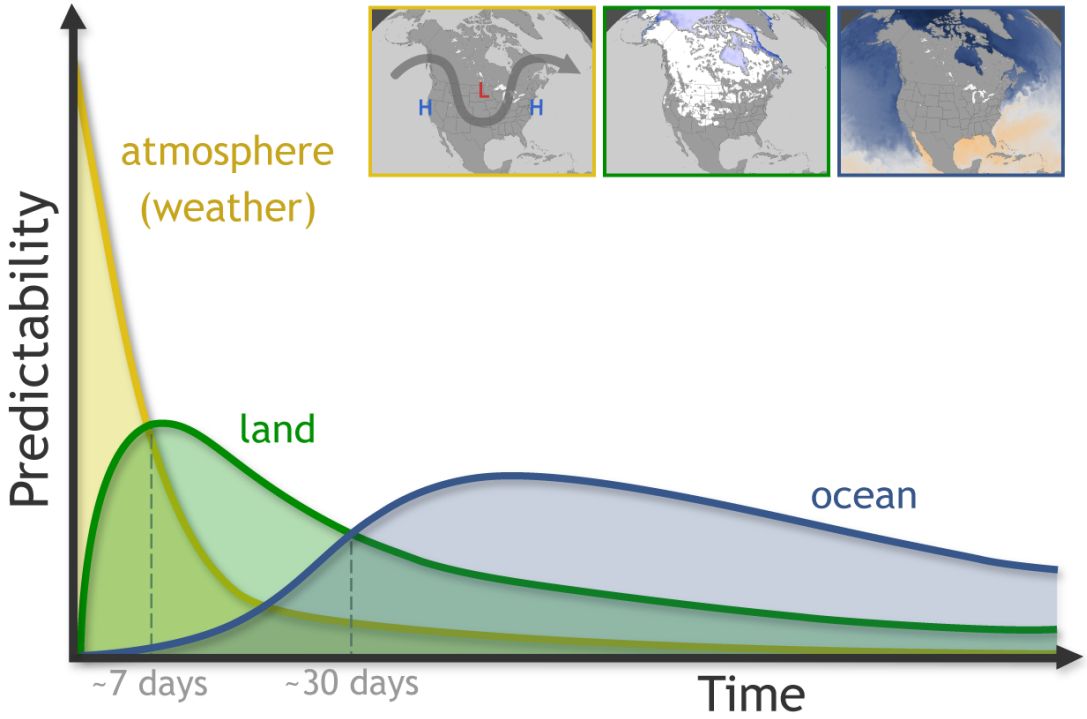
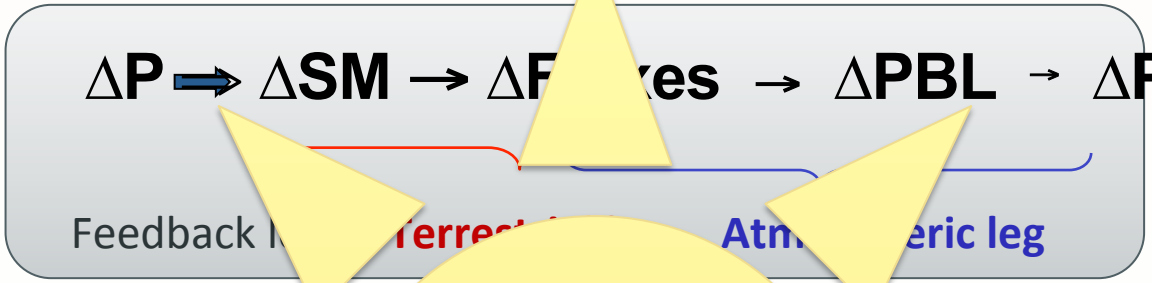
Predictability and Prediction

- Land states (namely soil moisture but also snow) can provide predictability in the window from deterministic (weather) to climate (O-A) time scales, peaking at S2S.
- Vegetation states, related to soil moisture anomalies, give predictability at/beyond S2S time scales.
- L-A coupling is active where there is sensitivity, variability and memory.
- Good models and analyses (of atmosphere and land) needed to exploit this source of skill.



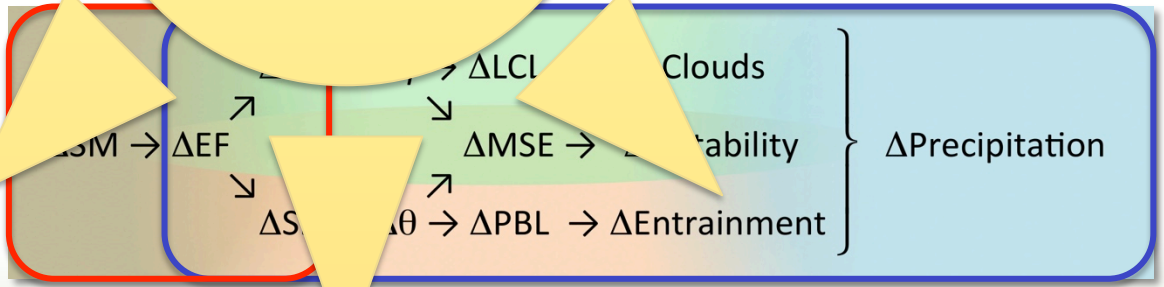
Land-Atmosphere feedback stands on 2 legs



- Terrestrial – When/whe re (snow, vegetation, etc.) controls the partitioni o sensible and latent heat fluxes
- Atmosphere – When/ xes significantly affect near surface atmosphe layer properties, clouds and precipitation.

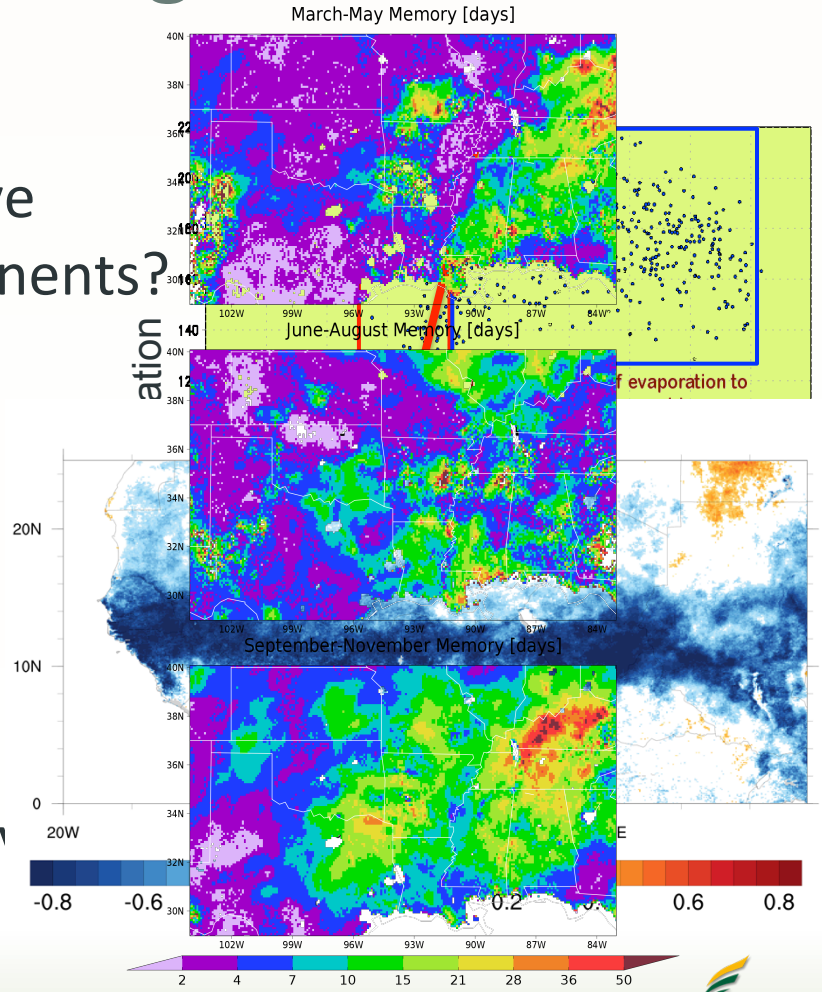
All Acts Through the Diurnal Cycle!

Process chains:



Climate Feedbacks: Three Ingredients

- Sensitivity
  - When and where is there an active coupling between climate components?
- Variability
  - A climate coupling results in a significant impact only when the fluctuations are large enough.
- Memory
  - If the coupling and fluctuation do persist, the impact will be short-li weaker.



Coupled Ocean-Atmosphere Models

- Early coupled O-A models suffered surface flux imbalances that caused drifting in climate simulations into unrealistic states.
- For short simulations (seasonal – annual), this drift was annoying, for long simulations, they were disastrous.
- "Flux adjustments" or "flux corrections" were introduced, empirically correcting surface fluxes of heat and salinity (fresh water) at the ocean surface (e.g., Manabe and Stouffer 1988).

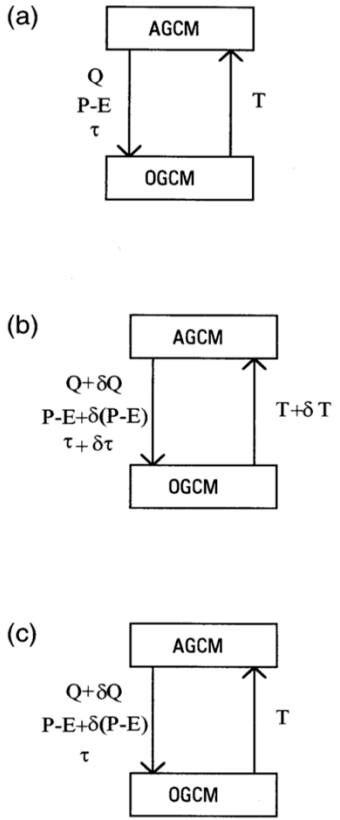
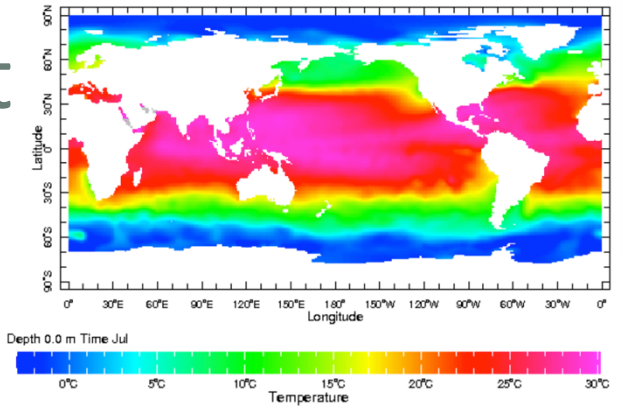


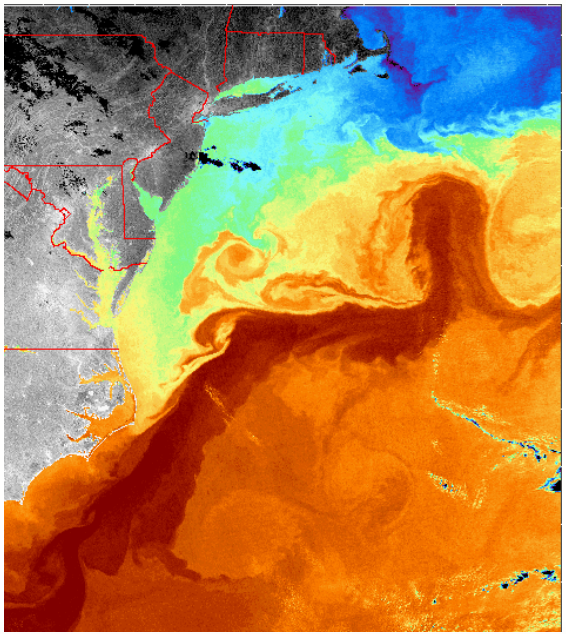
FIG. 1. Flux adjustment: (a) the coupled model; (b) adjustment of fluxes and SST; (c) adjustment of heat and water fluxes only.

Roberts et al. (1997; MWR)

Coupled O-A Model Development

- This drift was immediately recognized because sea surface temperatures are well observed. Global analyses (e.g., Levitus 1994; top) and satellite monitoring (NOAA AVHRR; bottom) have provided data of useful quality to validate and diagnose O-A model problems since the time coupled models were developed.
- This has also aided model development. Within 20 years of the first climate model application of “flux adjustment”, the practice had become unneeded.



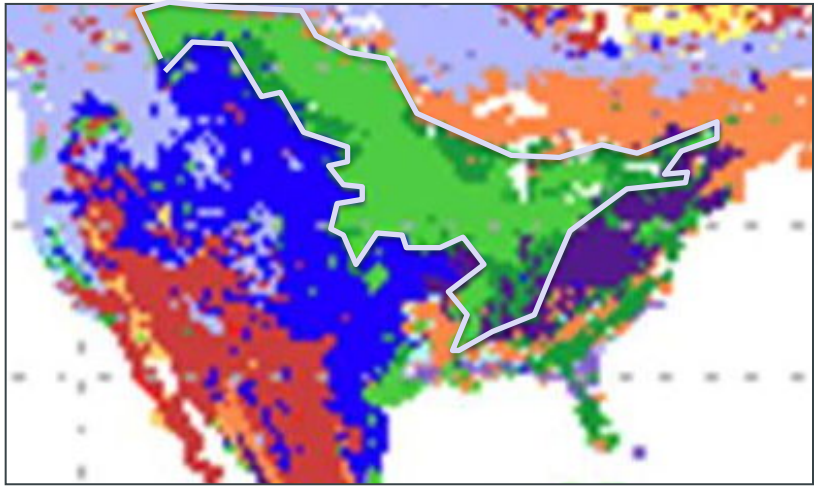


L-A Science: A Backwards Scientific Path

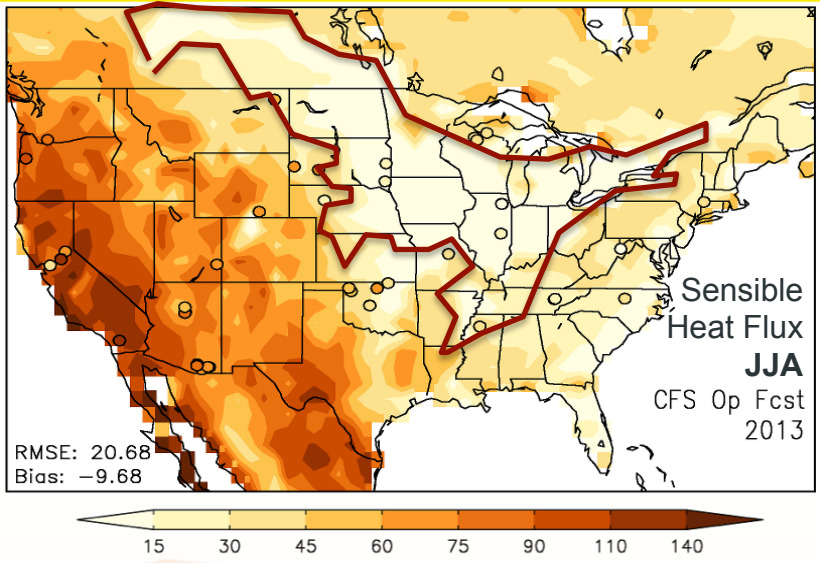
- The science of land-atmosphere interactions has proceeded backwards from the traditional progression from observation of natural phenomena, formulation of hypotheses, development of experiments and construction of models.
- LSMs were developed initially to provide BCs for AGCMs, before there were wide-ranging observations of the land surface or land-atmosphere interactions applicable to model development.

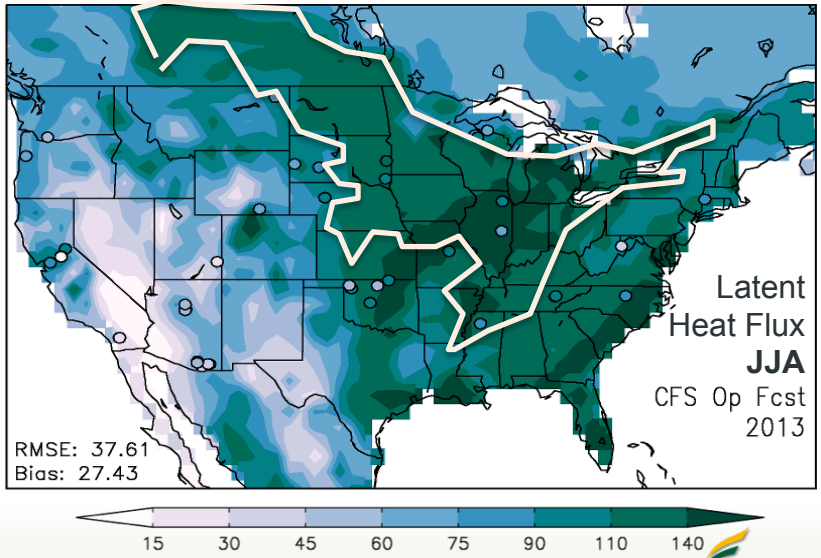
LSM as Scapegoat

- To correct warm biases in CFSR, roots for Noah crop vegetation type were extended to all 4 soil layers; it transpires too freely.



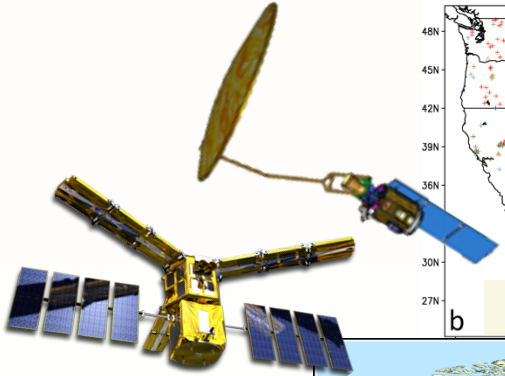
Green: Total and partial cropland

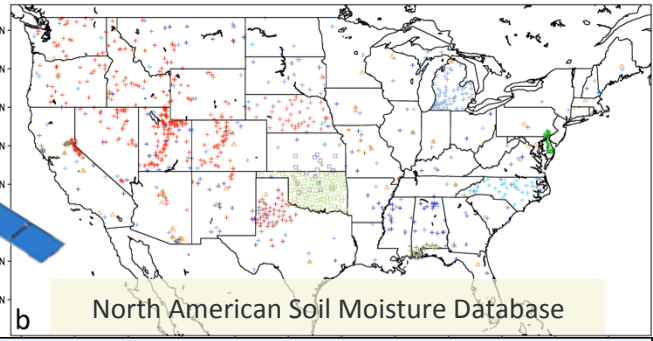


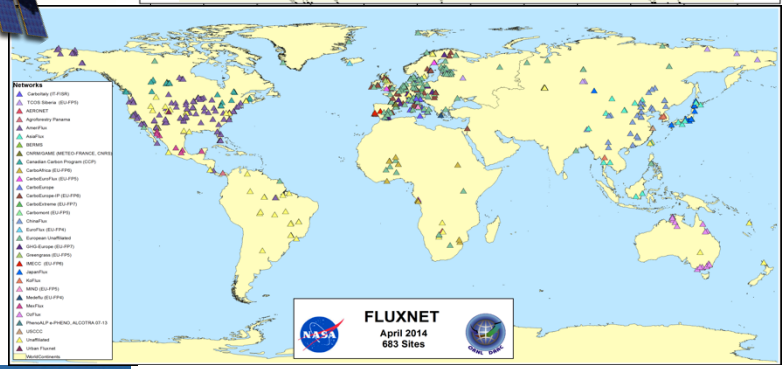


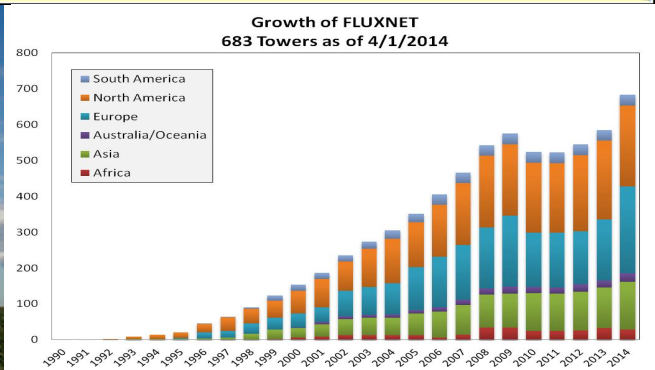
Finally… Data!

- *In situ* fluxes (FluxNET, ARM/ CART, field campaigns, etc.), soil moisture networks of networks (NASMDB, ISMN)
- Remote sensing (orbital platforms, radar, lidar, cosmic ray, GPS, etc.)
- Long time series, co-location, QC are essential – we need land, meteo & PBL measurements together!!





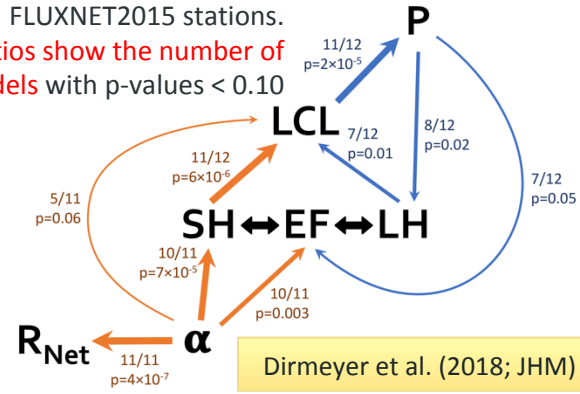




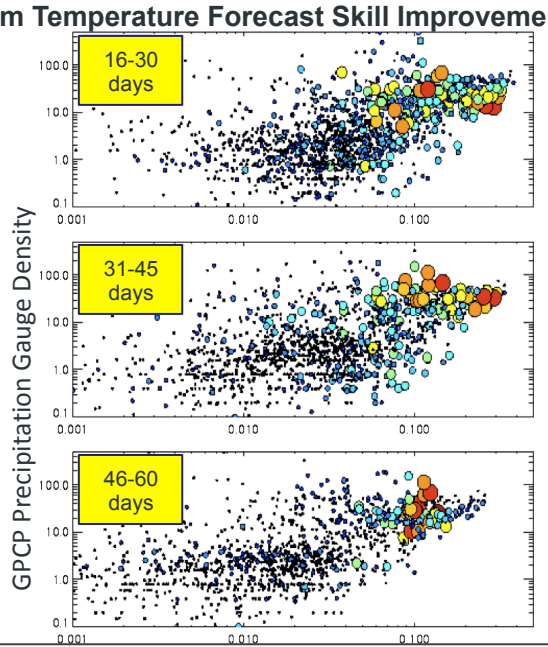
Multi-Model Studies

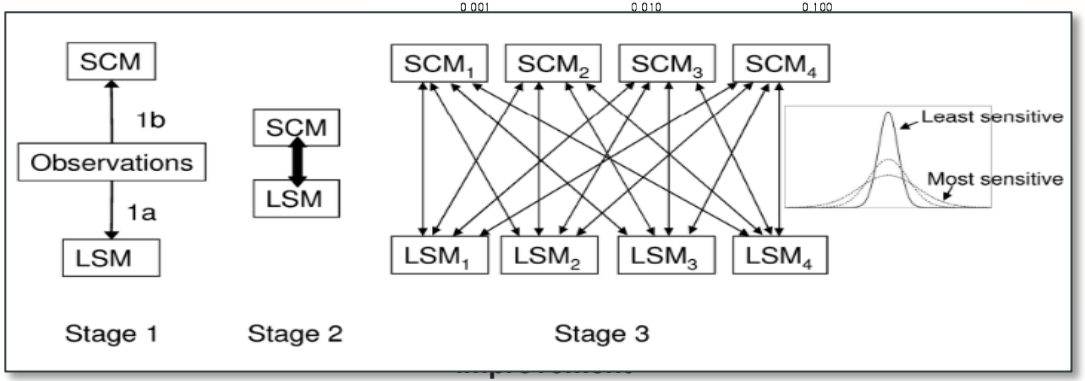
- GLACE demonstrated “hotspots” of L-A coupling
- GLACE-2 demonstrated L-A improves forecasts
- “Confronting” models to identify problems
- DICE taking first steps to investigate L-A coupling in models at the process level

Error propagation from their rank correlations across FLUXNET2015 stations. Ratios show the number of models with p-values < 0.10

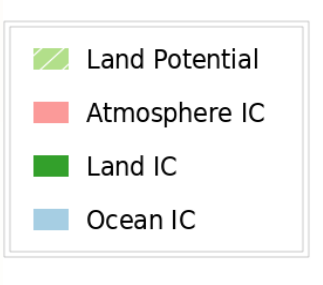


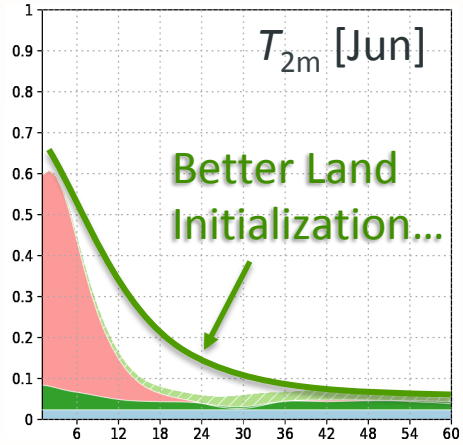
Dirmeyer et al. (2018; JHM)

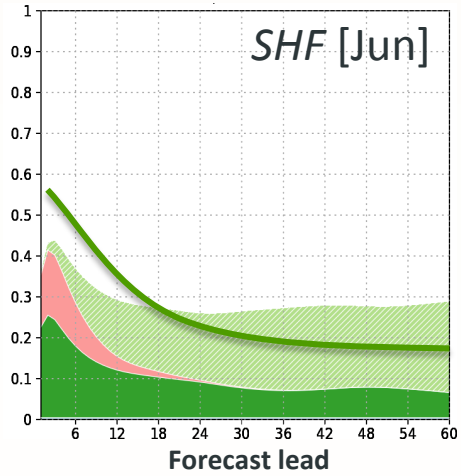


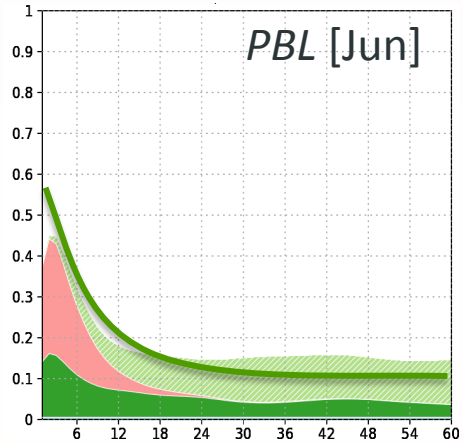


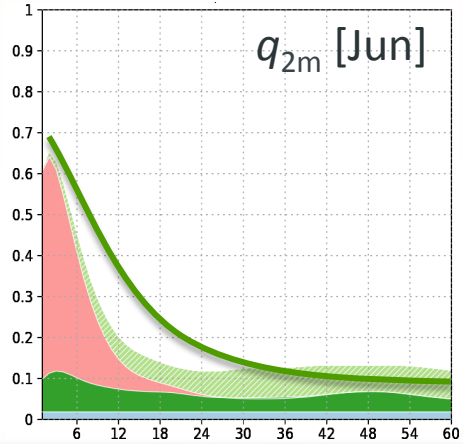
Contributions to Skill in CFSv2

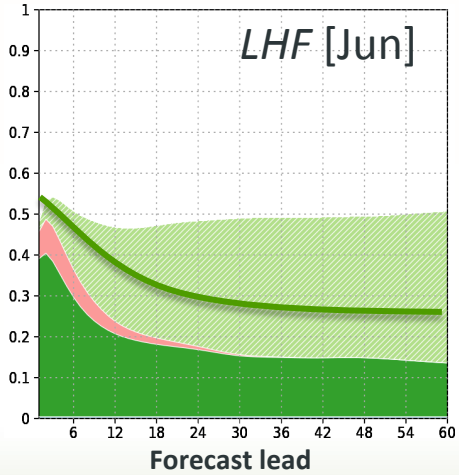


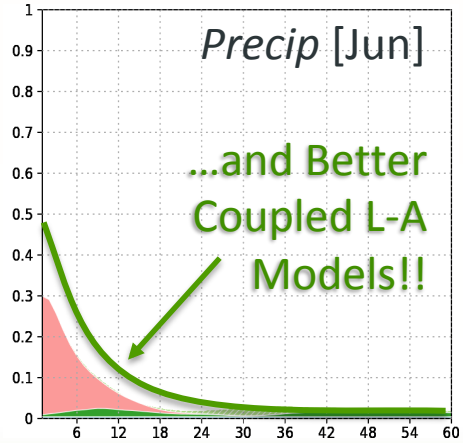










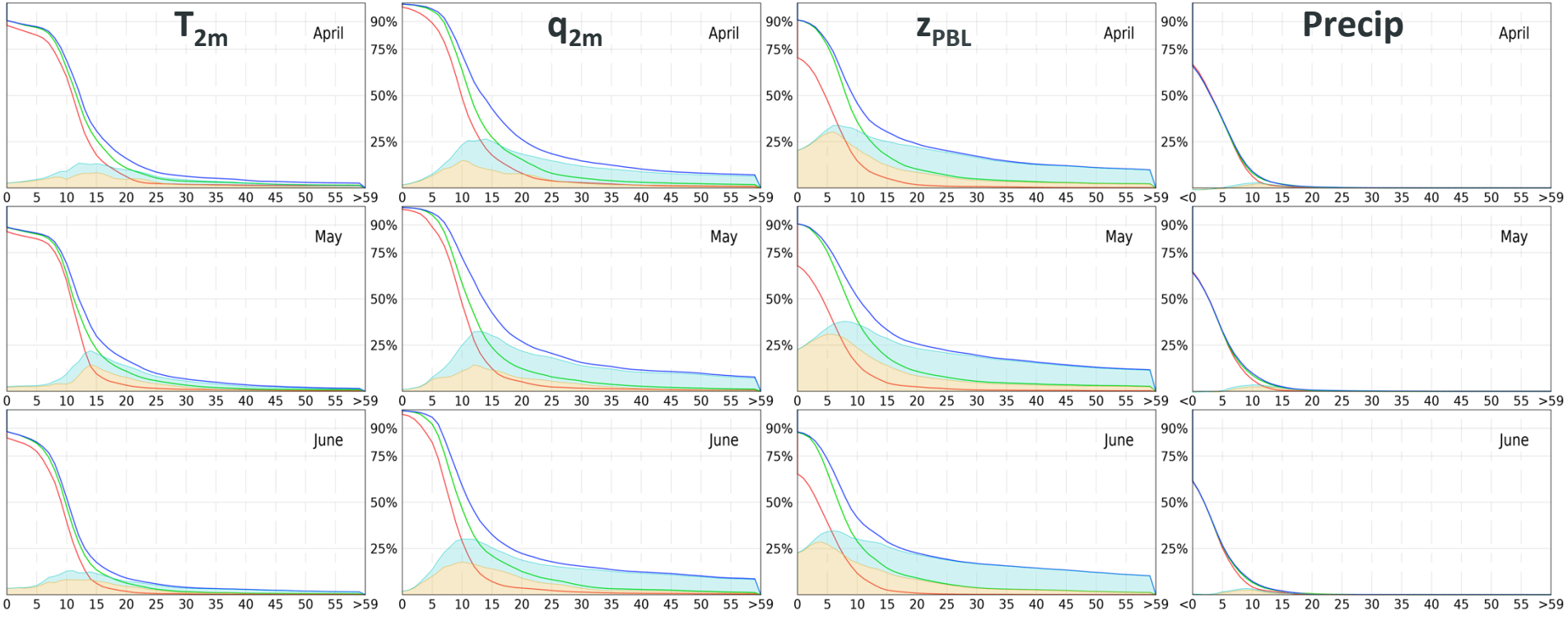


Convective parameterizations can decouple precipitation from PBL development and land surface influence.

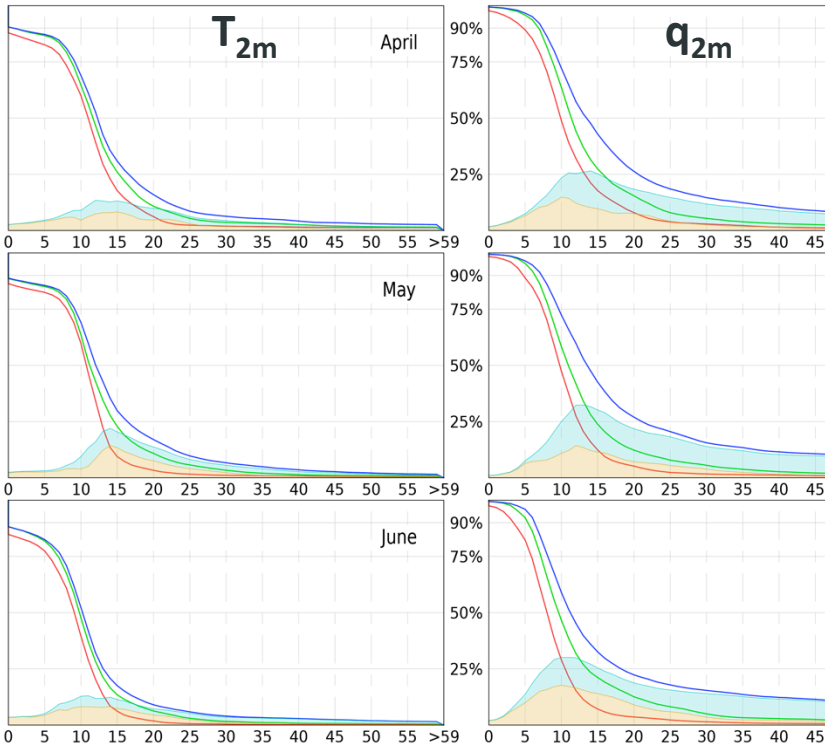
"Potential" is model-specific, unmeasurable.

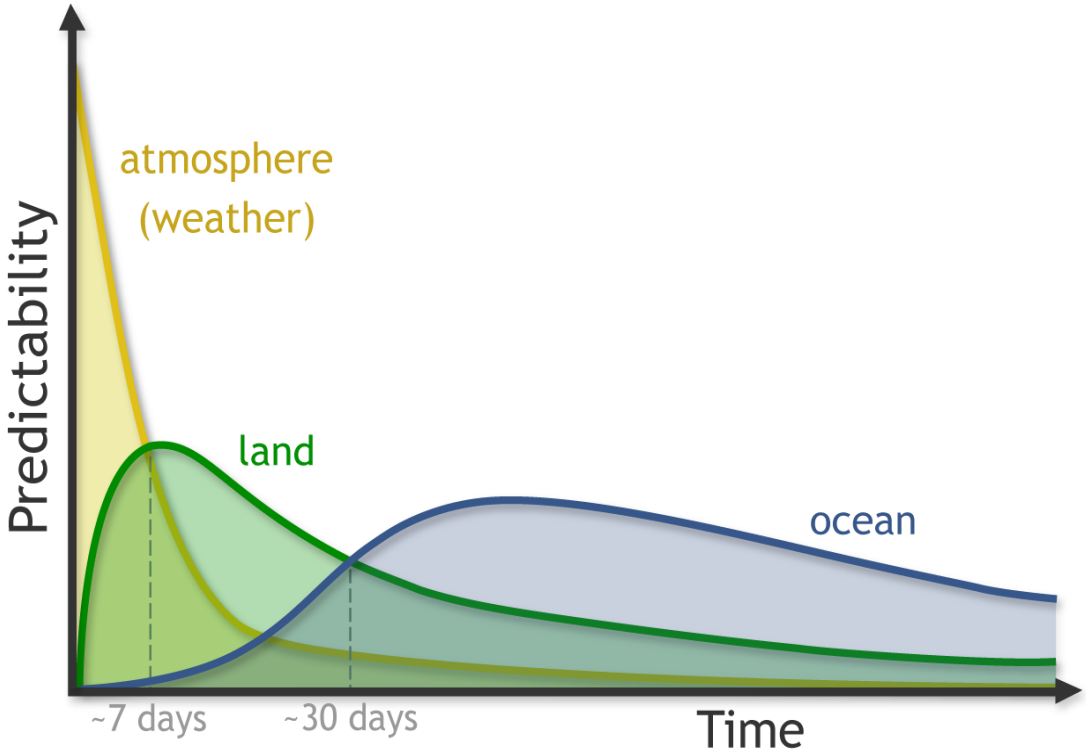
Dirmeyer et al., (2018; *JGR-Atmos. revised*)

The fraction of land area exhibiting significant skill as a function of forecast lead time with specified land states (blue), right land ICs (green) and wrong land ICs (red). Shaded curves show the difference between green and red curves (tan) and between blue and green curves (pale blue).



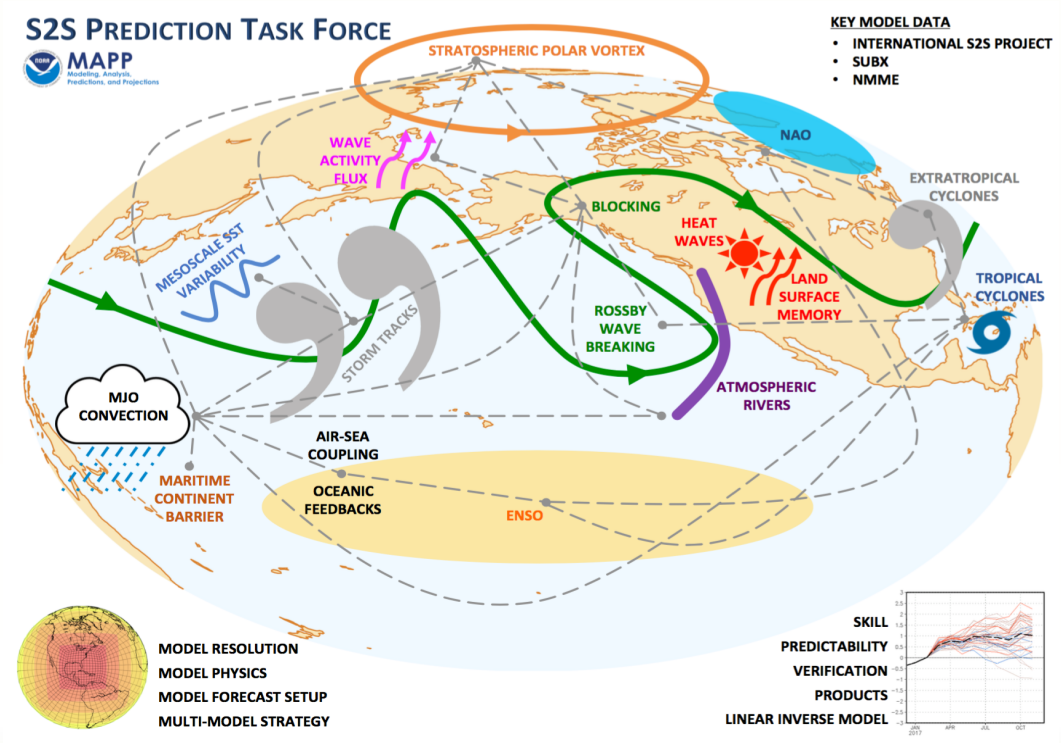
The fraction of land area exhibiting significant skill as a function of forecast lead time with specified land states (blue), right land ICs (green) and wrong land ICs (red). Shaded curves show the difference between green and red curves (tan) and between blue and green curves (pale blue).





New Analogy for S2S Forecasting

- Subseasonal to seasonal climate anomalies are often driven by persistent large-scale circulation features that have remote sources, communicated to affected regions by Rossby-wave propagation.
- Thus, predictable S2S phenomena are delivered by the atmosphere in much the same way that a freight company delivers packages, or the Internet delivers data.



New Analogy for S2S Forecasting

- Subseasonal to seasonal climate anomalies are often driven by persistent large-scale circulation features that have remote sources, communicated to affected regions by Rossby-wave propagation.
- Thus, predictable S2S phenomena are delivered by the atmosphere in much the same way that a freight company delivers packages, or the Internet delivers data.

New Analogy for S2S Forecasting

- Just like telecommunications or shipping, the biggest problems are in the "last mile"; once the delivery is *in the neighborhood*, 30% of the cost and most of the failures occur in that final step to the customer's door.
- In a forecast model, if the land surface is poorly initialized, or coupled L-A processes are not well represented, the delivery is broken, or lost, or garbled.

Models Are Balances of Errors

- Remove one model error, and the *tuning* that compensated for its presence becomes out of balance.
- This is why model development, calibration and validation must be carefully pursued and documented, and not done *ad hoc*.
- In coupled model systems, the scope of development and calibration grows broader; a system-level model development plan in necessary.

Summary: Coupled L-A Model Development

- Land models and atmosphere models have historically been developed separately and then plugged together. Not good for simulating coupled L-A processes.
- Until recently, not feasible to pursue model development and validation in a coupled way. With new understanding and data, now we can, now we should.
- We have a chance to model the climate over land much better – it's a coupled system. The potential is great.

Two Legs of Land-Atmosphere Coupling
Blended NASA MERRA-2, NOAA/NCEP CFSR & ERA-Interim