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Contribution of Land Surface States to Precipitation Variability in Boreal Summer with an Atmospheric General Circulation Model

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1. INTRODUCTION

Coupling strength (CS) between land and atmosphere controls atmosphere processes, such precipitation. Soil moisture anomalies can persist for months (Vinnikov et al. 1996). Precipitation is induced by soil moisture variation in seasonal scale (Koster and Suarez, 2001). Koster et al., (K02) focused on CS in comparison with four Atmospheric General Circulation Models (AGCMs) (Koster et al. 2002). The present authors participated GLACE (Global Land-Atmosphere Coupling Experiment), follows K02 experiments by using the CCSR/NIES AGCM5.6. Main purpose of GLACE is to know whether the prediction accuracy on atmosphere processes can be improved or not, when it is fully filled with "the observation data" on land surface processes. CS depends on the model used. Therefore CS was averaged across 12 AGCMs results for decreasing the model dependency. As a result of GLACE, hot spots (large CS region) were found over the central Great Plains of North America, the Sahel, equatorial Africa and India (Koster et al, 2004, Science).

In this paper, we evaluate the contribution of land surface processes to daily precipitation variation with using CS in CCSR/NIES AGCM5.6 and analyze that what land or atmospheric processes can constrain the land surface contribution to precipitation. In GLACE results, we could not mention that land surface can contribute to the accuracy for precipitation in locally. If soil moisture anomalies can affect precipitation in local scale, then the accuracy for seasonal forecast can be improved by the monitoring of soil moisture, with both the ground-based and the satellite based observation systems. We therefore, try to clear this question that the hot spots are produced by the land surface local influence or not with conducting another experiment. Furthermore, we focus on the difference of the land surface contribution to precipitation variation for several time scales (daily to 3 months). In previous studies, a parameter, which is used to quantify CS, was considered to show the similarity across several ensemble members (Koster et at. 2002 and Koster et al. 2004, Science); however, the mathematical structure of the parameter has not been revealed. Therefore, we try to deepen the mathematical characteristics or meaning of the parameter.

2. METHODOLOGY

2.1 Model

We use the CCSR/NIES AGCM 5.6 (hereafter, CCSR/NIES), which was developed and improved by the Center for Climate System Research, the University of Tokyo and the National Institute for Environmental Studies (Numaguti et al. 1997). CCSR/NIES adopts the level-2 turbulence closure scheme developed by Mellor and Yamada, which represent the effect of the planetary boundary layer (Meller and Yamada, 1982). For the deep convection scheme, the relaxed Arakawa-Schubert scheme is adopted (Arakawa and Schubert, 1974). For the land surface scheme, we adopt the Minimal Advanced Treatments of Surface Interaction and RunOff (hereafter, MATSIRO), which has been developed for climate studies at the global and regional scales (Takata et al. 2003). MATSIRO is designed to represent the role of the vegetation such as the photosynthesis (Sellers et al. 1996). Furthermore, the simplified TOPMODEL is adopted in MATSIRO (Beven and Kirkby, 1979).

2.2 Data and Experimental Period

The experiments are carried out in June to August (JJA), 1994. This year has the weak affect by the climate variation such the ENSO. For the sea surface temperature (SST) as

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a boundary condition on the ocean process, we adopt the Atmospheric Model Inter-comparison Project 2 (hereafter, AMIP2) monthly mean sea surface temperature.

2.3 Experimental Design

The design of the experiment consists of two parts, shown in Figure 1. Each 3-months simulation are repeated 16 times, using 16 different sets of atmospheric and land surface initial conditions, which are calculated in advance. One is so called, control simulations (Cont-Exp, Cont1-16). We calculate both land and atmosphere in Cont-Exp. In another experiment (Fixed-Exp, Fixed1-16), we calculate only atmosphere. Concerning the land surface, we assume that there are fully filled with "the observation data" over land like SST over ocean. Land surface boundary conditions at every time step are given by all land surface prognostic variables, which are recorded in a Cont-Exp. Land and ocean are given the boundary conditions, therefore, only atmosphere processes determine the chaotic variations of atmosphere in Fixed-Exp. As a result, the difference value for the similarity index across 16 ensemble members between two experiments at every grid cell shows CS (land surface contribution).

To quantify CS, we need to calculate the similarity parameter (Ω), which is used to evaluate CS. There are two types calculations to get Ω . In these two types calculations, we use 16 ensemble time series of each atmospheric variable. In analysis below, we take 6-day totals data. Here, we explain the analyses as precipitation. Small "P" in each expression shows the precipitation. We calculate the P; each simulation provides, at each grid cell, time series of 3 months (JJA). First, we make $\hat{\sigma}_P^2$ with $\hat{P}$, which is the averaged time series in each time period among 16 ensemble members by (1), shown in Figure 2-a. In (1), "i" is the number of the ensemble; "n" is the time period and "m" is the ensemble members (m=16). Next, we calculate the variance, σ_P^2, of P across all

$$\hat{P} = \frac{1}{m}\sum_{i=1}^{m} P_{ni} \tag{1}$$

$$\Omega_P = \frac{m\sigma_{\hat{P}}^2 - \sigma_P^2}{(m-1)\sigma_P^2} \tag{2}$$

$$CS = \Omega_P(Fixed-Exp) - \Omega_P(Cont-Exp) \tag{3}$$

ensemble members and time periods, shown in Figure 2-b. Finally, we calculate Ω_P at every grid cell, which measures the similarity of 16 ensemble members (2). If each ensemble member produces the exactly same time series of P, then $\hat{\sigma}_P^2$ is equal to σ_P^2, and Ω_P will be 1. On the other hand, if the time series are completely uncorrelated among ensemble members, then $\hat{\sigma}_P^2$ goes to approximately σ_P^2/m , and Ω_P will be about 0. Thus, Ω_P varies from 0 to 1, with values closer to 1 indicating a greater degree similarity of precipitation. CS between the land and the atmosphere by taking the difference of Ω_P in Cont-Exp and Fixed-Exp is obtained (3). When CS goes to 1, land surface will dominant for precipitation variation. Meanwhile, land surface cannot contribute for precipitation variation when CS equals 0.

3. COUPLING STRENGTH FOR ATMOSPHERIC VARIABLES

3.1 Coupling strength for precipitation

Figure 3 shows CS for precipitation in JJA. The land surface contribution to the precipitation daily (6-day totals) variation is quantified over global scale. In this figure, Hot spots are found over the central regions of North America, the central regions of Eurasia in mid-latitudes and South Asia. In these regions, the daily precipitation variation is strongly determined by the land surface variation, such as soil moisture. On the other hand, CS is relatively small over Sahara and the equatorial region of Africa. In short, over tropical or dessert region, CS tends to be small.

3.2 Comparison of CS among atmospheric variables

Figure 4 shows the global mean CS for several variables (precipitation, evaporation and temperature) over land. If each variable can be controlled by only land surface, CS should be 1. Large CS is evaluated for variables, which are existed near land surface, such surface temperature and evaporation. The value of CS for evaporation is evaluated about 0.3. On the other hand, CS located at the high altitude is small. Especially, CS for precipitation is small compared with other atmospheric variables. This can be shown that the difficulty for weather forecasting.

4. CONSTRAINT FACTORS FOR COUPLING STRENGTH

In the previous section, average values of CS over land for several variables are evaluated in global scale. In Figure 4, we found that CS for precipitation is small compared with other atmospheric variables. In the mean while, CS is large for variables, which are existed near land surface. We can focus on the process from land surface to precipitation what land and atmospheric processes mainly constrain the degree of CS or control its spatial distribution.

4.1 Dryness conditions near land surface

First, we focus on what constraint factors can affect CS evaporation. Figure 5 shows the relationship between CS for evaporation to the relative humidity at the lowest level of atmosphere (circle) and daily evaporation variability (standard deviation of evaporation, SDE) (triangle) in each grid cell over land. At a glace, the plotted marks are scattered, however when we take averaged lines (Histograms are not shown, here.) in each vale of the relative humidity, the maximum values are found for CS (solid line) for evaporation and SDE (dashed line). Both maximum values are existed when the relative humidity is between 0.2 and 0.4. This relationship between the land surface contribution to evaporation and the evaporation variability is shown in Kanae et al 2004. In their studies, the influence of inter-annual variability of evaporation is large in semi-arid regions. As a result, we can mention that the transition zones between dry and wet condition are existed for determining CS for evaporation.

Next, we focus on the relationship between CS for evaporation and the total amount of evaporation, shown in Figure 6. As explained above, CS for evaporation is large over the transition zones between dry and wet conditions. On the other hand, the total amount of evaporation (square and dashed line) has the maximum value when the relative humidity is between 0.5 and 0.8. CS is small when the relative humidity is extremely small dry condition. If atmosphere is in dryer condition, then soil moisture cannot strongly control evaporation for its small soil moisture content. CS for precipitation needs not only the sensitivity of land surface to evaporation but also the total amount of evaporation, because small evaporation rates should have a limited ability to affect precipitation (Koster et al. 2004, Science). Meanwhile, when the atmosphere near the land surface is in wetter condition, soil moisture variation cannot dominate for evaporation because the atmosphere has not much capacity to store moisture from the land surface.

4.2 Degree of land surface contribution in vertical scale

The reason what process constrains CS for evaporation was discussed in 4.1. As a result, we suggested that there is a suitable dryness condition near land surface for the degree of the land surface contribution. In this section, we discuss from evaporation (CS=0.3) to variables, which exist in high latitudes in Figure 4. Figure 7 shows global mean CS for temperature in vertical scale over land. Large CS is found between near land surface and 800hpa vertical level. In other words, the degree of land surface conditions to temperature is largely decreased by strong mixture in the atmospheric boundary layer (hereafter, ABL). This result is found in case of the vertical profile of the specific humidity, also (not shown). Cloud physics processes, especially cumulus cloud is formed for its base at the top of ABL. Therefore we suggest that the degree of the development or the thickness of the ABL is another main constraint factor for CS for atmospheric variables in high altitude, such precipitation.

5. PRECIPITATION TYPES

The atmosphere is amenable to precipitation generation where in the transition zones between wet and dry climates, especially cumulus precipitation can be triggered by the boundary layer moisture (Y. C. Sud et al. 1993 and Koster et al. 2004, Science). There are two precipitation types, which can be calculated in CCSR/NIES. One is cumulus cloud type precipitation and large-scale condensation type. Cumulus precipitation can be generated in the atmospheric instability in vertical scale and large-scale condensation precipitation the horizontally large scale.

Figure 8 shows CS for cumulus precipitation of boreal summer. CS is largely or widely distributed than CS of the total precipitation (cumulus + large scale condensation), shown in Figure 3. Especially, large CS for cumulus precipitation can be found over North America, the mid-latitudes over the central Eurasia.

Figure 9 shows CS for large-scale condensation precipitation. Large CS is evaluated over some regions (East Asia and South Asia), however the value or the geographical distribution is smaller than the cumulus precipitation. Therefore, we suggest that land surface can contribute more cumulus precipitation than large-scale condensation. This result may explain that land surface can influence precipitation variability in local scale. If land surface can contribute to precipitation in local scale, the meteorological or the satellite-based observation over the hot spots can improve the seasonal prediction.

6. HORIZONTAL SCALE OF LAND SURFACE CONTRIBUTION TO PRECIPITATION

In previous sections, we suggested that land surface could contribute the accuracy for precipitation in local scale. From these results, however, we cannot conclude that the hotspots can be generated by only the contribution of the local surface conditions. In this section, we focus on the horizontal scale of the land surface contribution to precipitation with further experiment. We conduct another fixed experiment (16 ensembles), named Regional Fixed-Experiment (R_Fixed-Exp). We give "the observation data" over land surface where large CS for precipitation (more than 0.05) in Figure 3. Over other regions, where small CS, we calculate the land surface processes. In short, atmosphere and the small CS regions in R_Fixed-Exp can give the chaotic variation of atmosphere. When we calculate (4) over every grid cell, CS for precipitation can be quantified, shown in Figure 10. Therefore, we can discuss whether the hot spots are largely influenced by land surface local effect by comparing with Figure 3 and 10.

$$CS = \Omega_P(R\_Fixed-Exp) - \Omega_P(Cont-Exp) \qquad (4)$$

The degrees of CS in Figure 10 are smaller than in Figure in 3 over many regions, however large CS for precipitation is found over North America, the mid-latitudes in Eurasia and South Asia. Therefore, geophysical distributions of the hot spots are quite similar as in Figure 3. This result can be a reason that the land surface has local influence to precipitation.

7. LAND SURFACE CONTRIBUTIONS IN SEVERAL TIME SCALES

The land surface contribution to daily precipitation variation was discussed in previous sections. Here, the different degree of land surface impact is focused in different time scales. We analyze it by comparing two variances of Cont-Exp and Fixed-Exp, shown in (5).

$$\frac{\overline{V_C}}{\overline{V_F}} = \frac{\sum_{i=2}^{m}\left\{\sqrt{\left(P_{C_i} - P_{F_1}\right)^2}\right\}}{\sum_{i=2}^{m}\left\{\sqrt{\left(P_{F_i} - P_{F_1}\right)^2}\right\}} \qquad (5)$$

where $\overline{V_C}$: average value of the variance among ensemble members in Cont-Exp, $\overline{V_F}$: average value of the variance among ensemble members in Fixed-Exp P_{C_i} : time series of each ensemble member in Cont-Exp, P_{F_i} : time series of each ensemble member in Fixed-Exp, P_{F_1} : time series of a member in which land surface prognostic variables are stored. m: ensemble members (m=16), i: ensemble number.

The land surface contributions to precipitation in several time scales (1day to 3 months scale) over 5 regions are shown in Figure 11. Focused on over East Asia, the ratio of the variance to variance is linearly decreased with longer time scale from June to July. Therefore, land surface contribution to precipitation in longer time scale may improve the accuracy for seasonal forecast over East Asia from June to July. However over other 4 regions, the degree of the land surface contributions to the precipitation cannot be found such a significant result.

8. MATHEMATICAL STRUCTURE OF SIMILARITY PARAMETER

The parameter Ω is considered to quantify the degree of "similarity " among time series of several ensemble members (Koster and Suarez, 2002, Koster et al, 2004, Science). However, the mathematical structure of Ω has not revealed. Therefore, we apply to find or deepen the mathematical meaning of Ω by inducing it. We need several pages for express all processes for incusing Ω , so the final expression is shown in

$$\Omega_P = \overline{R'} + \left(\frac{1}{m-1}\right)\frac{\left(\frac{1}{m}\sum_{i=1}^{m}\left(\tilde{\sigma}_{P_i}^2 - \tilde{\sigma}_{P_{ai}}^2\right) - \sigma_P^2\right)}{\sigma_P^2} \qquad (4).$$

where $\overline{R'}$: the average value of the cross correlation coefficient across all ensemble members, $\tilde{\sigma}_{P_i}^2$: the variance of variance in one ensemble member to the average variance across all ensemble members, $\tilde{\sigma}^2_{P_{ai}}$: the variance of mean value in each ensemble member to averaged mean value across all ensemble members, σ^2_P : the average value of variance among all time periods and all ensemble members, m: ensemble members (in this study, m=16), i: ensemble number. In (4), we can mention that the similarity parameter Ω is consisted of the two parts. One is the Average value of the Cross Correlation Coefficient (ACCC) among all ensemble members. Another is the similarity for the mean value and the variance, in short, the similarity for the "shape" among all ensemble members. Concerning the cross correlation coefficient, if there are two ensemble time series, which are completely correlated not regarding with their amplitudes, then the cross correlation coefficient becomes 1. Of course, cross correlation coefficient can show the similarity of variation period among ensemble members. On the other hand, from a stand viewpoint of the similarity of shape between two ensemble members, Ω is more suitable parameter, which can be considered the effect of the mean value and the variance of these ensemble members. Therefore Ω has more comprehensive meaning to show the similarity among ensemble members comparing the cross correlation coefficients.

9. SUMMARY

We discussed the land surface contribution for daily precipitation variation (6day totals) and focused on what atmospheric processes can mainly constrain the land surface contribution to precipitation. As results, we found that two main processes for it. One is the atmospheric dryness condition over the near land surface. Suitable land surface dryness condition is found over the transition zone between extremely wet and dry regions. Daily evaporation variability (standard deviation) is also large over the transition zones. This result could be the reason that the temporal frequency of the sunshine can strongly affect CS for the evaporation. Another constraint factor is the development or the thickness of the atmospheric boundary layer. CS for temperature is largely decreased within ABL.

Furthermore, we could have knowledge about the horizontal scale of the land surface contribution to precipitation. As a result, land surface can affect the precipitation in local scale. Cumulus precipitation is largely or widely influenced by the land surface than the large-scale condensation. This result also suggests that the locality of the land surface contribution to precipitation.

We also discussed that the land surface contribution to precipitation in different time scale from daily to 3-month scale. As a result, we found that the land surface contribution to precipitation is more dominant in longer time scale, especially over East Asia. This can be mentioned that the importance to know the land surface conditions in detail for longer time scale.

Finally, mathematical characteristics of the similarity parameter Ω were discussed. In this abstract, the final expression was shown in (4). As a result, we can mention that the similarity parameter Ω is consisted of the two parts. One is the Average value of the Cross Correlation Coefficient (ACCC) among all ensemble members. Another is the similarity for the mean value and the variance, in short, the similarity for the "shape" among all ensemble members.

REFERENCES

Arakawa, A. and W.H. Schubert, 1974: Interactions of cumulus cloud ensemble with the large-scale environment. Part I. *J. Atmos. Sci.,* **31**, 671-701.

Beven, K.J., Kirkby, M.J., 1979: A physically based, variable contributing area model of basin hydrology. *Hydrol. Sci.Bull*. **24**, 43-69

Kanae, S., Hirabayashi, Y., Yamada, T., and Oki, T., 2004: Influence of land-surface hydrologic conditions on inter-annual variability of precipitation in boreal summer,*J.Climate*, submitted

Numaguti, A. Takahashi, M., Nakajima, T., Sumi, A., 1997: Description of CCSR/NIES Atmospheric General Circulation Model. CGER's Supercomputer Monograph Report, **3**, NIES, Tsukuba, Japan, pp. 1-48.

R. D. Koster and M. J. Suarez, 2001: Soil moisture memory in climate models", *J. Hydro Meteor*, .**2**, pp. 558-570

R. D. Koster, P. A. Dirmeyer, A. N. Hahmann, R. Ijpelaar, L. Tyahla, P. Cox and M. J. Suarez 2002: Comparing the degree of land atmosphere interaction in four atmospheric general circulation models", *Amer Meteor Soc*, **3**, pp.363-375

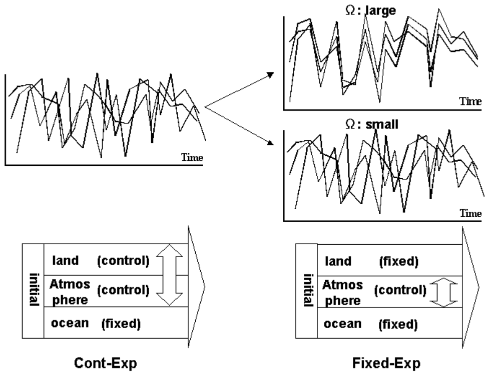
R. D. Koster, P. Dirmeyer, Z. Guo, G. Bonan, E. Chan, P. Cox, H. Davies, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C. H. Lu, S. Malyshev, B. McAvaney, K. Mitchell, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. C. Sud, C. M. Taylor, D. Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2004:Regions of Strong Coupling Between Soil Moisture and Precipitation, *Science*, **305**, pp. 1138-1140

Sellers, P. J., D. A. Randall, G. J. Collatz, J. A. Berry,C. B. Field, D. A. Dazlich, C. Zhang, G. D. Collelo, and L. Bounoua, 1996: A revised land surface parameterization (SiB2) for atmospheric GCMs. Part I: Model formulation, *J. Climate* **9**, 676-705.

Takata, K., S. Emori, T. Watanabe, 2003: Development of the minimal advanced treatments of surface interaction and runoff, *Global PlanetaryChange*, 209-222

Y. Vinnikov, Konstantin Ya., Alan Robock, Nina A. Speranskaya, and C. Adam Schlosser, 1996: Scales of temporal and spatial variability of midlatitude soil moisture. *J. Geophys. Res.*, **101**, 7163-7174.

Y. C. Sud, W. C. Chao, G. K. Walker, 1993: Dependence of rainfall on vegetation: Theoretical considerations, simulation experiments, observations and inferences from simulated atmospheric soundings, *J. Arid Envron*. **25**, 5



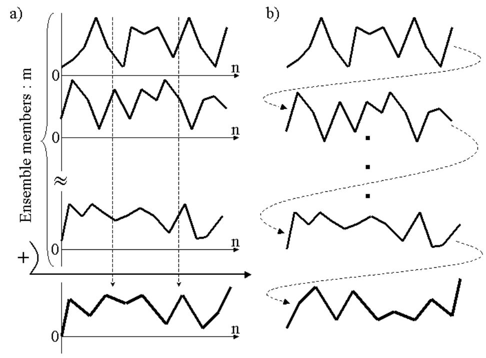


Figure 1(left). Schematic figures of the Cont-Exp (left) and the Fixed-Exp (right). control: control simulation, fixed : give the boundary condition. If m (m=16) ensemble time series are well (not) correlated, then Ω goes to 1 (0).

Figure 2(right). Schematic figures of two types of variances. Left (a): Variance is calculated from (1) which is the averaged time in each time period among 16 ensemble members. Right (b): Variance is calculated from a time series, which is the across all ensemble members and time periods.

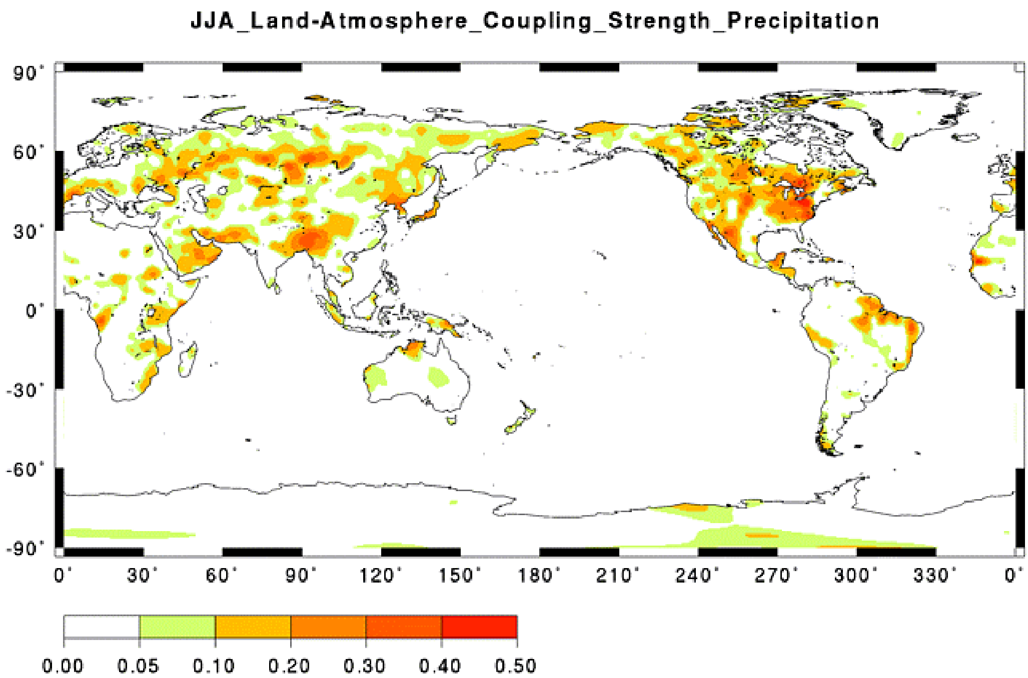


Figure 3. Global fields of CS for precipitation in JJA 1994. Large (small) number is the strong (weak) CS. Hot spots are appeared over North America, mid-latitudes in Eurasia and South Asia.

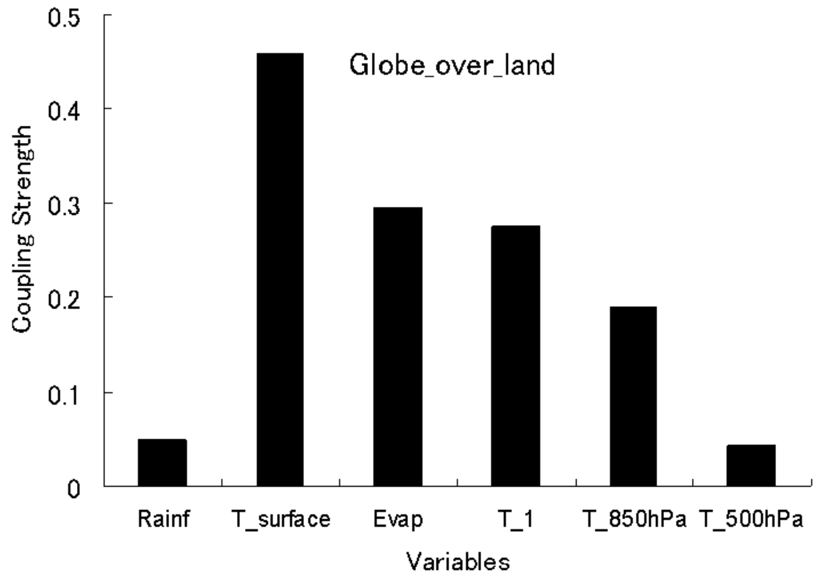


Figure 4. Average values of CS over land for 6 land and atmosphere variables (precipitation, surface temperature, evaporation, temperature in 3 vertical levels)

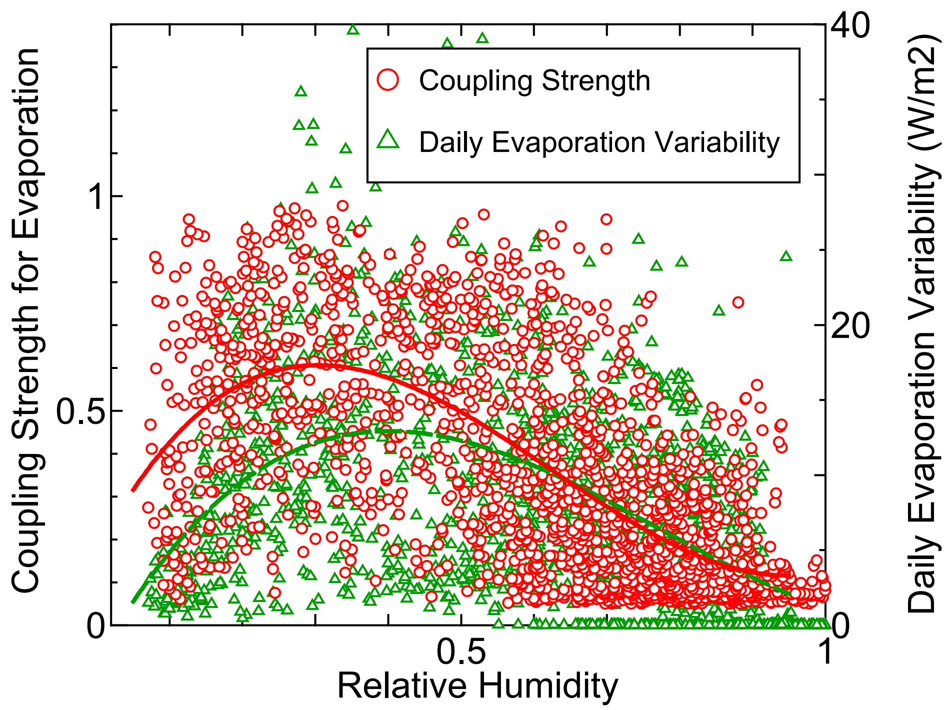


Figure 5. CS for evaporation (circle and solid line) and daily evaporation variability (standard deviation) (triangle and dashed line) to and surface dryness conditions over land.

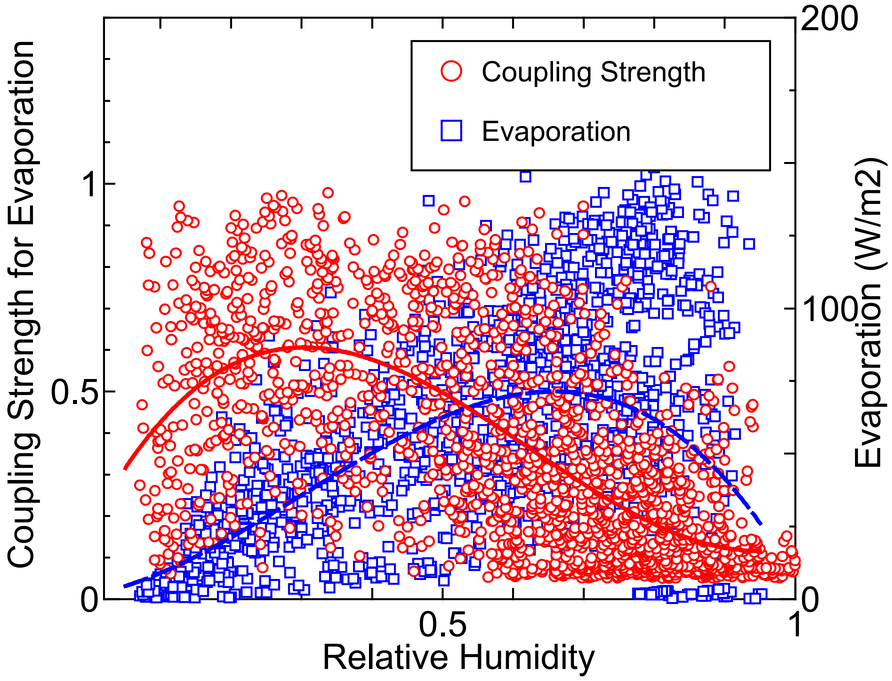


Figure 6. CS for evaporation to land surface dryness conditions over land (circle and solid line). 3 months averaged evaporation to land surface dryness conditions over land (square and dashed line)

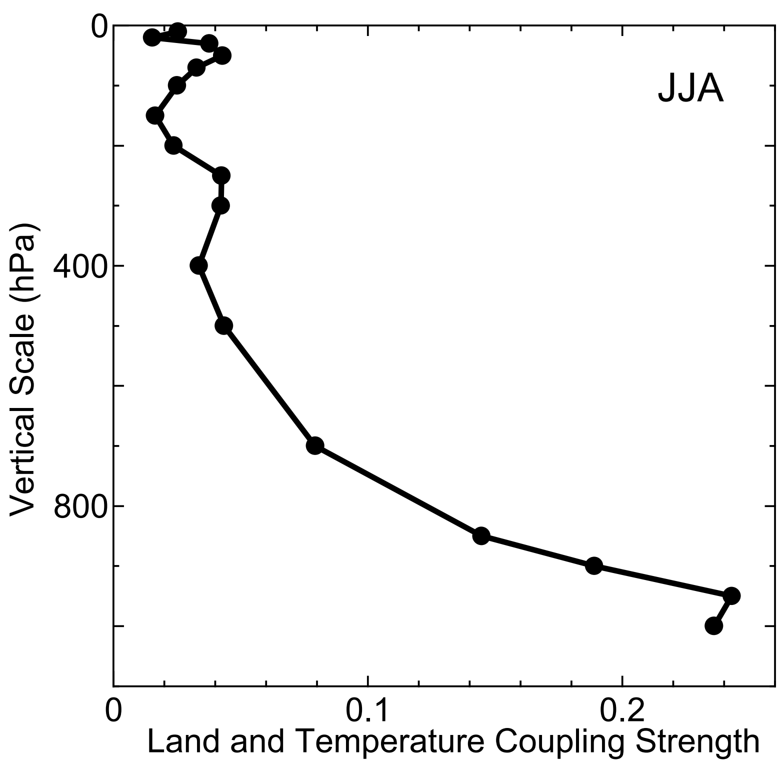


Figure 7. Vertical profile of CS for temperature in globe over land. CS is largely decreased within 800hPha vertical level.

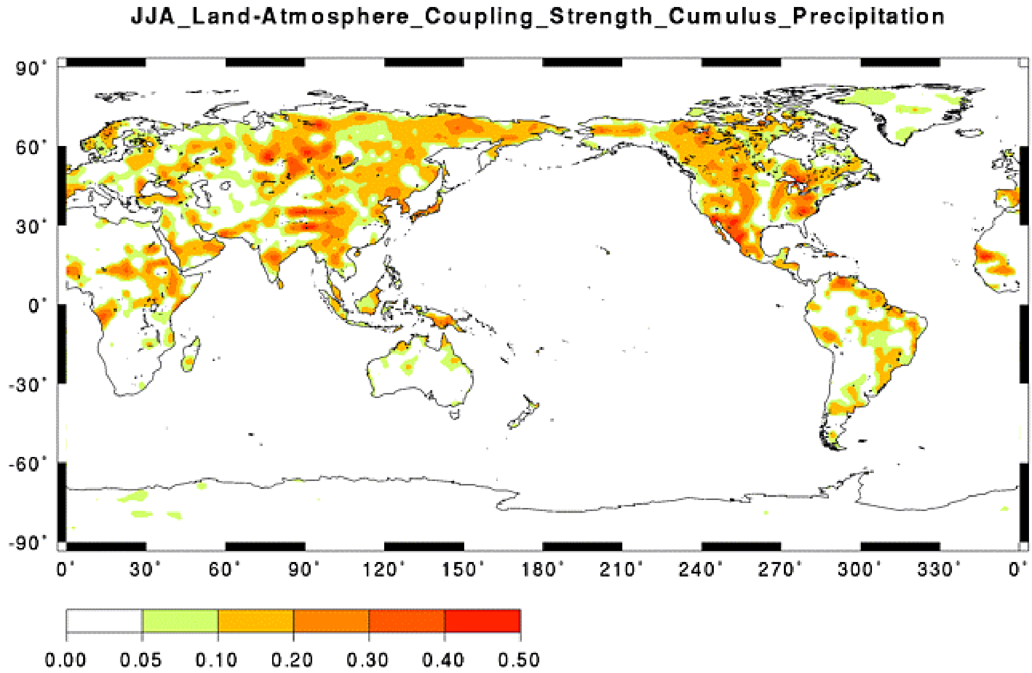


Figure 8. Global fields of CS for cumulus precipitation in JJA 1994. Large (small) number is the strong (weak) CS. Hot spots are more widely distributed than in Figure 3 (cumulus + large scale condensation).

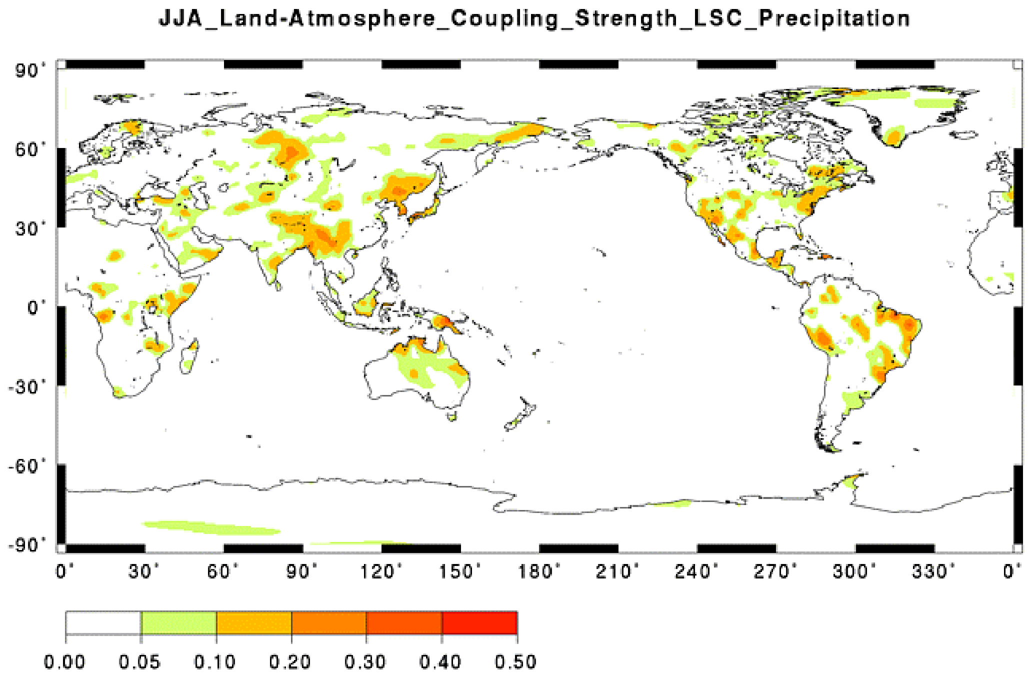


Figure 9. Global fields of CS for the large-scale condensation precipitation in JJA 1994. Large (small) number is the strong (weak) CS. Over many regions, CS is smaller than in CS for cumulus precipitation (Figure 8).

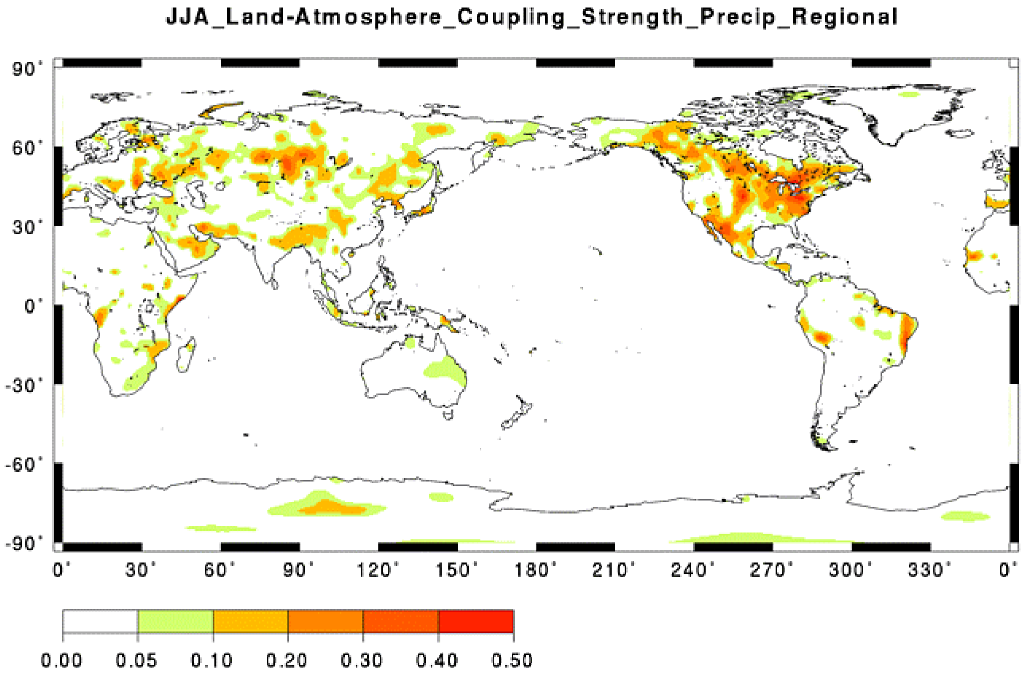


Figure 10. Global fields of CS for the precipitation in JJA 1994. Large (small) number is the strong (weak) CS. We give "the observation data" on land surface processes where large CS (more than 0.05) was evaluated in Figure3. Hot spots are found over North America, mid-latitudes in Eurasia and South Asia.

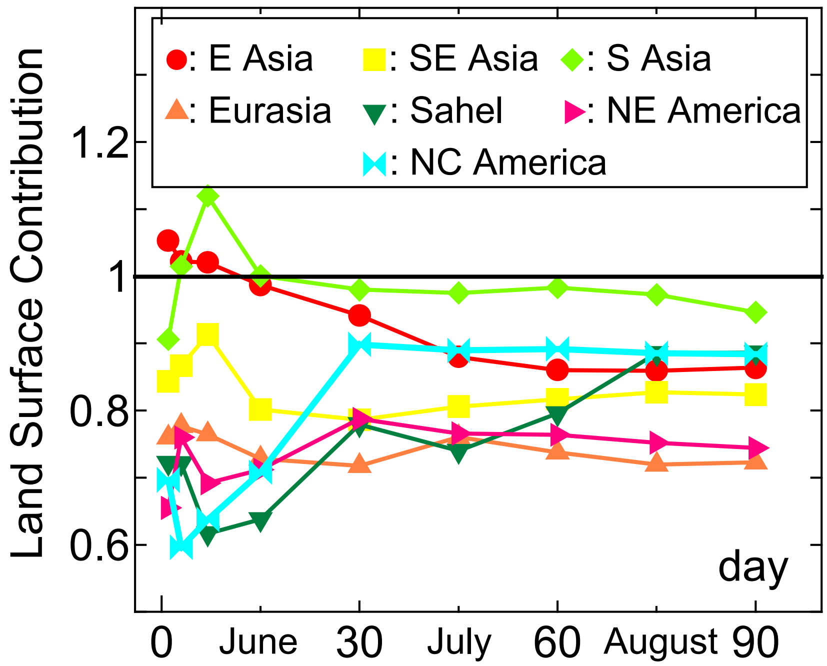


Figure 11. Land surface contribution to precipitation in several time scales. When the value goes to 0 (1), the land surface contribution becomes large (small).