgamating cells from an original fine grid, using cell-wise indicator functions to guide the amalgamation directions and the new grid resolution. We present an algorithmic framework with a set of modular components that can be combined in different ways to create fit-for-purpose grids, which can be used to develop highly efficient multi-fidelity transport solvers accompanying multiscale flow solvers.

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MS67

Gridding Diplomacy - Balancing Requirements

Grid construction for the complex geometries arising in reservoir modelling can be regarded as an act of diplomacy, where multiple requirements have to be balanced. For most practical applications, corner-point grids have been the preferred solution, applicable to both geological modelling and dynamic flow simulations. The presentation will discuss how conflicting requirements are balanced in current state-of-the-art gridding technology. Examples will be presented, illustrating challenges and solutions from field applications.

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MS68

Rifting and Diking

Abstract not available at time of publication.

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MS68

A Study on the Influence of the 2008 Wenchuan Earthquake on the Stability of the Qinghai-Tibet Plateau Tectonic Block System

In this paper, the 3D Finite Element Method was combined with a Discontinuous Deformation Analysis (DDA+FEM) to study the influence of the Wenchuan earthquake on the stability of the tectonic blocks system of the Qinghai-Tibet Plateau under the background of northward extrusion of the Indian Plate and obstruction of the strong crust of the Sichuan basin. With constraints from GPS data and focal mechanisms, we first calculated the velocity and stress fields of the region. Then, we numerically simulated the rupture process of the seismogenic fault of the 2008 Wenchuan earthquake in overthrust form with a right strike-slip component. We then studied the movement and deformation of the tectonic blocks that was caused by the earthquake and its influence on the stress state of the boundary faults. The numerical simulation indicates that the large earthquake causes the most tectonic blocks in the study zone at approximately a 1-mm deviation toward the northeast; in particular, the Wenchuan seismogenic fault obviously deviated eastwards, and the maximum deviation reaches 1.5 m. It seems that the large earthquake causes the Bayankala block at the west side of the Longmenshan fracture zone to extend farther eastward. The Wenchuan earthquake causes the Coulomb failure stresses on the boundary faults of the tectonic blocks in the study zone to change to different extents. The maximum change of the Coulomb failure stress reaches about 0.2 MPa at both ends of the Wenchuan seismogenic fault, the south section of the Xianshuihe fracture zone and part of the southeast section of the Dongkunlun fracture zone in the upper crust. Additionally, the Coulomb failure stresses also increase to different extents between 0.01 and .02 MPa in regions such as the southernmost end of the Xianshuihe fracture zone, part of the southeast section of the Dongkunlun fracture zone, the southwest and southeast edges of the Eerdos block, just to name a few.

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MS68

Rifting and Faulting

Abstract not available at time of publication.

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MS68

GAMR: A Free Paralell Adaptive Tectonics and Mantle Convection Code

The Computational Infrastructure for Geodynamics (CIG) has begun development of Gamr: a new community code for tectonics and mantle convection. The principle new improvement of Gamr over existing community codes such as CitcomS and Gale is the use of parallel adaptive mesh refinement (AMR) to better resolve fine features such as faults, plate boundaries, and mantle plumes. I will discuss the current status of Gamr and outline future milestones.

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MS69

On Conservative Remapping Transport Schemes using Icosahedral-hexagonal Grids

A high order incremental remapping scheme has been designed using the Icosahedral-hexagonal meshes. The

scheme has been tested for the advection of smooth scalar fields in both deformational and non-deformational flow fields. The incoming flux areas are approximated by great circle arcs using exact analytical trajectories. The bi-quadratic reconstruction functions are computed on projection space to approximate the tracer field. The overall order of a transport scheme is thus determined completely by accuracy of reconstructed tracer field and geometry of the flux areas. A comparison of errors due to reconstruction functions obtained by weighted least squares fits to point values versus area-averaged values will presented. Also the various simplifications to the shapes of flux areas have been analyzed. A comparison of loss in accuracy due to simplification of flux area geometry with respect to the gain in computation efficiency will be presented. Finally the effect of three very different limiters: Flux corrective transport, Multi dimension flux and multidimensional extension of vanLeer limiting will be presented.

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MS69

A 2D Non-Hydrostatic Atmospheric Model Based on a Non-Oscillatory Finite-Volume Method

Non-hydrostatic atmospheric modeling based on the finite-volume methods is becoming increasingly popular for the weather and climate simulations. A new two-dimensional non-hydrostatic model (compressible Euler system) has been developed. A semi-discrete central finite-volume method is used for the spatial discretization, and time integration relies on explicit Runge-Kutta method. The scheme does not employ expensive Riemann solvers and characteristic decomposition or any staggered grid system; and is computationally efficient. The non-oscillatory reconstruction removes spurious oscillations, and improves the quality of numerical simulations. The model is tested for various non-hydrostatic benchmark test-cases, and the results will be presented in the seminar.

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MS69

A Flux-based Characteristic semi-Lagrangian Method for Atmopspheric Modeling

Abstract not available at time of publication.

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MS69

A Family of High-Order Finite-Volume Schemes for Simulating Atmospheric Flows

We present our ongoing research on developing a set of numerical methods for simulating atmospheric flows. We have harnassed a high-order unstaggered finite-volume based approach in developing a family of both advective and shallow-water models on the cubed-sphere and verified our results against existing test cases. This approach has been shown to satisfy a relatively weak CFL condition and leads to more accurate results for the same order-of-accuracy, as compared with Galerkin-based approaches.

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MS70

Shaping Regularization in Geophysical Inverse Problems

Shaping regularization is a general method for imposing constraints on the estimated model in the process of solving an inverse problem. In the shaping framework, regularization enters the inverse problem in the form of a model or shaping operator, which maps the estimated solution into the space of admissible solutions. Although this framework does not explicitly involve optimization, a connection with the optimization framework can be established via the theory of proximity operators. Shaping regularization has been applied to a wide range of geophysical problems, from seismic velocity estimation to adaptive filtering, definition of local seismic attributes, and time-frequency analysis. I will describe both the general theory and the known applications.

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MS70

DG-based, UQ-equipped, Parallel, Adaptive, Scalable Elastic-acoustic Seismic Inversion

We describe mathematical and computational issues underlying an effort to create a new generation seismic inversion code. These include: elastic-acoustic coupling, discontinuous Galerkin discretization, gradient and Hessian consistency, parallel adaptivity on forest of octree meshes, uncertainty quantification via Bayesian inference, and scalability to petascale systems. Illustrations from global seismology are provided.

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MS70

A Fresh Look at Simultaneous Source

Many parameter estimation problems involve with a parameter-dependant PDEs with multiple right hand sides. The computational cost and memory requirements of such problems increases linearly with the number of right hand sides. For many applications this is the main bottleneck of the computation. In this talk we show that problems with multiple right hand sides can be reformulated as stochastic optimization problems that are much cheaper to solve. We discuss the solution methodology and use the direct current resistivity as a model problem to show the effectiveness of our approach.

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MS70

Seismic Volume Reconstruction Via Multilinear Rank Reduction

Consider a matrix S(n, m) where some entries are missing. For instance, the entries S(m, n) can be the scores assigned by buyer m to product n. Because not all buyers have bought and scored all products, the matrix contains empty entries. The goal of Collaborative Filtering (CF) is to predict the empty entries and therefore, predict products that a consumer might like. Seismic data reconstruction can also be interpreted as a matrix completion problem similar to those arising in the field of CF. Seismic completion, however, entails reconstructing a 5D volume (a tensor). Similar to the matrix completion problem, tensor completion can be achieved via rank reduction methods. The intention of this talk is to present our recent research in rank reduction methods for seismic data reconstruction and de-noising. We will discuss some of challenges that one needs to solve in order to create industrial-strength algorithms for multilinear seismic data processing.

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MS71

Model Reduced Variational Data Assimilation for Reservoir Models

Variational data assimilation or "the adjoint method" has been used very often for model calibration problems in reservoir models. This method however requires the implementation of an adjoint model. Even with the use of the adjoint compilers that have become available recently this is a tremendous programming effort. Therefore we propose another approach to variational data assimilation using model reduction that does not require the implementation of the adjoint of the original model. Model reduced variational data assimilation is based upon a POD (Proper Orthogonal Decomposition) approach to determine a reduced model for the original reservoir model. Once this reduced model is available, its adjoint can be implemented very easily and the minimization process can be solved completely in reduced space with negligible computational costs. In many reservoir models the adjoint states can be computed relatively easy and only the Jacobians with respect to parameters are hard to obtain. This makes a balanced POD-based method very attractive.

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MS71

Parameter Identification for a Coupled Fluid Flow and Geomechanical Deformation Model

We present an application of iterative regularization for data inversion from a coupled single-phase flow and a poroelastic reservoir. Production data and measurements of surface deflection are inverted to reconstruct petrophysical and elastic properties of the reservoir. By means of synthetic experiments we evaluate the contribution of surface deformation data in the estimation of uncertain properties. Our evaluations can be potentially applied to design cost-efficient InSAR and GPS configurations for optimal monitoring of reservoirs.

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MS71

The Large Dimensional Bayesian Inversion Proem with Application to a Reservoir Model

Petroleum reservoirs are complex geological formation encompassing a wide range of physical and chemical heterogeneities. These heterogeneities span over multiple length scales and are impossible to describe in deterministic detail. Geostatistics and, more specifically, stochastic modeling of reservoir heterogeneities are being increasingly considered by reservoir analysts and petroleum engineers for their potential in generating more accurate reservoir models together with usable measures of spatial uncertainty. The goal of reservoir characterization is to provide a numerical model of reservoir attributes such as hydraulic conductivities (permeability), storativities (porosity) etc.. These attributes are then used as inputs into complex transfer functions represented by various flow simulators to forecast future reservoir performance and oil recovery potential. Permeability is one of the most important quantities for prediction of fluid flow pattern.The estimation of permeability fields is therefore, critical and necessary for the prediction of the behavior of contaminant plumes in aquifers and the production of petroleum from oil fields. In this paper, we employ a Bayesian hierarchical model to quantify the uncertainty by formulating the posterior distribution of the fine-scale permeability field condition on both the coarse-scale data and production data and the observed fine-scale data at the well locations. To represent the spatial dependence in the permeability fields, Karhunen-Loéve expansion is used to reduce the number of parameters. We assume the number of terms in this expansion is unknown and develop a two stage reversible jump based MCMC algorithm to efficiently explore the posterior distribution. Furthermore, we introduce a multiscale data integration method with upscaling technique for spatial modeling of the permeability. Numerical results are presented by analyzing simulated as well as real data.

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MS71

Bayesian Uncertainty Quantification for Flows in Heterogeneous Subsurface Formations

We study the uncertainty quantification for flows in heterogeneous porous media. The permeability field is assumed to have channelized structure that are represented using level sets approaches. In particular, the parameterization of the channel boundaries is represented via the parameterization of velocity field in the level sets equations. The truncation in the parameter space introduces errors in the posterior measure that are investigated. Multi-stage MCMC algorithms are used for efficient sampling from the posterior. We present numerical results. This is a joint work with Y. Efendiev, A. Mondal, B. Mallick, and A. Datta-Gupta.

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MS72

Simulation of CO2 Migration Using Vertical Equilibrium Models

Recently, methods based on an assumption of vertical equilibrium (VE) has obtained renewed interest in the context of modeling CO_2 migration over long time- and spatial scale. It is expected that after the injection period, CO_2 will migrate over several kilometers in the horizontal direction, but only tens of meters in the vertical direction limited by the vertical boundaries of the aquifer. When the horizontal to vertical time scale becomes large, it is reasonable to approximate CO_2 migration using vertically averaged models. The fact that VE-methods reduces the spatial complexity of the problem from 3D to 2D may give important savings in computational time. Furthermore, because of improved vertical resolution the VE-approximation in many situations gives better solutions than standard 3D formulations. In this presentation we show results from field simulations taken from the Utsira and Johansen formation in the North Sea.

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MS72

Model Coupling for CO2 Sequestration Scenarios

Models for CO2 storage need to be able to describe non-isothermal, multiphase and compositional processes. However, in most cases it is not necessary to describe all the physical processes for the whole simulation time period. It is possible to describe a certain time scale with models of reduced/adapted complexity. By coupling these models of reduced complexity the model efficiency is increased without neglecting the relevant phenomena.

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MS72

A Multiphysics Approach for the Simulation of Multiphase Flow Processes in Porous Media

The contamination of the unsaturated zone with a light non-aqueous phase liquid is studied, corresponding to a domain with randomly distributed heterogeneities where complex three-phasethree-component processes are relevant only in a small (local) subdomain. This subdomain needs fine resolution as the complex processes are governed by small-scale effects. For a comprehensive fine-scale model taking into account three-phasethree-component processes as well as heterogeneities in the whole (global) model domain, data collection is expensive and computational time is long. Therefore, we developed a general concept where on the one hand, the global flow field influences the local three-phasethree-component processes on the fine-scale. On the other hand, a coarse-scale saturation equation is solved where the effects of the fine-scale multi-phasemulti-component processes in the subdomain are captured by source/sink terms and the effects of fine-scale heterogeneities by a macrodispersion term.

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MS72

Finite Volume Discretization of Multiphase Porous Media Flows for CO2 Geological Sequestration

This talk deals with the simulation of multiphase compositional Darcy flow for CO2 injection in saline aquifer. It will focus on the finite volume discretization of both Darcy fluxes and transport terms. The efficiency of the algorithms is illustrated on near well CO2 injection test cases including dissolution of CO2 in the water phase, drying of the near well region and salt precipitation.

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MS73

A Non-linear Correction and Maximum Principle for Diffusion Operators Discretized using Cell-centered Finite Volume Schemes

In the present work, we propose a nonlinear correction which gives nonoscillating solutions and which can be applied to standard cell-centered finite volume schemes. Using an analytical solutions, we show the robustness and the accuracy of this algorithm in comparison with results obtained by linear finite volume schemes which do not satisfy the minimum principles on this test.

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MS73

The Finite Volume Scheme Preserving Maximum Principle for Diffusion Equation

We construct a new nonlinear finite volume scheme for diffusion equation on polygonal meshes and prove that the scheme satisfies the discrete extremum principle. Our scheme is locally conservative and has only cell-centered unknowns. Numerical results are presented to show how our scheme works for preserving discrete extremum principle and positivity on various distorted meshes.

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MS73

Monotone Subfamily of Mimetic Finite Difference Discretization Methods

The family of the Mimetic Finite Difference (MFD) methods provides flexibility in the choice of parameters which define a particular member of the family. The correct choice of these parameters may guarantee that the resulting linear numerical scheme satisfy the DMP principle. The monotonicity limits of MFD method are investigated in several practically important cases including meshes generated using the Adaptive Mesh Refinement (AMR) strategy.

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MS74

Generalized Continua for Reinforced Geomaterials

The effective behaviour of soft elastic materials periodically reinforced by stiff slender elastic inclusions is investigated through the homogenization method of periodic media. A large stiffness contrast induces a full coupling between the beam behaviour of the inclusions and the shear behaviour of the matrix. Instead of the Cauchy continua usually obtained for homogenized composites, the macro behaviour is of second gradient type at the leading order, and differs from that of Cosserat media.

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MS74

Some Theoretical and Numerical Problems Related to the Modeling of Strain Localization by Second Gradient Continuum Theory

Generalized theories of continuum mechanics, as Cosserat's, micromorphic or, with regards to this presentation, second grade theories, have proven efficient to model the post strain localization behaviour of non-elastic media which the classical Cauchy's theory cannot do properly. The purpose of this presentation is to expound some theoretical and numerical results related to strain loalization and second grade computations as analytical evidence of localization, analytical solutions for second grade elastic problems, locking in FE computations.

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MS74

Micromechanics of Ductile Porous Geomaterials with Account of Pressure Sensitivity.

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Porosity strongly affects the overall ductile behavior of cohesive geomaterials undergoing plastic deformation. In the present study, we propose an original micromechanical approach which suitably couples Drucker-Prager type plasticity and evolving porosity under general triaxial loadings. The resulting model has the advantage to be based on a single macroscopic yield function which also plays the role of plastic potential. It is shown that this yield function is particularly appropriate to account for the voids collapse and plastic shearing mechanisms which govern the mechanical behavior of various porous geomaterials.

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MS74

Darcy Vs Brinkman

Different filtration laws have been proposed in history to describe a fluid flow through porous medium. We focus here on Darcy's law

$$\vec{v} = \mathbf{K}(f - \nabla p)$$

and Brinkman's law

$$\mathbf{B}\,\vec{v} + \nabla p - \mu\Delta\vec{v} = f \quad .$$

Using the method of homogenization we derive both laws, in case of porous medium with special structure. The goal of this work is to compare the two laws and see that they can be related with an appropriate choice of parameters.

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MS75

Super-resolution in Time-reversal by Homogenization

Over the past decades, much attention has been devoted to the detection of small inhomogeneities in materials or tissues, using non-invasive techniques, primarily electromagnetic wave-fields. The characterization of the signature of small inclusions is now well understood. But many questions remain regarding their accurate localisation, especially in non-homogeneous media. In contrast, during the same period it was shown that inhomogeneous media are more favorable than homogeneous ones for time reversal experiments, involving active sources. This talk will be devoted to recent results on the enhanced resolution available in structured media, and their consequences for the imaging of small inhomogeneities.

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MS75

Homogenization Effects in Domains with Oscillating Boundaries

We consider domains with microinhomogeneous boundaries. We study the asymptotic behavior of solutions to boundary value problems in domains with rapidly oscillating or rough boundaries and in multilevel and cascade thick junctions with rapidly oscillating transmission zone. Inhomogeneous Fourier boundary conditions with perturbed coefficients are set on the oscillating boundaries. We prove the homogenization theorems and convergence of energy integrals as the small parameter characterizing the microinhomogeneity, tends to zero. It is shown that there are several qualitatively different cases in the asymptotic behavior of the solutions.

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MS75

Representation Formulas for L^∞ Norms of Weakly Convergent Sequences of Gradient Fields in Homogenization

We identify local representation formulas that in the fine phase limit provide upper bounds on the limit superior of the L^∞ norms of gradient fields inside homogenized porous media. The local representation formulas are expressed in terms of the weak limit of the gradient fields and local corrector problems. The upper bounds may diverge according to the presence of rough interfaces. We identify explicit local formulas for the limit of the L^∞ norms of the associated sequence of gradient fields inside smooth periodic microstructures.

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MS75

Homogenization of Pseudo-parabolic Systems

Pseudoparabolic systems with periodic data are homogenized to obtain upscaled limits. The limit is characterized and convergence is established in various linear cases for both the classical binary medium model and the highly-heterogeneous case. The limit of vanishing time-delay parameter in either medium is included. The double-porosity limit of Richards' equation with dynamic capillary pressure is included.

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MS76

A Stochastic Approach to Modeling Effective Multiphase Flows in Heterogeneous Porous Media

Heterogeneity and buoyancy can compete or combine together to influence spreading in multiphase flows through porous media. In this work we study the interaction of the two with the goal of deriving an effective large scale equation that accurately quantifies the rate of spreading. To do so we work in a stochastic framework treating the medium permeability as random. In particular the rate of spreading is quantified by an effective dispersion (and effective permeability) coefficient. To validate the approach we perform a series of numerical simulations, which show good qualitative agreement. We find that the interplay between density and heterogeneity leads to an enhancement of the front spreading as well as a renormalization of the evolution of the mean front position relative to an equivalent homogeneous medium. The quantification of these phenomena plays an important role in several applications, including for example carbon sequestration and enhanced oil recovery.

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MS76

Nonlinear Transport Problems with Time-memory Effects

Contaminant transport in heterogeneous porous materials can be described by the convolution of a PDE with a time-memory kernel that accounts for the long correlations induced by the underlying flow. In this talk we will discuss how to extend this transport formalism to include nonlinearities (e.g., geomechanical, and geochemical effects), what is the interplay between nonlinearities and memory effects, and what are the mathematical challenges associated with the solution of such equations.

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MS76

Efficient Solution of Advection-Reaction Diffusion with Stochastic Forcing

We consider exponential based integrators for porous media flow in two and three dimensions. These methods are based on solving the linear problem exactly and exploit efficient methods for computing large matrix exponentials. We are particularly interested in the effects of time dependent stochastic forcing. The forcing is taken to model unknown movement between trapped and flowing solutes, unknown small scale variations in the reaction term or time dependent changes in permeability. We examine convergence and efficiency of new schemes for the stochastic PDEs for both additive and multiplicative noise and present numerical results for realistic flow type problems.

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MS76

Modeling Dispersion in Heterogeneous Porous Media with Stochastic Diffusion Processes for Fluid Particle Velocities

To model the dispersion of fluid particles induced by conductivity heterogeneity, we propose stochastic diffusion processes for the Lagrangian velocity of fluid particles. The corresponding processes are continuous in time and are able to accurately capture the dispersion behavior for log-conductivity variances σ_Y^2 ranging from $0.06 \ldots 4$. By validation with Monte Carlo data it is demonstrated that the model reproduces non-Gaussian velocity statistics and long-term velocity correlation effects very accurately.

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MS77

High-resolution Modelling of Geodynamic and Planetary Processes with Finite Differences and Marker-in-cell Techniques

Modern gross challenges in geodynamic and planetary modelling are: (i) creating high-resolution realistic 3D numerical models applicable to nature, and (ii) obtaining a rigorous understanding of geodynamic and planetary processes and the key physical parameters controlling them. One possible pragmatic strategy is to use a combination of conservative finite differences with marker in cell techniques on fully staggered rectangular Cartesian grid. This approach allows for both simplicity of numerical implementation and stability and robustness of numerical solutions. Possible drawback is in limited possibility of grid refinement that can indeed be efficiently compensated by low memory requirements and high speed of computations allowing for high resolutions in both 2D (thousands of points in each direction with direct solvers) and 3D (hundreds of points in each direction with multigrid solvers) by using only few CPUs. We developed a family of finite-difference, marker-in-cell codes I2ELVIS/I3ELVIS which can handle visco-(elasto)-plastic rheology, mineralogical phase changes, free surface and (when needed) self-gravitation. With these tools we created a number of predictive numerical models for various geodynamic and planetary processes, such as self-consistent mid-ocean rift formation with transform faults, oceanic and oceanic-continental subduction initiation and long-term evolution, continental collision with spontaneous slab breakoff, intrusion emplacement into the crust, planetary accretion and metallic core formation.

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MS77

On Geothermal Processes within the Lithosphere

Most heat and fluid flow simulations for geothermal plays couple thermal and darcy flow at the reservoir scale, however, non-conventional geothermal exploration requires certainty of heat and fluid flow at depth over much larger scales. We demonstrate approaches to assimilating 3D basin (and beyond) geological provinces to simulations that capture meter scale coupled thermal - fluid flows. These include utilizing a material point approach to the finite element method, a simplified PDE compositional language, SPH methods for geometry interpolation, simple forms of mesh refinement, parallelization to 1000s of CPUs and some of the benchmarks addressed.

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MS77

Positivity Preserving Well-balanced Methods for the Shallow-water Equations

Shallow-water equations with a non-flat bottom topography have been widely used to model flows in rivers and coastal areas. An important difficulty arising in these simulations is the appearance of dry areas, and standard numerical methods may fail in the presence of these areas. These equations also have steady-state solutions in which the flux gradients are non-zero but exactly balanced by the source term. In this presentation, we propose some recently developed high-order discontinuous Galerkin and weighted essentially non-oscillatory methods, which can preserve the steady-state exactly, and at the same time are positivity preserving without loss of mass conservation. Some numerical tests are performed to verify the positivity, well-balanced property, high-order accuracy, and good resolution for smooth and discontinuous solutions.

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MS77

High Order Interface Method for Solving Multiflow Navier-Stokes Equations in Geophysics

We developed a second-order accurate interface method, based on the matched interface and boundary approach, to solve the Navier-Stokes equations with discontinuous viscosity and density on non-staggered Cartesian grid. We derive for the first time the interface conditions for the intermediate velocity field and the pressure potential function that are introduced in the projection method. The differentiation of velocity components on a stencil across the interface is aided by using the coupled fictitious velocity values, whose representations are solved by using the coupled velocity interface conditions. These fictitious values and the non-staggered grid allow a convenient and accurate approximation of the pressure and potential jump conditions. A compact finite difference method is adopted to explicitly compute the pressure derivatives at regular nodes to avoid the pressure-velocity decoupling. Numerical experiments verify the designed accuracy of the numerical method. Applications to geophysical problems demonstrate that the sharp pressure jumps on the clast-Newtonian matrix are accurately captured for various shear conditions, moderate viscosity contrasts and a wide range of density contrasts. It is also shown that a large absolute difference of the viscosity across the interface will cause the simulation unstable, due to the large transfer error in computing the jumps in the pressure and potential interface conditions from the numerical solutions of the velocity field.

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MS78

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

A semi-implicit and semi-Lagrangian Discontinuous Galerkin method for the shallow water equations is proposed and analyzed. The method is equipped with a simple p-adaptivity criterion, that allows to adjust effectively the number of local degrees of freedom employed to the local structure of the solution. Numerical results in the framework of one dimensional test cases prove that the method captures accurately and effectively the main features of linear gravity and inertial gravity waves, as well as reproducing correct solutions in nonlinear open channel flow tests. The effectiveness of the method is also demonstrated by numerical results obtained at high Courant numbers and with automatic choice of the local approximation degree. Perspectives for extensions to geophysical flows applications are discussed.

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MS78
Jacobian Free Efficient Implicit Solver for HOMME

Abstract not available at time of publication.

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MS78
CG/DG Formulation of the Non-Hydrostatic Unified Model of the Atmosphere (NUMA)

We describe our progress in the development of a parallel 3D compressible Navier-Stokes model for use in non-hydrostatic atmospheric modeling. The explicit time-integration version of NUMA currently scales up to tens of thousands of processors but we would like to extend it to hundreds of thousands. We will describe our MPI implementation and challenges facing us in scaling the implicit solvers. NUMA is based on continuous and discontinuous Galerkin methods (CG/DG) and is high-order (arbitrarily high-order polynomials can be used), fully unstructured, and capable of using explicit, semi-implicit, and fully-implicit time-integrators. Finally, NUMA can be used both for regional and global modeling. We will report on benchmark test cases to show the accuracy and efficiency of the model and will discuss the many challenges remaining in the development of this model.

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MS78
Quasi-Monotone Advection Methods for Spectral Elements

High Order Method Modeling Environment (HOMME) is a spectral element dynamical core option in Community Earth System Model (CESM). The spectral element method in HOMME is a forth-order accurate continuous Galerkin method on quadrilateral elements. In this talk we discuss new quasi-monotone limiters for HOMME. We compare Zalesak-type FCT limiters with ones using optimal reconstruction. The optimal reconstruction is obtained by solving a quadratic programming problem local to each element. To illustrate our ideas, we use divergent and non-divergent advection tests for geophysical flows with distortive winds from the paper by Nair & Lauritzen, 2010.

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MS78
The Variable Resolution Spectral Element Dynamical Core in the Community Atmospheric Model (cam)

NCAR's High Order Method Modeling Environment (HOMME) uses high-order element-based Galerkin methods and the cubed sphere geometry to solve global PDEs on massively parallel computers in a coordinate system that is free of polar singularities. HOMME has been updated to allow static refinement via conforming quadrilateral meshes and this talk discusses the implementation of refinement in HOMME's spectral element dynamical core as used by the Community Atmospheric Model (CAM-HOMME).

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MS79
Title Not Available at Time of Publication

Abstract not available at time of publication.

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MS79
Assimilation of Production and 4D Seismic Data in Oil Reservoir Modeling by Virtual Sensing

Time-lapse (4D) seismic attributes can provide valuable information regarding the subsurface fluid flow. This spatially-rich source of information supplements the poor areal information attainable from production well data. While fusion of information from multiple sources holds great promise, in practice, this task is far from trivial. Joint inversion is complex for many reasons, including dissimilar temporal and spatial scales, ambiguous coupling mechanisms between the various parameters, and unclear relative statistical fidelity of the different data sources. These concerns limit the applicability of many data-assimilation techniques. Adjoint-based methods offer great efficiency and consistency; however their implementation generally requires extensive coding effort. In this study we present a formulation that exploits the adjoint functionality that modern simulators offer for production data, to consistently assimilate inverted 4D seismic attributes. The central idea is to incorporate seismic inverted attributes by virtual sensors. These sensors mimic production wells and thereby leverage adjoint functionality for the seismic data. Precautions are taken to ensure that such sensors will not interfere with the fluid dynamics. Other than the obvious consistency advantage in the proposed methodology, its implementation does not require re-programming legacy adjoint code, and in principle can be utilized for the incorporation of a broad range of data sources and attributes. We present numerical results demonstrating considerable

improvement in matching saturation distribution in different assimilation setups. This work was carried out as part of a joint Shell-IBM research project.

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MS79

Joint Electromagnetic-Seismic Inverse Modeling

Seismic data are first transformed into the Laplace-Fourier Domain, which changes the modeling of the seismic wave field from wave propagation to diffusion. Several benefits follow: (1) seismic and EM data are better matched in resolution, governed by the same physics of diffusion, (2) standard least squares inversion works well with diffusive type problems, and (3) possibilities to image across multiple scale lengths, incorporating different types of geophysical data and attributes.

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MS79

Including Multiply-Scattered Waves in Seismic Imaging

Imaging the subsurface in exploration seismology conventionally only makes use of primaries (singly reflected waves). In certain circumstances, multiples (waves that reflected more than once on the path from source to receiver), can be used to form an image. This allows better illumination of the bottom of subsurface structures, and near-vertical features. A method for jointly imaging using both primaries and multiples to enhance the result, will be presented.

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MS80

Data Assimilation Applications in Large Scale Reservior Models

Abstract not available at time of publication.

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MS80

Particle Ensemble Kalman Filtering with Application to a Reservoir Model

Abstract not available at time of publication.

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MS80

Reservoir Applications of the Adaptive Gaussian Mixture Filter

The ensemble Kalman filter (EnKF) is currently considered as a promising method for conditioning reservoir simulation models to production data. However, it has some shortcomings in estimating the correct posterior distribution. An alternative that avoids some of these shortcomings is the adaptive Gaussian mixture filter (AGMF) [Stordal et. al., 2010]. Here we will present a comparison between the EnKF and the AGMF on a well known test case, the PUNQ S3 model. high-level commands.

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MS80

Multi-level Parallelization of Ensemble Kalman Filter (EnKF) for Reservoir History Matching

The ensemble Kalman filter (EnKF) has been successfully implemented in parallel to assimilate data in reservoir history matching problems. In the EnKF method, a suite of reservoir models (set of ensemble members) runs independently forward in time (forecast step), and is continuously updated as new data becomes available (assimilation step). An efficient implementation of the EnKF is presented in which three-level parallelization is employed. The first level of parallelization is for the forecast step by running each ensemble member on a different computer processor. This is very efficient for a large number of ensemble members, but without additional parallization, the memory of a single processor constrains the size of the reservoir simulation. Therefore, a second level of parallelization which uses a parallel reservoir simulator for each realization is implemented. The assimilation step requires collecting a state vector from each ensemble member. If this data is collected on a single processor, this poses an additional limitation on the size of the EnKF problem in terms of both memory and computation time. Therefore, we propose an algorithm in which a third level of parallelization is acheived for the assimilation step.

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MS81

Benchmarking Multiscale Mixed Finite Element Method (MsMFEM) for Modeling Flow Accuracy and Computational Efficiency

Multiscale Mixed Finite-Element method attempts to capture sub-grid geological information directly into the coarse-scale via mathematical basis functions. These basis functions contain essential multiscale information and are coupled through a global formulation to provide highly accurate approximation of the flow solution. MsMFEM is used to simulate flow on highly heterogeneous geologically realistic corner-point grids with faults and fractures. The MsMFEM is benchmarked against a proprietary simulator and a fine-scale model for accuracy and computational efficiency.

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MS81

Multiscale Simulation for Two-phase Flow in Porous Media

In this contribution we develop multiscale simulation capabilities, with an emphasis on robustness in terms of grid irregularity and the duality between upscaling and preconditioning. We place particular emphasis on issues arising in 3 spatial dimensions, including the use of secondary (non-conserved) coarse variables.

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MS81

Goal Oriented Upscaling for Coupled Flow/Geomechanics Simulations

Abstract not available at time of publication.

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MS81

Incorporation of Diffusion into Compositional Multiphase Flow Simulation

Mixing of nonequilibrium phases in both open space and in permeable media is of fundamental nature with broad applications in CO2 injection in hydrocarbon reservoirs and for CO2 sequestration in saline aquifers, and measurement of diffusion coefficients. Despite the importance of mixing, the process has not been incorporated in current numerical reservoir simulators properly especially when one grid cell contains one of the nonequilibrium phases and the neighboring cell contains the other phase. To be specific suppose one cell contains CO2 and the neighboring cell contains water or oil phase. Current reservoir models cannot account properly for the flux between the two grid cells. A fundamental deficiency is that local equilibrium condition is not imposed at the interface. Consequently current simulators give erroneous results even with fine gridding. In this work, for the first time we incorporate the criteria of local equilibrium at the interface between the neighborhood grid cells to account for diffusion flux and convective flux properly. We use a mixed finite element framework to account for diffusion flux calculation both within a cell and interface flux. As a result allowance is made for the conditions that interfacial diffusion flux is much higher than interfacial convective flux while bulk phase convective flux is much higher than bulk phase diffusion flux. Two formulations are established, one for a moving interface and the other for a fixed interface. Our moving interface formulation is compared with open space formulation recently presented in another study. We also present a fixed mesh method that is much faster and appropriate for reservoir simulation. The efficiency of the fixed mesh method is mainly due to its larger time step size compared to the moving interface formulation. Except for CPU efficiency, the results from the two formulations are the same.

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MS82

Optimization-based Postprocessing of Finite Element Solutions for Recovering Monotonicity

Loss of monotonicity and violation of the discrete maximum principle are typical drawbacks exhibited by the numerical solutions of the conventional approximation methods, such as finite elements (FE), finite volumes (FV), and mixed finite elements. The problem is particularly important in cases of highly anisotropic diffusion tensors or distorted unstructured meshes. In this talk, we suggest a least-change correction to available FE solution. It is aimed on recovering the monotonicity properties. This postprocessing procedure is based on solving a monotonic regression problem with some extra constraints. The postprocessed solution preserves the accuracy of the discrete FE approximation in L2-norm, satisfies the discrete maximum principle and meets the conservativity requirement. We present an algorithm for solving the postprocessing problem. Its efficiency is demonstrated by the results of numerical experiments.

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MS82

A Monotone Discretization Method for the Convection-Diffusion Equation

We present a non-linear monotone finite volume method for the numerical approximation of the steady convection-diffusion equation on unstructured meshes in two spatial dimension. The method is formally second-order accurate as the convection flux is evaluated numerically by means of a piecewise linear reconstruction within each cell and at mesh vertices. Non oscillatory behavior in presence of strong gradients is achieved through suitable slope limiters in the solution. The edge gradients, required to discretize the diffusive fluxes, are defined inside additional quadrilateral cells centered at mesh edges, the so-called "diamond cells", by a gradient formula which is formally exact for linear solutions. A set of numerical results documents the performance of the method in treating problems with internal layers and solutions with strong gradients.

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MS82

Monotone Finite Volume Discretization of Two-phase Black Oil Equations on Polyhedral Cells

A new monotone finite volume method with a nonlinear two-point flux approximation is applied to the approximate solution of two-phase black oil equations on 3D meshes composed of polyhedral cells. In special cases of orthogonal grid with isotropic or grid-aligned anisotropic permeability tensor the linear and nonlinear approximations are identical. In general case the linear two-point flux discretization provides no approximation, whereas the nonlinear two-point flux discretization is at least first order accurate. Numerical experiments with two-phase black oil model demonstrate that the quality of the discrete flux approximation has a great effect on the front behavior and the water breakthrough time.

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MS83

A Multiscale Model for Thermo-hydro-mechanical Analysis of Porous Media and Constitutive Behaviour Including Capillary effects

We propose a thermo-hydro-elastoplastic model for partially saturated three-phase soil. Averaging theory leads from micro to macro level. Restrictions resulting from thermodynamics are imposed thus the description of the behavior at macro scale is thermo-dynamically consistent. Constitutive parameters are identified for a data concerning a see gas reservoir; capillary effects and micro collapse due to variation of load and saturation are found as an interpretation of a behavior observed at macro scale.

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MS83

Chemical Local Non-equilibrium: Origins, Modelling and Analysis

Transport of chemical species in heterogeneous geomaterials during the transient phase is very often characterized by the local non equilibrium conditions. In this presentation the different origins of such conditions and their consequences on the macroscopic behaviour, are reviewed. Particular attention is paid to the chemical heterogeneity of the geomaterial. In the second part, modelling by homogenization of the transport in a double porosity medium, including diffusion/dispersion, convection and reaction phenomena, is presented.

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MS83

Modelling and Simulation of Chemical Degradation Mechanisms in Porous Media with Evolving Microstructure

A prototypical reaction–diffusion system in a porous medium is considered, whose microstructure undergoes an evolution with respect to time. Employing the method of homogenization in domains with evolving microstructure, the limit problems are obtained. Attention is also paid to the scaling of the material parameters with powers of the homogenization parameter arising from a nondimensionalization. For one class of applications, an efficient adaptive finite element approach for the resulting limit problem is presented.

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MS83

Homogenization of Biot-type Multi-compartement Medium with Double Porosity for Multiscale Modeling of Diffusion-deformation Processes

In the paper we report on homogenization of the double porous fluid-saturated deforming medium which is described by the Biot model. Both compressible and incompressible cases were considered. It is shown, how the topology of microstructure defined w.r.t. the dual porosity influences structure of the homogenized model. Fading memory effects are explained in terms of flow in the dual porosity. Also large-deforming media were subject of homogenization applied to the updated Lagrangian formulation. For layered porous media with transversally periodic structure, the homogenization leads to models with reduced dimension: "3D to N times 2D". The models are developed for simulations of compact bone poroelasticity, or tissue perusion. Numerical examples are computed using our in-house FEM code Sfepy.

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MS84

Equations with Random Coefficients: Convergence to Deterministic or Stochastic Limits and Theory of Correctors

Equations with small scale structures abound in applied sciences. Such structures often cannot be modeled at the microscopic level and thus require that one understand their macroscopic influence. I will consider the situation of partial differential equations with random, highly oscillatory, potentials. One is then interested in the behavior of the solutions to that equation as the frequency of oscillations in the micro-structure tends to infinity. Depending on spatial dimension and the decorrelation properties of the random potential, I will show that the limit is the solution to either a deterministic, homogenized (effective medium) equation or a stochastic equation with multiplicative noise. More precisely, there is a critical spatial dimension above which we observe convergence to a deterministic solution and below which we observe convergence to a stochastic solution. In the former case, a theory of correctors to homogenization allows one to asymptotically capture the randomness in the solution to the equation with the small scale structure. Once properly rescaled, this corrector is shown to solve a stochastic equation with additive noise.

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MS84

Error Estimates on Homogenization of Free Boundary Velocities

I will talk about a free boundary problem which describes contact angle dynamics on an inhomogeneous surface. We obtain an estimate on the convergence rate of the free boundaries to the homogenization limit in periodic media. The method presented here also applies to more general classes of free boundary problems with oscillating boundary velocities.

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MS84

Multi-scale Analysis for Problems Where Classical Homogenization Fails

It is known that in many real situations, the classical homogenization theory fails to provide a robust and reliable macroscale approximation model for the given microstructure. In this talk I will discuss about possible alternative ideas to deal with such situations.

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MS84

Corrector Estimates for a Reaction-diffusion System Modeling Sulfate Corrosion

A semi-linear partially-dissipative reaction-diffusion system modeling concrete corrosion in sewer pipes is considered. The microstructure contains three non-overlapping regions: the solid matrix, the pore water clinging on solid fabrics and the air-filled part of the pore. A particular feature of the microscopic model is that two interface-reaction mechanisms, the Henry's law and a nonlinear chemical reaction on the boundary of pore walls, are balanced by the diffusive transport. The quality of the averaging procedure is defined by means of error estimates. We construct first order correctors and derive error estimates using the unfolding method, which enables the proof of error estimates without additional regularity of the correctors.

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MS85

Robust Convex Optimization for Closed Loop Reservoir Management

Abstract not available at time of publication.

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MS85

Integrated Dynamic Optimization and Control in Reservoir Engineering

Abstract not available at time of publication.

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MS85

Hierarchical Long-term and Short-term Production Optimization

Abstract not available at time of publication.

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PP1

Iterative Solution of Non-Autonomous Bloch Equations: Fluorescence Spectrum with Detuned Squeezed Vacuum Field

The non-autonomous Bloch equations modelling a driven 2-level atom in the presence of an off-resonant broadband squeezed vacuum (SV) field is treated analytically. This concerns iterative solutions valid for large SV detuning parameter but for arbitrary strength of the laser field. Computational results are presented for the averaged atomic variables for various data and compared with the resonant SV field case. The iterated analytical results for nonzero SV detuning are compared with the (exact) numerical solutions of the Bloch equations, hence we have an insight about the range of other system parameters (other than the Rabi frequency) for which the iterated solutions are valid to O(10-2) or less. The main purpose of deriving these analytical results is to calculate analytically the transient fluorescent spectrum. For an initially ground-state atom, both the SV phase and detuning parameters induce pronounced asymmetrical spectrum in the strong field case.

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PP1

On the Development of An Adaptive Triangular Discontinuous Galerkin Shallow Water Model

The precise simulation of geophysical phenomena is essential for the development of hazard warning systems. Therefore, we develop an adaptive two-dimensional shallow water model based on the Discontinuous Galerkin method. For spatial discretization we utilize high-order nodal basis functions as øfirst introduced by Giraldo et. al in 2002 and the underlying triangular mesh is generated with amatos (see Behrens et. al, 2005). We show fiørst results obtained from running several testcases.

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PP1

Pseudo-Steady State Attractors for Fully Transient Forchheimer Flows in Porous Media

This work is focused on the dynamics of the generalized Forchheimer flows for slightly compressible fluids in porous media with given total flux on the boundary. The class of the flows which are time invariant to certain characteristics is introduced and explored. We proved that each of the time invariant flow attracts fully transient flows for particular boundary conditions independently to the initial data. Some applied engineering aspects of the framework are considered.

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PP1

Developing Empirically Based Seismic Event Location Ground Truth Criteria for Regional Seismic Network in Ethiopia and Tibet

The International nuclear monitoring community relies on selection criteria for classifying seismic events at the Ground Truth 5km level, which specifies the absolute location to within 5km. Regional-network locations cannot be validated using existing criteria. Using the resampling methodologies developed by Bondr et al. (2004) and (Boomer et al., 2010), we have obtained empirical criteria based on measures of uniformity of azimuth and distance coverage. Criteria are being developed for Ethiopia and Tibet.

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PP1

Reduced Order Models for Uncertainty Quantification and Parameter Estimation in Subsurface Flows

Modern reservoir simulations with millions of degrees of freedom can be extremely costly to evaluate given a set

of input parameters representing boundary/initial conditions and flow field properties. Thus, studies that require many model evaluations at varying input parameters such as sensitivity analysis, uncertainty propagation, or history matching can be prohibitively expensive. Cheaper reduced order models are necessary for such analyses. We propose a method for reduced order modeling of nonlinear dynamical systems. The model reduction method is comparable to reduced basis methods and POD-based model reduction, where the reduced model is a linear combination of a small set of model runs. The coefficients of the linear combination are computed with a nonlinear least squares method, and the minimized residual is used as an a posteriori error estimate on the reduced model. This error estimate can also be used to find points in the parameter space whose solution will maximally enhance the reduced basis, i.e. as a guide for how to choose the parameters to run the full model. We consider as our model problem a one-dimensional two-phase, three-component compositional displacement. The parameters in our study are the component K-values, i.e., ratio of the each components phase composition; for simplicity we use a constant K-value model. The predicted recovery from a reservoir is dependent on the solution path which in turn has a highly nonlinear dependence on the K-values (even when these are taken to be constants). As a proof of concept, we use the reduced order model as a surrogate in a maximum entropy inversion method to find the K-values that are consistent with a given production history.

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PP1

Sensitivity of Co2 Storage Formation Pressurization and Migration to Uncertainty in Fault Zones and Reservoir Properties: a Case Study.

We investigate here the potential impact of geologic carbon sequestration in a partially compartmentalized sandstone basin in the Southern San Joaquin Valley in California, USA. Uncertainty about fault behavior is addressed by assessing four distinctive fault property scenarios. A systematic sensitivity study is conducted for each scenario to identify near- and far-field key hydrogeological parameters and processes affecting pressure buildup and brine migration.

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PP1

Flow of Compressible Fluids Through Cracks in Elastic Bodies and Excitation of Seismic Waves in Volcanic Eruptions

We investigate the eruption of fluids through conduits in elastic bodies, with particular focus on the excitation of seismic waves by conduit wall oscillations induced by fluid flow. The fluid, an isothermal mixture of exsolved gas and liquid melt, obeys quasi-one-dimensional mass and momentum balance equations and a nonlinear equation of state describing compressibility changes during gas exsolution. Both the elastic wave equation and the fluid equations are solved with high order finite differences.

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PP1

A Fully Implicit Solution Method Capability in the Spectral Element Community Atmosphere Model

Grid refinement of the Community Atmopshere Model (CAM) creates new algorithmic challenges including coupled nonlinear dynamics, physics, and chemistry, multiple disparate time scales, and scalability requirements. In addition, new capabilities to analyze model sensitivities are desired. Solution methods that address these issues are becoming increasingly important. A fully implicit (FI) solution method is applied to the shallow water and primitive equations within the spectral element dynamical core (CAM-HOMME) and early results are presented. FI provides a coherent nonlinear solution to all dependent variables and allows relatively large time steps to be taken stably without subcycling and with demonstrated accuracy. The solver implementation is occurring through the development of a Fortran interface package for the Trilinos project that has been applied to several components of the Community Earth System Model.

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PP1

Simulation of Supercritical Carbon Dioxide Seepage from An Injection Well

We present a numerical model that simulates flow and transport of CO2 into a multi-layered subsurface system. The model uses state-of-the-art multi-threaded finite element methods and unstructured adaptive mesh refinement scheme. Several scenarios spanning from a homogeneous single layered reservoir to heterogeneous multi-layered systems, which including cap-rock with embedded fractures, have been simulated under different operations of CO2 leaking conditions. Results show the impact of leakage rates impact on the evolution of the CO2 spread.

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PP1

Simulation and Upscaling of Nonaqueous Phase Liquid Dissolution in Three Dimensional Saturated Porous Media

We present an integrated experimental and computational approach aimed at quantitatively investigating the role of pore structure, entrapped DNAPL distribution and hydrodynamic conditions on core-scale mass transfer rates. A numerical model was developed using adaptive mesh refinement finite elements method. The numerical model solves simultaneously Navier-Stokes flow and transport with state-of-the art embedded interface tracking scheme. The model was used to derive upscaled mass transfer rates for different soil types.

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PP1

Application of Fractal Geometry in Evaluation of Plagioclase Mineralization: Case Study Igneous Rocks in Moshiran Area, Nw Iran

The area under study is situated in North-west of Iran. This area contains volcanic rock sequences from Basaltic to Andesitic composition related to volcanic processes in Eocene. Plagioclase were analyzed by statistical methods to test for fractal behavior. The analysis shows that self-affine fractal geometry can be used to characterize the zoning patterns of this minerals. Generally low abundance of small plagioclase crystals increases to 5-15% with some as large as 12 mm long. The crystal size distributions of these crystals mostly plot as almost straight lines on a classic CSD diagram. fractal dimension of Plagioclase crystals in this area have calculated using fractal geometric methods such as box-counting. we can from this studies results conclude that factors operating on scales much larger than the local interface processes are most important in controlling the zonation.

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PP1

Application of Fractal Geometry in Evaluation of Plagioclase Mineralization: Case Study Igneous Rocks in Moshiran Area, Nw Iran

It is widely accepted that many of Minerals show scale invariance, i.e. they are self-similar within a large range of scales. In this paper, fractal dimension of Plagioclase crystals in Basaltic, Andesitic rocks from Moshiran area in NW of Iran have calculated using box-counting method. Image analysis techniques are applied and fractal dimension varies between 1.5 to 1.85 that correspond with geochemical modeling of magma mixing Coupled fractal analysis and geochemical data reveal that D increases as the degree of magma interaction and show that homogenization paterns increases in magma. An other hand this study indicated that present of zoning structures in Plagioclase crystals have relation between fractal geometry functions .fractal geometry can help to interpretation of varies kind texture in rocks.

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PP1

An Alternative Splitting for Two-Phase Flow with Capillary Pressure

A subset of problems in two-phase groundwater flow feature diffusive capillary pressure terms that balance the advective motion of the fluid. One numerical method designed to solve these advection-diffusion PDEs is a split method where the advective and diffusive parts are solved separately. This works well when either advection or diffusion dominates; however, when these terms are supposed to balance, this splitting can lead to a severe time-step restriction. We propose a variation of this method that preserves the balance between the two effects while enabling a larger time-step that is based on an f-wave decomposition of the flux. We show results from this formulation for a groundwater flow problem.

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PP1

Direct Simulations of Dynamic Interfaces in Complex Geometry

Multiphase flow in porous media is dictated by the behavior of fluid-fluid interfaces, which affects phase distribution through hysteresis and instability. To investigate these phenomena, we perform direct numerical simulations of a 2D two-phase system. The full Navier-Stokes equations are solved in the pore space and the Volume of Fluid method is used to track the interfaces. Particular attention is paid to interfacial energy and to the effects of the velocity on phase distribution.

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PP1

Comparison of Preconditioning Techniques for Optimizing a Nonhydrostatic, Parallel Tsunami Simulation Model

The Tsunami Modelling Group at Alfred-Wegener-Institute has developed a tsunami simulation tool with a $P_1 - P_1^{NC}$ Finite Element discretization on unstructured grids and a Leapfrog time-stepping scheme. For higher accuracy a set of equations similar to the shallow water equations has to be solved. The major percentage of the resources is required by the computation of several large, sparse systems of equations. By comparison of miscellaneous preconditioning techniques their individual capabilities of optimization are presented.

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PP1

Synthetic 3D Simulations from Real Models with Topography

I show finite-difference discretizations of (visco-)elastic wave equations including free surface topography boundary conditions, using an exact transform from a vertically curved (stretched) grid to a rectangular (computational) grid. I simulate real areas of 3D models covered by topography. Qualitative effects are shown of prominent free surface topography on wavefields, comparing and isolating effects of using real and homogeneous interior media, as well as assessing effects of adding viscoelasticity to the results.

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PP1

A-Priori Estimates for Non-Equilibrium Systems

We discuss extensions and applications of a-posteriori analysis for a coupled linear system of PDEs known in multiscale analysis as Warren-Root model. Its structure extends readily to nonlinear models of non-equilibrium adsorption, Enhanced CoalBed Methane Recovery, and other kinetic models. In this poster we show numerical results for the a-posteriori analysis and for the applications.

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PP1

Vertical Equilibrium Simulation with 3D Near-Well Modeling

Lack of vertical resolution may cause 3D simulations of CO2 sequestration to be inaccurate. To increase accuracy and reduce computational cost, a thin CO2 plume can be approximated in terms of its thickness to obtain a 2D simulation model. However, the corresponding assumption of vertical equilibrium is not fulfilled near an injecting well. Herein, we therefore develop a method in which a vertical equilibrium formulation is coupled with a standard 3D discretization near the well.

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PP1

Mimetic Finite Difference Methods for Modeling Subsurface Flows

Mimetic finite difference (MFD) methods mimic important properties of underlying PDEs, such as conservation laws, symmetry and positivity of a solution, and fundamental identities of the vector and tensor calculus. This poster will summarize our progress in development and analysis of MFD methods as well as they usage in applied projects for modeling subsurface flows on distorted unstructured polyhedral grids.

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PP1

Seismic Processing of Diffractions

A main task in seismic data interpretation is the identification of sharpened objects in the subsurface, such as faults or channels. When these structures are small enough, they diffract the energy emitted by the acquisition process. We propose a method that optimize the traditional seismic processing, by considering the diffractions as information instead of noise, to locate points at the velocity model where diffractions are made, and thus generating better images of the subsurface.

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PP1

Reducing Hurricane Storm Surge Model Error Us-

ing the Ensemble Kalman Filter

Error is inherent in every dynamical model and in observations of the model solution. Given both, data assimilation methods are used to compute the best estimate of state. The Ensemble Kalman Filter is an advanced data assimilation method for nonlinear problems. Here it is applied to the Advanced Circulation (ADCIRC) model to better predict hurricane storm surge using water elevation measurements.

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PP1
Tectonic Evolution at Rift Zones: Geodynamics and Numerical Modeling

Tectonic evolution at rift zones is commonly considered symmetric along mid-ocean ridges, when modeling with relative plate motions and steady-state processes. However, the bathymetry of rift zones is generally asymmetric. Adopting an absolute frame of reference, we performed simulations using FEM: the mantle is modeled as a viscous non-newtonian fluid, and its dynamics is described by the Stokes equations. Results show an asymmetric thickening of plates along the ridge, as suggested by the observations.

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PP1
A New Adaptive Multiscale Fem Applied to Interface Problems

We introduce a new adaptive multiscale finite element method (AMsFEM) that greatly improves convergence whilst still being conforming. AMsFEM is an extension of the adaptive local-global multiscale finite element method by Durlofsky et al. The idea is to keep the mesh fixed and instead iteratively adapt the shape of the basis functions in the approximation space. This allows fine scale data to be incorporated in to local problems for the basis functions whilst still having a coarse global system to solve. We present applications of this to structural optimization problems but they can be applied to groundwater flow problems also.

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PP1
Coupled High-Order Finite Difference and Unstructured Finite Volume Methods for Earthquake Rupture Dynamics in Complex Geometries

Spontaneous rupture models are becoming increasingly used to study scenario earthquakes and to assess seismic hazard. High-order numerical methods are ideally suited for these problems, but stable, accurate, and efficient methods are needed to incorporate the nonlinear friction laws. We present our latest developments on the use of summation-by-parts finite difference methods and the simultaneous approximation term method for such problems, with a focus on using unstructured grids.

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PP1
Porescale Benchmark: Call for Participation

[Organizers; M. Peszynska, Dorthe Wildenschild, Oregon State University]. We propose to define a set of benchmarks in porescale modeling organized by a group of researchers involved in the computational and experimental modeling at porescale. We define the goals, propose the online venue, and outline the directions, applications, techniques, as well as timeline. In particular, we include single and multiphase flow, biofilms and reactive transport modeling, and a variety of techniques including continuum to discrete computations. This poster is intended as a call for participation in this benchmark.

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PP1
Testing Nonhydrostatic Sound-Proof Equations As Prospective Governing Pde for Regional Weather Prediction

The nonhydrostatic anelastic model EULAG, for research of multiscale atmospheric flows, is considered as a prospective dynamical core of a future operational regional numerical weather prediction (NWP) model of the European COnsortium for Small scale Modeling (COSMO), anticipated to operate at kilometer- and sub-kilometer horizontal resolutions. Results of dry and moist idealized and semi-idealized tests are summarized and supplemented with examples of realistic sub-kilometer NWP-like simulations of

the Alpine flows.

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PP1

The Impact of Single-Phase Upscaling on Polymer-Flooded Reservoirs

Upscaling of geological data to reservoir models is common practice in reservoir simulation. However, reducing the number of grid blocks introduces errors in the simulation due to computational discretization and loss of reservoir heterogeneity. Typically upscaling studies focus on Newtonian fluid injection, e.g. water flooding, whereas the effects of upscaling on non-Newtonian fluid flow behavior are not well understood. In this study, we examine the effect of upscaling polymer-floodings.

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PP1

An Alternative to Streamlines for Flow Diagnostics on Structured and Unstructured Grids

In this paper, we investigate finite volume methods as an alternative to traditional streamline-based methods for obtaining flow diagnostic information. Given a computed flux field, we solve the stationary transport equations for tracer and time of flight on a fixed grid to partition the reservoir into injector-producer pairs and to assess the heterogeneity of the reservoir. We show that a multi-dimensional upstream weighting scheme is able to reduce the numerical diffusion associated with the method.

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PP1

Energy Bounds for the Equations of Mantle Dynamics

We present energy estimates for the partial differential equations of mantle dynamics, in a somewhat simplified form. We show that the fluid pressure blows up as the melt is lost. Therefore the fluid pressure variable cannot be approximated in any simple way in a finite element and other approximation method.

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PP1

Coupling of the Evolution of Pore Pressure and the Retrogressive Slope Failure During Breaching

Breaching is a type of slope failure that, due to the pore pressure response, produces retrogressive sediment release. We study the connection between the pore pressure dissipation and the retrogressive slope failure through flume experiments and numerical modeling. We find the erosion rate of breaching is proportional to the coefficient of consolidation, and the spatial distribution of pore pressure is self-similar through time.

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PP1

Model of Mineralization of Rainwater Passing Through a Rock

Geochemical interactions of rainwater passing through a rock was modelled. The main chemical components and the governing equlibrium and kinetic chemical reactions were identified. Sensitivity analysis of some parameters of the model was done to better understand the model. The model was used to inverse modelling - calibration of several parameters of a real-world problem - using measurement data published before. Acknowledgement: This result was realized under the state subsidy of the Czech Republic within the project No. 1M0554

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PP1

Calibration of Rainfall-Runoff Hydrological Model and Flood Simulation Using Data Assimilation

This work focuses on the calibration of a distributed parsimonious event-based rainfall-runoff model using data assimilation. In the present work, a BLUE filtering technique was used to calibrate the initial water deficit and the velocity travel for each flood event assimilating the first available discharge measurements at the catchment outlet. The assimilation algorithm was applied on two Mediterranean catchment areas of different size and dynamics: Gardon d'Anduze and Lez. On both catchments, it was shown over a significant number of flood events, that the data assimilation procedure improves the flood peak forecast. The improvement is globally more important for the Gardon d'Anduze catchment where the flood events are stronger. The peak can be forecasted up to 36 hours head of time for some events. Such results are obtained assimilating very few observations (up to 4) during the rise of the water level. For multiple peaks events, the assimilation of the observations from the first peak leads to a significant improvement of the second peak simulation. It was also shown that the flood rise is often faster in reality than it is represented by the model. In this case and when the flood peak is under estimated in the simulation, the use of the first observations can be misleading for the data assimilation algorithm. The careful estimation of the observation and background error variances enabled the satisfying use of the data assimilation in these complex cases even though it does not allow the model error correction.

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