H72D-0891 1330h POSTER

Perchlorate Sorption/Transformation from Solution Using Activated Carbon.

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Because perchlorate (ClO4-) inhibits iodide uptake it is a contaminant of concern in groundwater. Therefore ClO4- contaminated drinking water must be treated to either remove ClO4- or reduce ClO4- to chloride (Cl-). Batch and column experiments using varying operational conditions with powdered activated carbon (PAC) and granular activated carbon (PAC) were performed to evaluate PAC and GAC capacity to adsorb ClO4- and/or reduce ClO4- to Cl-, chlorite (ClO2-) and chlorate (ClO3-). Varying operational conditions were particle size, pH, and ClO4- salt cation. ClO4- adsorption was affected by particle size, pH, and cation salt. ClO4- adsorption on PAC and GAC is partially reversible.

H72E MCC: Hall C Sunday 1330h

Remote Sensing of Land Surface Hydrological Processes Posters *(joint with GC)*

Presiding: **V Lakshmi,** University of South Carolina**; T Cahill,** Texas AM University

H72E-0892 1330h POSTER

Dew and Intercepted Precipitation: Invisible at 1.4 GHz?

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Soil moisture, vegetation temperature, and vegetation moisture all strongly influence the fluxes of heat and water at the land-atmosphere interface. At sufficiently low column densities, the microwave brightness of a vegetated surface is most sensitive to the water content of the first few centimeters of the soil. On the other hand, at high column densities sensitivity to vegetation temperature and moisture dominates. What are the relative effects of soil moisture, vegetation temperature, canopy moisture content, and canopy water, either in the form of intercepted precipitation or dew, on the microwave brightness?

We begin to answer this question with observations of 1.4 GHz brightness, soil moisture, soil and canopy temperatures, precipitation, wind speed, and radiative fluxes made in a field of corn. We find that when the corn is mature and at its highest level of column density, there is still meaningful sensitivity to soil moisture. Three different states of canopy water (a night with no dewfall, a night with approximately 0.1 mm of dew, and a night with a 21 mm precipitation event) captured in our data set reveal that the net effect of canopy water is a decrease in the brightness temperature. In other words, volume scattering in the vegetation is enhanced more than emission by canopy water. Furthermore, at high column densities, sensitivity to soil moisture and canopy water are of the same order of magnitude. If neglected, intercepted precipitation or dew will make the soil appear to be wetter than it actually is.

URL: http://www.eecs.umich.edu/grs

H72E-0893 1330h POSTER

Estimation of Land Surface Window (8-12 μm) Emissivity from Multi-Spectral Thermal Infrared Remote Sensing - A Case Study in a Part of Sahara Desert

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Land surface window (8-12 μm: 800-1250 cm^{-1}) emissivity is an important parameter for estimating the longwave surface energy balance. The window emissivity can vary significantly, because the spectral emissivity ranges from 0.7 to 1.0 for bare soils and rocks in this range. Because the large part of the earth's total radiative emission is lost directly to space within the 8-12 μm region, the knowledge of the surface emissivity is crucial in the study of earth-atmosphere system radiation budget. Several studies have been made to map the window emissivity using a global land classification map (surface type map) and corresponding emissivity calculated from spectral libraries. The advantage of this method is that it is possible to obtain global map. However, wide spatial variations of emissivity can be observed in rocks and soils, which are recognized as one only surface type such as barren or bare soil in the classification map.

This study focuses on estimating the window emissivity from the emissivities of the five channels on the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). ASTER is a sensor onboard the Earth Observing System (EOS) Terra satellite launched in 1999, and has five channels in the thermal infrared region (8-12 μm). Using this sensor, it is possible to estimate surface spectral emissivity for each channel at a spatial resolution of 90 m globally. A multiple regression was used to relate the five ASTER emissivities to the window emissivity. This regression was developed using two spectral libraries, ASTER Spectral Library and MODIS Emissivity Library. The window emissivities ranged from 0.80 to 0.99 for natural surfaces, such as, rocks, soils, vegetation, water, ice, and snow. The RMS error of the estimated window emissivity was less than 0.01 both in calibration and in validation.

We applied this calibrated regression to emissivities computed using ASTER data acquired in 2001 and 2002 over a 240 km by 1200 km area in Sahara Desert, Africa. We compared the estimated window emissivities derived from regression with the ones expected from the classification map and found significant difference ranging from -0.08 to +0.07.

H72E-0894 1330h POSTER

Estimation of Watershed Scale Soil Moisture from Point Measurements in SMEX02

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Understanding watershed scale soil moisture distributions is necessary to validate current remote sensing, such as the Advanced Microwave Scanning Radiometer (AMSR). Unfortunately, remote sensing technology does not currently resolve the land surface at a scale that can be easily validated with ground observations. One method of validation uses existing soil moisture measurement networks and scales up to the resolution of these remote sensing footprints. Soil Moisture Experiment 2002 (SMEX02) was an excellent opportunity to implement one such soil moisture gaging system which, when calibrated, provided robust estimates of the watershed scale soil moisture throughout the summer of 2002. Twelve fields distributed across the Walnut Creek watershed were instrumented with in situ soil moisture probes and were intensively sampled during the experiment, between June 25 and July 12, 2002. The sampling sites were analyzed for temporal stability and scaling relationships were developed. These point measurements were scaled up to the field scale ($\sim$ 800 m) and then to the watershed scale ($\sim$ 25 km) for the field experiment period and were shown to be accurate indicators of the large-scale soil moisture distribution. Point measurements were then used as a basis for a watershed estimate for several months beyond SMEX02, thereby providing a long record of watershed scale soil moisture which can be used for validation. The ability to estimate the soil moisture is measured by a variety of techniques, including split sample verification. This analysis is a first step in the implementation of large-scale soil moisture validation utilizing networks such as the Soil Climate Analysis Network (SCAN) as a basis for calibrating soil moisture satellite products.

H72E-0895 1330h POSTER

Spatial Classification Techniques for Synthetic Aperture Radar

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In this paper, we examine new methods for the classification of single frequency C-band Synthetic Aperture Radar (SAR) data using trigonometric functions to segment the information into primary band composites. The decomposition is shown to be scaleable from the complex series representation to a simple addition of real and imaginary terms. A condensed example is provided for four filter elements in the standard orientation. This example shows the spatial and radiometric classification of a meandering river system using the radiometric and spatial filters. A discussion of the primary effects is given with a complete derivation for the filter design, the transfer functions, and the related scalar applications.

H72E-0896 1330h POSTER

Spatial Variability in Radiant Stream Temperatures Estimated From Thermal Infrared Images

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Stream temperature is an important water quality indicator, for example, in the Pacific Northwest where endangered fish populations are sensitive to elevated water temperature. Regional assessment of stream temperature is limited by sparse sampling of temperatures in both space and time. Remotely sensed thermal infrared (TIR) imagery can be used to derive spatially distributed estimates of the radiant skin temperature (Tr) (top 100 nm) of streams, but spatial variability in these measurements makes it difficult to link Tr to the kinetic temperature of the stream (Tk). In image pixels that are fully resolved at the scale of the TIR data, this along-stream variability is primarily the result of evaporative cooling due to wind, and to surface effects along the stream, such as riffles and foam, which increase the apparent emissivity and therefore the measured radiance. The resulting distinct spatial pattern of Tr must be identified and corrected if accurate Tk is to be determined. We investigate spatial variability in Tr using medium-resolution (5m) TIR imagery from the airborne NASA-MASTER sensor, and coarse-resolution (90m) imagery from the ASTER sensor on the Terra satellite. Ground data of Tr and Tk within the Yakima River watershed in Washington State are used to validate analysis results. In a uniform reach with a Tk of 20.7 oC, the mean Tr observed using MASTER is 22.1 oC, with a standard deviation of 0.7 oC. Preliminary results show that the distinct along-stream patterns of Tr correspond to observed surface effects.

URL: http://depts.washington.edu/strmtemp/

H72E-0897 1330h POSTER

A downscaling framework for brightness temperature and near surface soil moisture images derived from ESTAR

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Brightness temperature images derived from electronically scanned thin array radiometer (ESTAR) may be used for validation of or assimilation into radiation transfer models, and for derivation of near-surface soil moisture images. Near-surface soil moisture may in turn be assimilated into land-surface models to improve their predictive capabilities. Thus, the availability of such images is crucial for a better understanding and characterization of atmosphere-surface dynamics and for improving weather forecasts. It is expected that brightness temperature images taken from space may eventually be available at a resolution of 10-km by 10-km. Various researchers have reported that the derived near surface soil moisture images posses scaling properties over scales ranging from 200-m to 90-km. These findings suggest that it may be possible to statistically characterize the effects of sub-grid variability of soil moisture. This study presents a new downscaling framework for brightness temperature and soil moisture images derived from ESTAR. The simple mathematical model used for this purpose is clearly defined. Validation is performed with the brightness temperature images taken during the Southern Great Plains Hydrology Experiment of 1997 (SGP97). The results obtained show that the proposed downscaling scheme is capable of accurately capturing the first and second order statistics of the observed brightness temperature images. The work presented here constitutes a first attempt to understand the spatial structure of brightness temperature and soil moisture images when viewed at different resolutions so that we may eventually be able to evaluate the effects of sub-grid variations of these variables in our land-surface representations and weather forecasts.

H72E-0898 1330h POSTER

Radar Measurement of Water Content Dynamics Over Bare and Vegetated Soil Surfaces

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Recent studies have shown substantial temperature dependence of microwave dielectric properties of soil-water mixtures, which could affect water content inferences from radar backscatter. Soil drying patterns were measured using ground-penetrating radar (GPR) with a 1 GHz center frequency horn antenna that was suspended (> 0.5 m) over bare and vegetated surfaces of soils with different textures. Soil water contents were derived from the surface reflection (SR) amplitudes and the propagation times (PT) to subsurface reflective interfaces.

GPR-SR and -PT water content measurements over bare soil surfaces were in good agreement with gravimetric and time domain reflectometry (TDR) measured values. Measurements over vegetated surfaces showed gradual reductions in the maximal values of GPR-SR measured water contents with increase in plant canopy height. In contrast, the maximal value of GPR-PT-derived water content remained unchanged. Above-ground canopy reflections became more pronounced with canopy growth. GPR-SR data showed noticeable diurnal patterns in water contents of bare surfaces. Water content extreme values vary with soil type - for low surface area soils (sand), the maximum occurs at nighttime, whereas for high surface area soils (clay loam) the maximum occurs around midday at normal incidence. An increase in incidence angle caused a shift in measured maxima times to morning hours. These measurements highlight the need for improved understanding of physical effects on dynamics of near-surface radar measurements often used for hydrological studies.

H72E-0899 1330h POSTER

ESTAR Brightness Temperatures for Soil Moisture Estimation and Spatial Characterization of the Retrieved Fields A Study From SGP99

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Surface soil moisture is an important variable in the modeling of hydrological and biophysical processes. Several field experiments have been carried out in the last decade in the Southern Great Plains region of the United States to evaluate sensors for soil moisture detection and retrieval algorithms. Previous studies have used the results of these experiments to study the temporal and spatial variability of soil moisture at various scales. This study focuses on extending this work to the Southern Great Plains Experiment 1999 (SGP99), which took place during the second and third weeks of July 1999 and covered an area greater than 10,000 km2. During SGP99 the Electronically Scanned Thinned Array Radiometer (ESTAR) was flown to study surface soil moisture. The ESTAR is a synthetic aperture, microwave radiometer operating at a frequency of 1.4 GHz. The brightness temperature of a vegetated surface at microwave frequencies depends on a number of land surface parameters including vegetation type, soil type, temperature, and roughness, in addition to soil moisture. Results of soil moisture retrievals from the ESTAR recorded brightness temperatures using a semi-empirical retrieval algorithm are presented. The retrieved soil moisture shows considerable agreement with ground measurements from various sites distributed over the study region. The validity of spatially interpolating the ground observations to obtain regionalized values of soil moisture over the entire watershed is also investigated. Also, this study investigates the spatial structure from the SGP99 retrieved fields by examining the transition from simple scaling to multi-scaling for various moments of soil moisture. Soil moisture scaling behavior is statistically characterized by parameters such as the scaling exponent, the order moment, and the fractal dimension. The relationship between rainfall and soil moisture is identified and its influence on scaling properties is discussed. The variations of these parameters are considered as a time series that enables us to observe climate induced variation. To improve future land surface modeling and to capture the critical forcing variables, the scaling properties of some physically derived features, such as latent heat flux, porosity, leaf area index, and topography are also evaluated. These results are compared to the previous studies using the Washita 92, Washita 94, and SGP97 soil moisture fields. Regressive parameters for previously derived best-fit relationships of soil moisture structure are examined for their robustness.

H72E-0900 1330h POSTER

Improving Satellite-Based LAI and FPAR Predictions With Simple Site-Specific Parameterizations

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Leaf area index (leaf area per ground surface area; LAI) and the fraction of photosynthetically active radiation absorbed by vegetation (fPAR) are fundamental elements of hydrologic modeling. Maps of LAI and fPAR are thus critical inputs for spatially extensive hydrology models. These maps can be derived from satellite data using relationships between LAI, fPAR, and spectral vegetation indices (SVI), but establishing these relationships and associated parameters requires time consuming and expensive ground-based measurements. Consequently, calibrations established for one site are frequently transferred to another site without considering site-specific elements of the parameterization or potential error introduced by the geographic transfer. We are evaluating this error and developing simple and effective corrections as part of a multi-laboratory Department of Energy (DOE) project investigating hydrometeorological processes in the Walnut River Watershed (WRW) in southeast Kansas. We applied relationships established for the North American Great Plains and Konza Prairie Long Term Ecological Research sites to the WRW and developed parameterizations using Normalized Difference Vegetation Index (NDVI) derived from 1km Advanced Very High Resolution Radiometer (AVHRR) and 30m Landsat Thematic Mapper. Ground-based reflectance, LAI, and fPAR were collected for 100+ sites on the WRW. Initial evaluation indicates that simple calibrations using site-specific satellite data to adjust parameters substantially improve predictions of the ported LAI/fPAR-SVI relationships. For example, estimating NDVI of bare ground from AVHRR data for the WRW and substituting that value into the Konza Prairie relationship greatly improved predictions of LAI for WRW grasslands. Our methods of site-specific parameterization may allow accurate use of geographically ported relationships in many different locations. This research was sponsored by the DOE Office of Science, Environmental Sciences Division, and performed by ORNL, which is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

H72E-0901 1330h POSTER

Comparison of Evaporation Estimated by Satellite Remote Sensing With Estimates From a Land Surface Model

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Evaporation provides the link between the energy and water budgets at the land surface. Accurate measurements of evaporation rates at large spatial scales are central to understanding the feedback mechanisms between the land and atmosphere. However, with the paucity of available surface observations for many portions of the globe, the use of modeled evaporation using satellite-based remotely sensed inputs is a potentially viable surrogate. Estimates of evaporation are made using two conceptually different models. The Surface Energy Balance System (SEBS) estimates atmospheric turbulent heat fluxes and evaporative fraction using satellite derived surface temperature and near-surface meteorological variables, usually from standard surface stations. The Variable Infiltration Capacity (VIC) model solves the land surface water and energy balances at scales from the point up to several 100km using standard radiative and meteorological inputs. A common set of land surface data, including vegetation type distribution and related parameters such as LAI and albedo, are used to specify the land surface in each model. Comparison of estimated evaporation from the two models is made over the Oklahoma region of the USA for a 2 month warm season period.

H72E-0902 1330h POSTER

Hyperspectral Remote Sensing to Detect Water Repellent Soil Conditions after Forest Fires

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The burning of organic surface litter during forest fires often results in a water repellent soil layer at or near the soil surface. Organic matter is volatilized and a significant fraction moves into the upper soil layers (top 5 cm). Upon cooling, soil particles are coated with hydrophobic organic substances and the soil displays

drastically reduced infiltration capabilities. The degree of water repellency is related to the amount of organic material on the surface prior to the fire, and the duration and temperature of the burn. Carbon compounds that are indicative of burned organic matter have been identified spectrally in soils under laboratory conditions. The 1000-2500 nm (near through short wave infrared) range is the span of the electromagnetic spectrum exhibiting significant adsorption for many organic compounds. Since burning alters surface organic matter and it is possible to detect such a change spectrally, a hyperspectral sensor should be able to provide information ultimately relating the change in organic matter to soil water repellency.

This study aims to use a hyperspectral sensor to determine the degree of water repellency of surface soil in three burn classifications (low, moderate, and high) after a forest fire. One hundred eighty plots (sixty per burn class) were selected within the Hayman fire perimeter in southern Colorado in July 2002. A handheld hyperspectral sensor was used to measure soil reflectance at several plots within each burn classification. An aerially- mounted hyperspectral sensor was also flown over the fire site. Twelve flight lines were flown to ensure contiguous coverage of the entire fire. The on-site ground truthing included both the Water Drop Penetration Time (WDPT) test and an infiltrometer test, with the former being a traditional method and the latter a new approach for testing water repellency. Both methods correlate the time to the start of infiltration with the degree of soil water repellency.

The measured soil reflectance from both types of hyperspectral sensors are currently being compared with the ground-determined water repellency in order to determine if spectral reflectance curves are distinctive for water-repellent and non-water repellent soils. If such a difference exists, a spectral library of water repellent soil conditions will be developed for use in future image analysis.

H72E-0903 1330h POSTER

Towards an Operational Monitoring of Actual Evapotranspiration With Modis Imagery

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Estimation of regional scale evapotranspiration (ET) is of major importance in hydrological, meteorological and climatological modeling. The estimation of available energy and the partitioning into turbulent sensible and latent heat fluxes is crucial in this process. Despite closure problems, point-based measurements of these quantities are considered fairly accurate. However, in heterogeneous terrain these measurements are not representative for regional estimates, a reason to incorporate remotely sensed data. Nowadays, models quantifying the soil-vegetation water loss (ET) approach the level of uncertainty in ET measurements. Progress toward operational monitoring of ET at scales of interest, has been hampered until recently due to lack of suitable sensors. This changed with the late availability of multi-band imagery from MODIS, developed for monitoring global change. Its data are used by algorithms for analysis of biophysical and geophysical products and, in parallel, models that use these products are developed from currently available satellite data sets. The model we used to test this is the Surface Energy Balance Algorithm for Land (SEBAL) which needs remotely sensed inputs of surface temperature, reflection and vegetation density. The model, which has mainly been validated using NOAA-AVHRR and Landsat data, is suitable for a variety of resolutions to estimate regional ET for heterogeneous areas. Algorithms developed from AVHRR datasets are used on MODIS data without modifications, justified by the radiometric similarity of AVHRR channels 1, 2, 4, and 5 and MODIS channels 1, 2, 31, and 32. Solar radiation, windspeed and air temperature are the only ancillary data required. MODIS data from 13 and 29 September 2001 are applied to a study site at Maun, Botswana. The area of 300 by 400 kilometer is heterogeneous, comprising densely vegetated swamps, grasslands and savannah. Model output resulted in 1 km scale instantaneous estimates of Rn, G, H and LE as well as daily rates of ET. They are compared with ground-based energy flux measurements using a meteorological flux tower, situated at a homogeneous site in the savannah. The model returns estimates of sensible and soil heat fluxes that agree well with the tower measurements, but net radiation and latent heat flux show deviations. The net radiation is slightly low and mostly due to differences between modeled and actual albedo. Latent heat fluxes are overestimated by about 35 Wm^{-2}, if compared to the eddy measurements. However, if the energy closure gap is due entirely to errors in the towers latent heat fluxes, which is done in the remote sensing approach, they are underestimated by about 30 Wm^{-2}. In other words, further improvement of the model is hampered by possible errors in the validation data. Using this model output, a regional estimate of daily ET can be retrieved, assuming a constant daytime evaporative fraction. Typical values that emerge are 6 mm for the swamps, 2 for the grasslands and 1 mm for the savannah.

H72E-0904 1330h POSTER

Mapping tree and impervious cover using Ikonos imagery: links with water quality and stream health

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Precision georeferened Ikonos satellite imagery was used to map tree cover and impervious surface area in Montgomery county Maryland. The derived maps were used to assess riparian zone stream buffer tree cover and to predict, with multivariate logistic regression, stream health ratings across 246 small watersheds averaging 472 km2 in size. Stream health was assessed by state and county experts using a combination of physical measurements (e.g., dissolved oxygen) and biological indicators (e.g., benthic macroinvertebrates). We found it possible to create highly accurate (90+ per cent) maps of tree and impervious cover using decision tree classifiers, provided extensive field data were available for algorithm training. Impervious surface area was found to be the primary predictor of stream health, followed by tree cover in riparian buffers, and total tree cover within entire watersheds. A number of issues associated with mapping using Ikonos imagery were encountered, including differences in phenological and atmospheric conditions, shadowing within canopies and between scene elements, and limited spectral discrimination of cover types. We report on both the capabilities and limitations of Ikonos imagery for these applications, and considerations for extending these analyses to other areas.

URL: http://www.geog.umd.edu/resac

H72E-0905 1330h POSTER

Impervious Surface Area Mapping using Landsat Imagery: Applications to Hydrology and Land Use Change Monitoring

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Impervious surfaces include rooftops, roads, parking lots and other areas that are impermeable to moisture. As the amount of built environment around urban areas has increased, it has been widely recognized that more impervious surface area (ISA) results in greater volume and intensity of stream flow, which can degrade stream health and require expensive modifications to flood control structures. Other effects include increased urban "heat island" influences and changes in local weather. If impervious areas could be accurately mapped using satellite imagery, it would provide valuable input to many applications, from hydrologic modeling to land use planning. We have developed a method to map subpixel ISA with Landsat Thematic Mapper (TM) imagery and classification - regression tree algorithms. This approach provides highly accurate (90+ percent) maps of ISA, but also permits estimation of the proportion of each cell occupied by impervious materials (between 0-100 percent). We report on a recently completed a map of ISA for the entire 163,000 km2 Chesapeake Bay watershed, a region of highly altered land cover and rapid land use change. We also report on the mapping of change patterns, indicated by ISA changes between 1986 - 2001, in an 18,000 km2 area centered on Baltimore - Washington, D.C. We review the methods, issues, technical challenges, results, accuracy, and advantages of this approach, and provide an overview of various applications for which the products are currently being used.

URL: http://www.geog.umd.edu/resac

H72E-0906 1330h POSTER

Riverbank Erosion Assessment with Airborne Laser Altimetry

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Non-point source pollution caused by sediment from agricultural runoff and bank erosion is one of the greatest threats to U.S. surface water quality. Detailed topographic data collected with an airborne laser scanner can help determine the contribution due to river bank erosion and identify banks that are more vulnerable to collapse. A 56-km length of Minnesota's Blue Earth River was scanned for changes in bank elevations in April 2001 and April 2002 with an helicopter mounted Topeye laser system. The database includes millions of X, Y, Z coordinates of laser returns from the river valley plus return intensity. Reflections from vegetation were stripped to construct two bare-earth digital elevation models. The absolute accuracy (15cm) and relative accuracy of the scanning laser data was determined by comparing measured elevations to known elevations of bridges crossing the river. The change in bank volume due to erosion was determined via layer subtraction. A mass wasting estimate as a proportion of total sediment load was calculated using bulk density of bank materials.

H72E-0907 1330h POSTER

Use of Spatial Variance Information From Remote Sensing Imagery to Map Vegetation Foliage Density

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Maps of foliage density expressed as leaf area index (LAI) are used for natural resources inventories, land surface-atmosphere interaction modeling, and hydrologic modeling. Remote sensing imagery can be used to produce these maps by relating spectral vegetation indexes (SVIs) to LAI calibration samples acquired at selected locations on the surface. This approach traditionally uses ordinary least squares (OLS) relationships between the surface measurements and the SVIs, and does not fully take advantage of the spatial information content of the imagery. Spatial information inherent in a semivariogram of the imagery may provide additional information for mapping LAI patterns. This is demonstrated using a spatially dense sample of corn LAI and calibrated airborne imagery. An LAI map is produced by interpolating surface measurements with a semivariogram from the imagery. The resulting LAI map captures the main spatial features of a LAI map produced by interpolating the surface LAI data with its semivariogram. The image semivariogram approach also provides a product that has less noise characteristic of OLS-based remote sensing methods. The use

of the image semivariogram with the surface LAI calibration samples suggests that the spatial domain information can complement spectral information for improving LAI maps especially at high spatial resolution where OLS methods may not perform well.

H72F MCC: 130 Sunday 1330h

Progress in Methods for the Evaluation, Parameter Estimation, and Quantification of Uncertainties of Hydrologic Models I

Presiding: **H Gupta,** University of Arizona**; Q Duan,** NOAA National Weather Service**; D P Boyle,** Desert Research Institute

H72F-01 1330h INVITED

Bayesian Total Error Analysis - An Error Sensitive Approach to Model Calibration

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The majority of environmental models require calibration of their parameters before meaningful predictions of catchment behaviour can be made. Despite the importance of reliable parameter estimates, there are growing concerns about the ability of objective-based inference methods to adequately calibrate environmental models. The problem lies with the formulation of the objective or likelihood function, which is currently implemented using essentially ad-hoc methods. We outline limitations of current calibration methodologies and introduce a more systematic Bayesian Total Error Analysis (BATEA) framework for environmental model calibration and validation, which imposes a hitherto missing rigour in environmental modelling by requiring the specification of physically realistic model and data uncertainty models with explicit assumptions that can and must be tested against available evidence. The BATEA formalism enables inference of the hydrological parameters and also of any latent variables of the uncertainty models, e.g., precipitation depth errors. The latter could be useful for improving data sampling and measurement methodologies. In addition, distinguishing between the various sources of errors will reduce the current ambiguity about parameter and predictive uncertainty and enable rational testing of environmental models' hypotheses. Monte Carlo Markov Chain methods are employed to manage the increased computational requirements of BATEA. A case study using synthetic data demonstrates that explicitly accounting for forcing errors leads to immediate advantages over traditional regression (e.g., standard least squares calibration) that ignore rainfall history corruption and pseudo-likelihood methods (e.g., GLUE) do not explicitly characterise data and model errors. It is precisely data and model errors that are responsible for the need for calibration in the first place; we expect that understanding these errors will force fundamental shifts in the model calibration/verification philosophy.

H72F-02 1350h INVITED

Rainfall-Runoff Modelling: New Tools and New Horizons

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Conceptual rainfall-runoff models underpin most hydrological simulation applications, ranging from flood forecasting to water quality modelling. There has been a growing recognition that the information content of input-output data, at least as represented by a single objective function, is limited, and that this leads to uncertainty in parameter values identified through optimisation. This uncertainty has severely restricted the scope of rainfall-runoff modelling applications; the implications for coupled models, for example of water quality, are only now being explored.

Several important recent developments in modelling tools are reviewed. These provide a powerful analytical capability to support model development and application. Stochastic methods are available to explore model structure and parameter uncertainty, and hence the trade-off between model complexity, performance and identifiability. Dynamic identifiability analysis has been developed to track parameter variability and identifiability through time. The information content of hydrological data has been increased by the use of multiple objectives, which in turn provide further insight into model structures and performance.

The implications of these developments for hydrological practice are illustrated. For example, analysis of the trade-off between performance and identifiability has led in the UK to parsimonious rainfall-runoff models capable of regionalisation. It is expected that the next generation of flood design methods will depend on the routine use of continuous simulation methods for flood design in gauged and ungauged catchments. Such regional analysis also opens up the prospect of new insights into catchment response, spatial variability and scale-dependence.

River water quality modelling is used to illustrate the wider potential of these tools in modelling more complex environmental systems. Recent work is reported which has highlighted a lack of identifiability of key parameters and processes in current models, and data deficiencies. The modelling of diffuse source nutrient pollution illustrates the potential of parsimonious models, consistent with the information content of available data, and the development of appropriate models through analysis of model structural deficiencies.

In conclusion, it is argued that these new tools point to the need for a more flexible and informed approach to environmental modelling, and offer potentially important new insights into environmental systems.

H72F-03 1410h

A Shuffled Complex Evolution Metropolis algorithm for optimization and uncertainty assessment of hydrological model parameters

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Markov Chain Monte Carlo (MCMC) methods have become increasingly popular for estimating the posterior probability distribution of parameters in hydrologic models. However, MCMC methods require the a priori definition of a proposal or sampling distribution, which determines the explorative capabilities and efficiency of the sampler and therefore the statistical properties of the Markov Chain and its rate of convergence. In this presentation, we present an MCMC sampler entitled the Shuffled Complex Evolution Metropolis algorithm (SCEM-UA), which is well suited to infer the posterior distribution of hydrologic model parameters. The SCEM-UA algorithm is a modified version of the original SCE-UA global optimization algorithm developed by Duan et al. [1992]. Two case studies demonstrate that the adaptive capability of the SCEM algorithm significantly reduces the number of model simulations needed to infer the posterior distribution of the parameters when compared with the traditional Metropolis-Hastings samplers.

H72F-04 1425h

Hydrologic Model Selection using Markov chain Monte Carlo methods

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Estimation of parameter uncertainty (and in turn model uncertainty) allows assessment of the risk in likely applications of hydrological models. Bayesian statistical inference provides an ideal means of assessing parameter uncertainty whereby prior knowledge about the parameter is combined with information from the available data to produce a probability distribution (the posterior distribution) that describes uncertainty about the parameter and serves as a basis for selecting appropriate values for use in modelling applications. Widespread use of Bayesian techniques in hydrology has been hindered by difficulties in summarizing and exploring the posterior distribution. These difficulties have been largely overcome by recent advances in Markov chain Monte Carlo (MCMC) methods that involve random sampling of the posterior distribution. This study presents an adaptive MCMC sampling algorithm which has characteristics that are well suited to model parameters with a high degree of correlation and interdependence, as is often evident in hydrological models. The MCMC sampling technique is used to compare six alternative configurations of a commonly used conceptual rainfall-runoff model, the Australian Water Balance Model (AWBM), using 11 years of daily rainfall runoff data from the Bass river catchment in Australia. The alternative configurations considered fall into two classes those that consider model errors to be independent of prior values, and those that model the errors as an autoregressive process. Each such class consists of three formulations that represent increasing levels of complexity (and parameterisation) of the original model structure. The results from this study point both to the importance of using Bayesian approaches in evaluating model performance, as well as the simplicity of the MCMC sampling framework that has the ability to bring such approaches within the reach of the applied hydrological community.

H72F-05 1440h

A stochastic approach for estimating the uncertainty associated to rainfall-runoff model predictions

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The evaluation of the uncertainty associated to the river flow predictions provided by rainfall-runoff models is a topical issue in applied hydrologic modeling. As a matter of fact, many experiences of application of rainfall-runoff models have highlighted the need for a consistent estimation of their accuracy, in order to provide decision-makers with an indication of the reliability of the model predictions. A statistical approach for facing this problem is herein proposed, based on the application of stochastic processes theory in order to estimate the range of variability of the model error. The proposed technique is based on the preliminary estimation of an optimal parameter set for the hydrological model and on the analysis of the time series of the model error in the simulation of observed data. A linear transfer function model is used in order to relate the range of the model error to the past values of the error itself and to the current and past values of the river discharge simulated by the model. This allows to estimate confidence bands for the simulated river flows, for a given confidence level. The proposed technique is applied to a case study of an Italian river, whose flows are simulated by using a conceptual spatially-distributed rainfall-runoff model.

H72F-06 1455h

Quantitative Characterization of Radar Rainfall Uncertainties

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The lack of systematic methods to quantify the uncertainties of radar rainfall (RR) estimates is one of the major obstacles in the development of radar hydrology. Without comprehensive mathematical description of the errors, conclusive evaluations and comparisons of different products are impossible. Without realistic models of the uncertainties, one cannot efficiently assimilate the RR data in hydrologic forecasts. In this study, we identify and discuss the main elements of the RR uncertainty analysis problem, and outline several results that we obtained in our effort to solve it.

The first group of questions concerns ground reference (GR) data that have to be used to estimate the RR uncertainties. The GR based on direct raingauge measurements is inevitably contaminated with the gauge representativeness errors. Their magnitude and selected characteristics are demonstrated using data from a super-dense local network (EVAC PicoNet) covering