which flux rates increase rapidly, is lower than the previously calibrated value, suggesting that post-fire ravel transport may preferentially strip the soil mantle along steep sideslopes. We quantified the morphologic implications of fire by modeling the evolution of hillslopes subject to episodic pulses of accelerated transport using the field-calibrated parameters from the post-fire data. Our results suggest that fire may not only regulate the magnitude and frequency of sediment production in the Oregon Coast Range, but also impart a signature in hillslope morphology.

### H41A-05 0900h

## Modeling the implications of fluvial erosion and bank failures on gully development and growth

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Exploring landscape development due to gully erosion has been an important component in Michael J. Kirkby's scientific career. Gully erosion is most commonly triggered by fluvial erosion due to natural and anthropogenic disturbances, or as a response to changes in climate and tectonic forcing, and base level drop. Field observations suggest that following the development of fluvial incisions, headward growth and widening of many gully systems can be attributed to the instability and collapse of steepened gully walls. Soil saturation, sapping and development of tension cracks contribute to the instability. Recent landscape evolution models treat such mass failures as slope dependent continuous sediment transport processes, sometimes conditioned on a slope threshold or with nonlinear dependence on slope gradient. In this study, first we present a theory for stability analysis of gully head and walls. The theory is based on force balance equation of an assumed planar failure geometry of a steep gully wall, with a potential failure plane dipping to the incised gully bed. We consider development of vertical tension cracks behind the face of the gully head that extend down to the failure plane. In the theory, storm water infiltrates in the tension cracks and generates hydrostatic forces in the vertical crack face, and uplift forces along the failure plane. During storms, water level in the crack is related to steady-state basin hydrology. In our model when tension cracks are either dry or completely filled with runoff water, instability occurs when headcut height exceeds a critical threshold (higher for the dry case). For the case when cracks are partially filled, our theory predicts an inverse relationship between headcut height and drainage area. We used field observations in Colorado and another published data set to test our model. Second, we have implemented this theory in the CHILD landscape evolution model and explored the effects of soil cohesion, erosion thresholds and climate on the tempo of gully development and morphology of eroding gullies. Preliminary results indicate that wider and shallower gullies develop and integrate forming wide valleys, when soil cohesion is small. As soil cohesion increases, gullies become deeper with steeper walls and episodic mass failures occur. Introducing a high runoff erosion threshold produces gentler headcuts. Variations in storm duration and intensity are predicted to have a significant impact on gully morphology.

### H41A-06 0915h

## Late Quaternary Intensified Monsoon Phases Control Landscape Evolution in the NW Himalaya

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The intensity of the Asian summer monsoon circulation varies over decadal to millennial timescales, reflected in changes in terrestrial depositional environments and marine sediment records. However, the influence and mechanisms of short-lived intensified monsoon phases on landscape evolution, their effect on sedimentation rates, and the related change in precipitation distribution are not well understood. Here, we use high-resolution satellite-derived precipitation data from NW India of the last decade and compare its distribution to the strengthened monsoon of 2002 as an analog for past, longer lasting monsoon intensifications. The 2002 event dramatically increased precipitation in the high-elevation, arid areas of the western and northwestern parts of the orogen and caused increased mass wasting and flooding. Similarly, during longer lasting late Pleistocene (27 ka) and mid-Holocene (6 ka) intensified monsoon phases that lag 3 ka behind maximum insolation, exceptionally large landslides were generated in these climatically sensitive regions and serve as proxies for increased precipitation and runoff. These episodes of high climatic variability were also coupled with a six-fold increase in sedimentation rates emphasizing the pronounced imprint of short lived climate change on surface processes and landscape evolution.

### H41A-07 0930h

## Estimating Geomorphically Effective Rainrates from Elevation Data

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The concept of a geomorphically effective rainrate is central to many fluvial landscape evolution models, but a precise definition of this concept has proven elusive. This rainrate must be large enough for critical shear stresses to be exceeded but must also persist for long enough to significantly alter the landscape. It is often associated with the bankfull discharge. A new inverse method has been developed for estimating this effective rainrate from elevation data for mature, fluvial landscapes. This method is based on a mathematical description of mass conservation for water flowing over a landscape in the direction of the water surface gradient and on a slope-discharge relationship. The slope-discharge relationship only needs to be first-order accurate, and is an immediate consequence of two famous formulas for the hydraulic geometry of mature landscapes that have been shaped primarily by fluvial processes. Combining these facts and applying them to each element in a triangular or rectangular grid results in a topographically-derived metric that can serve as an estimator for the geomorphically effective rainrate over that cell. This metric was tested on simulated fluvial landscapes as well as on several closed-form solutions to a steady-state fluvial landscape model and it performed remarkably well. While previous results by the author showed how effective rainrates could be derived from the spacing and slope of periodic gully features such as roadcuts, this new result provides an estimate for each grid cell in a fluvial landscape. It therefore makes it possible to examine the possible variation in effective rainrates throughout basins due to orographic and other effects.

### H41A-08 0945h INVITED

## Characterizing Water Erosion Processes for Hillslope Evolution Models

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Mike Kirkby formulated the co-evolution of topographic and soil profiles along hillslopes in terms of hydrologic and sediment transport processes and their environmental controls. His models emphasize the feedbacks and co-evolution of form and processes. He thus provided a road map for modeling the mass balance of regolith to link theories in geomorphology and soil science to theories in climatology, hydrology, and biology, and for doing this on the basis of concrete field data. This theoretical work challenged geomorphologists (and other environmental scientists) to develop formulae relating mineral and solute transport to its controls, and therefore to systematize their analyses of the geomorphic effects of climate, hydrology, vegetation, material properties, tectonism, and time. Field and laboratory measurements of the material transport processes responsible for landform evolution have accumulated more slowly than the theoretical developments, but are necessary for understanding actual magnitudes and rates of geomorphic change, the relative roles and interactions of various processes, and the influence of environmental factors on rates of landform change and sediment production. This talk will review progress and difficulties in responding to Kirkby's challenge for computing sediment transport by water on uncultivated hillslopes of realistic size and complexity over time periods sufficient to change the morphology of hillslopes. The question of validation will also be addressed.

# H41B MCC: 3024 Thursday 0800h

## Use of Remotely Sensed Boundary Conditions in Land Surface Modeling I *(joint with A, B, GC)*

***Presiding:*** **W P Kustas,** USDA Agricultural Research Service**; W Crow,** USDA Agricultural Research Service

### H41B-01 0805h INVITED

## A Multi-scale Remote Sensing Model for Disaggregating Regional Fluxes to Micrometeorological Scales

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Disaggregation of regional-scale ($10^3$ m) flux estimates to micrometeorological scales ($10^1$-$10^2$ m) facilitates direct comparison between land-surface models and ground-based observations. Inversely, it also provides a means for upscaling flux tower information into a regional context. The utility of the Atmosphere Land-Exchange Inverse (ALEXI) model and associated disaggregation technique (DisALEXI) in effecting regional to local downscaling is demonstrated in applications to thermal imagery collected with the GOES (5-km resolution) and Landsat (60-m) satellites. A related algorithm (DisTrad) sharpens thermal imagery to resolutions associated with visible/near infrared bands (30 m on Landsat), extending the range in scales achievable through disaggregation. The accuracy and utility of this combined multi-scale modeling system is evaluated quantitatively in comparison with ground-based eddy-correlation flux measurements, and qualitatively in terms of enhanced information content that emerges at high resolution where flux patterns can be identified with recognizable surface phenomena.

H

### H41B-02 0825h

## Effects of Remote Sensing Resolution on Surface Energy Flux Estimates

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Estimates of spatially distributed fluxes from remote sensing observations are strongly dependent upon imagery resolution, particularly over heterogeneously vegetated landscapes. For resolutions finer than 100 m it is sometimes possible to model surface fluxes with relatively pure vegetation and bare soil pixels, but for resolutions coarser than 100 m the pixels usually represent a mixture of the two components. Since energy balance modeling is sensitive not only to the relative fractions of vegetation and bare soil, but also to their spatial distribution, the consequence of decreased resolution is reduced model accuracy. To demonstrate this effect, high resolution thermal infrared remote sensing data from aircraft sensors (12 m) and the ASTER sensor (90 m) are modeled for a range of effective resolutions between 12 m and 4 km. Using a two-source, soil and vegetation approach, surface energy fluxes are modeled and validated for study sites over central Oklahoma and Jornada, New Mexico. Comparisons of results show predictable loss of spatial flux variance when

landscape heterogeneity scales are less than imagery resolution. However, where landscape scales are close to imagery resolution, spatial energy flux variance can increase as resolution decreases. This effect, caused by a transition from un-mixed to mixed pixel imagery, is most readily seen over the Oklahoma grasslands where heterogeneity scales are on the order of 200-400 m. At Jornada the change in spatial variance is not seen due to landscape heterogeneity scales typically less than 10 m.

#### H41B-03 0840h

### Comparison of Evaporative Fractions Estimated with AVHRR and MODIS Sensors over South Florida.

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We have developed an evapotranspiration estimation algorithm using primarily remote sensing observations. This algorithm is simple, input-data adaptive and scalable. It derives spatially distributed evaporative fraction by using a contextual interpretation of the Pristley-Taylor equation and a relationship between remotely sensed radiometric temperature and vegetation index. This model has been shown to work well with remotely sensed data from Advanced Very High Resolution Radiometer (AVHRR). To further investigate the applicability of the model to different sensors, we compare and contrast estimates of evaporative fraction from AVHRR and Moderate Resolution Imaging Spectroradiometer (MODIS) over South Florida. Our preliminary results suggest that evaporative fraction obtained from AVHRR and MODIS are comparable for a number of clear and partially cloudy days. In particular, evaporative fraction for two clear days show very good agreement between the sensors in terms of high correlation and low root mean square difference and bias.

#### H41B-04 0855h

### Evaporation-based Estimates of Water Use in the Euphrates River Basin (Turkey, Syria, and Iraq) Derived from MODIS Imagery and the MM5 Mesoscale Climate Model

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Almost 98% of the water available to the Euphrates River falls in the headwaters regions of central and southern Turkey. The river then flows 2,000 km through semi-arid and arid conditions on its way to the Persian Gulf, providing an essential agricultural and ecological resource for water deficit regions of Syria and Iraq. Both Turkey and the lower riparian nations have developed massive impoundment and diversion schemes over the past decades, boosting agricultural production from the region but causing tension over water extraction rights within the shared watershed. Indeed, the combined water use proposals of Turkey, Syria, and Iraq currently sum to twice the natural discharge of the river taken on an annual basis. Uncertainties associated with the measurement of water consumption make it difficult to quantify the impact of any particular irrigation scheme or cropping system on the hydrologic balance of the basin. Operational estimates are often derived from water withdrawal surveys or, more recently, from remotely sensed figures for total cropped area. Such estimates lack a physical link to water consumption. In this study, moderate resolution, high frequency images of the MODIS sensor were used to quantify water consumption in large irrigation schemes within the Euphrates basin. MODIS-based estimates of latent heat flux compared reasonably well with ground measurements, but the values differed considerably from latent heat fluxes predicted for the same period using the MM5 climate model with the NOAH LSM. The use of satellite imagery as an input to MM5 may rectify this discrepancy and improve understanding of land-use/climate interactions on the mesoscale.

#### H41B-05 0910h

### ANALYSIS OF LAND SURFACE PARAMTERS AND FLOOD DATA IN THE RED RIVER OF THE NORTH BASIN

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The movement and distribution of water in the hydrologic cycle is affected by the level and type of land surface parameters. Thus accurate representation of the physical and biological features of the landscape within a watershed is required. A strong link exists between climate variability and the resulting changes in such land surface parameters as energy fluxes, land-cover and surface microclimates. Imagery from Landsat and other satellites provide land-cover and surface microclimate information with high temporal and spatial accuracy. This paper utilizes the land surface temperature (LST) derived from the thermal band of Landsat images and Normalized Difference Vegetation Index (NDVI) derived from its red and near-infrared bands to further improve land-cover and surface microclimate mapping. Remotely-sensed spatially distributed surface latent and sensible heat fluxes were also estimated. The study was conducted on the Red River of the North basin, North Dakota/Minnesota. Over the period of 1974-2002, seven images from Landsat Multispectral Scanner, Thematic Mapper and Enhanced Thematic Mapper plus sensors were used. Landsat images were processed using an unsupervised classification. Corrected LST and NDVI, which indicate a strong relationship with the land-cover data, were identified using scattergrams. Surface microclimate parameters (fractional vegetation cover, FVC and fractional impervious surface, FIS area) were estimated and their spatial and temporal distributions determined. Surface energy fluxes (latent and sensible heat) were assessed over space and time. The results indicate that vegetation cover (FVC >0.5) increased from 7% in 1974 to 48% in 1998 due to cropland farming in the Red River Valley and an increase in impervious areas (FIS >0.5) (by 79% from 1974 to 2001) attributed to the growing cities in the valley for the period of study. The study also indicated an increase in sensible and latent heat fluxes from 1998 to 2002 for areas classified as developed and cropland, respectively. Hydrograph analysis of the flow at Grand Forks gauging station also indicated runoff response of the basin has increased between 1993 and 2002 with all years having percent runoff greater than 10

#### H41B-06 0925h

### Relations Between Albedos and Emissivities From MODIS and ASTER Data Over North African Desert

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This paper analyzes relations among MODIS surface albedos, ASTER broadband (3-14 $\mu$m) emissivities, and a soil taxonomy map over the arid areas of Algeria, Libya, and Tunisia in North Africa at 30 second (about 1 km) and 2 minute (about 4 km) spatial resolutions. The MODIS albedo data are from 7 spectral bands and 3 broadbands during dust-free seasons and the emissivity data are derived from a linear combination of the waveband emissivities of the ASTER five thermal infrared channels. Both albedo and emissivity data in the study region show similar considerable spatial variability, larger than assumed by most climate models, and such variability is related to the surface types (sands, rock, and soil orders). Emissivity over bare soils exhibits statistically significant correlations with albedos at both broadbands and most of spectral bands and decreases linearly with albedos. Albedo and emissivity are more strongly correlated with each other than either is to the surface types, apparently because of their higher resolution either spatially or in surface mineralogy. This paper provides guidance for the possible inclusion of such correlation to specify albedo and emissivity in climate models.

#### H41B-07 0940h

### A Comparison of Surface Flux Maps from Remote Sensing-based Models

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A number of energy balance models using remotely sensed boundary conditions for producing spatially distributed maps of surface fluxes have been proposed. Validation typically involves comparing model output to flux tower observations at a handful of sites, and hence there is no way of evaluating the reliability of model output for the remaining pixels comprising a scene. Moreover, there is also the issue of a mismatch between the spatial scale of model output defined by the satellite pixel resolution and the size and location of the flux footprint or source area contributing to the tower-based flux measurements. To gain some insight as to the uncertainty in flux estimation from various models over a remote sensing scene requires one to conduct pixel-by-pixel comparisons of the output. Two models, which have potential for operationally monitoring ET with satellite data will be described. Some preliminary comparisons of the spatially distributed flux maps from the two models with remotely sensed imagery collected over a semiarid rangeland site in Arizona and subhumid grassland site in Oklahoma will be presented and discussed. A framework for conducting future model comparisons will also be discussed.

## H41C MCC: Level 2 Thursday 0830h

## Environmental Impacts of Coal-Bed Methane Development II Posters

*(joint with B, GC)*

***Presiding:*** **R W Healy,** U.S. Geological Survey**; R L Smith,** U.S. Geological Survey

#### H41C-1017 0830h POSTER

### Coalbed Methane Co-Produced Water Budget at a Storage Impoundment Site, Beaver Creek Drainage, Powder River Basin, Wyoming

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Rapid coalbed methane (CBM) development in the Powder River Basin, Wyoming, has resulted in a dramatic increase in the number of producing wells, from less than 300 in 1997 to more than 10,000 in 2002, with as many as 40,000 new wells projected to be drilled during the next decade. CBM development involves the co-production of large volumes of coalbed water, which is most commonly discharged to impoundments. Little is known about the potentially significant effects that this co-produced water may have on shallow aquifers and water budgets. A small study site (1600 meters in length) was chosen in the Beaver Creek drainage (a tributary to the Powder River) to quantify the fate of CBM water. Discharge into two in-channel infiltration impoundments (areas of 4000 m$^2$ and 10,500 m$^2$) began in November, 2002. We installed monitoring wells at three locationsupstream, between, and downstream of the ponds. We emplaced a series of v-notch weirs between and dowstream of the ponds to quantify conveyance losses, and constructed a floating pan in one impoundment to measure evaporation. Over the study period from July 23 to August 21, 2003, we established a water budget from daily coalbed water production,