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その他のタイトル	モデル－データ統合による生態水文学的干ばつの解析
学位授与年月日	2016-03-24
URL	http://doi.org/10.15083/00073476

博士論文（要約）

Analyzing an ecohydrological drought by model-data integration

（モデル－データ統合による生態水文学的干ばつの解析）

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Summary

Drought causes severe damage in many regions of the world. Understanding, quantifying, monitoring, and predicting drought progress are strongly required to support decision makers responsible for water and food security. Since drought brings both the decrease of the water (hydrological drought) and the stress on vegetation growth (agricultural/ecological drought), the interactions of water and vegetation dynamics are important to analyze drought. In this thesis, we present the framework to analyze an "ecohydrological drought". In our approach, we explicitly calculate ecosystem damages induced by droughts as well as the deficit of hydrological states. The first aim of this study is to develop the toolkit to analyze an ecohydrological drought by integrating state-of-the-art numerical modeling and satellite observation technologies. Using this toolkit, we would like to contribute to 1) understand how ecosystem is adapted to extreme drought conditions; 2) quantify the hydrological and agricultural drought and analyze their interactions; 3) make it possible to monitor and predict mega-droughts in ungauged regions. In Chapter 1, the motivation and key literatures are explained.

In Chapter 2, we present a field-verified algorithm for retrieving vegetation water content (VWC), which is the mass of water in vegetation tissue per ground area, using observed microwave brightness temperatures. We can use 6.925 GHz and 10.65 GHz microwave observations to minimize the species-dependence of the relationship between vegetation optical depth (VOD) and VWC. Then, we can easily estimate the VWC after obtaining the VOD. Although the VOD retrieved at these frequencies is highly affected by uncertainties in the surface roughness, we found that the effects of the bias of the roughness parameters in a radiative transfer model can effectively be eliminated by introducing leaf area index (LAI) data. The brightness temperatures observed using ground based microwave radiometer and field observed LAI were used to successfully reproduce the field observed VWC below 2.0 [kg/m^2] (R^2=0.712, RMSE=0.393 [kg/m^2]). This strategy of surface roughness correction also positively impacts the performance of soil moisture retrieval. This field-verified algorithm can contribute to global-scale VWC retrieval using satellite microwave radiometers such as the Advanced Microwave Scanning Radiometer on Earth Observation Systems (AMSR-E) and its successor (AMSR2).

In Chapter 3, the principal idea developed in Chapter 2 is applied to satellite data. The uncertainty of surface soil roughness strongly degrades the performance of retrieving

surface soil moisture and vegetation water content from microwave observations. This study proposes an algorithm to objectively determine the surface soil roughness parameter of the radiative transfer model by fusing microwave and optical satellite observations. It was then applied to a semi-arid in-situ observation site. The roughness correction of this new algorithm positively impacted the performance of retrieving surface soil moisture and vegetation water content from AMSR2 and MODerate resolution Imaging Spectroradiometer (MODIS). Since this surface soil roughness correction can be transferred to the algorithm of the other microwave satellite observations (e.g., L-band passive microwave observations in the Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) satellites), this algorithm can contribute to the many microwave earth surface observation satellite missions.

In Chapters 4 and 5, we develop the new land data assimilation system (LDAS), named Coupled Land and Vegetation Data Assimilation System (CLVDAS) for simultaneous simulation of soil moisture and vegetation dynamics. In Chapter 4, we focus on the parameter optimization problem of a land surface model. To improve the skill of reproducing land-atmosphere interactions in weather, seasonal, and climate prediction systems, it is necessary to simulate correctly and simultaneously the surface soil moisture (SSM) and terrestrial biomass in land surface models. Despite the performance of hydrological and ecosystem models depends highly on parameter calibration, a method for parameter estimation in ungauged areas has yet to be established. We develop an auto-calibration system that can simultaneously estimate both hydrological and ecological parameters by assimilating a microwave signal that is sensitive to both SSM and terrestrial biomass. This system comprises a hydrological model that has a physically based, sophisticated soil hydrology scheme, a dynamic vegetation model that can estimate vegetation growth and senescence, and a radiative transfer model that can convert land surface condition into brightness temperatures in the microwave region. By assimilating microwave signals from the AMSR-E, the system simultaneously optimizes the parameters of these models. We test this approach at three in situ observation sites under different hydroclimatic conditions. Estimated SSM exhibits good agreement with ground-based in situ observed SSM and estimated LAI is also improved by the optimization, compared with satellite-observed LAI. The root mean square error of SSM and LAI at all sites, estimated by the model with optimized parameters, is much less than that estimated by the model with default parameters. Using microwave satellite brightness temperature data sets, this system offers the potential to calibrate parameters of both hydrological and ecosystem models globally.

In Chapter 5, we focus on the sequential data assimilation to adjust the model states. The CLVDAS first calibrates both hydrological and ecological parameters of a land surface model, which explicitly simulates vegetation growth and senescence. Then, it adjusts the model states of soil moisture and LAI sequentially using a genetic particle filter. We can adjust the subsurface soil moisture, which is not observed directly by satellites, because we simulate the interactions between vegetation dynamics and subsurface water dynamics. From a point-scale evaluation, we succeed in improving the performance of our land surface model and generate ensembles of the model state whose distribution reflects the combined information in the land surface model and satellite observations. We show that the adjustment of the subsurface soil moisture significantly improves the capacity to simulate vegetation dynamics in seasonal forecast timescales. The CLVDAS can contribute to the generation of ensemble initial conditions of surface and subsurface soil moisture and LAI for a probabilistic framework of weather and seasonal forecasting.

In Chapter 6, we analyze ecosystem responses to the Millennium drought in southeast Australia (2001-2009). The prolonged “Millennium drought” in southeast Australia provides a unique opportunity to analyze responses of the semi-arid ecosystem to severe droughts. In this paper, we analyze the vegetation dynamics in the Millennium drought using a visible-infrared observation, a passive microwave observation, and a simple ecohydrological model. From the satellite observations, the ecosystem can maintain their greenness in the Millennium drought, although the total aboveground biomass is significantly decreased by water scarcity. According to the results of our numerical experiments, this resilience of the greenness to the drought can be explained by their carbon allocation strategy sensitive to light and water availability and the temporal change of their traits. Our numerical experiments successfully simulate the decrease of total aboveground biomass with unchanged vegetation greenness in the Millennium drought.

In Chapter 7, we establish the methodology to quantify ecohydrological droughts using a catchment-scale ecohydrological model. Drought severely damages water and agricultural resources, and both hydrological and ecological responses are important for its understanding. First, precipitation deficit induces soil moisture deficiency and high plant water stress causing agricultural droughts. Second, hydrological drought characterized by deficit of river discharge and groundwater follows agricultural drought. However, contributions of vegetation dynamics to these processes at basin scale have not been quantified. To address this issue, we develop a catchment-scale eco-hydrological model that can calculate river discharge, groundwater, energy flux, and vegetation dynamics as diagnostic variables at basin-scale within a distributed hydrological modeling framework. The model is applied to drought analysis in the Medjerda River basin. From model inputs and outputs, we calculate drought indices for different drought types. The model shows reliable accuracy in reproducing observed river discharge in long-term (19-year) simulation. Moreover, the drought index calculated from the model-estimated annual peak of LAI correlates well (correlation coefficient r = 0.89) with the drought index from nationwide annual crop production, which demonstrates that the modeled LAI is capable of representing agricultural droughts related to historical food shortages. We show that vegetation dynamics have a more rapid response to meteorological droughts than river discharge and groundwater dynamics in the Medjerda basin because vegetation dynamics are sensitive to soil moisture in surface layers, whereas soil moisture in deeper layers strongly contributes to streamflow and groundwater level. Our modeling framework can contribute to analyze drought progress, although analyses for other climate conditions are needed.

In Chapter 8, we challenge the drought prediction using the CLVDAS. Despite the importance of the ecological and agricultural aspect of severe droughts, no drought monitoring and prediction framework based on a LDAS realizes to monitor and predict vegetation dynamics in the middle of droughts. We applied the CLVDAS to the Horn of Africa drought in 2010-2011 caused by the precipitation deficit in the two consecutive rainy seasons. We successfully simulate the ecohydrological drought quantified by the model-estimated soil moistures and LAI. The root-zone soil moisture and LAI can be the good indicator of the prolonged droughts because they have the long memory of the past precipitation deficit. Our application finds the precipitation deficit in 2010 significantly affected the land surface condition of the next rainy season in 2011, which indicates the importance to obtain the accurate initial conditions of soil moistures and LAI for predictions of the multi-seasonal droughts. In addition, we find the GCM-based seasonal meteorological prediction has the good performance to predict the land surface condition of the Horn of Africa drought.

In Chapter 9, we briefly summarize the achievements and our original scientific contributions of our series of studies.