Estimation of Global Hydrologic Components in the 20th Century.

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Abstract

A 100-year (1901-2000) off-line simulation by a land surface model (LSM) has been completed by obtaining 100-year atmospheric forcing data sets from available global observations. It was found that the long-term terrestrial water fluxes can be estimated well from a LSM driven by long-term atmospheric forcing data that was stochastically estimated from monthly mean time series of precipitation and temperature. High correlations of annual runoff variations are obtained at many basins globally, however, the correlations of annual runoff are low in dry areas. Low correlations are also obtained in cool-temperate zones. The model successfully replicated annual snow covered area in North America and annual summer soil moisture in Mongolia. Several trends indicated by previous studies, the descending trend of snow covered area in northern America, and the increasing trend of summer soil moisture in Mongolia were also appeared in the simulation. With the benefit of 100-year simulation results for these variables, however, these trends appear to be within a range of natural long-term variability rather than systematic changes in hydrological condition. The 100-year estimation of hydrological component, such as annual and inter-annual variation of runoff, snow and soil moisture, would be useful for examining behaviors of a LSM with a perspective of long-term variations. They are also useful for water resources assessment rather than short-term estimation, because of the inclusion of several extremes and longer natural variability. It is also useful to obtain long-term hydrologic component especially for less-observed variables or in poorly-gauged basins; they can be used as a reference data to check GCMs and LSMs and water resource assessment in un-gauged basins.

Keyword: LSM, global water cycle

1. Introduction

Long-term variations in water fluxes at the land surface have been getting more attention in recent decades. What is the natural temporal variability of runoff, snow and soil moisture, and do these variables exhibit long-term trends? How will they be impacted by future global warming? To answer such questions, description, understanding, and prediction of the global water cycle have been promoted by numerical land surface models (LSMs). LSMs range in complexity from simple budget models, such as the traditional bucket model, to sophisticated physically based models, which incorporate radiation transfer, evapotranspiration, runoff and snow processes. These models solve energy and water balance equations, driven by atmospheric forcing input such as precipitation, radiation, and wind velocity, to estimate the time series of runoff, snow and soil moisture.

In an "off-line" LSM simulation, atmospheric forcing data is applied in one direction to drive the LSM model, without any feedback. Where observed atmospheric forcing data is used, hydrological variables predicted by an off-line LSM simulation can be interpreted as a mixture of model and observation. There are a lot of global data sets obtained by off-line LSM simulations. In this study we estimate a set of hydrological components for the precipitation, wind, vapour pressure and downward longwave and shortwave radiation – although sub-daily data is preferable, where available. Since only monthly data for precipitation, precipitation days and maximum and minimum temperature were available for the objective period (1901-2000), this study used three procedures to derive higher resolution atmospheric forcing datasets from the available monthly data; these procedures are summarized in Figure 1. A stochastic distribution model was used to disaggregate monthly precipitation into a daily time series, and a stochastic weather generator was used to create daily downward shortwave radiation and temperature time series data. Empirical equations were then used to obtain downward longwave radiation and specific humidity. The parameters for these statistical models and equations are estimated from available daily global data sets.

2. Modeling

MATSIRO is a land surface process model, which is a component of the general circulation model of the Center for Climate System Research and National Institute for Environmental Studies (CCSR/NIES), which balances both energy and water, at spatial resolutions from a fraction of a degree to several degrees latitude by longitude. A detailed description of the MATSIRO model is given in Takata et al. (2003). In this paper, the grid size of MATSIRO was

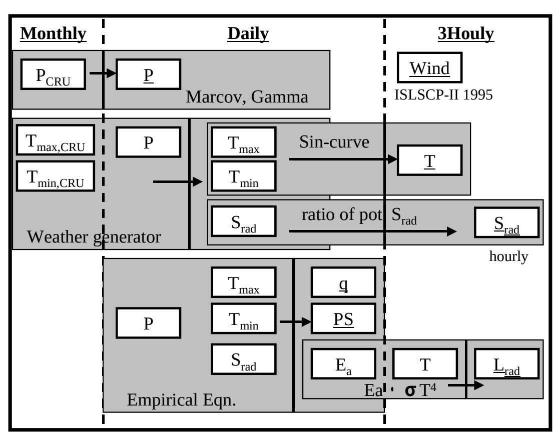

Fig. 1: Global data set for 100-year forcing.

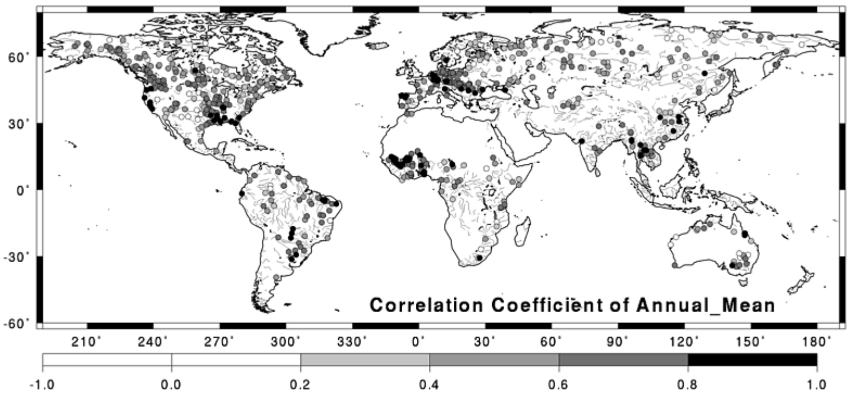

Fig.2: Correlation coefficient of annual runoff between model and observation.

defined as 1 degree by 1 degree globally.

The MATSIRO model computes vertical energy and water fluxes in a grid cell based upon specifications of soil properties and vegetation coverage for each grid. In the MATSIRO model, vegetation processes are mainly based on the SiB2 model, which uses the multi-layer canopy model of Watanabe (1994). In order to obtain river runoff, the grid runoff estimation was then integrated over the basin unit using a 1-degree version of the TRIP model (Oki and Sud, 1998); the combination is known as the MATRIP (MATSIRO + TRIP) model.

3. Result

3.1. Runoff

Figure 2 shows a map of the correlation coefficients between simulated and observed time series of annual runoff. Correlation coefficients were estimated at locations where discharge records were available for more than 10 years during the 100-year period. High correlations are obtained at basins along the west coast and eastern regions of the North America, as well as South America, Western Europe, Sahel, the Indochina peninsula and the central and southern regions of China. Correlations are low in dry areas, such as the central regions of the USA, the mid-latitude regions of the Eurasian continent and most parts of Australia. Low correlations are also obtained in cool-temperate zones, such as the basins of Canada, Eastern Europe and Russia. One possible reason of low correlations in dry areas is that MATSIRO model may not adequately estimate very low flow since runoff generation processes in the model are based on TOPMODEL. Because TOPMODEL was originally developed to simulate catchment under humid conditions (such as in the U.K, in the eastern USA and Scotland), the model has not likely provided good simulation of discharge under dry conditions. Another possible reason of low correlations in dry areas is human effect, because the percentage of total river water usage may be higher in dry regions. Inadequate detection of snow phase of precipitation and inadequate snow melting process, may lead inadequate runoff by snow melting in cool-temperate zones. River freezing and its break, that are not included in the TRIP model may play some role of poor estimations. Using calendar year to define annual runoff rather than using hydrological year may be a cause of low correlation of annual runoff. Since MATRIP do not employ calibration of model parameter values for specific river basins, Figure 2 provides an overview of the model's ability to simulate the annual variation in basin hydrology for a range of soil type, vegetation type, basin sizes and topographies, and contrasting climatic conditions around the globe. Only the global long-term simulation which is firstly conducted in this paper enable to provide this kind of global analysis of LSMs. Deficiencies of LSMs indicated from long-term LSM simulation would be helpful to improve future LSMs, with a help of detailed analysis in basin-scale validation such as a Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS).

LSM validation, especially for runoff simulation, has been conducted by comparing predicted and observed seasonal patterns in runoff hydrographs for locations with short historical runoff records, and using longer term comparisons for specific basins with longer historical records. The results shown in Figure 2 stress the importance of long-term validation of LSMs, particularly if they are to be used for long-term climate simulations.

3.2. Snow

Figure 3 plots predicted and observed annual variations in the spring (April and March average) snow covered area for the North America and Canada. Bars along the top indicate the fraction of the overall objective area which was not covered by CRU precipitation gauging in each year of the objective period. For North America, gauge coverage exceeds 95 % of the objective are since 1950.

Groisman et al. (1999) analyzed the snow covered area data obtained by satellite from 1973 to 1995 and showed that averaged snow area of April and March is clearly decreasing in the Northern hemisphere in spring; this reduction is also predicted by the 100-year simulation results shown in Figure 3. However, if the historical trends obtained by the model are correct, the decrease in spring snow covered area from the 1970's actually reflects

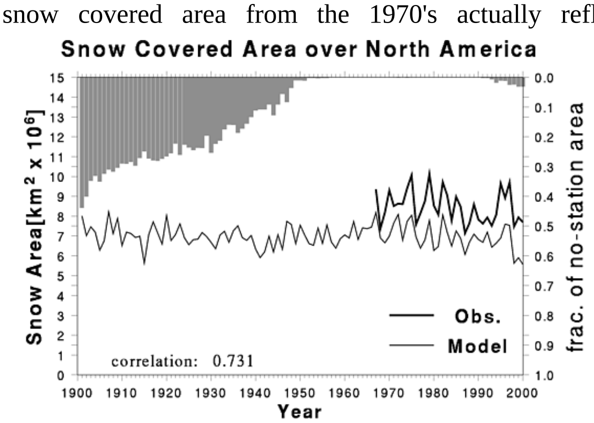

Fig.3: Spring (AM: average of April and March) snow area in North America.

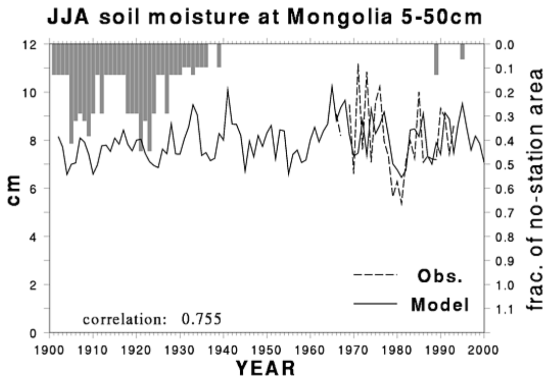

Fig.4: Annual trend of averaged JJA soil moisture in Mongollia. Area average of soil moisture from 5cm to 50cm depth of the 100-year simulation (thin solid) and station averages of observation (dot).

decadal-scale natural variability rather than a specific trend.

3.3. Soil Moisture

Temporal variations in soil moisture were examined for Mongolia (40-59N), where long-term observations of root-zone soil moisture are available from the Global Soil Moisture Data Bank (GSMDB) (Robock et al, 2000). Figure 4 compares observations of summer (JJA) soil moisture with model predictions, with both datasets representing the areally averaged root zone soil moisture from 5cm to 50cm depth over the region. Long-term trends in the predicted and observed values agree quite well, although predicted short-term inter-annual variability in average JJA soil moisture is larger than observed. The correlation coefficient between the model predictions and observations is 0.755.

By analysing GSMDB data, Robock et al. (2000) showd that JJA average soil moisture exhibits an increasing trend at the same region for the past several decades (1979 to 1994). This study also shows good agreement with predicted annual trends for Mongolia during the period 1975 to 1995 obtained in this investigation. However, the 100-year soil moisture data also pointed out that the increasing trend suggested by Robock et al. (2000) appeared to reflect natural long-term variability rather than systematic changes.

4. Summary

This paper describes the derivation of 100-year daily estimations of terrestrial land surface water fluxes, which have a wide applicability for various studies such as analyzing the inter-annual variability of land surface hydrology and detecting long-term trends of water fluxes. Most distinguished characteristic of this data set compared with prior data sets is its long coverage of 100 year. Global retrospective estimations of terrestrial water cycle by LSMs have been limited for few decades because of the limitation of available atmospheric forcing data. This study tried to estimate water fluxes for longer period than previous studies, driving a LSM under the long-term atmospheric forcing that was stochastically estimated from monthly mean time series of precipitation and temperature.

Globally, most place showed high correlation coefficients of annual runoff with observations. In dry regions and cold regions, however, predicted annual runoff time series was poorly correlated to observations. Correlation coefficients of annual snow covered area between satellite observation and MATRIP were 0.731 in North America and 0.577 in northern part of Eurasia continent. Summer soil moisture in Mongolia showed good correlation with observation with correlation coefficients of 0.755.

The 100-year estimation of hydrological component, such as annual and inter-annual variation of runoff, snow and soil moisture, would be useful for examining characteristics and behaviors of LSMs and GCM experiments, especially for less-observed variables such as soil moisture. Several errors of hydrological components that were found from the long-term estimation should be carefully analyzed, and investigation of the cause of model deficiency is highly expected. Because the 100-year LSM simulation suggested in this paper requires only monthly mean time series of precipitation and temperature, the method implemented in this study has wider applicability for simulating global-scale water fluxes even in poorly-gauged regions. Blind un-calibrated numerical simulation applied for global area in this paper clearly indicated regions where simulation result is bad. This is suggestive of systematic errors in the model scheme or errors in the atmospheric forcing for such regions, emphasizing the importance of long-term validation of land model simulations, to allow these deficiencies to be identified and resolved.

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