Impact of soil moisture on interannual variability of boreal summer precipitation

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Abstract:

A set of AGCM hindcast simulations for 1951-98 was carried out to investigate the influence of soil moisture on interannual variability of boreal summer (June, July, August) precipitation. It was achieved by the comparison of two simulations: a simulation forced with observed SST and a simulation forced with "realistic" land surface hydrological conditions, as well as observed SST, which were produced in an offline land surface simulation for the corresponding years. The influence of the "realistic" land surface specification is evident in the successful hindcast of interannual variability of boreal summer precipitation over certain regions of the world: Sahel, central Asia, the north of India, mid to western part of North America, the middle of Australia and so on, identified as “semi-arid regions.” This implies that predictability of boreal summer precipitation appears over the “semi-arid regions” if adequate land surface hydrological conditions are provided. However, it is also recognized that it is mostly only above the “semi-arid regions” (and tropical oceans) where the forcing from underlying surface has large variability that the interannual variability of precipitation is reproducible in AGCM simulations with the same land and ocean boundary conditions. There are insignificant reproducibility of precipitation variability, and insignificant predictability accordingly, in many other parts of the world. In some regions like the tropical Asian monsoon region, on the other hand, successful hindcast is not apparent despite the existence of significant reproducibility. These issues should be further investigated for the improvement of dynamical seasonal prediction of precipitation.

Keywords: soil moisture, AGCM, land surface-atmosphere interaction, predictability

1.Introduction

Because long-term, global-scale observation of soil moisture is not available so far, statistical analysis based on observation has a limitation in clarifying the land influence on precipitation. Thus, AGCMs have been a necessary tool for the investigation of such land impacts on precipitation. In the previous studies dealing with the land impact on precipitation, soil moisture and snow were mostly calculated in the coupled land-atmosphere system of an AGCM where their characteristics are not necessarily consistent with the characteristics of the real land surface hydrological states of the globe. Here, as an extension of the previous studies, we newly demonstrate the impact of soil moisture on precipitation in terms of interannual variability. It was realized by incorporating a long-term (48 years) dataset of "realistic" land surface hydrological conditions into AGCM simulations as a boundary condition. Evaluation of simulated precipitation variability will provide us an opportunity to examine a potential land impact on seasonal precipitation prediction, from the viewpoint of representation of interannual variability. The "realistic" land surface hydrological conditions for 48 years in this study, documented in Hirabayashi et al. (2004) (hereafter, H2004) in detail, were developed in an offline global simulation of a land surface model driven by observed or analyzed atmospheric forcing data. This study seems an analogue to a study dealing with the impact of El Nino on precipitation that can be conducted by prescribing the observed sea surface temperature (SST) fields for many years as a boundary condition in an AGCM. A full paper (Kanae et al. 2004) is now under review.

2. Design of experiments

We carried out a set of numerical simulations with an AGCM for 1951-98 forced with different boundary conditions. The global spectral AGCM used in this study has been jointly developed by Center for Climate System Research, the University of Tokyo and National Institute for Environmental Studies, Japan. The employed model resolution is horizontally T42 (corresponding to approximately 2.8 degree) with 20 vertical levels. The land surface part of the AGCM, MATSIRO, is a SiB2 type land surface scheme. Observed monthly SST from 1951 to 1998 was specified as a boundary condition in the simulations.

The first simulation is the control experiment (hereafter, CTRL) in which only the observed SST was forced as a lower boundary condition. There was no specification of land surface hydrological conditions. The coupled land-atmosphere system evolved freely in CTRL. Another simulation (hereafter, LND1) was forced with the “realistic” land surface hydrological conditions from 1951 to 1998 as well as the SST field of the corresponding month and year. The “realistic” land surface hydrological conditions are the products of an offline land surface simulation (H2004) using MATSIRO, the same land surface model attached to the AGCM. The detail is described in H2004.

3. Results: Regions where land surface hydrological conditions affect

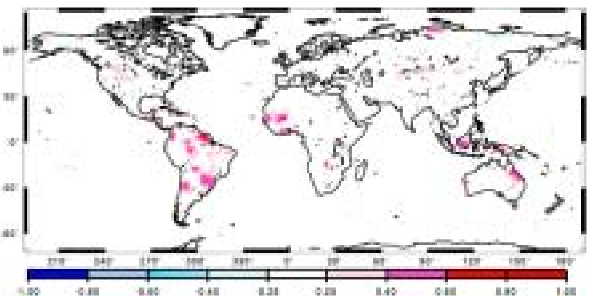

Figure1: Correlation coefficient of precipitation between CTRL and observation

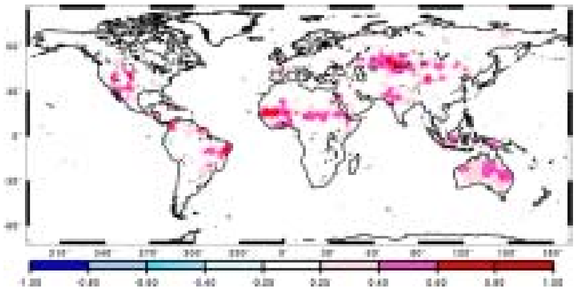

Figure2: Correlation coefficient of precipitation between LND1 and observation

We focus on seasonal mean precipitation amount of June, July and August (JJA). The correlation coefficient between simulated JJA precipitation of CTRL and observed JJA precipitation of CRU calculated from the interannual variability for 1951-98 shows almost insignificant over land globally. Major exceptions are the east coast of Brazil, the Indonesia maritime continent, the west coast of Sahel and Central America where their interannual variability seems to be controled by tropical SST variability. On the other hand the correlation between LND1 and CRU clearly shows the areas where the “realistic” land surface hydrological conditions have a positive impact in simulating interannual variability of boreal summer precipitation. Significant impacts are evident in the entire Sahel, central Asia, the north of India, the middle of Australia, and the mid to western part of North America. It can be argued that a successful hindcast of precipitation variability would be realized over these land areas if adequate land surface hydrological conditions are provided. These areas considerably correspond to the areas of strong land-atmosphere coupling in AGCMs (Koster et al. 2004) despite the differences in AGCMs, experimental design and the target time scale of precipitation. These areas are considered to be mostly located in the zones between dry and wet climates where soil moisture is enough dry to effectively control surface latent and sensible heat fluxes and the atmosphere is enough wet favorable to precipitation (Koster et al. 2004). Thereby, we call the areas “semi-arid regions” in the following. Further validity of the name will be described later. For the robustness of the above result, we should note a minor change in the significance level (for example, 5% to 1% or 5% to 10%) does not change the major impressions.

Next, in order to show reproducibility, we carried out the same AGCM simulation as LND1 only except for using a different initial condition of the atmosphere (hereafter, LND2). The correlation coefficient between LND1 and LND2 denotes that the interannual precipitation variability of such areas is significantly reproducible when land surface hydrological conditions as well as SST fields are specified, although an ensemble of more numbers of simulations is helpful for more adequate expression of reproducibility. The distribution of areas with reproducibility resembles that of areas with successful hindcast of precipitation variability); for example, the "semi-arid regions," the equatorial Pacific, the equatorial Atlantic and so on. Predictability can be represented as a good-correlation with observation located inside the areas with reproducibility. The areas with reproducibility, broader than the areas with predictability, can be considered as potentially predictable areas.

4. Discussion

Predictability has been exhibited only in the "semi-arid regions" where "water" in the land surface regulates the surface fluxes. Is predictability hopeless over other land areas outside the "semi-arid regions"?

For the appearance of predictability, certain reproducibility should be secured firstly. Figure 4 indicates that, except for the "semi-arid regions," even reproducibility does not exist in most of mid to high latitude even when both the land and ocean conditions are specified as boundary conditions. This seems not to be unique to our study. It has been pointed out using the current AGCMs that monthly to seasonal precipitation variability in mid to high latitude, opposite to that in the tropics, is controlled mostly by chaotic atmospheric dynamics (e.g. Shukla 1998; Koster et al. 2000). While this chaotic nature of the atmosphere seems to inhibit reproducibility, it has been speculated that the land surface hydrological conditions may strongly modulate the phase and amplitude of a major mode of climate variability in northern latitude and that the interannual variability of precipitation at many locations in Monsoon Asia is correlated, at least, with the equatorial Pacific SST variability. It suggests the existence of certain predictability of precipitation variability in these regions with the specification of realistic land conditions and SST fields.

When we look back again at the successfully-hindcasted areas, there also remains an important issue. It is indicated that precipitation variability is well hindcasted mostly just above such semi-arid land areas (and tropical oceans). The assumption that the influence of land is predominantly local is no more an assumption. The current AGCMs seem to be only capable of simulating predominantly local impact of land (and ocean) on precipitation where the forcing from underlying surface is evident. We need to further investigate whether this characteristic of AGCM is appropriate for representing the climate variability of the earth, because it is crucial for the improvement of the predictability of other regions.

Currently, the phase 2 of GSWP has been under progress, and 10-year (1986-95) land surface hydrological variables are calculated using a dozen of land surface models in a highly controlled manner. Each model can be basically attached to each AGCM. Thus, utilizing the outputs of GSWP2 will enable us to realize a multi-AGCM analysis.

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