Observational Analysis of Land-Atmosphere Coupling for Climate Model Evaluation

Research Highlight

The state of the land can influence surface energy and moisture fluxes, boundary-layer clouds, and regional convection and precipitation, especially in summer when it couples more intensely with the atmosphere. Therefore, investigations of the cloud life cycle over continents need to consider the role played by land-atmosphere interactions.

Coarse-resolution global climate models tend to simulate a relatively strong land-atmosphere coupling (e.g. between soil moisture and precipitation) in semi-arid zones, like the central United States. Whether these climate model predictions are realistic can be tested observationally by exploiting the extensive archives of high-frequency data recorded at the Atmospheric Radiation Measurement Southern Great Plains (ARM SGP) site near Lamont, Oklahoma. By employing ARM measurements of surface and atmospheric boundary-layer variables, along with soil moisture observations at SGP, aspects of the local land-atmosphere coupling manifested in diverse pairings of land and atmospheric variables can be investigated.

To visualize various aspects of the SGP land-atmosphere coupling, daily averages were constructed from hourly measurements of all the observed variables during the summers of 1997-2008, and different pairing of land-atmosphere variables were displayed as scatter plots. The relative strength of the various couplings of land variable x and atmospheric variable y were then inferred from the correlation R of y versus x.

Because land-atmosphere coupling is modulated by soil moisture W, particular attention was given to correlations of atmospheric variables with a normalized soil moisture index (SMI) ranging between values of 0 and 1 that corresponded, respectively, to the multi-year minimum and maximum values of W at a soil depth of 10 centimeters. Examples of scatter plots of surface relative humidity (RH) and air temperature T versus SMI at 10 centimeters depth are shown in Figures 1a and b. While surface RH increases over wetter soil, T tends to decrease, resulting in an atmospheric boundary layer (ABL) that is wetter and cooler than when the soil is drier. The absolute value of the correlation of RH with SMI also is larger (R = 0.51) than that for T (R = -0.38), implying a stronger coupling of soil moisture with relative humidity.

In a moist and cool ABL, the corresponding lifting condensation level (LCL) at which clouds are expected to initially form will be lower. Such a relationship is manifested by the negative correlation of the daytime LCL with soil moisture (R = - 0.46), shown in Figure 2a. The cloud base heights (CBH) of daytime ABL clouds observed at the ARM SGP site exhibit a similar anti-correlation with soil moisture (Figure 2b), but showing substantially less coherence (R = - 0.26). (The base heights of a subset of shallow cumulus clouds#indicative of a greater local influence of the land on the atmospheric boundary layer#correlate somewhat more strongly with soil moisture.) In addition, the coupling between SMI and other variables, such as those shown in Figures 1 and 2, were found to strengthen, as the soil becomes drier in the aftermath of precipitation events.

Contrary to the typical global climate model predictions, however, no statistically significant correlations of soil moisture with subsequent precipitation events were found at the ARM SGP site. This result reflects a general failure of the coarse-resolution climate models to correctly simulate the observed characteristics of SGP precipitation, which derives mostly from convective cells that are triggered remotely during the night, and then propagate over the site.

The observed characteristics of land-atmosphere coupling observed at the ARM SGP site provide a basis for further evaluation and diagnosis of climate model predictions over the United States Southern Great Plains. Future model investigations of this kind are planned that will make use of procedures developed by the DOE-funded

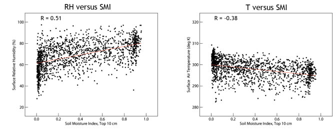

Figure 1. This figure shows the 1997-2008 summer co-variation of daily averages of surface relative humidity RH (left) and of surface air temperature T (right), with respect to the 10-centimeter SMI. In both cases, the regression line drawn through the scatter of points and the correlation coefficient R also are shown.

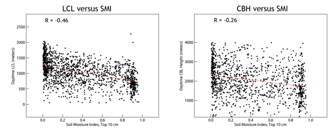

Figure 2. Similar to Figure 1, this shows daytime averages of the lifting condensation level LCL (left) and of the observed base heights of boundary-layer clouds CBH (right).

Cloud-Associated Parameterization Testbed (CAPT) at Lawrence Livermore National Laboratory.

Reference(s)

Phillips TJ and SA Klein. 2014. "Land-atmosphere coupling manifested in warm-season observations on the U.S. southern great plains." Journal of Geophysical Research – Atmospheres, 119(2), doi:10.1002/2013JD020492.

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Cloud Life Cycle