indices and LST nor does it require closure assumptions such as those that assume ground heat flux is a given fraction of peak net radiation. This study recognizes that there are two major unknown parameters in the estimation of land evaporation (near-surface air turbulent conductivity and evaporative fraction). Uncertainties about the values for these parameters drive the errors of estimation. This study advances the approach in two major new directions. First and foremost it re-casts the variational assimilation system as a multi-scale framework where satellite LST estimates from several sensors are assimilated. Secondly the remotely sensed LST treated as a combination of contributions from the canopy and the bare soil surface. Application of the assimilation system to a large area within the U.S. Great Plains is shown. Spatial patterns of the retrieved parameters and their correspondence to observed land use maps and their consistency with seasonal phenology across the Great Plains are demonstrated. The daytime total latent heat flux maps (across the Great Plains domain) for the several periods within the Summer of 1997 and resulting from the assimilation system are presented. These maps represent the ultimate goal of the approach.

### H12B-03 1100h

## Retrieving Soil Moisture States Using Streamflow Assimilation

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It has been shown that soil moisture has an important impact on seasonal to interannual climate prediction through evapotranspiration controls, especially in heavily forested areas like the Amazon. Hence, it is important that the land surface component of climate models have an accurate initialisation of soil moisture. While remote sensing of soil moisture holds much promise for near-surface soil moisture measurement, and root zone soil moisture retrieval when assimilated into a land surface model, its application to such heavily forested areas is limited. This is due to the masking effect of dense vegetation canopies on remote sensing signals. However, soil moisture also has a strong impact on streamflow, through its control on baseflow and partitioning of rainfall into infiltration and runoff. Thus the use of streamflow data to constrain model predicted soil moisture is a potentially viable alternative to near-surface soil moisture remote sensing. This research demonstrates this potential using a synthetic twin-experiment. The study is based on typical conditions for both a semiarid and humid environment, using the catchment-based land surface model used by NSIPP (NASA Seasonal to Interannual Climate Prediction Project). First we produce a "truth" dataset which provides the streamflow observations and soil moisture validation data. Second, we make an "openloop" simulation where only the initial soil moisture states have been degraded to represent our lack of knowledge on soil moisture. We then assimilate streamflow observations from the truth run into the degraded simulation, in order to retrieve back the true initial soil moisture states. The results shown from this demonstration are for single subcatchments of much larger catchments, so that runoff routing could be ignored. Future research will include larger nested catchments interconnected via a routing model.

### H12B-04 1115h

## Testing Remotely Sensed Evapotranspiration Estimates Using Airborne and Ground Measurements

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Evapotranspiration (ET) is a key hydrologic flux that is rarely monitored. Remotely sensed measurements of land surface characteristics, including surface temperature, in combination with surface energy balance models provide an opportunity to improve the frequency and accuracy of ET estimates. Here we compare results from two ET estimation models with ground and airborne measurements of latent and sensible heat fluxes from an irrigation district in South-Eastern Australia during January 2003 (mid-summer). The irrigation district contains a mixture of wet and dry patches at the scale of hundreds of metres. Ground data collected during the field campaign include eddy covariance measurements of latent and sensible heat flux at two sites, a variety of associated meteorological measurements and detailed soil moisture and vegetation (NDVI) patterns about these sites. The airborne data include eddy covariance measurements of latent and sensible heat flux, line measurements of surface temperature, and detailed (1m resolution) NDVI images over the field sites. Landsat ETM+ and ASTER images are available during the field campaign. ET estimates from these images are made with a two-source model and the Surface Energy Balance Algorithm for Land (SEBAL). Results of comparisons of these with the ground and airborne data will be presented and the models will be intercompared. Some issues with the spatial averaging techniques for the airborne flux data will be discussed.

### H12B-05 1130h

## Large-Scale Soil Moisture Observations Using the Advanced Microwave Scanning Radiometer During the 2002 Soil Moisture Experiment

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Soil moisture is of fundamental importance to many hydrological, biological and biogeochemical processes. Improved characterization of surface soil moisture can lead to significant forecast improvements of weather patterns and precipitation. However, the heterogeneous nature of soil moisture creates difficulty in obtaining in situ large-scale regional values needed for numerical weather models simulations. Microwave remote sensing allows frequent, regional and global-scale soil moisture patterns to be observed with confidence. The launch of NASA 's Aqua satellite on 4 May, 2002 provided the first opportunity for high temporal, global-wide soil moisture to be observed. The Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) instrument onboard Aqua improves the spatial resolution and frequency range of earlier generations of passive microwave instruments. In this study, 10.69 GHz and 6.9 GHz brightness temperatures are simulated using collected in-situ ground data in an attempt to analyze heterogeneity effects and moisture retrieval methods for comparison with available observed AMSR-E and the airborne C-band Polarimetric Scanning Radiometer (PSR/C) data during the 2002 Soil Moisture Experiment (SMEX02) in Iowa. A description of the model simulation and heterogeneity effects is given in addition to comparisons of simulated and observed brightness temperatures of both instruments. These studies will help us to gain confidence in using the AMSR derived soil moisture in regions of the world which lack in situ observations.

### H12B-06 1145h

## Effects of land-use modification on surface fluxes and climate: A numerical mesoscale study over Southeastern Turkey

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Over the course of last two decades, Southeastern Turkey has experienced major land-use changes, primarily in the form of irrigated agriculture. Recent work by authors based on remote sensing and observational climatology indicate that irrigation has significantly altered the hydrologic fluxes mainly through changes in wind velocities. To further understand the mechanisms by which hydrologic fluxes are affected as well as to assess potential climatic impacts of irrigation, we used a fine-scale (10 km) nested regional model. Two different simulations were conducted. The first experiment has a small domain, designed to capture the effects of progressive irrigation on hydrologic fluxes under different initial surface conditions. The second experiment has a larger domain with the main goal of determining climatic influences of irrigation under current and future irrigation scenarios. The results from the first experiment show that irrigation significantly affects the partitioning of water between the land surface and the atmosphere during summer months. The area-averaged model results for the second experiment indicate significant differences in humidity, temperature, and wind direction between the control (no irrigation) and irrigated runs under present and future land-use scenarios. Overall, these experimental results suggest that land-use modifications involving irrigation has strongly modified the lower atmosphere over Southeastern Turkey in a way that appears consistent with Bouchet's complementary theory.

# H12C CC: 520 F Monday 1030h

## Understanding Flow and Reactive Transport Processes in Sulfide-Bearing Porous Material II

*Presiding:* **J W Molson,** Ecole Polytechnique**; R Lefebvre,** Institut National de la Recherche Scientifique

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### H12C-01 1030h INVITED

## Recent Advances in Numerical Modeling of Reactive Chemical Transport in Sulfur-Bearing Rock-Fluid Systems

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Redox processes that involve sulfur-bearing mineral phases play a crucial role in the development of ore deposits, in the degradation of mining wastes, and in geologic disposal and sequestration of sour gases. The underlying processes involve considerable physical and chemical complexity, and microbial interactions may play an important role as well. Fluid flow and mass transport typically take place in settings that involve heterogeneities on multiple scales, and may be dominated by fast preferential pathways such as fractures. Both aqueous and gas phases may actively participate in chemical interactions, and redox processes that are kinetically controlled may play a dominant role. System behavior is further complicated by non-stoichiometric and metastable mineral phases, and by feedbacks between hydraulic, chemical, and thermal effects. Effective processes and their characteristic parameters are dependent on space and time scales, and vastly different time scales can be relevant for the hydraulic and chemical systems. The complexity and diversity of sulfur-bearing rock-fluid systems is illustrated with two examples of reactive transport, the supergene enrichment of copper protores due to weathering processes during desertification over geologic time, and the disposal of gas mixtures including SO2 and H2S through underground injection. We highlight the description of physical and chemical processes, mathematical modeling approaches, numerical solution techniques, and illustrative results. Mineral assemblages in natural analog systems provide important constraints for thermodynamic data, that must be honored in order that realistic results may be obtained. Our paper concludes with a summary of current challenges for modeling reactive chemical transport. This work was supported by the Director, Office of Science, Office of Basic Energy Sciences of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

### H12C-02 1045h

## Prediction and Control of Air Flow in Acid-Generating Waste Rock Dumps

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Air movement and associated oxygen transport through waste rock dumps has the potential to significantly enhance the rate of oxidation of pyrite-bearing material. While this is a desired outcome for most heap leach operations, airflow in waste rock storage facilities can result in significant increases in generation and acceleration of acid rock drainage. Hence, a good understanding of internal airflow through waste rock dumps is required to control ARD and minimize any associated liability. The principal mechanisms contributing to airflow and oxygen transport in a waste rock pile include (i) diffusion, (ii) advection due to a thermal gradient (chimney effect) and/or wind pressure gradients and (iii) advection due to barometric pumping. While diffusion is typically limited to a near-surface zone of a few meters depth, advection and barometric pumping have the potential to move air (and oxygen) to much greater depths into the pile. In general, the more permeable the waste rock material, and the greater the height-to-width ratio of the waste rock pile, the greater is the potential for advective air movement. The reactivity of the waste rock material as well as the coarseness (hence air permeability), and the spatial variability of these properties within a pile, have a strong influence on the magnitude of thermally induced advection. In contrast, air movement due to barometric pumping is controlled by the waste rock porosity, changes in ambient air pressure and the heterogeneity of air permeability of the waste rock dump. Results of field monitoring and numerical modeling using TOUGH AMD are presented to illustrate the concepts on air movement in waste rock piles. During the design and construction phase, airflow can be controlled by judicious placement of reactive waste rock and use of selective placement techniques to control the internal structure of the waste rock facility (e.g. introduction of horizontal layering, prevention of inclined, high-permeability, channels (“chimneys”)). Several closure measures are available to minimize airflow including (i) placement of a low-permeability cover to reduce air entry, (ii) placement of a non-reactive cover material to isolate reactive material from the zone of active airflow and/or regrading of the waste rock pile to obtain a geometry and internal structure less susceptible to advective airflow.

## H12C-03 1100h

### A Wood-Waste Cover Prevents Sulphide Oxidation and Treats Acid Effluents at the East-Sullivan Mine Site

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At the East Sullivan site, wood wastes covering the abandoned mine tailings impoundment prevent sulphide oxidation by creating an anoxic environment. The addition of coarse ligneous wastes favours infiltration, resulting in a water table rise. This maintains most tailings saturated and thus provides an additional protection against sulphide oxidation. Moreover, high infiltration allows a more rapid flushing of acid prone groundwater generated prior to the cover placement. Finally, the pore-waters under the cover are characterized by a strong reducing potential and high alkalinity. These conditions favour sulphate reduction and base metal precipitation as sulphides and carbonates. The restoration strategy capitalized on the alkaline and reductive properties of the waters underlying the wood-waste cover. An original treatment of acid effluents, based on the recirculation of water discharging around the impoundment through the organic cover, was implemented in 1998. In 2003, the total volume of water treated was 725 000 $m^3$. Data gathered near the dispersal zone show that despite dispersing acid water, the groundwater pH decreases by only one unit from 7 to 6, during the recirculation period: May to October. However, alkalinity decreases from 800 to 100 mg/L-$CaCO_3$. But it is back up to 800 mg/L the following spring, thanks to sulphate reduction. $Fe^{2+}$ concentrations near the dispersal zone are maintained below 2 mg/L. Evolution of the iron mass in the surface waters suggests that the contaminated groundwater flush is completed in the north and west sectors of the impoundment; the east and south ones are expected to be recovered within 3 to 4 years. A wood-waste cover, besides limiting sulphide oxidation, can fill the role of alkaline reducing barrier for the treatment of these acidogenic waters, until a balance between acidity and alkalinity in the effluent is reached.

## H12C-04 1115h

### Modelling fracture flow surrounding a pit using a discrete approach

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Pore waters within mining wastes are sometimes very acidic and can be contaminated with radioactive isotopes and dissolved metals. Contaminant discharge, or acid mine drainage (AMD) from these wastes is often controlled by the rate of internal water flow. Hydraulic isolation of these wastes is therefore critical in order to prevent or to minimize the environmental impact. Long-term waste isolation often involves disposal within ancient mining pits. However, when the hydraulic conductivity of the mine waste is higher than the surrounding host rock, regional groundwater flow may become focussed within the waste and AMD may increase. A pervious blanket, or envelope, between the pit and waste material can help lower the hydraulic gradients within the wastes and can serve as a preferential conduit for regional flow, thus reducing AMD migration outside the pit domain. In this study, the behaviour of the pervious envelope concept for mine wastes isolation is studied using the numerical model FRAC3DVS. The wastes are assumed porous while the host rock is assumed discretely fractured. The calculated control efficiency is based on the proportion of regional flow which is diverted from the wastes. The reference case is a square open pit measuring 105x105m in plan, and is 73m deep with 45$^\circ$ internal slopes. The orthogonal rock fractures are spaced 10m horizontally and 5m vertically. The pervious blanket is 5.6m thick and the regional hydraulic gradient is 2%. The flow systems were simulated in the 2D horizontal plane and within a 2D vertical section. The results of the sensitivity study indicated that the main factors affecting the efficiency of the pervious envelope in controlling flow through the wastes are its thickness, the dimension of the pit and the conductivity contrasts between the waste, porous envelope and host rock.

## H12C-05 1130h

### Parameter Selection and Model Uncertainty in the Evaluation of Contaminant Transport From a Proposed Sulfide Mine Tailings Perpetual Storage Facility, a Case Study.

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An independent contaminant transport model (hereafter, ITM) was created, using MT3D96 (Zheng, 1996), to evaluate the movement and concentration distribution of constituents of concern that would likely leach out of a proposed Tailings Management Area (TMA) for the formerly proposed Crandon Mine in Forest County, Wisconsin. The Crandon Mine proposal included mining of zinc and copper ore from an identified high sulfide mineral deposit, with on-site processing and perpetual storage of mine tailings. The contaminant transport model was developed using an independently-derived groundwater flow model (hereafter, IFM), created by the investigators and others, as part of a comprehensive analysis of site hydrogeology and solute transport dynamics. Data and discretization of solute transport parameters, simulation specifications, and TMA activity phases, were performed using existing information provided in the Crandon Mine proponent's submissions. The only initial modification to the proponent's transport model (hereafter, PTM) was the substitution of a revised conceptual model of the hydrogeology as depicted in the IFM. The new ITM provided a baseline for comparison to the proponent's evaluation of potential acid mine drainage (AMD) from the TMA and into the surrounding groundwater. Receiving surface waters and wetlands are located approximately 1,500 feet from the proposed TMA. Activities at the proposed TMA were evaluated through a series of six discrete MT3D model simulations, representing the various proposed operations and leakage phases for the facility and associated reclaim pond. Contaminant transport model results were superpositioned to provide a cumulative contaminant concentration response over time and evaluated at a distance of 1,200 feet from the proposed TMA. A simplifying assumption was that AMD constituents flowed conservatively through the groundwater system, with neither adsorption, decay, nor reactivity over time and travel. The maximum concentration response for the baseline ITM occurred at year 45, with a peak concentration response that was roughly 1.5 times greater than the maximum concentration response for the PTM, which occurred in year 80 in that model. The peak concentration response appeared to be driven by leakage during the full operational and consolidation phases of the TMA cells in all models. Deviations in timing and magnitude of concentration responses were attributed to differences between the conceptual analysis and mathematical representation of the site hydrogeology in the ITM and PTM. Sensitivity analysis focused on reduction of the vertical dispersivity parameter assumed in the PTM and baseline ITM, from 0.5 feet to 0.05 feet, to obtain a more reasonable estimation of transport dynamics in the hydrologic system. The results of this test, using the ITM, produced an increase of nearly 2 times that of the baseline PTM, again with disparity in the year of peak response due to depiction of site hydrogeology in the models. The identification of reasonable and foreseeable source AMD constituent concentrations played a primary role in evaluating ultimate predicted groundwater concentrations away from the proposed tailings storage facility. Clearly, selection of appropriate contaminant transport parameters and depiction of site hydrogeology are critical in evaluation of contaminant transport. The importance of parameter accuracy and minimization of model uncertainty is further critical when considering the potential degradatory effects resulting from AMD drainage to pristine groundwater and nearby surface receiving waters.

## H12C-06 1145h

### Seasonal Variation in Metal-Laden Acid Drainage From an Adit of the Lynx Mine, Myra Falls Operations, Vancouver Island, BC, Canada

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Before it ceased operations, the Lynx mine produced copper and zinc concentrates from massive sulfide deposits on a mineral lease within the mountainous interior of Vancouver Island, Canada. Annual precipitation at the site averages more than 2500 $mm$ and occurs mainly as rainfall between October and February. Previous studies suggested that acid mine drainage from the 8-Level adit may be caused by groundwater leaching of tailings used to backfill a shallow stope in close hydraulic connection with the surface. In this detailed follow-up investigation, temporal variations in the flow rate, electrical conductivity and temperature of discharge from the adit were monitored continuously over a two-year period while effluent chemistry was sampled weekly. The flow hydrograph was observed to rise steeply with the first autumn rains with discharge peaking at over 4000 $m^3/d$. From then on, it fluctuated sharply with recharge from successive weather systems over the winter. The hydrograph of head measured in a packed-off underground borehole also reacted sharply to autumn rains, quickly reaching a plateau of about 40$m$ as the storage capacity of the rock mass above the adit was reached. The amplitude of annual head fluctuations suggested that a significant portion of the rock mass undergoes seasonal saturation and desaturation. Effluent conductivity was relatively constant throughout most of the year but peaked with the first autumn rains. Thereafter, conductivity spikes gradually attenuated as recharge from successive events flushed accumulated soluble secondary minerals from the groundwater system. Concentrations of sulfate and most metals were closely correlated with conductivity as was pH. This made it possible to construct continuous chemographs of these parameters by regression on conductivity. Values of pH as low as 2.2 coincided with spikes of high conductivity as stored acidity was released along with dissolved and suspended species during the initial flushing. Partitioning of Fe, Al and Cu between dissolved and particulate phases was closely associated with fluctuations in pH. Seasonal variations in discharge chemistry observed here were qualitatively similar to those described in the literature although the intensity and timing of flushing events are particular to local hydrometeorological conditions.