The GLACE-2 Experiment

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(with tremendous help from the GLACE-2 participants listed in section 4)

1. Introduction

Numerical weather forecasts rely on atmospheric initialization – the accurate specification of atmospheric pressures, temperatures, winds, and humidities at the beginning of the forecast. Such initialization may contribute to forecast skill at leads of up to about ten days. Forecasts at longer leads, however, require a different strategy. They must take advantage of slower modes of the climate system, modes with states not so quickly dissipated by chaos.

Soil moisture is one such slower variable, one that is beginning to garner attention in the forecast community (e.g., Dirmeyer et al., 2003). The timescales of soil moisture memory are typically 1 or 2 months (Vinnikov and Yeserkepova 1991; Entin et al. 2000. For the prediction of summer midlatitude precipitation over continents at subseasonal and longer leads, soil moisture initialization may be more important than ocean initialization (Koster et al., 2000).

Note that for a realistic land surface initialization to improve a forecast, two things must happen: (i) the initialized soil moisture anomaly must be remembered into the forecast period, and (ii) the atmosphere must respond in a predictable way to the soil moisture anomaly. The second requirement was addressed comprehensively by the first phase of the Global Land-Atmosphere Coupling Experiment (GLACE-1). Full details of the GLACE-1 experimental design and an overview of the results are provided by Koster et al. (2006). A key result was the determination of a "model consensus" of where week-to-week precipitation variability can be influenced by prescribed variations in deeper (below 10 cm) soil moisture reservoirs. As expected, the "hotspots" of relatively strong coupling are, for the most part, found in the transition zones between humid and dry areas – zones for which evaporation is both large and responsive to variations in soil moisture.

The findings of GLACE-1 set the stage for GLACE-2, a study of both aspects together, i.e., the full initialization question. In GLACE-2, participants utilize established seasonal forecast systems to quantify the degree to which accurate land surface initialization contributes to skill in subseasonal forecasts (out to two months). The use within GLACE-2 of a common experimental framework with a wide variety of models has produced the first comprehensive examination and consensus evaluation of land initialization impacts on forecast skill. Participants in GLACE-2 are learning, for the first time ever, the quantitative benefits that can stem from the use of realistic land surface state initialization in their forecast algorithms.

GLACE-2, like GLACE-1 before it, is jointly sponsored by the Global Land-Atmosphere System Study (GLASS) panel of the Global Energy and Water Cycle Experiment (GEWEX) and the Working Group on Seasonal-to-Interannual Prediction of the Climate Variability Experiment (CLIVAR). The joint emphasis on land surface initialization and subseasonal prediction clearly spans GEWEX and CLIVAR, making GLACE-2 a strong contribution to the COPES (Coordinated Observation and Prediction of the Earth System) program through the Task Force for Seasonal Prediction (TFSP).

2. Experiment overview

Participants in GLACE-2 perform the following two series of forecasts:

Series 1	
Description	Forecast simulations using realistic land surface state initialization
Length of each forecast	2 months (more precisely, 60 days)
Start dates	April 1, April 15, May 1, May 15, June 1, June 15, July 1, July 15, August 1, and August 15 in each of the years 1986-1995
Total number of start dates	100
Number of ensemble members per forecast	10
Equivalent number of simulation months	2000 (=166.7 years)

Series 2	
Description	Forecast simulations not using realistic land surface state initialization
Length of each forecast	Same as for Series 1
Start dates	Same as for Series 1
Total number of start dates	Same as for Series 1
Number of ensemble members per forecast	Same as for Series 1
Equivalent number of simulation months	Same as for Series 1

These two series represent the base set of GLACE-2 simulations; they are the only "mandatory" simulations. However, modeling groups with the necessary interest and computational resources may perform additional forecast simulations, as described later. The non-mandatory additional forecasts cover a much broader span of years and thereby would allow for a more accurate quantification of forecast skill.

Optimally, initial land surface states for Series 1 are established through participation in the Global Soil Wetness Project – Phase 2 (GSWP-2; Dirmeyer et al. [2006]). GSWP is a modeling research activity of GLASS and the International Satellite Land-Surface Climatology Project (ISLSCP), both of which are contributing projects of GEWEX. Through GSWP-2, modelers produce global fields of land surface fluxes, state variables, and related hydrologic quantities by driving their models offline with global arrays of observations-based meteorological forcing. This forcing spans the period 1986-1995 at a resolution of 1 degree. GSWP-2 model states at the forecast start times are used to initialize the 2-month forecasts in GLACE-2.

For Series 2, the initial land states for a given forecast ensemble are not identical; rather, they are drawn from a distribution of potential states, the distribution determined from long-term retrospective simulations with the land model. Series 2 is identical to Series 1 in every way except for the fact that it does not benefit from the use of realistic land state initialization.

Outputs submitted to the GLACE-2 data center include 15-day-averaged precipitation, air temperature, soil moisture, evaporation, net radiation, and relative humidity fields for each ensemble member. Daily soil moisture values are submitted for a subset of the ensemble members.

3. Details of Experiment

A more complete discussion of the technical details of the GLACE-2 experiment is provided at the GLACE-2 website: http://gmao.gsfc.nasa.gov/research/GLACE-2/docs/GLACE2c.pdf. A brief summary is given below.

3.1. Model resolution

The participating modeling group is allowed to choose the model resolution for both the land and atmosphere components of the prediction system. Model outputs are provided to the GLACE-2 Data Center at the model's resolution.

3.2. Land surface variable initialization

The preferred method of attaining initial land surface states for the Series 1 forecasts is through offline simulation. The GSWP-2 atmospheric forcing is available at a 1^o x 1^o resolution; this forcing is aggregated, disaggregated, or interpolated to the grid used by the forecast modeling system. The regridded forcing data is then used to drive the forecast system's land model globally, using the land resolution and boundary parameters (vegetation type, soil type, etc.) used by the full forecast system. Alternative approaches, less desirable but still allowed, include the regridding of 1^o x 1^o GSWP-2 multi-model land state products to the atmospheric model's resolution.

Once the land states are generated, participants are encouraged to "scale" the states to the forecast system's climatology to account for biases in the forecast model. By scaling, a relatively dry state in the GSWP-2 offline exercise is converted to a correspondingly dry state for the coupled model system. Effective scaling approaches involve the interpretation of states in terms of standard normal deviates or the use of cumulative distribution function matching. Scaling is absolutely critical if, for example, the multi-model products from GSWP-2 are used for the initialization.

For the Series 2 forecasts, the land initial conditions are not the same amongst the ensemble members, being drawn instead from a distribution of potential initialization datasets, as established (for example) from the mining of archived restart files.

3.3. Meteorological datasets for land initialization

GSWP2 (http://www.iges.org/gswp2/sensitivity.html) offers a number of 10-year forcing datasets. GLACE-2 relies on the baseline (B0) forcing dataset, mostly because some groups have already performed the baseline runs and may depend on using those data for GLACE-2.

3.4. Atmospheric initialization

If possible, the atmosphere is initialized realistically, i.e., with fields representing the actual state of the atmosphere on the forecast start date. Most participants extract appropriate atmospheric conditions from existing reanalyses. Ten different sets of atmospheric initial conditions are constructed for each ensemble, using the user's choice of ensemble generation technique.

3.5. Use of prescribed SSTs vs. the use of coupled ocean-atmosphere models

The SSTs prescribed during each forecast period are provided by the GLACE-2 organizers; the time series of SST fields were constructed by applying a simple persistence measure to the SST anomalies present on the forecast start date. Because this persistence measure was derived from observations outside of the year in question, no knowledge of SST evolution during the forecast period is assumed.

Some groups (e.g., those involved in operational seasonal forecasting), however, found it logistically easier or scientifically more productive to run their forecasts in coupled mode, i.e., with the full interactive ocean running together with the atmospheric model. In the coupled approach, the SSTs (and subsurface ocean states) are only initialized at the start of the forecast; SSTs during the forecast period are predicted rather than prescribed.

4. Participants

At present, eleven groups, representing thirteen models, have produced data for GLACE-2. These groups are as follows:

Group	Model	Points of Contact
Canadian Centre for Climate Modelling and Analysis	CanCM3	W. Merryfield W.-S. Lee, A. Berg, G. Drewitt
CCSR/NIES/FRCGC (Japan)	CCSR GCM	T. Yamada
Center for Ocean-Land-Atmosphere Studies (USA)	COLA GCM V3.2; NCAR CAM3.5+CLM3.5	P. Dirmeyer, Z. Guo, D. Lawrence
ECMWF	Integrated forecast system (coupled to ocean model)	G. Balsamo, F. Doblas-Reyes, F. Vitart
ECMWF/KNMI	ECMWF forecast system with prescribed SSTs	B. van den Hurk
Florida State University / Center for Ocean- Atmosphere Prediction Studies	FSU/COAPS model	M. Boisserie
Geophysical Fluid Dynamics Lab (USA)	GFDL global atmospheric model	T. Gordon, S. Malyshev
Inst. Atmospheric and Climate Sciences (Switzerland)	ECHAM/JSBACH	S. Seneviratne, T. Stanelle
NASA/GSFC (USA)	GMAO seasonal forecast system (old and new)	R. Koster, S. Mahanama, Z. Li
Princeton University (USA)	NCEP system(GFS/NOAH)	E. Wood, L. Luo
U. Gothenburg (Sweden)	NCAR CAM3.0	J.-H. Jeong

5. First results

The forecasted 15-day precipitation and air temperature values are standardized and plotted against the corresponding standardized observations. The resulting square of the correlation coefficient (r^2) between the forecasts and observations is our measure of forecast skill. To isolate the contribution of realistic land initialization to forecast skill, the r^2 value for the Series 2 forecasts (i.e., that obtained without realistic land initialization) is subtracted from that of the Series 1 forecasts (i.e., that obtained *with* realistic land initialization). The GLACE-2 analyses consider separately the four 15-day periods within a forecast, so that the fall-off of land-related forecast skill with lead time can be quantified.

In our first analyses, we focus on 15-day averages falling in the June-August timeframe because evaporation is strongest during this period, so that land conditions would have the greatest impact. We also focus our first analyses on the continental United States, which satisfies two critical conditions: (i) it hosts an extensive observational network, and (ii) the models participating in GLACE-1 show it to contain a large land-atmosphere coupling “hotspot”.

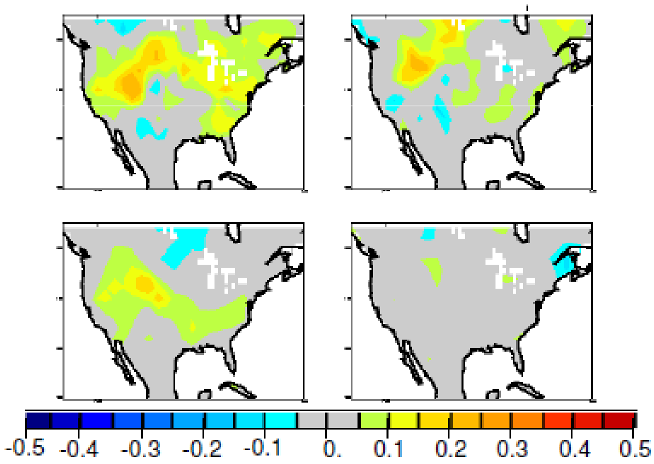

Figure 1. Contributions of realistic land initialization to air temperature forecast skill at days 16-30, for four different forecast systems.

Figure 1 shows, for four modeling systems, the land contributions to air temperature forecast skill (r^2 for Series 1 minus r^2 for Series 2) for the 2nd 15-day period (days 16-30). Models are intentionally not identified in this figure; the figure is provided solely to illustrate how differently the models behave. One of the models (bottom right) shows no skill associated with land initialization; two others appear to show moderate levels, with r^2 differences exceeding 0.2 in places.

Of course, for a given model the aforementioned standardization has no impact on the calculated r^2 differences. The standardization does, however, allow forecast/observation pairs from different modeling systems to be placed on the same scatter plot, allowing in turn the calculation of a statistically robust "consensus" vision of land-related forecast skill from a much greater number of points. Details are provided in a recent paper in Geophysical Research Letters (Koster et al., in press). The model consensus view is that realistic land initialization contributes slightly (but in a statistically significant way) to precipitation forecast skill in parts of the central U.S. out to 45 days and more substantially to temperature forecast skill in most of the U.S. out to 60 days (r^2 differences often higher than 0.05).

Forecast skill increases substantially when conditioned on the size of the initial soil moisture anomaly. Figure 2, a variation on a figure in Koster et al. (in press), shows the skill associated with land initialization when only a subset of the start dates is considered: those start dates for which the initial soil moisture conditions in the root zone are particularly dry (in the lowest quintile of all realized values) or particularly wet (in the highest quintile of all realized values). The local soil moisture value is used to condition the local forecasts; thus, the subset of start dates contributing to Figure 2 varies with location. Land-related skill

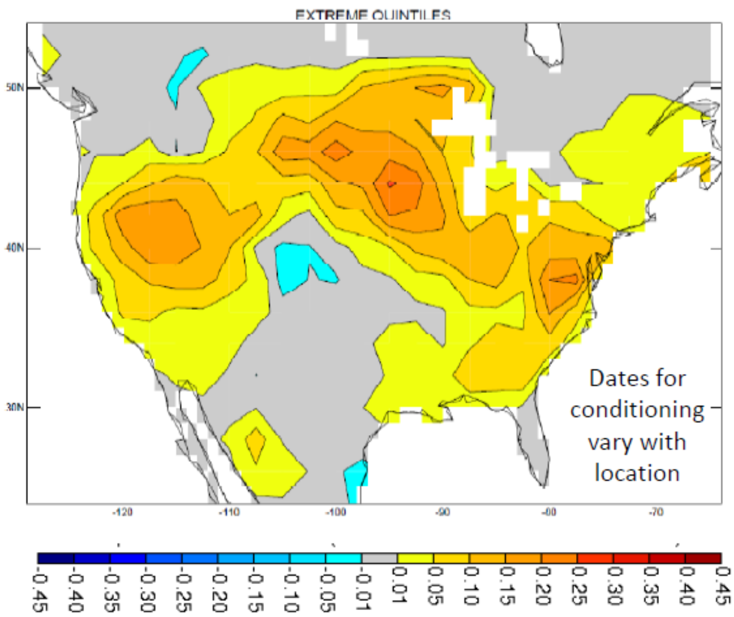

Figure 2. Conditional air temperature forecast skill (r^2) associated with land initialization. The quantity predicted is the average air temperature over days 31-45 of the forecast. Forecasts at a given location are conditioned on the initial soil moisture at that location – only those start dates for which the initial soil moisture lies in the lowest or highest quintile of all realized values are used in the skill calculation. Adapted from Koster et al. (in press).

contributions (r^2 from the forecasts with realistic land initialization minus r^2 from the forecasts without it) are generally positive and statistically significant across the U.S. (see Koster et al. [in press] for significance results) and r^2 contributions higher than 0.2 are seen in the center of the country.

6. Planned additional analyses

GLACE-2 provides a wealth of data for land-atmosphere prediction studies. A few of the studies planned for the near future include the following:

a. *Analysis of model predictability (as opposed to skill).* The GLACE-2 experimental design allows us to quantify the degree to which a model can "predict itself", i.e., the degree to which one ensemble member in a forecast can capture the average behavior of the other ensemble members. This is an intrinsically model-dependent property that, while not necessarily a good measure of nature's true predictability, is nevertheless important to quantify for the interpretation of forecasts with that model. The contribution of land initialization to predictability will be estimated by comparing the predictability diagnosed from the Series 1 forecasts with that diagnosed from the Series 2 forecasts.

b. *Global scale focus.* The results above focus on the continental United States. One ongoing study involves the analysis of ROC scores over Europe, and other region-specific analyses will almost certainly evolve.

c. *Extended time frame for analysis.* The 10-year GSWP-2 time frame can be extended by using a longer-term atmospheric forcing dataset, such as that provided by Sheffield et al. (2006). Some groups are planning such an extension. The longer series of forecasts would allow more robust statistics, as well as the study (for example) of the recent European heat wave.

d. *Analysis of potential asymmetry.* Are dry anomalies easier to predict than wet anomalies? Careful analysis of the GLACE-2 outputs may reveal the answer.

e. *Local vs. remote impacts.* The skill scores described in Koster et al. (2010) condition the skill calculations on local soil moisture anomalies. Are there remote impacts? Carefully designed analyses may reveal an answer.

f. *Impacts of water holding capacity.* One group performed the GLACE-2 suite twice, the second time using a land model with an artificially increased water-holding capacity. The higher capacity led to some increase in temperature forecast skill.

g. *Decay of predictability and skill with lead time.* This is being addressed with daily precipitation and air temperature diagnostics provided by a subset of the groups.

h. *Impacts of scaling the land surface initial conditions.* When initial conditions are not scaled to account for model climate biases, forecast skill levels may change. One group has addressed this by repeating the experiments without the scaling.

Naturally additional analyses will suggest themselves as participants begin poring through the data.

7. References

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