Comparison of GFDL's Atmospheric Models against Observations

Claire Radley, Leo Donner & Stephan Fueglistaler

GFDL, Princeton University, Princeton, NJ

Motivation:

1. General Circulation Models
   - Needed for predicting changes
   - Tools for understanding physical processes

2. Evaluate accuracy
   - Compare base state with observations – will have been tuned!
   - Force system and compare perturbations

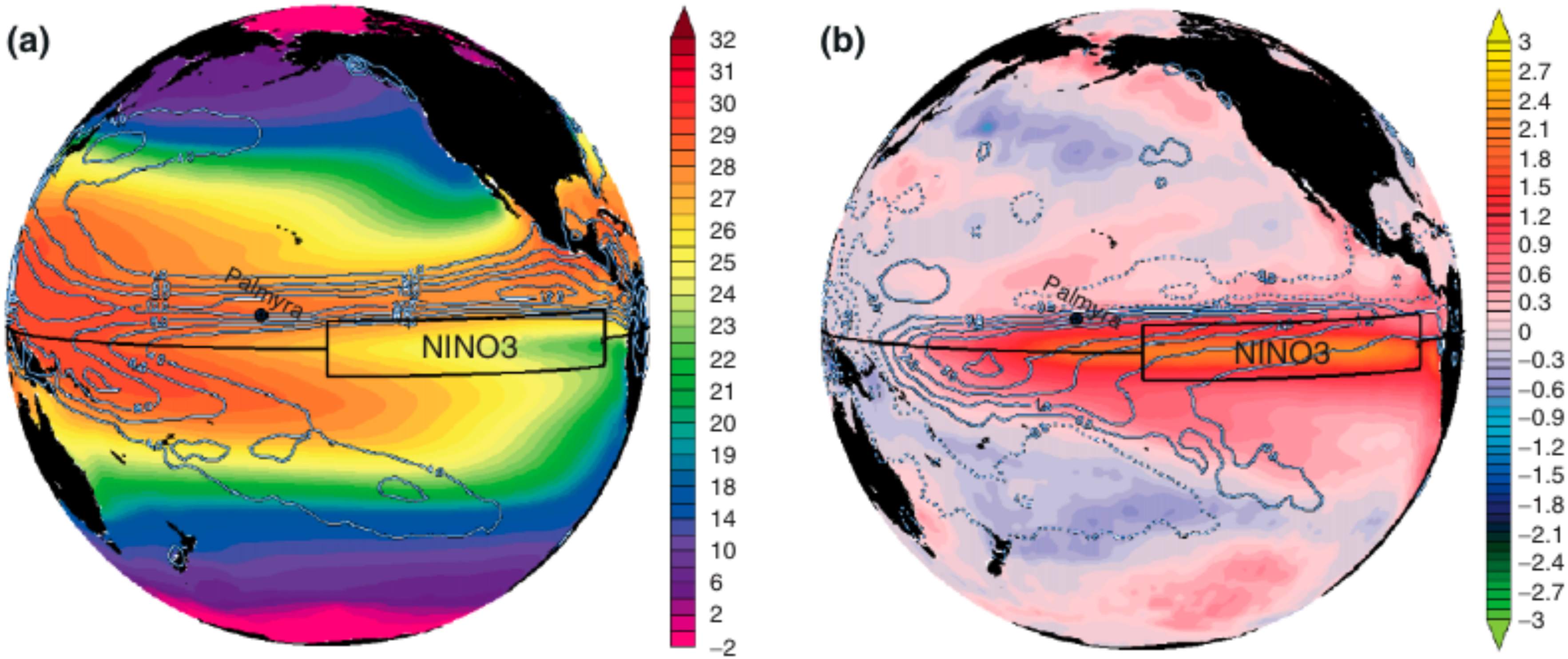
3. What forcing can we use?
   - Must have several events over observational periods
   - Must be strong

4. El Nino
   1. Occurs every 2-7 years
   2. Dominant mode of variability in tropics
   3. Can evaluate atmospheric component by prescribing anomalous SSTs and analyzing how model responds

Tropical Pacific Climatology – El Niño

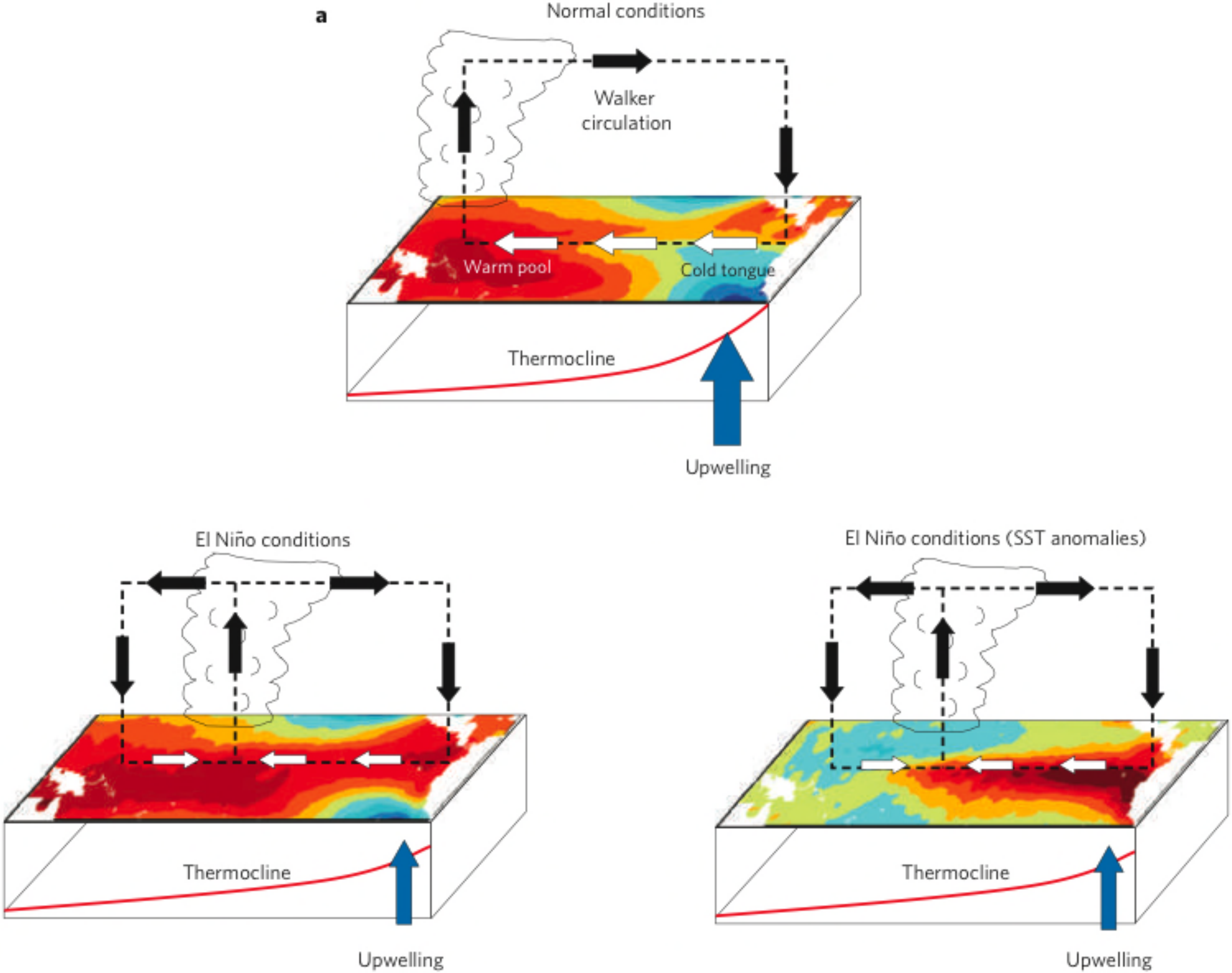
Annual Average

Anomaly (June-December) during El Niño



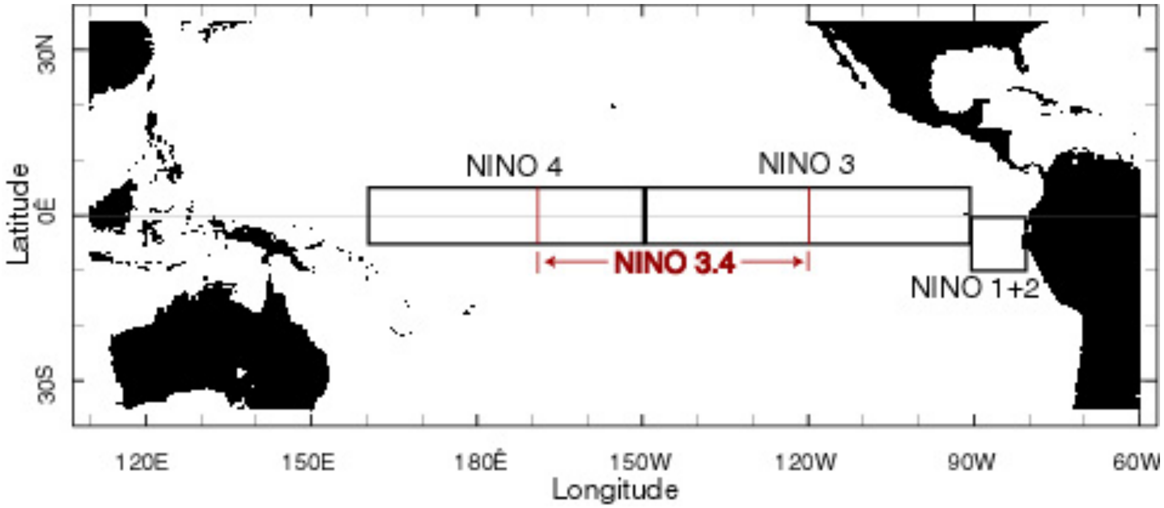
SST (°C, shaded) & Precipitation (mm/day, contoured)

(Vecchi & Wittenberg 2010)



(Collins et al. 2010)

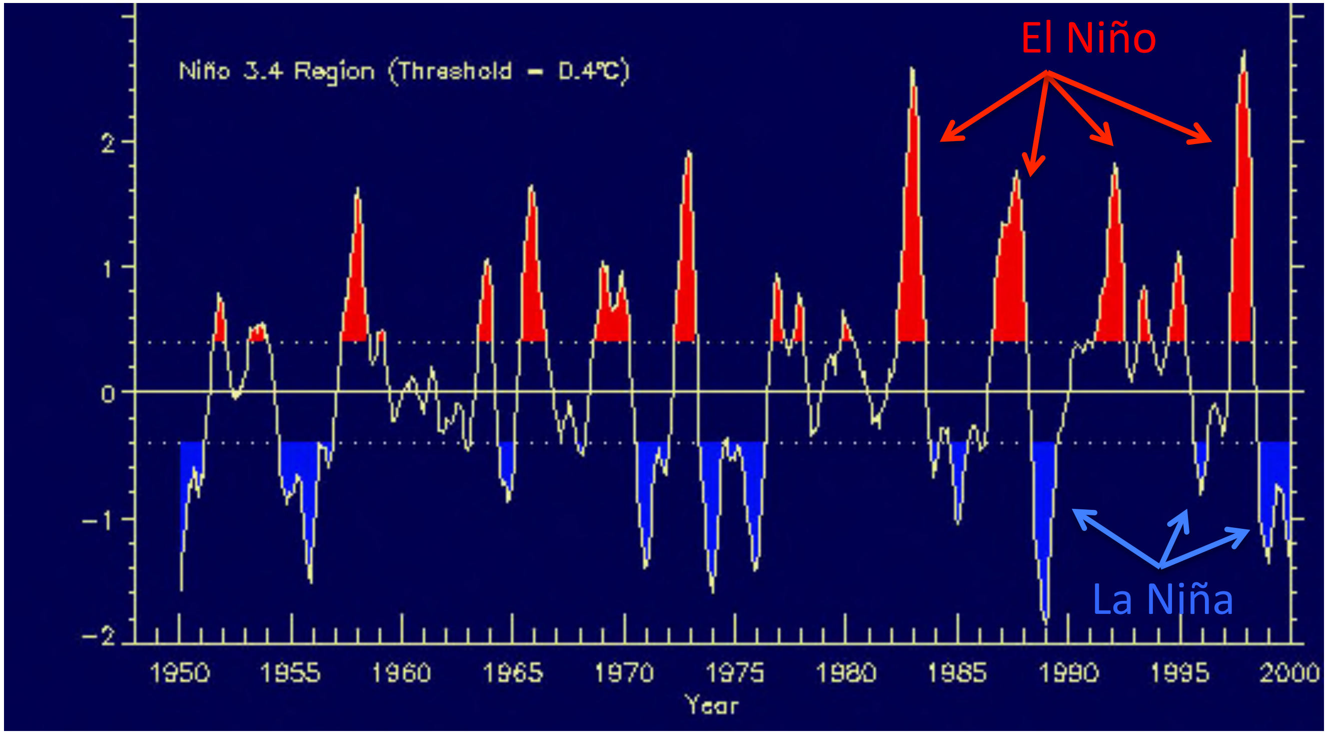
How do we define an El Niño event?



• Calculate monthly SST anomalies relative to a base period climatology of 1950-1979

• ENSO event occurs when the 5 month running mean anomaly exceeds the threshold for a minimum of 6 months *(Trenberth 1997)*

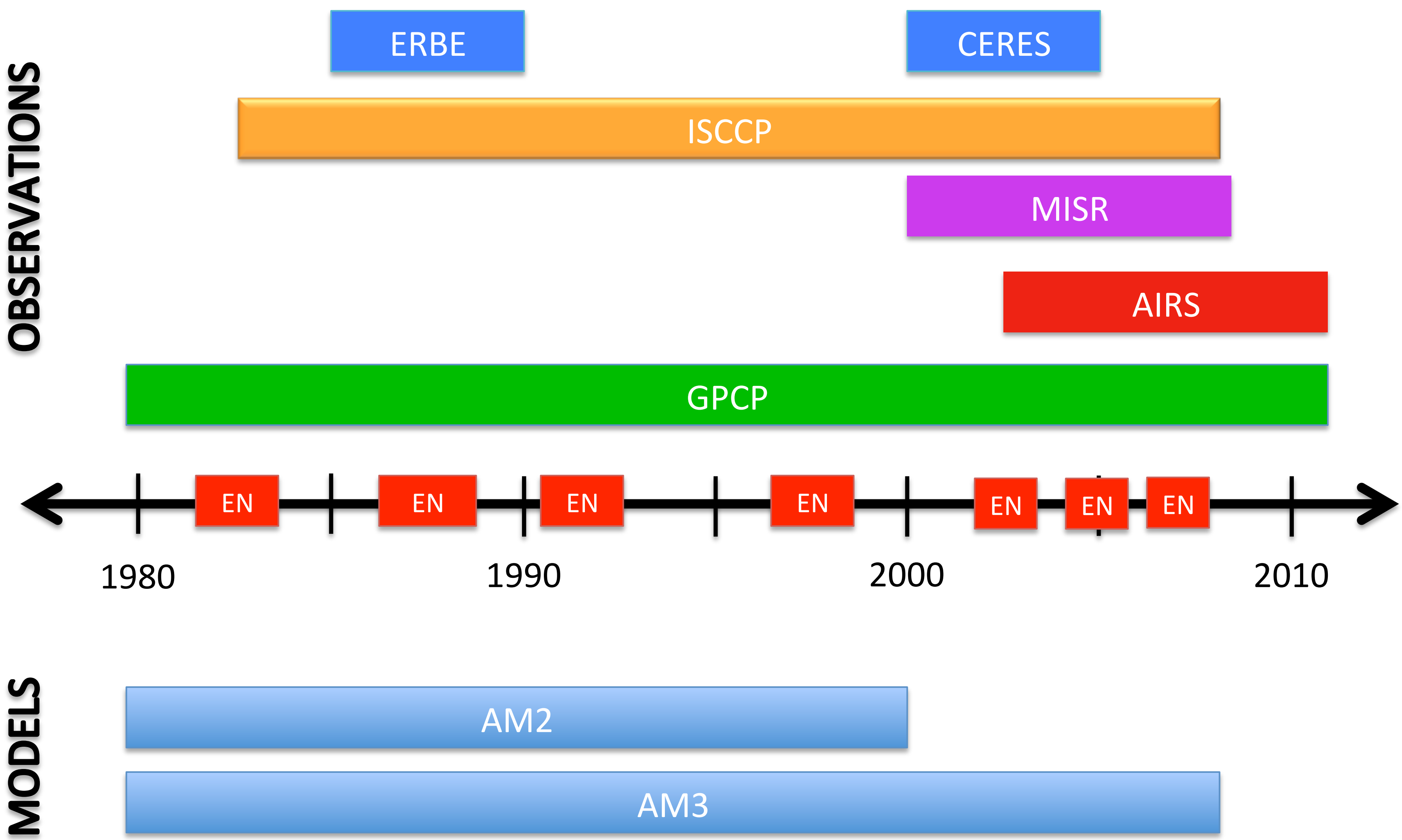
Monthly SST Anomalies (5 month running mean)



Source: NCAR

Event type	Date
El Niño	Apr ‘82 – Jul ‘83 Aug ‘86 – Feb ‘88 Nov ‘90 – Jul ’92 Apr ‘97 – May ‘98

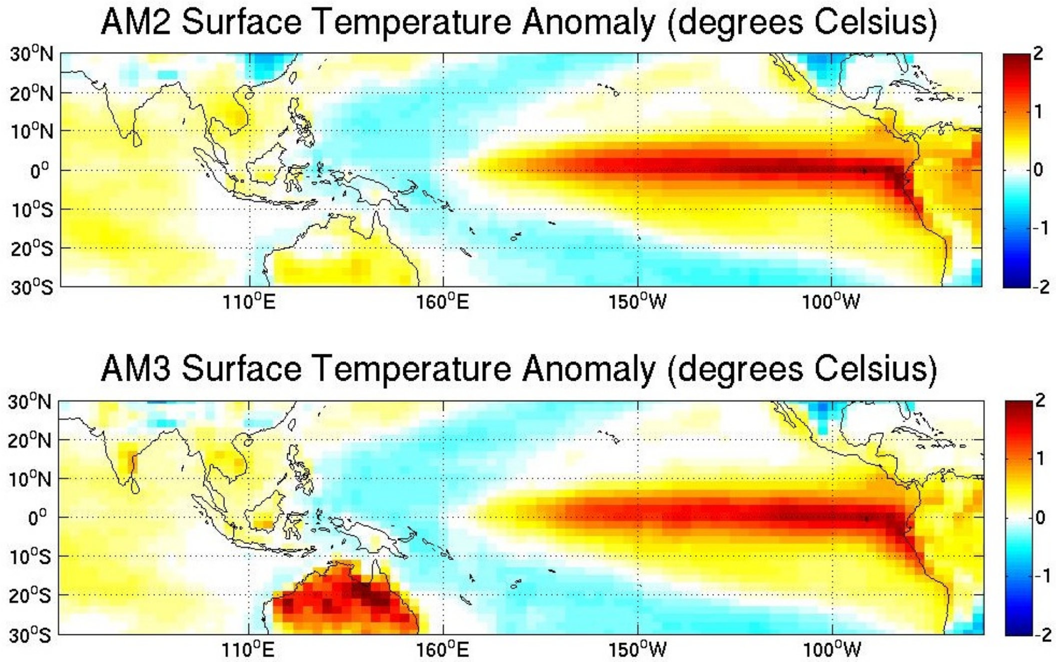
Timeline



OBSERVATIONS
ERBE
CERES
ISCCP
MISR
AIRS
GPCP
EN
EN
EN
EN
EN
EN
EN
1980
1990
2000
2010
MODELS
AM2
AM3

Model Setup:

- Use Atmospheric Model Inter-comparison Project (AMIP) experimental design
  - Use AMIP II monthly mean sea surface temperatures and sea ice



GFDL models: AM2 & AM3

- AM2 model:
  - 2° latitude × 2.5° longitude; 24 vertical levels
  - Convection uses Relaxed Arakawa-Schubert
  - Detrainment of cloud liquid, ice, and fraction from convective updrafts. Precipitation calculated as fraction of condensate

- Improvements made in AM3:
  - 48 vertical layers and also extends further into stratosphere
  - Uses Donner deep convection and Bretherton shallow convection parameterizations
  - Includes mesoscale updrafts and downdrafts → extensive detrainment in mid-troposphere
  - Cloud microphysics based on aerosol activation & cumulus-scale vertical velocities

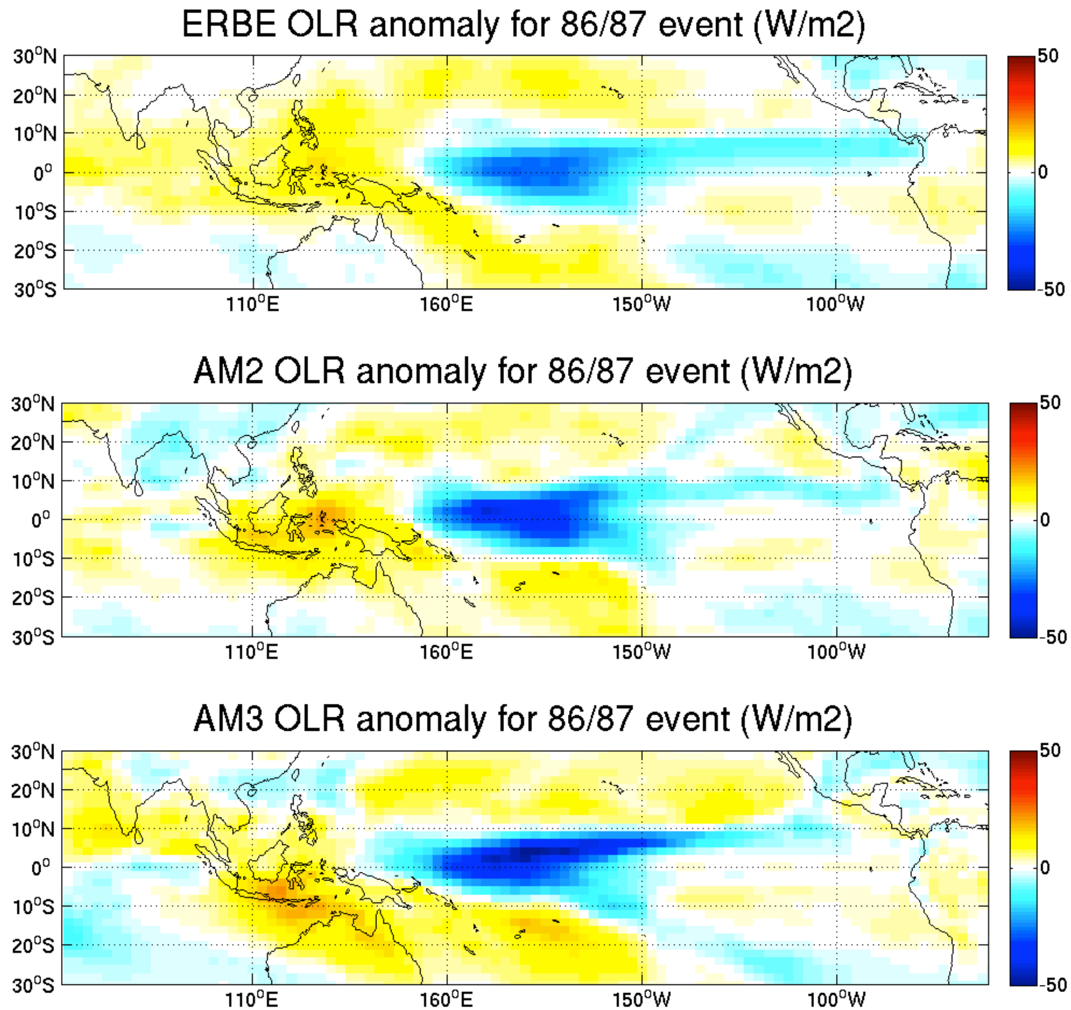
(For further details see *GFDL GAMDT 2004* and *Donner et al. 2010)*

TOA Radiation Anomalies:

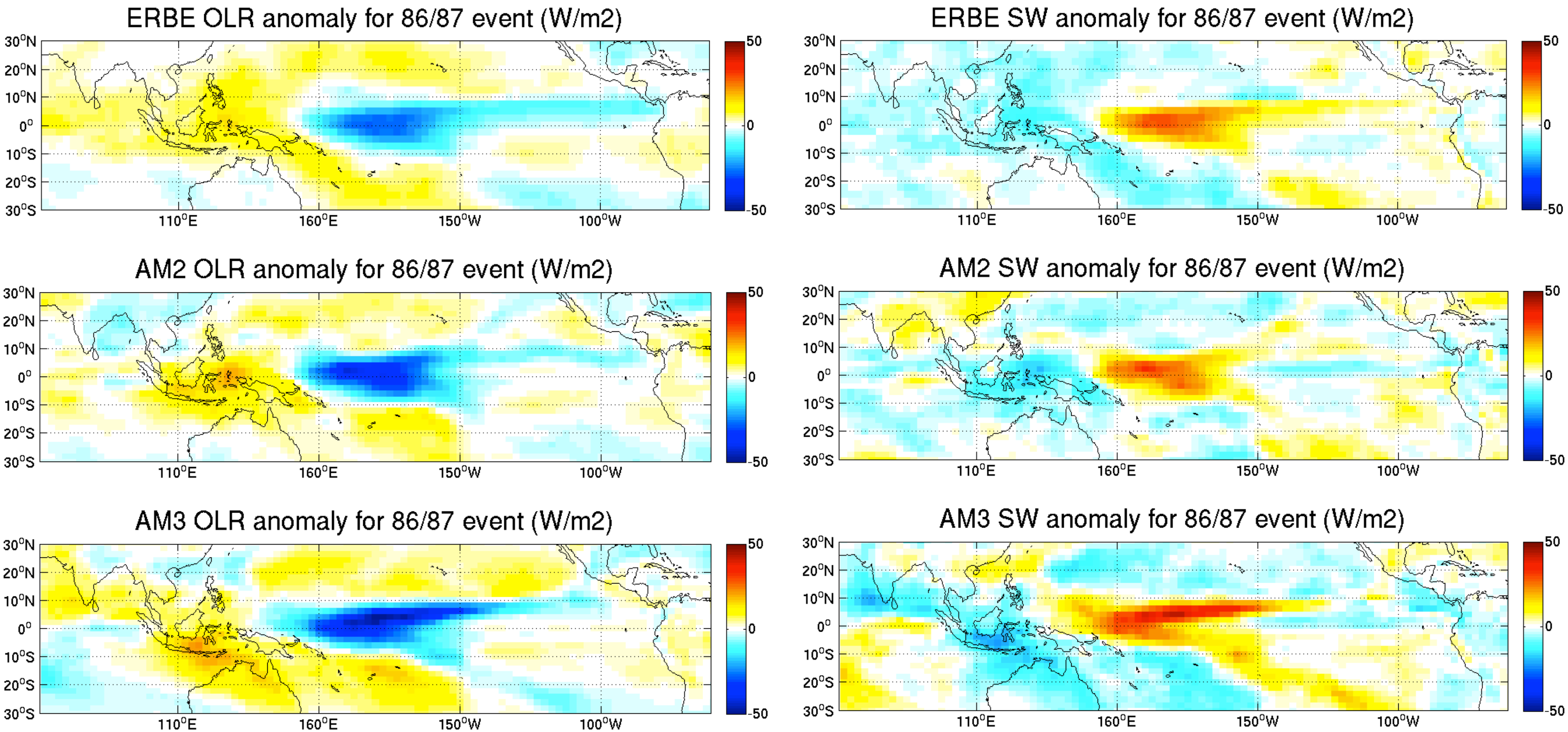
Observations

AM2

AM3

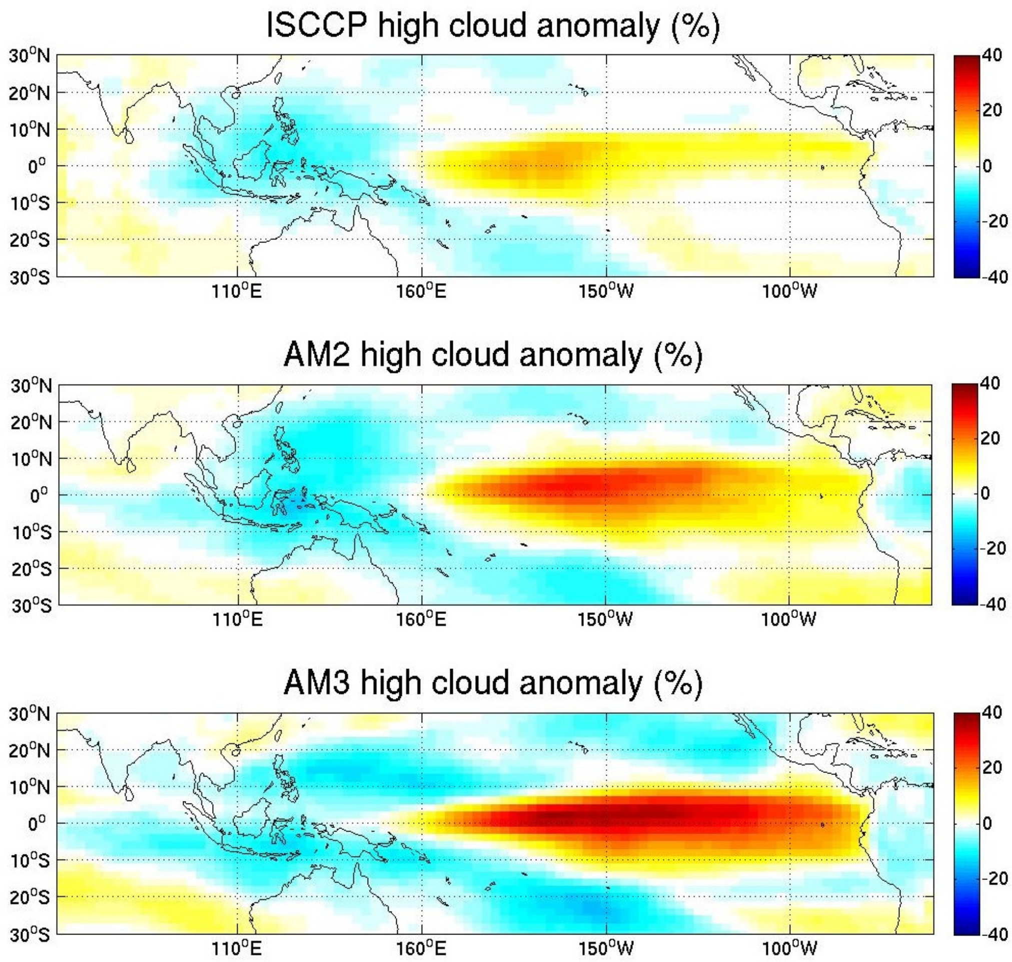


TOA Radiation Anomalies:



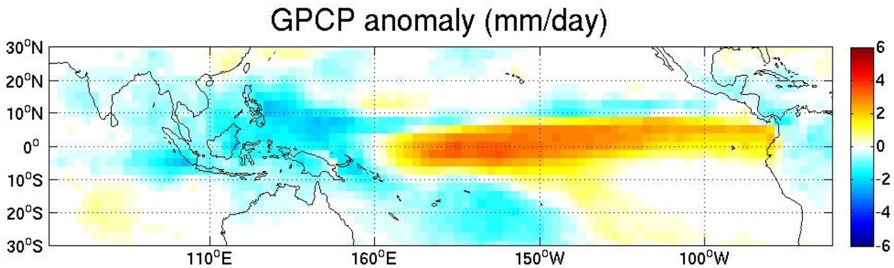
What's causing these large anomalies?

How do high-level clouds change?

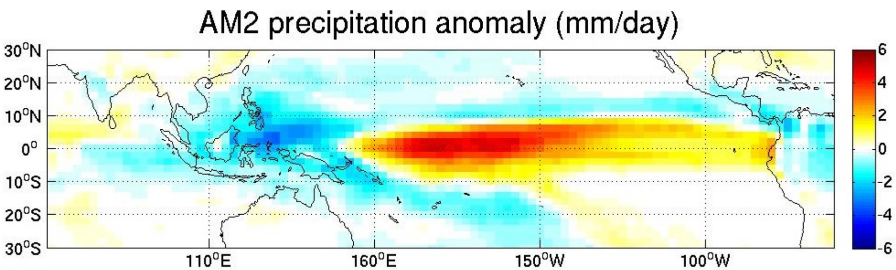


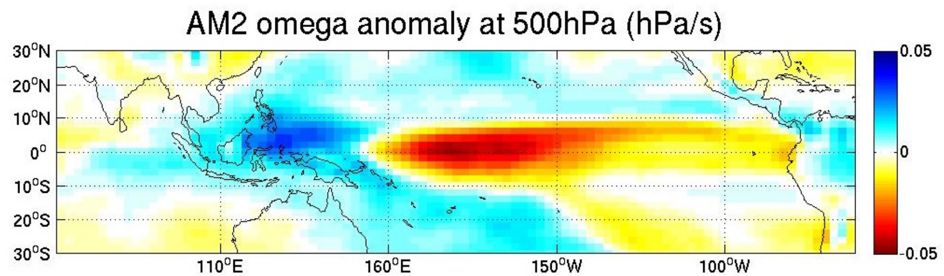
- AM2 and AM3 have a much larger high cloud anomaly than observations
- But how reliable is ISCCP since it relies heavily on radiance measurements?

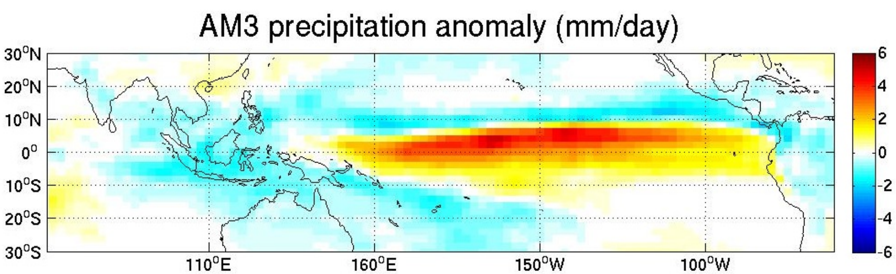
Precipitation and Omega anomaly:

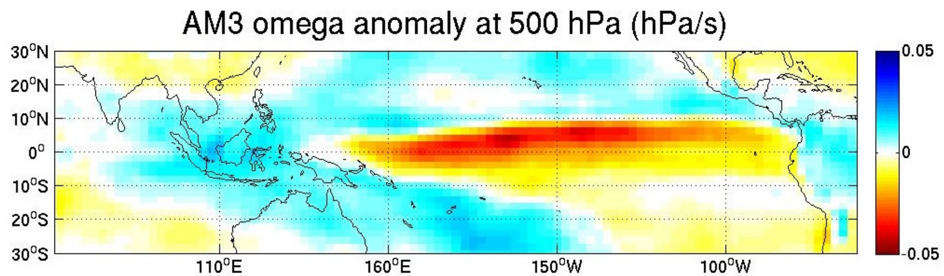


Red = ascent
Blue= descent



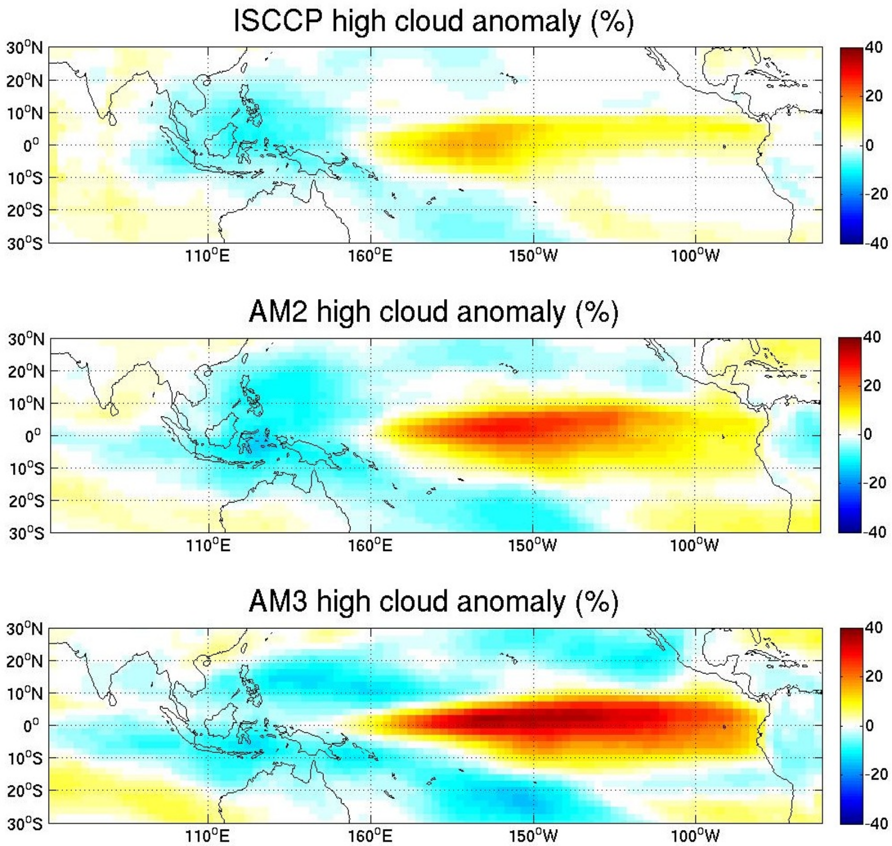






- Omega larger in AM2 than AM3, consistent with the precipitation fields

High Cloud and Omega anomaly:



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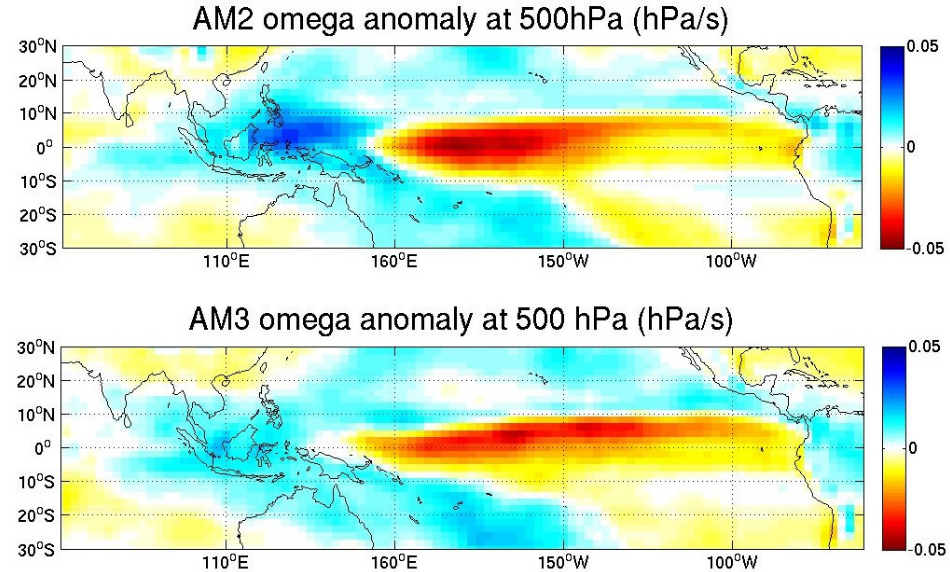
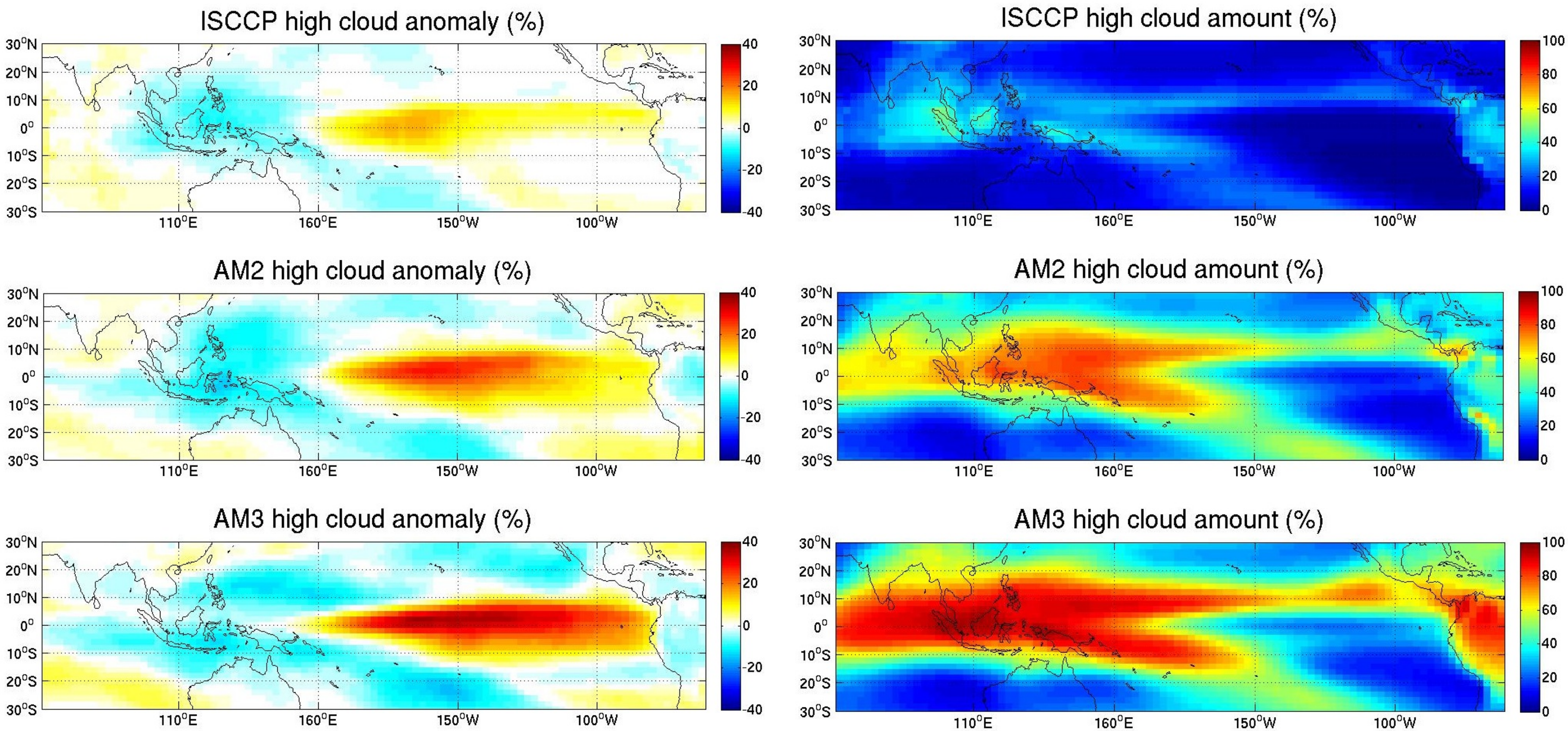


- AM3 cloud anomaly larger than AM2 but smaller omega
- Difference between AM2 and AM3 not attributable to large scale circulation

High Cloud Anomaly & Mean Amount:

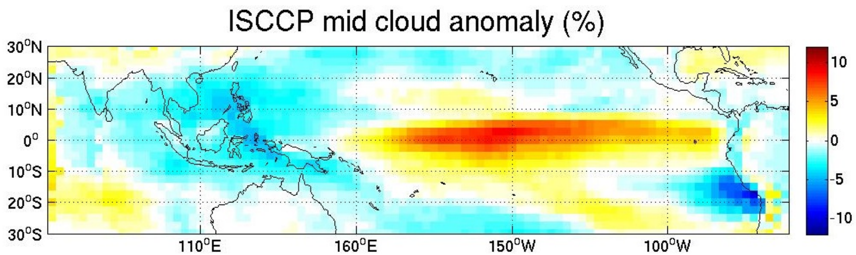


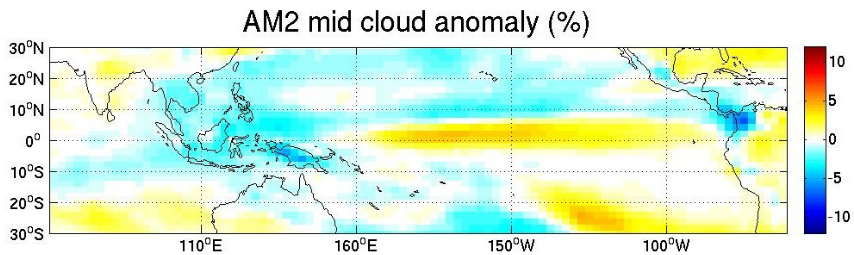
- AM2 and particularly AM3 mean cloud amounts are high → anomaly will be higher

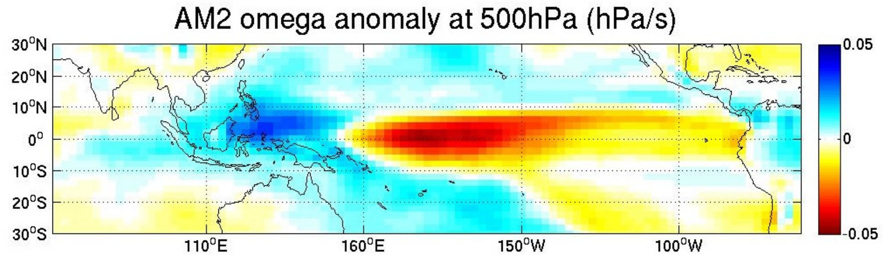
- Mesoscale convective anvils have too much ice in AM3. Ice water path is at the upper end of the range of uncertainty derived from CloudSat observations (*Saltzmann et al. 2010)*

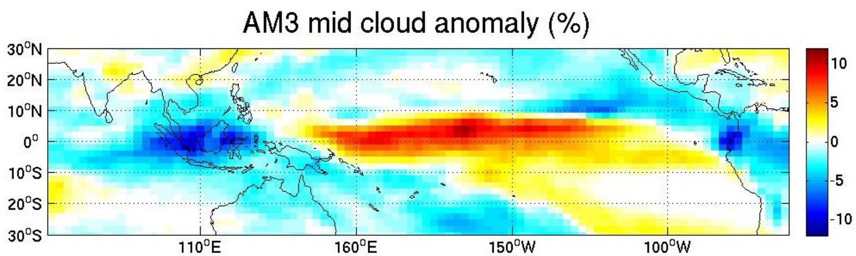
- Ice water path in AM2 is lower than observed with CloudSat *(Lin et al. 2011)*

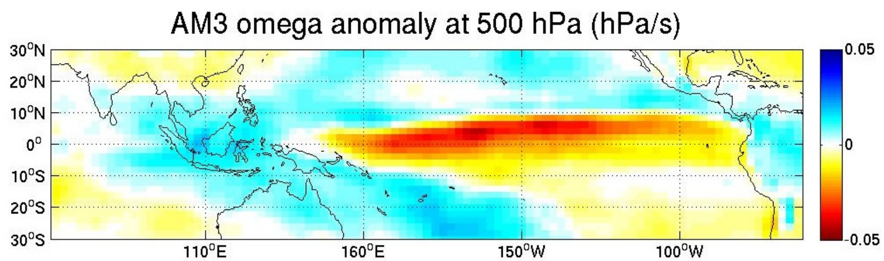
Mid Cloud Amount & Omega Anomalies:









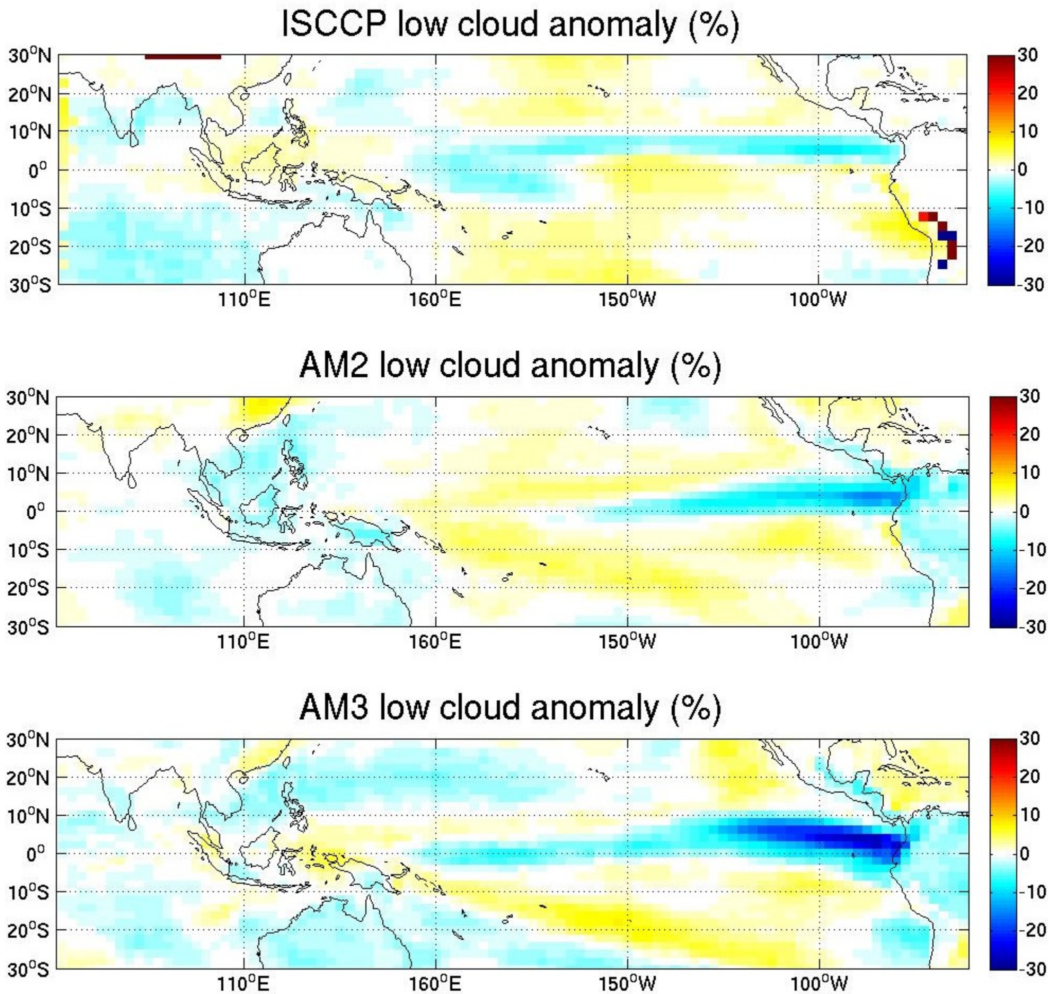


- Differences between AM2 and AM3 cannot be explained by the large scale anomalies of either precipitation or omega

- AM3 includes parameterization for mesoscale updrafts and downdrafts, which have been shown to significantly improve simulation of deep convection *(Donner et al. 1993)*. AM2 has no mesoscale circulation.

- AM3 has more mid-level detrainment from convection than AM2, which causes more mid-level clouds *(Donner et al. 2007)*

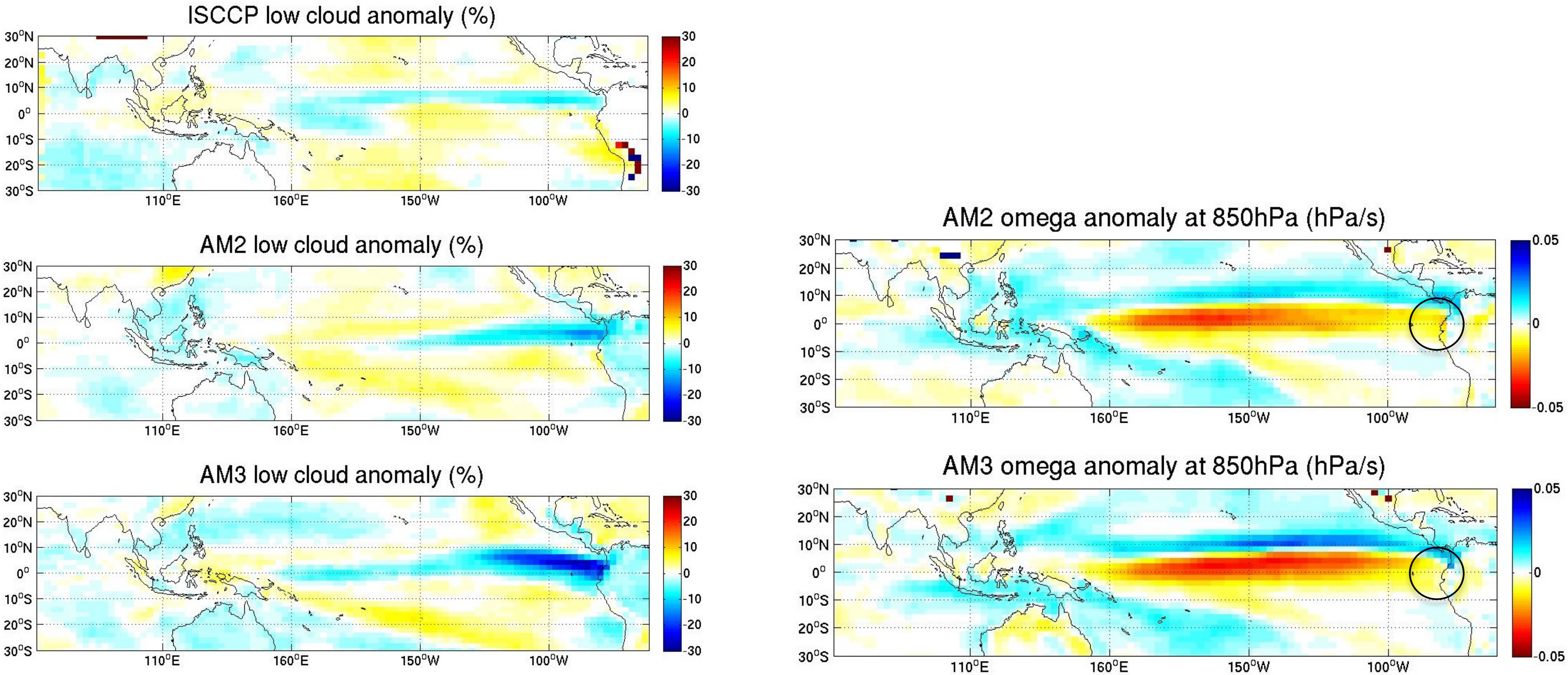
How do low clouds change?



- Increase in SST causes breakup of stratiform low level cloud types into more cumuliform clouds (trade cumulus), and thus to a smaller cloud fraction *(Bony et al. 2005)*

- Can ISCCP accurately measure low clouds? Why the large difference between AM2 and AM3?

Low cloud and omega anomalies inconsistent…



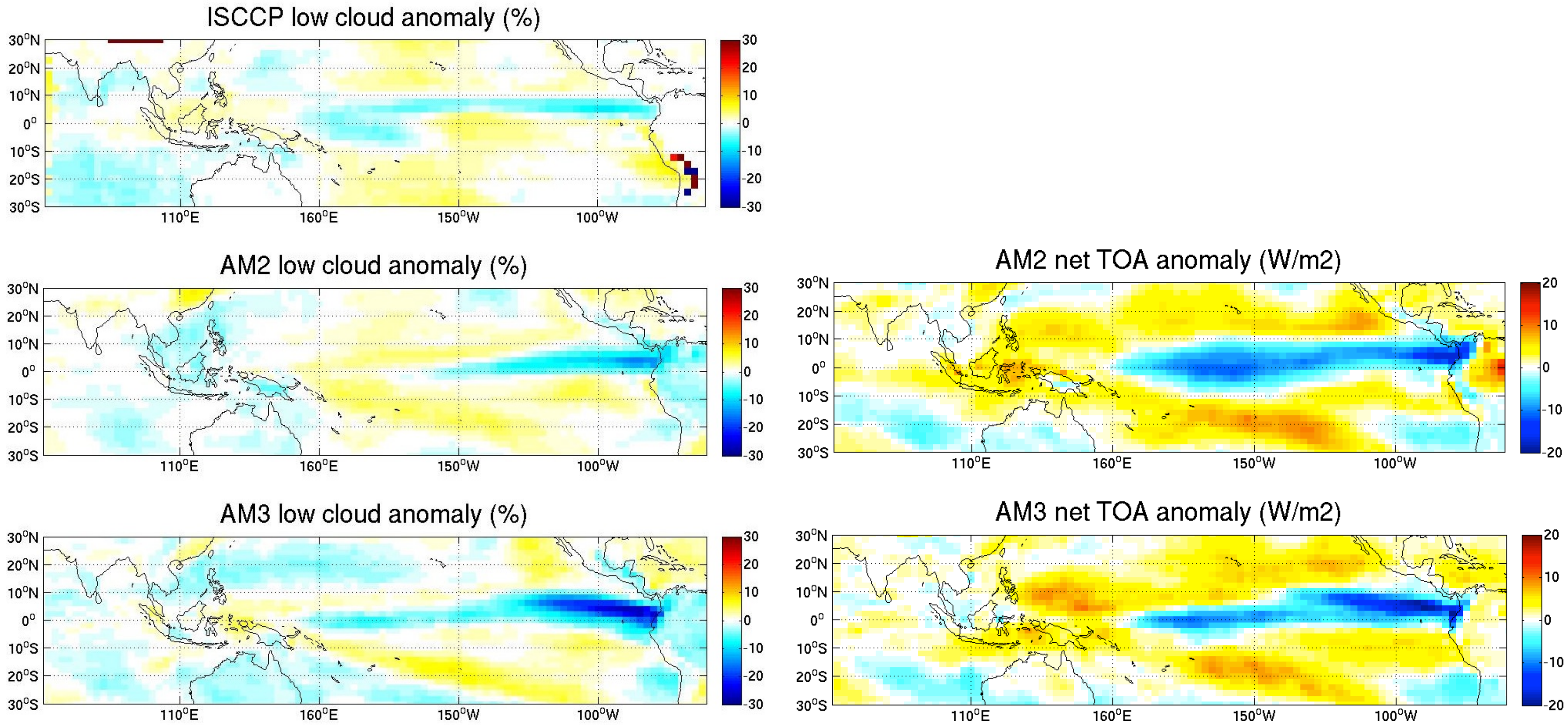
- From Omega field we would expect AM2 low cloud anomaly to be greater than AM3
- Could difference between AM2 & AM3 be due to small scale physics?

Stratiform cloud erosion:

- Turbulent mixing with environment air and subsequent evaporation
- Occurs if grid box mean vapor mixing ratio is less than its saturation value
- Rate of erosion of cloud fraction is proportional to the erosion coefficient (*Salzmann et al. 2010*)
- Erosion coefficients are 40% larger in AM3 than AM2 (*Donner et al. 2010)*

→ Under the same conditions AM3 stratiform clouds are easier to breakup than in AM2

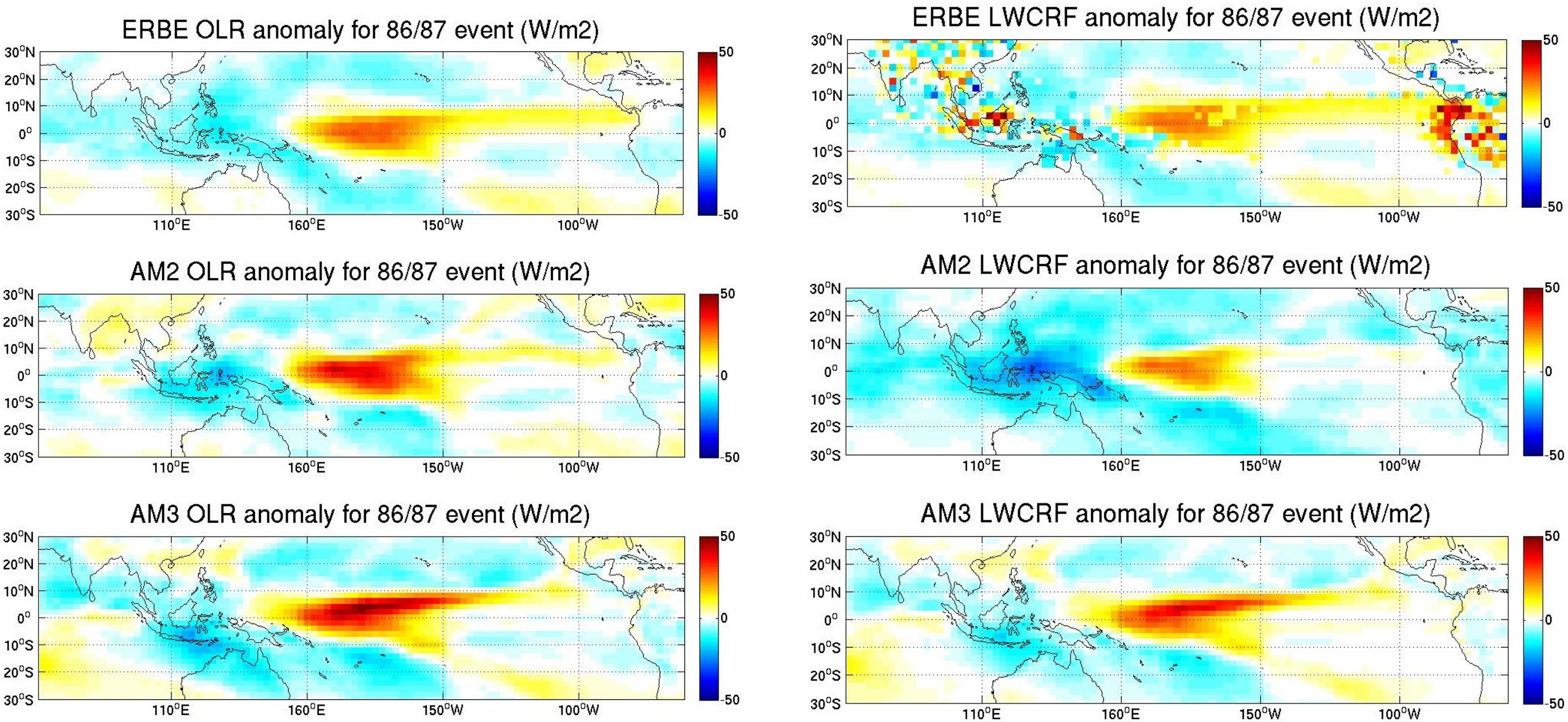
Including all El Niño events:



- Decrease in low cloud fraction → decrease in albedo but small change in greenhouse effect → increase in net absorbed radiation *(Bony et al. 2005)*
- Changes in central Pacific are due to mid/high clouds

→ Strong positive feedback in East Pacific of ~20W/m^2

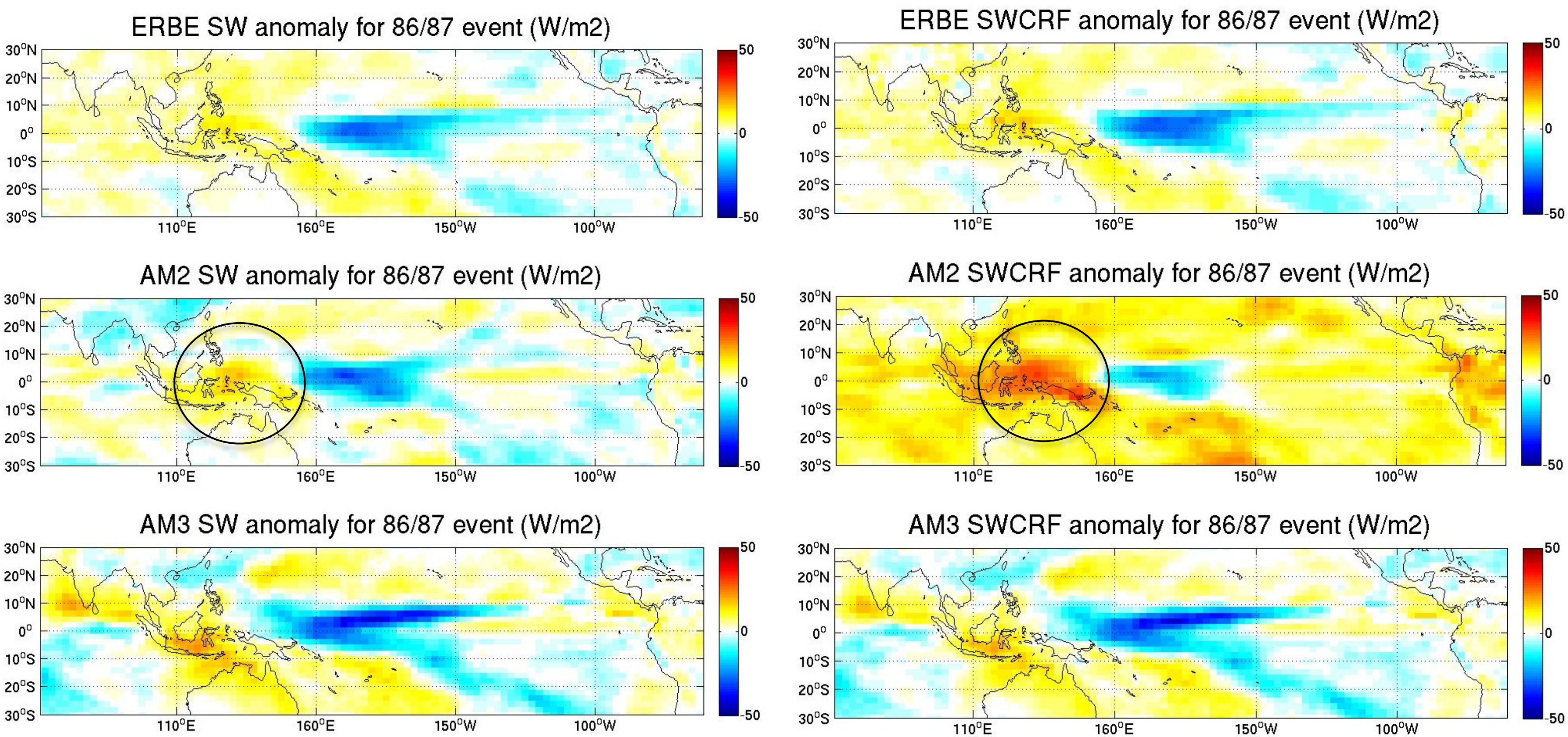
How do clouds affect the longwave TOA radiation budget?



LWCRF=longwave cloud radiative forcing

- AM2 & AM3 anomalies are larger than observations
- AM2 larger anomaly in west Pacific, AM3 larger in central Pacific
- Radiation changes are tied more to cloud anomalies than variation in the large scale circulation

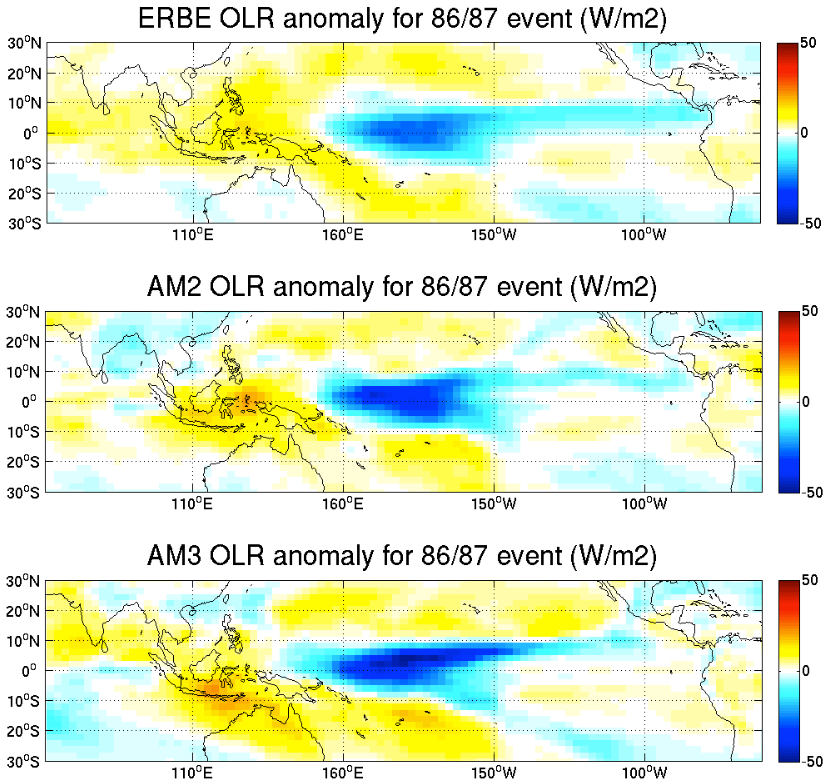
How do clouds affect the shortwave TOA radiation budget?

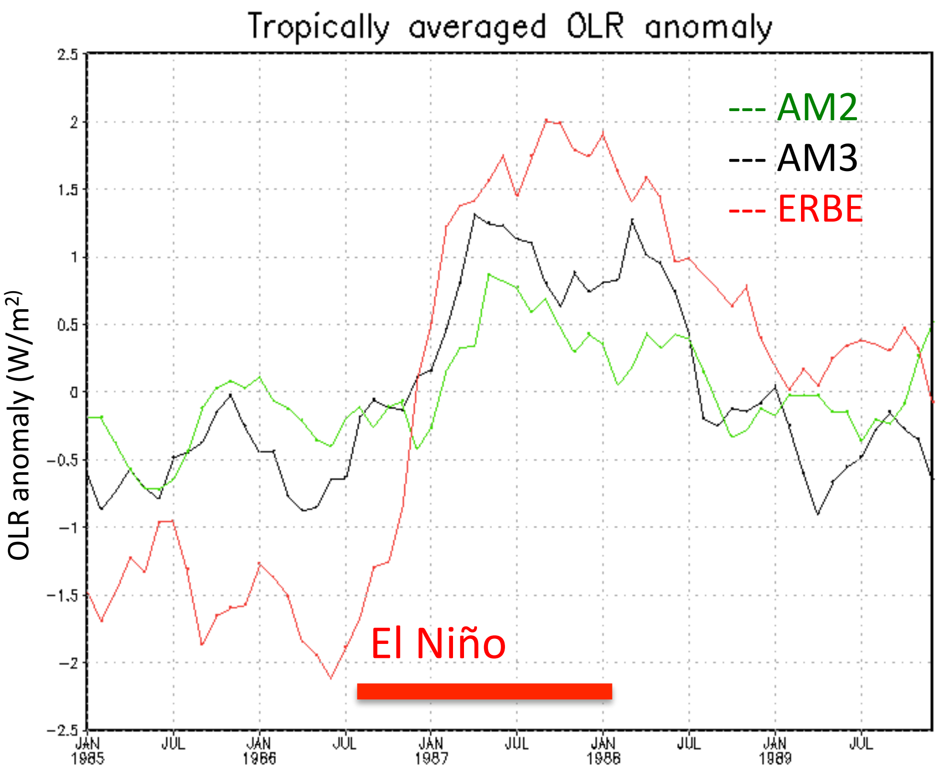


SWCRF= shortwave cloud radiative forcing

- SW radiative forcing at TOA can be primarily attributed to clouds
- AM3 SWCRF closer to observations than AM2 *(Donner et al. 2010)*. AM2 SW flux tuned so errors in SCWRF reflect errors in clear sky values as well

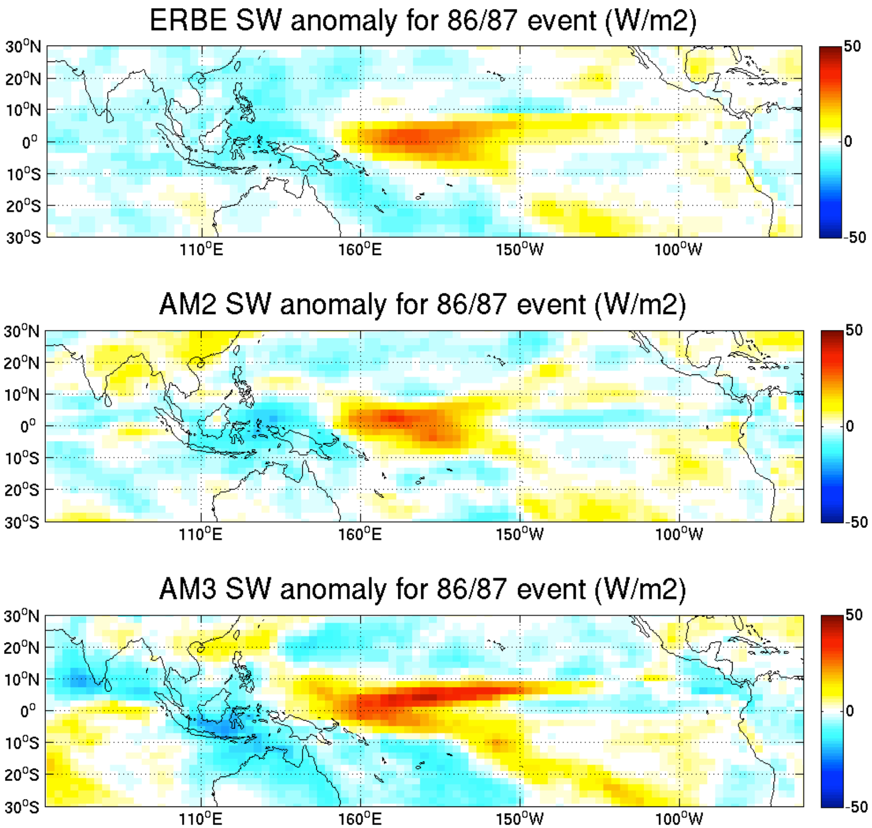
Tropical Average vs. Regional results: OLR

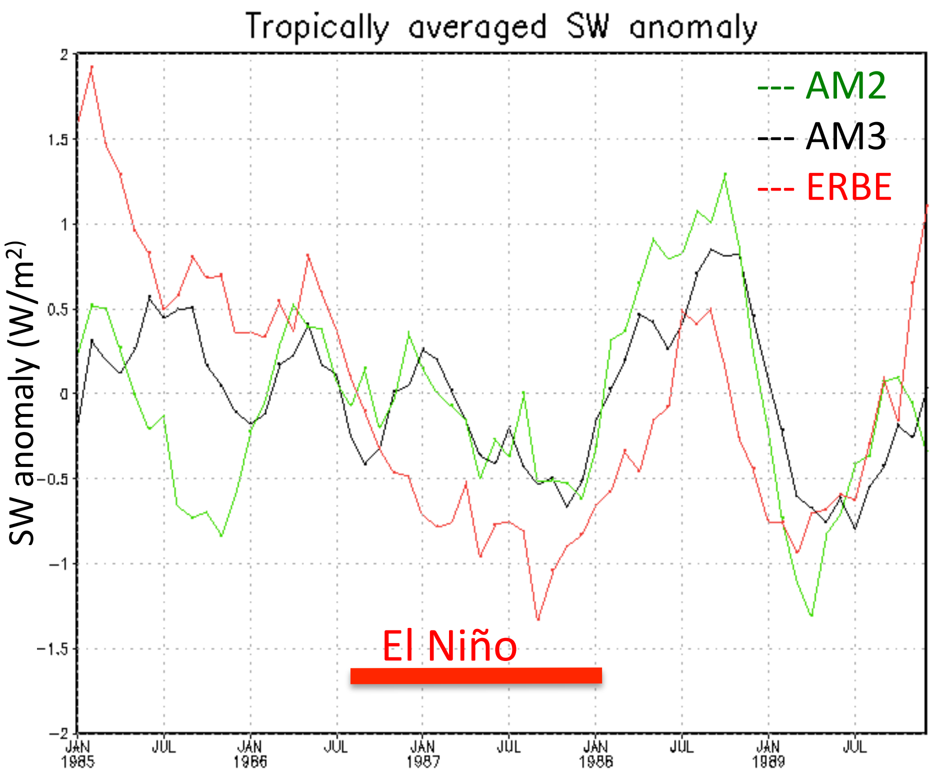




- Tropically averaged results imply smaller variability in models than observations
- But in terms of regional anomalies, we see larger variability in the models than in the observations

Tropical Average vs. Regional results: SW





• Again the large model variability we see in the central Pacific does not carry through to the tropical averages

Conclusions:

- High Clouds:
  - AM3 has a larger anomaly than AM2 and observations for high cloud, despite AM2 having larger vertical velocities at 500hPa.
  - Large anomaly can be attributed to AM3 having ice water paths larger than observed, whilst AM2 has ice water paths smaller than observed.
  - AM2 has too little mid-cloud amount, possibly caused by too little detrainment at mid-levels
- Low Clouds:
  - Differences between the small scale physics in AM2 and AM3 gives rise to much larger low cloud anomalies in AM3. This is possibly caused by differences in the erosion coefficient
- Radiation Budget:
  - From tropically averaged calculations it appears the AM2/AM3 underestimate radiation budget variability
  - Regional analysis showed that the opposite is true, AM2/AM3 have too much variability compared to observations
  - Implications for definitions of globally averaged climate feedback

Future work:

1. Run AM2/AM3 with different cloud parameterizations to confirm their role in the differences between observations and models

2. Compare AM3 runs with post-2000 satellites e.g. AIRS, MISR, Calipso, CloudSat to look at

    - Vertical structure – how does the distribution change during an El Nino events? Or are the clouds simply shifting horizontally?

    - How do cloud properties change? E.g IWP, optical depth

3. Investigate the spatial variation and cancellation effects. What determines the tropical average change in TOA radiation?