

H62B-0868 1330h POSTER

Thermally-Driven Reaction Fronts in Porous MediaTim Jupp¹ (tim@bpi.cam.ac.uk)Andrew W. Woods¹ (andy@bpi.cam.ac.uk)¹BP Institute, University of Cambridge, Madingley Rise, Madingley Road, Cambridge CB3 0EZ, United Kingdom

We present a mathematical model of the reaction fronts that develop when an undersaturated 'injection fluid' displaces a saturated 'formation fluid' in a chemically reactive porous medium. Flows of this kind are relevant to the geothermal and hydrocarbon industries, and are important natural geological processes. The injection and formation fluids differ both in temperature and in chemical composition. We assume that the equilibrium concentration of a reactive mineral species in the fluid is a linear function of temperature. Firstly, we consider the case where the formation fluid is isothermal at $t = 0$. We then extend this solution to the case where the formation fluid has a constant temperature gradient at $t = 0$.

The undersaturation of the incoming fluid drives a dissolution reaction and leads to the formation of a 'depletion' front. Under certain circumstances, which we describe, the temperature difference is able to drive a separate thermal reaction front. Two distinct regimes arise. If the compositional difference between the injection and formation fluids exceeds a critical value, the depletion front travels faster than the thermal front, leaving the porous medium depleted of reactant from the source to a point beyond the thermal front and no thermal reaction front develops. Conversely, if the compositional difference is smaller than the critical value, the thermal front forms downstream of the depletion front and so there is a double reaction front structure.

When we allow for a temperature gradient in the formation fluid, the magnitude of this gradient dictates whether the depletion front speeds up or slows down over time. It is therefore possible for the depletion front to form downstream (upstream) of the thermal front but move upstream (downstream) of it over time. In the cases where the depletion front moves from one side of the thermal front to the other, we derive approximate expressions for the time at which this 'crossover' occurs.

We derive the six dimensionless parameters which control the evolution of the system and find some approximate solutions of the governing equations which are valid at long times. We illustrate the evolution of the thermal and compositional fields towards these asymptotic solutions with numerical simulations.

H62B-0869 1330h POSTER

Numerical Simulation of Non-Fickian Transport in Geological Formations with Multiple-Scale HeterogeneitiesAndrea Cortis¹ (andrea.cortis@weizmann.ac.il)Claudio Gallo² (fender@crs4.it)Harvey Scher¹ (harvey.scher@weizmann.ac.il)Brian Berkowitz¹ (972-8-9342098; brian.berkowitz@weizmann.ac.il)¹Weizmann Institute of Science, Department of Environmental Sciences and Energy Research, Rehovot 76100, Israel²Center for Advanced Studies Center for Advanced Studies, Research and Development, VI Strada OVEST Z.I. Macchiareddu VI Strada OVEST Z.I. Macchiareddu, C.P. 94, Uta 09010, Italy

We develop a numerical method to model contaminant transport in heterogeneous geological formations. The method is based on a unified framework that quantifies non-Fickian and Fickian transport and the transition between them over a broad range of temporal and spatial scales. As such, the method takes into account the different levels of uncertainty often associated with characterizing heterogeneities at different spatial scales. The resulting formulation leads to a Fokker-Planck equation with a memory term and a generalized concentration flux term. The former term captures the non-Fickian behavior arising from unresolved, small-scale heterogeneities, which are treated probabilistically using a continuous time random walk (CTRW) formalism. The latter term accounts for large-scale heterogeneity variations, which are included deterministically with explicit treatment at the heterogeneity interfaces. The parameters defining the small-scale and large-scale heterogeneities are measurable quantities. The advection-dispersion equation is seen to result as a special case of our unified framework. Numerical treatment of the equations involves solution for the Laplace transformed concentration by means of classical finite element methods, and subsequent inversion in the time domain. We use the numerical method to quantify transport in one- and two-dimensional domains, for a wide range of (large-scale) heterogeneity structures, (small-scale) material

properties, and boundary conditions. The calculations demonstrate long tailing arising (principally) from the memory term, and the effects on arrival times that are controlled largely by the generalized concentration flux term.

H62B-0870 1330h POSTER

Non-Darcy Effects for Fluid Flow in a Rough-Walled Rock FractureAzzan H. Al-Yaarubi¹ (+44-207-594-7428; azzan.al-yaarubi@ic.ac.uk)Chris C. Pain¹ (+44-207-594-9322; c.pain@ic.ac.uk)Carlos A. Grattoni¹ (+44-207-594-7371; c.grattoni@ic.ac.uk)Robert W. Zimmerman¹ (+44-207-594-7412; r.w.zimmerman@ic.ac.uk)¹Department of Earth Science and Engineering, Imperial College, Prince Consort Road., London SW7 2BP, United Kingdom

An experimental and computational study has been conducted of fluid flow in a rough-walled rock fracture, with emphasis on deviations from Darcy's law in the regime of Reynolds numbers greater than unity. First, profiles of a fracture in a red Permian sandstone were measured with a profilometer, to within +/- 2 microns in elevation, at intervals of every twenty microns in the fracture plane. These profiles were then used to create a three-dimensional finite element grid. The full Navier-Stokes equations were then solved over 2 cm x 2 cm regions of this grid, using no-flow boundary conditions along two opposing sides, and constant pressure boundary conditions along the inlet and outlet faces. The apparent fracture transmissivity was computed from the ratio of the total flowrate to the overall pressure drop. The simulations were carried out for a range of values of the mean aperture.

At Reynolds numbers much less than 1, the computed transmissivity is constant. Appreciable deviations from Darcy's law began to be observed when the Reynolds number (defined using the mean aperture as the length scale) exceeded unity. In the range of Reynolds numbers between 20-100, the computed transmissivities could be fit very well to a Forchheimer-type equation, in which the additional pressure drop varies quadratically with the Reynolds number. The initial deviations from linearity, for Reynolds number around 1, are consistent with the "weak inertia" model developed by Mei and Auriault (J. Fluid Mech., 1991) for porous media, and with the results obtained computationally by Skjetne et al. (J. Fluid Mech., 1999) on a two-dimensional self-affine fracture.

Flow tests are currently being conducted on this same 2 cm x 2 cm fracture region, with a mean aperture of 130 microns. The boundary conditions are the same as those used in the finite element simulations. For $Re < 1$, the measured transmissivity was indeed constant, and corresponded to a "hydraulic aperture" of about 71 microns. Results for higher Reynolds numbers will be compared to the predictions of the analytical weak inertia model and Forchheimer's empirical model.

H62C MCC: Hall C Saturday 1330h

Orographic Precipitation Posters

(joint with A, GC)

Presiding: T Lang, Harvard University; A Barros, Harvard University

H62C-0871 1330h INVITED POSTER

Orographic precipitation: Physics and Dynamics

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We review recent theoretical work on orographic precipitation, including several themes. 1) Studies of air mass transformation over the Alps show processes occurring on a range of scales from 10 to 100km. Parcels crossing the Alps are dried but also scrambled due to different amounts of latent heating. 2) Numerical models have been used to evaluate the use of moist stability to model the airflow dynamics. For the purpose of predicting upslope flow and blocking, the moist stability is quantitatively useful. 3) The influence of evaporating precipitation on airflow dynamics varies from case to case. In general, down-slope lee-side evaporative heating has little effect on upstream dynamics, while upslope melting or evaporation of falling hydrometeors is influential. 4) Even with latent heat, upslope flow can become non-linear and blocking can occur.

This blocking leads to reverse flow driving a broad upstream arc of precipitation. 5) Clouds with significant riming, accretion or collection respond non-linearly to cloud water generation. The precipitation efficiency remains low until a certain threshold in cloud generation rate is met, whereupon, heavy precipitation occurs. 5) Horizontal scale has a profound effect upon precipitation efficiency. Small-scale hills produce patterns of ascent that extend only a short distance upward into the moist layer. Little condensation occurs. The ascent and condensation produced by broader hills may be limited too, due to wave dynamics. Precipitation from small-scale hills is also limited by condensed water advection and lee-side descent. We describe a new linear model for precipitation in complex terrain that includes 3-D dynamics and condensed water advection. The difficulty in testing models in complex terrain is discussed.

H62C-0872 1330h POSTER

Evaluation of an Upslope Precipitation ModelIdar Barstad¹ (1-203-4325669; idar.barstad@yale.edu)Ronald B. Smith¹ (1-203-4323129; ronald.smith@yale.edu)¹Idar Barstad Ronald B. Smith, Geology and Geophysics Dept. Yale University, New Haven, CT 06520-8109, United States

A linear orographic precipitation model applicable on complex terrain for an arbitrary wind direction has been developed. The model includes mountain wave dynamics as well as condensed water advection and two micro-physical time delay mechanisms. Atmospheric input variables in the model are wind speed and direction, specific humidity, wet static stability and two conversion factors for the micro-physics. In addition, the underlying terrain is needed. Various closed-form solutions for the precipitation behavior over ideal mountains have been derived and verified with numerical mesoscale models. The model is tested in real terrain against observations. Several locations are used to evaluate the model performance (southern Norway, the Alps and the Wasatch mountains in Utah). The model results are of same magnitude as the observations, which indicate that the fundamental physics is included in the model. The ratio of condensate that is carried over the mountain crest to the amount that is left as precipitation is crucial, and the model seem to reproduce this well. When the model results are evaluated against observations with statistical measure such as correlation coefficient, it performs well overall. This requires that detailed input information such as wind direction and stability are provided and that the observations are taken frequently. Traditional observation samplings are normally unevenly distributed between valleys and mountain tops which cause a bias in objective analysis. Such an analysis can, in this case, not be held directly against model results. For the same reason, if a model for instance perform well on mountain tops, but poorly in valleys, observations will give a wrong impressions of the model performance. From our tests, the model perform well in smaller region where the input variables are representative for the whole area. Some model deficiencies are also discovered. The model performance seems to improve with slightly smoothed terrain which partly compensates for non-linear effects of flow in complex terrain.

H62C-0873 1330h POSTER

Probing Orographic Land-Atmosphere Interactions in the Himalayas During the Monsoon Using Satellite ImageryAna Barros¹ (barros@deas.harvard.edu)

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The linkages between the space-time variability of weather (and climate) and topography in Northern India and the Himalayas were investigated using remote sensing data. The research purpose was to test the hypothesis that cloudiness patterns are dynamic tracers of rainstorms, and therefore their temporal and spatial evolution can be used as a proxy of the spatial and temporal organization of precipitation and precipitation processes in the Himalayan range during the monsoon. The results suggest that the space-time distribution of precipitation, the spatial variability of the diurnal cycle of convective activity, and the terrain (landform and altitudinal gradients) are intertwined at spatial scales ranging from the order of a few kms (1-5 km) up to the continental-scale. Furthermore, this relationship is equally strong in the time domain with respect

to the onset and intra-seasonal variability of the monsoon. Infra-red and microwave imagery of cloud fields were analyzed to characterize the spatial and temporal evolution of mesoscale convective weather systems and short-lived convection in Northern India, the Himalayan range, and in the Tibetan Plateau during three monsoon seasons (1999, 2000 and 2001). The life-cycle of convective systems suggests landform and orographic controls consistent with a convergence zone constrained to the valley of the Ganges and the Himalayan range, bounded in the west by the Aravalli range and the Garhwal mountains and in the East by the Khasi Hills and the Bay of Bengal, which we call the Northern India Convergence Zone (NICZ). The NICZ exhibits strong night-time activity along the south-facing slopes of the Himalayan range, which is characterized by the development of short-lived convection (1-3 hours) aligned with protruding ridges between 1 and 3 AM. The intra-annual and inter-annual variability of convective activity in the NICZ were assessed with respect to large-scale synoptic conditions, monsoon activity in the Bay of Bengal, and the modulating role of orography. EOF (Empirical Orthogonal Function) and Canonical Correlation analysis suggest that joint modes of variability of monsoon weather and topography, which we call orographic land-atmosphere interactions, modulate the space-time variability of cloudiness in the region. Finally, scaling analysis of cloudiness suggests three different scaling regimes of orographic land-atmosphere interactions: 1) a synoptic-scale regime [>70 -80 km]; 2) an orographic meso-B regime [30-70 km] associated with the succession of wide valleys and bulky terrain features; and 3) an orographic meso-A regime [<30 km] associated with the complex succession of protruding south-facing ridges and narrow valleys that characterize the Himalayan foothills between 3,000 and 5,000 m. We propose to use these results, along with rain gauge observations, and output from a cloud-resolving model to deconvolve the space-time variability of rainfall in the Himalayan range during the monsoon from satellite data (e.g. TRMM).

H62C-0874 1330h POSTER

Observations and Modeling of Winter Storms in the Himalayas

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Based on observations from a hydrometeorological network on the eastern slopes of the Annapurna Range, the summer monsoon (June-September) is responsible for 80-90% of annual precipitation at low elevations (<2000 m MSL) in Nepal, with nearly all of it in liquid form even during the winter. However, high elevations can receive up to 25% of their annual precipitation as snowfall during the winter, with the percentage of the annual total an increasing function of elevation. Significant snowstorms often are associated with terrain-locked low-pressure systems that form when an upper-level disturbance passes over the notch formed by the Himalayas and Hindu Kush mountains. These systems cause deep upslope flow over central Nepal, resulting in orographic precipitation. Notable case studies for three winters (January-March 2000-2002) are reviewed using local precipitation (snow and rain) and other meteorological data, as well as satellite (Meteosat-5 and TRMM) and NCEP/NCAR Reanalysis data. Based on these results, a 15-year (1988-2002) climatology is developed and interannual variability of winter storms is diagnosed. Finally, a cloud-resolving model with realistic topography is used to investigate mechanisms for controlling the spatial and temporal variability of precipitation during winter storms.

H62C-0875 1330h POSTER

Geomorphologic Applications of Precipitation Estimates from TRMM Satellite Data

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Precipitation data with high spatial resolution is in great demand for studying interactions between climate and topography. Although few such data sets exist,

there is increasing interest in modeling fluvial erosion in mountainous areas where precipitation is highly variable spatially. The Tropical Rainfall Measuring Mission (TRMM) satellite carries a precipitation radar with a spatial resolution of 4.3 km and covers the region between 35°N and 35°S. Four years of TRMM-derived precipitation at a resolution of 0.1° is available for the area around Namche Barwa, in the eastern syntaxis of the Himalaya. Finnegan et al. (this meeting) use this pattern in a model of fluvial incision to investigate the evolution of this striking landscape. However, TRMM can also provide insight into the controls on precipitation: the pattern of TRMM precipitation estimates in the Namche Barwa area shows a strong correlation with elevation and follows the functional form of the Clausius-Clapeyron relation. Interest in using TRMM data as a proxy for annual average precipitation motivates an analysis of measurement and sampling errors. We compare TRMM-derived precipitation rate to the precipitation rate from half-hourly accumulation totals at a calibration site in Nepal. In addition, we explore the potential magnitude of sampling errors inherent to TRMM data. Spatial differences in precipitation across the study area are of great interest for addressing patterns of fluvial incision, so we focus on determining the spatial scale at which patterns in TRMM data reflect significant differences in annual precipitation totals. Preliminary analysis indicates that the temporal distribution of rainfall is a key parameter controlling the error associated with the temporally discrete sampling by TRMM. At large spatial scales, the TRMM satellite samples representatively over the daily cycle. But when used at a small spatial scale, it samples infrequently enough the inferred rainfall may not closely approximate the actual total precipitation. Hence, the storminess of a given area controls the minimum spatial resolution at which TRMM data can be considered robust indicators of annual total precipitation.

H62C-0876 1330h POSTER

The IMPROVE II Field Experiment: A Study of Cloud and Precipitation Structure and Physics Over the Central Oregon Cascades

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The primary goal of IMPROVE-2 (Improvement of Microphysical Parameterization through Observational Verification Experiment, Phase II), which was conducted over the central Oregon Cascades from 26 November through 22 December 2001, was to simultaneously and comprehensively measure both basic-state and cloud and precipitation microphysical fields in a variety of weather systems. The data will not only help verify and improve bulk microphysical parameterizations, but it will also help enhance our understanding of orographic precipitation processes. Observational assets included the NOAA P3 and UW Convair 580 aircraft, the NCAR S-Pol polarized Doppler radar, three 915 MHz radar wind profilers, the ETL S-Band vertically pointing radar, surface ice crystal observers, the PNNL PARSL observing suite, 14 additional rain-gauges, a disdrometer, and two radiosonde launching sites

The IMPROVE II observation period was characterized by consistently wet and stormy conditions, providing an extraordinary opportunity for collection of cloud and precipitation data. This presentation will describe the IMPROVE II experiment and present some samples of the massive data set collected during the observing period.

URL: <http://improve.atmos.washington.edu/>

H62C-0877 1330h POSTER

Intercomparison of orographic precipitation observations during the IMPROVE campaign

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Precipitation on the western slopes of the Cascade Mountain range in Oregon typically exhibits a strong precipitation gradient due to orographic influences. This area provided the focus for the second phase of the IMPROVE (Improvement of Microphysical Parameterization through Observational Verification Experiment), IMPROVE II, which studied orographic precipitation in the Oregon Cascades, and specifically on the area including the Santiam River basin. The intensive field observation campaign of IMPROVE II was carried out during the period 26 November through 22 December 2001. Measurements from the field campaign were collected to perform comprehensive verification of cloud and precipitation microphysical processes parameterized in mesoscale models. To measure precipitation, observations were compiled from a variety of sources during the field campaign, including an S-band radar, a disdrometer, and a custom network of five all-weather precipitation gauges placed at varying elevations through the basin. The present study utilizes these measurements to determine the spatial patterns of precipitation through the Santiam River basin derived using different ground measurements of precipitation, including the data collected specifically for the IMPROVE II effort as well as NCDC Cooperative observer sites, airport observing sites, and snowpack telemetry (SNOTEL) sites. The results are also compared to the climatological precipitation gradient in the PRISM (Parameter-elevation Regressions on Independent Slopes Model) precipitation data set. The influence of the varying representations of orographic precipitation using these different data sources is demonstrated using a land surface hydrology model to generate outflow from the basin.

H62C-0878 1330h POSTER

Coastal Orographic Rainfall Processes Observed by Radar During CALJET

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The overarching goal of the California Land-falling Jets Experiment (CALJET; December 1997/March 1998) was to help improve the 0-24 h forecasts of damaging weather impacting the Western United States, with a particular emphasis on the coast of California. During CALJET, we identified a quasi-steady, orographically-forced, shallow rain process observed primarily beneath the melting level in California's coastal mountains using the NOAA Environmental Technology Laboratory's vertically-pointing S-band radar with extended dynamic range. This shallow rain, which did not possess a radar bright-band signature that is normally associated with midlatitude stratiform precipitation systems, contributed substantially to the record-setting rainfall during CALJET and, yet, occurred mostly beneath the coverage of the operational network of National Weather Service (NWS) Doppler precipitation surveillance radars (WSR-88D). The shallow non-bright-band (NBB) rain consistently occurred with weaker radar reflectivity and smaller Doppler vertical velocity than its bright-band rain counterpart possessing equivalent rain rates, implying that NBB rain consists of smaller drops. Consequently, existing radar-derived and satellite-derived quantitative precipitation estimation (QPE) techniques may indicate little or no rain is falling when, in fact, heavy non-bright-band rain is occurring. During CALJET, the NBB rain process created sustained rain rates capable of producing floods in this region (i.e., >12 mm h⁻¹ rule-of-thumb rain-rate threshold used by local forecasters for guidance in issuing flood statements). Knowledge gleaned from these new observations can ultimately be applied operationally by improving forecasting of shallow rain events in the coastal zone, by revising reflectivity-based QPE algorithms that take into account small drop size distributions associated with this class of rain, and by improving satellite-derived QPE products based on microphysical attributes and cloud-top temperatures.

H62C-0879 1330h POSTER

The Statistical Relationship Between Upslope Flow and Rainfall in California's Coastal Mountains: Observations during CALJET

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The California Land-falling Jets Experiment (CALJET) was carried out during the winter of 1997-98, in part to study orographic rainfall in California's coastal mountains using coastal wind profilers. This observational study statistically links hourly rainfall rates observed by tipping-bucket rain gauges in California's quasi-linear coastal mountains to the hourly averaged upslope component of the flow measured by coastal wind profilers immediately upstream. Vertical profiles of the linear correlation coefficient of upslope flow versus rain rate are calculated on a case-by-case basis, for all cases containing a low-level jet (LLJ), and for the winter season of 1997-98. These correlation coefficient profiles show a direct relationship between the magnitude of the upslope flow impacting the coast and the magnitude of the rain rate in the downstream coastal mountains. The layer of upslope flow that optimally modulates orographic rainfall is at 1 km above mean sea level, which corresponds to the mean altitude of land-falling LLJs observed by the coastal profilers. The presence of shallow, terrain-blocked flow modulates the correlation coefficient profiles below mountain top, such that the low-level flow at the coast is poorly correlated with rain rates observed in the coastal mountains. However, cases without significant blocking retain relatively large correlation coefficient values below mountain top. In all scenarios, standard surface anemometers are unable to reveal the orographic connection between upslope flow and rain rate clearly enough for forecasting purposes.

URL: <http://www.etl.noaa.gov/programs/2002/pacjet/>

H62C-0880 1330h POSTER

A Hydrometeorological Testbed For Western Water Issues

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Based on experience gained between 1997 and 2002 in a series of three West Coast experiments focused on improved prediction of precipitation in land-falling Pacific winter storms, NOAA is leading the creation of a regional Hydrometeorological Testbed (HMT). The goal of this effort is to advance both the understanding of fundamental physical processes influencing primarily winter-season precipitation (rain and snow) in mountainous regions, and to improve quantitative precipitation forecasting, main-stem river flood warnings and flash-flood warning lead time in such regions. The focus will be on processes spanning the weather-climate connection, from the mesoscale to tropical-extratropical connections that modulate regional short-term climate anomalies influencing precipitation. The geographic area covered by the initial HMT encompasses the flood-prone Russian River and Sacramento River watersheds in northern California. While these watersheds represent some of the greatest flood risks in the nation, the scientific and operational results developed there will have bearing on winter season hydrometeorological prediction in many other locations. These

goals will be addressed through a joint effort between scientists, weather forecasters, hydrologists and forecast users that will define both the needs and methodologies to tackle this important problem. Annual field activities will begin in the winter of 2002/03, building on results from earlier studies in the region. Priorities and leveraging opportunities for wider participation in the winter 2003/04 season will be explored in upcoming planning meetings where broad input is encouraged.

H62C-0881 1330h POSTER

The NAME, Topographically Enhanced Precipitation Observing Network in Northwest Mexico

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Although existing surface networks and the recent development of satellite-derived precipitation products have elucidated some features of convective activity over the core region of the North American Monsoon (NAM), a detailed examination of the spatial and temporal structure of such activity has, until recently, been prohibited by the lack of a surface observation network with adequate temporal and spatial resolution. Specifically, the current network of sparsely spaced climate stations in the rugged terrain of northwestern Mexico inhibits a detailed diagnosis of the timing, intensity, and duration of convective rainfall in general, and of the topographic-convective relationship in particular. This, in turn, limits the development of the predictive skill needed for weather risk mitigation and the dynamic management of water resources. This presentation details the installation and maintenance of an enhanced surface raingage network in the core region of the North American Monsoon, in the Sierra Madre Occidental (SMO) mountains of northwestern Mexico. Data obtained from this network will prove invaluable for the purposes of diagnosing the topographic dependency of diurnal convective precipitation and providing a rich, time-dependent, verification database for mesoscale hydrometeorological modeling efforts in the NAM region. Additionally, the enhanced observing network supported under this contract will provide important 'ground-truth' data for remote sensing platforms deployed as part for the North American Monsoon Experiment (NAME) field campaign during the summer of 2004. Brief, descriptive analyses will be presented using data collected during the 2002 NAM, which has proven to be a drier than normal year, and plans for future enhancements will be outlined.

H62C-0882 1330h POSTER

Orographic Modulation of Lee-Side Precipitation

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We present evidence of a correlation of cross-mountain zonal flows and ambient vorticity fields. When the zonal flow across the Rockies increases, a cyclonic vortex tends to spin up during the summer season, promoting stronger low-level-jets to the east, and enhancing dynamic support for precipitation over the Mississippi River Basin. We present statistics for monthly averages of the NCEP Reanalysis that support these connections, and numerical simulations with a global model that illustrate the relevance of this dynamical process relative to regional surface evaporation anomalies. The results suggest that dynamical atmospheric effects related to the orographically bound vortex may be at least as important as anomalies of surface evaporation on time scales of a week or more. Furthermore, the predictability of related precipitation anomalies may be relatively long in cases where the initial atmospheric anomaly possesses large scale and carries a longer "memory". In such cases, the orography of western North America focuses the large-scale signal into smaller-scale synoptic responses that determine regional rainfall evolution. Sample 2 week simulations will be presented and discussed.

H62C-0883 1330h POSTER

Orographic precipitation enhancement during extreme flood events in mid-Europe

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Several extreme flooding events occurred in mid-Europe in the recent years (Rhein 1994, Oder 1997, Donau 1991), and most recently the Donau- and Elbe-floods in August 2002. The latter caused enormous losses, which drew back Eastern Germany's development for many years.

A data analysis of such extreme precipitation events in particular in Germany shows a distinct influence of orographic lifting on the precipitation patterns. A linear numerical model, being developed for describing the basic processes of flow around and above mountains and precipitation formation, turns out able to describe the spatial distribution of precipitation from stratiform clouds in close agreement with observations. The controlling parameters for the model results are the integral moisture content of the advected air masses and the Froude number as an atmospheric stability index, which is decisive for the prevailing flow types. For high Froude numbers flow above the mountains prevails and precipitation is enhanced on windward sides.

Since the model is only able to represent the orographic effects and not the synoptic scale processes, it is mainly applied for spatial interpolation and statistical risk assessment.

URL: <http://www.gknk.uni-karlsruhe.de/>

H62C-0884 1330h POSTER

Orographic and Meteorological Influences on the Spatial Organization of Thunderstorms in Mountainous Regions

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The use of numerical weather prediction (NWP) models to provide input of spatial rainfall patterns for distributed hydrologic models has gained increasing popularity over the past decade. One of the key challenges in this approach is the discrepancy between the typical scale of NWP forecasts and the scale needed for accurate hydrologic predictions, especially in moderate to extreme topography. Issues of scale also arise when driving hydrologic models with observed precipitation as the observations may have space-time resolutions that are too coarse (satellite) or fine (gauge) for the needs of the hydrologic model. A better understanding of the space-time scaling and dynamics of convective precipitation across spatial resolutions from 1 km to 50 km and temporal integrations from 5 minutes to 3 hours is needed to bridge these scale gaps. Substantial progress has been made on characterizing the space-time organization of midwestern convective systems and tropical rainfall, which has led to the development of statistical/dynamical downscaling models. Space-time analysis and downscaling of orographic precipitation has received much less attention due to the complexities of topographic influences on precipitation processes.

Characterizing the space-time scaling and dynamics of orographic convective precipitation and the development of downscaling methods to transfer precipitation fields from one scale to another is the overall motivation for this research. This paper investigates the space-time organization of several heavy convective rainfall events in mountainous terrain using multi-scale statistical analysis. Focus is placed on the Appalachian region and the Front Range of the Rocky Mountains. Case studies which are characteristic of organized thunderstorms that produce heavy rainfall and catastrophic flooding in mountainous regions have been studied to explore the multi-scaling behavior of orographic precipitation and specifically investigate differences in the scales of topographic dependency and spatial organization between western and eastern United States orographic thunderstorms. The potential for developing a space-time statistical downscaling model for orographic convective precipitation based on the interplay between meteorological forcings and orographic influences on the scale-invariant properties of orographic precipitation will be assessed.

H62C-0885 1330h POSTER

Scales of Topographic Dependence of Alpine Precipitation

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Scales of topographic dependence of daily precipitation over the Swiss Alps are examined using a new multivariate precipitation interpolation technique. The method of additive regression splines has been designed to incorporate spatially varying dependences on several topographic variables. It avoids the "curse of dimension" by restricting the underlying spline structure to be two-dimensional. This is in keeping with the overall goal of delivering essentially two-dimensional maps. Moreover, it permits a separation between physical process, as represented by various topographic variables, and the empirically determined, continuous two-dimensional effects of these variables on precipitation across the landscape.

The analysis determines horizontal and vertical scales of the interaction of precipitation with topography. A common limitation with existing precipitation interpolation methods lies in their difficulty in identifying effective topographic parameters other than elevation. Orographic effects associated with slope and aspect are often discussed but are not always statistically significant. The effects of two topographic parameters, the northern and eastern components of the unit normal to an appropriately vertically exaggerated digital elevation model, are investigated. These parameters have some basis in process modelling studies and, unlike topographic aspect, are continuous functions of horizontal position. They are used to identify significant topographic aspect effects on precipitation without prior knowledge of the prevailing wind field.

Short range correlation structure has rarely been explicitly identified in precipitation interpolation studies but its impact is surprisingly strong. Evidence for its existence in these precipitation data was provided in an earlier study but effective methods for calibrating such correlation in spline analyses have only recently been developed. The spatial scale of correlation found here, around 5 km, is large enough to permit its calibration from the data network. This entails a significant reduction in complexity of the fitted additive regression splines and in fact directly facilitates their calibration. This short range correlation structure appears to be closely linked to the horizontal scale of topographic dependence. Moreover, it suggests that there are intrinsic limits to the accuracy of precipitation fields interpolated from standard precipitation gauge networks. This has significant implications for spatial precipitation analyses and the design of effective precipitation gauge networks.

URL: <http://cres.anu.edu.au/>

H62D MCC: Hall C Saturday 1330h

Progress in Hydrometeorological Data Assimilation Posters (joint with A, B, GC)

Presiding: P Houser, NASA Goddard Space Flight Center; R Reichle, NASA Goddard Space Flight Center

H62D-0886 1330h INVITED POSTER

Overview of the European Land Data Assimilation System (ELDAS) Project

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The European Land Data Assimilation System (ELDAS) project aims at the construction and evaluation of a routine system for soil moisture initialization in NWP applications. It is partially inspired on the US Global Land Data Assimilation System (GLDAS) Project, but for the time being is limited to soil moisture estimation. Also it is not intended to operate on a near-realtime basis during the duration of the project.

The paper will present a brief overview of the structure and goals of the ELDAS project. Also, a number of examples will be shown of forcing data bases of precipitation, surface radiation and surface temperature changes that have been produced so far.

The European Union has funded the ELDAS project, which will run until late 2004.

URL: <http://www.knmi.nl/samenw/eldas>

H62D-0887 1330h POSTER

A soil Moisture Analysis System for ELDAS

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Within the framework of the European Land Data Assimilation system (ELDAS) a soil moisture analysis scheme is built for the optimal estimate of soil moisture. The aim is to combine different sources of information on soil moisture: 2m temperature, relative humidity, IR heating rate and microwave brightness temperature observations. The system is developed and tested with a single column model (SCM) version of the full ECMWF-numerical weather prediction model. The SCM is forced with ERA40 data, but precipitation and solar radiation are prescribed from observations to avoid errors in the forcing crucial for soil moisture. The soil moisture analysis is based on a 1DVAR system with a Kalman filter (KF) update of the background error covariance matrix. Additionally, an approach to adapt the model error covariance matrix at each cycle is tested (adaptive KF).

In a first step only 2m temperature and relative humidity observations are assimilated. The model results for two different case studies (FIFE 1987 and MUREX (France) field experiments) show that the new assimilation system performs better than systems based on optimal interpolation (currently operational at ECMWF) or nudging (operational till 1999 at ECMWF). The main reason for the improved performance of the 1DVAR scheme is that in this framework the gain matrix depends on the synoptical situation rather than being fixed to statistically derived values. Current work includes the incorporation of IR heating rates and brightness temperatures into the system and testing with the MUREX and SGP97 data sets.

H62D-0888 1330h POSTER

Assimilation of Latent Heat Fluxes and Soil Moisture Values Into a Land-Surface Model Through a Kalman Filtering-Based Method

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We investigate the possibility to improve the performance of hydrological models through the assimilation of both observed soil moisture values and latent heat fluxes. The study is performed on a small hillslope in the Zwalm catchment in Belgium, which is equipped with Bowen-ratio energy balance and eddy-correlation instruments. A methodology to assimilate both the soil moisture values and latent heat fluxes based on extended Kalman filtering is developed. An extended Kalman filter is used to assimilate the soil moisture values. Analogue equations are derived to assimilate the latent heat fluxes, resulting in an assimilation algorithm similar to the extended Kalman filter. The assimilation methodology is then applied to the in-situ measurements. The effect of the assimilation of either the soil moisture values or the latent heat fluxes, or a combined assimilation, is assessed. It is found that the assimilation of the soil moisture measurements has a small impact on the modeled energy balance terms, and that the assimilation of the measured latent heat fluxes has a small impact on the modeled soil moisture values. This can be explained by the good performance of the model before the assimilation procedure. The best model results are obtained when the soil moisture and latent heat flux observations are simultaneously assimilated into the model.

H62D-0889 1330h INVITED POSTER

Assimilation of Remotely-Sensed and Micrometeorological Station Observations into a Coupled Land Surface-Atmospheric Boundary Layer Model

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The most effective way to obtain land surface fluxes of moisture and energy with the accuracy and coverage required for hydrologic and meteorological applications is to merge information from satellites, ground-based stations, and models. In our recent work we have designed a framework for the estimation of land surface states and fluxes through the assimilation of remotely sensed and micrometeorological station observations into a coupled land surface-boundary layer model. Satellite-based surface radiance measurements are typically characterized by infrequent sampling, and are sensitive only to the state in the upper few centimeters of the soil column. Because of the strong coupling between the land surface and overlying atmospheric boundary layer, valuable information about subsurface states and surface fluxes is contained in available surface layer and boundary layer observations (micrometeorological temperature and humidity, radiosonde data, satellite-based soundings, etc.). Using the coupled model requires minimal auxiliary information and variables that are typically required as forcing for offline models (and often available at higher temporal resolution) can instead be assimilated with satellite-based radiance measurements, providing a further constraint on the flux estimates. In this work we present results using both variational and ensemble filtering approaches applied to the First ISLSCP (International Satellite Land Surface Climatology Project) Field Experiment (FIFE) site in Kansas.

H62D-0890 1330h POSTER

Assimilation of Multi-resolution Passive and Active Remote Sensing Data for the Estimation of Soil Moisture Fields

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The objective of this study is to estimate surface soil moisture fields using low frequency microwave (L-band) radiobrightness and backscatter measurements. The relative advantages of each of these measurement sources (resolution for radar and greater sensitivity for radiometer) are combined in the data assimilation framework (ensemble Kalman filter). In this framework, a dynamic model of land surface processes is used to generate an ensemble of prior estimates by randomizing the uncertain parameters and forcing variables. When measurements are available, a multi-resolution measurement operator is used to estimate prior radiobrightness and backscatter values that can be merged with remotely sensed observations at their native resolutions. Posterior estimates of soil moisture fields conditioned on the observations are thus produced. In this study a framework for evaluating the advantage of assimilating active along with passive measurements is introduced. The representation of smaller scale variability where radar data are included may affect algorithmic issues such as the minimum number of ensemble members required for robust estimation. Criteria for the implementation of the data assimilation system for this estimation problem are also introduced.

H62D-0891 1330h POSTER

Estimation of Surface Energy Balance Components Over the US Midwest using Multi-Platform and Multi-Resolution Satellite Measurements

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