ABSTRACT VOLUME

CAHMDA VI AND HEPEX-DAFOH III JOINT WORKSHOP

Austin, Texas, USA
8–12 September 2014

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Sponsored by

Bureau of Economic Geology

The University of Texas at Austin CIESS Center for Integrated Earth System Science

ESI

AUGUST 22, 2014

http://www.jsg.utexas.edu/ciess/cahmda-vi-hepex-dafoh-iii/

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Session 1. Extreme events: Detection

Description

There has been a marked increase in the frequency of extreme hydrologic events during the past decades. This sub-theme presents evidence on changes in precipitation, soil moisture, evapotranspiration, streamflow, water table, lake levels, agriculture, vegetation, and social-economic factors through *in situ* measurements, surveys, and satellite remote sensing (e.g., MODIS, AMSR-E, GRACE, SMOS). Errors in observations will also be discussed.

Keynote presentations

S01K01

Detection of Extreme Events with GRACE and Data Assimilation

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A unique aspect of GRACE is its ability to quantify changes in all forms of water storage, including groundwater and water ponded on the surface. Thus GRACE is well suited for identifying both hydrological droughts, when total water storage is low, and floods, when total water storage is high. The potential for GRACE to detect and help predict droughts and floods is clear, but first it is necessary to overcome GRACE's low spatial and temporal resolutions (relative to other hydrological observations) and data latency. To do so we synthesize GRACE data with other ground and space based meteorological observations within a land surface model. The resulting high resolution, near real-time fields of soil moisture and groundwater storage variations are then used to generate wetness index maps, which are now being distributed through the University of Nebraska's National Drought Mitigation Center website and incorporated into the U.S. and North American Drought Monitors. At present, such wetness index maps are scarce outside of North America. We intend to address this need by expanding our drought indicator production to the global scale over the next 1–2 years.

S01K02

Detection of Drought at High Spatial Resolution Using Bias-Adjusted Stage IV Precipitation

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The National Weather Service produces a Stage IV Mosaic of precipitation estimates on an hourly and daily basis across the contiguous United States for the purposes of flood and river forecasting. In the central and eastern United States, the precipitation analysis is based largely on radar estimates of precipitation, adjusted to agree with gauge values. However, the signal-to-noise ratio of 24-hour precipitation is low, and biases accumulate over time. We have developed a three-step process to minimize long-term biases in the Stage IV mosaic for accumulation periods of one month or longer, making the product suitable for drought monitoring. The three-step process eliminates spatial patterns of bias inherent in radar observations before performing a conventional two-dimensional bias correction procedure. The resulting analyses are used to produce

Standardized Precipitation Index (SPI) maps of drought intensity. We have also developed a new drought index, the SPI Blend, which merges different accumulation periods to give a more realistic depiction of drought development. The bias-adjusted analyses are also useful as input to high-resolution land surface and hydrologic models.

ORAL PRESENTATIONS

S01O01

Advancing Flood Detection and Preparedness through GEOSS Water Services

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Since 2012, a growing team of academic and government research centers, regional and national water resource reporting agencies, and commercial software companies, have been coordinating development of web applications for regional and national water data reporting. This work has benefited from the adoption in 2012 of international standards developed by the Open Geospatial Consortium (OGC) for water data time series (WaterML 2.0), as well as OGC web services for publishing, mapping, and cataloguing water monitor locations and time series of water data variables.

By leveraging GEOSS as a hub for registering the many community portals for water data services, as well as for brokering discovery and access across all these web resources, we can see the beginnings of a global interoperable network of water data that will help many types of users from local farmers and emergency responders, to scientists across multiple domains, and national policy makers.

This presentation provides a progress update on development efforts in 2014, which focus on integration of global flood monitoring and prediction systems being developed in the United States and Europe. By integrating web-based real-time precipitation and streamflow observations to stream network routing and inundation models, it should be possible to advance the detection and mitigation actions for flood events much earlier than presently practical.

S01O02

Climate Change Adaptation Involving Land Use Management and Grazing Strategies by Use of Social Survey, Statistics, and Numerical Modeling

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This study focus on climate change adaptation involving land use management and grazing strategies by use of social survey, statistics and numerical modeling. The results suggest that the adaptation must keep the balance between sustainable development of local economics and ecological system. Our investigation shows that grazing ban and ecological migration are two major adaptation policies in Alxa League, west Inner Mongolia. Grazing ban has led to a quick regeneration of local steppe on one hand, and meanwhile the migration has enhanced pressure to emigrant towns, on the other. The grazing ban has led to a series of negative effects, such as increase in mouse population that damage grassland, enhance in fire risk due to accumulation of dry matter, and biological diversity tend to decrease. The local shrubs become declining without grazing. It turned out that ungulate is one of important roles in keeping ecological system of the west Inner Mongolia. To quantitatively investigate the grazing effect we made a numerical simulation of local grassland NPP under different grazing pressures with a forest dynamical model (FORSPACE), which incorporating ungulate grazing, wild fire, hydrological process, ecological system, and climate change. It confirmed that suitable grazing would be not only in favorable to dry land vegetation, especially to local shrubs. By contrast, over grazing would destroy surface vegetation and lead to animal death, instead. These results suggest that local adaptation policy modification is proposed to allow some extent grazing, and encourage having their economical animals enclosed.

POSTER PRESENTATIONS

S01P01

Impact of Warming Climate and Monsoon on Water-Resources and Need of Future Hydrological Modeling in a Western Himalayan Watershed of Upper Indus Basin

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This study discusses impact of warming climate and monsoon on Astore watershed water resources, one of the major tributary of Upper Indus Basin (UIB), using long time series climatic stations precipitation and temperature (1954–2010), Tropical Rainfall Measuring Mission (TRMM) 3B43 (1998–2010), Global Precipitation Climatology Project (GPCP) precipitation (1979–2010), flow (1974–2010) monthly datasets, and Landsat images. Average temperature data show statistically significant increasing trends for November-June during 1988-2010, while June and July, which bear more episodic and intense precipitation, show statistically significant increasing/decreasing trends during 1974–1992/1993–2009. Decrease in summer snow-cover has also been confirmed during 1978–2008, particularly during 1998–2008, using Landsat data for visual inspection. Increasing spring discharge, shift in timing of annual peak discharge, and increase in melt component with simultaneous increase in glacial melt component in river flows are accompanied by depletion of glacial storage within Astore watershed, during 1997–2009 as compare to 1974–1996. Besides increase in glacier-melt during 1997–2009, flows have milder increasing trends as compare to 1974–1996 due to decrease in monsoon precipitation. If current trends in river flows continue in the future for long and the climate change continues to follow the same path that it has been following during the past decades then river flows will eventually take a falling path once the glacial reserves will no longer be able to provide a sustained nourishment to the river waters. Thus, there is intense need to adopt current flow and climatic parameters' trends in future hydrological and reservoir operation models.

S01P02

A Remotely Sensed Reservoir Storage Product in South Asia and Its Uncertainty Analysis

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Reservoir storage information is essential for accurate flood monitoring and prediction. South Asia, however, is dominated by international river basins where communications among neighboring countries about reservoir storage and management are extremely limited. A suite of satellite observations were combined to achieve high quality estimation of reservoir storage and storage variations in South Asia from 2000 to 2012. The approach used water surface area estimations from the MODerate resolution Imaging Spectroradiometer (MODIS) vegetation indices product and the area-elevation relationship to estimate reservoir storage. The surface elevation measurements were from the Geoscience Laser Altimeter System (GLAS) on board the Ice, Cloud and land Elevation Satellite (ICESat).

In this study, storage information was retrieved for a total of 21 reservoirs, which represents 28% of the integrated reservoir capacity in South Asia. The satellite-based reservoir elevation and storage were validated by gauge observations over five reservoirs. The storage estimates were highly correlated with observations (i.e., correlation coefficients larger than 0.9), with normalized root mean square error (NRMSE) ranging from 9.51% to 25.20%. Uncertainty analysis was conducted for the remotely sensed storage estimations. The storage mean relative uncertainty associated with the parameterization of uncertainty surface area retrieval was 3.90%. The storage mean relative uncertainty was 0.67% with regard to the uncertainty introduced by ICESat/GLAS elevation measurements.

S01P03

TxSON: Linking Soil Moisture to Water Resources in the Texas Hill Country

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The 2011 drought in Texas resulted in a total water storage deficit of 62 km^3 with soil moisture accounting for potentially 20–100%. This uncertainty, stemming from model output, is difficult to overcome without observational data; yet, soil moisture networks are currently sparse across Texas. Although we can observe stream flow, reservoir capacity, and groundwater levels, soil moisture storage is more subtle. As drought continues in Texas, water managers are becoming aware of the soil moisture deficit and its linkage to reservoir and groundwater levels. To assist managers and to advance the science of monitoring soil moisture, we have two primary goals: (1) to serve as a calibration and validation point at 3, 9, and 36 km to support NASA's Soil Moisture Active Passive (SMAP) satellite that launches later in 2014 and (2) to operationalize soil moisture into water forecasting models used by water authorities at state and county levels. For this presentation, we will focus on the implementation of our forthcoming Texas Soil Moisture Observation Network (TxSON): an intensively monitored 36 km cell (1300 km^2) located near Fredericksburg, Texas, along the Pedernales River and within the middle reaches of the Lower Colorado River Authority. TxSON consists of over 40 soil moisture monitoring stations with sensors installed at 5, 10, 20 and 50 cm depth. The network will support SMAP's Calibration and Validation Program by operating within the Equal-Area Scalable Earth (Version 2) Grid. Using a nested design, TxSON will replicate soil moisture at 3, 9 and 36 km cell footprints corresponding to SMAP retrievals. The grid location was determined through temporal stability analysis of soil moisture time series data from the North American Land Data Assimilation System model across each Hydrologic Unit Code (HUC8) within the Middle Colorado drainage basin. Subgrid locations at 3- and 9-km were based primarily on land accessibility and secondarily on geomorphic settings including soil thickness, bedrock geology, and terrain. The end goal is to establish areally-averaged soil moisture estimates at each spatial scale through additional field measurement campaigns. Although the primary motivation for this study is to provide on-ground calibration for the SMAP program, our project goal is to assure that the data is valued by Texas water resource managers, by linking soil water to surface water and groundwater resources.

Session 2. Extreme events: Modeling

Description

Qualitative and quantitative analysis of extreme events can be conducted through land surface/hydrological modeling. To achieve this goal, key parameters and physical processes need to be identified and uncertainty needs to be documented. A physically-based and validated model is important for improving predictive skill of extreme events. Modeling capabilities to deal with responses to climatic and social-economic impacts need to be assessed.

Keynote presentations

S02K01

Towards Multisensor Snow Assimilation: A Simultaneous Radiometric and Gravimetric Framework

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Snow is a critical resource and serves as the dominant freshwater supply for 1+ billion people worldwide. Recent events in California, for example, highlight the importance of snow and its impact on extreme drought. Accurate measurements of snow are vital for predicting (and mitigating) the effects of extreme drought. However, global estimates of snow mass (a.k.a. snow water equivalent [SWE]) contain significant uncertainty and are often unavailable in regions of the globe where SWE is greatest. Further, satellite-based remote sensing products of SWE are severely limited when the snow pack contains liquid water, internal ice layers, surface ice crusts, or is overlain by forest canopy. Recent advances in data assimilation offer the potential to improve our estimates of global SWE. In particular, the merger of passive microwave remote sensing (e.g., AMSR-E) with satellite-based gravimetric retrievals (e.g., GRACE) offers unique opportunities to bridge remote sensing scales in space and time, "see" deeper into the snow pack, and add vertical resolution to the gravimetric retrievals that currently does not exist. A discussion of current and emerging data assimilation techniques as applied to snow is presented with an emphasis on regional- and continental-scale SWE estimation.

S02K02

National Flood Interoperability Experiment

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The National Weather Service (NWS) has opened a new National Water Center on the Tuscaloosa campus of the University of Alabama. The NWS intends that this center be operated in conjunction with its partners in IWRSS (Integrated Water Resources Science and Services), which are the US Geological Survey and the US Army Corps of Engineers, with the Federal Emergency Management Agency (FEMA) in the process of joining the partnership. The NWS also intends to gradually synthesize the activity of its thirteen regional river forecast centers to provide a national river forecasting function through the National Water Center. As this new center begins its functions, it provides an opportunity to propose and compare new approaches for high spatial resolution, near-real-time flood simulation and forecasting that can be applied on a national scale. A National Flood Interoperability Experiment (NFIE) has been proposed that will be led by the academic community coordinated by the Consortium of Universities for the Advancement of Hydrologic Science, Inc (CUAHSI), and will be supported by the National Weather Service. The NFIE will operate from September 2014 through August 2015 in two phases: a mobilization phase from September 2014 to May 2015 in which components of the proposed system will be made operational at the National Water Center, followed by a Summer Institute from June to August 2015, when students and faculty from the University of Alabama and from CUAHSI institutions elsewhere, will work together at the National Water Center to test and assemble a new shared set of national services for flood data, modeling, forecasting and inundation mapping.

ORAL PRESENTATIONS

S02O01

Numerical Simulation of Urban Ponding and Its Application in Beijing

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Based on the complex terrain and large city characteristics, the geographic information of Beijing was cut into 6458 grids and corresponding channels. Focused on the urban hydrodynamic and hydrographic process, the Beijing Urban Waterlogging (BUW) numerical model was built to simulate the ponding depth. Driven by high-resolution precipitation observation, BUW could simulate the spatial distribution of the record-breaking urban ponding on 21 July 2012 in Beijing well, and the variation and max depth under concave bridges were close to actual condition too.

In the scene of 2-yr Return Period (2-RP), there would be some isolated ponding points inside the 4th-Ring. The depth and range of ponding aggravated in 10-RP and 50-RP. Under 100-RP, there would be server ponding within the whole 5th-Ring, most exceeding 50 cm in the south. With the rainfall at the 21 July 2012 level, urban drainage would not be improved obviously with 20% broadening of pipe diameter (20%+PD). The ponding weakened distinctly between the 4th-Ring and the 5th-Ring and slightly inside the 4th-Ring in the 60%+PD experiment. When the pipe diameter were broadened continuously, there would be only shallow ponding between the 2nd-Ring and the 4th-Ring in the 100%+PD experiment and no ponding inside the 6th-Ring in the 140%+PD experiment.

In actual service, three rainfall sequences are connected to drive the BUW model. The first 5-hr rainfall observation is used for spining-up and initializing ponding depth and pipe flow. The second 6-hr blending QPF and last 6-hr BJ-RUC rainfall forecast is used for simulating and forecasting the next 12-hr urban waterlogging risk. Furthermore, a decision-making service system based on GIS was built to improve service effect. The ponding observation data and urban waterlogging risk warning update timely in this platform.

Key Words: rainstorm, urban waterlogging, ponding depth, return period, drainage

S02O02

Hydrological Projections over the 3H Region of China Using Climate Change Scenarios

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A hydrological evaluation and projection over the Huang-Huai-Hai Plain (3H) region of China was carried out using the VIC model under different climate scenarios, which aims at providing the scientific background for the adaptation to climate change in water resource management and rural development. To consider the uncertainty of climate change projections, 12 climate scenarios were designed with respect to the baseline of historic climate change and possible variation magnitude in the future. The results will present the generally large-scale hydrological variation under climate change. For example, the results from the six representative types of climate scenarios (+2 ℃ and +5 ℃ warming, and 0%, 15%, –15% change for precipitation) show that the temperature rise enhances evapotranspiration, and its general increasing pattern over the 3H region is high in the south and low in the north when precipitation has no change and a 15% increase. The simulation will also give some key regions of hydrological variation sensitive to climate change, which can be used as the scientific baseline in implementing adaptation by local provinces of 3H. The temperature rise can lead to the south-to-north decreasing gradient of surface runoff across the 3H region. For scenarios of 3-type percentage change of precipitation, the large variation of runoff exits in the south end of the 3H region, which reflects that this zone is sensitive to climate change in surface runoff change. As for the soil moisture variation, Jiangsu province in the southeastern part of the 3H region, shows an obvious sensitivity to climate change. At the regional mean scale, the hydrological change amplitude induced by the larger precipitation variation of 30% in contrast with 15% is more obvious than that induced by greater warming of +5 ℃ relative to +2 ℃.

Key words: hydrological projection, climate change scenario, 3H, VIC

S02O03

Assimilation of MODIS Snow Cover and GRACE Terrestrial Water Storage Data through DART/CLM4

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The Gravity Recovery and Climate Experiment (GRACE) terrestrial water storage (TWS) anomaly data are assimilated into the Community Land Model version 4 (CLM4) via the Data Assimilation Research Testbed (DART) to improve the snowpack estimate. The MODerate resolution Imaging Spectroradiometer (MODIS) snow cover fraction (SCF) data are assimilated jointly. The spatial map of the error of the GRACE data provided along with the data is used in this work.

A freely available ensemble of reanalysis data created by DART and the Community Atmospheric Model (CAM4.0) is used as the meteorological forcing for each CLM ensemble member. This induces spread in the CLM ensemble during a spin-up phase and helps maintain spread during the assimilation.

This study compares the open loop run and the assimilation runs. When only the MODIS SCF is assimilated, the root-mean-square-error (RMSE) of SCF is largely reduced in most regions when MODIS data are assimilated. However, the innovation (i.e. the difference between analysis and forecast) is marginal in the regions where snow cover reaches unity regardless of snow mass changes. Further assimilation of GRACE TWS anomalies, however, can adjust the modeled snowpack, resulting in noteworthy improvements over the MODIS-only run in the high-latitude regions. The effectiveness of the assimilation is analyzed over various land cover types. Data assimilation results are evaluated against the Canadian Meteorological Center (CMC) snow depth data on daily timescales in the regions with dense observation sites.

There still are some areas where a more accurate SCF estimate is not guaranteed even though we insert a SWE estimate that incorporates MODIS SCF information. We infer that this could be related to the SCF parameterization in CLM4. This study also compares two SCF parameterizations and their effectiveness on data assimilation results. CLM4 parameterizes SCF as a function of snow depth and density, which is based on an analysis between monthly observed SCF and snow depth. The newest version of CLM (CLM4.5) incorporates a stochastic SCF parameterization, which is demonstrated to produce more realistic SCF estimates. This study replaces the snow density-based SCF parameterization scheme in CLM4 with the stochastic SCF parameterization scheme to test if the new SCF parameterization scheme can improve the effectiveness of SCF data assimilation.

S02O04

Implementing a Vector-based River Routing Scheme within the WRF-Hydro Modeling System

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Vector-based (as opposed to grid-based) river routing scheme has several advantages that would potentially benefit hyper-resolution modeling: 1) better representations of hydrologic features (e.g. river network, water bodies, dams, etc.) 2) data structures/format that are more easily manageable by end-users and water managers and 3) increased computational efficiency. In this study, we implemented a vector-based river routing scheme named RAPID (Routing Application for Parallel ComputatIon of Discharge) as an alternative in the WRF-Hydro system. WRF-Hydro is a model coupling framework between the Weather Research and Forecasting (WRF) model and components of terrestrial hydrological models, which is a recommended tool for hydroclimate research.

In this study, the vector-based RAPID model is coupled to the land components in the WRF-Hydro system. To test the code and the new model capability, several test cases have been conducted over the Texas Hydrologic Region 12, where the vector-based NHDPlus has 60k+ river links instead of 1 million+ nodes. Through the test cases, we see much higher computational efficiency as compared with the original grid-based routing scheme. The newly coupled WRF-Hydro/RAPID framework is expected to advance flash flood forecasts resulted from extreme weather events. Besides, the coupling enriches the host of hydrological models and their coupling with 1) the WRF model 2) different forcing data and 3) different resolution land models within the WRF-Hydro architecture, potentially supporting a variety of hydrometeorological applications and new data assimilation capabilities.

POSTER PRESENTATIONS

S02P01

Development of a Satellite-based Coupled Land and Cloud Data Assimilation System with WRF and its Application to Heavy Rain Precipitation

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For flood prediction and optimized dam control, it is crucial to predict whether a rain area will be over the river basin or not after few hours, and this needs very fine prediction of time and space distribution of rain. For system development focusing on the `location` of precipitation, it is effective to introduce the information of cloud distribution from the observations into the model as initial conditions. Clouds can be observed by microwave remote sensing by satellite. But it is difficult to directly observe cloud over land from the satellite because emissivity of clouds is so week compared to that of land surface. In order to observe cloud over the land, the heterogeneous and strong emission from land surface has to be removed as background information in coupled system of atmosphere and land.

We developed a satellite-based coupled land and cloud data assimilation system with the Weather Research and Forecasting Model (WRF) and applied it to a heavy rain event in the Kanto area of Japan. The assimilation algorithms are Ensemble Kalman Filter (EnKF) and 1DVAR for land and cloud, respectively. Soil moisture and vertically integrated cloud water content are assimilated with different frequency of microwave.

The experimental results show that the system effectively assimilated information of clouds, reproduced precipitation in the correct location, and generated consistent atmospheric field around the cloud area. Furthermore, precipitation amount and duration were represented well.

S02P02

Integrated Hydrological Model Development for Comparative Socio-Economic Analysis

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The field of hydrological science is a relatively young discipline, with only 70 to 80 years of strong development. Since the 1970s, a wide variety of hydrological models have been created; initially for lumped processing of catchments with empirical equations, and later for spatially distributed processing based on physically-based principles. In tandem with this development required capabilities and domain applicability of new models have been increasing. Most recently development has been extending beyond the realm of models covering individual disciplines to systems of models capable of simulating cross-disciplinary phenomena. The target of these systems is the ability to predict social effects of climatological phenomena and to address socio-economic needs of society.

This study outlines a method of model coupling and support aimed at maximizing model productivity and streamlining the implementation of biophysical processes in the coupled model. Processes relating to climate, land-surface, hydrological and riverflow, two-dimensional inundation, and socio-economic hazard evaluation are addressed, considering feedback between models wherever feasible. The individual hydrological models have been modified to ensure that new physical schemes and phenomena can be incorporated seamlessly. Based on this structure a case study on inundation within the Indus river basin was conducted. Results show that for the years under simulation the flood inundation regions broadly matched the observed data. Moving forward, inundation coverage and depth as well as riverflow information will be used to identify socioeconomic shocks to drive a general equilibrium economic model for the comparison of socioeconomic damage due to various mitigation strategies.

S02P03

High-Resolution Modeling of Hydraulic Response of Urban Catchments to Extreme Precipitation Events

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Accurate and timely predictive mapping of inundation extent and related hazards is one of the most important needs in highly populated urban areas such as the Dallas-Fort Worth Metroplex (DFW). Due to scale-dependent interactions among the hydrologic, hydraulic and hydrometeorological controls, the integrated response of urban catchments to extreme precipitation is complex. In addition, accurate high-resolution physiographic information necessary for such modeling is often not readily available in practice. With urbanization and climate change, there is an increasing need to improve understanding of the above response for improved prediction of water-related hazards in urban areas. In this work, we investigate the effects of hydrometeorological, hydrologic and hydraulic controls on inundation mapping in two contrasting study areas in the City of Fort Worth, i.e., the Edgecliff Branch of the Sycamore Creek and the Forest Park-Berry Catchment. The former has an area of 2,890 acres (11.7 km^2) with a well-developed open channel network. The latter has an area of 810 acres (3.3 km^2) with a well-developed underground storm drainage system. For the above, we use PCSWMM which runs the Strom Water Management Model (SWMM) engine and has the additional capability to model 2D surface water flow. We present the initial results from a series of controlled simulation experiments and real-word case studies.

S02P04

Assimilating MODIS Snow Cover Products into Land Surface Model: A Case Study in Northern Xinjiang, China

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Accurate prediction of the spatiotemporal distribution and variation of snow is important for snowmelt runoff simulation and water resources management especially in mountainous areas. In this work, we develop a snow data assimilation scheme based on the ensemble Kalman filter (EnKF) algorithm and the Common Land Model (CoLM). The constructed best-fitting snow depletion curve is used as observation operator to assimilate MODIS snow cover fraction (SCF) to update CoLM snow depth and snow cover area. To validate the proposed scheme, several assimilation experiments are conducted by available data during 2004–2007 in northern Xinjiang, China. The preliminary assimilation results are very promising and show that the assimilation of

SCF could significantly improve prediction of snow cover area and snow depth and rectify underestimation of snow depth. The assimilation results are much closer to those of observations, which have more reliable accumulation and melting trends during the whole snow season. After assimilating MODIS SCF observations, the Root Mean Square Error (RMSE) and Mean Bias error (MBE) of snow cover and snow depth are significantly reduced compared to the simulated results. The Normalized Error Reduction index (NER) is achieved to 0.58 and 0.29 on average for snow cover and snow depth respectively, which prove that the scheme can effectively improve the estimation accuracy of the snow cover area and snow depth.

S02P05

A Flexible and Extensible Land Data Assimilation System Using NCAR's Community Land Model (CLM) and Data Assimilation Research Testbed

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Land plays an important role in shaping regional and global climate and the water cycle. However, many of these processes are not well understood, which is largely due to the lack of high quality datasets. Recently, multi-institution efforts involving UT-Austin, NCAR and NASA have been focused on developing a global-scale multi-sensor snow data assimilation system based on NCAR's Data Assimilation Research Testbed (DART) coupled to the Community Land Model version 4 (CLM4); CLM4 can be replaced by CLM4.5 or the latest versions as they become available. This data assimilation system can be applied to all land areas to take advantage of high-resolution regional-specific observations. The DART data assimilation system has an unprecedented large ensemble (80-member) atmospheric forcing (temperature, precipitation, winds, humidity, radiation) with a quality of typical reanalysis products, which not only facilitates ensemble land data assimilation, but also allows a comprehensive study of many feedback processes (e.g. the snow albedo feedback and soil moisture–precipitation feedback). DART has long been linked with ocean and atmospheric models as well as the WRF model, but the CLM4 and DART have just been linked and initial results have been reported in the past AGU and AMS meetings and in Zhang et al. (2014). Besides our prototype snow data assimilation, the coupled CLM4/DART framework is useful for data assimilation involving other variables, such as soil moisture, skin temperature, and leaf area index from various satellite sources and ground observations. Such a truly multi-mission, multi-platform, multi-sensor, and multi-scale data assimilation system with DART will, ultimately, help constrain earth system models using all kinds of observations to improve their prediction skills from intraseasonal to interannual. For an offline application, however, we are interested in using this framework to produce mutually consistent state and flux variables for energy, carbon, and water balances as well as to use these products to study extreme events such as drought and flooding.

Zhang, Y.-F., T. J. Hoar, Z.-L. Yang, J. L. Anderson, A. M. Toure, and M. Rodell, 2014: Assimilation of MODIS snow cover through the Data Assimilation Research Testbed and the

Community Land Model version 4, *J. Geophys. Res. Atmos.*, **119**, 7091–7103, doi:10.1002/2013JD021329.

SESSION 3. EXTREME EVENTS: PREDICTABILITY

DESCRIPTION

Predictability of extreme events is generally scale-dependent and limited. For effective improvement in predictive skill, it is necessary to characterize and ascertain the hydrological, meteorological and climatological controls that occur over a wide range of scales in flash floods to droughts. Given the generally large uncertainty in predicting extreme events, it is necessary to capture and convey the predictive uncertainty via both physically-based and statistical modeling. This sub-theme presents predictability studies including those from ensemble streamflow forecasting.

KEYNOTE PRESENTATIONS

S03K01

Earth Surface Modelling Advances at ECMWF and Their Connection with Extreme Events Prediction

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Improving the realism of soil, snow, vegetation and lakes parameterisations has been subject of several recent research efforts at ECMWF. These Earth surface components work effectively as energy and water storage terms with memory considerably longer than the atmosphere counterpart.

Their role regulating land-atmosphere fluxes is particularly relevant in presence of large weather and climate anomalies and it has been assessed in dedicated land reanalyses. Improved predictions associated with land representation in the Integrated Forecasting System (IFS) is detected with the aid of research and operational observing networks. Results will be presented and discussed together with the missing slow processes and future plans.

S03K02

Land Data Assimilation Systems at NCEP: Predicting Extreme Hydrometeorological Events

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The NCEP North American Land Data Assimilation System (NLDAS) provides support for drought interests and water resources applications over the continental U.S., while the Global Land Data Assimilation System (GLDAS) provides initial land states in a semi-coupled mode to the NCEP Climate Forecast System (CFS) for global seasonal climate prediction. Both systems run uncoupled land models and depend on reliable land-surface model physics and appropriate land data sets for accurate hydrometeorological simulation of surface energy and water budgets, and are forced by atmospheric analyses (or reanalyses) but rely heavily on observed precipitation. We use NLDAS and GLDAS output to examine drought and flooding events, and associated seasonal hydrometeorological predictions from CFS.

S03O01

Discharge Modelling Experiments with the TIGGE Archive

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A multi-disciplinary show case was setup to produce river discharge forecasts for TIGGE (THORPEX Interactive Grand Global Ensemble) ensemble models in the framework of the European Commission funded project GEOWOW (GEOSS Interoperability for Weather, Ocean and Water). The modelling work was based on the HTESSEL land-surface model used operationally at ECMWF. The offline version of HTESSEL was extended to accommodate ensemble forecast runs from TIGGE with climate and initial conditions taken from ECMWF. The model output runoff was then coupled to the CaMa-Flood river routing scheme to provide river discharge for hundreds of global catchments.

In this study discharge forecasts were generated with four of the TIGGE models (ECMWF, UKMO, NCEP and CMA) for the period of 2007-2013. The performance of these models and the extra added value of the multi-model combination were highlighted by comparing with a global GRDC (Global Runoff Data Centre) based discharge observation data set. The work had special focus on extremes occurring during this 7-year period, and the behavior of the models in terms of these extremes were analyzed. In addition to this the sensitivity to the atmospheric forcing setups in HTESSEL (as TIGGE required modifications in the use of the atmospheric forcing) were investigated and some interesting behavior was highlighted in the impact of wind, radiation, temperature, humidity and precipitation on the global discharge forecasts.

S03O02

Application of Multi-Frequency Passive Microwave Observations and Data Assimilation Strategies for Improving Numerical Weather Forecasting in the Developing Regions

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A greater number of reliable observations of atmosphere and land surface would greatly improve the performances of Numerical Weather Prediction (NWP) models. However, obtaining ground-based observations in developing regions is very challenging. As a result, the development of satellite based forecast systems is one of the few affordable solutions to improve weather forecasting in these regions.

To incorporate near-real time soil moisture information within a mesoscale model simulations, we developed an on-line land data assimilation system coupled with a mesoscale model, which directly assimilates satellite passive microwave low-frequency radiance. The results showed improvements in land surface variables and land-atmosphere interactions when the surface forcing (i.e. downward radiation and rainfall) were simulated accurately. Due to limited satellite data (e.g. AMSR-E/AMSR-2) the improved land surface conditions often suffer from significant errors and drift from the biases in the predicted forcing.

Clouds directly influence the forcing and affect the estimation of surface water and energy budgets. Passive microwave images (e.g., AMSR-E/AMSR-2 and Global Precipitation Measurement) also contain information on cloud fields at higher frequencies (e.g., 89 GHz), which is more sensitive to cloud fields, but it also contains information of land surface emission. To retrieve cloud fields from the strong heterogeneous land emissions, we developed Coupled Atmosphere and Land Data Assimilation System [CALDAS], which introduces existing land as well as atmospheric moisture heterogeneities from multi-frequency AMSR-E data into a mesoscale model.

The results simulated in Tibet and Niger showed that CALDAS improved the cloud distributions and surface forcing (i.e., solar radiation and rainfall) significantly. Improvements in both forcing and surface conditions enhanced land-atmosphere interactions in model simulations. In addition, rainfall forecast also showed high-correlation with satellite retrievals. Further development of the system to integrate more data from other satellites and future missions will be discussed at the conference.

POSTER PRESENTATIONS

S03P01

Modeling of Radiative Effects of Middle East Dust on Indian Summer Monsoon System

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The Indian summer monsoon (ISM) is the world's strongest monsoon system and brings about eighty percent of total annual rainfall in South Asia. The variability of ISM can cause great loss to more than sixty percent of the world's population. Therefore, it is very important scientifically and practically to understand the mechanism responsible for the variability of ISM on different time scales. Using the Weather Research and Forecast model coupled with chemistry (WRF-Chem), we will study the radiative effects of dust aerosols in the Middle East on ISM rainfall. Satellite aerosol optical depth (AOD) data sets shows strong boreal summer dust storms in the Middle East and the Arabian Sea. These dust aerosols could cool down the SST over the Arabian Sea, reducing the evaporation. On the other hand, dust aerosols are absorbing and can heat up the atmosphere, which could change ISM circulation, especially the Somalia low-level jet that brings most of water vapor for ISM. In WRF-Chem experiments, we will first study the dust loadings using two different dust emission schemes and compare them with satellite observed AOD, followed by analysis of radiative forcing induced by dust aerosols. Finally, the impact of dust loadings on monsoon circulation and rainfall will be addressed. Our study highlights the interaction between local rainfall in India and remote dust emission in the Middle East.

SESSION 4. UTILIZATION OF MULTI-SOURCE OBSERVATIONS

DESCRIPTION

Various ground-based and space-borne sensors provide an extraordinary opportunity to monitor the Earth, and are promising to track and predict extreme events. Harmonizing data series across different missions and relevant data fusion experiments is critical. This sub-theme presents progress in dealing with problems on scaling (upscaling of point ground measurement, downscaling of low resolution microwave retrieval), integration (e.g., MODIS, GRACE and AMSR-E), and error estimates, especially within the framework of multi-source land data assimilation.

KEYNOTE PRESENTATIONS

S04K01

Towards Multivariate Land Data Assimilation in the NASA GEOS-5 System

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Much of the progress in land data assimilation over the past decade has been made using so-called uni-variate systems. In such a system, only one particular type of observation is assimilated. For example, retrievals of surface soil moisture from space-borne passive microwave observations can be assimilated to obtain improved estimates of the soil moisture profile. Slightly more complex assimilation systems may include more than one type observation but are still focused on estimating one particular geophysical variable. For example, soil moisture retrievals from active and passive microwave observations can be used in a soil moisture assimilation system, or snow cover and snow water equivalent retrievals can be used in a snow assimilation system. While the benefit of assimilating more than one type of observation is already apparent in such systems, they can still be considered uni-variate systems because the analysis targets only one kind of geophysical variable. By contrast, multi-variate systems use several types of observations to analyze different kinds of geophysical variables. Progress towards such a multi-variate system is illustrated using examples from the NASA GEOS-5 land data assimilation system. The first example discusses the assimilation of satellite microwave brightness temperatures (Tbs) along with observations of large-scale terrestrial water storage (TWS) to estimate the TWS components at the scale of the model grid. The challenge is to configure the system such that the estimated uncertainties are realistic at the multiple spatial and temporal scales needed for a successful analysis. The second example addresses the assimilation of Tbs and freeze-thaw observations in the soil moisture and temperature analysis of the NASA SMAP L4_SM product, which involves the use of coarse-resolution radiometer Tbs and retrievals based on high-resolution radar backscatter.

S04K02

Towards a Hyper-Resolution Integrated Water Observation and Prediction System

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Society's welfare, progress, and sustainable economic growth—and life itself—depend on the abundance and vigorous cycling and replenishing of water throughout the global environment. The water cycle operates on a continuum of time and space scales and exchanges large amounts of energy as water undergoes phase changes and is moved from one part of the Earth system to another. We must move toward an integrated observation and prediction paradigm that addresses broad local-to-global science and application issues by realizing synergies associated with multiple, coordinated observations and prediction systems. A central challenge of a future water and energy cycle observation strategy is to progress from single variable water-cycle instruments to multivariable integrated instruments in electromagnetic-band families. The microwave range in the electromagnetic spectrum is ideally suited for sensing the state and abundance of water because of water's dielectric properties. Eventually, a dedicated high-resolution water-cycle microwave-based satellite mission may be possible based on large-aperture antenna technology that can harvest the synergy that would be afforded by simultaneous multichannel active and passive microwave measurements. A partial demonstration of these ideas can even be realized with existing microwave satellite observations to support advanced multivariate retrieval methods that can exploit the totality of the microwave spectral information. The simultaneous multichannel active and passive microwave retrieval would allow improved-accuracy retrievals that are not possible with isolated measurements. Furthermore, the simultaneous monitoring of several of the land, atmospheric, oceanic, and cryospheric states brings synergies that will substantially enhance understanding of the global water and energy cycle as a system. The multichannel approach also affords advantages to some constituent retrievals—for instance, simultaneous retrieval of vegetation biomass would improve soil-moisture retrieval by avoiding the need for auxiliary vegetation information. This multivariable water-cycle observation system must be integrated with high-resolution, application relevant prediction systems to optimize their information content and utility is addressing critical water cycle issues. One such vision is a real-time ultra-high resolution locally-moasiced global land modeling and assimilation system, that overlays regional high-fidelity information over a baseline global land prediction system. Such a system would provide the best possible local information for use in applications, while integrating and sharing information globally for diagnosing larger water cycle variability. In a sense, this would constitute a hydrologic telecommunication system, where the best local in-situ gage, Doppler radar, and weather station can be shared internationally, and integrated in a consistent manner with global observation platforms like the multivariable water cycle mission. To realize such a vision, large issues must be addressed, such as international data sharing policy, model-observation integration approaches that maintain local extremes while achieving global consistency, and methods for establishing error estimates and uncertainty.

ORAL PRESENTATIONS

S04O01

Development of an Algorithm for Soil Moisture with High Spatial- and Temporal-Resolution

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Soil moisture has a high spatial and temporal variability. This study present a new downscaling approach which combines Advanced Microwave Scanning Radiometer for EOS (AMSR-E) and Phased Array type L-band Synthetic Aperture Radar (PALSAR) data by using a land data assimilation system (LDAS) to achieve a high spatial and temporal resolution data set of soil moisture. We focus on the effects of soil characteristics and vegetation type, by using a high spatial resolution soil moisture derived from PALSAR and a high spatial resolution Leaf Area Index (LAI) derived from MODerate resolution Imaging Spectroradiometer (MODIS) as initial conditions and by calibrating a model parameter. Furthermore, a high spatial resolution rainfall data from Global Satellite Mapping of Precipitation (GSMaP) is introduced to consider the effect of rainfall pattern qualitatively.

The system developed in this study has a parameter optimization step and a data assimilation step. We use a high spatial resolution soil moisture and LAI as initial conditions, and then we optimize parameters or assimilate soil moisture by using a high temporal resolution brightness temperature. The target spatial resolution is 0.01° (approximately 1 km) by downscaling from the AMSR-E 0.25° (approximately 25 km) resampled data resolution. The downscaling approach is applied to the semiarid CEOP/Mongolia reference site.
The spatial distribution of soil moisture within the AMSR-E foot print could be outlined by this system. The author believes this method will contribute to monitoring of spatial and temporal behaviors of soil moisture.

S04O02

Using Multivariate Data Assimilation to Improve Streamflow Predictions for a Mountainous Watershed

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Water resource management for reservoirs located in snow dominated regions relies heavily on an accurate portrayal of the snow water equivalent (SWE) spatial and temporal distribution in order to make accurate streamflow predictions. Traditionally, SWE samples have been used to provide precise information at a specific location without necessarily being representative of the surrounding area. More recently, remote sensing data has been used to provide snow cover information over a wide area, although it is generally limited by environmental factors such as topography, vegetation and cloud cover. Water resource managers with access to both types of data, such as Rio Tinto Alcan which operates the Nechako reservoir in British-Columbia, Canada, could benefit from a potential synergy resulting from these different sources of data and hydrological modeling. The study aims to provide a methodology to assimilate different data sets over the Nechako watershed using an Ensemble Kalman filter into a distributed hydrological model and evaluate the value of each data set for hydrological forecasting purposes. More specifically, the data to be used includes the water level of the reservoir, SWE measurements from three snow pillows and the MODIS Terra and Aqua daily snow cover L3 products. The methodology will be used to find out 1) which configuration is adequate regarding the state vector (which variable and/or parameter to update), 2) how to properly specify model and observation variance and 3) evaluate which data set, used either individually or collectively, is most useful for short-term (days) and mid-term (weeks) hydrological forecasting.

Keywords: Data assimilation, ensemble Kalman filter, rainfall-runoff model, ensemble forecast, snow

POSTER PRESENTATIONS

S04P01

Separated Snow-Glacier Inventory and its Significance in the Hydrological Modeling of Hindukush Karakoram Himalayas; Upper Indus Basin

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Hindukush Karakoram Himalayan (HKH) mountains consist large glaciers of the world, and supplies melt-water from perennial snow and glaciers, in the Upper Indus Basin (UIB); upstream of Tarbela dam, constitutes > 50% annual flow, and cater far needs of millions of people in the Indus Basin. It is therefore important to study responses of perennial snow and glaciers in the UIB under changing climatic conditions, using precise hydrological modeling, glacier mass balance, and glaciers climate impact responses. However, available snow/glacier datasets/inventories only provide total perennial-snow and glacier cover areas, besides the fact that snow, ice and debris covered ice have different melt rates and densities. This study, therefore, presents separated perennial snow-glacier inventory (perennial snow-cover (at > 25˚ slopes), perennial snow-covered ice, bare ice and debris covered ice) based on semi-automated method that combines datasets of Landsat images and surface slope information in a supervised maximum likelihood classification to map distinct snow-glacier zones, followed by manual post processing. Current study's outputs can be used; to produce precise hydrological models, to estimate degree day factors for hydrological modeling, to separate glacier and snow-melt contributions in river flows, to study glacier mass balance, to study glacier responses in changing climate, to study snow-cover dynamics and to correct MODIS under-estimated small and debris-covered glaciers area in UIB. Methodologies explained in current study are robust and can be adopted and utilized in other regions of the world.

S04P02

An Integrated Multi-sources Data Assimilation System for Heihe River Basin at Catchment Scale – HDAS

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A High resolution land Data Assimilation System (HDAS) was developed for Heihe River Basin and the multi-sources measurements can be assimilated into the Community Land Model using HDAS. This paper first presents the software design and the scientific framework behind HDAS. Different approaches from the data assimilation community were selected and integrated in HDAS

for the better assimilation performance. There are eight key components in HDAS: assimilation methodologies; model parameters and forcing data perturbation; model sensitivity analysis; model operator; observation operator; parallel computing; input/output data management and visualization. Then the multi-sources assimilation of ASCAT soil wetness index products, MODIS Terra/Aqua land surface temperature products and MODIS Terra snow cover fraction products were evaluated using the spatial similarity metrics of Hausdorff distance in HDAS. The assimilation results show the capability of HDAS to reduce the land surface model bias. Taking the limited spatial and temporal coverage of multi-sources measurements, and the representative of measurements to the reality into account, HDAS is able to integrate the multi-sources measurements into the spatio-temporal simulations of land surface model CLM to obtain better characterization of the land surface variables that are related to the catchment scale water and energy cycles.

S04P03

Improving Accuracy of High-Resolution Radar Quantitative Precipitation Estimates (QPE) Via Fusion of Multiple Radar-Based QPEs

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Accurate high-resolution radar-based QPEs are highly desirable for a wide spectrum of applications. With increasingly widespread use of weather radars, multiple radar-based QPEs are now routinely available in many places. In the Dallas-Fort Worth Metroplex (DFW), for example, the Multisensor Precipitation Estimator (MPE), Q2 (Next Generation QPE) and CASA (Collaborative Adaptive Sensing of Atmosphere) QPEs are available. Because these products are based on different radar systems, different sources of additional information, and/or processing algorithms, they have different error characteristics and spatiotemporal (nominal) resolutions. In this work, we explore improving the accuracy of the highest-resolution radar QPE by fusing it with lower-resolution QPE(s). Two approaches are examined. The first is to pose fusion as a Fisher linear optimal estimation problem in which the state vector is the true unknown precipitation at the highest resolution and the observation vector is made of all radar QPEs at their native resolutions. The second is to upscale the higher resolution QPE(s) to the lowest resolution, merge them via optimal linear estimation, and disaggregate the merged estimate based on the spatiotemporal patterns of precipitation in the high resolution QPE. In both approaches, we compare Fisher estimation with conditional bias-penalized Fisher-like estimation which improves estimation of heavy-to-extreme precipitation. For evaluation, we compare the high-resolution precipitation estimates from the two approaches with rain gauge observations in the DFW area.

S04P04

The Scale-dependence of SMOS Soil Moisture Accuracy and Its Improvement through Land Data Assimilation in the Central Tibetan Plateau

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This study evaluates SMOS (soil moisture and ocean salinity) soil moisture products against a newly established soil moisture network in the central Tibetan Plateau. Based on the results, the

validity of assimilating the SMOS soil moisture retrievals into a land surface model is further evaluated. The ground truth is obtained by spatial upscaling from the network measurements within an area of approximately 10,000 km^2. Results show that both SMOS L2 and the preliminary version of L3 soil moisture products have large biases at the SMOS node scales (15 and 25 km), but they can reflect the surface wetness conditions well when averaged at a 100-kmscale during the unfrozen season (June to October). This finding indicates the applicability of SMOS retrievals is scale-dependent. Meanwhile, very few retrievals are available in winter due to the presence of frozen soil and snow cover, and the accuracy of ascending retrievals degrades during transition when the diurnal freezing–thawing cycle occurs. Considering the SMOS L2 product has a better accuracy than that of L3, we assimilate it into a land surface model using a dual-pass land data assimilation scheme. The data assimilation estimate without in-situ tuning proves superior to either remote sensing or land surface modeling in estimating surface soil moisture for the unfrozen season, and its accuracy fulfills the SMOS measurement requirements (RMSD $\leq 0.04\ m^3\ m^{-3}$). Thus, the assimilation of SMOS retrievals holds promise to produce a regional soil moisture dataset with acceptable accuracy for the Tibetan Plateau semi-arid region.

Zhao, L., K. Yang, J. Qin, Y. Chen, W. Tang, H. Lu, and Z.-L. Yang, 2014: The scale-dependence of SMOS soil moisture accuracy and its improvement through land data assimilation in the central Tibetan Plateau, *Remote Sens. Environ*., **152**, 345–355, doi:10.1016/j.rse.2014.07.005.

S04P05

A Preliminary Study of Improving Global Leaf Area Index Estimation Based on the Data Assimilation Research Testbed and the Community Land Model Version 4

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The leaf area index (LAI) influences the exchanges of momentum, carbon, energy, and water between the terrestrial biosphere and the atmosphere. As such, it is a key variable in regulating the global carbon, energy, and water cycles. In order to improve the LAI estimation, the MODerate resolution Imaging Spectroradiometer (MODIS) LAI was assimilated into the Community Land Model version 4 (CLM4) based on the Data Assimilation Research Testbed (DART). In this paper, 20 forcing members from DART and the Community Atmosphere Model version 4 (DART/CAM4) were chosen randomly to drive 20 CLM members on the global scale during the year of 2002, with the resolution of $1.25° \times 0.9°$. The focus is the improvement on spatial and seasonal variations of assimilated LAI, with particular attention to regions where largest differences between the modeled and assimilation occur.

SESSION 5. DATA ASSIMILATION DEVELOPMENT AND EVALUATION

DESCRIPTION

Errors in data assimilation estimate can originate from various sources. This sub-theme discusses the impacts of uncertainties in model parameters, biases in forcing data, and errors in the assimilated observations. In addition, a series of data assimilation algorithms (EnKF, PF, and 4DVAR, etc.) have been widely investigated, and their efficiency and applicability are presented. This sub-theme also discusses the status and plans for community-based open-source tools for hydrologic and land DA to support such investigations.

KEYNOTE PRESENTATIONS

S05K01

Development of Data Assimilation Techniques for Hydrological Applications

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Hydrologic data assimilation aims to utilize the knowledge of hydrological process as embodied in a hydrologic model and the information gained from observations. Model predictions and observations are both imperfect and contain different kinds of information. Nonetheless, when used together, they provide an accuracy level that cannot be obtained when used separately. This process is extremely valuable for providing initial conditions for hydrological system prediction and/or correcting hydrological system prediction, and improving parameterization of hydrological system.

In this presentation recent developments of data assimilation in hydrology are briefly reviewed and development of two new data assimilation algorithms for two different case studies is introduced.

In the first case, an F/T assimilation algorithm is developed for the NASA Goddard Earth Observing System, version 5 (GEOS-5) modeling and assimilation framework. The algorithm includes a newly developed observation operator that diagnoses the landscape F/T state in the GEOS-5 Catchment land surface model. The F/T analysis is a rule-based approach that adjusts Catchment model state variables in response to binary F/T observations, while also considering forecast and observation errors. To evaluate the accuracy of the model, a regional observing system simulation experiment is conducted using synthetically generated F/T observations. For F/T classification errors below 20%, the assimilation of F/T observations reduced the root-mean-square errors (RMSE) of surface temperature and soil temperature when compared to model estimates. This F/T assimilation scheme is being developed to exploit planned operational F/T products from the NASA Soil Moisture Active Passive (SMAP) mission.

In the second case, a data assimilation approach is developed for estimating key parameters governing moisture and heat diffusion equation and the closure function which links these equations. Parameters of the system are estimated by developing objective functions that link atmospheric forcing, surface states, and unknown parameters. A single objective function is expressed that measures moisture and temperature dependent errors solely in terms of observed forcings and surface states. This objective function is minimized with respect to the parameters to identify evaporation and drainage models and estimate water and energy balance flux components. Uncertainty of parameter estimates is obtained from the inverse of Hessian of the objective function, which is an approximation of the error covariance matrix. Uncertainty analysis and analysis of the covariance approximation, guides the formulation of a well-posed estimation problem. Accuracy of this method is examined through its application over different field sites. The applicability of this approach to diverse climates and land surface conditions with different spatial scales, using remotely sensed measurements is also presented.

S05K02

Particle Markov Chain Monte Carlo Simulation: Theory, Practical Implementation, and Limitations

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In this talk I will summarize recent advances in Particle Markov chain Monte Carlo (PMCMC) simulation for environmental (hydrologic) data assimilation. PMCMC uses a ensemble of particles (trajectories) to approximate the state and output forecast distribution and avoids sampling collapse by periodic MCMC resampling steps. This approach allows for joint parameter and state estimation but care should be exercised how to estimate the model parameters. I will illustrate some preliminary results and discuss the advantages / limitations of the proposed methodology for operational real-time forecasting.

ORAL PRESENTATIONS

S05O01

Microwave Data Assimilation Practice in the Tibetan Plateau and Its Implication for Land Hydrological Modeling

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Soil moisture plays a key role in the land-atmosphere interactions but its estimation is a major challenge in land surface modeling and satellite remote sensing. In this talk, our efforts in this field will be presented.

1. We established a multi-scale soil moisture network on the Tibetan Plateau that may serve to validate regional soil moisture products. The experimental area is characterized by low biomass, large soil moisture dynamic range and typical freeze-thaw cycle. The network consists of 56 stations and measure soil moisture and temperature at three spatial scales (1.0, 0.3, 0.1 degree). All data have been calibrated according to measured soil texture and soil organic matters. A new spatial upscaling method was developed to obtain the regional mean soil moisture truth from the point measurements. The accuracy of current major soil moisture products retrieved from AMSR-E for this region is presented.

2. We developed a dual-pass land data assimilation system. The essential idea of the system is to calibrate a land data assimilation system before a normal data assimilation. The calibration is based on satellite data rather than in situ data. Through this way, we may alleviate the impact of uncertainties in determining the error covariance of both observation operator and model operation,

as it is always tough to determine the covariance. The performance of the data assimilation system will be presented through applications with Mongolian and Tibetan Plateau soil moisture measuring networks.

Chen, Y. Y., K. Yang, J. Qin, L. Zhao, W. J. Tang and M. L. Han, 2013: Evaluation of AMSR-E retrievals and GLDAS simulations against observations of a soil moisture network on the central Tibetan Plateau, *J. Geophys. Res. Atmos*., **118**, doi:10.1002/jgrd.50301.

Qin, J., K. Yang, N. Lu, Y. Chen, L. Zhao, and M. Han, 2013: Spatial upscaling of in-situ soil moisture measurements based on MODIS-derived apparent thermal inertia, *Remote Sens. Environ*., **138**, 1–9, doi:10.1016/j.rse.2013.07.003.

Yang, K., J. Qin, L. Zhao, Y. Chen, W. Tang, M. Han, Lazhu, Z. Chen, N. Lu, B. Ding, H. Wu, and C. Lin, 2013: A Multi-Scale Soil Moisture and Freeze-Thaw Monitoring Network on the Third Pole, *B. Am. Meteorol. Soc*., **94**, 1907–1916, doi:10.1175/BAMS-D-12-00203.1.

Yang, K., T. Watanabe, T. Koike, X. Li, H. Fujii, K. Tamagawa, Y. Ma, and H. Ishikawa, 2007: Auto-calibration system developed to assimilate AMSR-E data into a land surface model for estimating soil moisture and the surface energy budget, *J. Meteor. Soc. Japan*, **85A**, 229–242.

Zhao, L., K. Yang, J. Qin, Y. Y. Chen, W. J. Tang, C. Montzka, H. Wu, C. G. Lin, M. L. Han, and H. Vereecken., 2013: Spatiotemporal analysis of soil moisture observations within a Tibetan mesoscale area and its implication to regional soil moisture measurements, *Journal of Hydrology*, **482**, 92–104 doi:10.1016/j.jhydrol.2012.12.033.

S05O02

Multivariate Assimilation of Satellite-derived Remote Sensing Datasets in the North American Land Data Assimilation System (NLDAS)

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The North American Land Data Assimilation System (NLDAS) has produced over 34 years (Jan 1979 to present) of hourly land-surface meteorology and surface states, including soil moistures and temperatures, snow cover, runoff, and evapotranspiration. NLDAS uses the best-available observations and reanalyses to create near-surface forcing for land-surface models (LSMs) in "off-line" mode, but to-date has not included the assimilation of relevant hydrological remote sensing datasets. Several recent works have independently demonstrated the value of assimilating Advanced Microwave Scanning Radiometer-Earth observing system (AMSR-E) based soil moisture, AMSR-E based estimates of snow depth; MODerate resolution Imaging Spectroradiometer (MODIS)-based estimates of Snow Covered Area (SCA); Gravity Recovery and Climate Experiment (GRACE)-based terrestrial water storage (TWS) and MODIS-based estimates of irrigation intensity. In this presentation, we will demonstrate results of assimilating these datasets in the NLDAS configuration using the NASA Land Information System (LIS) as part of the new phase of the NLDAS project. The results from individually assimilating of AMSR-E based soil moisture and snow depth into the Noah LSM indicate that systematic improvements are obtained not only in soil moisture and snow states, but also on evapotranspiration and streamflow estimates. We will also present results from the combined assimilation of the above-mentioned multi-sensor datasets in NLDAS and an evaluation of the resulting improvements and trends in soil moisture, snowpack, evapotranspiration and streamflow.

S05O03

Investigating Crop Water Productivity by Using Remotely Sensed Approach for Summer Maize at Hebei Plain in North China

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Water is the first and foremost factor constraining crop production in water-short bread baskets at Hebei Plain (HBP) in North China. Quantifying regional crop water productivity (CWP) is relevant to decision makings in water allocation at larger spatial scales. The objectives of the research were thus twofold: 1) quantifying water productivity as measured by economic grain output per unit of evapotranspired water using remotely-sensed approach; 2) validating the remotely-sensed CWP with that obtained by a hydrological model-based approach. Through combining surface energy balance system (SEBS), a terrestrial water vapor algorithm, and radiation use efficiency-based crop yield estimator, a pilot study was conducted to investigate regional CWP of summer maize (growing season from June to September, 2009) at HBP using public-domain MODIS 1-km products, i.e. MOD09GA, MOD11A, and MOD15A2. The results revealed that CWP of summer maize at HBP in 2009 growing season fell into a sensible range, with a mean value of 1.59 kgm^{-3}, which proved quite reasonable upon comparing with a hydrological model-based approach, 1.53 kg m^{-3}. Further researches are required of addressing such issues as data assimilation to trade off spatial and temporal resolutions in remotely-sensed information, e.g. using much finer remote sensing data like ETM+ or SPOT to enhance the spatial resolution of crop evapotranspiration and yield estimation while reducing computation loading for a large research area like HBP (over 70,000 km^2).

POSTER PRESENTATIONS

S05P01

An Improved Characterization of Riverbed Heterogeneities and River-Aquifer Exchange Fluxes with the Normal Score Ensemble Kalman Filter

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Interactions between surface water and groundwater play an essential role for hydrology, hydrogeology, ecology, and water resources management. A proper characterization of riverbed structures is important for estimating river-aquifer exchange fluxes. Ensemble Kalman filter (EnKF) is commonly used in subsurface flow and transport modeling for estimating both states and parameters. However, EnKF performs optimally only for multi-Gaussian distributed parameter fields, but the spatial distribution of streambed hydraulic conductivities often shows non-Gaussian patterns which are related to flow velocity dependent sedimentation and erosion processes. In this study, riverbeds were generated which showed Non-Gaussian distributed hydraulic parameters. These riverbeds were inversely conditioned to state information, using the normal score ensemble Kalman filter (NS-EnKF) which builds a normal-score transformation of states and parameters, updates these normal-score transformed states and parameters and back-transforms. For reasons of comparison, also simulations with riverbeds with multi-Gaussian distributed hydraulic parameters were carried out. Numerical experiments were carried out for a synthetic 3-D river-aquifer model with a river (conceptualized into eight lines of river nodes) in the middle of a homogeneous aquifer to evaluate the performance of NS-EnKF in characterizing riverbed properties. For comparison, it was found that if Non-Multi-Gaussian riverbed properties are present, better simulation results are achieved if also Non-Multi-Gaussian random fields are generated and conditioned. The Multi-Gaussian assumption gives especially worse estimates of the river-aquifer exchange fluxes. In addition, it was concluded that both EnKF and NS-EnKF improve the characterization of riverbed properties, hydraulic heads and exchange fluxes with assimilation of piezometric heads. NS-EnKF outperforms EnKF when only parameters are normal-score transformed but states are not transformed.

S05P02

Development of a Data Assimilation System for the Integrated Land Surface-Subsurface Model PARFLOW-CLM

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The coupling of land surface and subsurface models might improve the overall predictive accuracy of hydrological and atmospheric models. An example of such an integrated modeling approach is the recently established modeling platform TerrSysMP which consists of three sub-models; ParFlow for subsurface processes, CLM for land surface processes and COSMO for the atmosphere. These components are coupled via state variables and fluxes by the coupling software OASIS-MCT. In general, predictions with such highly parameterized coupled models are associated with a considerable degree of uncertainty due to uncertain initial conditions and the poorly known subsurface and vegetation properties. Therefore, there is a need to constrain the model predictions with field observations which can be achieved with different data assimilation algorithms. We constructed a data assimilation system for the land surface-subsurface part of TerrSysMP (CLM and ParFlow) by linking the model with the PDAF (Parallel Data Assimilation Framework) software. This approach is highly efficient for high-performance computing systems because it avoids frequent re-initializations of the model and allows for a memory based communication between model and data assimilation routines. The feasibility of this approach is demonstrated with a synthetic model setup where soil moisture data are assimilated into a medium-scale hydrological model of the Rur catchment (Germany) with ensemble based data assimilation algorithms.

S05P03

Effects of Different Soil Inputs of SWAT on Basin-scale Hydrological Simulations – A Case in Huai River, China

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The well-informed spatial and attribute bio-physical databases are essential inputs for distributed hydrological models when investigating water cycles at basin scale. China lacks such data, i.e. national-scale soil database. The objectives of the research were thus threefold: 1) introducing and adapting FAO global soil databases into SWAT (Soil and Water Assessment Tool) to perform water cycles analysis; 2) developing SWAT-specific China National Soil Database based on the soil profiles data of China National Soil Survey; 3) comparing the effects of the two soil databases on simulating hydrological cycles at basin level. Five scenarios of soil databases were formulated:

1) original FAO soil, FAO1; 2) FAO soil with revised available water content (AWC), FAO2; 3) original China soil, China1; 4) China soil with revised AWC, China2; 5) China soil with revised AWC and soil depth, China3. Huai River was the case study basin. The results revealed that China1 performed better than FAO1 in simulating daily stream flow, while FAO1 better than China1 in simulating soil moisture. After equally revising soil AWC, China soil database displayed better results than FAO database in all three components simulation. For China soil database, the effects of combined revision of AWC and soil depth obtained a much more satisfactory outcome than singly revision of AWC. The paper concluded that the revised China soil data could be applicable in simulating hydrological cycles at basin scale; the revised FAO soils were second-best alternatives and still appropriate for similar investigations in context of scarcer soil data availability.

S05P04

Passive Microwave Radiance Data Assimilation for Estimating Snow Water Equivalent over North America

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Snow is a critical component of the global energy and water balances, in particular at middle to high latitudes, because of snow's high albedo, low thermal conductivity, and water holding capacity. Data assimilation has been an important tool to obtain the distribution of snow depth and snow water equivalent (SWE), which are critical for climate and water resource applications. In previous studies, passive microwave (PM) radiance assimilation (RA) has shown promise for improving SWE estimations at point, local, and basin scales. In this study, we aim to address the feasibility of RA to improve SWE estimates at the continental scale. We use the Community Land Model version 4 (CLM4) for snow dynamics and the Dense Media Radiative Transfer–Multi Layers model (DMRT-ML) for snowpack brightness temperature (TB) estimations. Atmospheric and vegetation radiative transfer models (RTMs) are also incorporated to consider the effects of atmosphere and vegetation on TB at the top of the atmosphere. We assimilate the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) TB observations at 18.7 and 36.5 GHz vertical and horizontal polarization channels into the coupled CLM4/DMRT-ML using the Data Assimilation Research Testbed (DART) developed by the National Center for Atmospheric Research (NCAR). The RA results over North America are compared with the Canadian Meteorological Centre (CMC) and Snowpack Telemetry (SNOTEL) SWE data. The results show that RA improves SWE estimations over most areas of North America compared to the Open-loop case. In particular, the improvement is most evident for deep snowpack regions over the Rocky Mountains.

S05P05

Improving Water Quality Prediction Employing Maximum Likelihood Ensemble Filter (MLEF)

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One effective way to improve accuracy of water quality prediction is to reduce uncertainties in the initial conditions (IC) of water quality models, which are due to large dimensionality of the state vector and limited number of available observations. We developed and evaluated an ensemble data assimilation procedure for the Hydrologic Simulation Program – Fortran (HSPF) model to improve accuracy of water quality prediction by updating the model IC based on real-time observations of hydrologic and water quality variables. The procedure uses maximum likelihood ensemble filter (MLEF) which combines strengths of variational assimilation (VAR) and ensemble Kalman filter (EnKF) and is capable of handling both nonlinear model dynamics and nonlinear observation equations. In addition, we incorporated a form of linear regression in the observation equations of the procedure to account of the error that are not due uncertainty in the initial condition. For evaluation, we implemented the procedure for the Kumho Catchment in the Nakdong River Basin in the Republic of Korea for prediction of 7 water quality variables and streamflow. Then, an extensive sensitivity analysis has been carried out to optimize the DA parameters consist of model error, size of assimilation window, observational error variances and ensemble size. A set of performance measures including root mean square error (RMSE), the decomposition of mean squared error (MSE) and MSE skill score was used to assess the DA procedure for analysis and prediction of water quality variables and streamflow. The results showed that DA procedure reduces the RMSE of most water quality variables and streamflow. The largest reduction in RMSE was for nitrate (NO_3) and phosphate (PO_4) but these improvements are largely due to the bias correction component of the DA procedure and it suggests that correction of model bias, as part of the observation equation is important.

S05P06

Assimilation of MODIS Snow Cover and GRACE Terrestrial Water Storage Data through DART/CLM4

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The Gravity Recovery and Climate Experiment (GRACE) terrestrial water storage (TWS) anomaly data are assimilated into the Community Land Model version 4 (CLM4) via the Data Assimilation Research Testbed (DART) to improve the snowpack estimate. The MODerate resolution Imaging Spectroradiometer (MODIS) snow cover fraction (SCF) data are assimilated jointly. The spatial map of the error of the GRACE data provided along with the data is used in this work.

A freely available ensemble of reanalysis data created by DART and the Community Atmospheric Model (CAM4.0) is used as the meteorological forcing for each CLM ensemble member. This induces spread in the CLM ensemble during a spin-up phase and helps maintain spread during the assimilation.

This study compares the open loop run and the assimilation runs. When only the MODIS SCF is assimilated, the root-mean-square-error (RMSE) of SCF is largely reduced in most regions when MODIS data are assimilated. However, the innovation (i.e. the difference between analysis and forecast) is marginal in the regions where snow cover reaches unity regardless of snow mass changes. Further assimilation of GRACE TWS anomalies, however, can adjust the modeled snowpack, resulting in noteworthy improvements over the MODIS-only run in the high-latitude regions. The effectiveness of the assimilation is analyzed over various land cover types. Data assimilation results are evaluated against the Canadian Meteorological Center (CMC) snow depth data on daily timescales in the regions with dense observation sites.

There still are some areas where a more accurate SCF estimate is not guaranteed even though we insert a SWE estimate that incorporates MODIS SCF information. We infer that this could be related to the SCF parameterization in CLM4. This study also compares two SCF parameterizations and their effectiveness on data assimilation results. CLM4 parameterizes SCF as a function of snow depth and density, which is based on an analysis between monthly observed SCF and snow depth. The newest version of CLM (CLM4.5) incorporates a stochastic SCF parameterization, which is demonstrated to produce more realistic SCF estimates. This study replaces the snow density-based SCF parameterization scheme in CLM4 with the stochastic SCF parameterization scheme to test if the new SCF parameterization scheme can improve the effectiveness of SCF data assimilation.

S05P07

CLM4-DART Based Global Soil Moisture Estimation by Assimilating AMSR-E Microwave Signals

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The Community Land Model version 4 (CLM4) is known to have noticeable biases in estimating global surface soil moisture. It is hypothesized that such biases can be reduced by assimilating microwave brightness temperatures (TB) of Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) into CLM4 via the Data Assimilation Research Testbed (DART) using an ensemble size of 40. An empirical microwave Radiative Transfer Model (RTM) is used to calculate TB based on CLM–simulated ground surface variables (e.g. surface soil moisture, soil temperature, and vegetation temperature) and MODIS leaf area index (LAI). Increments are applied to surface soil moisture based on comparisons between calculated and observed TB at each assimilation cycle. Evaluation of the assimilation output is facilitated through comparison with ground-based soil moisture observations available from the International Soil Moisture Network (http://ismn.geo.tuwien.ac.at/) and TAMU NASMD (http://soilmoisture.tamu.edu/). This presentation, however, addresses two practical issues regarding the global scale data assimilation. These are specifically 1) to balance between the computational cost and the data assimilation performance by spatially upscaling observations to 1–degree resolution and shifting forcing time series to enable global assimilation at a daily time step, and 2) to account for uncertainties in the biased, spatially highly variable parameters in RTM, by implementing parameters pre-calibration at each global grid. The latest results of pre-calibration and post-assimilation will be presented.

S05P08

Enhanced Frequency Retention and Data Assimilation of GRACE Terrestrial Water Storage Information

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The NASA/DLR GRACE mission has now delivered over a dozen years of time-variable gravitational information that has seen widespread use in the study of processes in hydrology, oceanography, cryosphere, and is particularly critical to inform, improve, and validate computational models of the Earth system. Within hydrology, assimilation of GRACE information into land surface models has been investigated using the monthly smoothed and destriped gridded-mass (Level-3) datasets. However, the coarse spatial and temporal resolution of these fields has limited their use for data assimilation. This study offers advances in (1) improving the high frequency signal content of the GRACE terrestrial water storage information via the use of sliding windows in the estimation process and (2) assimilation of these new and traditional monthly solutions of GRACE TWS information into the Community Land Model (CLM) within the Community Earth System Model (CESM).

Presently, approximately thirty equally weighted days of information are used to estimate each field, referred to as a 30-day boxcar window. However, through differential weighting of the daily GRACE information files read into each monthly solution it is possible to boost the low frequency signal retention - especially in the range of 4-12 cycles per year - and reduce the gain at higher, more noise-prone frequencies in the GRACE data. This differential weighting process is designed to optimize these desired signal characteristics while fulfilling the observability requirements. Each solution typically utilizes 21 days of data, though due to the differential weighting scheme the effective window length spans a shorter scale, resulting in pseudo-daily or weekly “sliding window” products. Therefore, the frequency retention is increased in two ways: by increasing the low frequency gain and providing gravity field solutions on shorter time scales. This study informs and assesses the effectiveness of the modified solutions by assimilating both the sliding window and traditional monthly solutions into CLM using the Data Assimilation Research Testbed (DART). The addition of improved frequency retention offers increased effectiveness and new methods of data extraction from time-variable gravity datasets from the GRACE and future geodetic observing missions.

SESSION 6. DEVELOPING SYNERGISM WITH OPERATIONAL HYDROLOGY

DESCRIPTION

Recent advances in hydrologic modeling and DA offer large potential for improving operational hydrologic forecasting and water resources management. Conversely, additional needs for such improvements present new opportunities and challenges for hydrologic modeling and DA. This sub-theme discusses the status and plans for the Hydrologic DA Testbed, an ongoing effort to promote such synergism, and presents the initial results.

KEYNOTE PRESENTATIONS

S06K01

Challenges and Limitations of Hydroclimatological Forecasting and the Relative Role of Its Three Pillars: Models, Observations and Parameterization

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In response to society's need for more effective tools to address hydrologic hazards and manage water resources systems, engineers and scientists have become more reliant on the use of predictive models and stochastic methods. Depending on the problems, the hydrometeorological information needed may range from hourly forecasts (i.e., in the case of flash floods) to seasonal to inter-annual (i.e., in the case of reservoir operation), and to decadal to century (i.e., in the case of long range water supply planning and structural designs). While there is a rich body of literature reporting on progress related to both, "weather-scale" and "climate-scale" hydrologic predictions, many challenges face the research community attempting to extend the lead time and accuracy of predictions.

More specifically, despite the progress in each of the three pillars of hydrometeorological prediction system (models, observations and parameterization) over the past several decades, the improvements in the overall forecast quality is yet to reach the users expectations. This presentation will provide a summary of both the progress and the related challenges. It will be a personal reflection of over 3 decades of research experience with hydrologic modeling and involvement with a number of international initiatives.

S06K02

Toward Improving Operational Streamflow Forecasting at Regional and Continental Scales by Assimilating Satellite-Based Snow Observations Using the NASA Land Information System

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In snow-dominated river basins, snowpack represents a major uncertainty source for the forecast model. Hence, accurate analyses of snowpack conditions and its spatiotemporal variability are essential to producing reliable hydrologic forecasts at regional and continental scales. Satellite-based observations are increasingly being considered for assisting hydrologic forecasting in recent years due to their relatively short latency, increasing spatial resolution, and reasonable spatiotemporal continuity. A great deal of research has recently been conducted at NASA GSFC with regards to assimilating satellite-based products of snow depth and snow cover into the NASA Land Information System (LIS) for various hydrologic applications. In this presentation, we focus on the impacts of satellite-based snow data assimilation on streamflow forecasting in the Upper Colorado River Basin and across the contiguous US. Our results indicate that, with proper preprocessing to account for potential biases, satellite-based snow observations can have potential in improving streamflow predictions at various spatiotemporal scales.

ORAL PRESENTATIONS

S06O01

High-Resolution Flash Flood Forecasting for the Dallas-Fort Worth Metroplex (DFW)

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Given the high population density, high-resolution observing and modeling capabilities are necessary for prediction of flash floods in urban areas. Continuing urbanization and climate change put such areas in a particularly vulnerable position where even a small-scale but intense rainfall event can cause deadly flash floods and extensive damages. For high-resolution observing and modeling of large urban areas, the use of weather radar and distributed hydrologic modeling is a natural progression. Quantitative precipitation estimates (QPE) from radars, however, are subject to various sources of error. High-resolution distributed modeling is subject to nonlinear growth of error due to errors in QPE and in model parameters and structures. Widely varying imperviousness in land cover, and density, capacity and complexity of storm drain networks present additional challenges. In this presentation, we describe an ongoing effort for real-time flash flood forecasting using the CASA (Collaborative Adaptive Sensing of the Atmosphere) radar network, the potential role of data assimilation in bridging the information gap, and plans for integrative sensing and prediction of urban water in DFW.

S06O02

Real-time Control of Irrigation by Assimilating Measured Soil Moisture Contents into CLM: A Case Study in Spain

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Increasing water stress in many parts of the world, related to increasing water needs for agricultural production and climate change, demand intelligent irrigation strategies. This study explored real-time control of irrigation. We investigated for a study site near Picassent (Spain) the real-time control of irrigation for citrus trees orchards in the year 2013. Three fields were irrigated with a traditional approach, using FAO-based evapotranspiration calculation. Three other fields were irrigated with our approach, modelling water and energy fluxes at the land surface with the Community Land Model (CLM) and assimilating measured soil moisture contents at 10-cm and 30-cm depth, with the Local Ensemble Transform Kalman Filter (LETKF). Both methods used ECMWF weather predictions from 51 ensemble members. Measurement data were automatically sent from the field to a database, which was assessed by the model. The model was run each two days and provided soil moisture evolution for the next days as well as irrigation need. The calculated irrigation need was sent automatically to the site operators at the Picassent site. At the site further logistic and hydraulic constraints were taken into account to schedule irrigation amount in time. It was found that with real-time control 30% less irrigation was used than with the traditional approach. Less irrigation did not have negative effects: soil moisture content at 50 cm and 70 cm did not decrease, stem water potential data did not indicate drought stress and citrus production was not reduced.

S06O03

Extension of Regional River Flow Modeling to the Continental Scale of the Mississippi River Basin by Using High Resolution River Data from NHDPlus Dataset

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Hydrologic science requires the integration of multidimensional, spatiotemporal data into an atmospheric model linked with a land surface model and a river model for long lead time forecasting and extreme events modeling. The next generation of river routing models should consider flow and transport on a continental scale, with high spatio-temporal resolution in terms of physical and biogeochemical processes. This study presents an extension of regional river flow modeling to the continental scale of the Mississippi river basin, which encompasses 1/3 of continental United States by using high resolution river data from NHDPlus dataset. This research discovers obstacles of flow computations for river a network with hundreds of thousands river segments in continental scales. The Routing Application for Parallel computatIon of Discharge (RAPID) model was run with runoff obtained from Mosaic and VIC land surface models from 2000 to 2008. The benefit of vector-based river network is that the locations of river gauges are more easily determined (e.g. no need for snapping), therefore one can use as many gauges as needed. Another advantage of vector river network is that, physical visualization of river segments is superior to the gird river network. This research identifies drainage area as a key factor in the flow simulation, especially in a wetter climate. The application of the VIC land surface model significantly improves the RAPID performance.

S06O04

SMAP High Resolution Data for Assimilation in Geophysical Applications

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NASA's Soil Moisture Active Passive (SMAP) Mission is scheduled for launch in early November 2014. The objective of the mission is global mapping of soil moisture and freeze/thaw state. SMAP utilizes L-band radar and radiometer sharing a rotating 6-meter mesh reflector antenna. The instruments will operate onboard the SMAP spacecraft in a 685-km Sun-synchronous near-polar orbit, viewing the surface at a constant 40-degree incidence angle with a 1000-km swath width. Merging of active and passive L-band observations of the mission will enable an unprecedented combination of accuracy, resolution, coverage and revisit-time for soil moisture and freeze/thaw state retrieval. The Level-2 Active-Passive soil moisture product (L2_SM_AP) at 9 km is retrieved from the disaggregated/downscaled brightness temperature obtained merging of active and passive L-band observations. The baseline L2_SM_AP algorithm disaggregates the coarse-resolution (~36 km) brightness temperatures of the SMAP L-band radiometer using the high-resolution (~3 km) backscatters from the SMAP L-band SAR. Due to inherent errors/noise in the inputs (brightness temperatures and backscatters) to L2_SM_AP algorithm, assumptions in the algorithm and errors in the algorithm parameters, the output disaggregated brightness temperatures from the L2_SM_AP algorithm are noisy. The errors in inputs to L2_SM_AP algorithm are fairly defined making it possible to characterize and understand their individual contribution in the disaggregated brightness temperatures at 9 km. Analytical approaches are already developed to provide reasonable estimates of uncertainty in disaggregated brightness temperatures at 9 km. Soil moisture values are retrieved from the disaggregated brightness temperatures using several ancillary data and parameters. Due to uncertainty in disaggregated brightness temperatures, errors in ancillary data and parameters the retrieved soil moisture estimates have errors. Mechanisms are already in place to provide uncertainty estimates for relevant soil moisture retrievals. Inclusion of uncertainties for disaggregated brightness temperature and retrieved soil moisture in L2_SM_AP product will facilitate data assimilation in all relevant geophysical applications.

Poster presentations

S06P01

HEPEX - Achievements and Challenges!

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HEPEX is an international initiative bringing together hydrologists, meteorologists, researchers and end-users to develop advanced probabilistic hydrological forecast techniques for improved flood, drought and water management. HEPEX was launched in 2004 as an independent, cooperative international scientific activity.

The applications of hydrological ensemble predictions span across large spatio-temporal scales, ranging from short-term and localized predictions to global climate change and regional modelling. Within the HEPEX community, information is shared through its blog (www.hepex.org), meetings, test beds and intercomparison experiments, as well as project reports.

Key questions of HEPEX are:
* What adaptations are required for meteorological ensemble systems to be coupled with hydrological ensemble systems?
* How should the existing hydrological ensemble prediction systems be modified to account for all sources of uncertainty within a forecast?
* What is the best way for the user community to take advantage of ensemble forecasts and to make better decisions based on them?

This year HEPEX celebrates its 10th year anniversary and this poster will present a review of the main operational and research achievements and challenges prepared by HEPEX contributors on data assimilation, post-processing of hydrologic predictions, forecast verification, communication and use of probabilistic forecasts in decision-making. Additionally, we will present the most recent activities implemented by HEPEX and illustrate how everyone can join the community and participate to the development of new approaches in hydrological ensemble prediction.

SESSION 7. ADVANCING DATA ASSIMILATION SCIENCE FOR OPERATIONAL HYDROLOGY

DESCRIPTION

The research community has demonstrated large potential of DA in improving predictive skill and reducing uncertainty in hydrologic forecasts. Within the operational community, however, automatic DA is still a relatively new concept and its adoption and implementation often face considerable challenges. This sub-theme discusses theoretical and practical aspects of hydrologic DA that require additional attention by the research community to advance DA science for operational hydrology and to accelerate research-to-operations transition.

KEYNOTE PRESENTATIONS

S07K01

Advancing Data Assimilation Science for Operational Hydrology: Methodology, Computation, and Algorithms

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Data assimilation (DA) for operational hydrology is an important area of hydrologic development that addresses the transitioning of DA research into cost-effective operational forecasting. This effort requires close collaborations among DA developers, hydrologic modelers, and operational forecasters. Several challenges of DA theory and practice that have an impact on DA for operational hydrology will be discussed in this presentation, including: (a) data assimilation methodology, (b) computational implications, and (c) algorithmic aspects. We will also discuss the development of coupled hydrology-land-atmosphere-chemistry and its relevance to DA for operational hydrology. Finally, a new framework for unified ensemble-variational data assimilation, with a potential for use in operational hydrology, will be presented.

S07K02

Combined Data Assimilation and Multimodeling for Seasonal Hydrologic Forecasting- A more Complete Characterization of Uncertainty

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Uncertainties are an unfortunate yet inevitable part of any forecasting system. Within the context of seasonal hydrologic predictions, these uncertainties can be attributed to three causes: imperfect characterization of initial conditions, an incomplete knowledge of future climate and errors within computational models. This presentation proposes a method to account for all threes sources of uncertainty, providing a framework to reduce uncertainty and accurately convey persistent predictive uncertainty. In currently available forecast products, only a partial accounting of uncertainty is performed, with the focus primarily on meteorological forcing. For example, the Ensemble Streamflow Prediction (ESP) technique uses meteorological climatology to estimate total uncertainty, thus ignoring initial condition and modeling uncertainty. In order to manage all three sources of uncertainty, this study combines ESP with ensemble data assimilation, to quantify initial condition uncertainty, and Sequential Bayesian Combination, to quantify model errors. This gives a more complete description of seasonal hydrologic forecasting uncertainty. Results from this experiment suggest that the proposed method increases the reliability of probabilistic forecasts, particularly with respect to the tails of the predictive distribution. In addition, the presentation includes recent development in advancing data assimilation theory and practice using Particle filter and Markov Chain Monte Carlo method where the objective perturbation approach by means of variable variance multiplier is also elaborated.

ORAL PRESENTATIONS

S07O01

Impacts of State Updating of Combined Hydrologic and Hydraulic Models for Streamflow Forecasting via Data Assimilation

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While important advances have been achieved in flood forecasting, due to various uncertainties from simulation models, observations, and forcing data, it is still insufficient to obtain accurate prediction results with the required lead times. To increase the certainty of the hydrological forecast, data assimilation may be utilized to consider or propagate all of these sources of uncertainty through hydrologic and hydraulic modeling in a flood prediction system. Although integrated modeling with hydrologic and hydraulic models has high potentials to improve flood forecasts in terms of accuracy of water stage as well as discharge, there have been few attempts to apply data assimilation for a combined modeling system. In this study, we evaluate impacts of state updating of combined hydrologic and hydraulic models for streamflow forecasting via data assimilation driven by numerical weather predictions. The combined modeling system consists of a spatially distributed hydrologic model, WEP (Water and Energy transfer Processes) and a two-dimensional dynamic wave model to predict flood discharge from a catchment and water stage in the stream, respectively. Then, particle filtering (PF), one of sequential data assimilation techniques for non-linear and non-Gaussian models, is applied to sequentially update state variables in hydrologic and hydraulic models when new observations are arrived from monitoring systems. The procedure is evaluated for streamflow hindcasting in a fast-responding catchments in Japan, where inundation happened due to heavy rainfall induced by typhoon. The discussion will be focused on illustration of a novel DA method and its applicability on extreme floods.

S07O02

Improving the Performance of an Eco-Hydrological Model to Estimate Soil Moisture and Vegetation Dynamics by Assimilating Microwave Signal

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The skill to quantitatively simulate land surface conditions such as soil moisture and vegetation dynamics is important from the hydrological and agricultural point of view. Because microwave signals are highly sensitive to both surface soil moisture (SSM) and vegetation dynamics, the microwave data assimilation (DA) is useful to improve the performance of an eco-hydrological model that simultaneously simulate soil moisture and vegetation dynamics. We develop a dual-pass microwave land data assimilation system that includes an eco-hydrological modeling framework. In this system, we firstly optimize the unknown hydrological and ecological parameters in the eco-hydrological model by assimilating microwave brightness temperatures from the advanced microwave scanning radiometer for earth observing system (AMSR-E) and using shuffled complex evolution (SCE-UA) algorithm. Secondly, we adjust model forecasts of vertical soil moisture profile and leaf area index (LAI) by using genetic particle filter (GPF). We apply this system to three observation sites under different hydroclimatic conditions. We show the microwave DA greatly improves our capability to simulate both SSM and LAI without using any in-situ observed data. In addition, we can improve the estimation of sub-surface soil moisture which cannot be observed directly by AMSR-E. Because vegetation growth and senescence are explicitly related to root-zone soil moistures in our eco-hydrological modeling framework, assimilating aboveground vegetation information contributes to reproduce the root-zone soil moisture through this model's process. Our microwave satellite DA system can contribute to the unknown parameter estimation and improvement of forecasts in operational hydrology especially in an ungauged area.

S07O03

Ensemble Data Assimilation of Water Quality Variables

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When ensemble Kalman filter is applied for water quality simulation, covariance among water quality variables is important as it affects the assimilation results considerably. However, issues related to the covariance have not gained much attention. In this study, we tested several synthetic cases to clarify the issues and the effects of ill-posed ensemble in terms of covariance of water quality variables on data assimilation (DA) results. First, we produced a synthetic ensemble of water quality variables in which the relationship among the variables is well represented. For that, the synthetic ensemble is generated by perturbing one external forcing variable in a way that the generated ensemble fully obeys the model dynamics and reflects the relationship described in the model equations. Then we examined the effect of DA with one variable (observation) on the other variables and compared it with the case of ill-posed ensemble case (the relationship is poorly reflected in the ensemble). Second, we tested the case of DA with one variable, say chlorophyll-a in this study, and the case of DA with multiple variables such as phosphate, nitrate, ammonia etc. Synthetic observations are generated for the variables and they are used to evaluate the effect of each DA case. Preliminary results show that in the first synthetic ensemble case, the DA effect with one variable on the other variables well reflects the relationship expressed in the model equations. For example, when chlorophyll-a is assimilated with observed chlorophyll-a data to be increased, phosphate is decreased, which keeps mass balance.

S07O04

Comparative Evaluation of EnKF and MLEF for Assimilation of Streamflow Data into NWS Operational Hydrologic Models

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In recent years, data assimilation (DA) has been gaining great attention to reduce uncertainties in initial and boundary conditions of hydrologic models in operational streamflow forecasting. For ensemble forecasting, ensemble Kalman filter (EnKF) is an appealing candidate for familiarity and relative simplicity. EnKF, however, is optimal in the second-order sense, only if the observation equation is linear. As such, without an iterative approach, EnKF may not be appropriate for assimilating streamflow data for updating soil moisture states due to the strong nonlinear relationships between the two. Maximum likelihood ensemble filter (MLEF), on the other hand,

is not subject to the above limitation. Being an ensemble extension of variational assimilation (VAR), MLEF also offers a strong connection with the traditional single-valued forecast process through the control, or the maximum likelihood, solution. In this work, we apply MLEF and EnKF as a fixed lag smoother to the Sacramento (SAC) soil moisture accounting model and unit hydrograph (UH) for assimilation of streamflow, mean areal precipitation (MAP) and potential evaporation (MAPE) data for updating soil moisture states. Comparative evaluation with respect to the model errors associated with soil moisture dynamics, the ensemble size and the number of streamflow observations assimilated per cycle showed that, in general, MLEF outperforms EnKF under varying conditions of observation and model errors, and ensemble size. Also, MLEF is not very sensitive to the uncertainty parameters and performed reasonably well over relatively wide ranges of parameter settings, an attribute desirable for operational applications where accurate estimation of such parameters is often difficult.

S07O05

Analysis of Streamflow Trends in San Jacinto River Basin, Texas

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This study presents results of basin wide streamflow trend detection in San Jacinto River basin, the second most populous basin in Texas. Monthly and annual streamflow data of 29 stream gages and peak streamflow data of 43 gages across the basin were downloaded from the USGS website. This analysis included data from gages with at least 15-year continuous record. Trend analyses were conducted using the Mann-Kendall trend test for the following time scales: i) annual mean daily discharge, ii) seasonal mean daily discharge [winter (Dec - Feb), spring (March - May), summer (June - August) and fall (Sept - Nov)], and iii) annual instantaneous peak discharge. The results show statistically significant upward trends of annual mean daily discharge at 12 stream gages and downward trend in one stream gage out of the 29 used gages. Ten and two of the streamflow gages at the urbanized Buffalo - San Jacinto and Spring sub-basins show upward trends. Based on seasonal data analyses, 11 gages showed significant upward streamflow trend during the fall; whereas, only 6 gages showed statistically significant upward trend in spring. However, there is only one station that showed a downward trend during the spring season. Fourteen streamflow gages out of 25 showed significant upward trends for annual peak discharge in Buffalo – San Jacinto sub-basin. However, there was no statistically significant trend in annual instantaneous peak discharge in the other three sub-basins of the study area. The trends in these streamflow data could be due to one or more of the following potential factors: landuse change, changes in precipitation, groundwater use, and inter-basin water transfer. There seems to be no consistent trend in rainfall data of selected rain gages. The analysis of changes in land cover using National Land Cover Data (1992 – 2011) showed that the urbanized areas are increasing; however, there is a significant decrease in the forested and hay/pasture areas across the basin. Further analysis is required to determine the effect of other factors. A hydrological modeling exercise is needed to predict future potential trends in streamflow and rainfall data across the basin.

POSTER PRESENTATIONS

S07P01

Simultaneously Correcting the Precipitation Biases and Improving the State Estimation in Hydrologic Data Assimilation

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Recent studies in hydrological data assimilation have focused on improving the operational hydrological forecasting capability and handling multi-source uncertainties rising from the model parameterization scheme, meteorological forcing input, model physical processes, and etc. However, precipitation as the vital forcing dataset endures considerable instrumental (station gauges) and retrieval error (satellite retrieved products) and hence reduce the simulation and forecasting capability of hydrological models. Meanwhile, simplicity approaches adopted to ignore the heterogeneity and scaling discrepancy in precipitation record impose negative effects on its accuracy. This study has simultaneously assimilated the streamflow and the surface soil moisture, aiming at correcting the precipitation biases and improving the hydrological state estimation. The ensemble Kalman smoother is applied to reduce the meteorological forcing biases through the assimilation of outlet streamflow, while the surface soil moisture is further induced to decrease the estimation error. Results demonstrated that this assimilation scheme could diminish the precipitation bias to some extent especially when the precipitation is under- or over-estimated. Yet, the false alarms or missed rain had got no improvement. Further, moderately enhancements in hydrologic modeling and forecasting had been achieved with the joining of the surface soil moisture observation.

Key words: precipitation biases, streamflow, surface soil moisture, hydrologic data assimilation

S07P02

Assimilating Airborne L-band Brightness Temperature to Improve Soil Moisture Estimation and Operational Hydrological Forecast in the Southern Appalachians

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The Intense Observing Period (IOP) of the Integrated Precipitation and Hydrology Experiment (IPHEx-IOP) for supporting the ground validation campaigns for NASA's Global Precipitation Measurement Mission (GPM) Core satellite, was conducted in the Southern Appalachians in the southeast US in May-June 2014. Daily operational hydrological forecasts were performed every day for 12 headwater catchments including the Pigeon River Basin, the Upper French Broad River basin, the Upper Broad River basin, the Upper Catawba River Basin and the Upper Yadkin River Basin in the Southern Appalachians using the three-dimensional physically-based and fully-distributed Land Hydrology Model (3D-LHM). The regional weather forecast results from NU-WRF (NASA/GSFC) and RAMS/ICLAMS (University of Connecticut) were used as atmospheric forcing. The radar-based MRMS and StageIV rainfall products were used to produce hindcasts from which soil moisture conditions were initialized for the hydrological forecast. Meanwhile, a large amount of ground measurements (including precipitation, soil moisture, soil temperature,

etc.) and airborne measurements from various sensors including the SLAP (Scanning L-band Active/Passive) instrument were collected during the IPHEx-IOP. The SLAP, an aircraft scale simulator of the NASA's upcoming SMAP (Soil Moisture Active Passive) mission, conducted four flights during May and collected observations from both radiometer and radar over extensive area in the Upper Catawba River basin and Upper Yadkin River basin. Here, the SLAP multi-resolution brightness temperature observations (< 1-km spatial resolution) generated using the algorithm proposed by Das et al. (2014) are assimilated into the 3D-LSHM in order to improve the operational hydrological forecasts in three headwater basins (one in Upper Catawba River basin and two in Upper Yadkin River basin) using the ensemble Kalman Filter (EnKF) method. This study illustrates that benefits of assimilation of L-band brightness temperature observations from SLAP into the 3D-LSM improves soil moisture estimation from hindcasts leading to improved streamflow forecasts. After the launch of SMAP (Oct. 2014), operational systems will be able to directly assimilate SMAP L-band brightness temperature at much more frequent time scale (~ 3 days) though coarser spatial scale (10s km). Potential challenges and opportunities for flood forecasting and water management will be discussed.

Das, N.N. et al., 2014: Tests of the SMAP Combined Radar and Radiometer Algorithm Using Airborne Field Campaign Observations and Simulated Data, *IEEE Transactions on Geoscience and Remote Sensing*, **52** (4), 2018–2028.

SESSION 8. REAL-WORLD APPLICATIONS OF DATA ASSIMILATION IN OPERATIONAL HYDROLOGY

DESCRIPTION

A number of scientific and technical challenges still exist to realize the potential of DA in operational hydrology, such as quantification of uncertainties in the observations and model forecasts and making the DA process transparent to operational forecasters. This sub-theme presents examples of real-world applications of DA in operational hydrologic forecasting and water resources management with the goal of fostering collaborations in DA research, development and transition to operations, including those for supporting techniques and tools.

KEYNOTE PRESENTATIONS

S08K01

Operational Data Assimilation at NWS River Forecast Centers

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Operational data assimilation techniques offer tremendous advantages and benefits to forecasters responsible for generation short, medium, and long range hydrologic predictions. The objective of even the most primitive technique is pretty straightforward: "use available information to inform the forecast process and generate a better prediction." DA procedures that have won favor with forecasters tend to have very specific attributes. This presentation will identify a series of common DA approaches used in NWS River Forecast Centers as well as their favorable attributes as applications. Challenges, goals and benefits of advanced DA techniques will be discussed in the context of the real time hydrologic forecasting process.

S08K02

Towards Operationalizing Ensemble Data Assimilation in Hydrologic Forecasting

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The need for transitioning of hydrologic DA research into effective operations is evident given the frequent occurrence of extreme events in recent years, increasing availability of new observations and ongoing ICT developments. However, uptake of Ensemble DA in the (operational) hydrologic forecasting arena is still very limited. Obstacles and ways forward have been discussed and reported (Liu et al., 2012). This presentation will discuss several recent advances which result from different past and on- going projects. Opportunities, limitations and lessons learned will be highlighted by looking at three different cases studies: forecasting with distributed hydrologic models (Belgium/France, Meuse), water quality forecasting (South Korea) and forecasting with lumped hydrologic models (USA).

S08O01

Developments in Water Supply Forecasting: Combining New Methods and Existing Models

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The ABRFC currently uses two modeling techniques to develop internal (to NWS) water supply forecasts. The use of two independent modeling methodologies permits the results of each to be cross-validated, in effect creating an ensemble of possible forecast values. This ensemble is used to inform the forecaster when developing an initial monthly water supply forecast. The monthly forecast is then discussed with the Natural Resources Conservation Service (NRCS). The NRCS discussions serve as a third ensemble member used to inform the water supply forecast that is issued to the public.

Recent developments in Water Supply forecasting techniques have resulted in significant changes in water supply forecast operations within the NWS. The two most notable changes are the expansion and increased frequency of NWS-produced ensemble forecasts and the discontinuation of formal coordination with the NRCS. At the ABRFC, formal coordination has given way to an informal collaboration. This continuing communication assures that the NWS retains access to forecasting skill and data available from other agencies. Increases in forecast frequency generally require increases in automation that result in decreased influence of situational awareness in the forecast process. Such a reduction may negatively affect the forecaster's familiarity with the content of the forecast model. The ABRFC is currently seeking to balance the use of increasingly automated forecasting techniques while assimilating data and forecast skill from other sources, such as outside agencies, SNOTEL and Snow Course Data, Snow Analyses from the National Operational Hydrology Remote Sensing Center (NOHRSC), and other knowledge.

S08O02

Data Assimilation for Operational Watershed Water Quality Forecasting at the National Institute of Environmental Research in Korea

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To improve accuracy of watershed water quality forecast, data assimilation (DA) technique based on maximum likelihood ensemble filter (MLEF) has been applied to the Hydrologic Simulation Program – Fortran (HSPF) watershed model, referred to herein as MLEF-HSPF, with aid of a newly developed HSPF processor. A MLEF-HSPF adapter has also been developed for operational implementation of MLEF-HSPF into the Water Quality Forecast System at the National Institute of Environmental Research (WQFS-NIER), which uses the Flood Early Warning System of Deltares (FEWS). Compared to operational hydrologic forecasting, operational water quality forecasting is a larger challenge due to additional complexities and uncertainty sources associated with physiobiochemical processes. There exist needs for assessment and quantification of uncertainty in water quality forecasting via, e.g., ensemble techniques. To support ensemble water quality forecasting, it is necessary to produce reliable forecast and analysis ensembles. In this presentation, we identify the science and operational challenges for improving performance of MLEF-HSPF and present progress and plans toward producing reliable ensembles.

S08O03

Operational Water Quality Forecasting Using Ensemble Data Assimilation for EFDC and HSPF Model

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NIER have been operating the water quality forecasting to prevent water quality deterioration for the major rivers in South Korea through FEWS-NIER (Flood early warning system) which developed by the international joint research with NIER and Deltares from 2011 to 2013.

The coupled the Hydrologic Simulation Program – Fortran(HSPF) and the Environmental Fluid Dynamic Code(EFDC) models are being used to quantitatively predict the water quality.

HSPF watershed model are used to generate the flows and water quality loads of the major tributaries which are used as the boundary conditions for EFDC model.

The uncertainties in water quality forecasting are contributed by various factors such as input uncertainty, model structure uncertainty, parametric uncertainty, initial conditions uncertainty, of which to reduce uncertainty on the initial conditions is relatively effective in improving accuracy of short term water quality forecast.

To reduce initial conditions uncertainties, data assimilation (DA) techniques are applied to the HSPF and EFDC models. DA is to condition the model state on the observations to get a better estimate of state. Maximum likelihood ensemble filter (MLEF) is applied to the HSPF model and ensemble Kalman filter (EnKF) is applied to the EFDC model.

In this presentation, we will show how much DA techniques improve or affect accuracy of water quality forecast under different DA options.

Keywords: data assimilation, water quality, ensemble Kalman filter (EnKF), maximum likelihood ensemble filter (MLEF).

POSTER PRESENTATIONS

S08P01

Relationship between Water Resources and Agricultural Production across the Brazos Watershed, TX

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Increase demand for water resources across the Brazos watershed, Texas as a result of substantial land use changes requires an evaluation of the impact of the impact of some of the major crops grown on this watershed. This study is evaluating the potential effect of four major row crops on the effective rainfall, the portion of gross rainfall that infiltrates into the crop rootzone across the growing season, runoff, and groundwater recharge. Five locations in five different counties across the Brazos watershed (upper, middle and lower parts) were selected. Historical daily weather data (rainfall and evapotranspiration, ET,), soil physical properties, and crop water parameters were used as input for the Irrigation Management System (IManSys); model (Fares, 2012). Daily water budget components were calculated by the model. From the upper to the lower parts of the watershed rainfall increase by as much as 300% while ET decrease by 30%. Water yield and groundwater recharge increase with increase in rainfall across the watershed irrespective of the crop. Among the crops growing during similar growing season Sorghum had the highest recharge rates and water yield and consequently the lowest effective rainfall. Wheat and sorghum crops seem to more conducive to higher water yield and groundwater recharge than Corn. Further analyses are needed for more conclusive conclusions and recommendations.

S08P02

Monthly Streamflow Forecasting Using Gaussian Process Regression

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In this work, Gaussian Process Regression (GPR), an effective kernel-based machine learning algorithm, is applied to probabilistic streamflow forecasting. GPR is built on Gaussian process, which is a stochastic process that generalizes multivariate Gaussian distribution to infinite-dimensional space such that distributions over function values can be defined. The GPR algorithm provides a tractable and flexible hierarchical Bayesian framework for inferring the posterior distribution of streamflows. The prediction skill of the algorithm is tested for one-month-ahead prediction using the MOPEX database, which includes long-term hydrometeorological time series collected from 438 basins across the U.S. from 1948 to 2003. Comparisons with linear regression and artificial neural network models indicate that GPR outperforms both regression methods in most cases. The GPR prediction of MOPEX basins is further examined using the Budyko framework, which helps to reveal the close relationships among water-energy partitions, hydrologic similarity, and predictability. Flow regime modification and the resulting loss of predictability have been a major concern in recent years because of climate change and anthropogenic activities. The persistence of streamflow predictability is thus examined by extending the original MOPEX data records to 2012. Results indicate relatively strong persistence of streamflow predictability in the extended period, although the low-predictability basins tend to show more variations. Because many low-predictability basins are located in regions experiencing fast growth of human activities, the significance of sustainable development and water resources management can be even greater for those regions.

S08P03

Treating Precipitation Uncertainty and Bias during an Extreme Event with Data Assimilation

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The Colorado Front Range experienced heavy rainfall and catastrophic flooding in September 2013. Considerable disagreement amongst a variety of operational, quantitative precipitation estimates resulted in large uncertainties for forecasters and decision makers (Gochis et al., submitted). In the end, predicted rainfall was far below what was observed. In this study we ask if real-time streamflow observations might have helped reduce uncertainty in these forecasts via their assimilation into a hydrologic model? Can assimilation of streamflow observations flag precipitation bias in real-time? Can operational streamflow assimilation diagnose precipitation bias or is an off-line DA mode an important tool (e.g. Seo et al., 2009) for treating input uncertainty? (For example, Salamon and Feyen, 2009). Can input precipitation bias be corrected to improve streamflow forecasts in near real time? Our experiments are conducted using the WRF-Hydro

model with the Noah-MP land surface component and a selection of different data assimilation approaches.

Gochis, D. J. , R. Schumacher, K. Friedrich, N. Doesken, M. Kelsch, J. Sun, K. Ikeda, D. Lindsey, A. Wood, B. Dolan, S. Matrosov, A. Newman, K. Mahoney, S. Rutledge, R. Johnson, P. Kucera, P. Kennedy, D. Sempere-Torres, M. Steiner, R. Roberts, J. Wilson, W. Yu, V. Chandrasekar, R. Rasmussen, A. Anderson, B. Brown, 2014: The Great Colorado Flood of September 2013, *Submitted to: The Bulletin of the American Meteorological Society*, 7 April, 2014.

Salamon, P., and L. Feyen, 2009: Assessing parameter, precipitation, and predictive uncertainty in a distributed hydrological model using sequential data assimilation with the particle filter, *Journal of Hydrology*, **376**, no. 3, 428–442.

Seo, D.-J., L. Cajina, R. Corby, and T. Howieson, 2009: Automatic state updating for operational streamflow forecasting via variational data assimilation, *Journal of Hydrology*, **367**, no. 3, 255–275.

S08P04

Operational Data Assimilation for Improving Hydrologic, Hydrodynamic, and Water Quality Forecasting Using Open Tools

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Data assimilation holds considerable potential for improving water quantity (hydrologic/ hydraulic) and water quality predictions. However, advances in hydrologic DA research have not been adequately or timely implemented in operational forecast systems to improve the skill of forecasts for better informed real-world decision making. In contrast to most operational weather (related) forecast centers operational hydrologic forecast centers often are unable to support & maintain or lack the required computing support to implement such intensive DA calculations. Moreover, it remains difficult to achieve coupling of models, data, DA techniques and exploitation of high performance computing solutions in the operational forecasting process. Several potential components of a future solution have been or are being developed, one of those being the open source project OpenDA (www.openda.org). The objective of this poster is to highlight the development of OpenDA for operational forecasting and its integration with Delft-FEWS that is being used by more than 40 operational forecast centers around the world. Several applications of OpenDA using open source (and available) model codes from various fields will be highlighted.