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Physical processes in present and future large-scale models

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Summary

Land surface processes and interaction with the atmosphere - Paul Dirmeyer

Land surface models (LSMs) represent the exchanges of light, heat, water, momentum, and carbon between the atmosphere and land surface, as well as accounting of the reservoirs of water, heat and carbon on and under the surface of the land. The land surface is important for weather and climate forecasting because there are feedbacks between land and atmosphere that are a source of predictability. Soil moisture-controlled feedbacks can impact forecasts from hours out to 2-3 months, but appear to have the greatest effect in the 2-4 week "sub-seasonal" range between traditional weather forecasts and seasonal climate forecasts governed by remote sea surface temperature anomalies (Dirmeyer et al. 2015a). These feedbacks follow from our understanding of the physical processes involved (e.g., Betts 2004, Ek and Holtslag 2004), but are extremely difficult to diagnose in nature. In numerical models we have a tool to identify and understand the distribution of these feedbacks in space and time, but only to the extent that we can verify that models of land and atmosphere are behaving as nature does on similar scales.

We define "coupling" between land and atmosphere as the condition by which feedbacks from land to atmosphere exist and anomalies in land states can affect weather and climate. Coupling is often diagnosed by significant temporal correlations between surface and atmospheric variables. However, coupling alone is insufficient to insure the land surface has important consequences for the atmosphere. Also necessary is sufficient variability in time of the land states that force responses in the atmosphere, and sufficient persistence or memory of those land states so that their accumulated affect on the atmosphere has ramifications.

The Global Energy and Water Exchanges (GEWEX) Global Land-Atmosphere Coupling Experiment (GLACE; Koster et al. 2004) demonstrated with 12 different weather and climate models that certain continental regions are "hotspots" of land-atmosphere coupling. In these areas, soil moisture was demonstrated to exert a significant control on atmospheric temperature and precipitation during boreal summer. Subsequent experiments demonstrated regional hotspots in other seasons (Dirmeyer et al. 2009), and how hotspots can vary in time (Guo and Dirmeyer 2013). The linkage from land to atmosphere has two "legs" (Guo et al. 2006). There is a terrestrial leg by which soil moisture controls the partitioning of net radiation at the land surface between sensible and latent heat fluxes; this exists in areas where evapotranspiration (ET) is moisture limited rather than energy limited (Dirmeyer 2011). The second leg is atmospheric, where the Bowen ratio significantly affects boundary layer properties and the likelihood of cloud formation and precipitation (Tawfik and Dirmeyer 2014). For precipitation, there can be regions of positive feedback where increased ET and humidity favor clouds and rainfall, and regions of negative feedback where increased sensible heat flux results in deeper boundary layers and a greater chance of condensation of water vapor (Findell and Eltahir 2003a,b). Surface gradients can spur mesoscale circulations that favor precipitation (Taylor et al. 2011).

A follow-on experiment to GLACE demonstrated that sub-seasonal prediction skill can be improved by realistic initialization of soil moisture fields (Koster et al. 2010). However, only 4 of

12 models demonstrated notable improvement (Koster et al. 2011), suggesting many models lack one or more aspects of the necessary feedbacks – coupling, variability or memory. Benchmarking of LSMs (Best et al. 2015) and observable metrics of land-atmosphere coupling are now being developed and applied to validate and improve models so that the predictability from land surface states can be harvested. Yet there remain many issues in the application of *in situ* and remotely sensed land surface states and fluxes to model validation and data assimilation because of differences in scale, the impact of observational errors, instrument calibration and maintenance (Dirmeyer et al. 2015b). In particular, soil moisture as represented by LSMs is not representative of nature (Koster et al. 2009). Nevertheless, coupled metrics are demonstrating that model development should also be coupled; land surface and atmospheric models can no longer be developed separately with the expectation that they will behave realistically when plugged together (Dirmeyer et al. 2015a).

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