1. Header

Land-Atmosphere Predictability Using a Multi-Model Strategy

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Final Report

2. Results and Accomplishments

Output from multiple land surface schemes (LSS) averaged together produces better simulations of soil moisture than any individual model (Guo et al. 2007), and the addition of a "poor" model does little to degrade the multi-model mean, while addition of a "good" model can substantially improve performance. Multi-model coupling (interactive ensemble) has been shown to be effective in coupled ocean-atmosphere prediction. Can a similar approach be exploited for multiple LSSs coupled to an atmospheric general circulation model (AGCM)?

This project has shown that coupling multiple LSSs to a single AGCM is computationally practical and economical. We have accomplished this with two different AGCMs and three different LSSs. SSiB and CLM3.5 have been coupled to the GFS AGCM, and have been tiled to run concurrently with the native Noah land scheme (Zhang et al. 2010). Similarly, Noah and CLM3.5 have been coupled to the COLA AGCM (Wei et al. 2010a,b). A full suite of GLACE-style seasonal ensemble simulations have been produced, as well as 18-year AMIP-type simulations with each LSS coupled to each AGCM, and all three coupled simultaneously with equal 1/3 weights.

Although the three LSSs receive the same atmospheric forcing when jointly coupled to the same AGCM, their inter-model spread of latent heat flux can be larger or smaller than

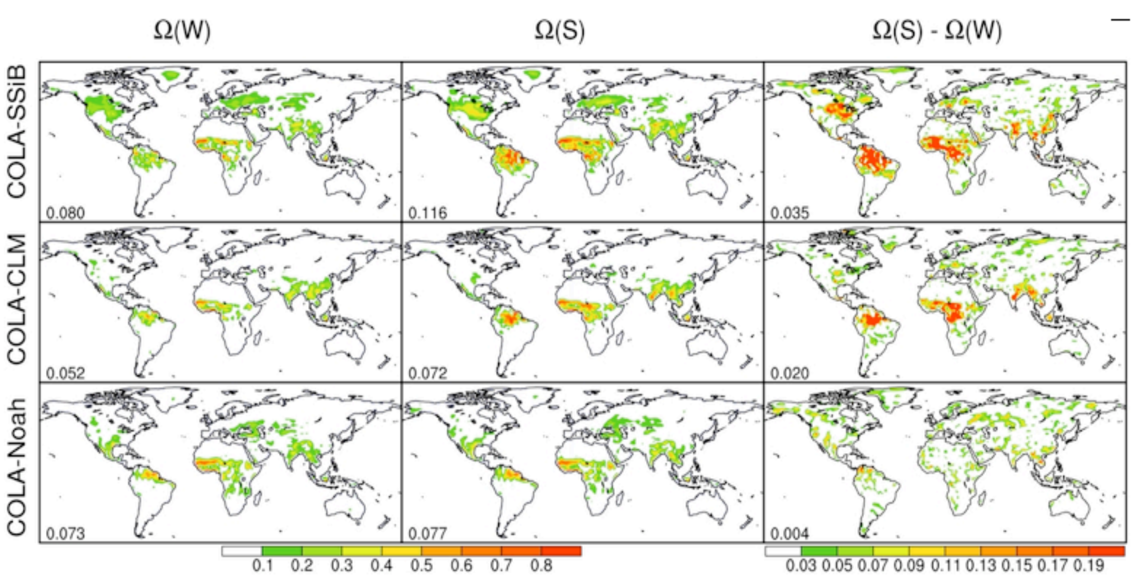

Figure 1 . The GLACE parameter Ω for precipitation from ensembles W (left column) and S (middle column), and their difference (right column). Top row: COLA-SSiB. Middle row: COLA-CLM. Bottom row: COLA-Noah. The global mean (land only) value of each panel is shown at the left corner.

the individually coupled experiment, depending mostly on the evaporation regime of the models in different regions (Fig 1). The influence of LSS uncertainties on the simulation of surface temperature is stronger in dry regions/seasons, and its influence on daily maximum temperature is stronger than on minimum temperature. Land-atmosphere interaction can damp the impact of LSS uncertainties in tropics, but can strengthen their impact in middle to high latitudes. The Noah land model has much shorter memories of surface heat fluxes, but its impact on the global pattern of precipitation persistence is very little.

GLACE-type experiments reveal that coupling to different land models or prescribing subsurface soil moisture does not change the global pattern of precipitation predictability (W) and variability very much. However, the regional impact of soil moisture can be highlighted by calculating the land-atmosphere coupling strength, which shows very different patterns for the three land schemes. The estimated precipitation predictability and land-atmosphere coupling is mainly associated with the low-frequency component of precipitation. Based on these findings, the land-atmosphere coupling strength is conceptually decomposed into the impact of low-frequency external forcing and impact of soil moisture. As most models participating in GLACE have overestimated the low-frequency component of precipitation, compared to several observational data sets, a scaling of the GLACE land-atmosphere coupling strength is performed. The scaled coupling strength is generally weaker, but the pattern does not change much (Wei and Dirmeyer 2010).

We have found that the weak coupling strength of the Noah LSS in experiments when sub-surface soil moisture is controlled is actually a product of its thick surface soil layer (10 cm). The Noah scheme performs comparably to other LSSs when all soil layers are constrained in estimating land-atmosphere coupling strength (Table 1). Nevertheless, GFS appears to have properties of its parameterizations of PBL and/or convection that still limit its sensitivity to variations of the land surface, relative to other AGCMs. So its weak coupling strength in the official GLACE experiments cannot be attributed to the Noah land surface scheme (Zhang et al. 2010).

Model	Subsurface soil moisture			All land states		
	SW-P	SW-ET	ET-P	SW-P	SW-ET	ET-P
GFS/OSU (GLACE)	-0.004	0.02	-0.17	0.036	0.41	0.09
GFS/Noah	-0.007	0.07	-0.11	0.013	0.27	0.05
COLA/Noah	0.016	0.15	0.11	0.036	0.20	0.18
COLA/SSiB	0.035	0.28	0.13			

Table 1 Changes in GLACE coupling strength Ω for various model configurations. Shown are metrics for the path from soil wetness to precipitation (SW-P), soil wetness to ET (SW-ET) and the metric for ET to precipitation (ET-P). Weak coupling with Noah when subsurface soil moisture is controlled is alleviated when all state variables are specified. However, Noah in GFS is still much weaker than Noah in the COLA AGCM.

Our findings regarding progress on this research, and Noah and GFS behavior in particular, have been presented to colleagues at NCEP/EMC and to the community at large through a series of meetings, including presentations in the Climate Test Bed seminar series, CPPA PI meetings, NCAR CCSM Land Model Working Group workshops, and the 2nd NCEP/NOAA Workshop on Numerical Weather and Climate Modeling in Austin, TX in April 2010.

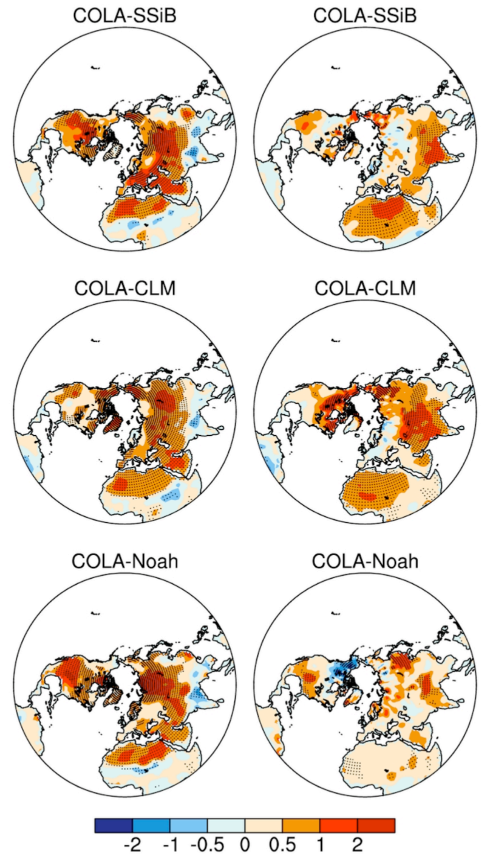

Figure 2. Northern Hemisphere average TS change (2xCO2-CTL) in JJA (left column) and DJF (right column) for different coupled models. The stippled regions have significant (p<0.05) changes according to a two-tailed t-test.

We have also used this model configuration for timeslice climate change experiments, doubling CO_2 in the COLA AGCM and examining the sensitivity of climate change projections to the choice of land surface scheme in the same AGCM (Wei et al. 2010c). We find that while there is no impact on global mean values, which are controlled by the atmospheric composition and specified SST, regional differences in the climate change signal do vary depending on the LSS (Fig 2). Impacts are larges in winter, and the variation in the climate change signal is generally smaller than differences in mean climate among the LSSs. Variations among LSSs in climate change projections are largest and potentially significant in warm regions and seasons.

We also examined the role of land-atmosphere interactions in coupled climate models and contrasted that to standard land-atmosphere only configurations as described above. We found that the differences between a coupled ocean-atmosphere model and the same AGCM forced with observed SST are larger over the continental US in the boreal summer season than in the winter. One of the main reasons for such larger differences in the boreal summer is traced to the stronger land-atmosphere feedback that causes the divergence of the solutions between the two integrations (Misra and Dirmeyer 2009). It is also demonstrated from both observations and a climate model integration that the dominant interannual variations of the precipitation over northern tropical South America (NTSA) associated with ENSO variability in the eastern equatorial Pacific Ocean resides in its diurnal scales. Further analysis of the model results suggests that the local land-atmosphere feedback over NTSA does not show as robust an interannual variation as precipitation. It is shown from the model results that the moisture flux convergence is probably the dominant source of this variability over NTSA including its diurnal variations of the interannual variability of precipitation. It is therefore proposed that the moisture flux convergence in the NTSA region acts as a conduit for the local amplification of the large-scale interannual signal at diurnal scales (Misra 2009).

3. Highlights of Accomplishments

- Extensive coding of COLA AGCM and GFS to accommodate multiple LSSs coupled simultaneously and running in tandem on the same land/sea mask at the same resolution, with weighted average of fluxes from all schemes returned to the AGCM each time step (only equal weights and single weights (1,0,0) tested extensively).
- The apparently weak coupling strength in Noah is a product of its thick surface soil layer, which works to this LSS's disadvantage in the standard GLACE experimental framework. Noah performs on par with other LSS's when surface and subsurface soil moisture is considered together.
- By elimination we find that GFS does have intrinsic weakness in conveying land surface anomalies and variability to the atmosphere (precipitation) compared to COLA AGCM, and its weakness of coupling strength in the original GLACE experiments (coupled to the OSU LSS at that time and compared to 11 other AGCMs) was no fluke.
- Findings about Noah and GFS behavior have been conveyed to NCEP/EMC land modeling group.
- We discovered that much of the land-atmosphere coupling strength found in the GLACE framework for many AGCMs comes via low-frequency (>20day) precipitation variability, which is too robust in most AGCMs. Model estimates of coupling strength may be too high.
- This unique multi-LSS model configuration has been used to show the sensitivity of regional temperature responses to GHG forcing over land depend on the LSS used.

4. Publications From the Project

Guo, Z., P. A. Dirmeyer, X. Gao, and M. Zhao, 2007: Improving the quality of simulated soil moisture with a multi-model ensemble approach. Quart. J. Roy. Meteor. Soc., 133, 731-747.

Koster, R. D., Z. Guo, P. A. Dirmeyer, R. Yang, K. Mitchell, and M. J. Puma, 2009: On the nature of soil moisture in land surface models. *J. Climate*, **22**, 4322–4335.

Misra, V., and P. A. Dirmeyer, 2009: Air, sea and land interactions of the continental US hydroclimate. *J. Hydrometeor.*, **10**, 353-373.

Misra, V., 2009: The amplification of the ENSO forcing over Equatorial Amazon. *J. Hydrometeor.*, **10**, 1561-1568.

Wei, J., P. A. Dirmeyer, and Z. Guo, 2008: Sensitivities of soil wetness simulation to uncertainties in precipitation and radiation, *Geophys. Res. Lett.* **35**, L15703, doi: 10.1029/2008GL034494.

Wei, J., P. A. Dirmeyer, Z. Guo, L. Zhang, and V. Misra, 2010a: How much do different land models matter for climate simulation? Part I: Climatology and variability. *J. Climate*, **23**, 3120-3134.

Wei, J., P. A. Dirmeyer, and Z. Guo, 2010b: How much do different land models matter for climate simulation? Part II: A temporal decomposition of land-atmosphere coupling strength. *J. Climate*, **23**, 3135-3145.

Wei, J., P. A. Dirmeyer, and J. Zhang, 2010c: Land caused uncertainties in climate change simulations. Quart. J. Roy. Meteor. Soc., 136, 819-824.

Wei, J., and P. A. Dirmeyer, 2010: Toward understanding the large-scale land-atmosphere coupling in the models — the roles of different processes. *J. Geophys. Res.*, (submitted).

Zhang, L., P. A. Dirmeyer, J. Wei, Z. Guo, and C.-H. Lu, 2010: Land-atmosphere coupling strength in the Global Forecast System. *J. Hydrometeor.*, (submitted).

5. PIs Contact Information

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6. Budget for Coming Year

N/A.

7. Future Work

N/A.