Global energy constraints and local variability – Insights from natural variability?

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&
discussions with Isaac Held, Caroline Muller, Sarah Kapnick & Tim Merlis

Motivation

Open questions concerning climate's "base" state:
- latitudinal heat flux, and its ocean/atmosphere partitioning,
- planetary albedo, clouds,
- atmospheric humidity,

(precipitation consistent with above processes)
etc.

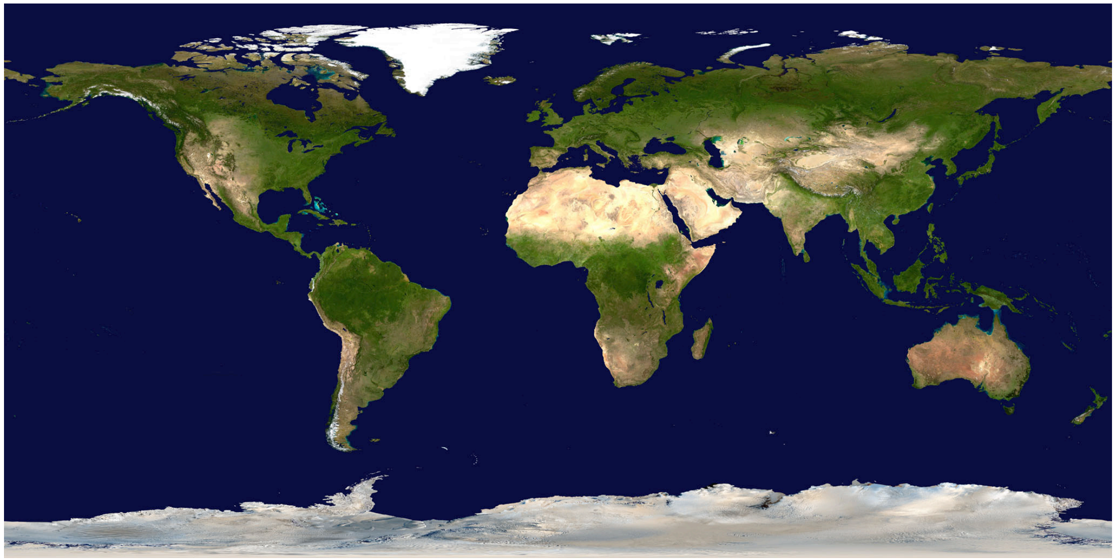
System is energetically constrained – in the global mean.
How does this constraint affect the local balances?

With improved observational data and modern re-analyses, we can begin to address these questions in more detail.

Motivation

Uneven distribution of landmasses allows insights from processes that shift patterns:
- annual cycle,
- ENSO.

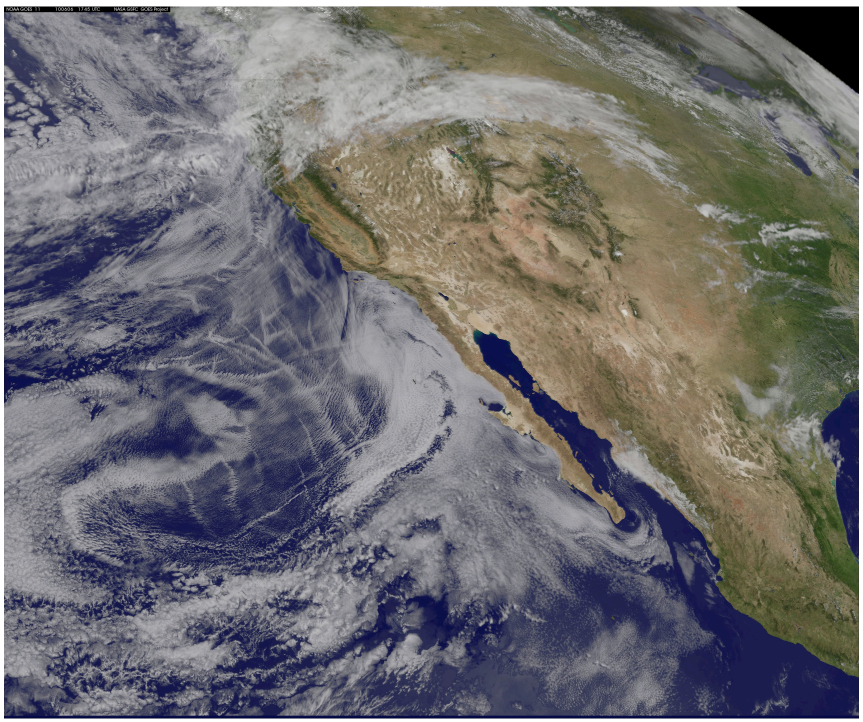
Q: Is the system "invariant" to shift of patterns in terms of global averages?



-> Pushing models out of the comfort zone, what about "observations"?
-> Your feedback is highly appreciated!

Motivation

Models (GCM's) capture base state quite well, but not perfect – and there are partially compensating biases.
Significance?
Do these biases matter when models are driven away from the "comfort zone"?



Example: Low level clouds account for much of the differences in model predictions for the future –> differences in representation of the base state project onto response to forcings.

This talk ...

... is about **questions** ...

Discuss:

- Aspects of the annual mean and seasonal cycle.
- ENSO.

Premise: No observational dataset is "the truth", no model is "the truth" – we do not seek to "validate" models/observations, but we're interested how the balance of terms shifts in each dataset associated with variability.

This talk's ...

"Observational" data:

- CERES EBAF (CERES_EBAFTOA_Ed2.6r_Subset_200003-201106.nc)
- GPCP (v2.2)
- also some ERBE and ISCCP data.

(And we also use other A-train data, ECMWF & MERRA reanalyses etc.)

GFLD models:

- CM2.1: coupled model, control run (100+ years), produces ENSO.
- AM2: Atmospheric General Circulation model, forced with SSTs (1979 – 2000).
- AM3: Ditto, new model.
- HiRAM: High Resolution Atmospheric Model (~50km resolution).

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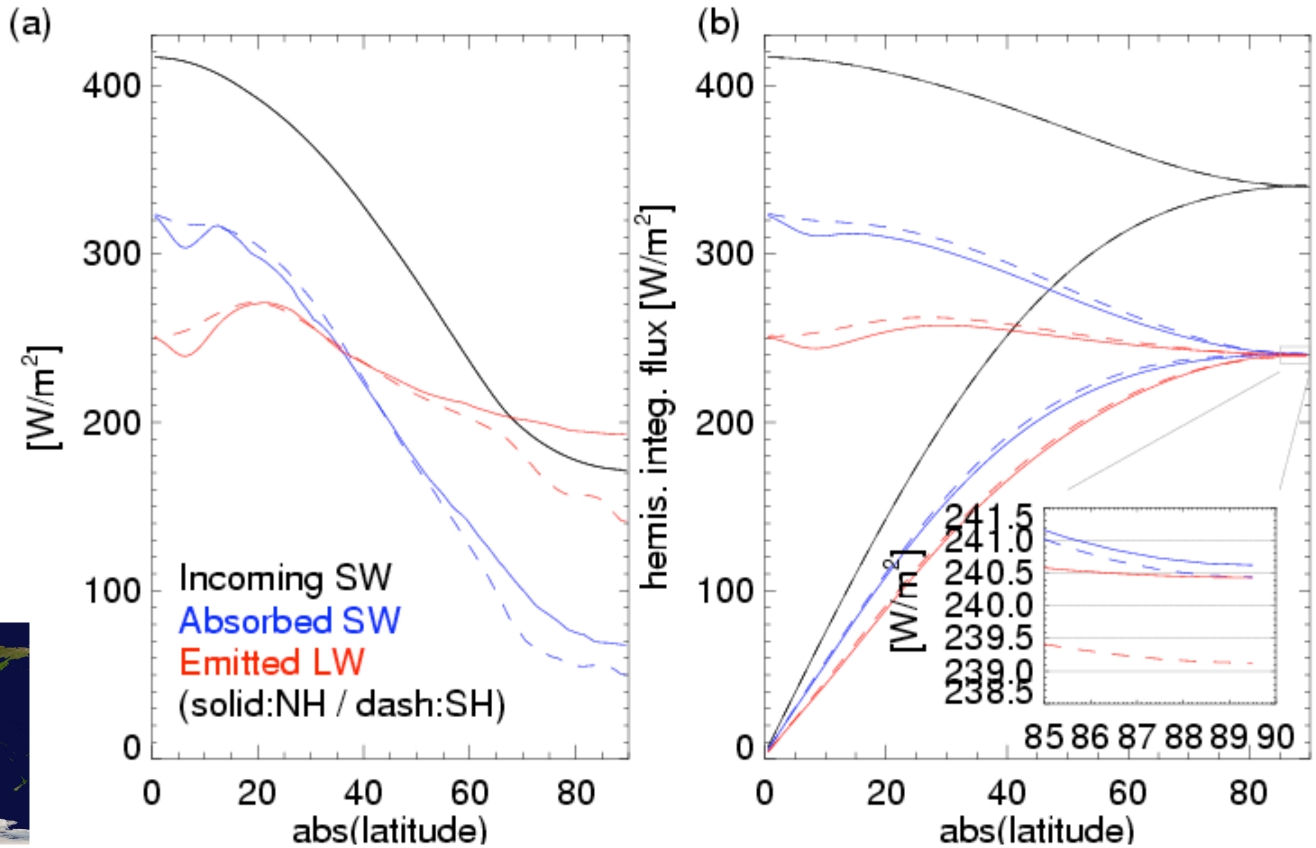
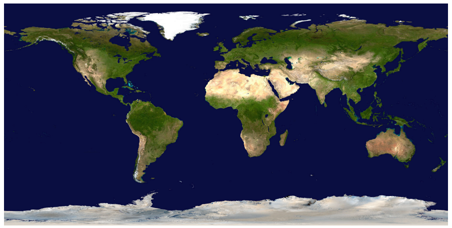
The annual mean state (CERES/EBAF)

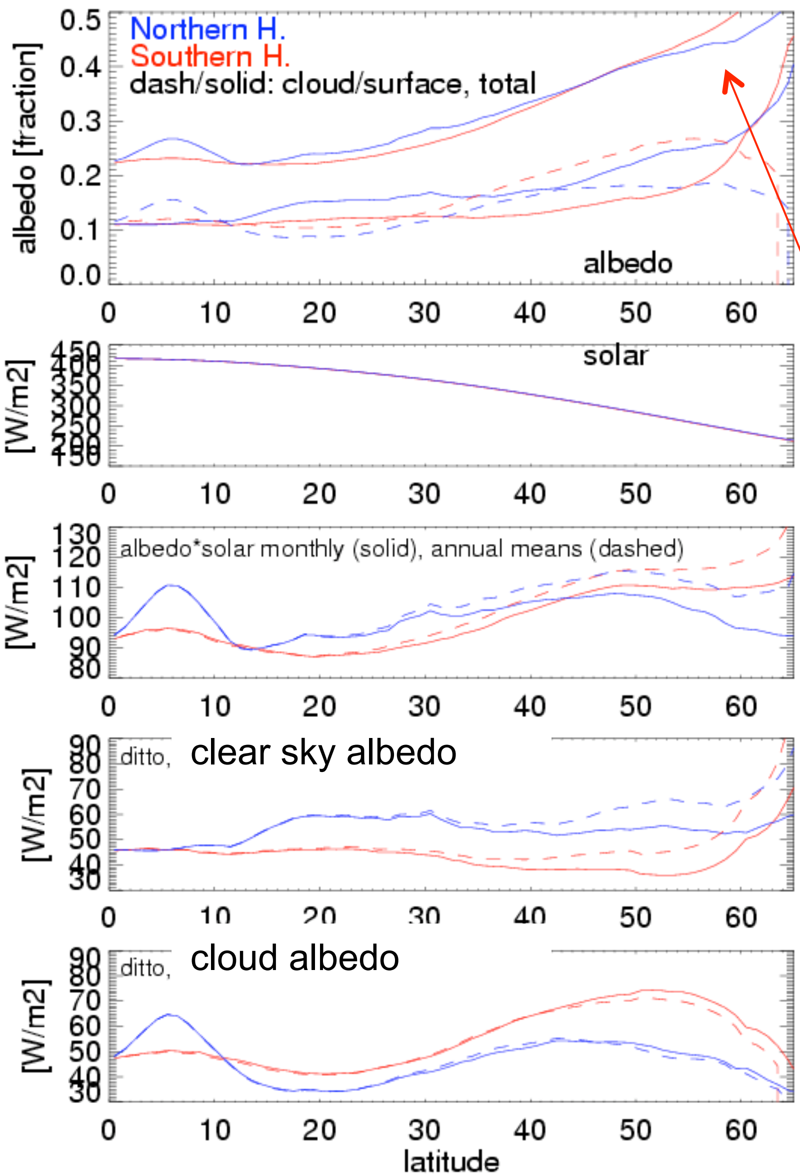
Absorbed shortwave is nearly identical between hemispheres in CERES/EBAF (quite remarkable given land/sea distribution).



Recall:



The annual mean state (CERES/EBAF)

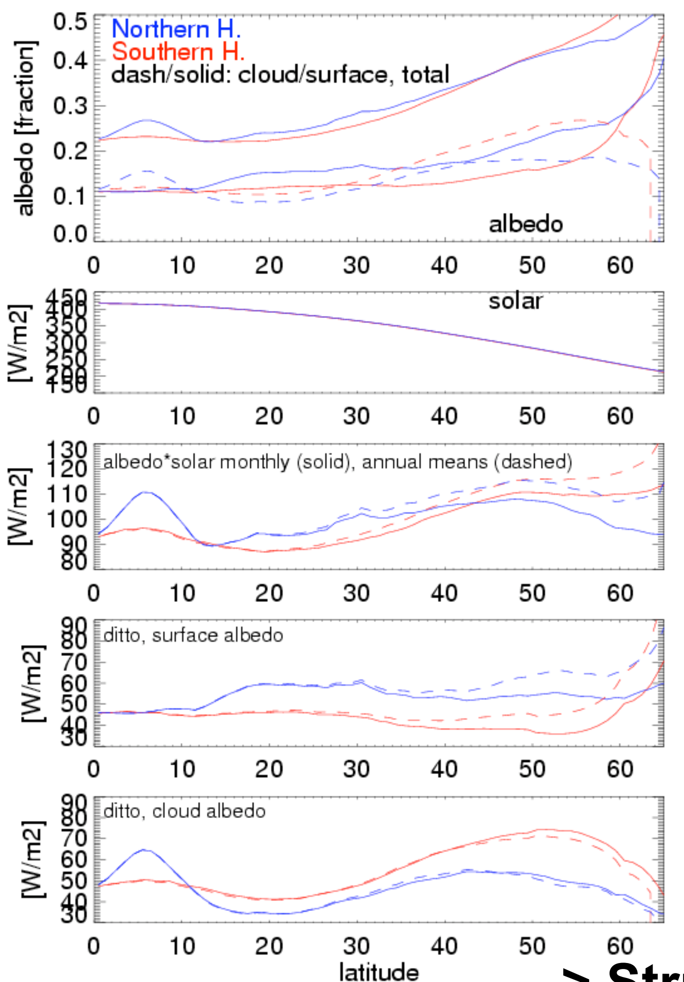


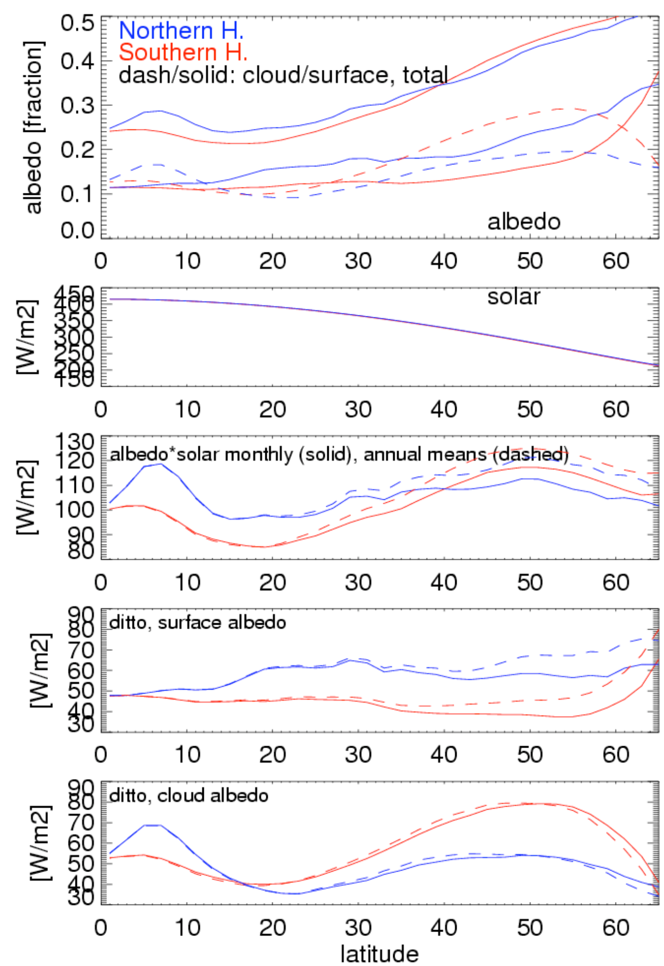
Reflected shortwave is only weakly dependent on latitude

NH: surface albedo+
SH: cloud albedo+
-> sum very similar.
Further:
- Insolation decreases with latitude (factor 2)
- albedo increases with latitude (factor 2)
-> reflected SW varies +/-10% with latitude.
- Annual mean albedo x annual mean insolation 1st order

The annual mean state

CERES/EBAF ⇔ AM3

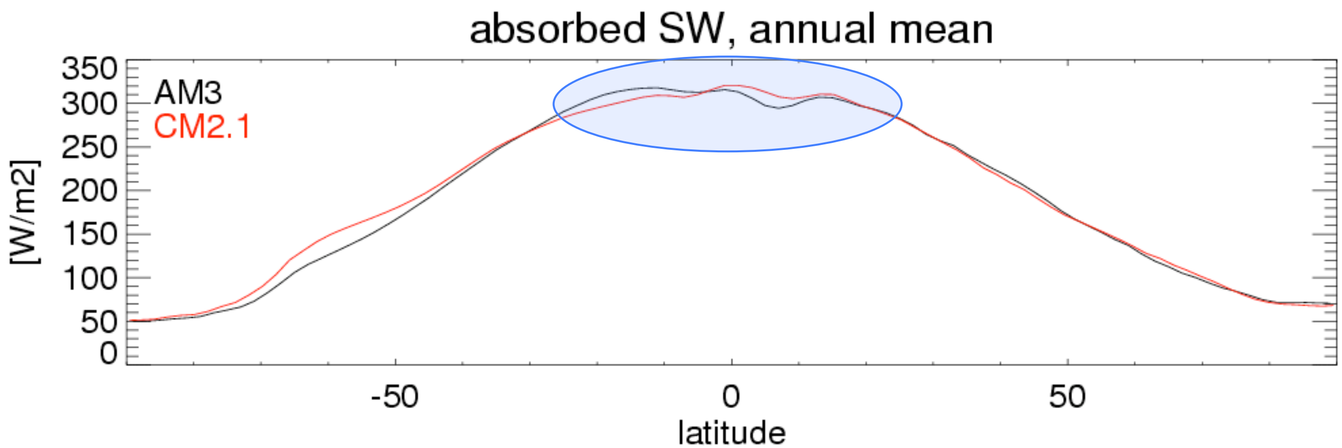




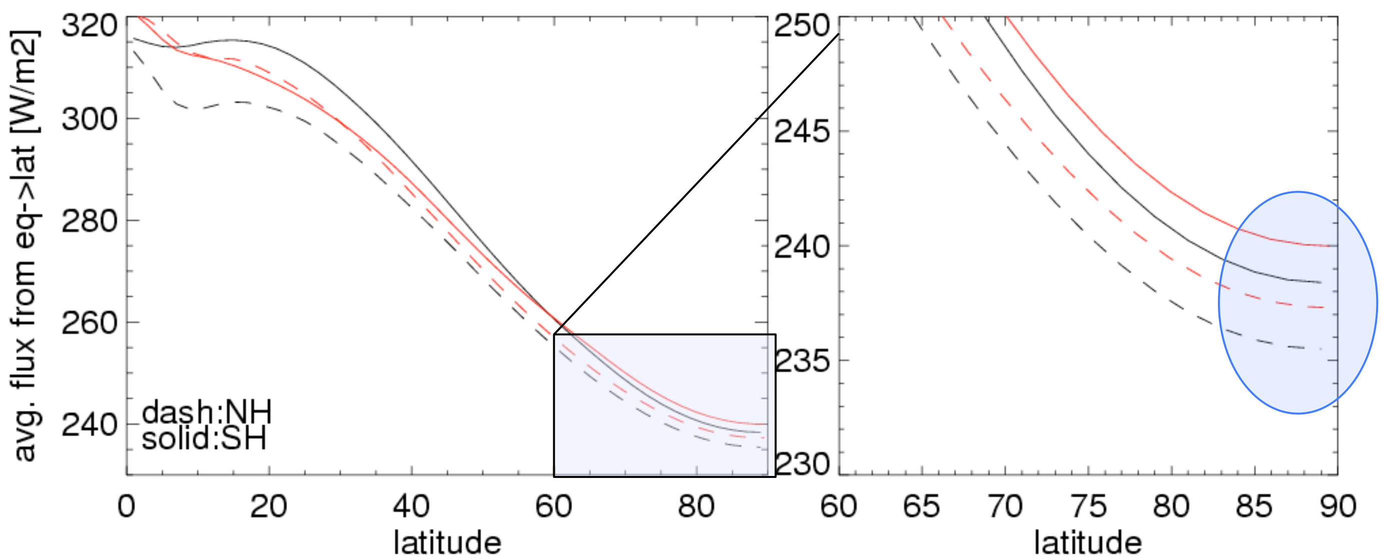
-> Structures fairly similar.

The annual mean state (Models)

But: Neither AM3 nor CM2.1 has the nearly identical SW absorption of SH/NH seen in CERES/EBAF. Is this important?



ITCZ of coupled model



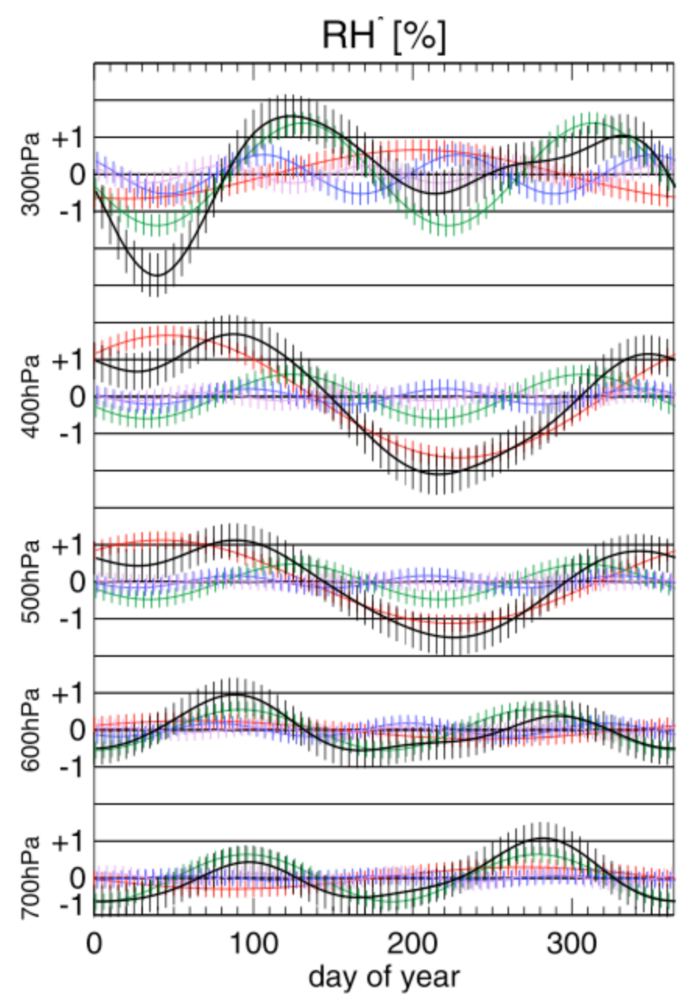
Diff: ~5W/m2

Mean annual cycle in global mean quantities

A number of key parameters have a seasonal cycle in global mean quantities. E.g. temperature (straightforward, land warms faster than ocean),
but also:

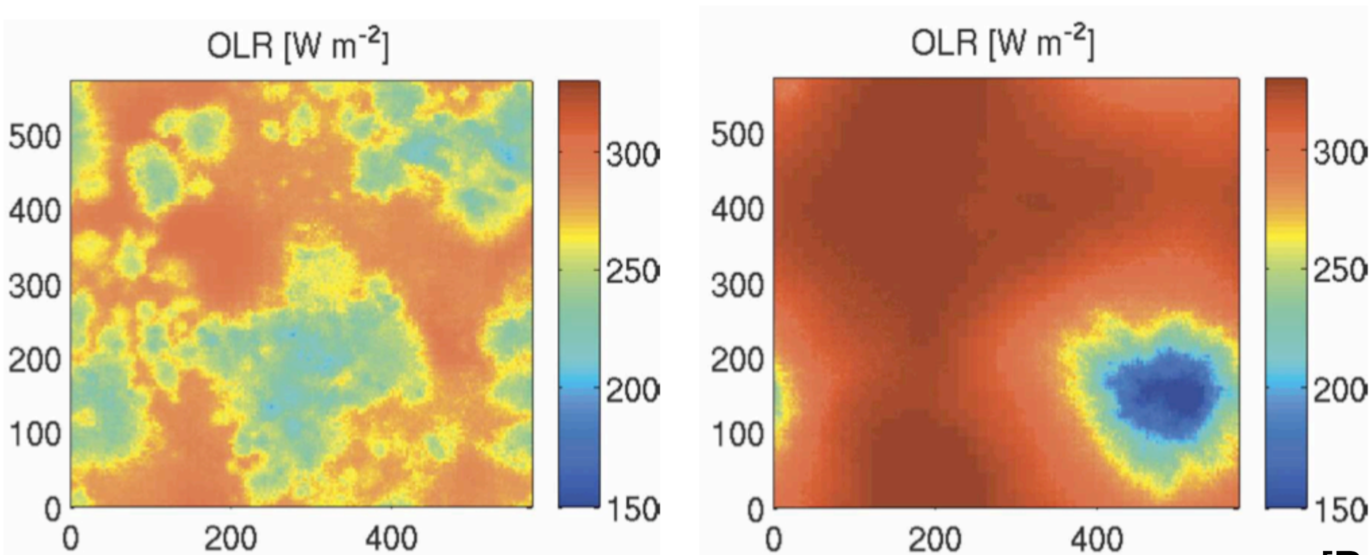
- Total albedo based on CERES/EBAF (not shown).

- Relative humidity based on AIRS (black: all coefficients of linear regression; colors individual harmonics).



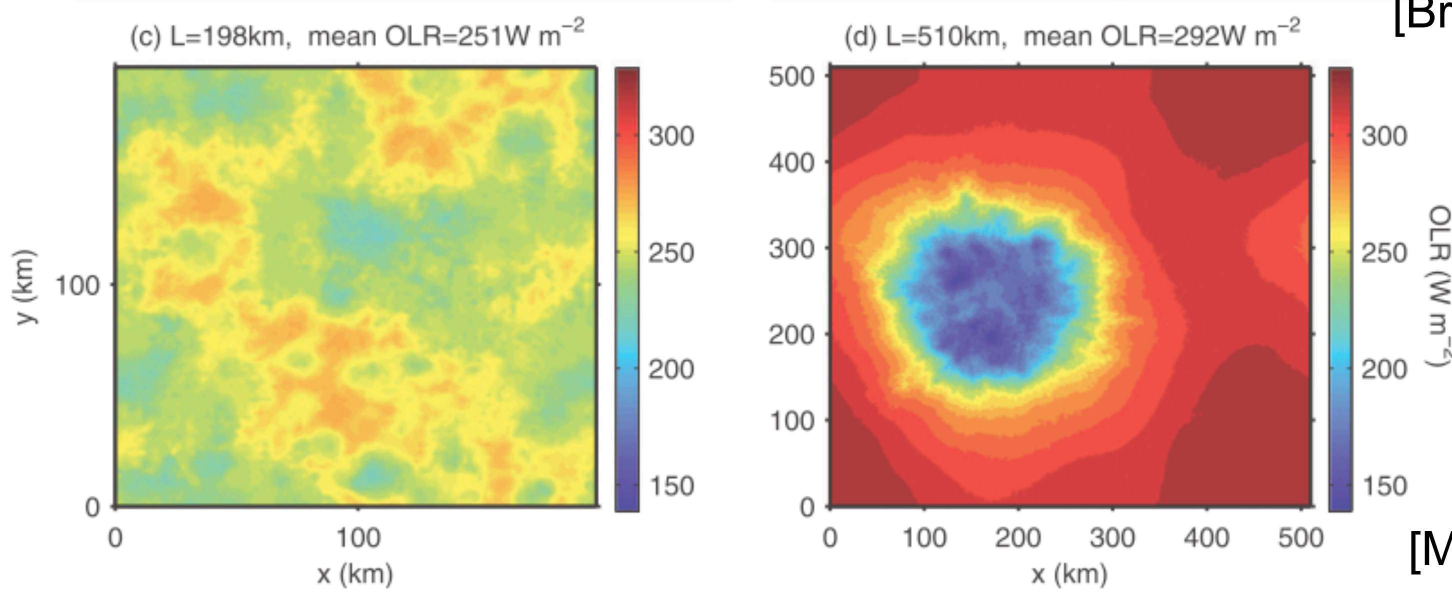
[Du, Cooper, Fueglistaler, JGR 2012]

Models show spatial distribution is important



CRM show "self aggregation", with large impact on OLR.

[Bretherton et al., 2005]



(40W/m^2 difference)

[Muller&Held, 2012]

ENSO

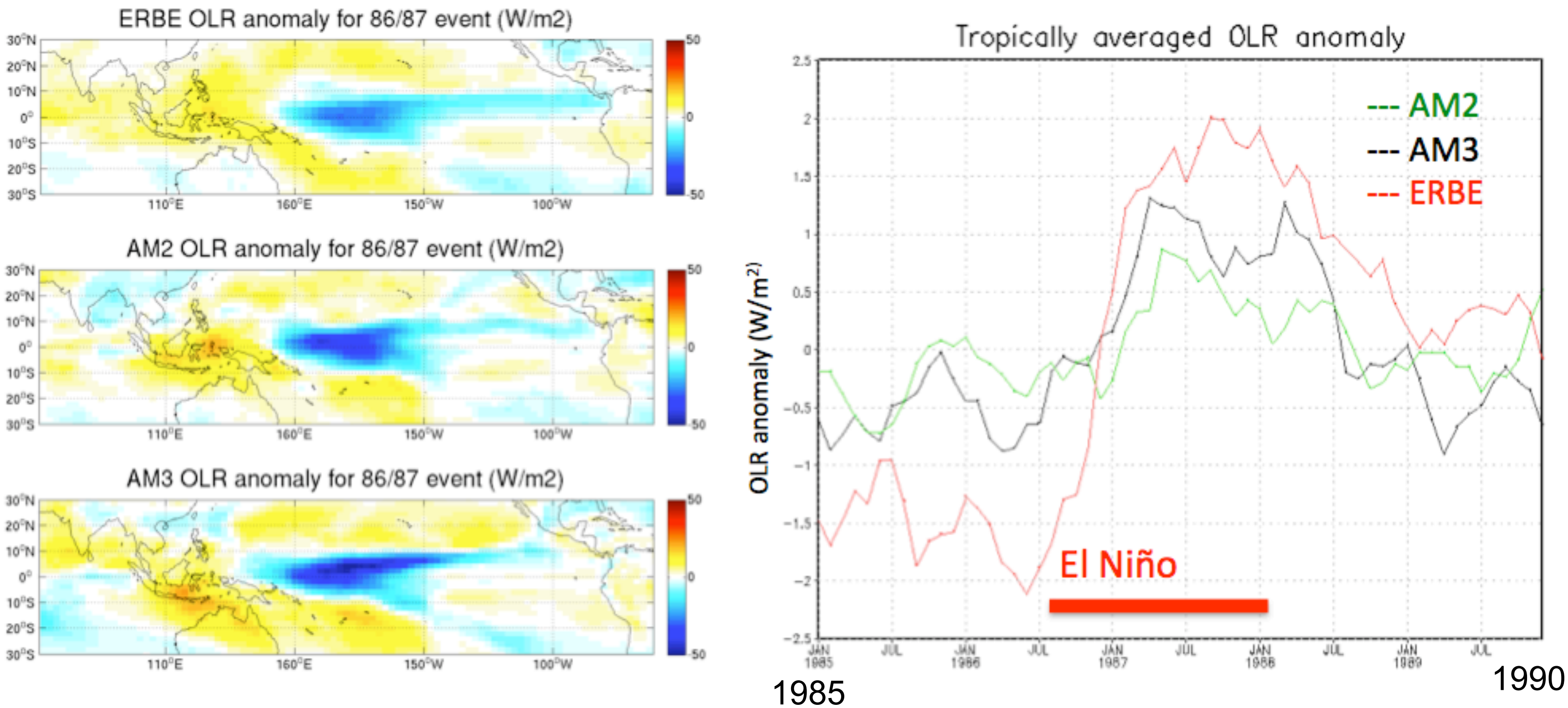
ENSO: Massive re-arrangement of cloud & rainfall distribution.

How well do observations and models agree?

Do biases in mean state (e.g. "too few, too bright tropical low clouds") project onto biases in representation of ENSO?

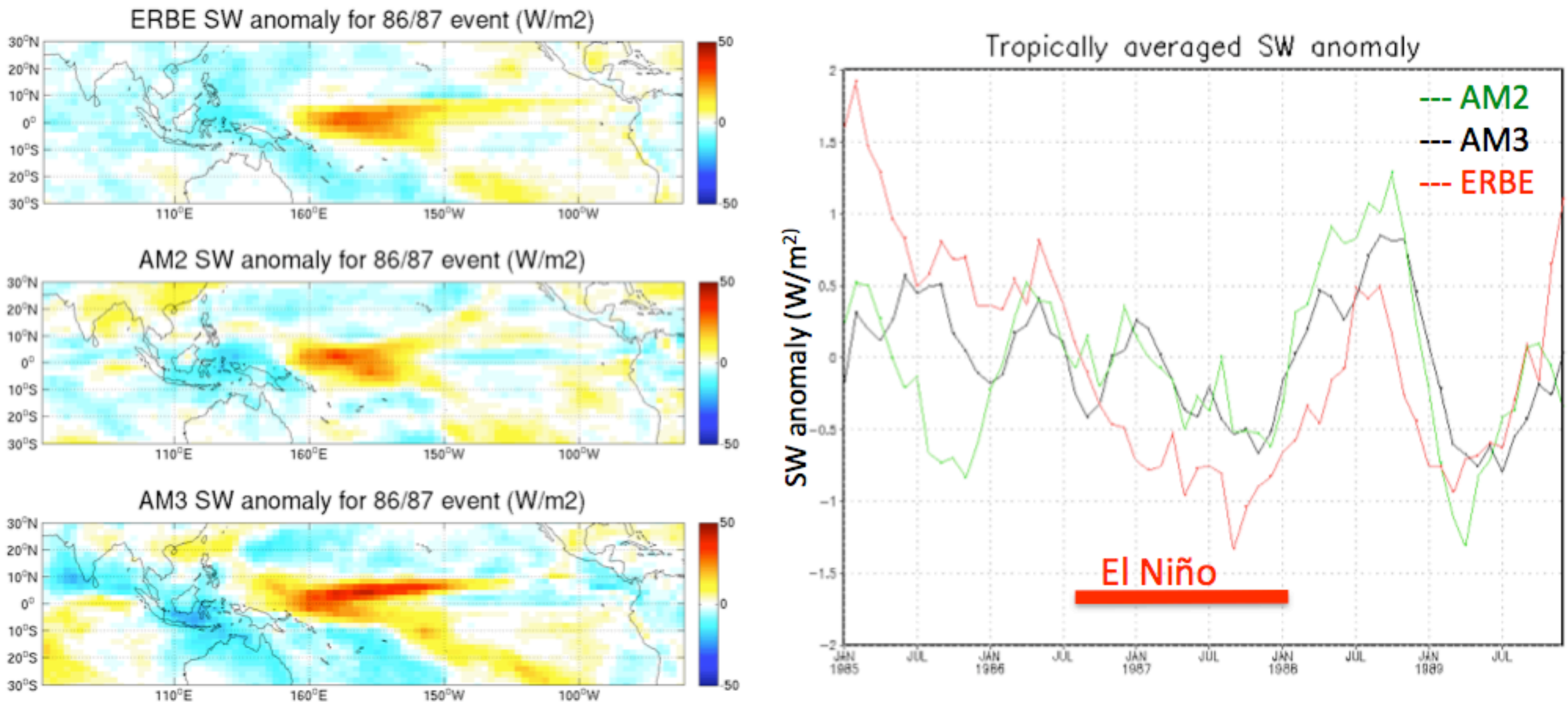
Model cannot be expected to capture spatial distribution perfectly – how shall we best analyse the data? -> changes in mean, and PDFs.

ENSO & OLR – ERBE results



Models (AM2/AM3) have **locally larger changes**, but **smaller tropical mean changes**.

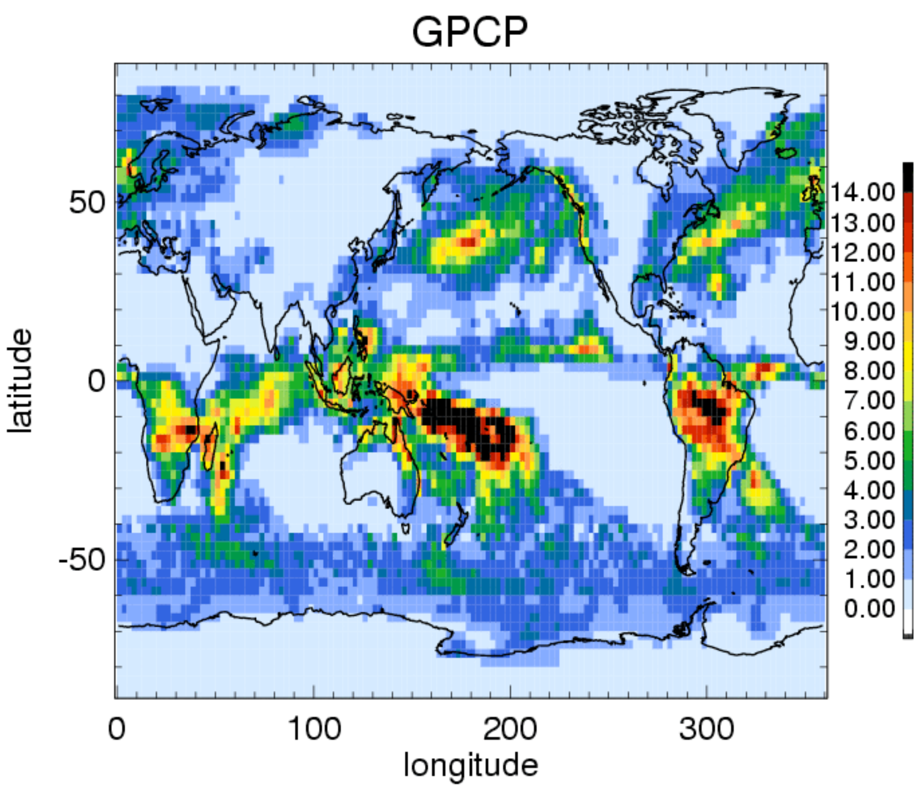
ENSO & reflected SW – ERBE results



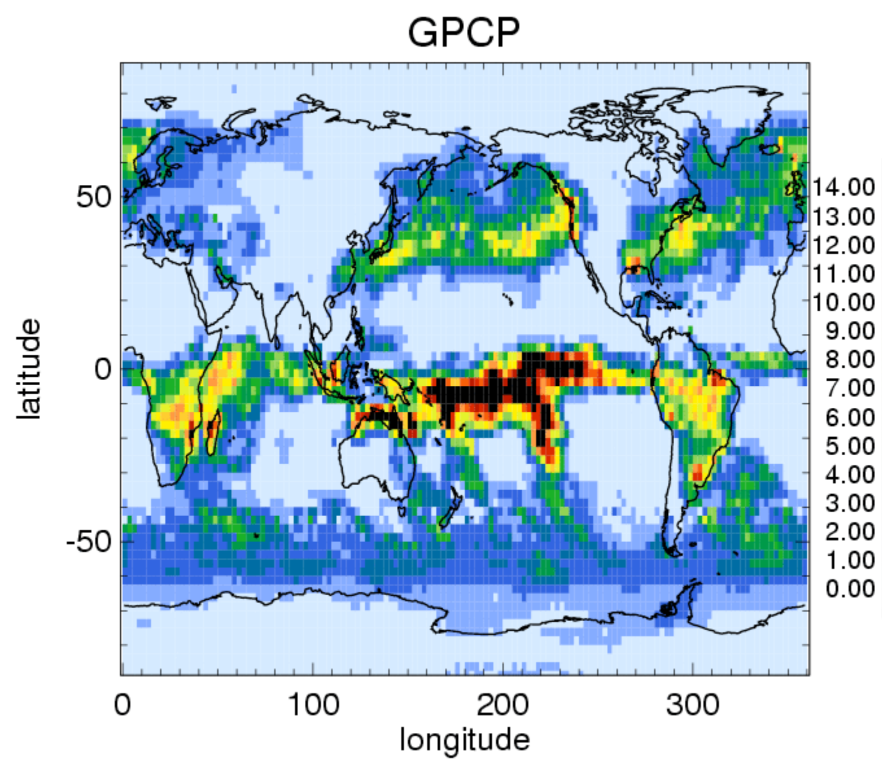
AM2 about similar to ERBE, AM3 has locally larger changes; what about tropical mean values?

ENSO & Precipitation

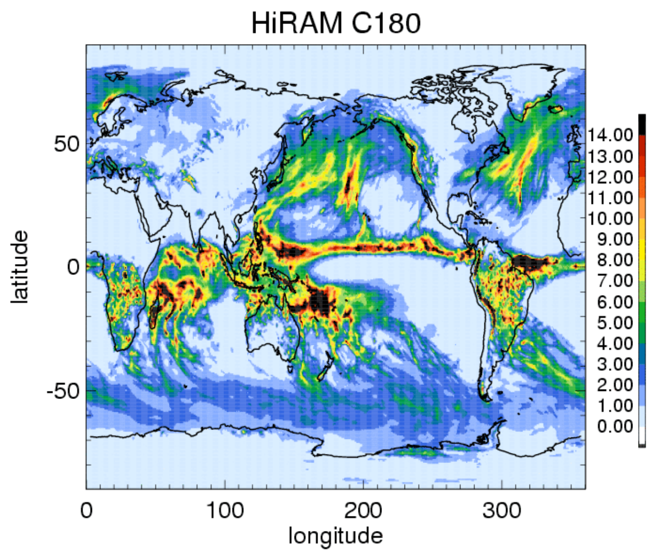
January 2008 "La Nina"



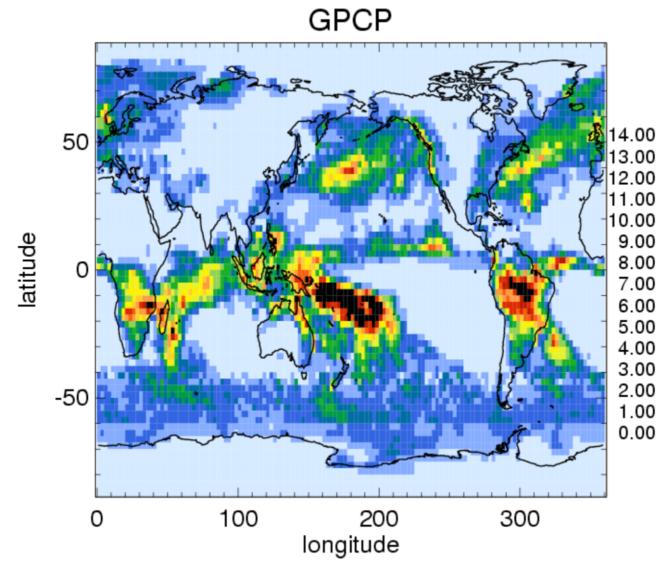
January 1998 "El Nino"

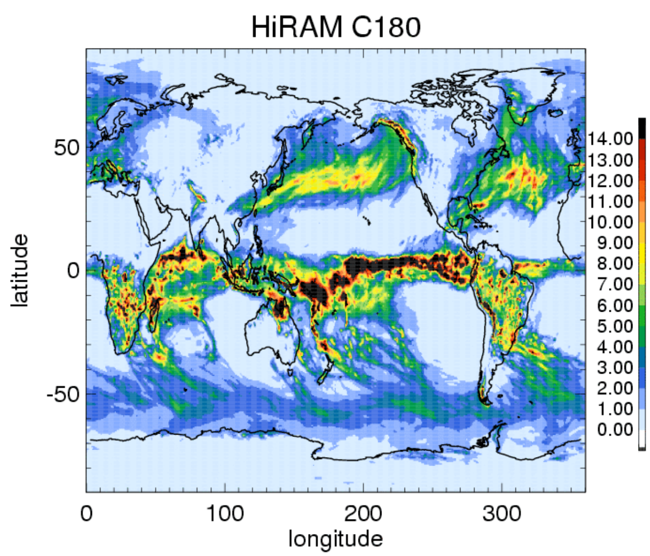


ENSO & Precipitation

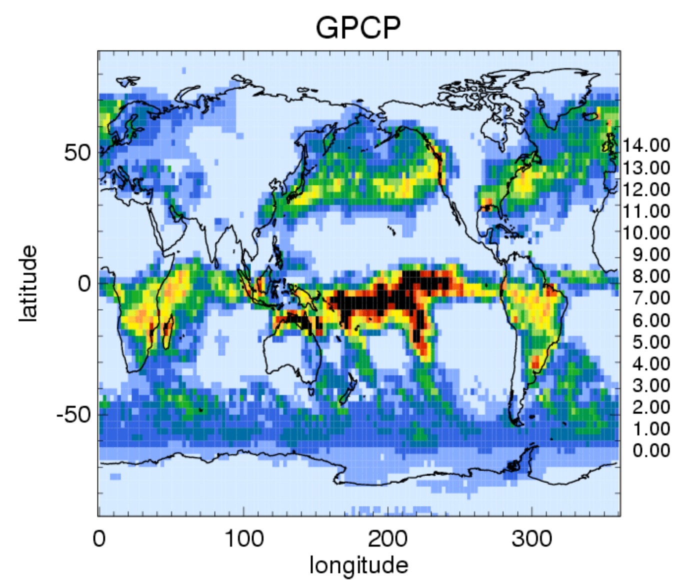


La Nina
(January 2008)

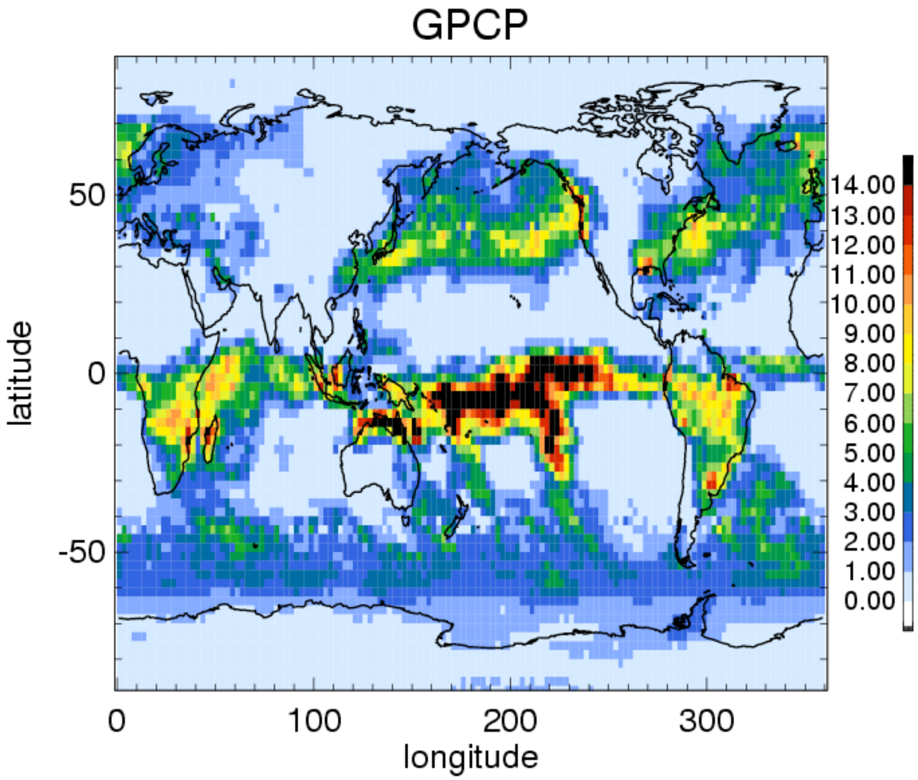




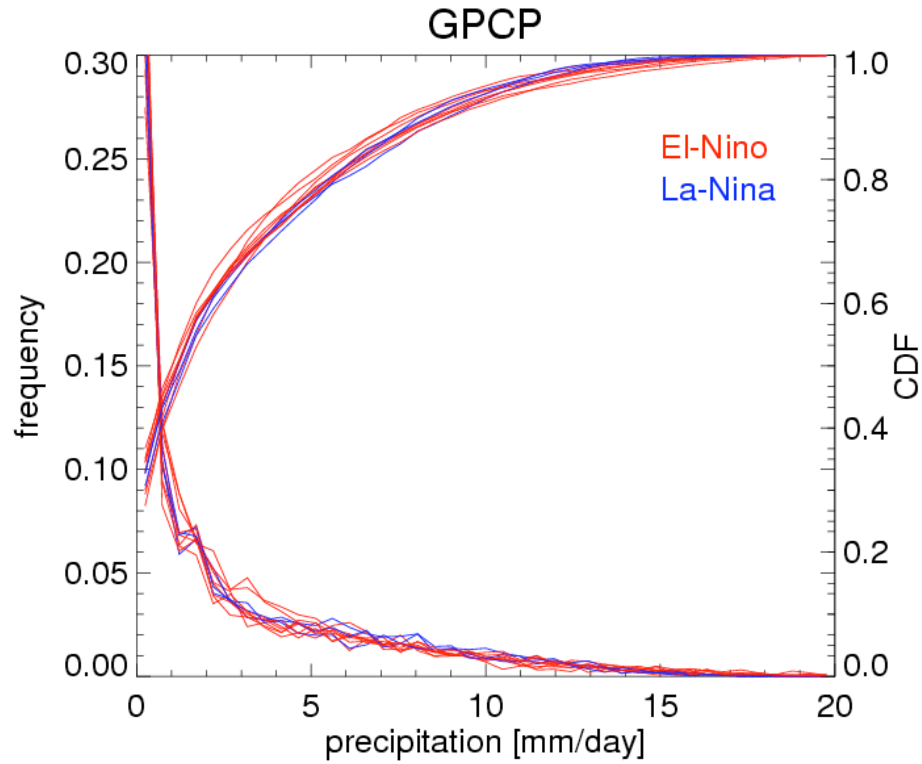
El Nino
(January 1998)



ENSO & Precipitation, GPCP



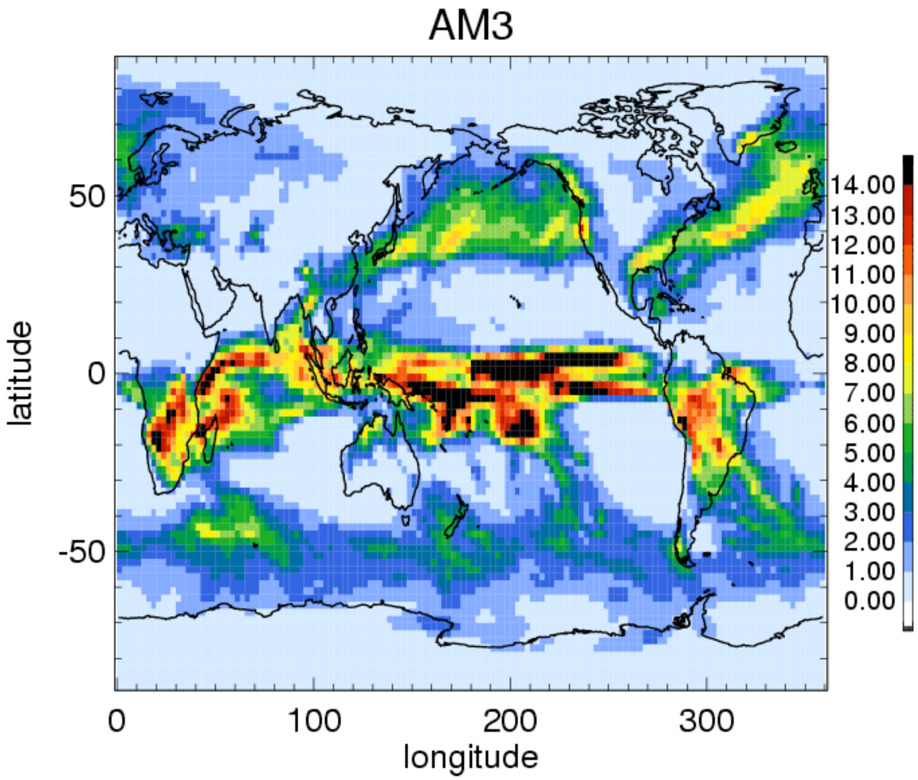
Precipitation, January 1998



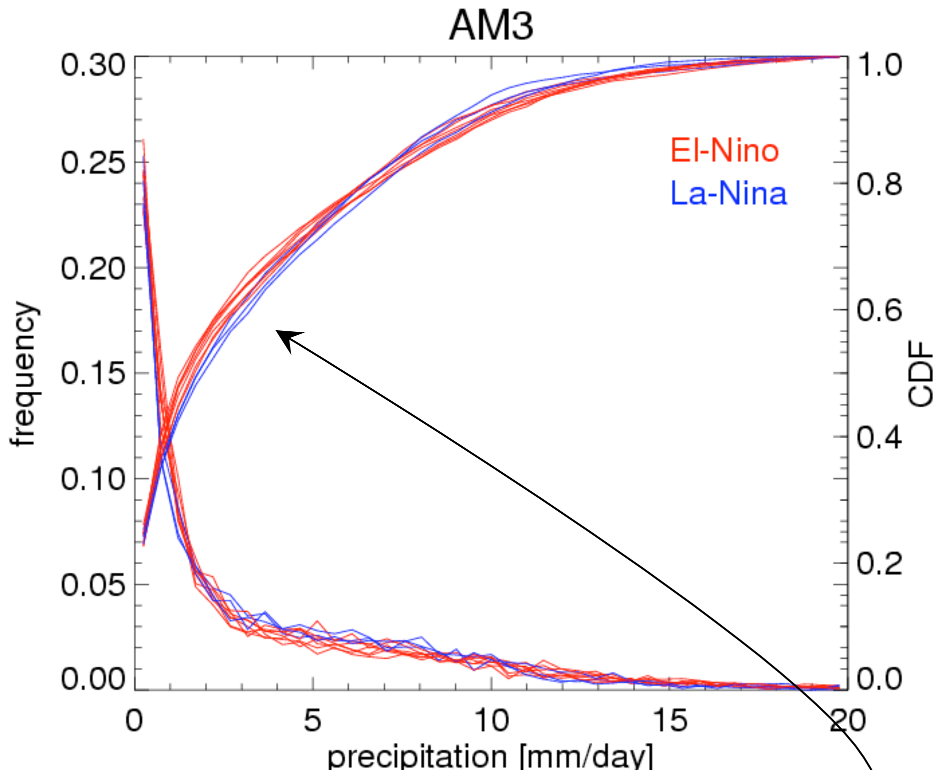
Precipitation PDF 30S-30N, 1979-2011, January; (|MEI| >= 1).

-> PDF's look rather similar.

ENSO & Precipitation, AM3



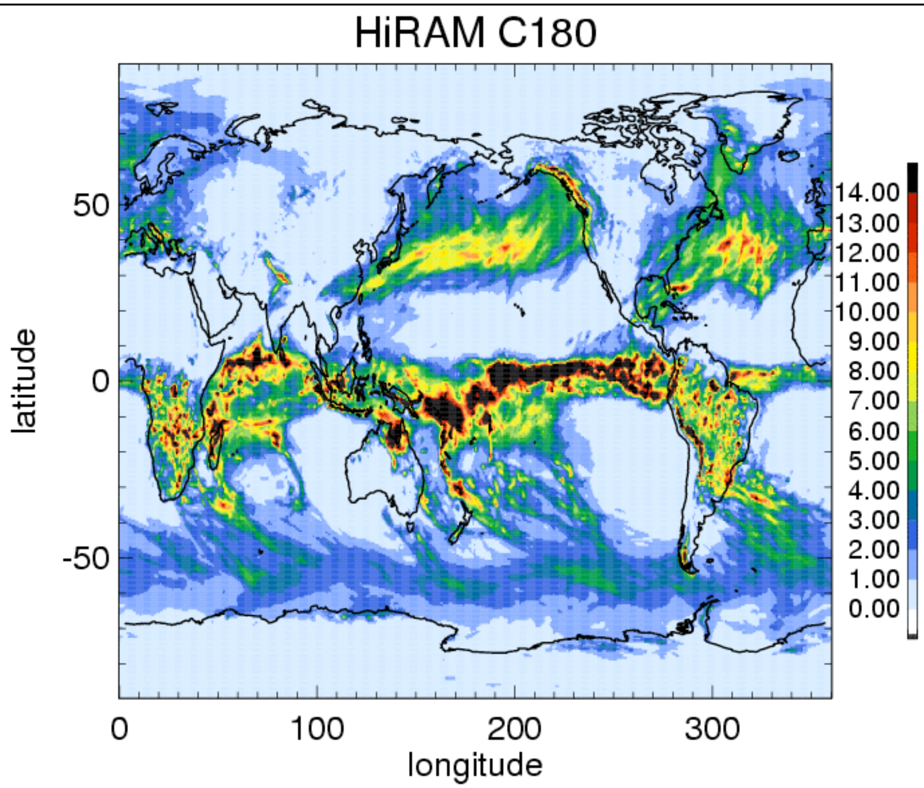
Precipitation, January 1998



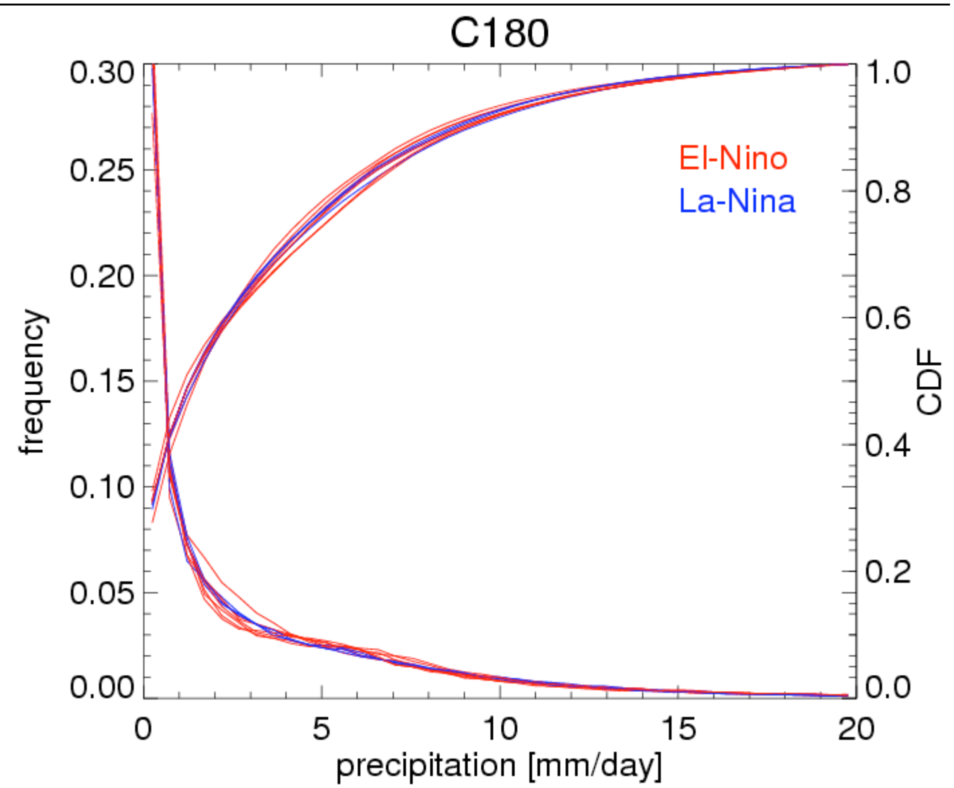
Precipitation PDF 30S-30N, 1979-2011, January, (|MEI| >= 1).

-> PDF's show weak sign of concentration during La Nina.

ENSO & Precipitation, HiRAM



Precipitation, January 1998



Precipitation PDF 30S-30N, 1979-2011, January, (|MEI| >= 1).

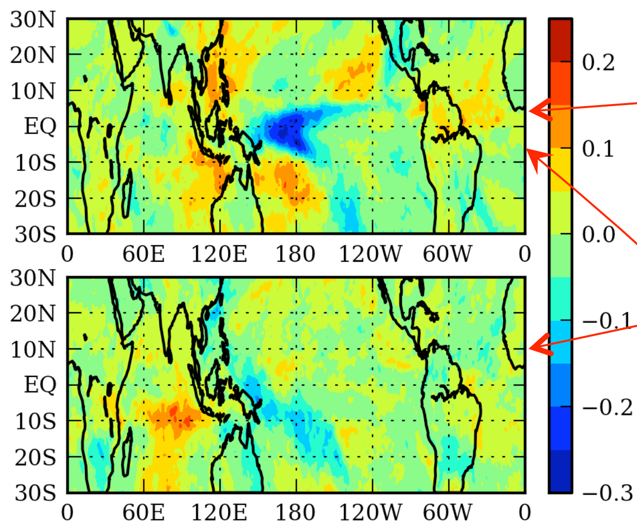
-> PDF's look rather similar.

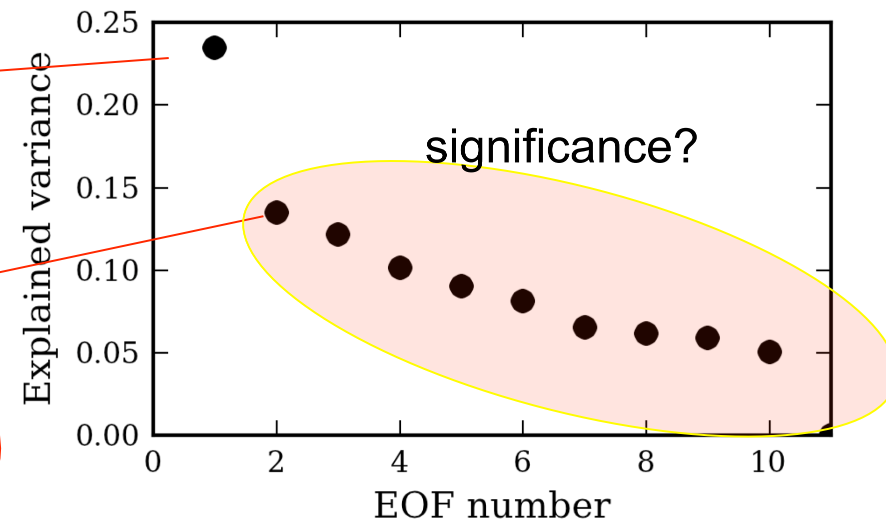
Contributions to change of mean: EOF's

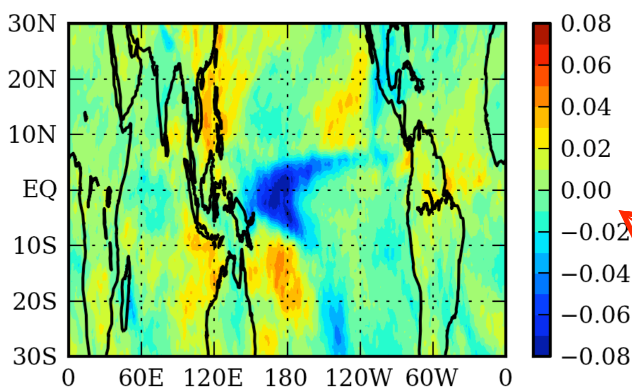
Q: Is leading order spatial structure also leading order of domain average variance?

CERES albedo – EOF's

January, EOF 1&2





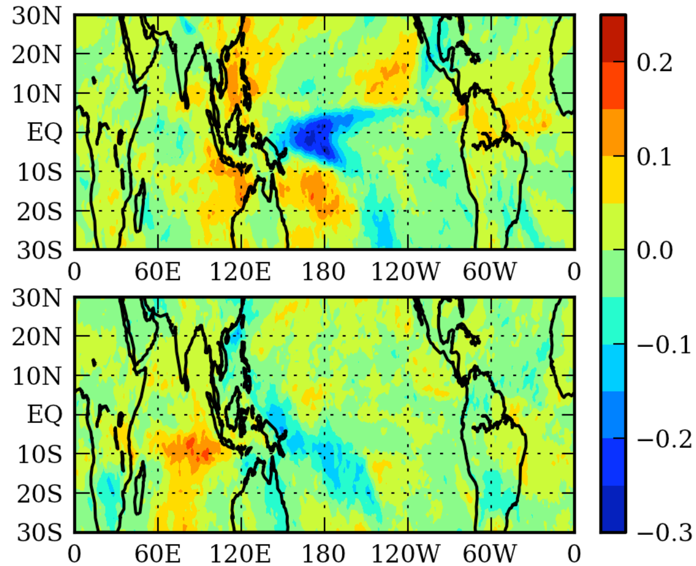


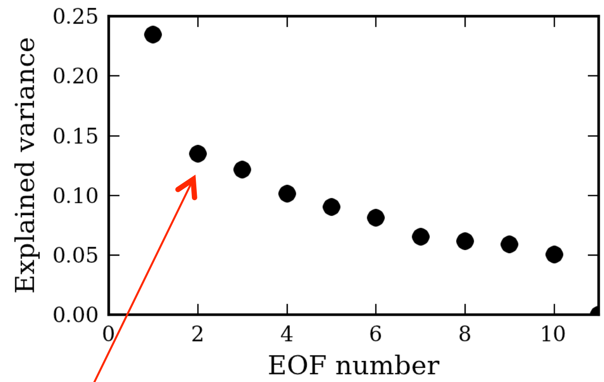
(quite similar)

Slope of linear regression against MEI * stddev(MEI)

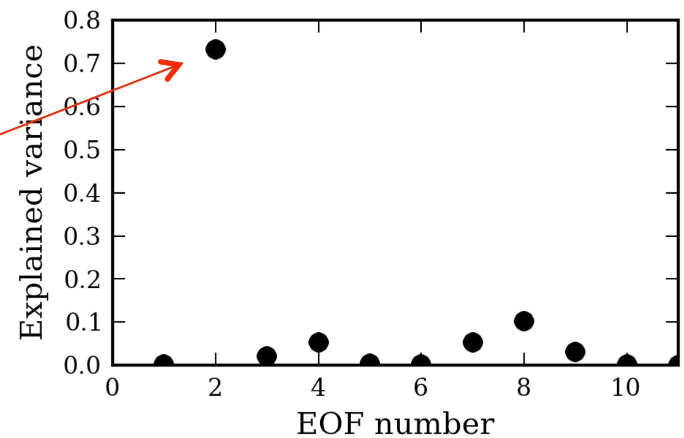
CERES albedo – EOF's

January, EOF 1&2





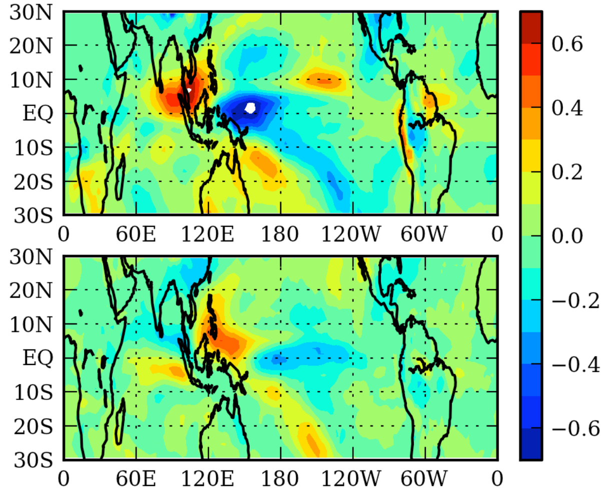
Explained variance of domain average:

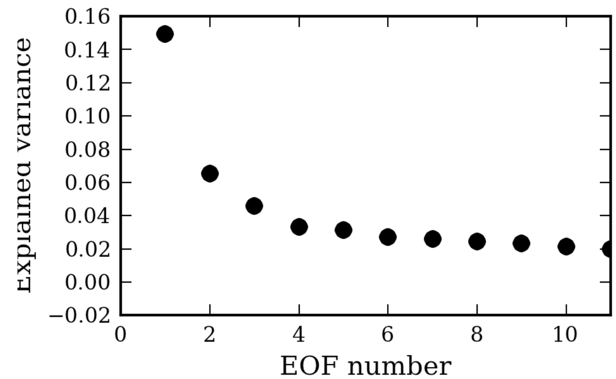


EOF **2** is dominant for the domain average, while EOF 1 has domain average ~0!

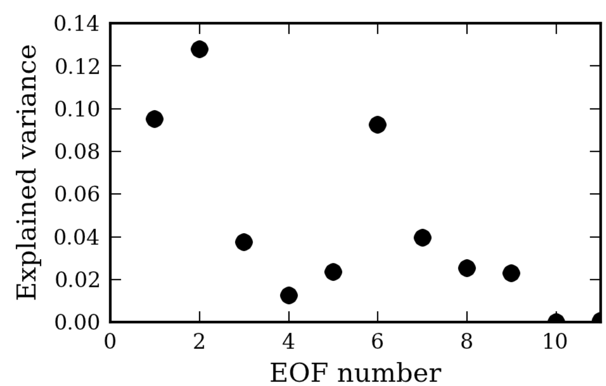
CM2.1 albedo & EOF's

January



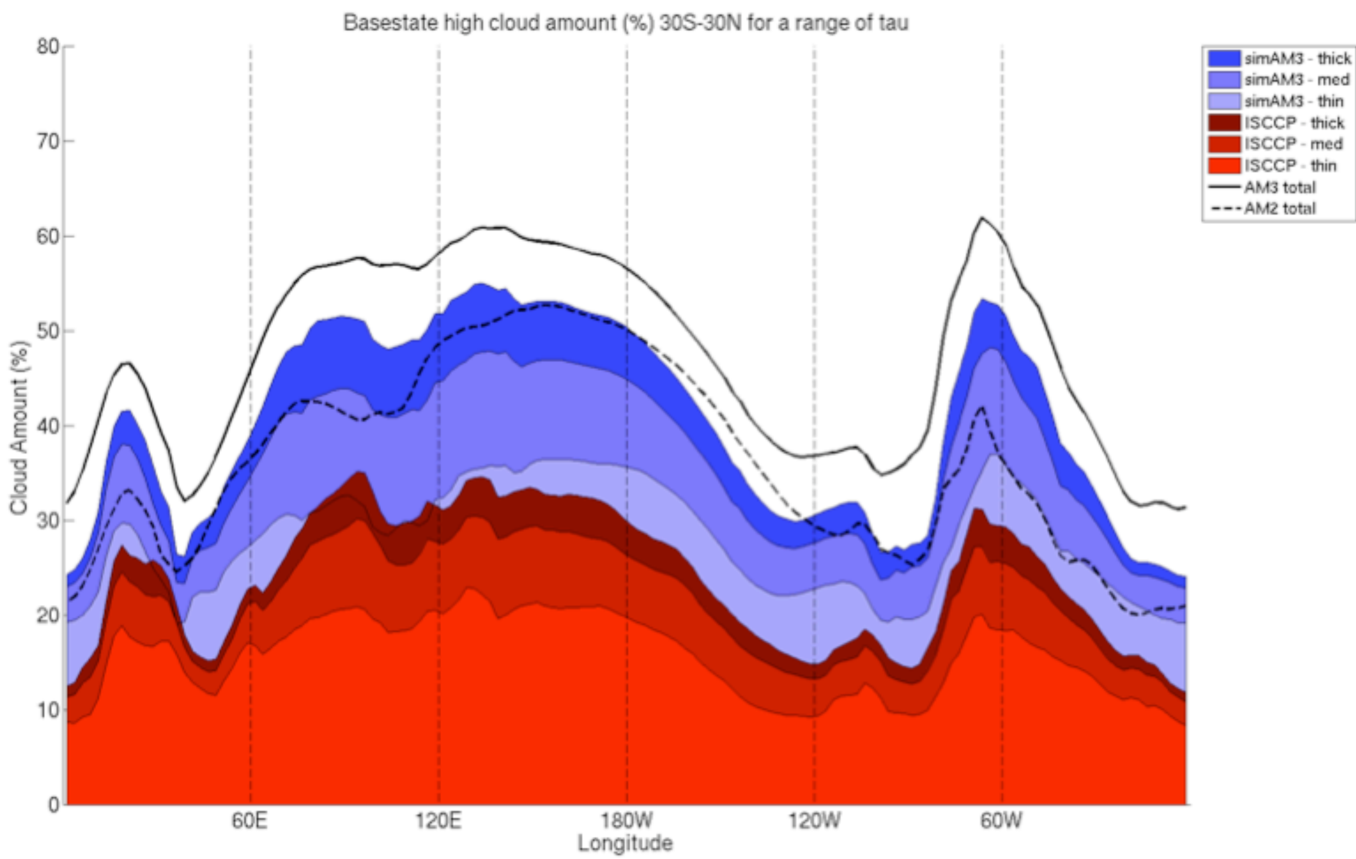


Explained variance of domain average



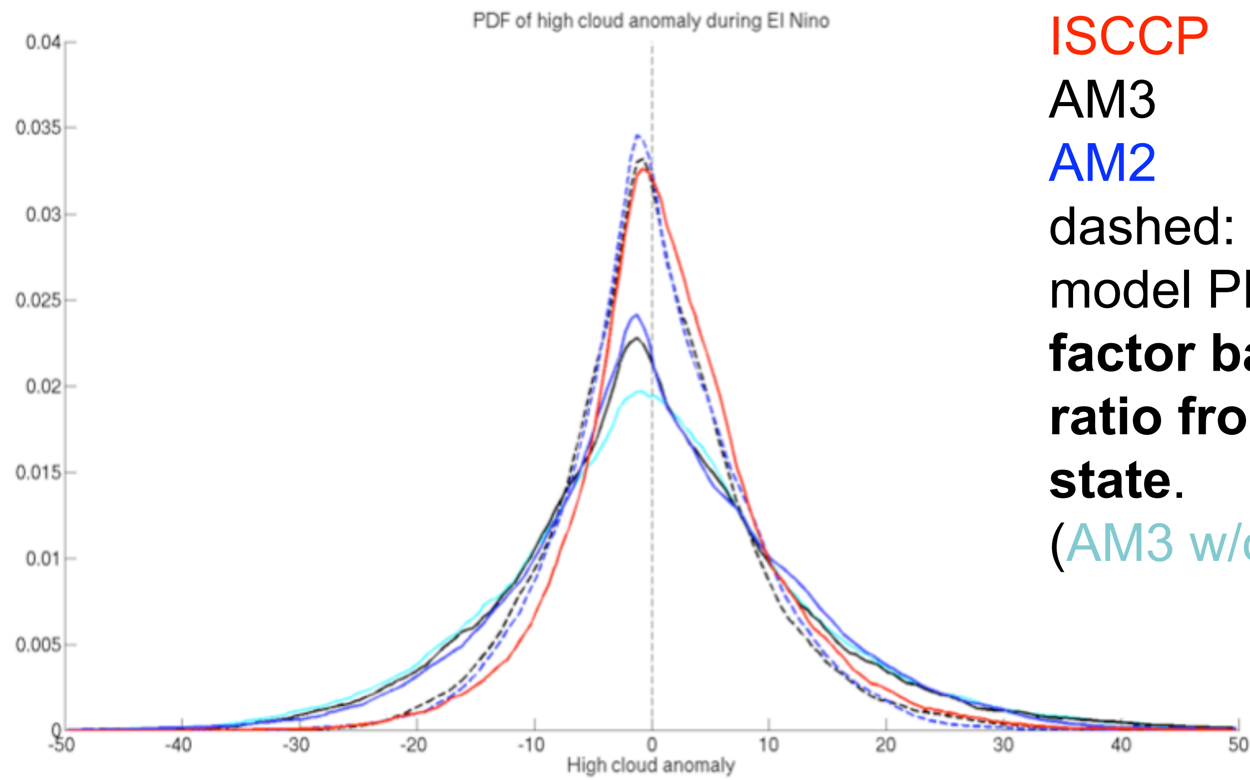
-> As in CERES/EBAF, leading mode of variability (ENSO) has smaller impact on domain average.

Biases in the base state: high cloud amount



High cloud amount [%] in base state for AM3 and ISCCP (3 categories for optical depths). In all categories, AM3 exceeds ISCCP.
(Note: apples/pears problem – simple simulator for ISCCP.)

ENSO biases & the mean state, high clouds



ISCCP
AM3
AM2
dashed: scaled model PDF's, **factor based on ratio from mean state**.
(AM3 w/o simulator)

Base state biased ("too much high cloud"), scale anomalies with fraction -> better agreement with ISCCP.

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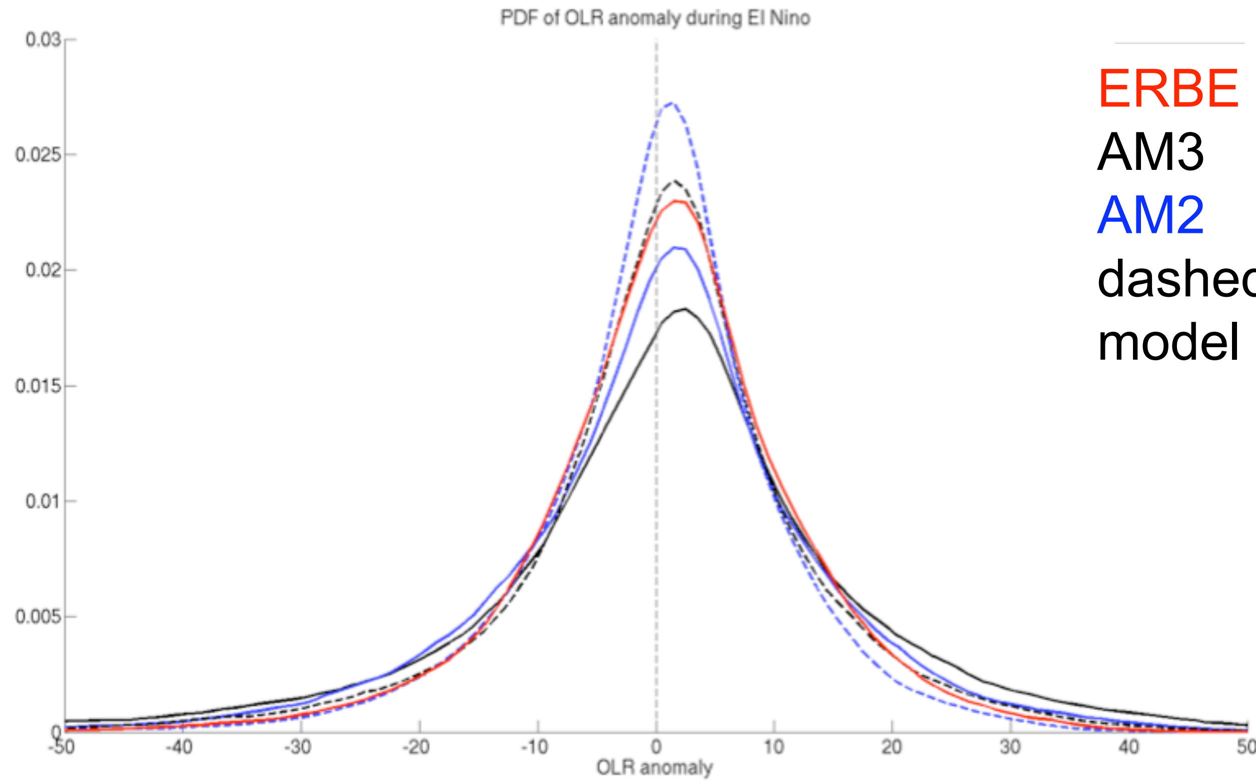
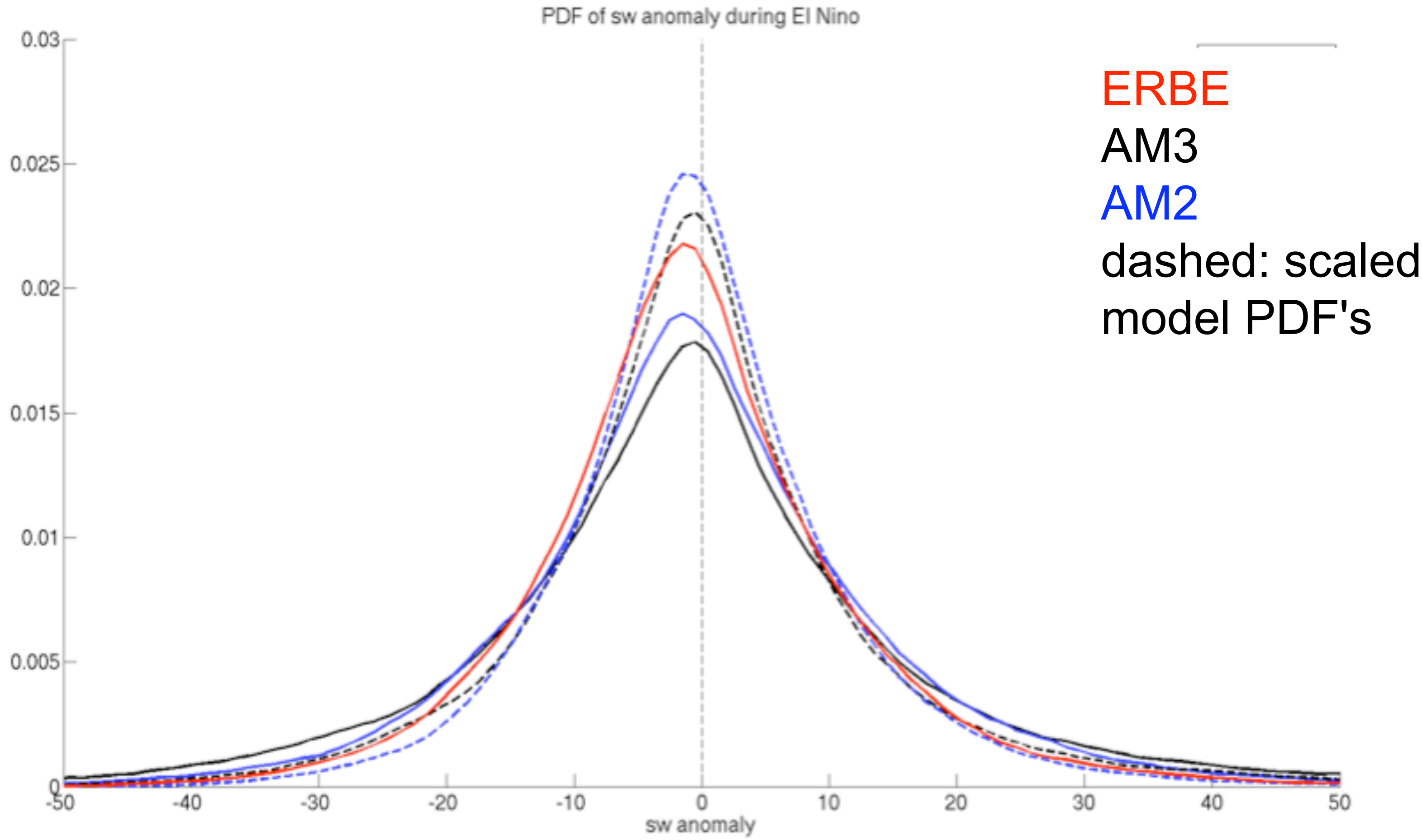
ENSO biases & the base state, OLR



ERBE
AM3
AM2
dashed: scaled model PDF's

Scaling factor (around 0.75) much larger than bias of mean state.
(i.e. OLR_{model} / OLR_{ERBE} ~ 1%)

ENSO biases & the mean state, SW reflected



As with OLR, scaling factor larger than ratio of base state.

Summary & outlook

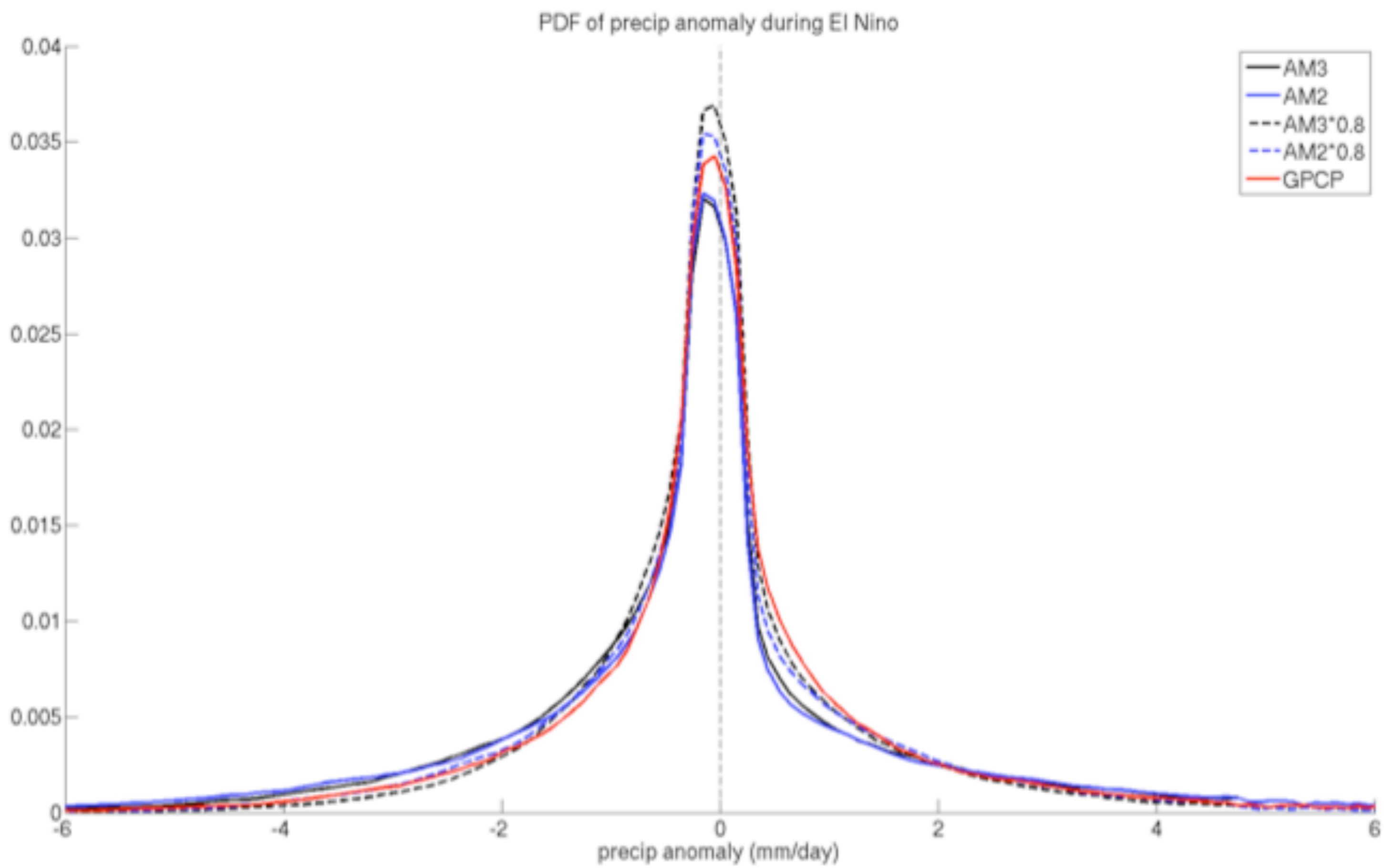
- Remarkable high degree of "compensation" in climate system, both for aspects of the mean annual cycle and ENSO-related variability.
- La Nina not necessarily a more localised atmospheric forcing from latent heat release.
- Models' responses to forcings locally biased, partially linearly related to bias in mean state (e.g. too much high cloud on average gives too large high cloud anomalies).
- This is not the case for the radiative properties – PDF's require much larger scaling factor than based on mean state bias.
- For both models and CERES/EBAF, ENSO has little impact on SW.
- The largest contributor to variations in the mean is not necessarily explaining most of the variance – i.e. higher order EOF's can be more important than leading EOF.

Summary & outlook

-> The variations in (global) mean can be easily understood from the perspective of the global mean energy balance, but emergence of the "mean" signal is a challenge to understand.

Thanks!

ENSO biases and mean state - precipitation



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OLR & reflected SW correlations with Nino3.4