論文の内容の要旨

Abstract of Dissertation

Title: Development of a Distributed Runoff Model coupled with a Land Surface Scheme

(陸面モデルを組み込んだ分布型流出モデルの開発)

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A new biosphere hydrological model, so-called Water and Energy Budget based Distributed Hydrological Model (WEB-DHM), has been developed by coupling a biosphere scheme (SiB2) with a Geomorphology Based Hydrological Model (GBHM).

In WEB-DHM, the improved SiB2 incorporating descriptions of sparse canopy processes, describes the transfer of the turbulent fluxes (energy, water, and carbon) between atmosphere and land surface for each WEB-DHM grid; while the GBHM redistributes water moisture laterally through simulating both surface and subsurface runoff using grid-hillslope discretization and then flow routing in the river network using the kinematic wave approach. The subgrid parameterization of WEB-DHM represents topographical characteristics using fine resolution DEMs, while the model keeps high efficiency for simulations in large-scale river basins by simplification of the streams in the large model grids. After model development, model validations and further studies were carried out step by step.

Firstly, the WEB-DHM was validated in Upper Tone River Basin of Japan (a humid region with long-term mean annual precipitation around 1500 mm) and Yongding River Basin of China (a semi-arid region with long-term mean annual precipitation about 400 mm), which supply water for Tokyo and Beijing, respectively. The applications to the two basins with different climate are detailed as follows.

(1) In Upper Tone River Basin, high flood risks come from heavy rainfall events occurring from June to October, which are commonly associated with typhoons and Mei-yu front activities. Several reservoirs were constructed for protecting the Lower Kanto plain from floods. Based on 3-year (2000-2002) meteorological data, the model was calibrated at 2000, and validated from 2001 to 2002. Comparing to GBHM, the new model is more physically-based in describing land-atmosphere interactions and

estimation of evapotranspiration (ET), and thus has less parameters to be calibrated. Good results have been achieved in simulating hydrological processes and water budget. Hourly hydrographs showed the model's prediction capability of floods, including the ones after periods of low water flows. Water budgets analysis has demonstrated the model's accuracy in estimating long-term ET. Simulated annual largest flood peaks matched well with observed ones in both flood peak and flood time.

(2) The semi-arid river basin, Yongding often suffered from water shortage. For improved water resources management, hydrological recovery is necessary for estimating the total natural surface water resources. In this study, a new approach for hydrological recovery is presented. Observed precipitation and other meteorological data sets from JRA-25 reanalysis project were used to drive the biosphere hydrological model (WEB-DHM) for hydrological recovery, through a complete simulation of natural hydrological processes using physically-based governing equations. Good performance in simulating annual natural surface water resources has been shown from the two-year (1990-1991) applications.

Secondly, the sensitivity of river runoff to input radiations was investigated in Agatsuma River Basin. The WEB-DHM was driven by different radiation inputs from empirical model estimates and/or reanalysis data for this sensitivity study. In traditional hydrological studies, the input radiations were used to estimate potential ET empirically, but the accuracy of input radiations was not highlighted as precipitation. However, the solar and longwave radiation incident at land surface are crucial for hydrological cycle, since they determine the radiation budget, which, in turn, modulates the magnitude of the terms in the surface energy budget (e.g., ET). The results showed that river runoff was sensitive to magnitudes of input radiations in the humid region, indicating the importance of the accurately estimating input radiations.

Thirdly, the WEB-DHM has the potential to give projections of future water resources considering the dynamical response of river runoff to rapidly rising CO_2. Much attention is paid to climate change-induced precipitation patterns and land evaporation alteration, while the CO_2-induced transpiration adjustment received less attention. As a result, most projections of future water availability have tended to neglect stomatal-closure effects since most of current DHMs did not consider the direct CO_2 effect on river runoff due to lack of descriptions of biospheric processes. In the Agatsuma River Basin, the biosphere hydrological model (WEB-DHM), incorporating a canopy photosynthesis-conductance model to describe the simultaneous transfer of CO_2 and water vapor into and out of the vegetation respectively, was used to investigate the direct CO_2 effect on vegetation transpiration and thus runoff quantitatively, while neglecting vegetation structural feedbacks to CO_2 increases. Although the countering direct effect of increased photosynthesis and resulting increases in biomass (and LAI) from CO_2 enhancement has not been yet incorporated into WEB-DHM, however, the work was one of the earliest explorations in CO_2-induced variability of streamflow using a biosphere hydrological model.

Through validations in both humid and semi-arid river basins, WEB-DHM has shown good performance in simulating both single flood event and long-term continuous hydrological processes. Therefore, the model can be used for flood prediction as well as long-term water resources estimation. Sensitivity study on input radiations showed the significant differences between simulated river runoff from various radiation products. It indicated the urgency to improve radiation products in Predictions in Ungauged Basin (PUB), where the calibration could not be finished. The evaluations of direct CO_2 effect on river runoff due to vegetation physiological feedback to CO_2 increase, has shown the potential of WEB-DHM for future water resources projections under a CO_2 changing climate.