A Distributed Biosphere-Hydrological Model for Continental Scale River Basins
（大陸河川のための分布型生物圏水文モデルに関する研究）

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Water cycle is essential substance move for human survival. Mathematical modeling of hydrology is the key tool to meet the more and more critical societal needs for improved water management and hazards prediction. The development of hydrological modeling has been in the direction from the first generation empirical and lumped models, to the second generation distributed hydrological models, and then to the third generation distributed biosphere-hydrological model. The new generation models incorporate the advanced schemes to understand the response of hydrological cycle to the change of biosphere, human society and climate system. The advances of methods for translating satellite data into global surface parameter sets have driven the development of the third generation models. With the new generation model, many of the merging advances in monitoring, computation, and telecommunications are brought to bear on disaster prevention, food supply, health, security and development issues facing Earth's growing population.

Multidisciplinary developments have prompted hydrological simulation. These advances include the new insights into mass/heat flux in the Soil-Vegetation-Atmosphere Transfer (SVAT) processes, progress in getting reliable land surface information from satellite remote sensing (RS), and developments of Geographic Information System (GIS) technique to extract topographic variables from digital elevation models (DEMs). This study has aimed at developing a new generation distributed biosphere-hydrological model accounting for the merging multidisciplinary advances. The main objectives include: extraction of hydrology related information from nontraditional datasets, development of a time-continuous distributed process-based land surface hydrological model accounting for the representations of the terrains, soil, vegetation, and hydrological response, model evaluation of the new generation model, and model application to evaluate the effects of human activity and natural climate variability on hydrology cycle.

The credibility of extraction of hydrology related information from nontraditional datasets is examined with a distributed biosphere-hydrological (DBH) model system. The nontraditional datasets to address water resource problems are largely from satellite remote sensing. The DBH model system is applied to the Yellow River basin, a continental scale river basin in semi-arid area, to compare the satellite remote sensing data with in situ observations. The relationship between nontraditional dataset and traditional in situ observation on cloud cover, which is characterized by large spatial and temporal variations, shows strong correlations, implying the credibility of use of nontraditional datasets in hydrological simulation. The DBH model system is then used to analyze hydro-climatic change and stream flow change, exploring the possible connections between hydrology, vegetation, climate and human activity in the Yellow River basin. The analysis, using station, satellite metadata and interpolated coverage, indicates that the precipitation decreases in most part of the Yellow River basin, climatic factors such as temperature and evaporative demand of the atmosphere have large trend in special part of the basin, and that human activities have changed the vegetation condition in the irrigation districts. The Loess Plateau, the Tibetan Plateau, and the irrigation districts are suggested as precipitation, temperature, and human activities "hot spots" of the Yellow River drying up, respectively.

A realistic distributed biosphere-hydrological (DBH) model has been developed for representing the role of both topography and land cover characteristics in hydrological cycle. The model is designed for use in a continental scale river basin and coupling with atmospheric models. The vegetated surface is calculated by a realistic land surface model SiB2. The vegetation phenology is described by satellite data, and the transfer of energy, mass and momentum between the atmosphere and land surface. The hydrological part estimates the surface runoff and calculates the interlayer exchanges within the soil profile and interaction between soil water and groundwater. The geomorphologic properties are abstracted from Digital Elevation Model using a distributed hydrological sub-model. Realistic watershed map and river way map are used to delineate sub-river basins and river network. The sub-river basins are coded following a natural numbering scheme which is self-replicating and is possible to provide identification numbers to the level of the smallest sub-basins. The river network routing order of the sub-basins is implicated in the numbering scheme. The runoff is then accumulated and routed to outlet using kinematic wave approach. The parameters and forcing data are obtained from various ways, including remote sensing, ground observation, and statistical surveys. The hydrology-related information was digitized into the model system in order to diminish the uncertainty in the hydrological simulation.

The model evaluation processes, such as model verification, validation and credibility, are preformed in the Yellow River basin, China. The effects of natural and anthropogenic heterogeneity on hydrological simulation were evaluated using the DBH model system. The model system embeds a biosphere model into distributed hydrological scheme, representing both topography and vegetation conditions in mesoscale hydrological simulation. An irrigation scheme has been included in the model system. The effects on hydrological processes of two kinds of variability, precipitation variability and the variability on irrigation redistributing runoff, was investigated in this study, representing the natural and anthropogenic heterogeneity, respectively. Runoff is underestimated if the rainfall is spatially uniformly put over large grid cell. And runoff simulation could be improved by taking into account the precipitation heterogeneity. However, the negative runoff contribution cannot be simulated by only considering the natural heterogeneity. This constructive model shortcoming can be eliminated by taking into account anthropogenic heterogeneity, irrigation water withdrawals. Irrigation leads to increased evapotranspiration and decreased runoff. Surface soil moisture in the irrigated area increases because of irrigation. Simulations performed for the Yellow River basin indicates that stream flow decrease of 41% by irrigation. The latent heat flux increase in peak irrigation season (June, July, August: JJA) is 3.3 Wm^{-2} with a decrease in ground surface temperature of 0.1 K of the river basin. The maximum simulated increase in latent heat flux is 43 Wm^{-2} and ground temperature decrease is 1.6 K in peak irrigation season (JJA).

A comprehensive application of the DBH model system is performed in the Yellow River basin with the use of data analysis results to evaluate the effects of human activity and natural climate variability on hydrology cycle. Scenario simulations are performed from 1960 to 2000 to quantify the effects of human activity on hydrology, and to distinguish it from the effects from natural climate variability. The linear tendency of the forcing data is removed to provide input for non-change scenarios. The model results from six scenarios, i.e. most realistic control scenario, non-climate change scenario, non-vegetation change scenario, non-irrigated area change scenario, stable scenario without linear tendency and stable scenario without climate pattern change, are compared. The results show that climate change is dominated in the upper and middle reaches, but human activities are dominated in the lower reaches of the Yellow River basin. The runoff and evapotranspiration decrease over the Loess Plateau is dominated by the contribution of climate change. The intensively affected area by irrigation and vegetation change is the irrigation districts especial in the Weihe irrigation district and lower reaches irrigation districts. The river discharge at the river mouth nearly half is affected by climate change and half by human activities. The linear climate change contributes to the water consumption, but the climate pattern change is more important than the linear climate change. The river channel flow is more significant affected by the direct irrigation water withdrawals than by the climate change, which dominantly contributes to the annual water resources change. The reservoirs are believed to make more stream flow consumption for irrigation, at the same time, our results demonstrate the reservoirs help to keep environment flow and counter zero-flow in the river channel.