ESTIMATING IMPACTS ON TERRESTRIAL WATER CYCLES BY INTEGRATING RESERVOIR OPERATION AND IRRIGATION PROCESSES TO HYDROLOGICAL SIMULATION

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1000 words
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Rapid growths of the world population and economy have increased anthropogenic impacts on the terrestrial water cycles. It is important to integrate major anthropogenic activities to hydrological simulations for understanding terrestrial water cycles properly. The authors have developed an integrated hydrological model that comprises four sub-models: land surface, river routing, irrigation, and reservoir operation models. The integrated hydrological model simulates terrestrial water cycles as interactions between these four sub-models. The model benefits on not only simulating in-land natural water cycles, but also considering anthropogenic activities such as reservoir operations and irrigation. Additionally, simulations can be performed with and without the irrigation and reservoir operation sub-models to estimate those impacts on water cycles. Terrestrial water cycles simulations have been performed from 1994 through 2003 using reanalyzed meteorological forcing and land surface parameters. This study integrates reservoir operations and irrigation processes to hydrological simulations in order to estimate their impacts on terrestrial water cycles.

The integrated hydrological model is based on a land surface model. For land surface analysis, the simple biosphere model including urban canopy (SiBUC; Tanaka, 2004), which was developed based on the simple biosphere model (Sellers et al., 1996), is used. The river routing model uses kinematic wave equations to calculate river discharge with simulated runoff from the land surface model. The river routing model also considers intake and drainage for irrigation fields from river channels. The irrigation model is coupled with the land surface model. Soil moisture and water level on croplands are interchanged between the land surface and irrigation models. The reservoir operation model regulates river discharge with considering irrigation water requirements from downstream areas. The reservoir operation model (Hanasaki et al., 2006) is also coupled with the river routing model.

The irrigation model maintains water level or soil moisture on croplands within the appropriate ranges for each crop defined by crop calendars. The crop calendars, used in the land surface analysis, have been generated by time-series analysis of normalized difference vegetation index (NDVI) provided by the Spot-Vegetation satellite images. The crop calendars generated for six crops (rice, spring wheat, winter wheat, maize, cotton, and soybean) agree well with crop calendars commonly used in many countries. Estimated annual irrigation water demands correspond to statistical data in many countries, suggesting that irrigation water requirements are simulated properly.

Impact of irrigation on vapor supply from land surface was performed by the land surface simulations with and without irrigation model globally. The vapor supply from the land surface has been also estimated by the atmospheric water balance method using reanalyzed climate conditions. The atmospheric water balance method calculates vapor supply from the land surface properly when atmospheric conditions were reproduced well in reanalysis data. The estimated vapor supply differs by 40% between land surface simulations with and without the irrigation model on the large scale irrigation fields. The vapor supply simulated by the land surface analysis with the irrigation model agrees well with estimated vapor supply calculated by atmospheric water balance conditions on irrigated fields in north China and United States. It suggests that land surface model including irrigation reproduce vapor supply better than the model including no irrigation. Our study demonstrates that atmospheric conditions in global or regional climate models can be improved by adding irrigation into their land surface modeling.

The reservoir operation model uses irrigation water requirements calculated by the irrigation model. The model regulates river discharge in order to satisfy water demands in downstream areas and to prevent floods and inundations. The reservoir operation model reduces peak river discharge and increases low river discharge. Global river channel networks have been scaled up from a 1 km resolution flow direction map to the model mesh size of 20 km resolution. Large reservoirs, whose locations are obtained from the global lakes and wetlands database (Lehner et al., 2004), have been allocated on the global river channel networks data.

Assessment of the impact on river discharge from reservoir operations, intakes and drainages for irrigation fields was performed by simulations of river discharge globally with and without the reservoir operation and the irrigation models. River discharge simulated monthly is compared with recorded data provided by the global river discharge center. The simulation with the reservoir operation model agrees the recorded data in many stations better than without the reservoir operation model. On the other hand, intake and drainage for irrigation fields affect river discharge in small rates. Reservoir operations have a strong impact on seasonal river discharge compared to intake and drainage for irrigation fields.

The integrated hydrological model has been used to investigate impacts of irrigation and reservoir operations on terrestrial water cycle. The model is applicable to data assimilation systems using observations from several satellites, which would be performed in our future study.