"Climate Dimensions"

Paul Dirmeyer
Center for Ocean-Land-Atmosphere Studies
Calverton, Maryland

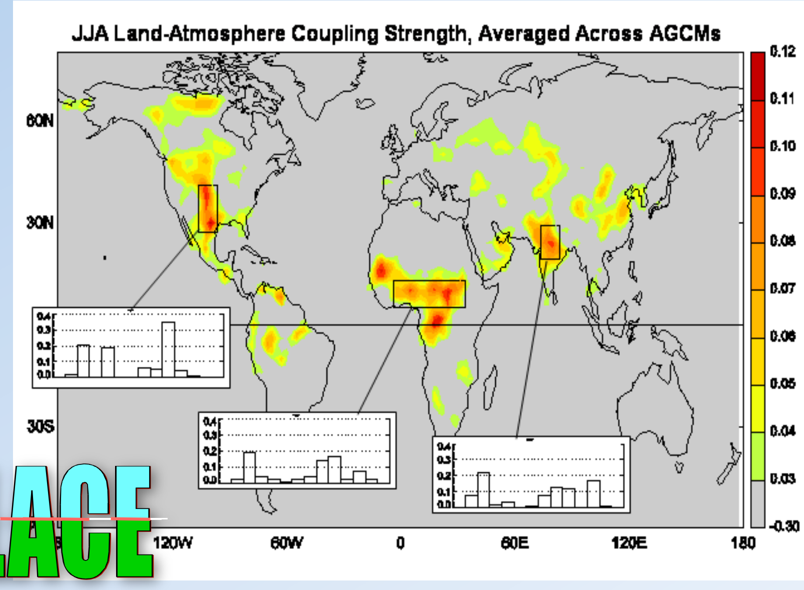
Punch Lines

- A positive impact of land surface initialization on numerical forecasts out to several months has been demonstrated. There should be a real effort to exploit this for operational forecasting.
  - However, not all of the potential predictability is being harvested – land and atmosphere models need to be developed and improved together and not treated as independent plug-and-play pieces.
  - There is not an adequate observing system to provide real-time observations of the land surface state that can be assimilated into analyses for operational forecast initialization.

Seminal L-A Result

The **Global Land-Atmosphere Coupling Experiment (GLACE)** : A joint GEWEX/ CLIVAR modeling study

Koster et al., 2004: *Science*, **305**, 1138-1140.

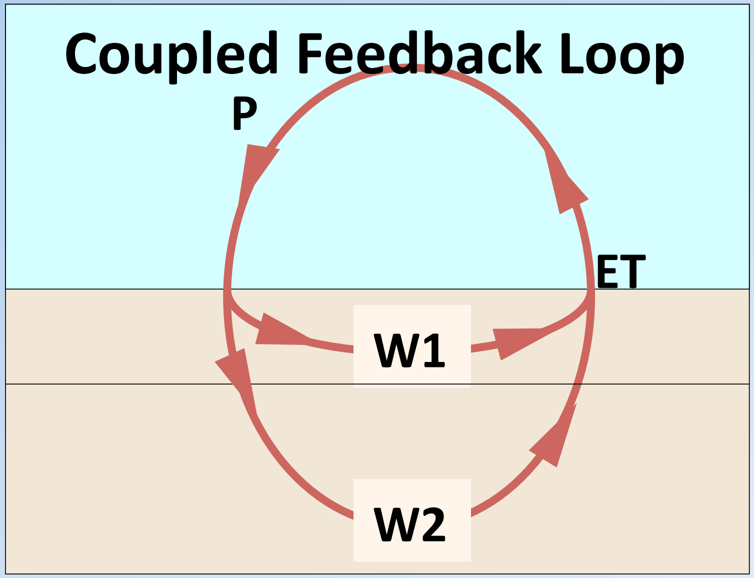


GLACE

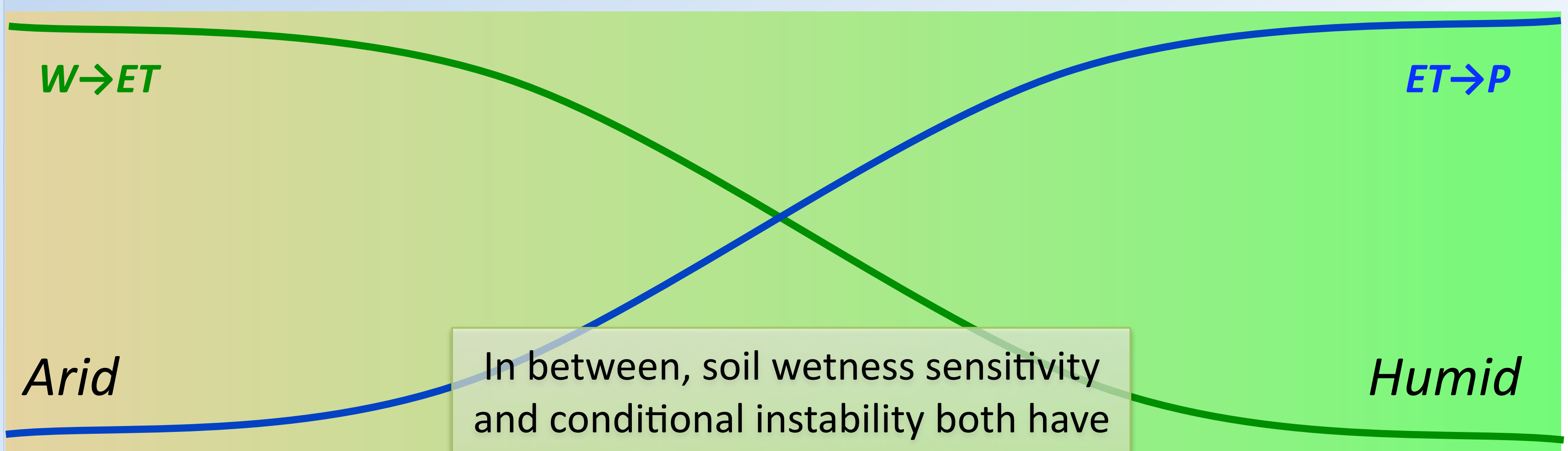
- Multi-model results indicate that there are geographic "hot spots" where the atmosphere is responsive to the state of the land surface (soil moisture).
- There have been many subsequent studies using models, analyses and observations that corroborate and help explain this result.
- Similar "cold spots" have been found for snow in at least one GCM.

Location of Hot Spots

Arid regime:
ET (mostly surface evaporation) very sensitive to soil wetness variations, but the dry atmosphere is unresponsive to small inputs of water vapor.

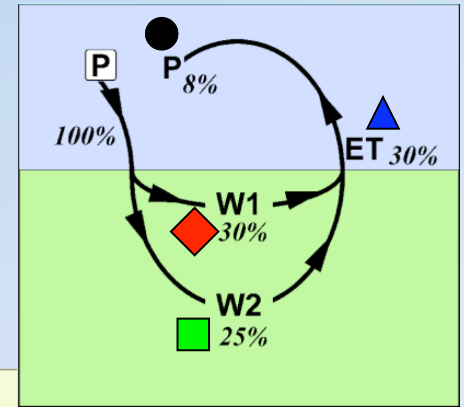


Humid regime:
Small variations in ET affect the conditionally unstable atmosphere (high moist static energy), but deep-rooted vegetation (transpiration) is not responsive to nominal soil wetness variations.



In between, soil wetness sensitivity and conditional instability both have some effect.

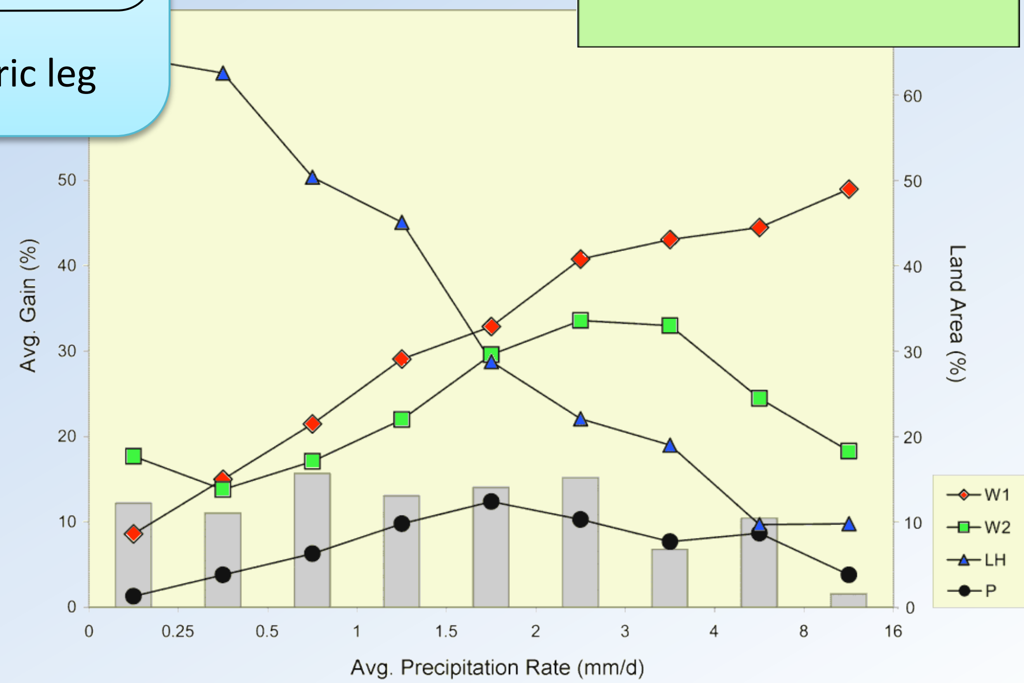
Feedback Stands on 2 Legs



$\Delta P \rightarrow \Delta SM \rightarrow \Delta E \rightarrow \Delta P$

Feedback path: Terrestrial leg Atmospheric leg

- Weak signal in ET (LH) over humid regions.
- Precip signal gain maximizes in between - in the transition zone between arid and humid.



Spatially averaged gain in skill G_P for JJAS categorized by mean model precipitation rate. Bars indicate the percentage of total land area (between 60°S and 80°N) in each category.

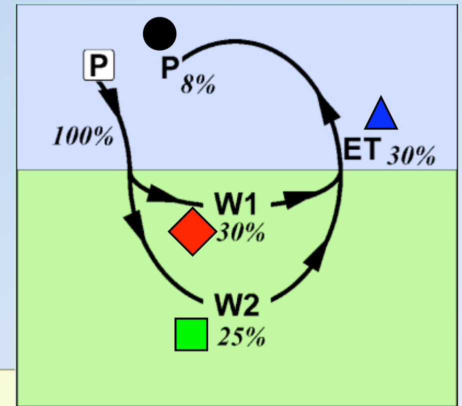
Dirmeyer, 2006: *JHM*, **7**, 857-867.

COLA Center for Ocean-Land-Atmosphere Studies

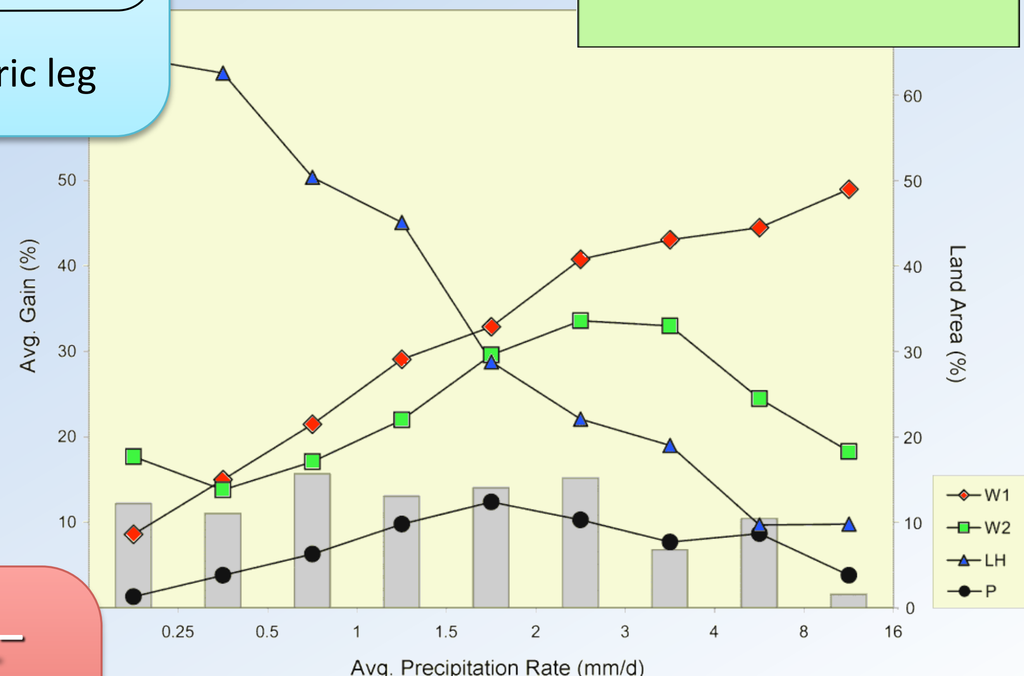
Feedback Stands on 2 Legs

$\Delta P \rightarrow \Delta SM \rightarrow \Delta E \rightarrow \Delta P$

Feedback path: Terrestrial leg ($\Delta SM \rightarrow \Delta E$) Atmospheric leg ($\Delta E \rightarrow \Delta P$)



- Weak signal in ET (LH) over humid regions.
- Precip signal gain maximizes in between - in the transition zone between arid and humid.



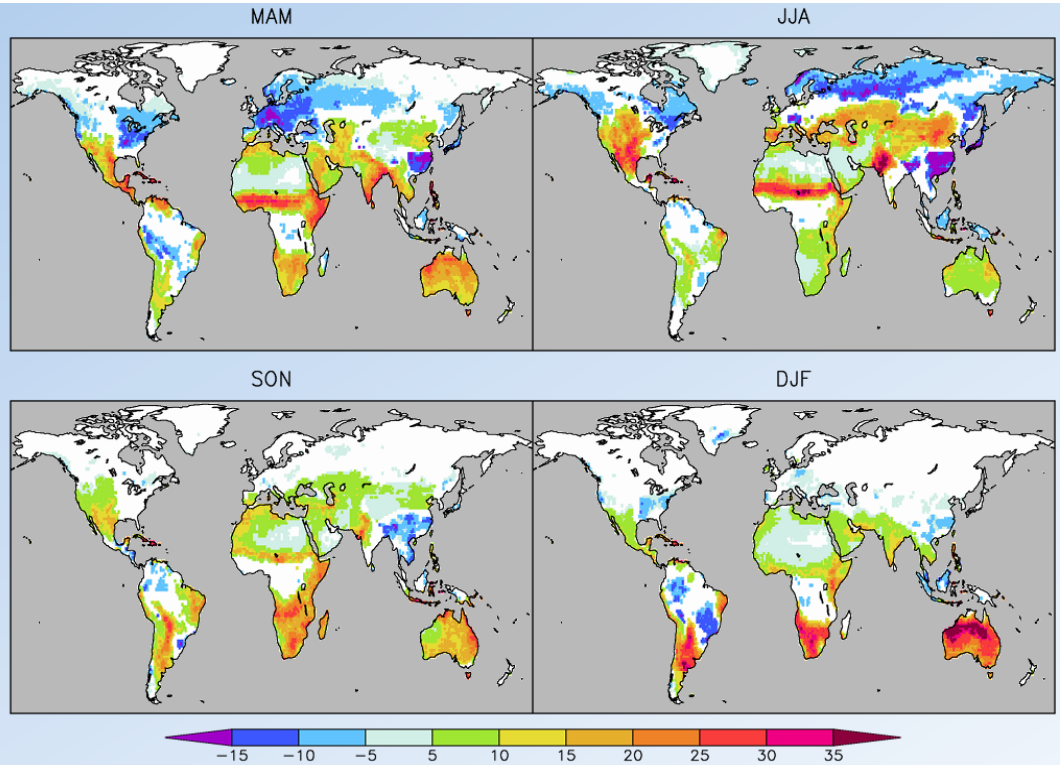
Spatially averaged gain in skill G_P for JJAS categorized by mean model precipitation rate. Bars indicate the percentage of total land area (between 60°S and 80°N) in each category.

<u>Land and atmosphere both contribute –</u> they need to be studied, understood and modeled as a coupled system, not separately. <u>This is not done currently, especially in model development</u>.

Dirmeyer, 2006: *JHM*, **7**, 857-867.

Terrestrial Part

$\Delta SM \rightarrow \Delta E$



- Index: local SD of soil moisture times linear fit slope E(SM):

$$I_E = \frac{\partial E}{\partial SM}\sigma_{SM}$$

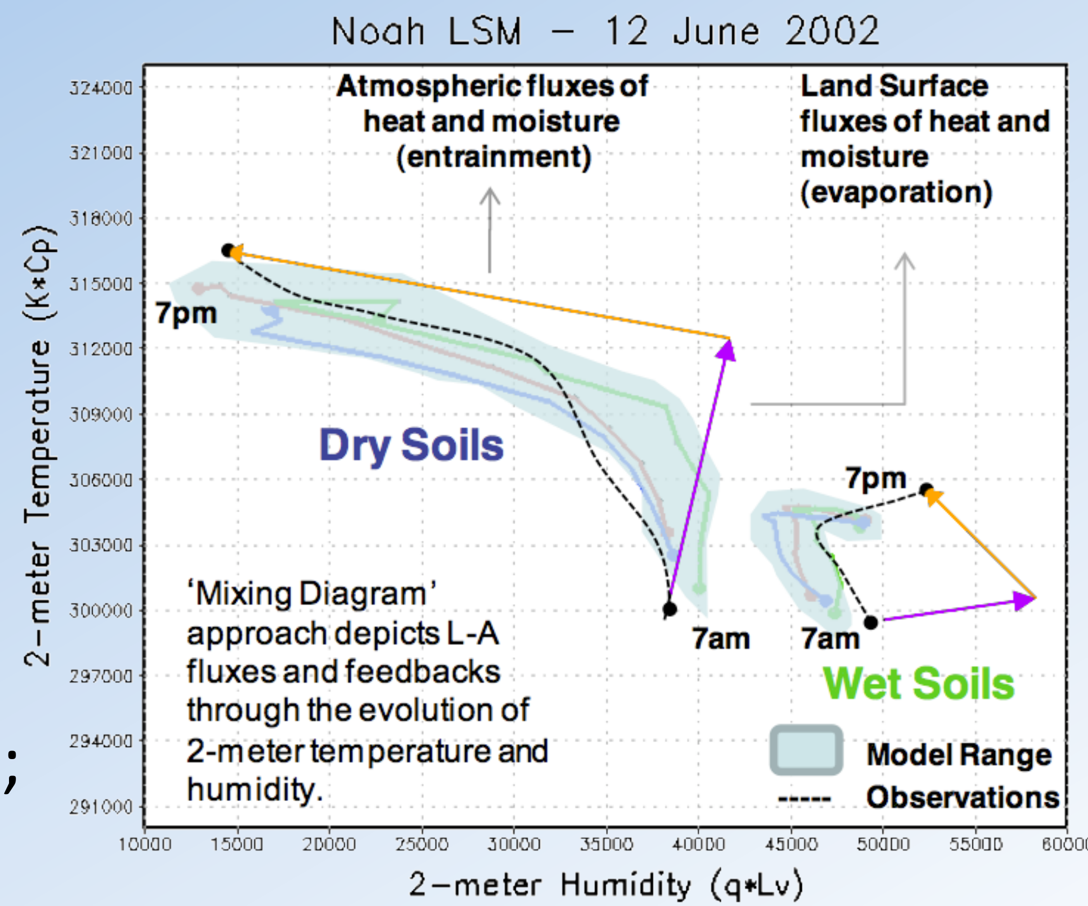
- Units are same as the flux (can be applied to energy too).
- Bears strong resemblance to hot-spots.
- Negative = evaporation drives soil moisture
- Masked where correlation(SM:E) not signif (99%)
- Based on GSWP-2 multi-model analysis.

Dirmeyer, 2011: *GRL*, **38**, L16702.

PBL Part

ΔE → ΔP

- PBL moisture content is balance of surface fluxes (at bottom), entrain-ment (top), and advection (lateral; usually small).



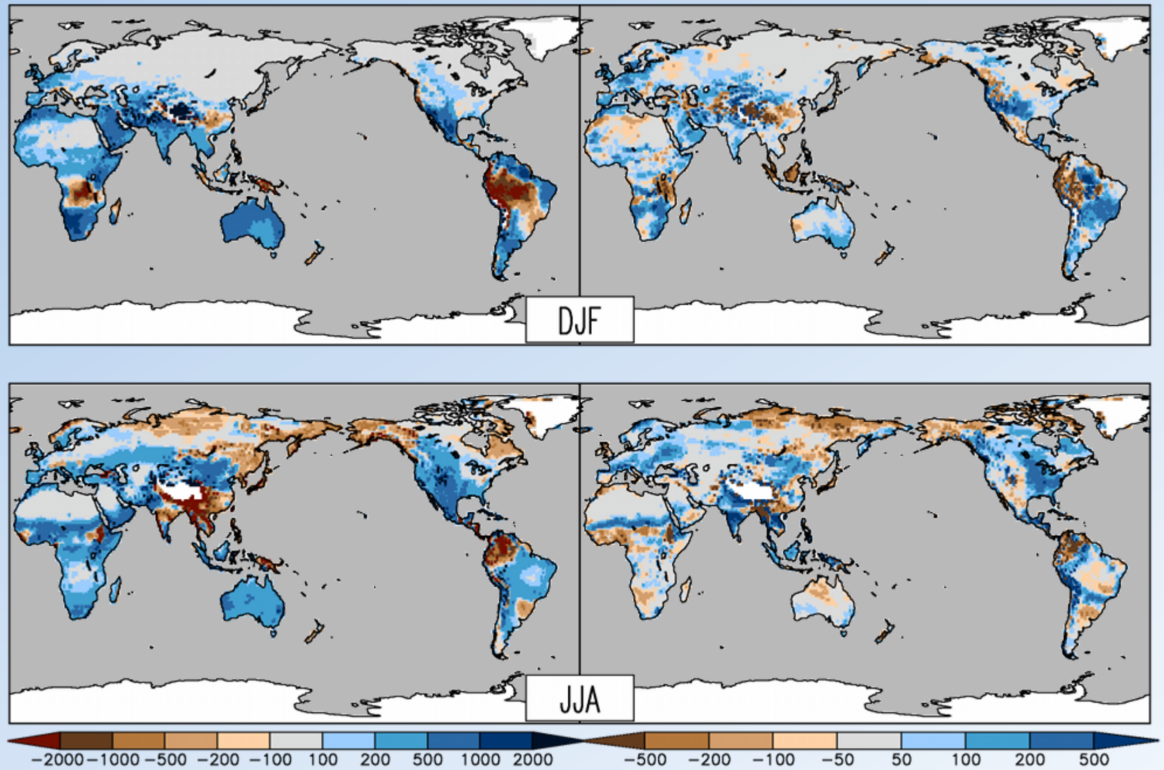
- Land surface is important driver where the surface flux impacts are large compared to entrainment.
- *cfr* Alan Betts' analyses.

Santanello et al., 2011: *JHM*, (early release).

COLA Center for Ocean-Land-Atmosphere Studies

L+A

- Substituting land index into the Santanello et al. "Mixing Diagram" formulation, we get a total coupling.



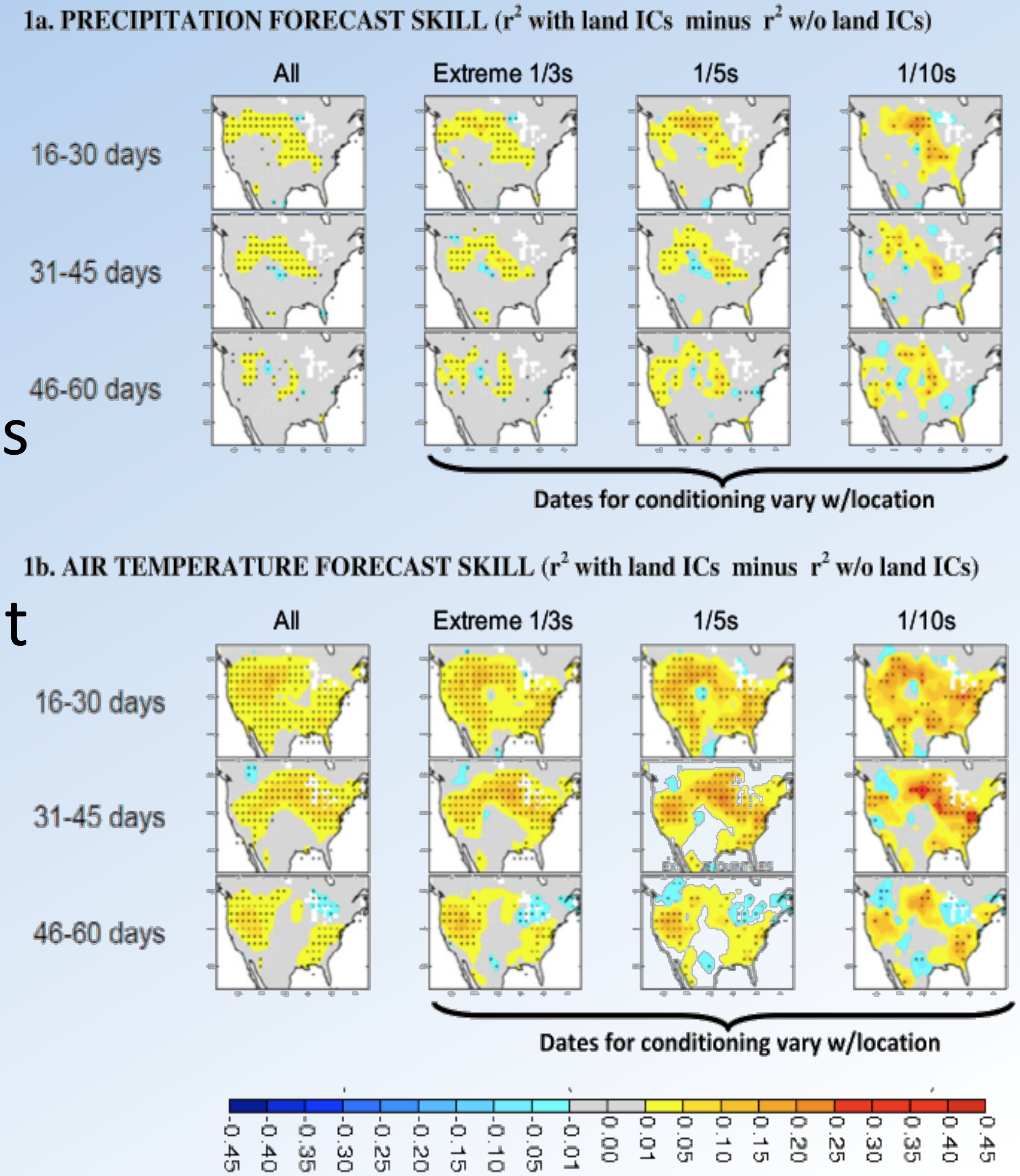
- Figure shows strength of complete feedback path (left).
- Positive = strong SM control of ET, and shallow PBL.
- Right panels – climate change (late 20C to late 21C) from IFS simulations (Athena HPC Project).
- Could be applied to observations, network deployment.*

Dirmeyer et al., 2011: *JHM*, (submitted).

COLA Center for Ocean-Land-Atmosphere Studies

GLACE-2

- Multi-model prediction skill derived from realistic vs. random land ICs 1-2 months lead.
- Significant improvement over large part of NA, especially for large SM anomalies.
- ICs for AMJJA included.

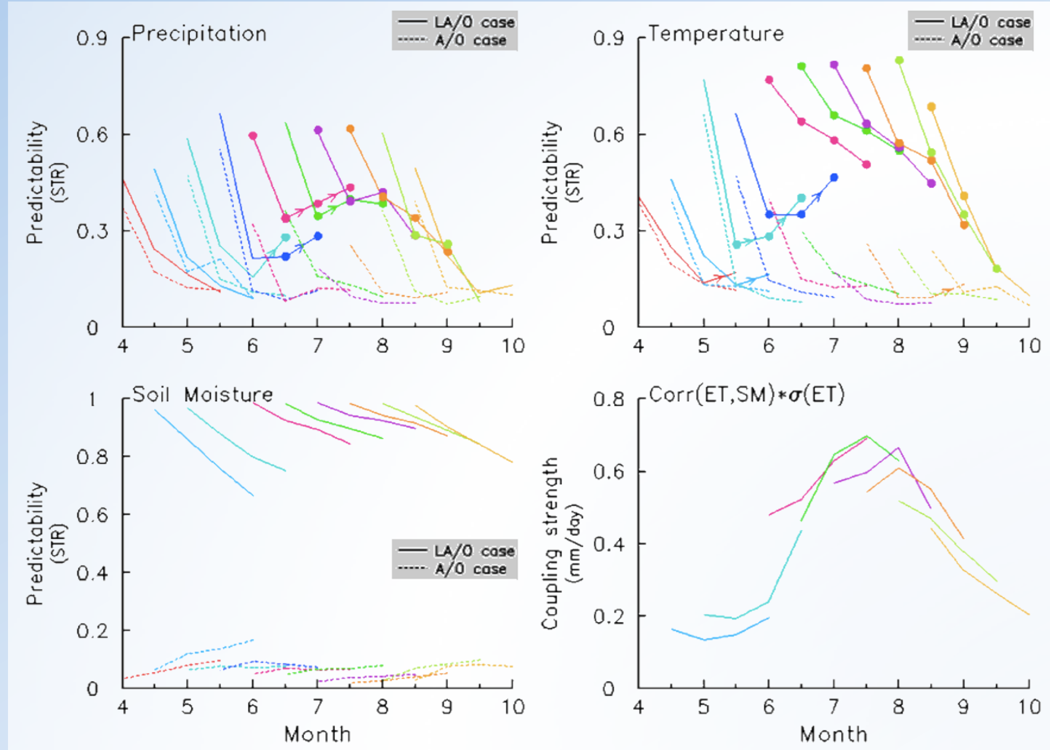


Koster et al., 2010: *GRL*, **37**, L02402.
Koster et al., 2011: *JHM*, (early release).

COLA Center for Ocean-Land-Atmosphere Studies

Predictability

- Seasonality over CONUS in predicta-bility from the land surface state kicks in at the end of May, erodes by September.



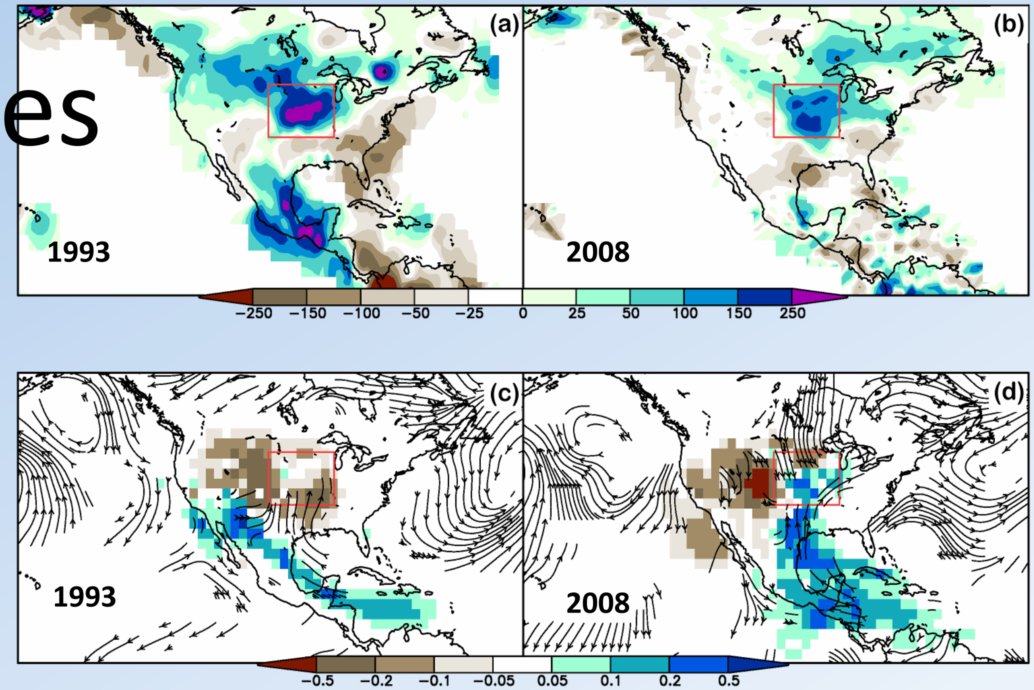
- Predictability is linked to the land-atmosphere coupling – it appears when the correlation(SM:ET) becomes high.
- There is a "rebound" of predictability for the spring forecasts (arrows) – land ICs are "stored" and then later "released" to the atmosphere when coupling occurs.

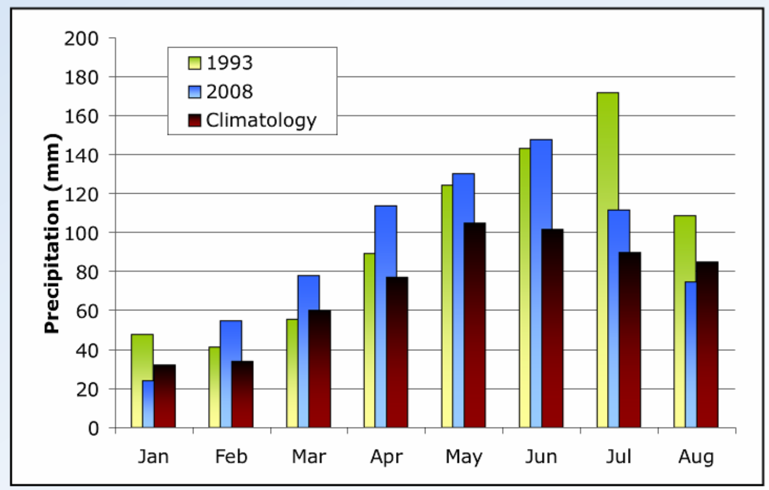
Guo et al., 2011: *NatureGeo*, (submitted).

COLA Center for Ocean-Land-Atmosphere Studies

Non-Local Sources

- Rainfall anomalies (mm) for JJ1993 and MJ2008 (top) for two recent Midwest flood years.
- The moisture source anomalies (middle) show reduced source from the west, and enhanced sources from the south (“Maya Express”), all the way from the Caribbean Sea.
- Both 1993 and 2008 were characterized by above average rainfall during the preceding months (bottom) and anomalously high soil moisture consistent with a local positive feedback from the land surface.





Streamlines show wind anomalies in the lowest 30 hPa that exceeded 1 ms^{-1}.

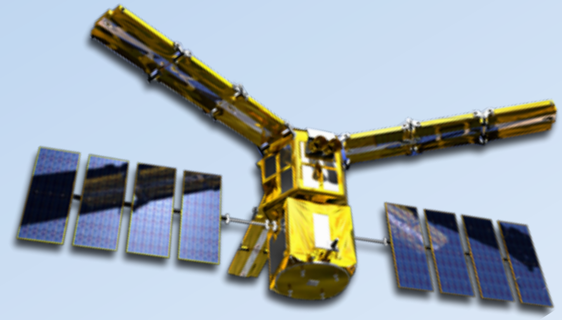
Dirmeyer & Brubaker, 1999: *JGR*, **104**, 19383-19397.
Dirmeyer & Brubaker, 2007: *JHM*, **8**, 20-37.
Dirmeyer & Kinter, 2009: *Eos*, **90**, 101-102.
Dirmeyer & Kinter, 2010: *JHM*, **11**, 1172-1181.

COLA Center for Ocean-Land-Atmosphere Studies

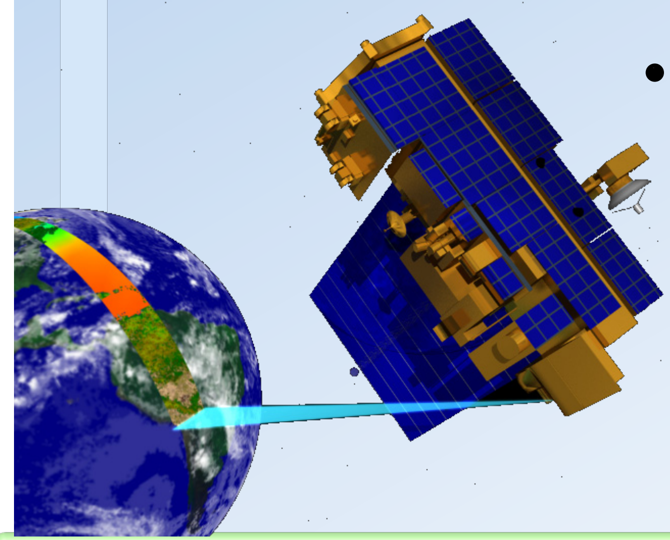
LDAS needs the A

- …For operational application of land surface initial states in numerical forecasts to improve weather, climate, and ultimately hydrologic prediction.
- Currently, LDAS is a real-time GSWP, not well constrained by observations of the land surface state.
- A combination of *in situ* anchoring observations, and *remote sensing* to provide spatial coverage, is needed.
- Slowly-varying red-spectrum variability of land surface is well suited to periodic remote sensing.

Remote Sensing

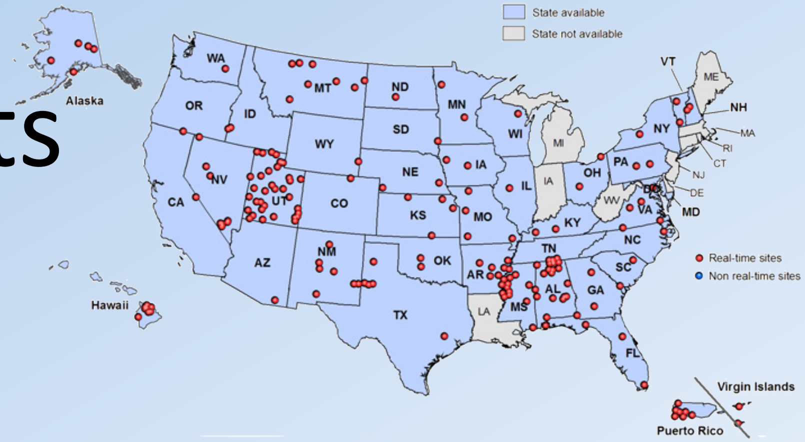


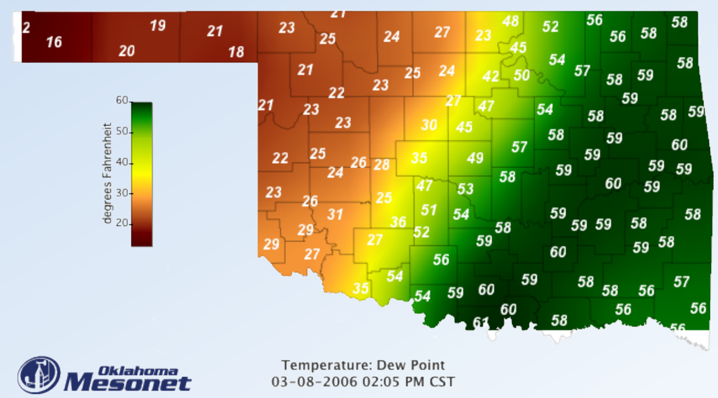
- SMOS and later SMAP can provide surface soil moisture measurements where vegetation is not dense.
- MODIS can monitor snow coverage, vegetation state, etc.
- Operational land analyses will require robust real-time monitoring and preferably redundancy.

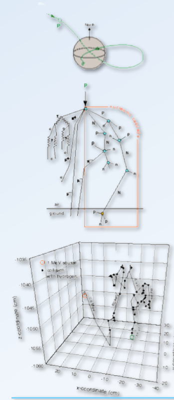


In Situ Measurements

- National networks like USDA/SCAN could be fleshed out, made operational.
- Mesonets could be linked together, put on GTS.
- COSMOS provides a way to measure deeper than satellite, broader than probes.
- Very large numbers of cheap sensors?







Recap

- It has now been shown with high confidence that sub-seasonal to seasonal forecasts can be improved by initializing the land surface of weather/climate models with realistic anomalies.
- Research is needed to understand how to exploit fully this source of predictability, and how to best transfer this to operations.
- This requires development on two fronts:
  - Improved simulation of the <u>coupled</u> L-A system (models)
  - A robust <u>real-time</u> observing system (in situ + satellite)