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Preface “Observing and modeling the catchment scale water cycle”

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1 Introduction

The hydrology community has a long history of using experimental catchments as a test bed for new observation methods and new models. What distinguishes catchment hydrology from neighboring disciplines is that it uses drainage basins as an integration entity (Uhlenbrook, 2006). However, observing and modeling at the catchment scale is more challenging than at the point scale because of inherent multi-scale heterogeneity (Sivapalan et al., 2003). Point based hydrological measurements are rapidly evolving to a multi-scale hydrological observing system, which includes not only traditional point measurement, but also large-scale observation methods, such as eddy covariance (EC), large aperture scintillometer (LAS), wireless sensor networks, and remote sensing observations. However, how to take advantage of new means of observation to improve modeling strategies for catchment hydrology, and how to capture macro-scale processes as well as quantify the uncertainties associated with heterogeneity, are still challenging issues (Savenije, 2009; Wagner et al., 2009; Committee on Integrated Observations for Hydrologic and Related Sciences, NRC, 2008).

This special issue was organized with the aim to address the above challenges and discuss the advances of hydrological observation and modeling at the catchment scale. Key components of the water cycle at the catchment scale are addressed. These include evaporation, precipitation, snowmelt, soil moisture, frozen soil, stemflow, and groundwater. In addition, a few of the papers discuss the relationship between ecosystems and hydrology. Most of the papers in the issue are related to the Watershed Allied Telemetry Experimental Research (WATER), which is a simultaneous airborne, satellite-borne, and ground-based remote sensing experiment taking place in the Heihe River Basin, the second largest inland river basin in the arid regions in Northwestern China, aiming to improve the observability, understanding, and predictability of hydrological and related ecological processes at the catchment scale (Li et al., 2009). A few other papers contribute results (or observations) from some representative catchments in other places.

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2 Summary of the special issue papers

The first theme of this special issue deals with the estimation of evaporation and other water fluxes at point to catchment scales.

Evaporation is a key hydrological process and is intensively discussed in this special issue. From the observational perspective, Liu et al. (2010a,b) report experiments on large-scale observation of evaporation for different landscapes in the Heihe River Basin and its vicinity, including irrigated cropland, alpine meadow, spruce forest, and desert, using EC systems and large aperture scintillometer (LAS). They described typical diurnal and seasonal variations of fluxes in these sites and the heterogeneity effect, i.e., the influence from their different source areas. Both the LAS and EC measurements seemed to underestimate evaporation (latent heat flux) and sensible heat flux. However, when comparing the sensible heat fluxes simultaneously measured by LAS and EC at an alpine site, the LAS measurement was found to be larger than the EC measurement. This difference seems to be caused by the heterogeneity of the underlying surfaces and the difference between the source areas of the LAS and EC measurements. This study implies that large-scale observation of evaporation and other fluxes is important to understand the scaling problem and to eventually close the energy and water budget.

Modeling of evaporation was carried out at both footprint/pixel scale and catchment to regional scale by using above observations and other related ground and remote sensing data. Two papers in this special issue report new modeling approaches for evaporation. Xin and Liu (2010) developed a Two-layer Surface Energy Balance Parameterization Scheme (TSEBPS) and tested it in an oasis station of WATER. TSEBPS is based on the theory of the classical two-layer energy balance model and on a set of new formulations derived from assumptions of energy balance at limiting cases. It treats foliage and soil independently, therefore it needs the component surface temperature, which is usually obtained from multi-angular thermal infrared (TIR) data. Their paper discusses a simplified case using ground based TIR data, which lays the foundation for using multi-angular TIR airborne remote sensing data collected during the intensive observation period of WATER. TSEBPS has proven to be capable of improving the estimation of evaporation of sparse vegetation at the footprint scale.

Zhao et al. (2010) discuss the applicability of the Penman-Monteith model with different parameterization schemes for bulk canopy resistance of maize in another oasis site in the Heihe River Basin. They compared the Noilhan and Planton (N-P) approach and the Jacobs and DeBruin (J-D) approach and found that the N-P approach slightly underestimates the bulk canopy resistance, whereas the J-D approach overestimates it. They also found a strong diurnal variation of bulk canopy resistance. Their study further demonstrates the importance of correct parameterization of canopy resistance, which is necessary to make the Penman-Monteith model more applicable.

The majority of atmospheric/hydrological and remote sensing models need aerodynamic roughness in the area perspective. However, traditionally, the roughness is calculated from simple semi-empirical formulations. A more physically-based and detailed computation of roughness structure is important. Colin et al. (2010) developed a novel method to combine computational fluid dynamics model and LiDAR observations to invert wind profiles for each calculation grid and compute a roughness length. The basis of this model is that the canopy height obtained by the difference between the digital surface model (DSM) and the digital elevation model (DEM) gives the distribution of roughness elements over the entire area. This manuscript gives an example of how aerodynamic simulations can benefit from high resolution 3-D surface structure models acquired by remote sensing. It also shows that detailed observation of roughness structure is essential to understanding complex momentum and heat exchange over heterogeneous land surfaces.

At the catchment scale, Ma et al. (2009) dealt with the challenging issue of evaporation estimation in heterogeneous landscapes of arid and cold regions by taking advantage of high resolution remote sensing data, such as the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER). The Surface Energy Balance System (SEBS) method was applied in their study, and estimation of the components of heat fluxes in the upper and middle reaches of the Heihe River Basin were validated by ground flux observations obtained in the WATER project. The conclusion is that the proposed methodology was successful over the study area.

Much of the heterogeneity in mountainous areas is caused by the terrain. Solar radiation is a key force, and its spatial distribution and time series need to be effectively and efficiently calculated for hydrological applications. A topographic solar radiation algorithm using limited data and simple methods was developed by Aguilar et al. (2010). This model was tested in a mountainous watershed in southern Spain and found to have good accuracy. Then, evaporation fields were estimated through the Penman-Monteith model using both corrected and uncorrected radiation values. The paper demonstrates the influence of spatial distribution of solar radiation on evaporation and indicates that the evaporation estimation may be improved by using topographically corrected solar radiation.

X. P. Wang et al. (2011) reported an interesting experiment on the contribution of shrub stemflow on water flux and storage for desert ecosystems. They found that a threshold value of corresponding rainfall of 4 mm is required for stemflow water to replenish soil moisture at the stem basal area and concluded that the shrubs may concentrate water flux to the stem basal area of ten to a hundred times the rainwater amount reaching a non-vegetated area. Therefore, stemflow plays an important role in plant survival and the general ecology of arid desert environments.

There is also a methodological paper on flux estimation in this special issue. Zhu et al. (2010) coupled a photosynthesis model and a stomatal conductance model to simulate CO_2 and H_2O exchange at the leaf scale of *Populus euphratica*. Parameters in the model were calibrated using a genetic algorithm. Prediction of net photosynthesis by the coupled model agreed well with the validation data collected by a photosynthesis system.

The second theme discusses a few challenging issues on observing catchment scale water cycles.

Catchment scale water storage is traditionally inaccessible by hydrological measurement techniques. A novel method using temporal gravimeter to estimate water storage change (WSC) was proposed by Creutzfeldt et al. (2010). The WSC was reliably estimated by combining hydrologic and gravimetric models. The authors coupled a hydrological and a geophysical model to "predict" the gravimetric response directly, and simultaneously calibrated model parameters using the generalized likelihood uncertainty estimation (GLUE) method. The authors concluded that gravimeters might contribute to upscale point measurements to the field scale and can narrow the gap to the catchment scale.

The observations of high-resolution precipitation and raindrop size distribution were seldom available for high mountain areas, where the variability of precipitation is greater. Zhao et al. (2009) reported an experiment measuring precipitation in the upper stream of the Heihe River Basin using a truck-mounted high-resolution (250 m) and dual-polarization Doppler radar, disdrometers, and numerous rain gauges. A novel aspect of this work is that this is the first study where drop size distributions from the marginal area of the Qinghai-Tibetan Plateau are analyzed. Based on the 1074 raindrop size distributions measured by a Parsivel disdrometer, a state-of-the-art optical laser instrument, the rain rate estimator of meteorological radars were improved. Different rain rate estimators were evaluated based on the observations, and the results showed that for the best rain rate estimation, the polarized radar signals and the drop diameter must be considered.

The third theme, dealing with the relationship between ecology and water cycle, consisted of two papers: one on a relatively small scale and the other on the whole river basin scale.

Leaf area index (LAI) is one of the most important biogeophysical parameters that is closely related with water cycle. Fan et al. (2010) developed a new hybrid canopy reflectance model by analyzing the canopy anisotropy and applied the model to estimate LAI from a multi-angular imaging spectrometer, i.e., the Compact High-Resolution Imaging Spectrometer/Project for On-Board Autonomy (CHRIS/PROBA). The retrieved LAI was validated by the ground truth at eleven sites of the WATER project, and the new method proved to be accurate and effective.

Jia et al. (2010) analyzed the relationship between the development of modern irrigation schemes in the middle reach of the Heihe River Basin and the water resources available for the downstream ecosystems (Ejin oasis). They found that the primary driver of vegetation development in the Ejin oasis was the previous year's streamflow modulated by streamflow in the spring of the current year. The competition of water resources among different sections in the Heihe River Basin is clearly visible in long time series remote sensing data.

The last theme of this special issue addressed the modeling of catchment hydrology in cold and arid regions.

Snow and frozen soil processes are key hydrological processes in cold regions. L. Wang et al. (2010) coupled a frozen soil parameterization scheme into the water and energy budget based-distributed biosphere hydrological model (WEB-DHM) developed by the authors. The model was then validated at point and catchment scales in the cold region of the hydrological experiment area of WATER. Results showed that WEB-DHM gave a much better performance with the frozen scheme than without the frozen scheme in simulations of soil moisture profiles and river discharge for the catchment at cold regions. Li et al. (2010) combined mass balance and energy balance methods to model snow-melt runoff in the same watershed. Daily snow cover fraction, as one of the most important inputs to the model, was obtained from MODIS, using a linear interpolation method to estimate the snow cover fraction under clouds. Drifting snow and snow sublimation were parameterized in the model. Modeling long-term snow runoff change is important because of its sensitivity to climatic change. J. Wang et al. (2010) used a conceptual snow runoff model to simulate snow runoff in mountainous areas of the Heihe River Basin. As a methodologically new aspect the authors use terrain-corrected snow cover remote sensing products in the model. The results show that the snowmelt runoff kept increasing from 1970 to the present, and the snowmelt onset will most likely shift to earlier times for catchments in cold regions of northwest China.

In arid regions, the vadose zone can be very thick (larger than 100 m), and the interactions between ground and surface water are very complex. X. S. Wang et al. (2010) attempted to address these challenges. A nonlinear leakage model was developed to calculate the monthly leakage of the Heihe River in considering changes of streamflows, river stage, and irrigation. In addition, a triple-reservoir model was developed to understand the interactive relationships among surface water bodies, the vadose zone, and groundwater. Based on these models, the response of groundwater to leakage of surface water in the middle reaches of the Heihe River Basin was studied. It was found that the annual leakage of Heihe River is 15–30% of the annual streamflow from the mountain outlet 1989–2008.

3 Conclusions

This special issue will contribute to the understanding of hydrological observation and modeling at the catchment scale.

Advances in hydrological observation, both ground based and remotely sensed, will significantly contribute to our understanding of catchment hydrology. Currently, we can measure larger-scale hydrological and ecological states and fluxes by taking advantage of new technologies, such as eddy covariance, LAS, distributed temperature measurement, cosmic-ray neutrons, wireless sensor networks. In addition, spatial variations and uncertainties can be captured and quantified. Remote sensing is currently providing revolutionary new methods that are reshaping hydrological observations. Many traditionally unobservable variables such as groundwater and river flow can now be retrieved by remote sensing. However, as stated in Sivapalan et al. (2003), "How can we employ new observational technologies in improved predictive methods?" There are still many challenges that must be overcome.

Modeling is lagging behind new observation techniques. New generation models should take advantage of technical advances, such as remote sensing and distributed ground observations. The modeling strategy needs to shift from spatial-explicit to scale-explicit. To do so, data assimilation methods will play a key role. However, how to effectively combine modeling and observation using data assimilation methods is a big challenge that we need to face in the next decade.

Using a well instrumented catchment as a test bed of new ideas for hydrological observing and modeling is essential to advancing catchment hydrology. Catchment scale hydrological experiments should therefore be encouraged. In designing this kind of an experiment capturing multi-scale heterogeneity must be taken into account so that the knowledge obtained can eventually be scaled up to sub-basin and basin scales.

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