the methodology is extremely powerful, it suffers from the disadvantage of being numerically intensive.

URL: http://www.ees6.lanl.gov/staff/monty/

H12D-0330 1330h POSTER

Conditioning Fracture Networks through the Gradual Deformation Method

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A stochastic optimization technique has been developed to characterize fracture networks from mass transport. First, we introduce a new method to generate fracture networks consistent with some prior knowledge, that is the knowledge of the major components of the fracture system. Then, we focus on the representation of fracture networks that respect both the prior information and the hydrologic data collected in multiple wells. A good way to go about this characterization stage is through optimization. The optimization process provides a fracture network which reproduces all the observed data. The hope is that networks that can at least duplicate the observed data are more likely to make good predictions. Up to now, simulated annealing has been widely implemented to identify lattice configurations matching the hydrologic data. However, this optimization approach creates fracture networks that reproduce more or less the hydrologic data, but without honoring the prior information. Therefore, we suggest to base the optimization process upon a geostatistical parameterization technique, called the gradual deformation method. Independent fracture networks are combined sequentially to modify continuously a starting fracture model until the matching is satisfactory enough. This new approach, in addition to be quicker than simulated annealing, allows for determining networks consistent with the hydrologic data observed in the field and the prior knowledge about the fracture distribution. It was used successfully to find lattice configurations consistent with tracer data.

H12E MC: Hall D Monday 1330h

Midcentury Effects of Climate Change on Water Resources in the West I *(joint with A, GC)*

Presiding: **T P Barnett,** Scripps Institution of Oceanography**; W T Pennell,** Global Environmental Change Research Organization

H12E-0331 1330h POSTER

Influence of Increased CO2 on Regional Climate Simulations

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Several PCM (Parallel Climate Model) coupled (atmosphere-ocean) simulations have been developed starting from a period back in the 1800s through 2095, using historical CO2 concentrations for the past and "business-as-usual" CO2 concentrations for the future. What differences occur if these global low-resolution (T42L18) simulations are down-scaled with a regional climate model? Toward this goal, three basic numerical simulations with the regional spectral model (RSM) at a spatial resolution of about 50 km are being conducted to investigate regional US responses. Both the NCEP Reanalysis II (T62L28) and the PCM simulation (T42L18) data are used as initial and boundary conditions for present-day conditions (1986-present). The observed sea surface temperature (SST) is used in the RSM-reanalysis run while in the RSM-PCM run, the SST is given by the global simulation. The other surface fields in both runs are given by the climatological data. Initial comparisons indicate that the RSM simulations preserve the larger scale features of the reanalysis and PCM simulation, while providing more realistic smaller scale features not present in the driving large-scale fields. The years of 2040-2060 with the increased CO2 found in the PCM simulations are chosen for the period of increased CO2. Several additional ensemble PCM members will be used as boundary conditions in order to assess uncertainty at regional scales from both the global PCM and regional RSM.

H12E-0332 1330h POSTER

Implications of a range of climate scenarios for water resources in the Pacific Northwest

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The Pacific Northwest's water resources are heavily dependent on snowmelt to transfer water from the wet winters to the dry summers, and are therefore sensitive to the snow-determining influences of climate variations and climate change. Anthropogenic climate change is expected to produce significant warming in the Northwest, and needs to be included in plans for future water resources. To quantify the responses of Northwest water resources to projected changes in both temperature and precipitation, we have implemented the Variable Infiltration Capacity (VIC) model at 1/8 degree resolution. We used projected changes in temperature and precipitation for the Pacific Northwest region from four climate models, and performed simulations with the VIC model by perturbing observed 20th century weather data. The resulting range gives better guidance to policymakers than a single climate-change scenario.

H12E-0333 1330h POSTER

Modeling Future Snow Accumulation for a Small Alpine Watershed in the Southern Canadian Rockies Using the CCC CGCM1

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Synoptic downscaling from GCM has been widely used to develop local and regional scale future precipitation scenarios under global warming. An analysis of the linkages between the CCCma CGCM1 (Canadian Centre for Climate Modelling and Analysis first version of the Canadian Global Coupled Model) 2000 model output and local/regional precipitation time series is presented. The GCM 500 hPa geopotential heights were visually classified for synoptic patterns using a GIS. The pattern frequencies were statistically compared to historical data from Changnon et al, 1993 for the winter period 1962-85. The CGCM1 synoptic frequencies compare favorably to the historical data; and represent a substantial improvement over the 1992 Canadian Climate Centre Global Circulation Model synoptic climatologic output. Future pattern frequencies for 2021-50 were also classified and compared to historic pattern frequencies to determine changes in future precipitation patterns.

Under forecast climate warming, alpine snowpacks may vary substantially due to changes in long-term synoptic scale precipitation and regional warming that may increase the rain to snow ratio in a watershed. Snowmelt contributes more effectively to river flow than does rainfall. Hence conversion of winter snowfall to rainfall likely results in declining runoff. We used precipitation and temperature scenarios from the CGCM1 for wintertime along with a meso scale alpine hydrometeorology model to evaluate the joint impact(s) of forecast climate change on mountain snowpacks. The hydrometeorology model is applied to a small alpine watershed in the southern Canadian Rockies. We hypothesize that the increase in winter precipitation due to synoptic conditions will not compensate for regional changes in the rain to snow ratios. The net result is a decline in winter accumulations of precipitation as snow.

H12E-0334 1330h POSTER

Multivariate characterization of drought in California

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A principal components-based, multivariate drought index has been used to identify intervals of drought within three NCDC climate divisions in California over the approximate period of 1970-2000. The index has been computed on a monthly basis, using observational data for precipitation, streamflow, dam reservoir storage, evaporation, and snowpack (where appropriate). Additionally, numerical computations of soil moisture have been included. By anchoring its calculations upon hydroclimatological norms for the climate division, the multivariate drought index presents an objective methodology for the regional assessment of drought severity. The findings are compared to drought descriptions from the Vegetation Condition Index and Palmer Drought Severity Index over the period examined.

H12E-0335 1330h POSTER

Linking the CCC CGCM1 Upper Air Winter Synoptics to Winter Precipitation in the Western U.S.

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Future precipitation scenarios are routinely derived using downscaling techniques that use GCM upper air synoptic pattern frequencies as an indicator of winter time precipitation. This technique has proven to better replicate historical precipitation regimes for winter periods; and hence we assume the technique provides more accurate estimates of future precipitation than typical GCM estimates of precipitation. We have reported previous work performing these analyses based on the 1992 Canadian Climate Centre GCM and a series of precipitation stations for western North America. Here we have repeated the analysis using the new runs from the CGCM1 model released in 2000. The downscaling methodology is described elsewhere (Lapp et al, 2001). The CGCM1(3) run is a transient CO2 model that accounts for the effects of greenhouse gases and the direct effect of sulphate aerosols (CCCMA, 2000).

Historical synoptic frequencies and the approximate 1xCO2 (1962-85) upper airflow conditions are quite similar, but there are substantive variations in the approximate 2xCO2 (2021-50) upper airflows. Relative occurrence (dominance) of historical synoptic patterns are statistically linked to historical spring runoff for the study region. These linkages are used to forecast changes in future winter precipitation based on variations in synoptic pattern statistics for the 2xCO2GCM upper airflow patterns. The changes in future winter precipitation is presented for a number of western North American locations.

H12E-0336 1330h POSTER

Evaluation of Hydrologically Relevant PCM Precipitation Characteristics over the Continental U.S.

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Space-time characteristics of precipitation critically affect the land surface hydrologic response. Of particular importance, in addition to mean quantities, are seasonal variability, storm inter-arrival times, space-time correlation, and the diurnal cycle and variability.

The ability of the US Dept. of Energy Parallel Climate Model (PCM) to reproduce selected precipitation statistics over the continental U.S. was evaluated using a historical climate run and gridded observations over a range of temporal scales from sub-daily to annual. The observation data, taken from long-term Cooperative Observer stations and gridded to 1/8 degree over the U.S., were aggregated to the PCM scale (T42 horizontal resolution, about 2.8 degrees) for comparison. Primary statistics of interest included: a) spatial variation in the annual mean and spread; b) reproduction of the monthly/seasonal cycles, by region; c) a variety of statistics at the daily scale, including dry/wet days per year and transition probabilities between the two states, mean storm inter-arrival lengths and storm durations, by season, and daily precipitation intensity distributions, by season; and d) reproduction of the diurnal precipitation cycle along selected latitudinal and longitudinal transects.

H12E-0337 1330h POSTER

Analysis of VEMAP II Projections of Future Runoff in the U.S. Under Climate Change

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The VEMAP II model experiments investigate the response of biogeochemical and biogeographical models to variability in climate over the conterminous United States using historical and projected transient scenarios of climate and atmospheric CO2. We have been analyzing the runoff produced by five of the models. Validation of the runoff generated during the historical period of 1895-1993 was the focus of our initial work. Here we build upon that work by extending our analysis to 2100 to cover the future scenarios period during which both CO_2 and temperature increase. For each of the five models we examine two scenarios (with and without CO_2 increases of 1% a year) derived from two GCMs, the Hadley Centre's HadCM2 and the Canadian Climate Centre's CGCM1. In general, the CGCM1 projects a US climate that is warmer and drier than the HadCM2 projection. The forcings derived from both GCMs under the increased CO_2 scenario yield increases in annual runoff by three of the VEMAP models (CENTURY, MC1, and LPJ) and a decrease by BiomeBGC. However, the magnitude of the increases is smaller under CGCM1 than HadCM2, and the decrease is larger under CGCM1 than HadCM2. TEM shows no difference between the scenarios as the model's hydrologic processes are insensitive to changes in CO_2. The effects on 13 selected watersheds are presented including changes in the magnitude and timing of runoff compared to a baseline period of 1961-1990.

H12F MC: 130 Monday 1330h

Evaluation of Unsaturated Flow Models, Recent Advances, and Applications I

Presiding: **B R Scanlon,** Univ. of Texas at Austin**; J Simunek,** USDA, ARS

H12F-01 1330h

Modeling Preferential flow in Soils

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Preferential water flow and solute transport are first defined, and the mechanisms underlying different preferential flow/transport processes in the unsaturated zone are briefly described. Various approaches to modelling preferential water flow and solute transport in the unsaturated zone are then reviewed and compared. One case study is presented of the field application of a dual-porosity dual-permeability model to quantify the impact of macropore flow on tracer, pesticide and nitrate movement through the unsaturated zone of a well-structured clay soil in south-west Sweden. Finally, some unresolved issues concerning process descriptions in preferential flow models are discussed, as well as the possibilities and problems of parameterizing these models through the use of pedotransfer functions and by automatic inverse procedures.

H12F-02 1350h

Inclusion of Dynamic Capillary Pressure in Unsaturated Flow Simulators

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Traditional equations to describe unsaturated flow assume an algebraic relationship between capillary pressure and saturation. This algebraic relationship is consistent with an assumption of instantaneous equilibrium between phase pressure differences and phase saturation. Both experimental and theoretical evidence point to a more general dynamic relationship between pressures and saturation, with the traditional algebraic relationship being reached only at equilibrium. This so-called dynamic capillary pressure equation may be expressed as a first-order differential equation, with the time rate of change of saturation being equal to a measure of disequilibrium between the dynamic phase pressures and the equilibrium capillary pressure. The dynamic equation may be combined with the mass balance and Darcy equations for the water phase, and coupled to an assumption of infinitely mobile air phase, to produce a new set of equations to model water flow in unsaturated soils. The equations may be solved directly as a set of two coupled equations, or the two equations may be combined to form a single equation that takes the form of the traditional Richards' equation with an additional mixed derivative term. In either formulation, one new parameter is introduced, which characterizes the time scale for local saturation to respond to local changes in pressure. In this presentation, we review relevant experimental and theoretical evidence for dynamic behavior between saturation and pressure, present the modified forms of the governing equations, discuss discretization and numerical solution techniques, and present example simulations to demonstrate the effects of dynamic capillary pressure on unsaturated flow systems.

H12F-03 1405h

An Investigation of Numerical Grid Effects in Unsaturated Zone Automated Calibration

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Large site characterization projects such as Yucca Mountain require calibration of both unsaturated zone and saturated numerical models. Because of hydrogeologic complexity that includes many units (often dipping) and known faults, compromises are frequently made in the gridding and numerical models. These approximations are often necessary to produce a numerical model that is efficient for the many model (forward) runs used in the calibration process and later for many performance assessment calculations. We investigate one common practice. This is the neglect of connection terms in the numerical difference formula in an attempt to replicate the geometry of hydrogeologic units. This is similar to common practice in saturated zone work where finite difference cells with variable vertical thickness are used to approximate a variable thickness confined aquifer with a constant number of vertical cells. Both situations produce nonorthogonal difference schemes. In unsaturated zone simulations, the motivation for simplified differencing is more complicated. Here the nonlinearities of the relative permeability require a positive connection term for stability considerations. In a complex 3-D simulation, the easiest way to insure positive connection terms in a vertical plane while following a sloping geologic contact is to use a standard difference stencil and simply ignore any additional terms that would arise from the nonorthogonal nature of the grid. This is especially true if a complicated differencing scheme is already used in plan view. The numerical truncation error in this approach is proportional to the grid angle and would appear to be small for gently sloping formations. However, UZ flow in a complex stratigraphic setting, especially with sloping geologic contacts, produces horizontal to vertical flow ratios that varies orders of magnitude. The error arising from nonorthogonal grids directly affects this horizontal to vertical flow ratio. We investigate this effect by comparing, on a large-scale problem, the correct numerical formulation and the approximate difference formulation. By considering a synthetic problem (for calibration purposes) and varying the geologic contact angle, the effect of the approximate differencing can be determined.

H12F-04 1420h

Modeling Unsaturated Flow and Transport using Zones: Aliasing Errors

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It is difficult and costly to accurately determine the spatial statistics of unsaturated hydraulic properties, whereas it is often easier to define hydraulic property zones. When heterogeneous hydraulic property fields are subdivided into zones, however, flow and transport predictions show aliasing errors that alter predicted concentrations and breakthrough curves. The amount of error varies with the number of zones, the character of the heterogeneity, and boundary and initial conditions. The objective of this work is to determine the number of zones required to preserve critical transport behavior during numerical simulation of flow and transport. For this exercise, we consider unsaturated flow and non-reactive transport only. We assume that Richard?s Equation is valid and that the Gardner-Russo parametric model exactly describes unsaturated constitutive relationships. Correlated random parameter fields are generated and unsaturated flow and transport through these fields is simulated. The fields are then zoned using quantiles (0.25, 0.1, 0.05, and 0.025), appropriate zonal averages are determined, and flow and transport is simulated through the zoned fields. Aliasing errors are assessed by comparing the first, second and third moments of concentration for the full and zoned fields. The number of zones is varied to elucidate the character of aliasing error. The style of heterogeneity is varied to reflect geologically relevant end members (statistically isotropic vs. perfectly layered fields). Simulations are repeated under unit gradient conditions at mean tensions of 10, 100, and 1000 cm. Aliasing errors will tend to be smallest in layered systems with flow perpendicular to layering, because zonal averaging does not obscure fast paths. In statistically isotropic systems, fast paths are reduced as the coarseness of the zones increases. At higher tensions, finer zones are required to preserve transport behavior.

H12F-05 1435h

The TRACR3D Family of Unsaturated Flow and Transport Codes

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Unsaturated zone flow and transport present unique challenges from a modeling viewpoint. The governing flow equations are nonlinear, and transport lies in a different regime from the saturated zone because of the possibility of rapid diffusion of reactive components through the air/vapor phase. The TRACR3D family of codes has evolved over a couple of decades to simulate unsaturated zone processes, including air and water and vapor movement, NAPLs, chemical and biological reactions, colloid transport, interactions with surface water, complex geology, perched water zones, and parameter estimation at lab and field scale. Recent developments focus on means of capturing subgrid scale variability in flow and transport using ideas from fractal mathematics. Verification and validation of codes becomes more difficult as their capability increases. Parts of the models can be calibrated against lab and field experiments, but data for testing the full coupled models is rare, and testing of models at the field scale is generally subject to the uncertainty of unknown lithology or unanticipated processes. These issues relate to how models can be used.

H