Scale Dependence of Land-Atmosphere Interactions in CESM

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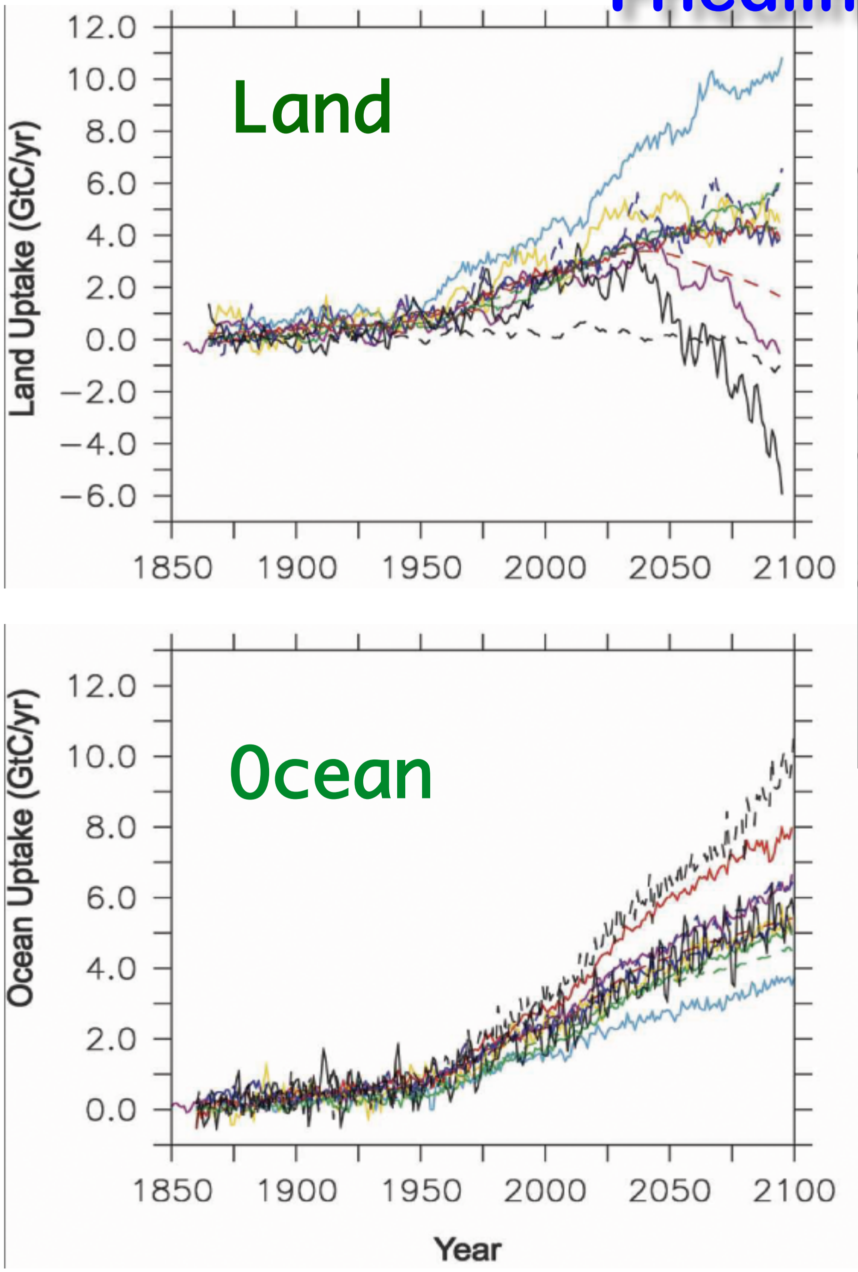
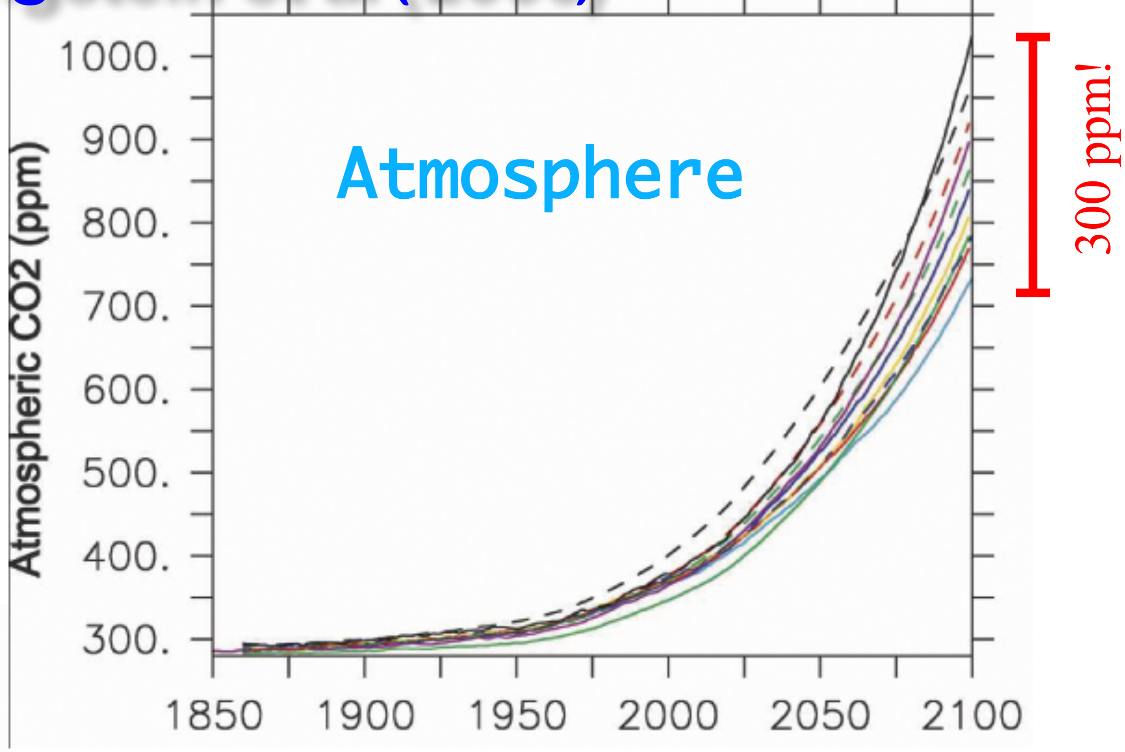
Carbon-Climate Futures

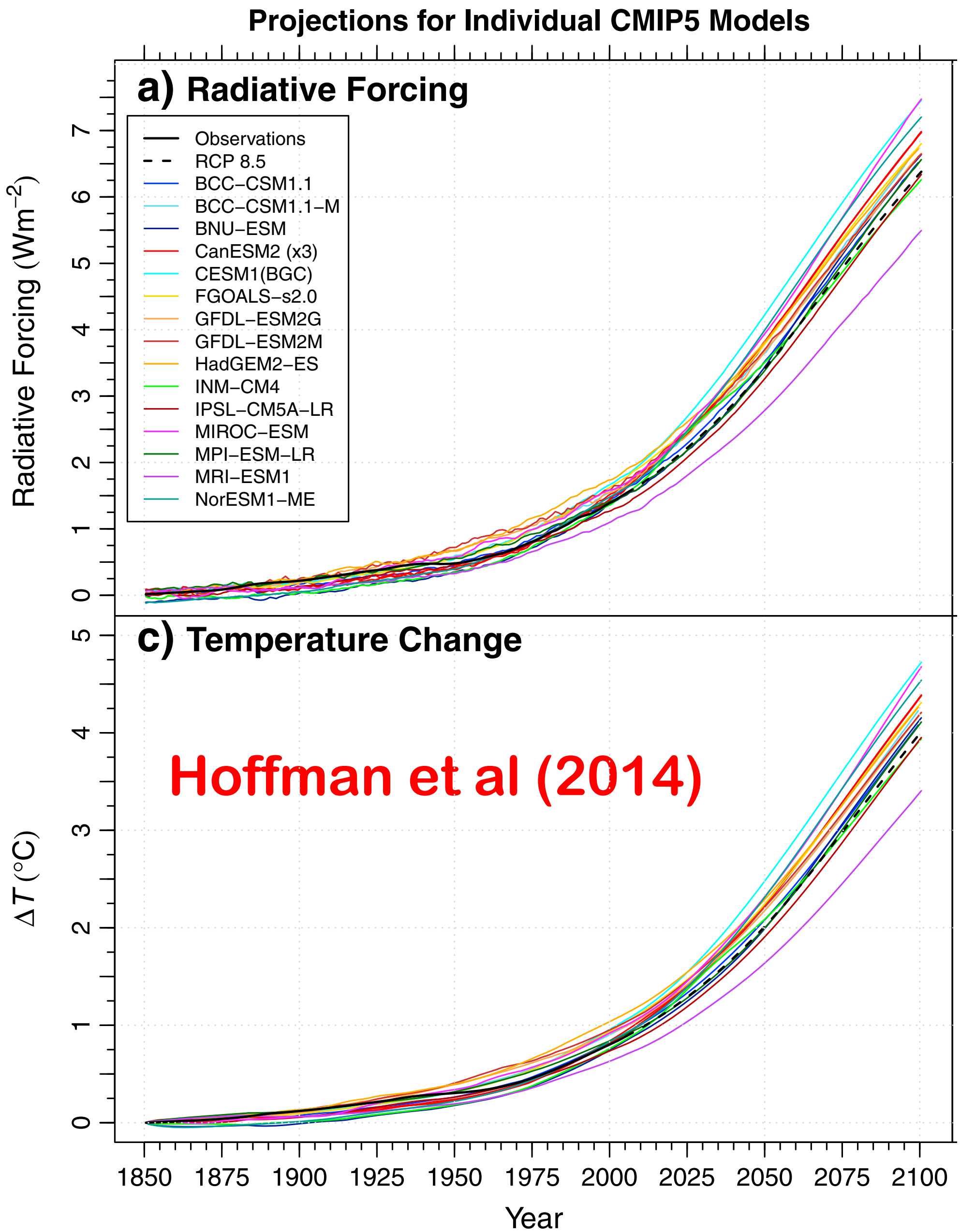
Friedlingstein et al (2006)





- Coupled simulations of climate and the carbon cycle (CMIP3, C4MIP)
- Given nearly identical human emissions, different models project dramatically different futures!
- Mostly depends on CO_2 fert & temp

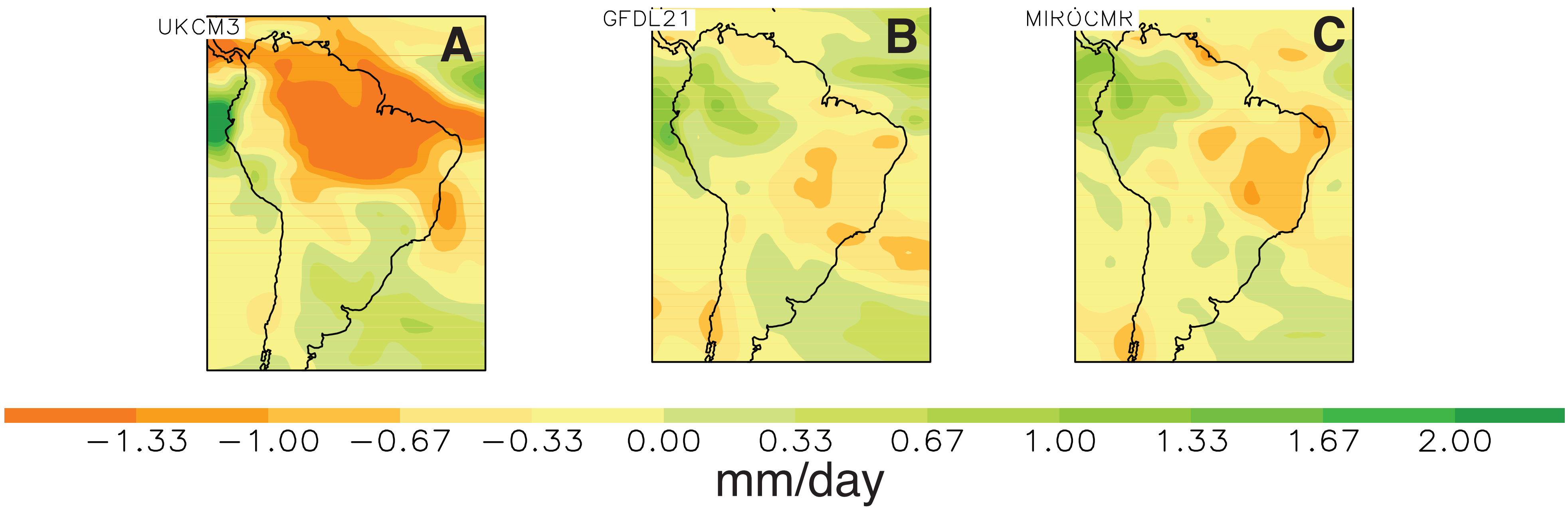
Even Worse in CMIP5 !



- More processes (land use, regrowth, nitrogen, fire)
- Now more than 350 ppm spread in CO_2!
- For identical emissions, radiative forcing varies by almost 2 W m^{-2} (more than RCP 4.5 vs RCP 6)
- Warming varies by 1.5 ° C (comparable to spread in physical climate)
- Carbon cycle impacts climate uncertainty as much as clouds or people!

Amazon Drought?

Change in annual precipitation predicted during the 21st century



Amazon Gradient

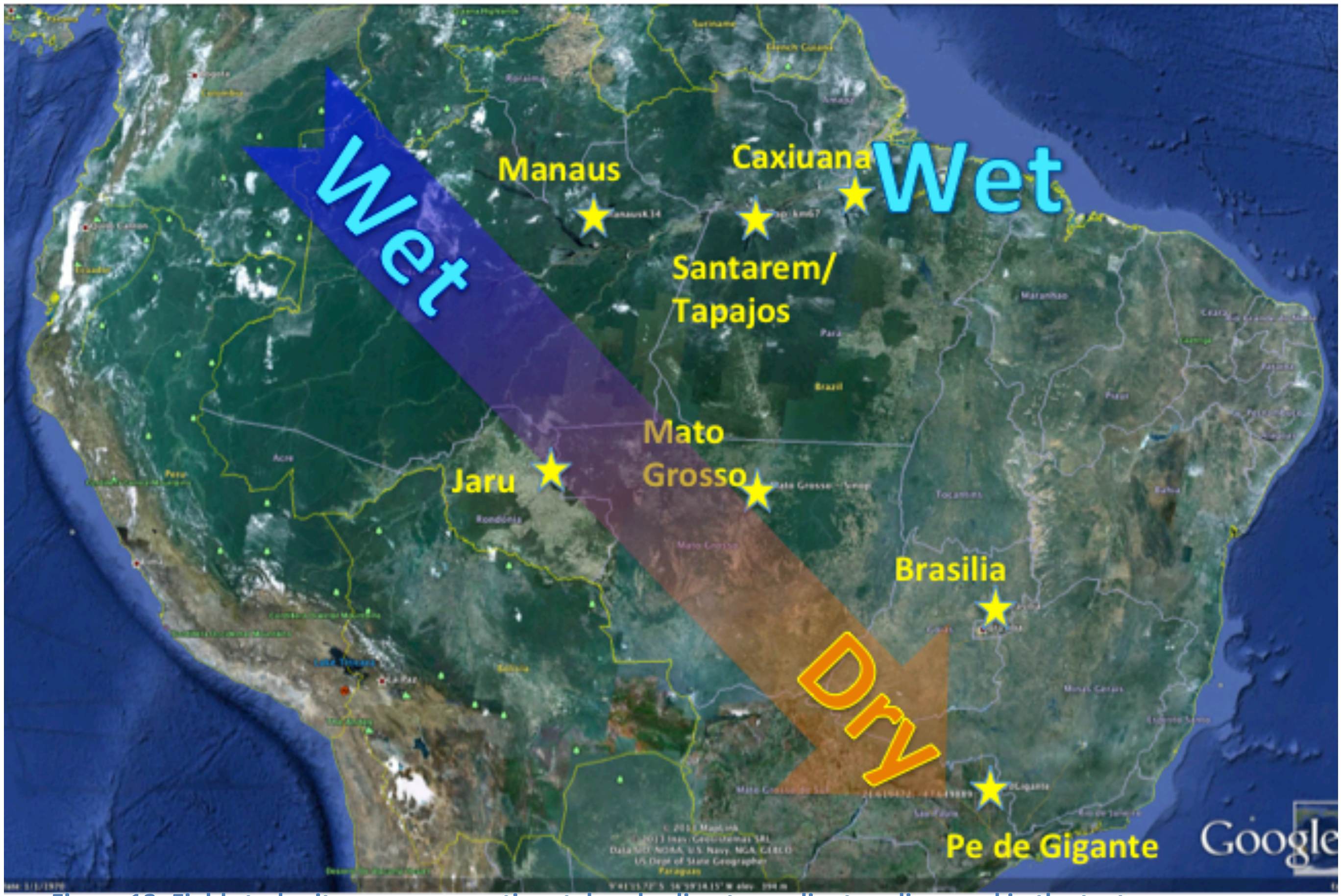
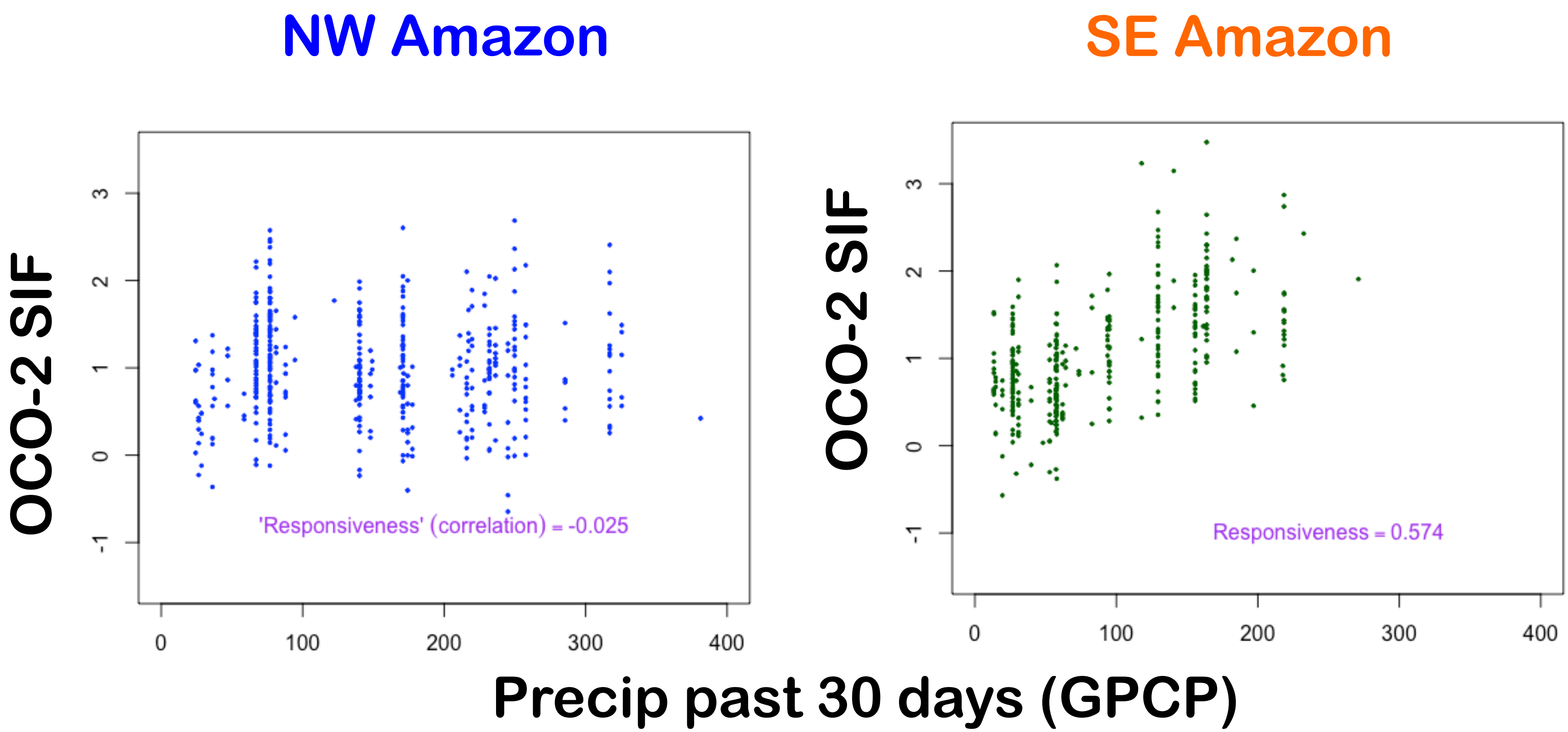


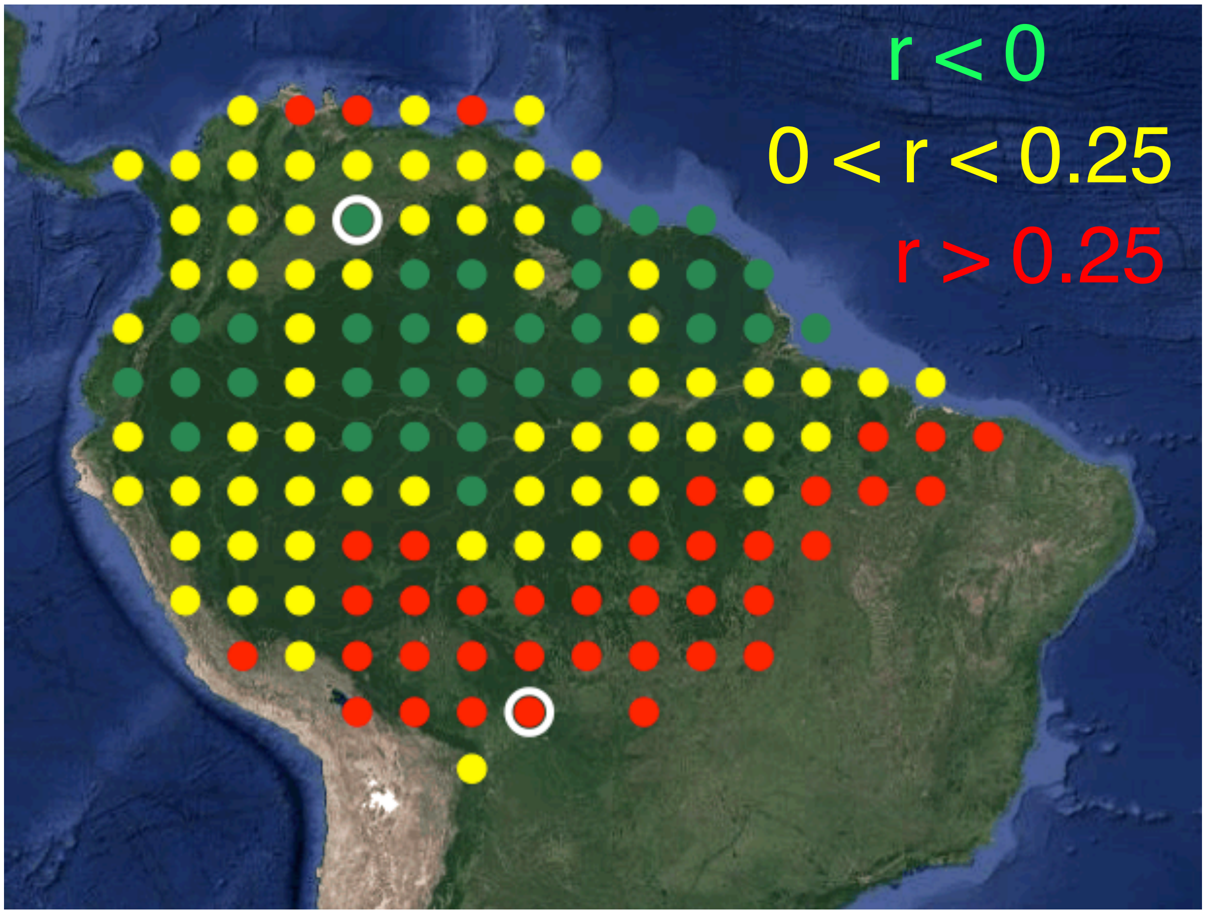
Figure 12: Field study sites across a continental-scale climate gradient as discussed in the text

Drought Stress
constrained using OCO SIF



Maximum correlation confidence interval for inclusion: 0.34

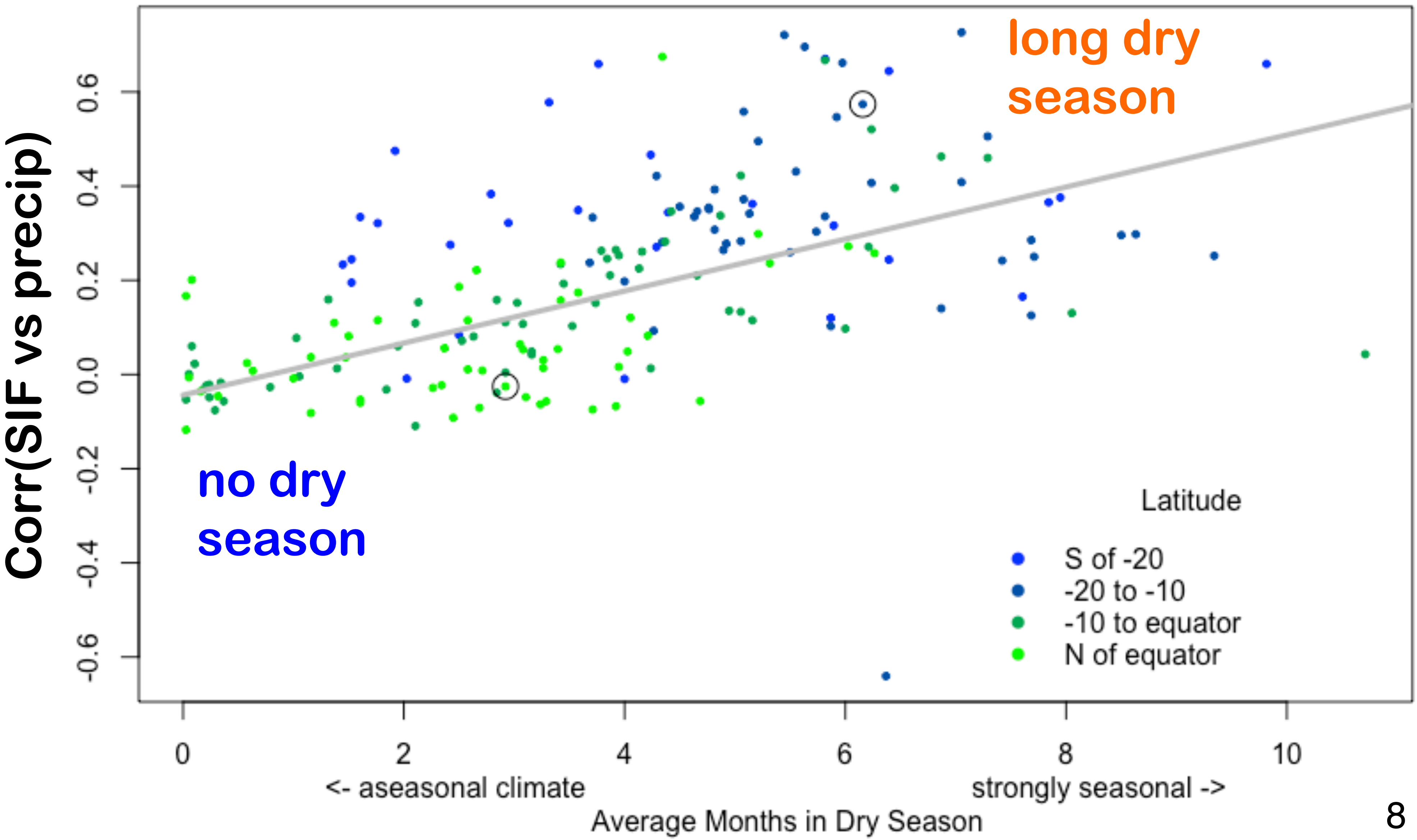
Drought Stress
constrained using OCO SIF



- **Weak correlation in Central Amazon**
- **Strong correlation over periphery**

Drought Stress

constrained using OCO SIF

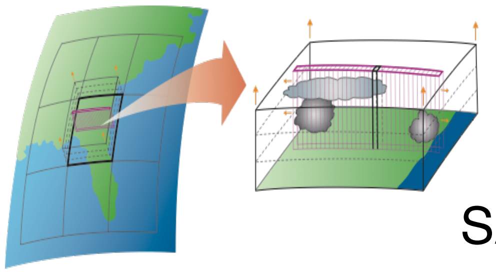


Scaling in Space & Time

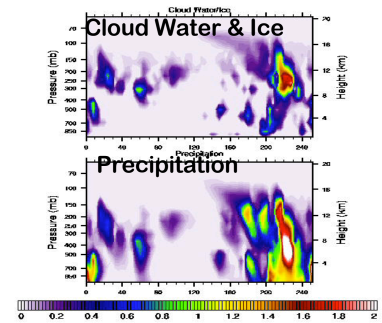
Comparing models to obs is hard

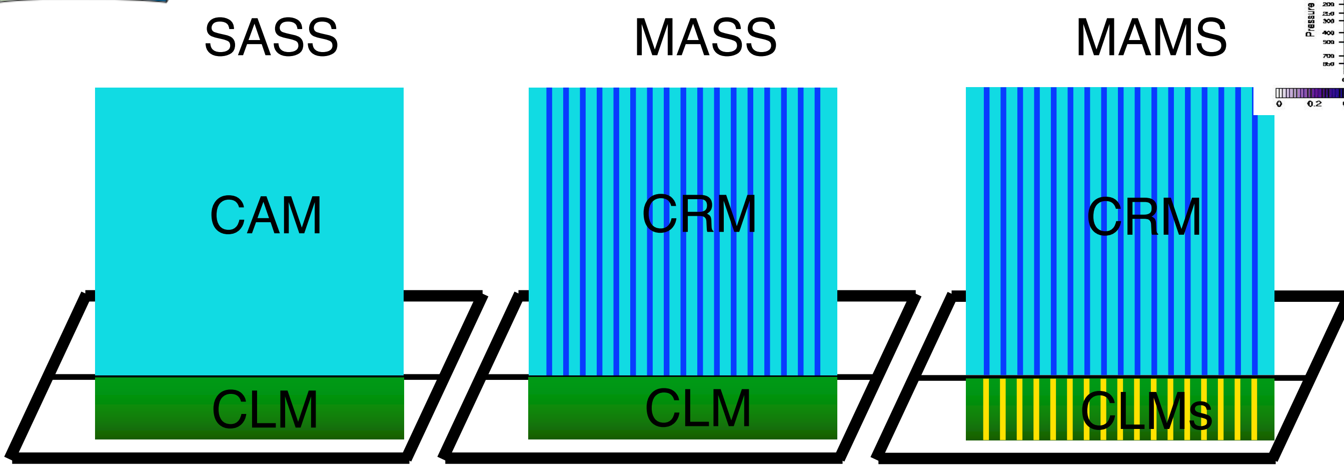
- Earth System Models are supposed to use mechanisms derived locally to estimate emergent changes at much larger scale
- Lab and field data from chloroplasts to cuvettes to eddy covariance get extrapolated to climate model grid cells
- An emphasis on "carbon weather" in the observations, but critical questions are about "carbon climate" in the models
- Sampling vs averaging
- Seeing the forest for the trees

Multiscale Modeling



$$f(\overline{x}) \neq \overline{f(x)}$$



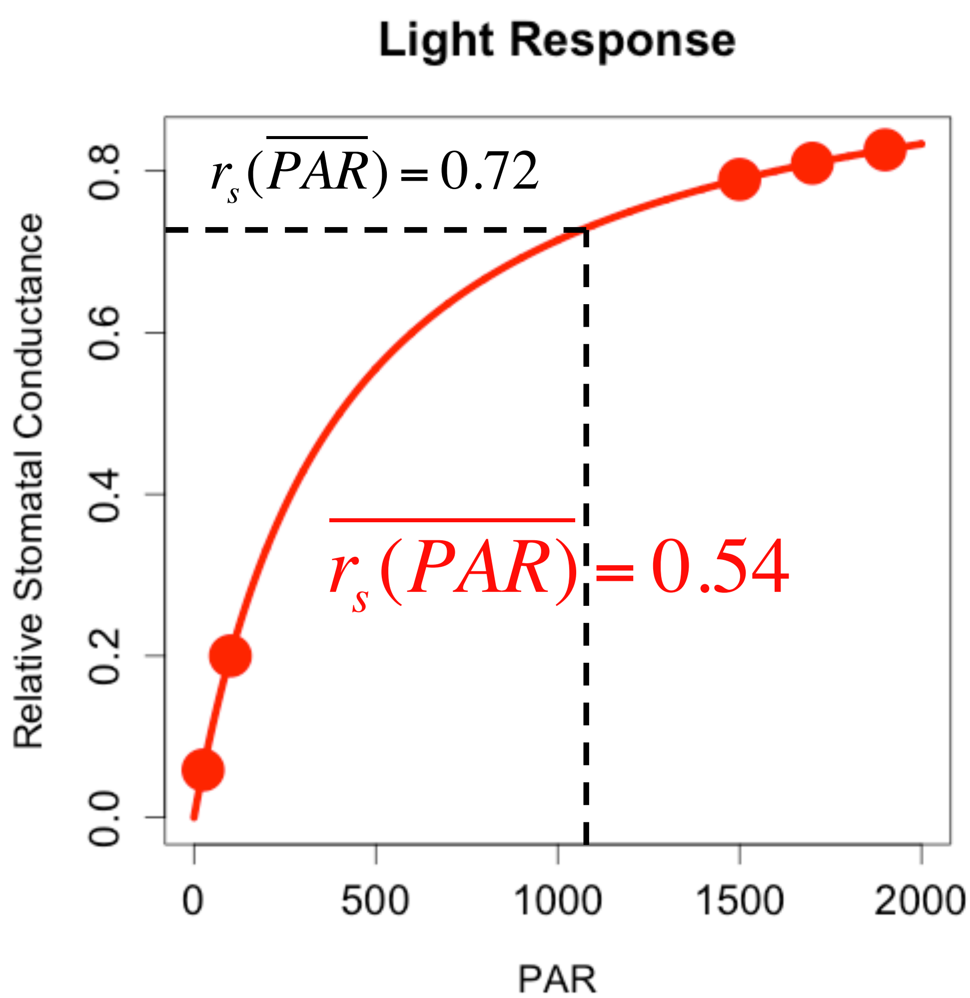


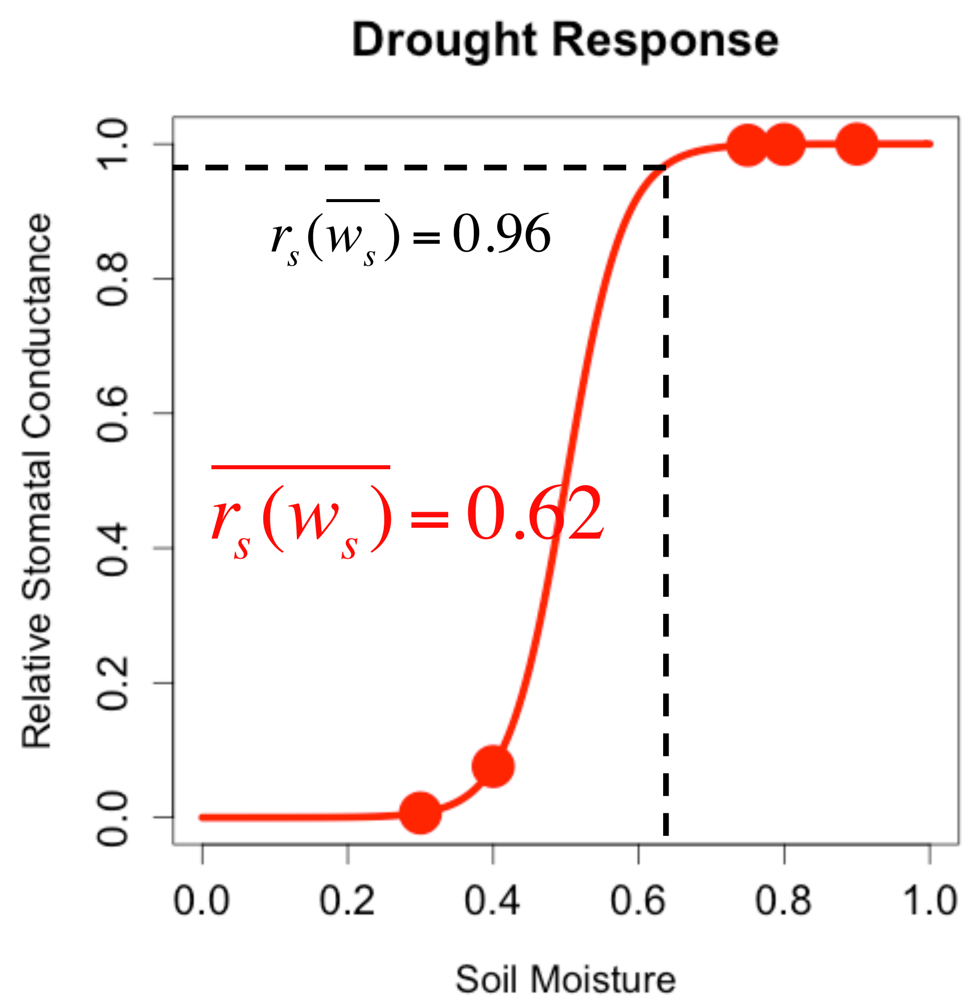
Single Atmosphere Single Surface	Multi-Atmosphere Single Surface	Multi-Atmosphere Multi-Surface
(standard CESM)	(SP CESM)	(“multi-instance” SP CESM)

GOOD NEWS:
Surface water cycling much more realistic (canopy evap, infiltration, transpiration)

BAD NEWS:
About 100x more arithmetic than standard CESM!

Nonlinear Plants



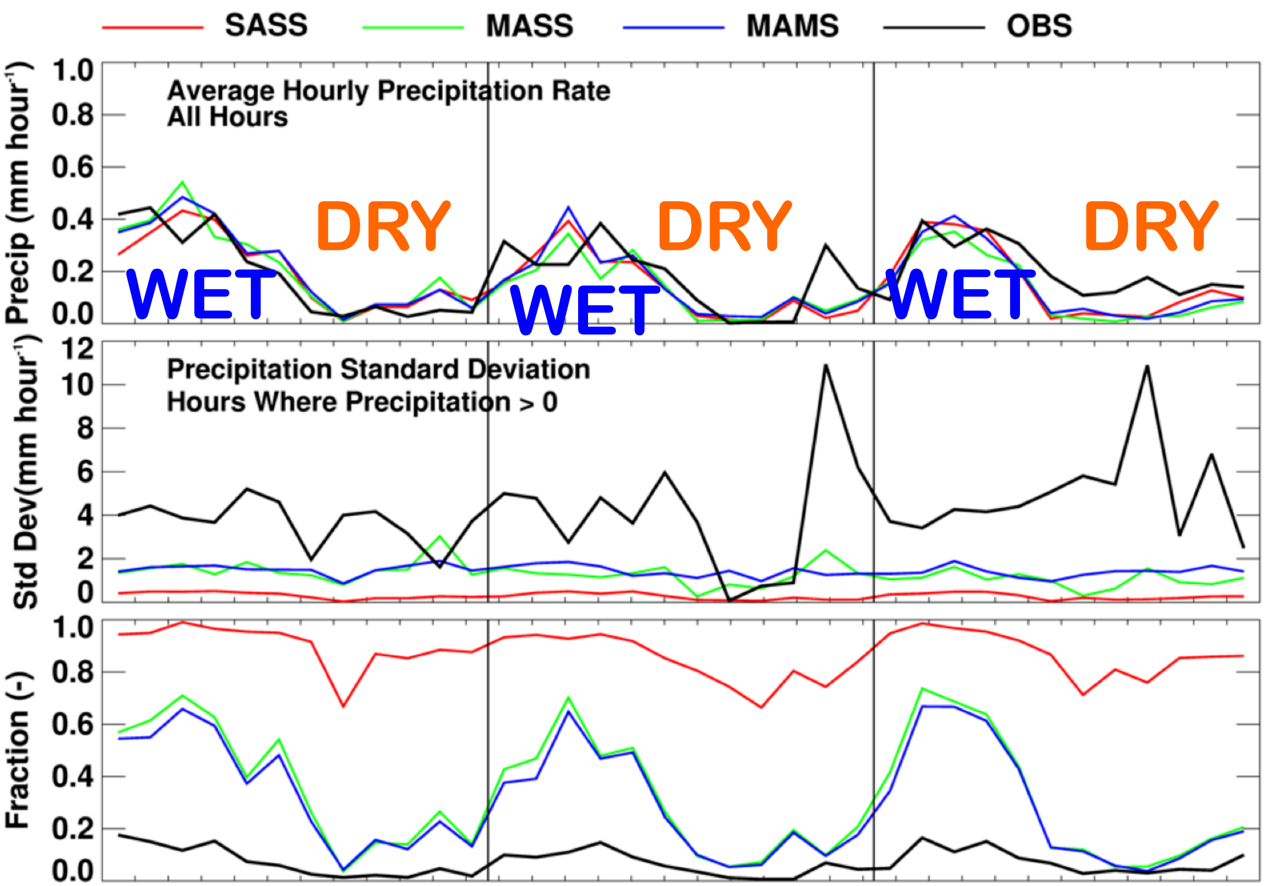


$$f(\overline{x}) \neq \overline{f(x)}$$

Single Column Model

- Land-atmosphere coupling using three configurations (SASS, MASS, MAMS)
- SiB-SCM (one column) vs SiB-SAM (64 columns)
- Soundings of T, q, wind relaxed to NCEP reanalysis on 6 hr timescale
- Local convection, precip, radiation, physiology, soil moisture, hydrology
- Three years 2001-2003 repeated

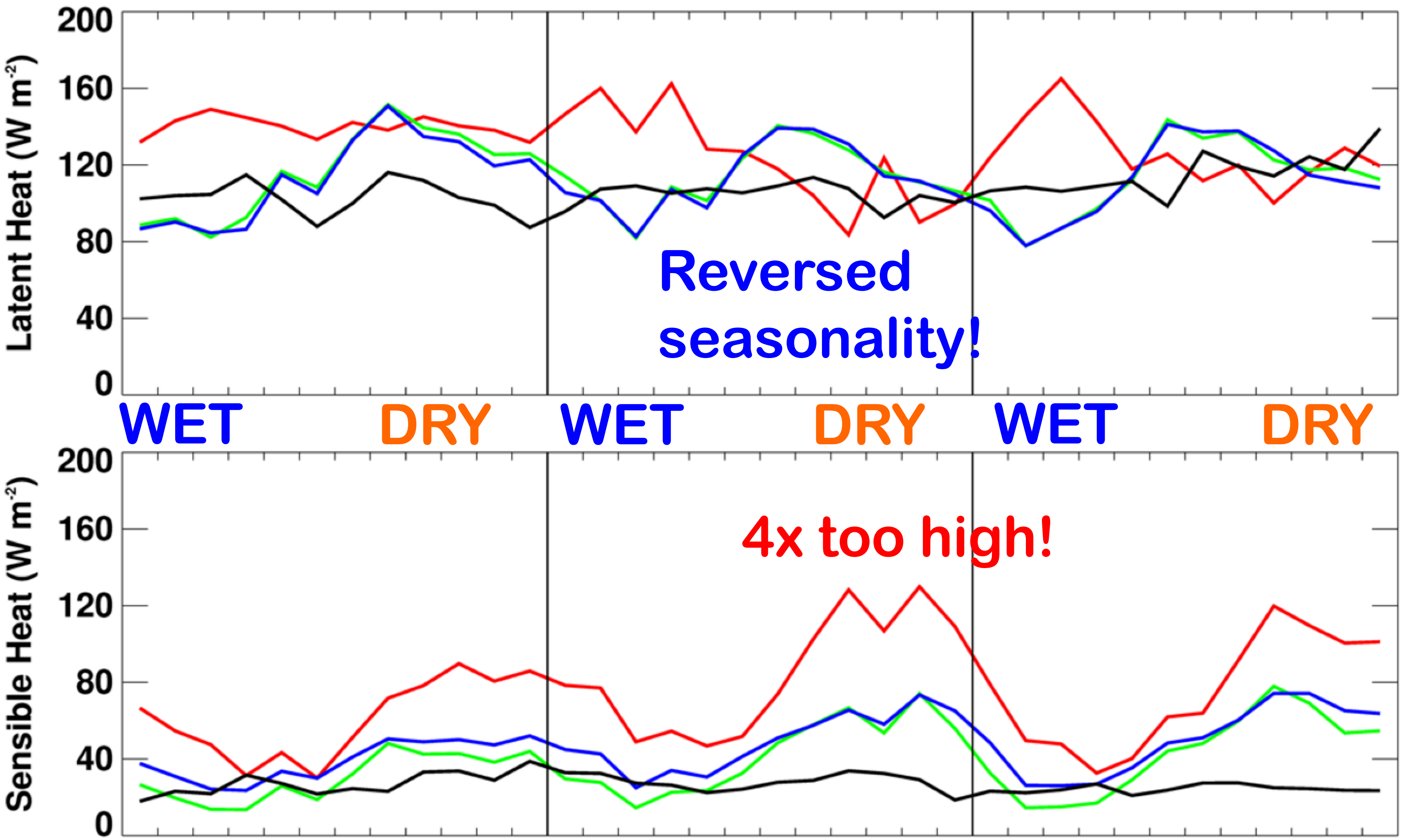
SCM: Drizzle vs Downpours



Monthly precipitation (top), standard deviation during hours with precipitation (middle), fraction of time when precipitation occurs (bottom) for the 3 models, and as observed.

- All 3 experiments reproduce observed precipitation (constrained by LBC)
- Constant drizzle in SASS
- Still too much drizzle in MASS & MAMS

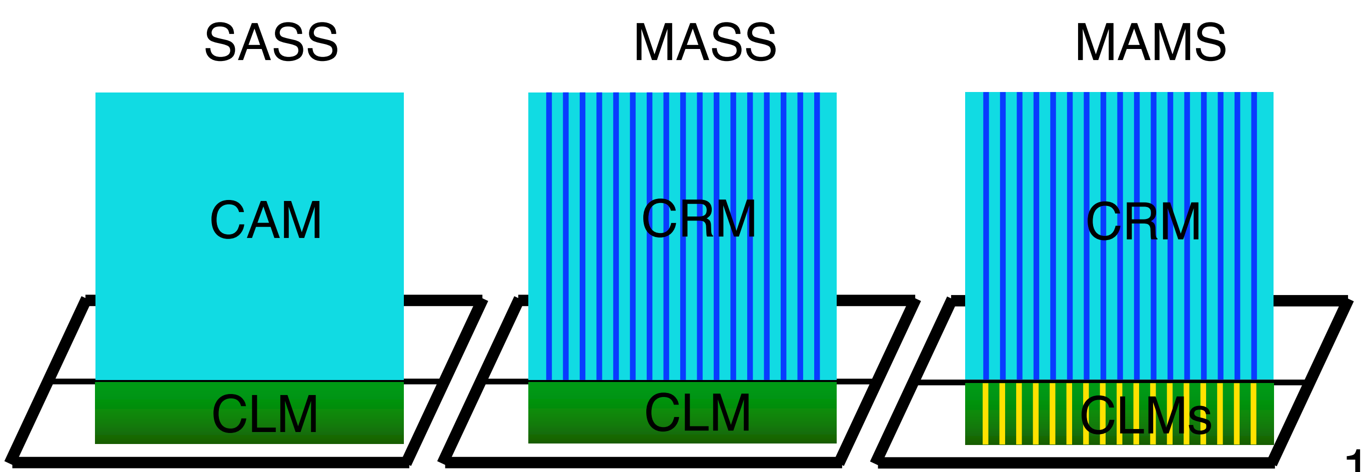
SCM: Surface Fluxes



Obs almost aseasonal

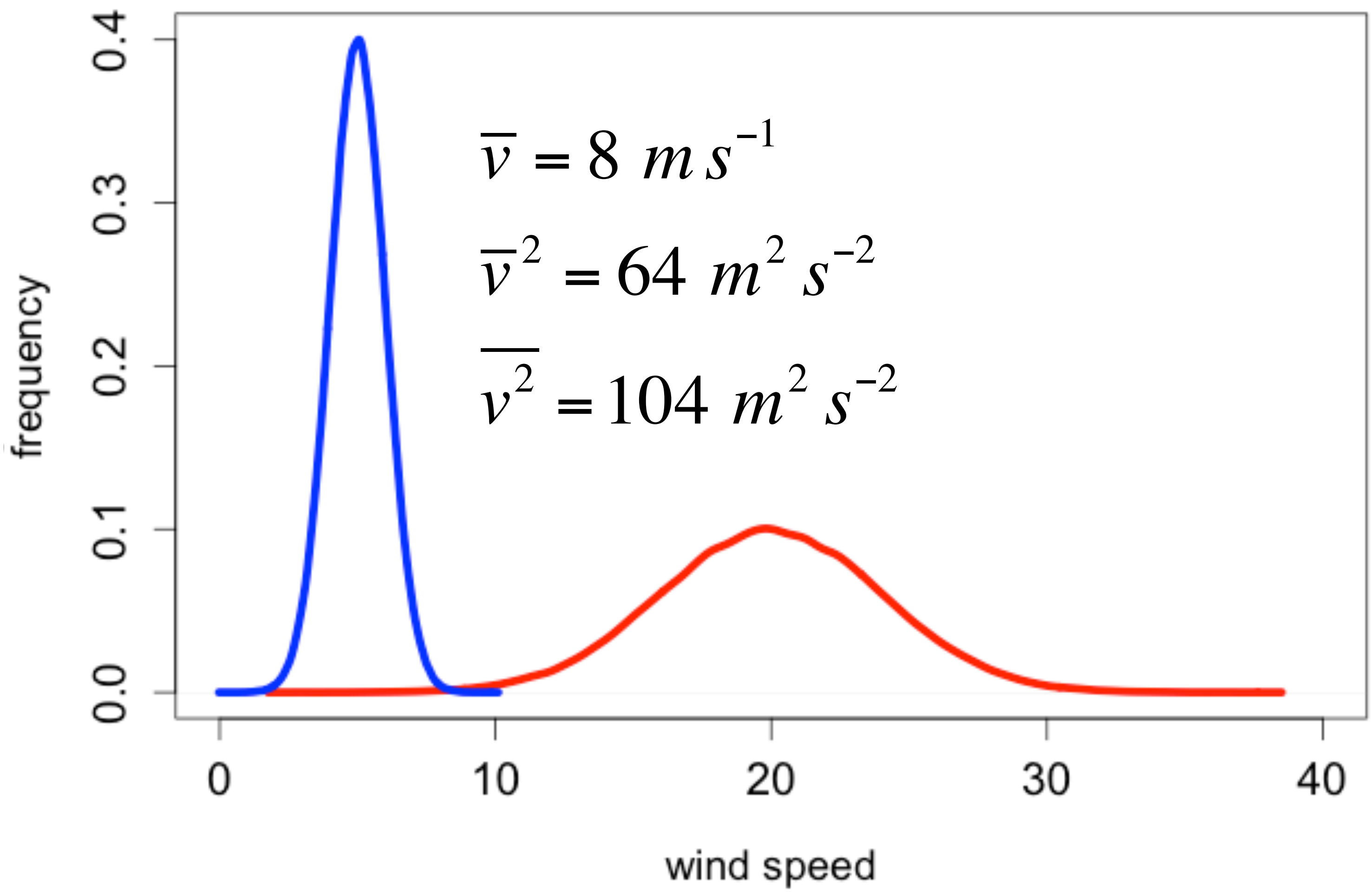
Global Multiscale Climate Simulations with SP-CESM

- AMIP-style integrations of SP-CESM, with prescribed SSTs (27 years: 1979-2006)
- Coupled three ways: SASS, MASS, & MAMS
- MAML run uses 32 instances of CLM with identical parameters in each CAM column, each coupled to its own CRM column
- Hourly CRM diagnostics for 1 year



Nonlinear Fluxes

Hypothetical Wind Speeds
over the Tropical Pacific



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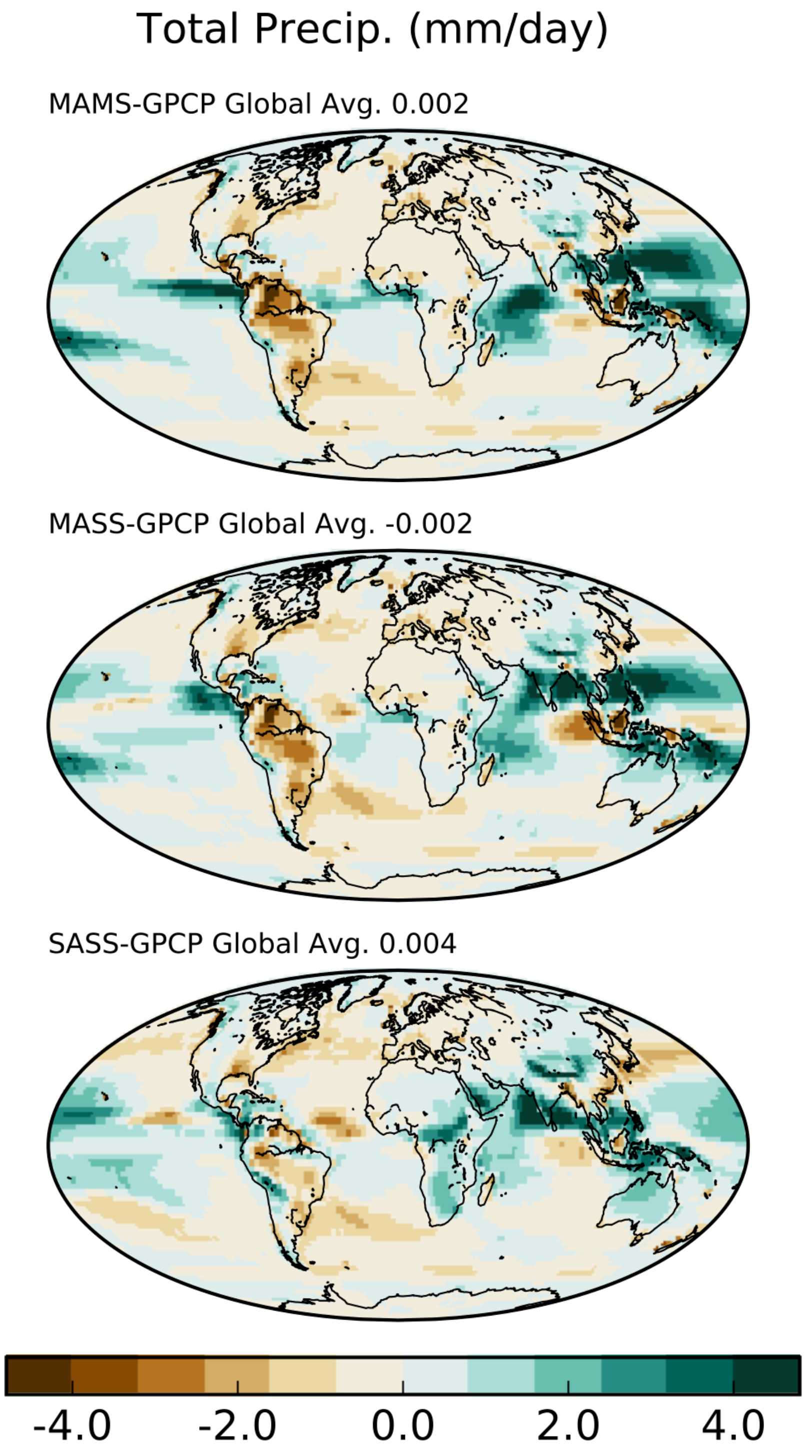
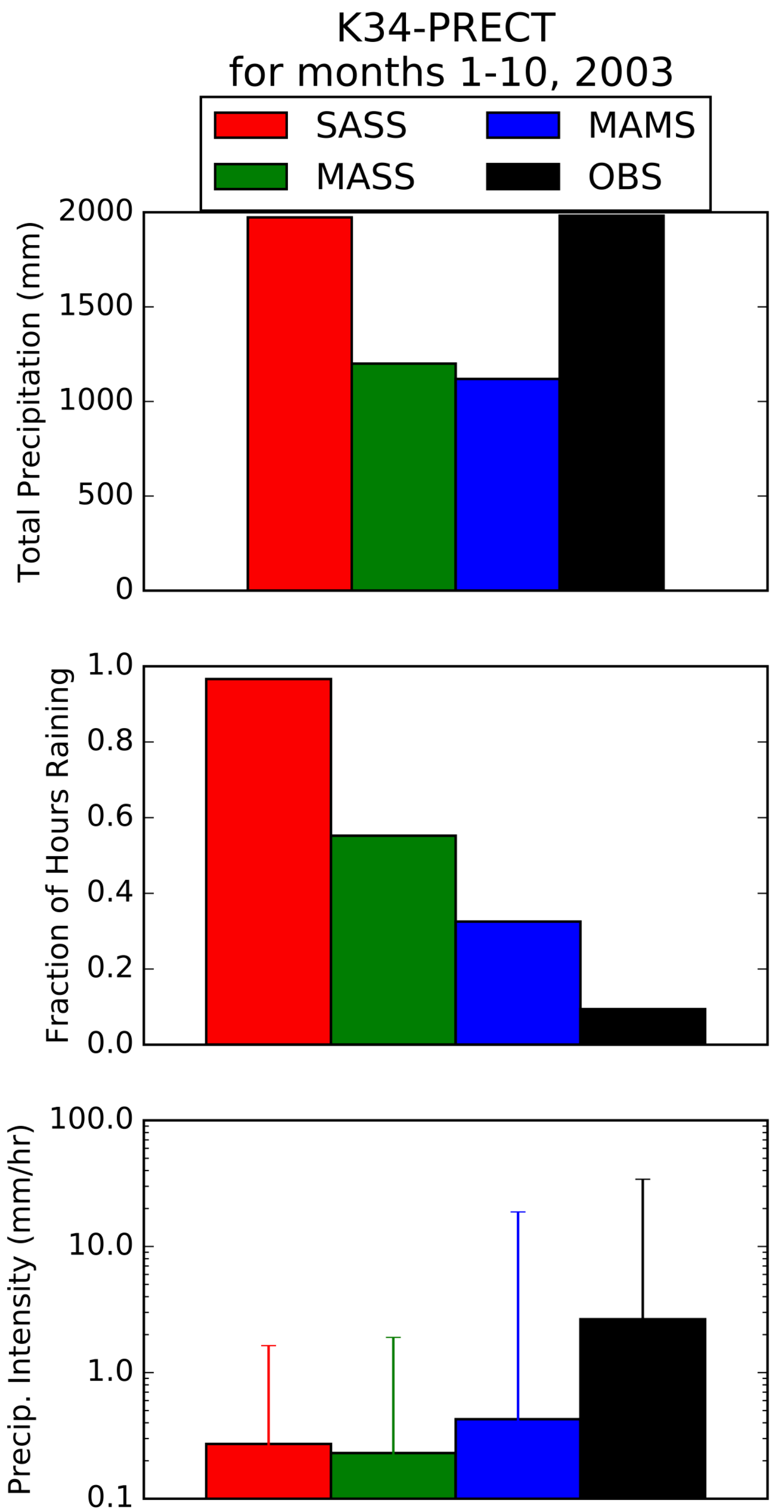


Precipitation Evaluation

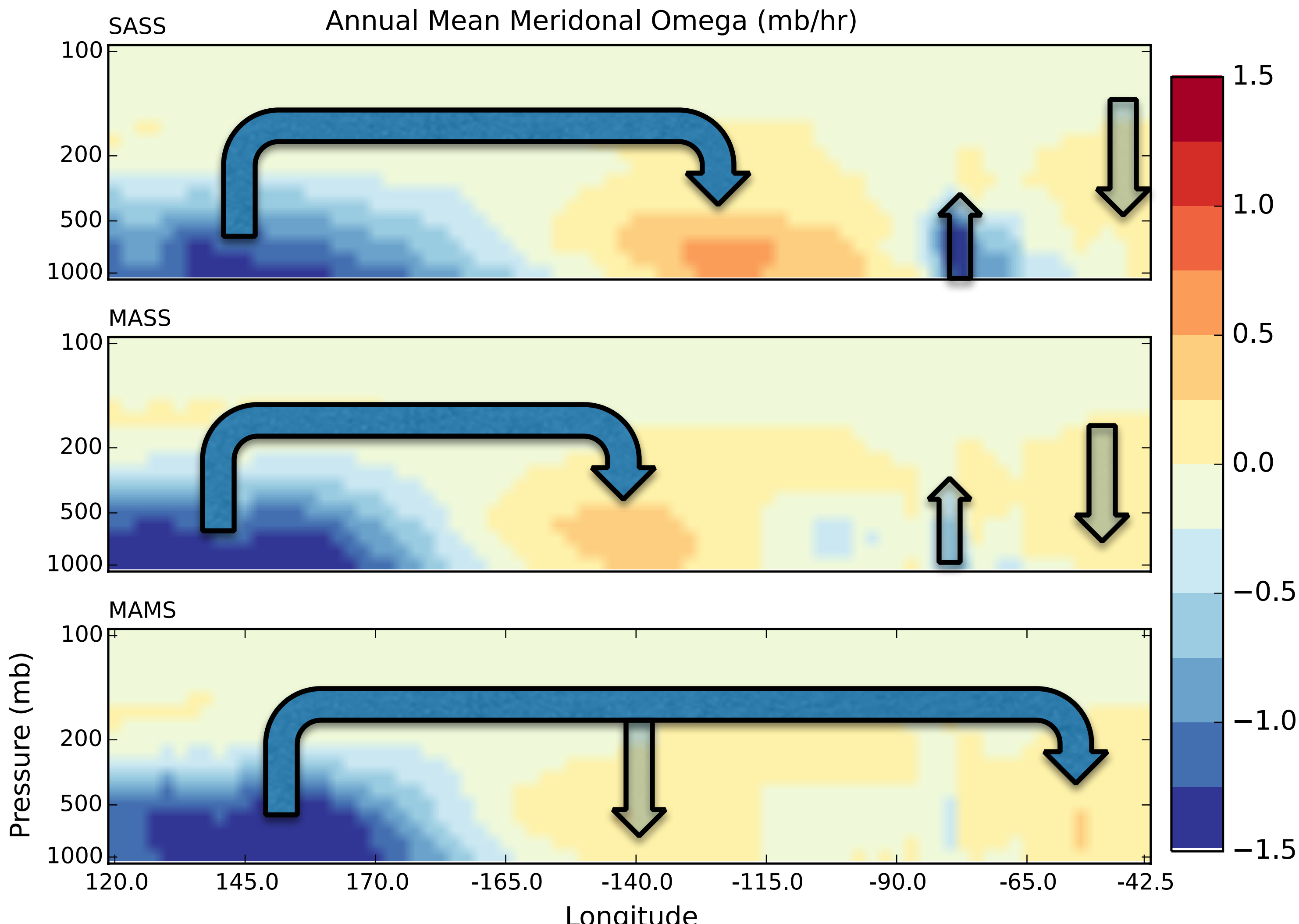
- Shift in western Pacific from Equator to off-Equator in SP-CAM
- Dramatic drying of Amazon!
- Indian Monsoon is much more realistic in fine-coupled run (MAMS)

Site Precip Evaluation



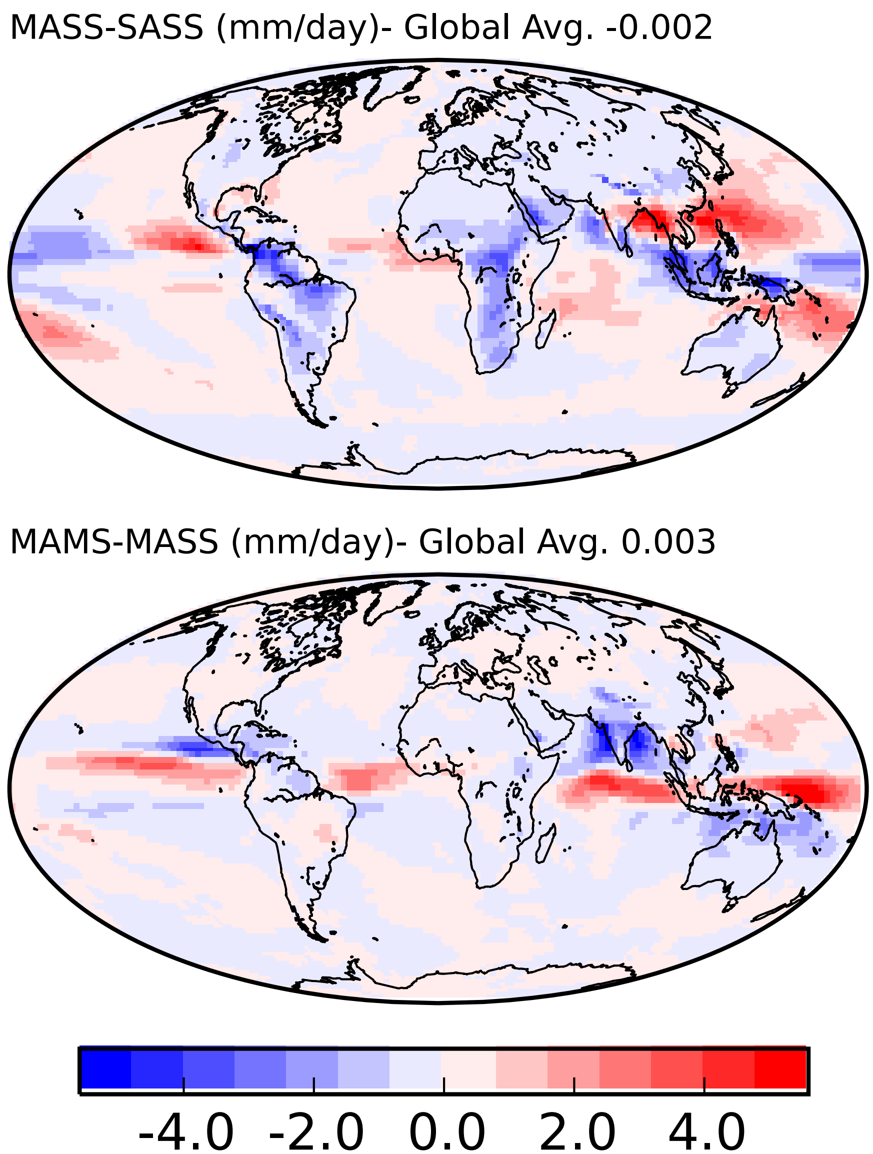
- **Tower site (K34) near Manaus in Central Amazon**
- **SASS has most realistic total precipitation by far**
- **SASS has drizzle 95% of the time vs actual rainfall about 10% of time in obs**
- **Multiscale runs are intermediate btwn control and obs**

Walker Circulation



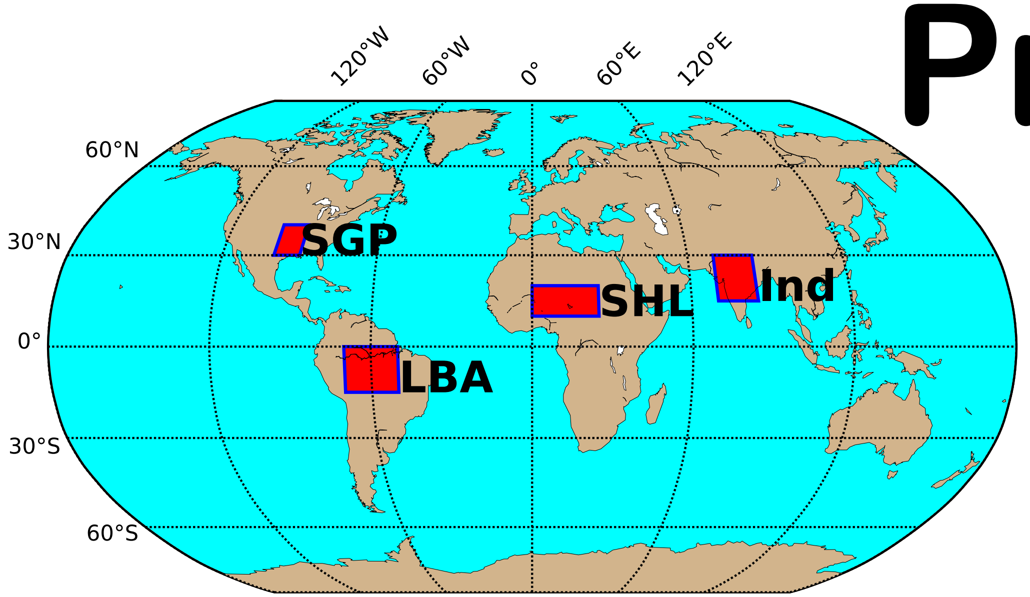
Intensification of convective precipitation overWarm Pool region produces enhanced subsidence over Amazon

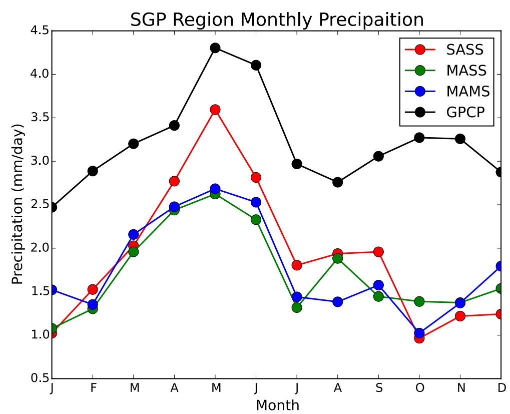
Precipitation

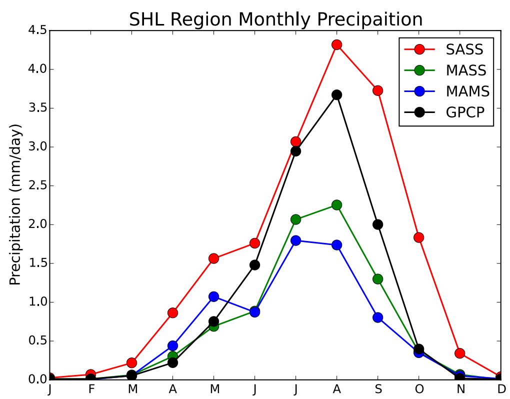


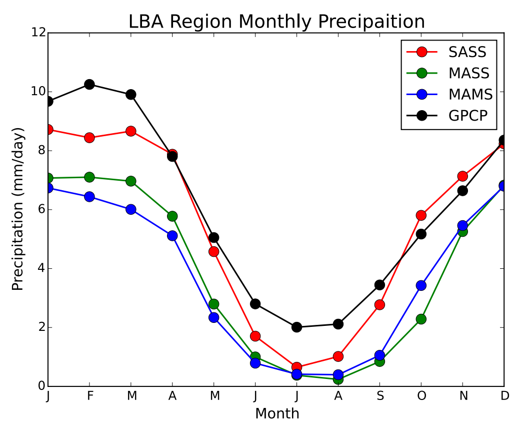
- **MASS (SP-CAM) produces a much drier Amazon**
- **MAMS produces a much more realistic Indian Monsoon**

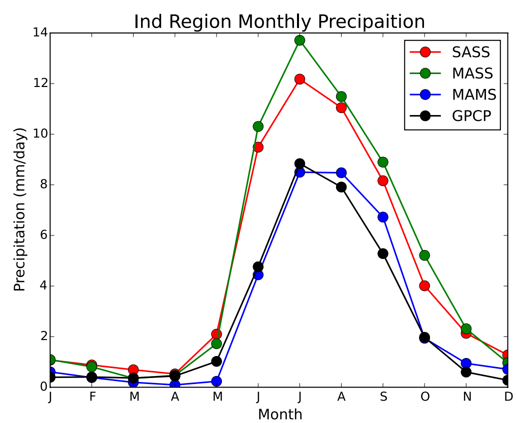
Precipitation vs Obs





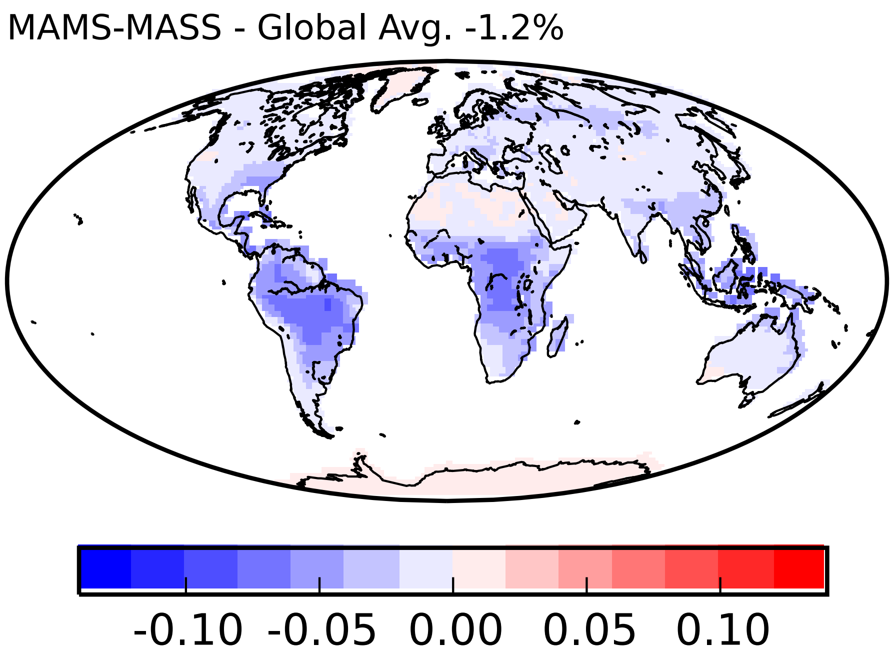




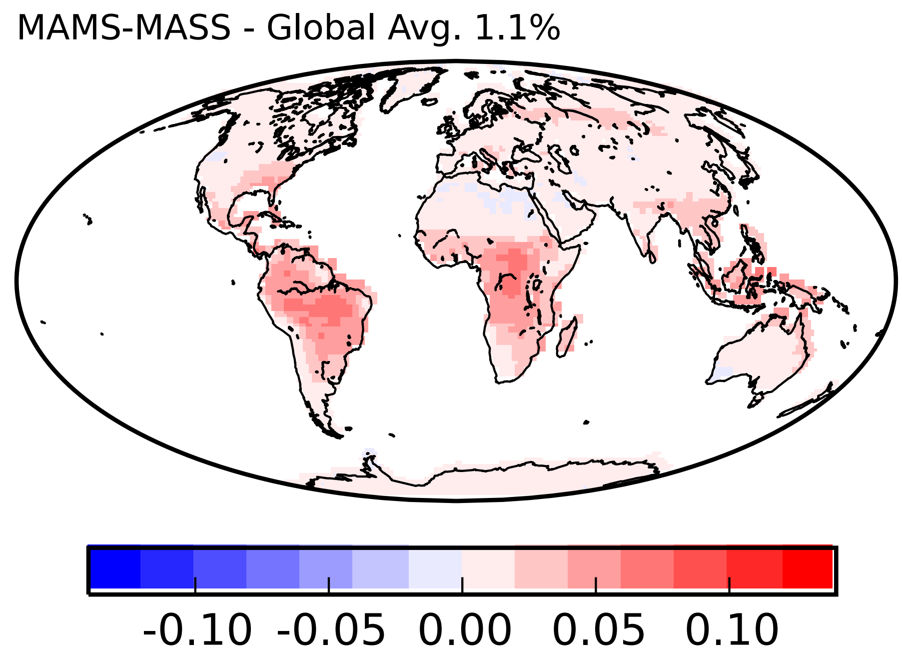


Precipitation Pathways

Canopy Evaporation / Precipitation

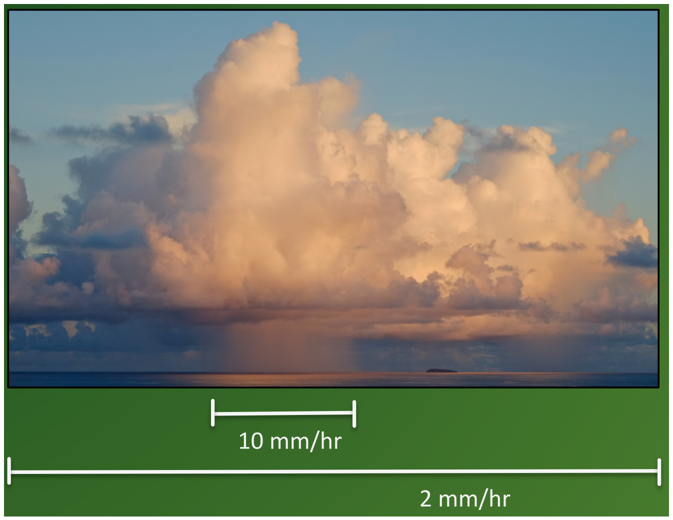


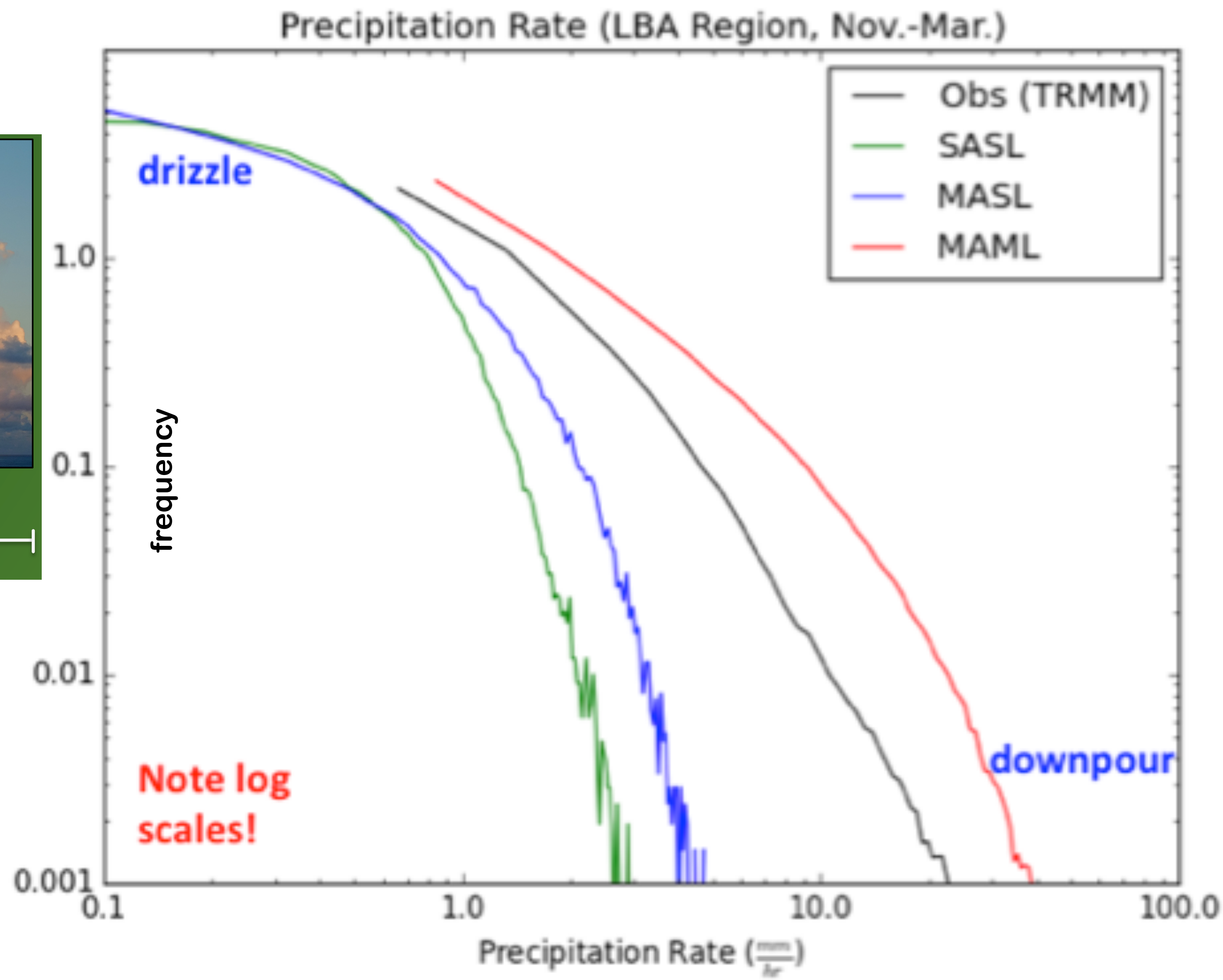
Throughfall / Precipitation



Fine-scale coupling produces much more throughfall and less canopy evaporation due to more intense precipitation

More Intense Rainfall



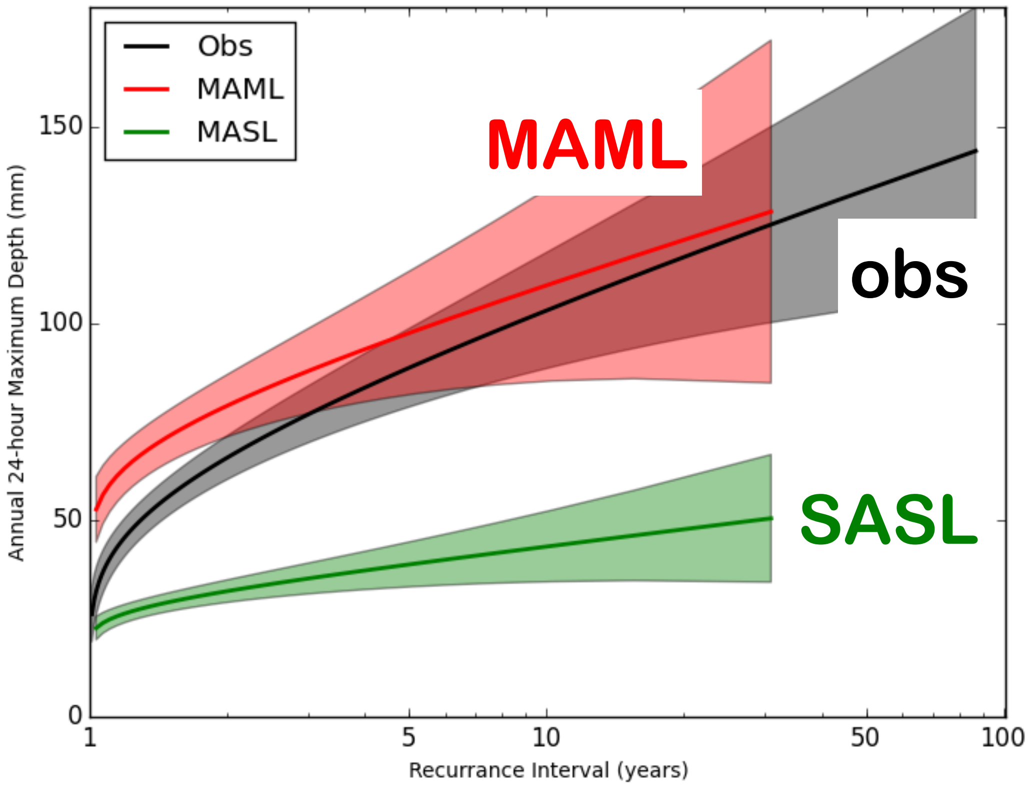


Intensity depends on resolution

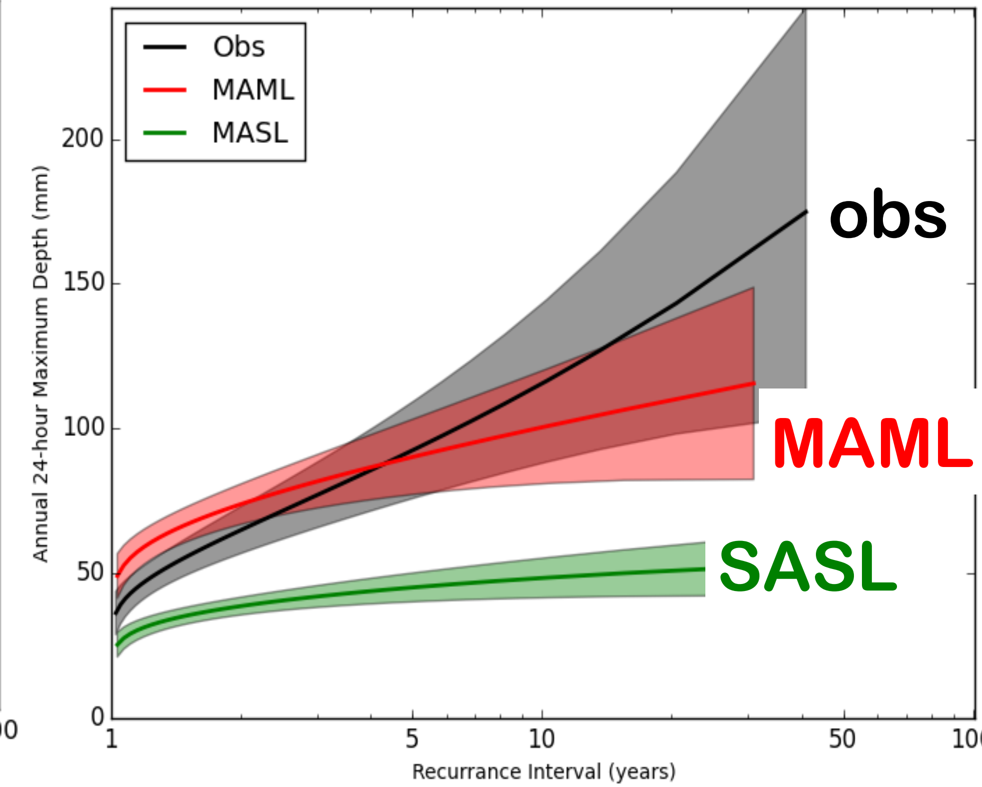
Intensity also depends on physics!

More Intense Rainfall

Chicago



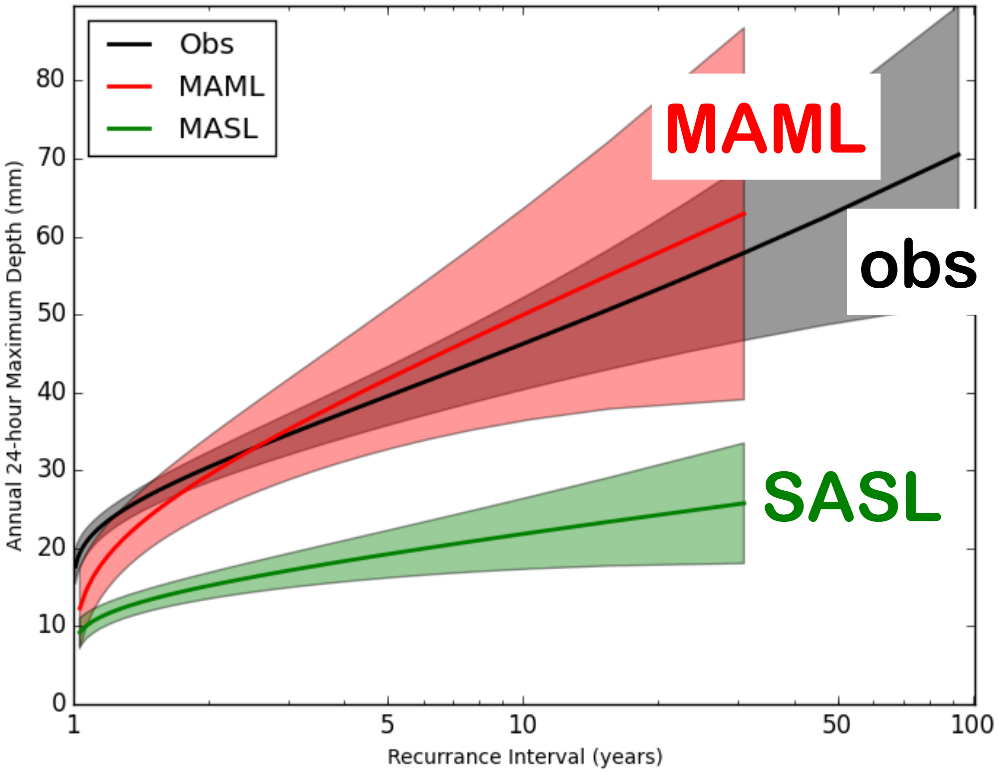
Atlantic City



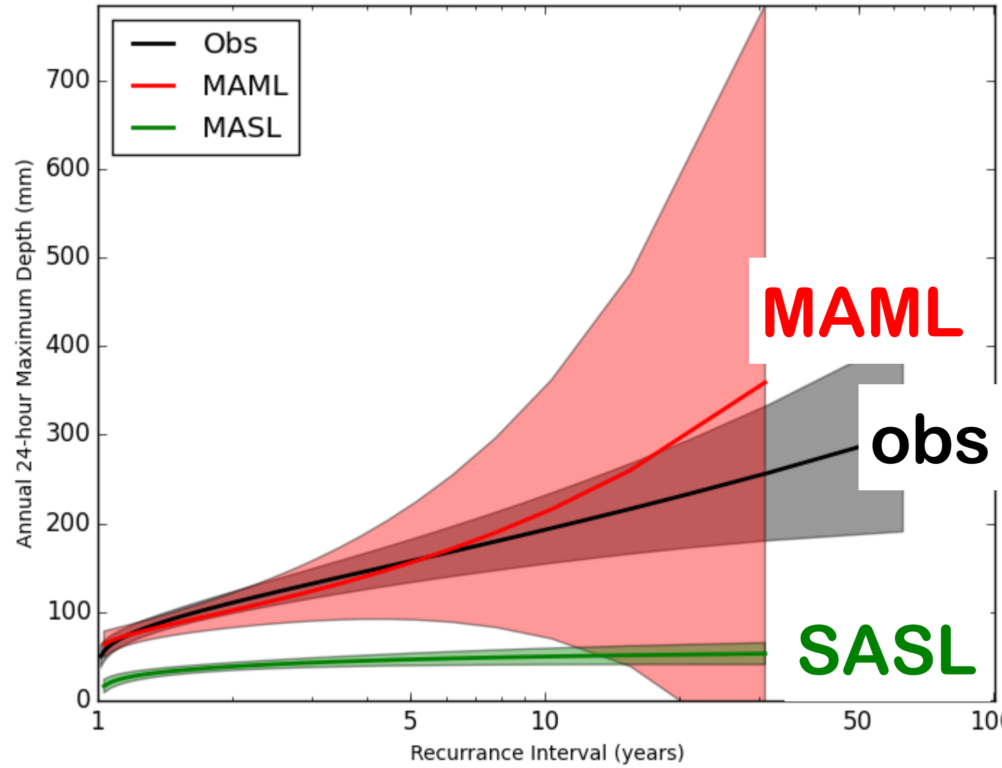
"Dynamical Downscaling"

More Intense Rainfall

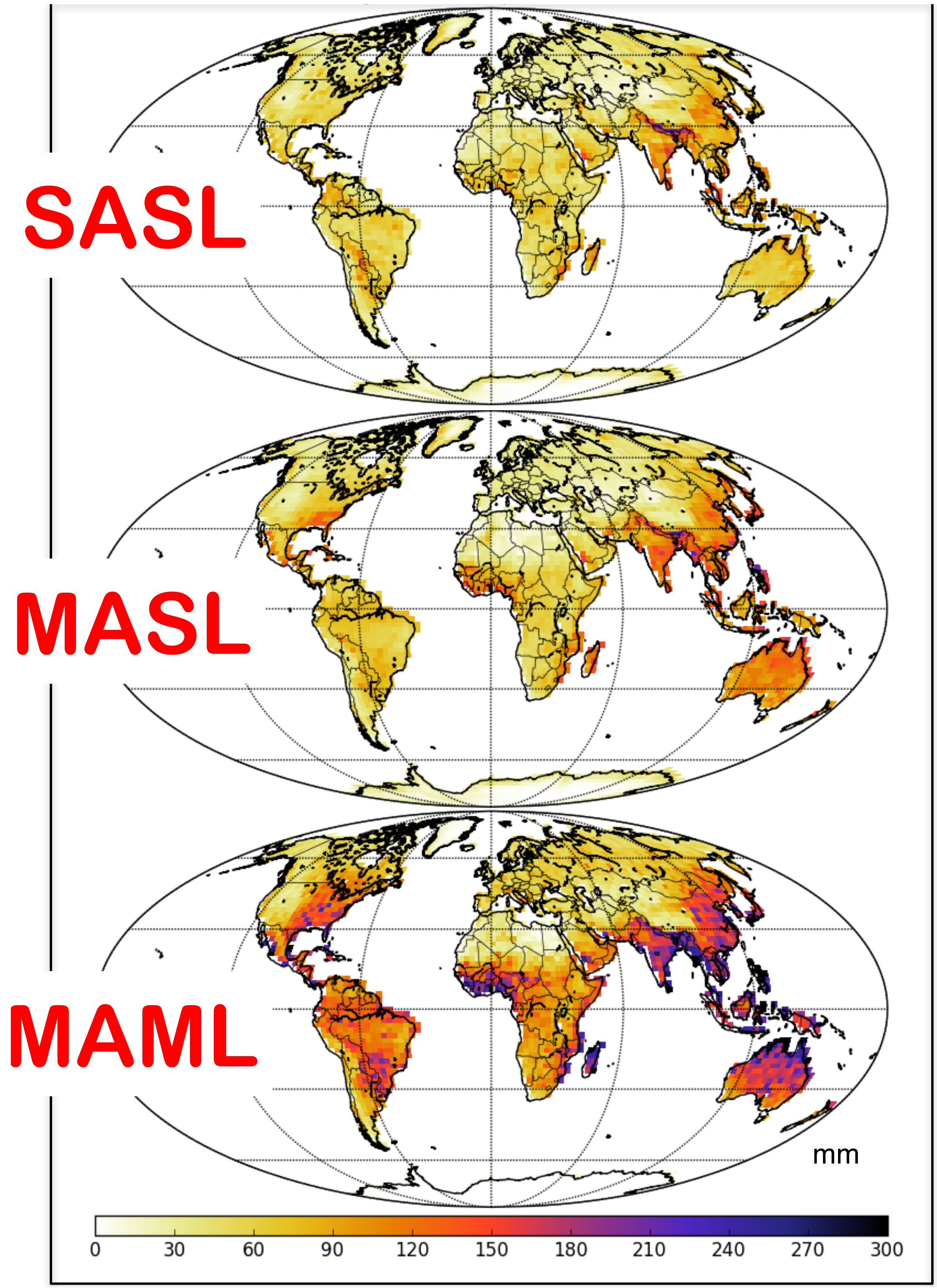
Madrid



Miami

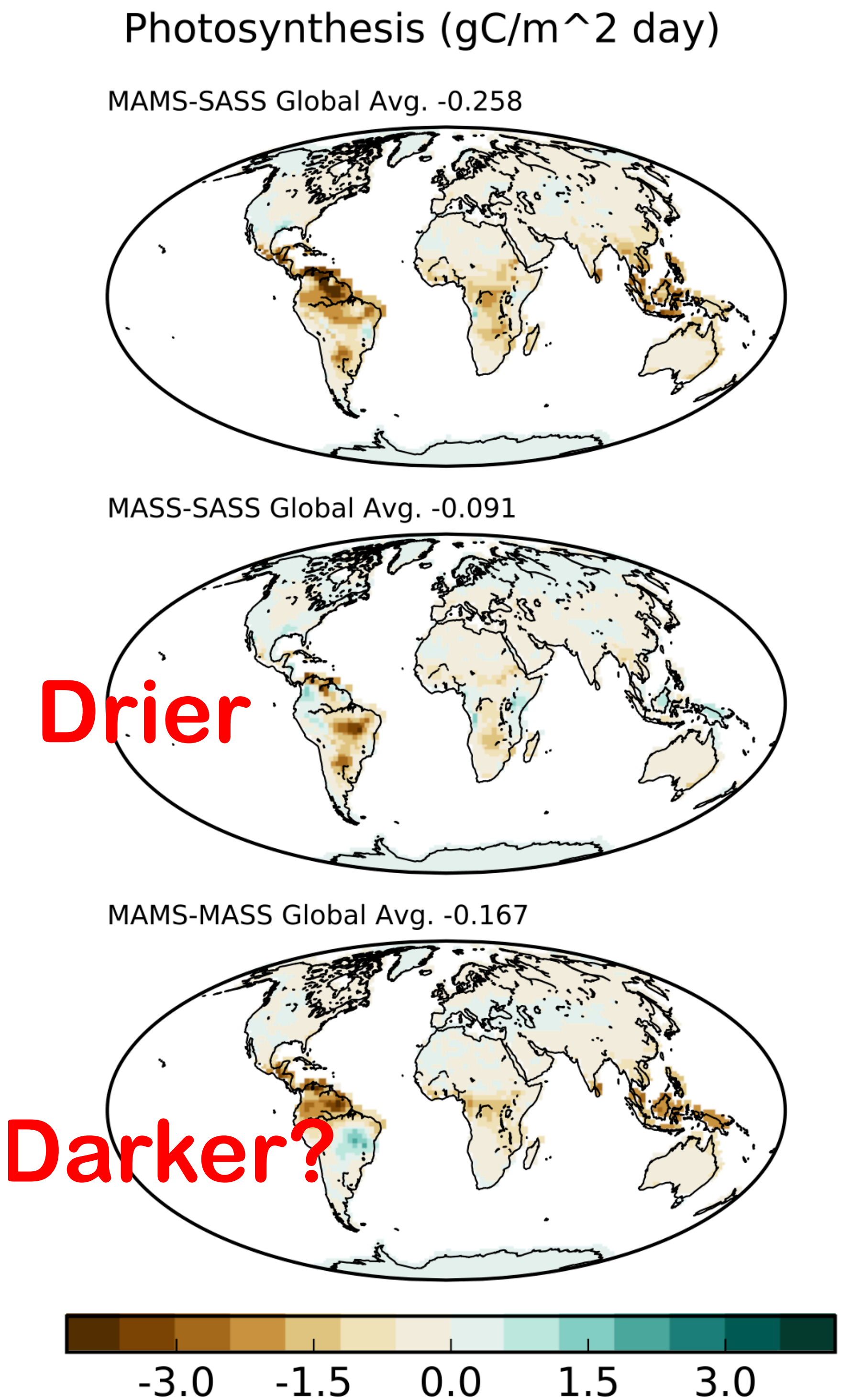


"Dynamical Downscaling"



30-Year Max Rainfall

- SASL < MASL < MAML
- Average precip not very different
- Extreme precip is much greater (& more realistic)

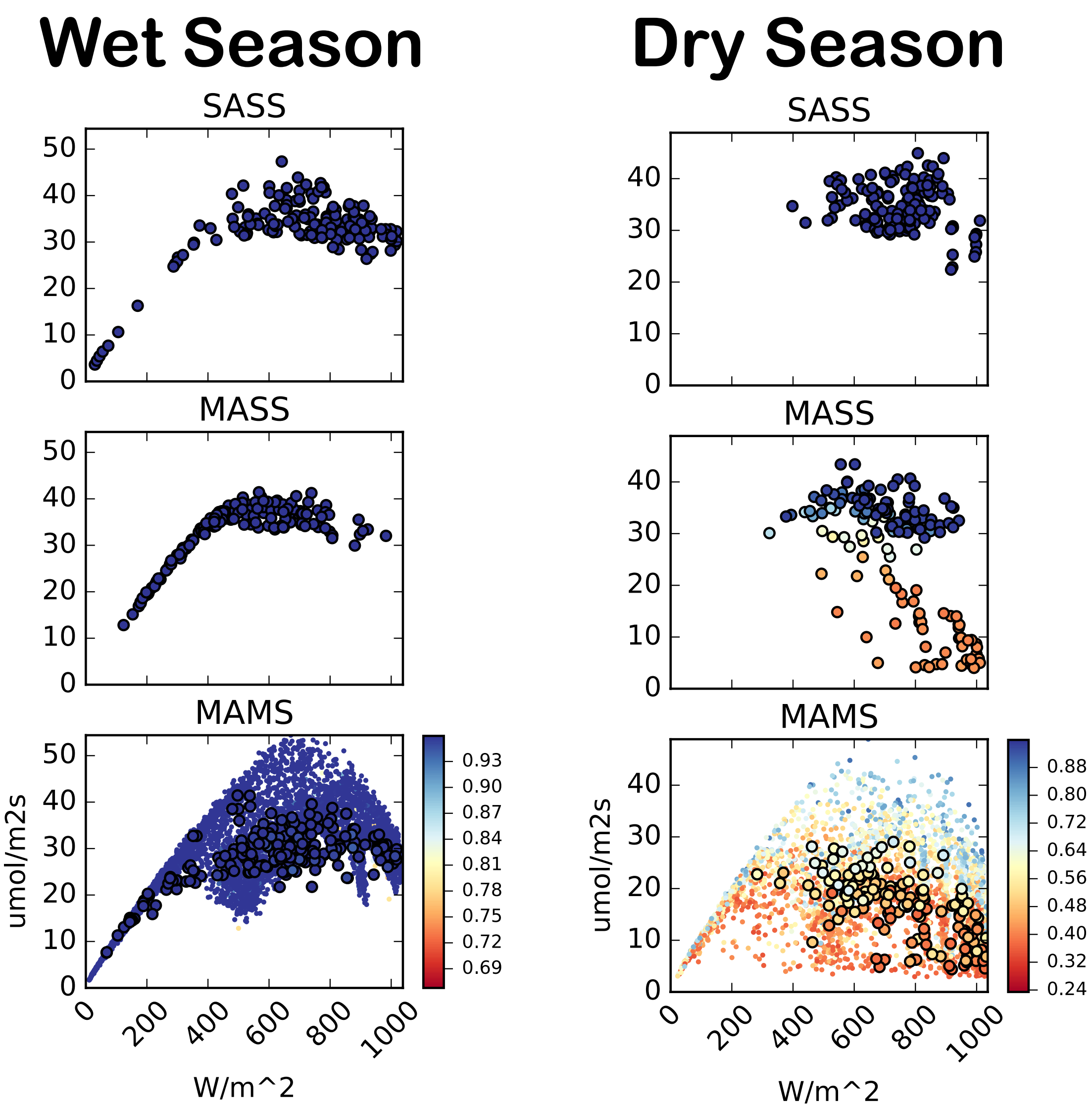


GPP

- Reduction in GPP in MASS vs SASS due to reduction in precip overall
- Shift in precip from Amazon to savanna in MAMS vs MASS correlated with changes in radiation distribution

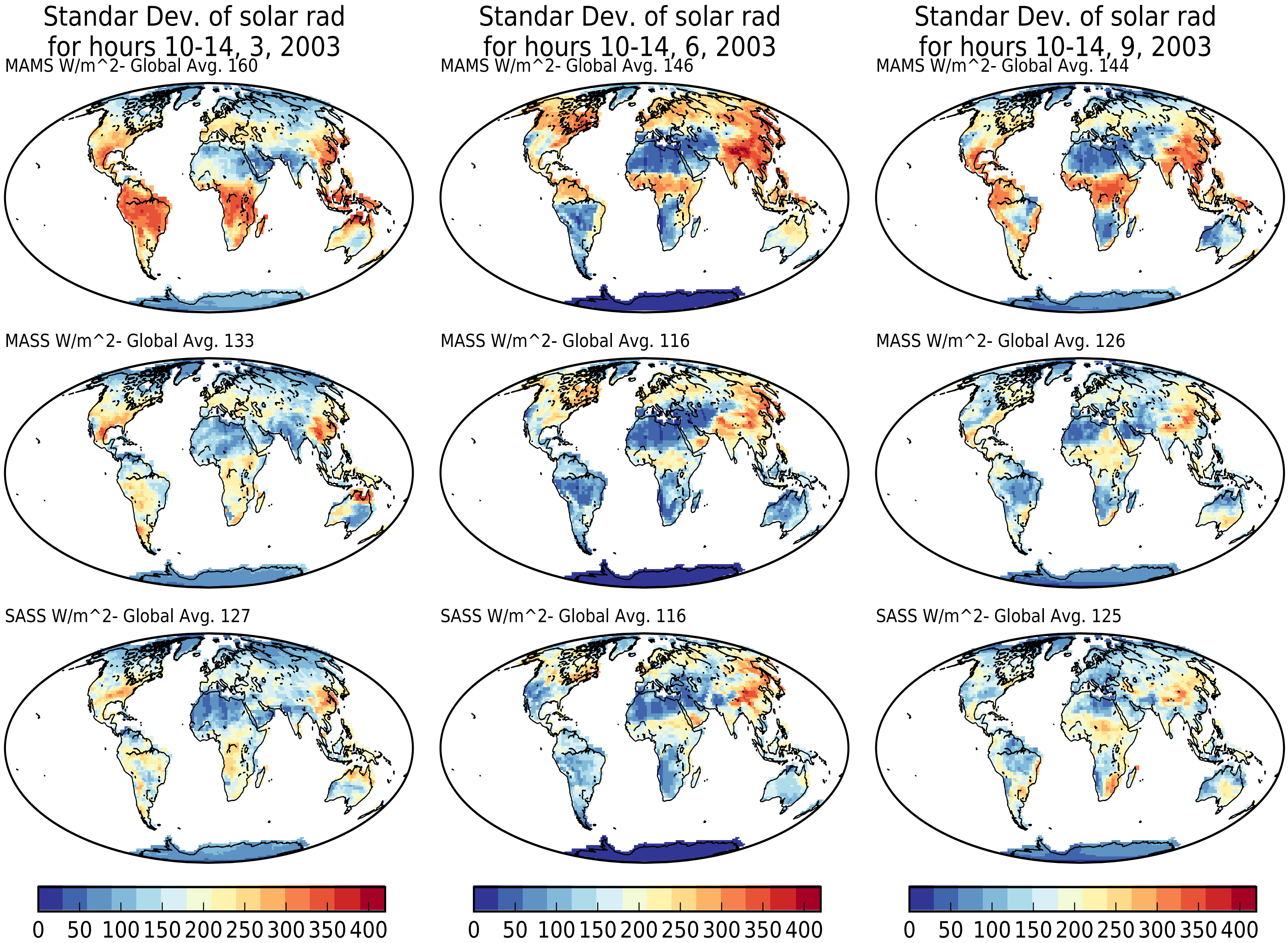
Light & Water Limits

Light Response Curves



- Hourly GPP vs SW at CLM scales; colors show BTRAN (stress)
- Mid-day samples at K34 tower (Manaus) for wet season (3/2003) vs dry season (9/2003)
- Fine-scale coupling produces more light limitation due to covariance of bright and dry conditions

Radiation Variability



Summary

- Responses to changes in Amazon drought are among the most uncertain carbon-climate feedbacks for 21st Century
- GCM diagnostic: Seasonal drought strongly correlates with SIF
- Cloud-scale vs CAM-scale coupling:
  - Much more realistic precip intensity
  - Water storage wet-to-dry season!
  - Shift in Walker Circulation – drought!
  - Covariation between water & light limitation (reduced GPP)