Getting our Heads out of the Clouds:
The Role of Subsident Teleconnections in Climate Sensitivity

John Fasullo

Climate Analysis Section, NCAR

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Motivating Question

Can we reframe the cloud feedback problem in the context of the environment in which clouds occur?

If so, can a process study constrain sensitivity?

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Outline

- Background (CMIP5 status)
- Motivating Process Studies
- Subtropical winter dry zones
- Model Biases
- Ties to sensitivity
- CMIP5

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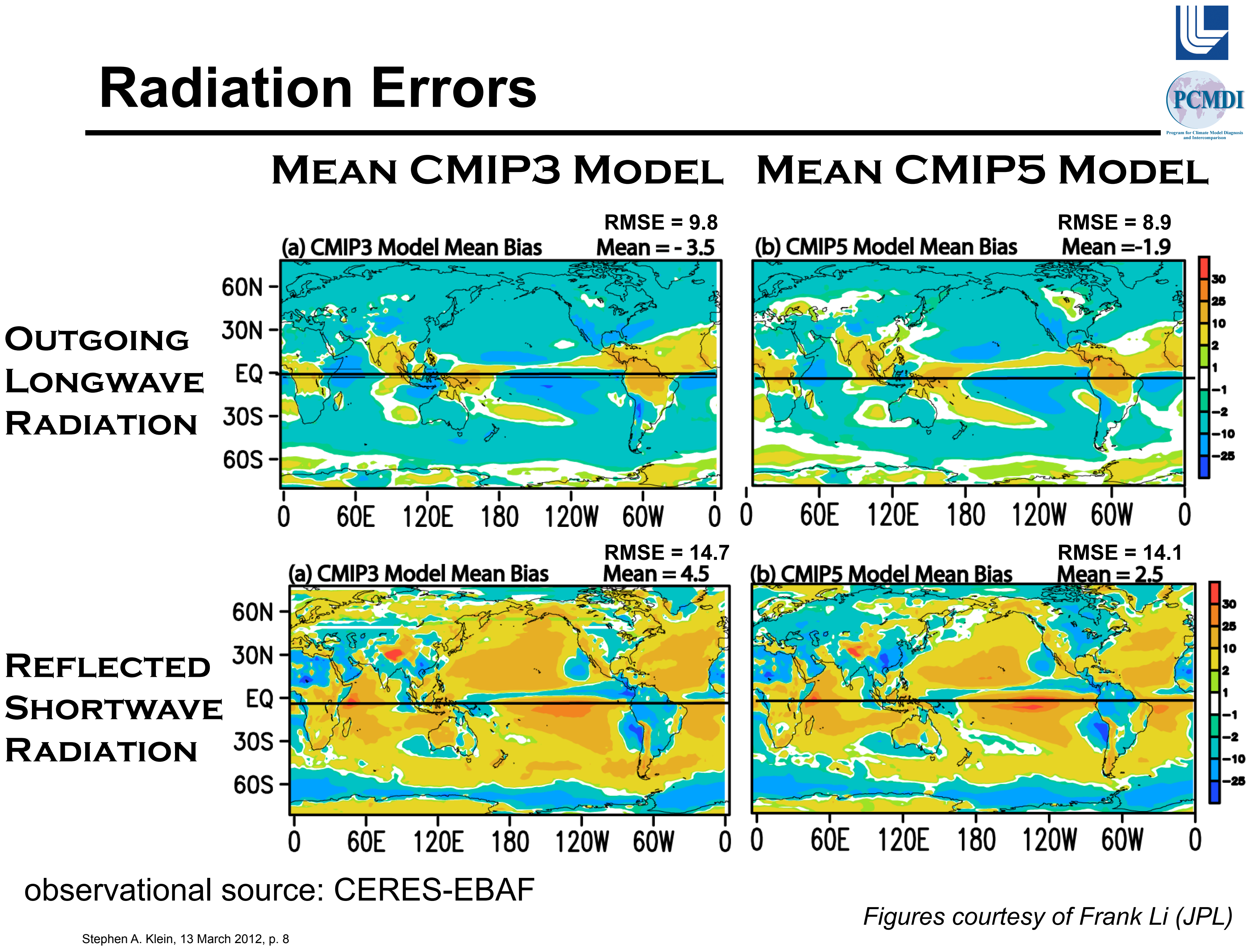
Background Motivation

- Uncertainty in climate sensitivity has not decreased considerably since the Charney report (1979). also CMIP5.
- Clouds are key determinants of climate sensitivity. But are obs of clouds our best constraint? Hard to observe. Clouds are tuned.
- Cloud physics can be perfect but if the environment in which clouds occur is biased, the cloud feedback will be biased as well. Is there evidence for such biases?
- Clouds are parameterized by RH. How well do models reproduce observed variations of RH?

Misperceptions?

- As models reduce their mean biases their feedbacks will improve and uncertainty will decrease. The CMIP archives provide direct evidence that this is not the case.
- With a longer record of key fields (e.g. TOA fluxes), we will be able to substantially constrain climate sensitivity. Depends on what is meant by “longer”. Unlikely to happen in the coming decade.
- Community efforts (e.g. CMIP3) have provided the fields needed to understand climate sensitivity at a process level. Most models didn’t use model simulator packages and many relevant fields were not part of the archive. But in CMIP5 this is likely to change.



Radiation Errors

MEAN CMIP3 MODEL **MEAN CMIP5 MODEL**

OUTGOING LONGWAVE RADIATION

REFLECTED SHORTWAVE RADIATION

observational source: CERES-EBAF

Stephen A. Klein, 13 March 2012, p. 8

Figures courtesy of Frank Li (JPL)

There is modest improvement in radiation in CMIP5. Many of the canonical biases however remain. (albedo too high in tropics, SH biases)

Progress over time

Root Mean Square Errors for Outgoing Longwave Radiation

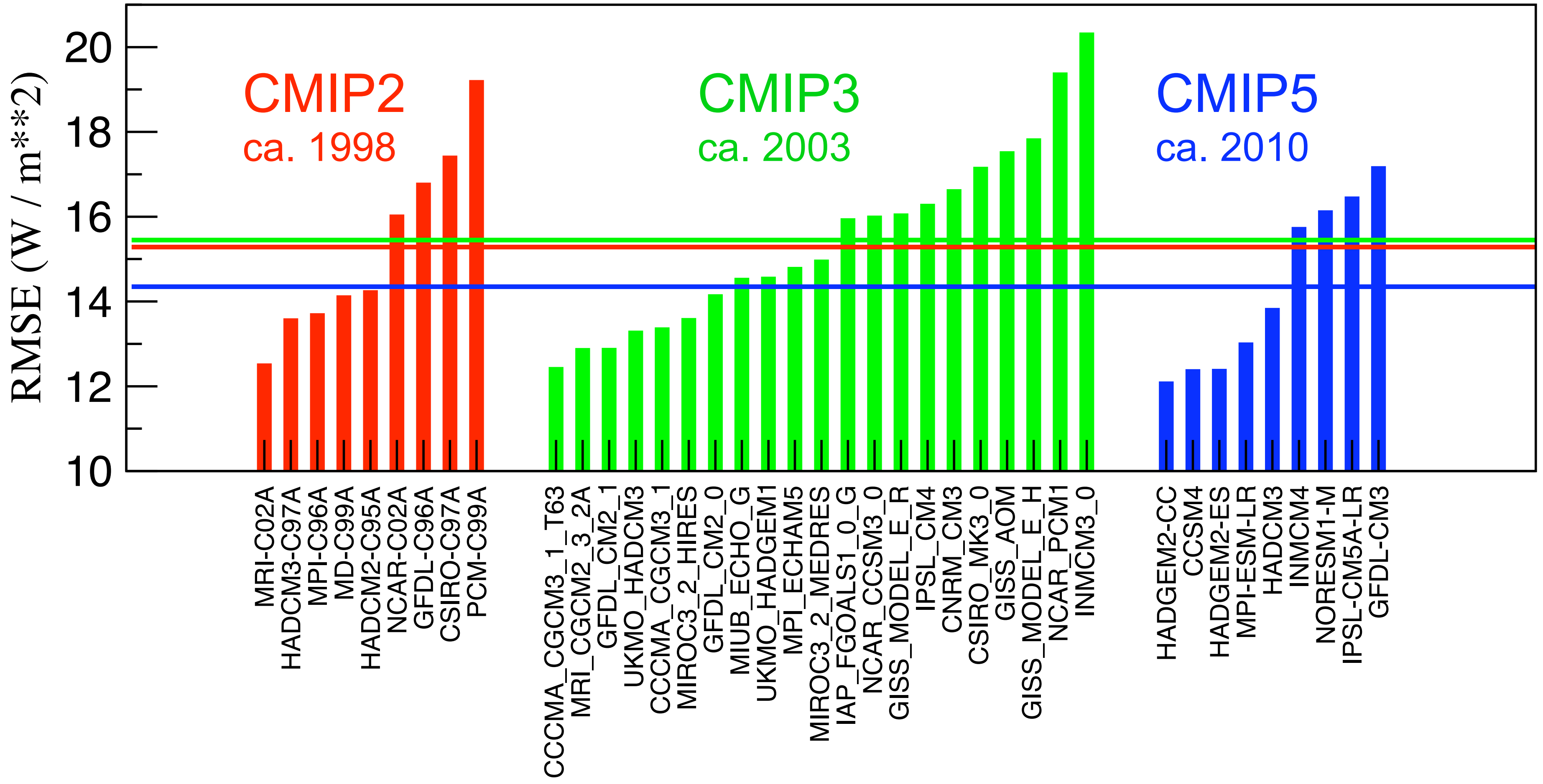
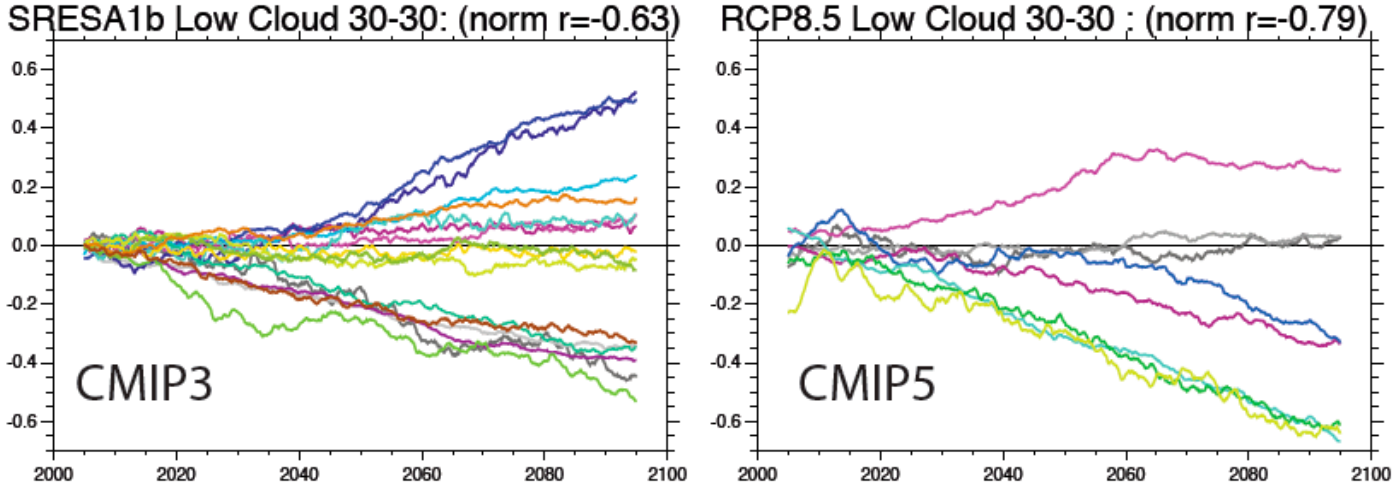


Figure courtesy of Peter Gleckler (LLNL)

Stephen A. Klein, 13 March 2012, p. 9

Feedbacks are sensitive to the response of low-clouds but …

- The inter-model spread in low cloud responses at low-latitudes is correlated with the inter-model spread in warming, *but …*

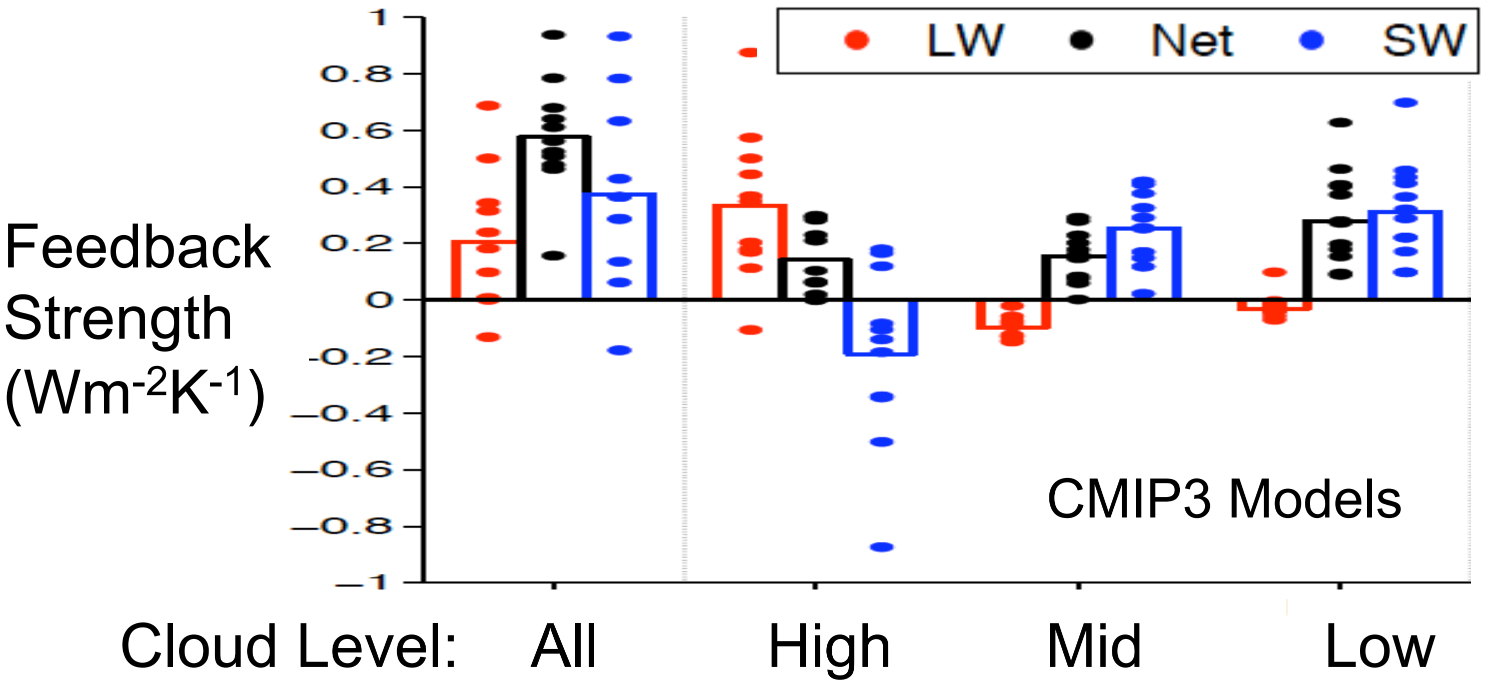


SRESA1b Low Cloud 30-30: (norm r=-0.63)

RCP8.5 Low Cloud 30-30 ; (norm r=-0.79)

Figure courtesy of John Fasullo (NCAR)

- The spread in feedbacks from other cloud types is also significant and should not be ignored



Zelinka et al. (2012)

Low cloud feedback has been a focus of attention for some time yet remains a main source of uncertainty. We know all clouds types depend strongly on RH.

The Wild West of Observational Constraints
The Good, The Bad, and The Ugly

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Lindzen and Choi 2009: - a contrived result that exploits noise in the TOA net flux to “demonstrate” a negative cloud feedback.
Lesson: Lacks robustness, objectivity, and relevance. But gets on Glen Beck in the lead up to Copenhagen.

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Dessler 2010: An examination of TOA fluxes in the 2000s v.s. T_S.
Noise and variance associated with ENSO over a decade fails to offer a strong constraint on models.
Lesson: Obs don’t yet provide strong guidance on forced response.

Developing a process-based constraint

Basic requirements should include that it:

- explain contrasting SW feedbacks under climate change in a warming-normalized framework,

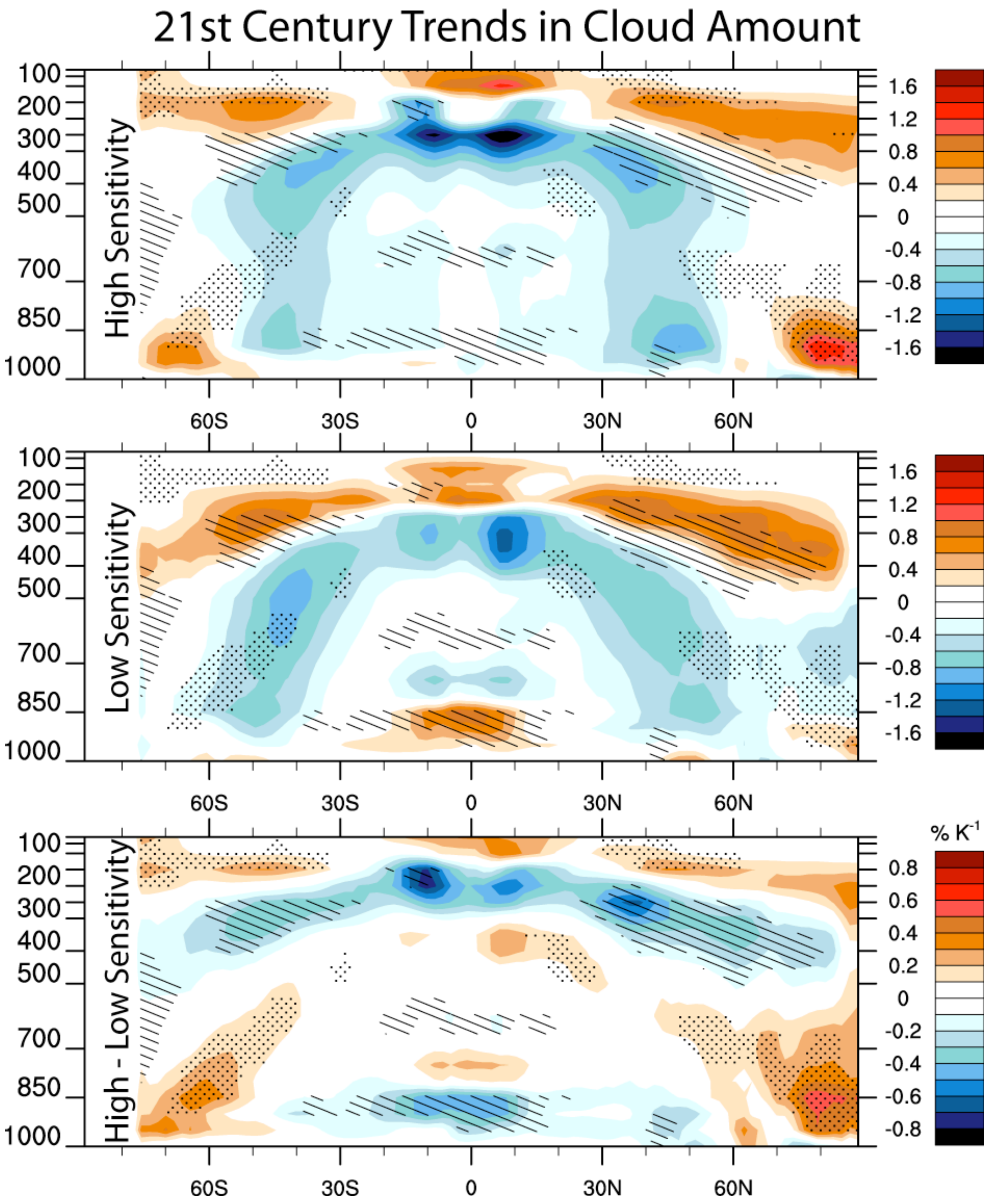
- focus on processes at low latitudes where the area-integrated energy imbalance is dominant,

- explain variance not just at a statistically significant threshold but at a large % of total variance explained,

- be physically consistent with the notion of a forced response in clouds (not coupled, not ENSO).

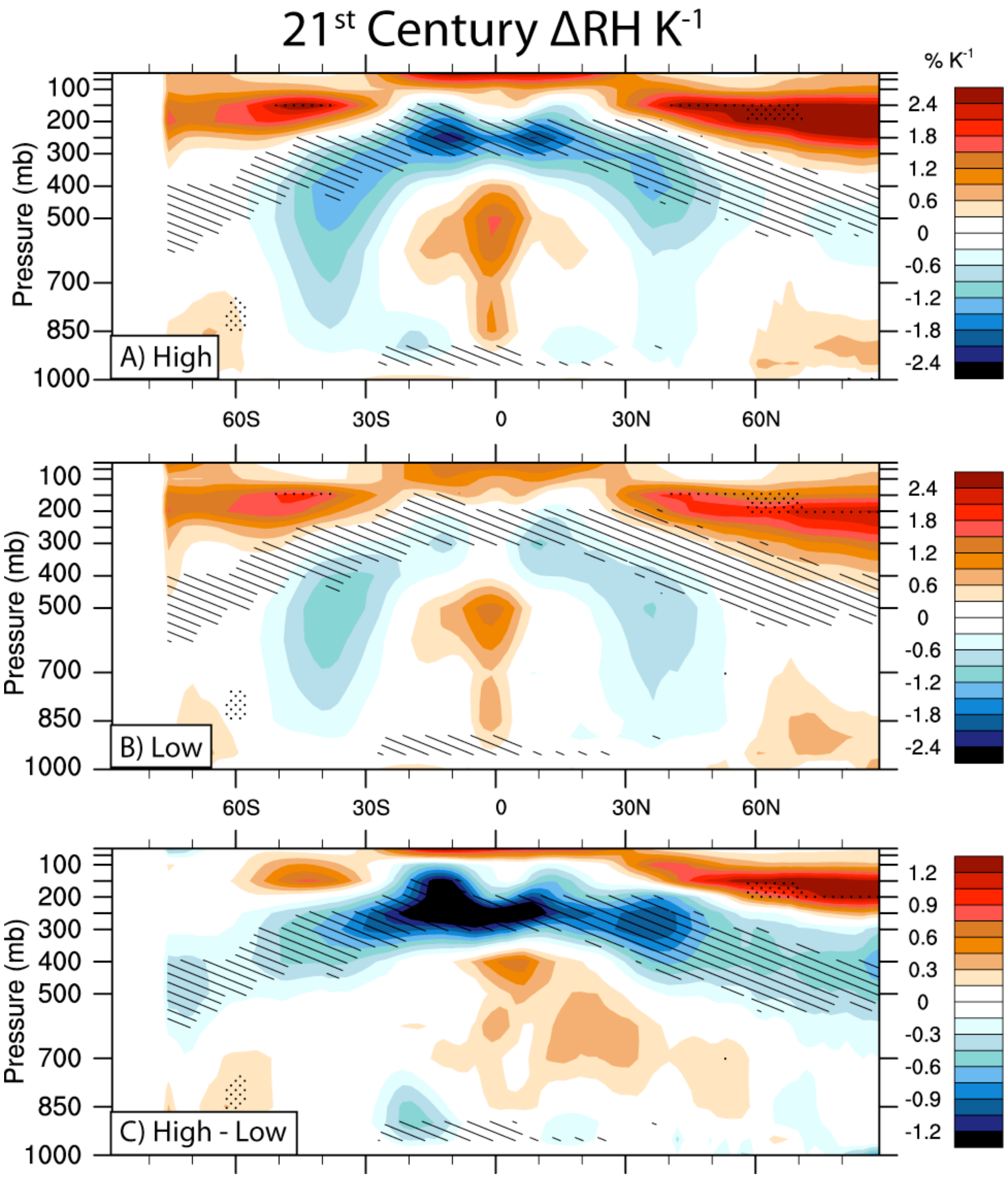
But this still allows for a large number of potential processes. How to narrow down?

Zonal Mean Cloud Trends (hatching=correlated with warming across all models)



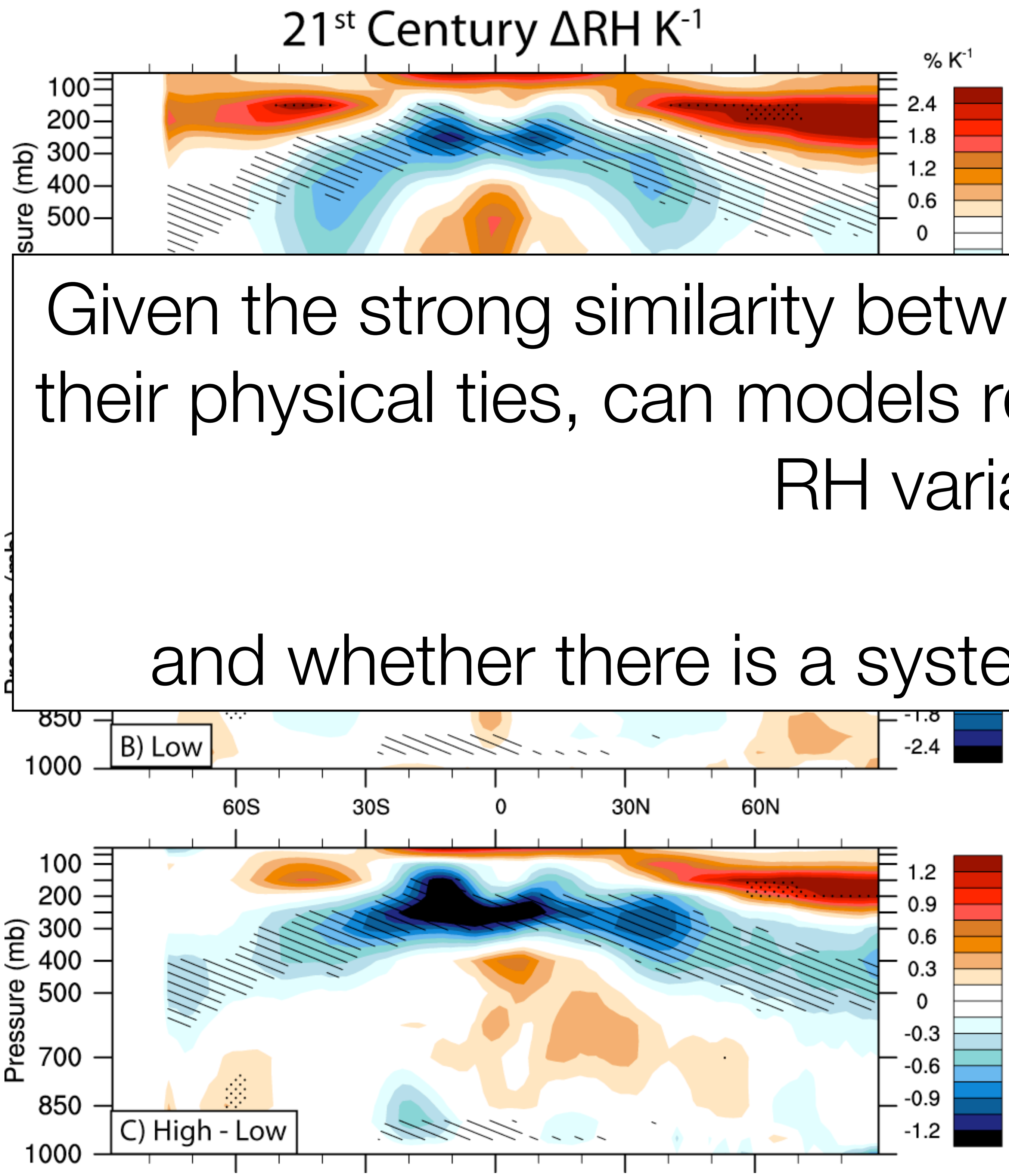
- ubiquitous loss of cloud below 200 mb
- decrease in low cloud
- ubiquitous loss of cloud below 300 mb
- gain of low cloud in low sensitivity models
- high sensitivity models lose more high cloud and don’t gain as much low cloud
- variance in cloud trends greater for high cloud

Zonal Mean RH Trends (hatching=correlated with warming across all models)



- high sensitivity have substantial reductions in RH below 150 mb, particularly in the middle and upper troposphere
- moistening in the deep tropics
- smaller reductions in RH but similar pattern
- high sensitivity models have greater RH decreases in the upper troposphere and boundary layer
- strong spatial similarity with cloud trends

Zonal Mean RH Trends (hatching=correlated with warming across all models)



- high sensitivity have substantial reductions in RH below 150 mb, particularly in the middle and upper troposphere

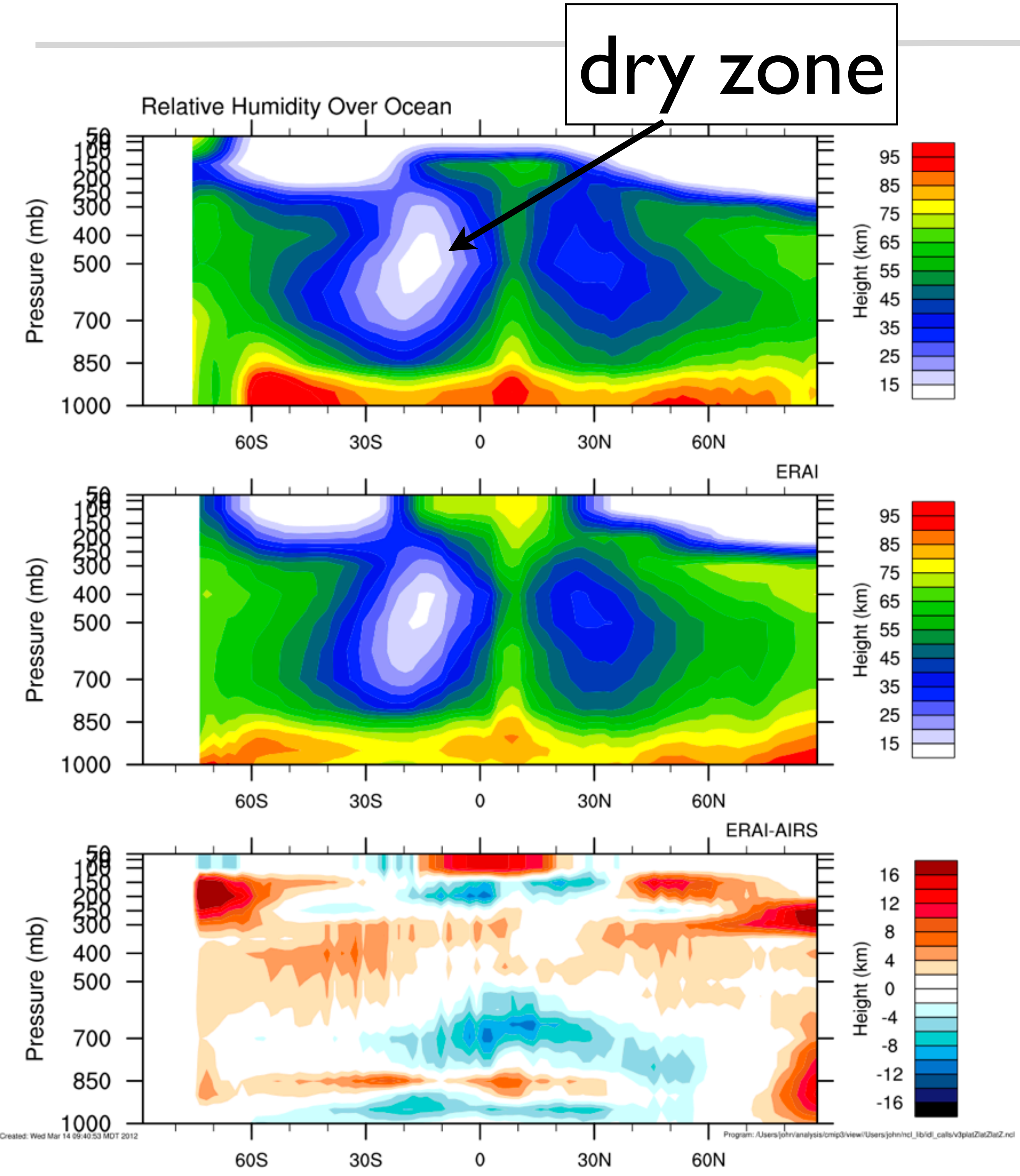
Given the strong similarity between cloud and RH trends, and their physical ties, can models reproduce observed features of RH variability?

and whether there is a systematic relationship to ECS?

- high sensitivity models have greater RH decreases in the upper troposphere and boundary layer

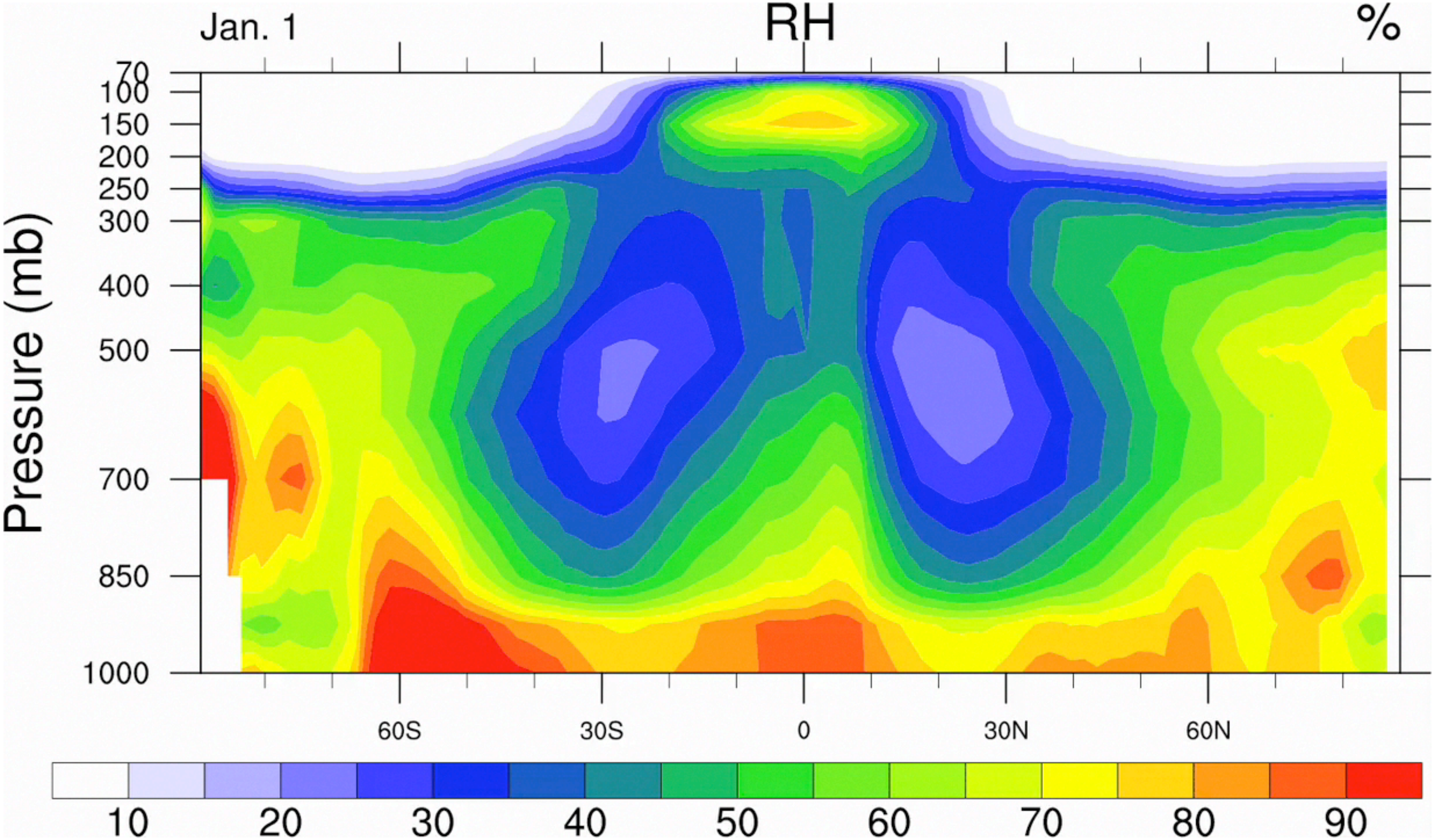
- strong spatial similarity with cloud trends

Seasonal Winter Subtropical Dry Zone: May-Aug



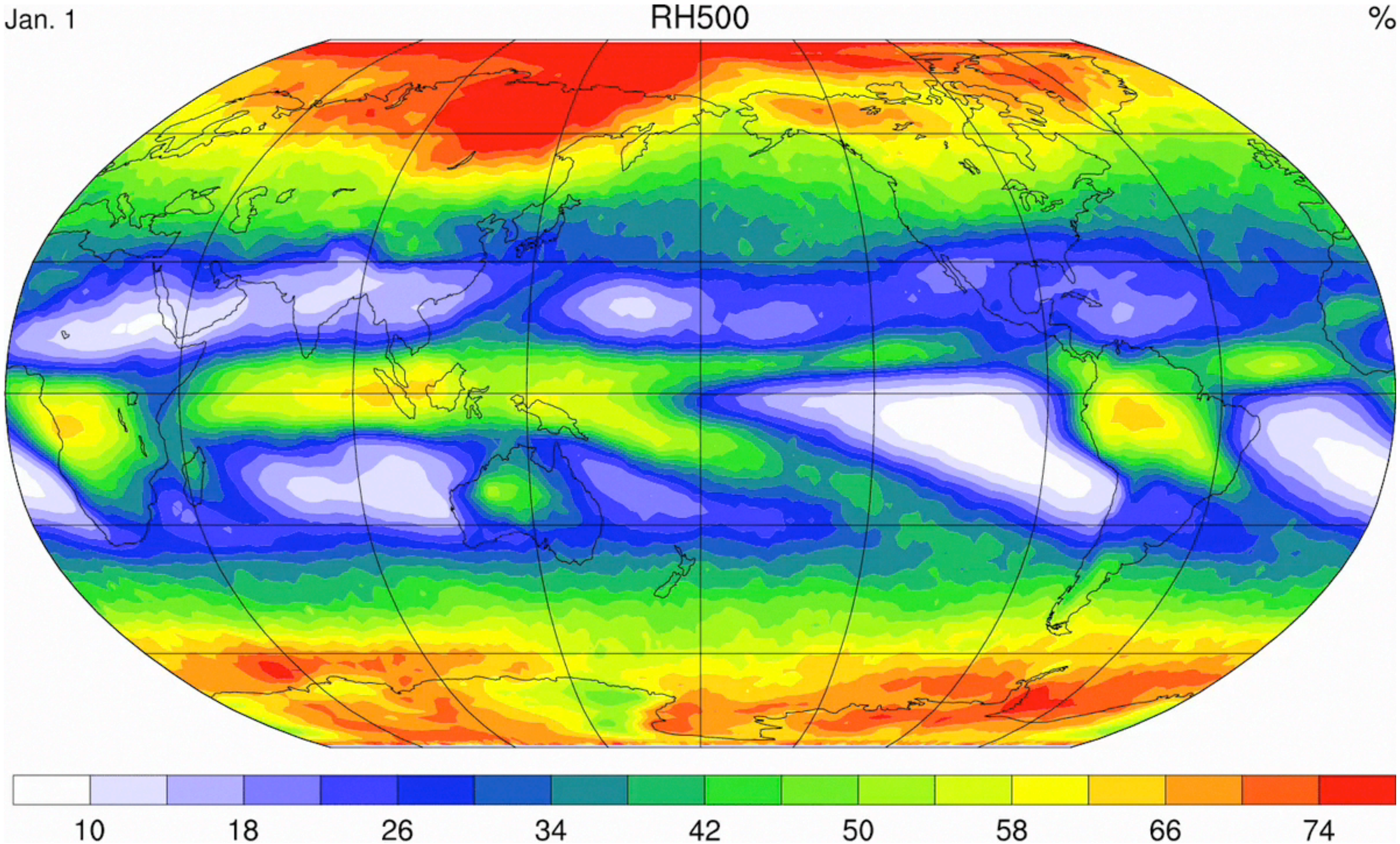
- Rapid and sustained drying of upper troposphere (700-200 mb)
- Associated with subsidence forced by the summer monsoons
- Perhaps well-viewed as a forced response - the seasons (TSI).
- A key test of the interactions between dynamics, moisture, and clouds - and the tropics and subtropics.

Zonal Mean Seasonal Cycle of RH: Movie



- Look for: seasonal variations of tropical deep convection (RH>60).
- Implied updrafts bounded by neighboring subsidence (RH<30)

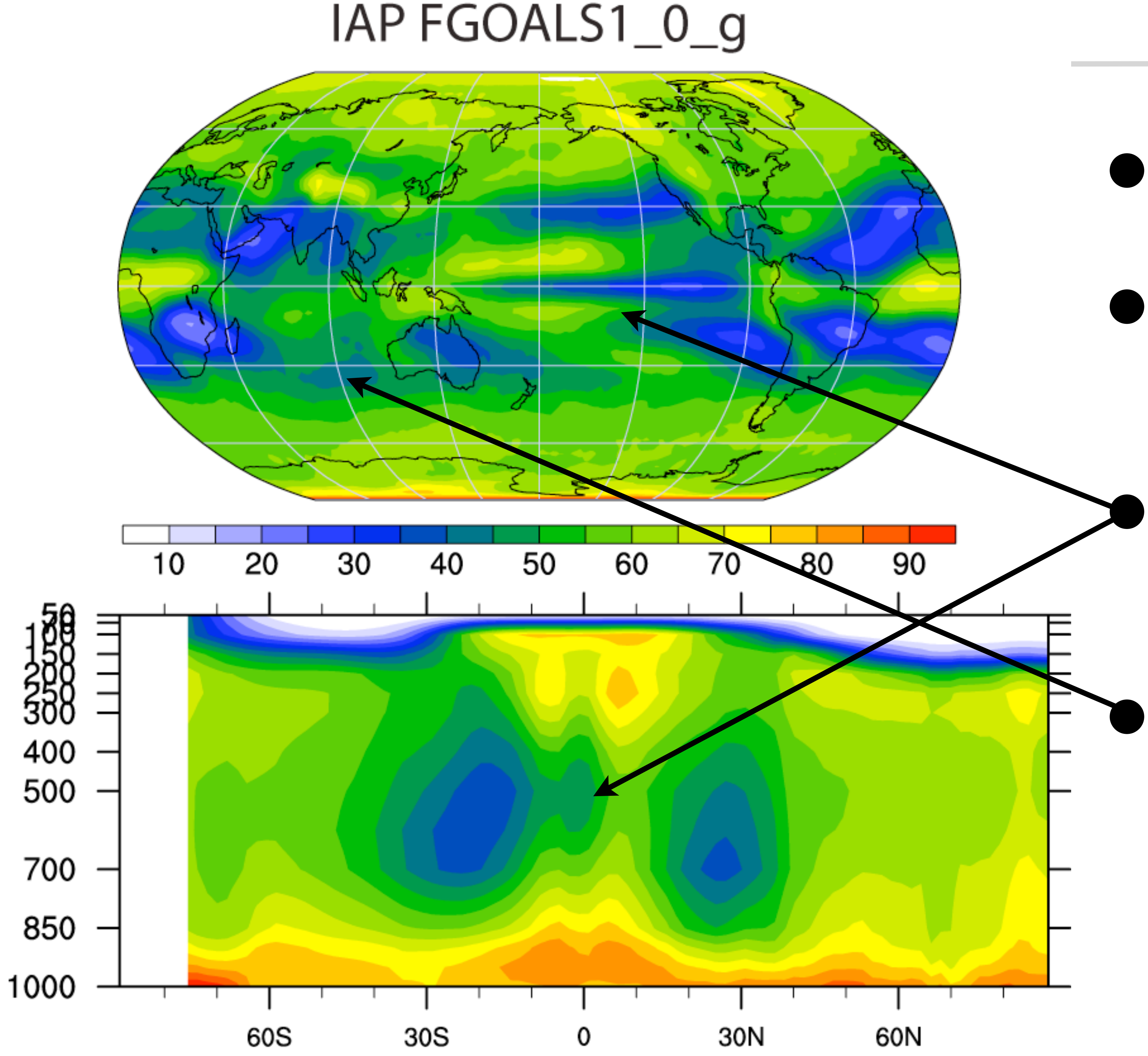
Seasonal Cycle of RH 500 mb: AIRS



- Look for: spatial coincidence between seasonal variations of tropical deep convection and subsidence.
- The uniqueness of the SH dry zone.
- SPCZ's inability to moisten the SH

Model Mean State Biases RH500: May to Aug: FGOALS

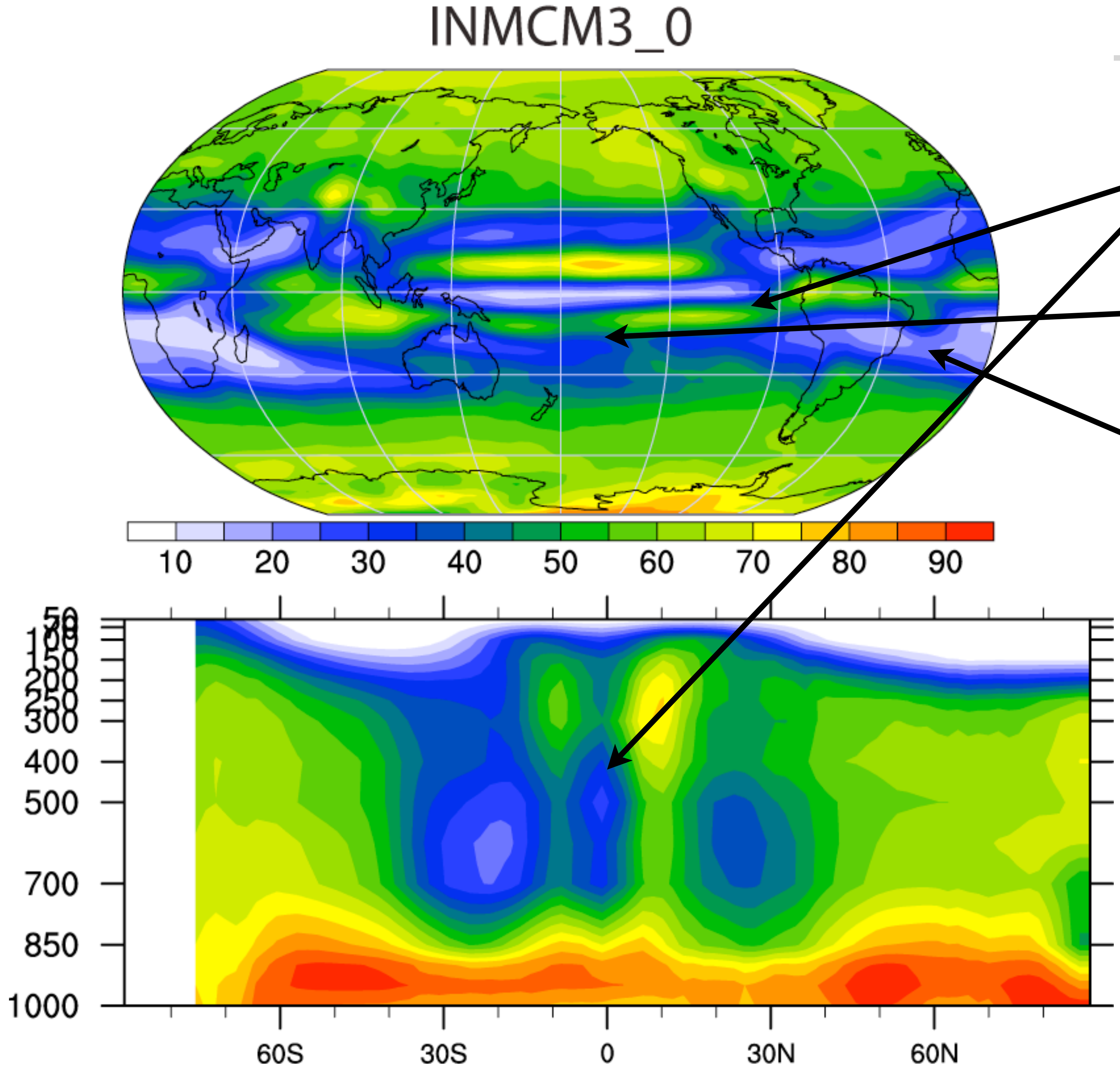
sensitivity = 2.3



- RH >> obs
- Deficient lateral contrasts
- Evidence of double ITCZ
- Poorly formed subtropical highs.

Model Mean State Biases RH500: May to Aug: INMCM

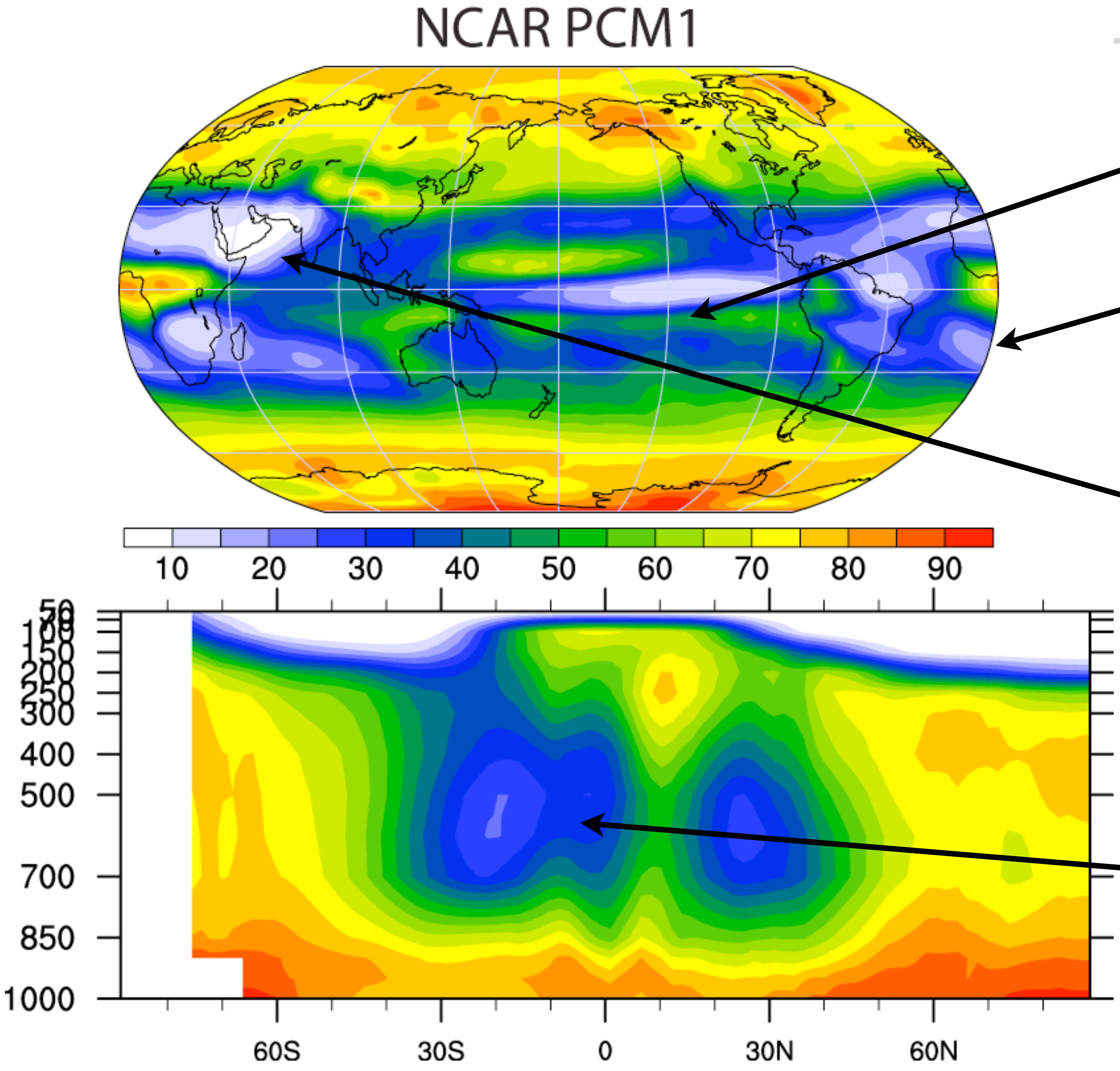
sensitivity = 2.1



- strong double ITCZ
- poorly formed SPCZ
- weak subtropical highs

Model Mean State Biases RH500: May to Aug: PCM1

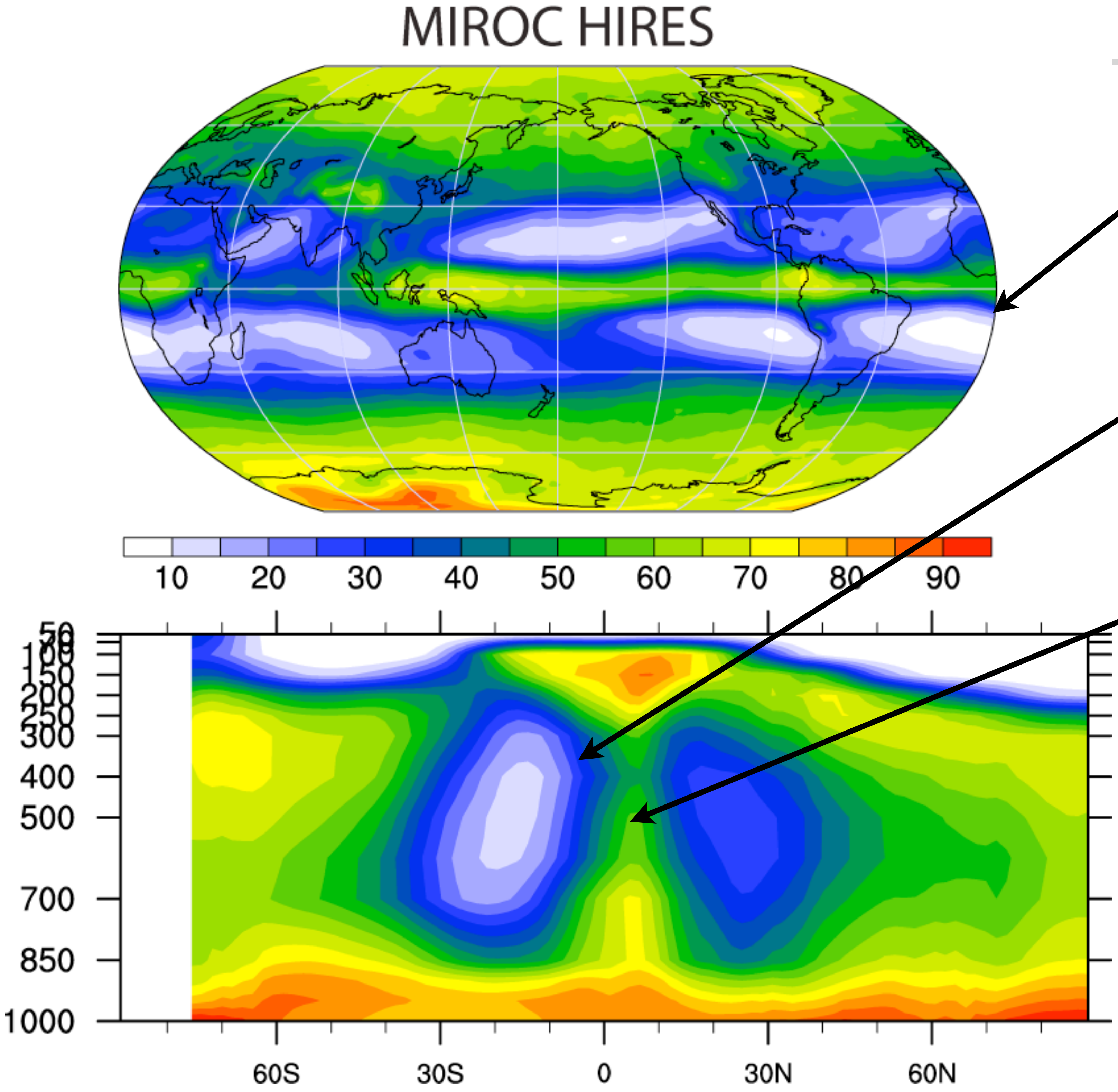
sensitivity = 2.1



- no SP High/SPCZ
- deficient SH subtropical highs
- too strong a lateral monsoon - too weak a transverse monsoon?
- RH > 25%

Model Mean State Biases: May to Aug: MIROC HIRES

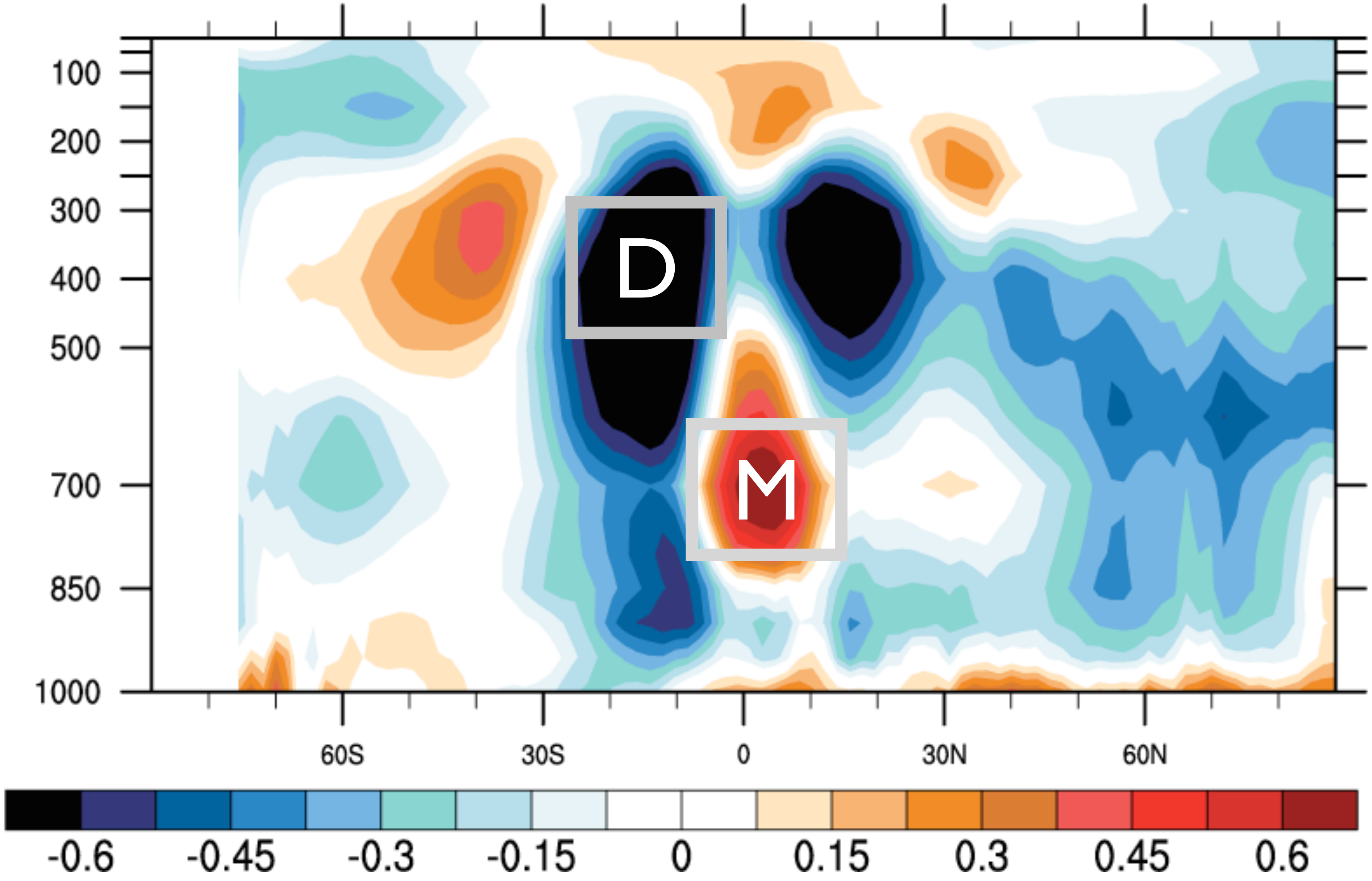
sensitivity = 4.3



- Improved SH subtropical highs
- Well formed zonal mean dry zone
- little sign of double ITCZ bias
- very high sensitivity model. all models that do this well have sensitivity > 3.2

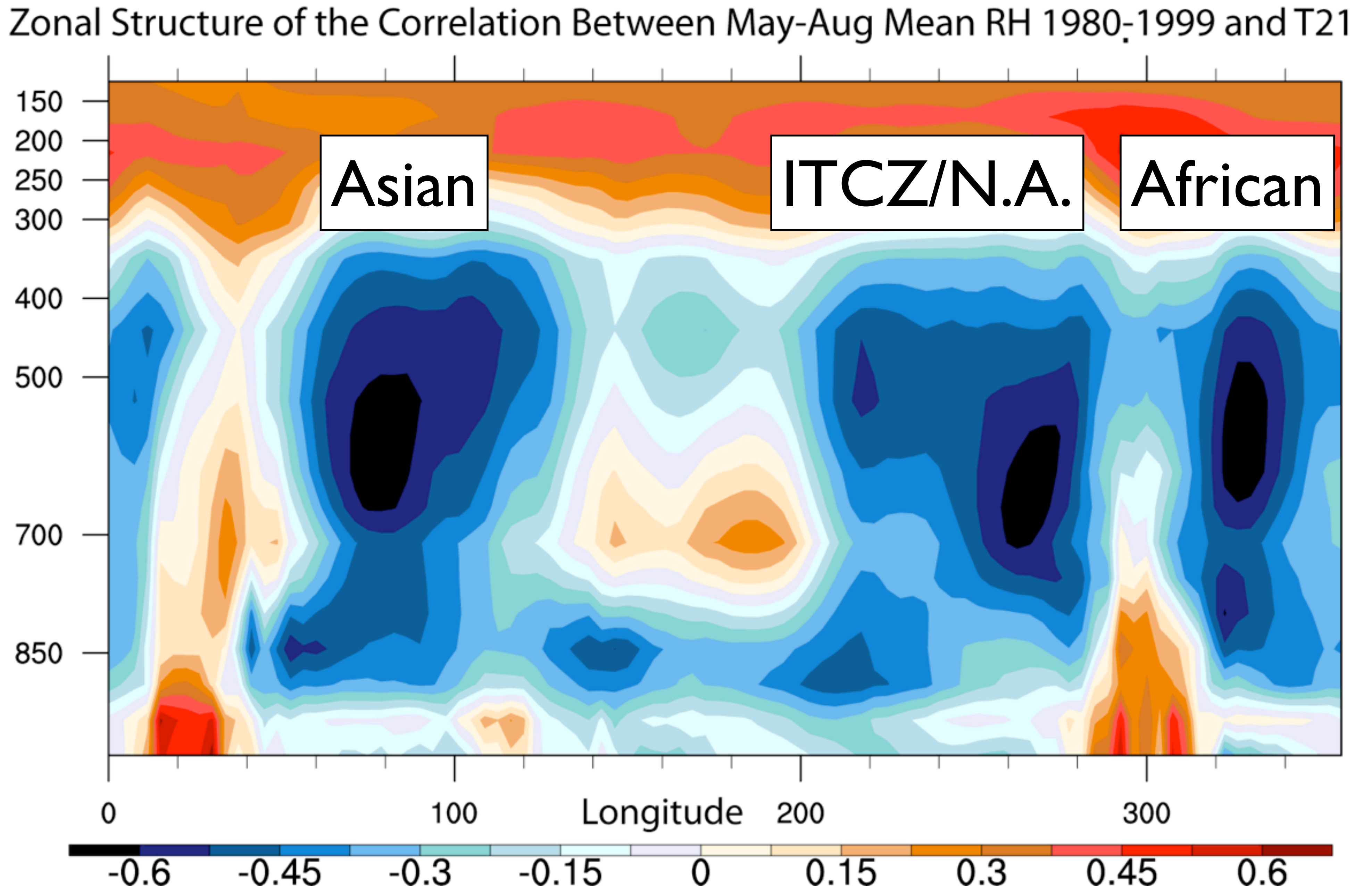
Zonal Mean Correlations: ECS

Correlation of 20th C RH (May-Aug) with ECS



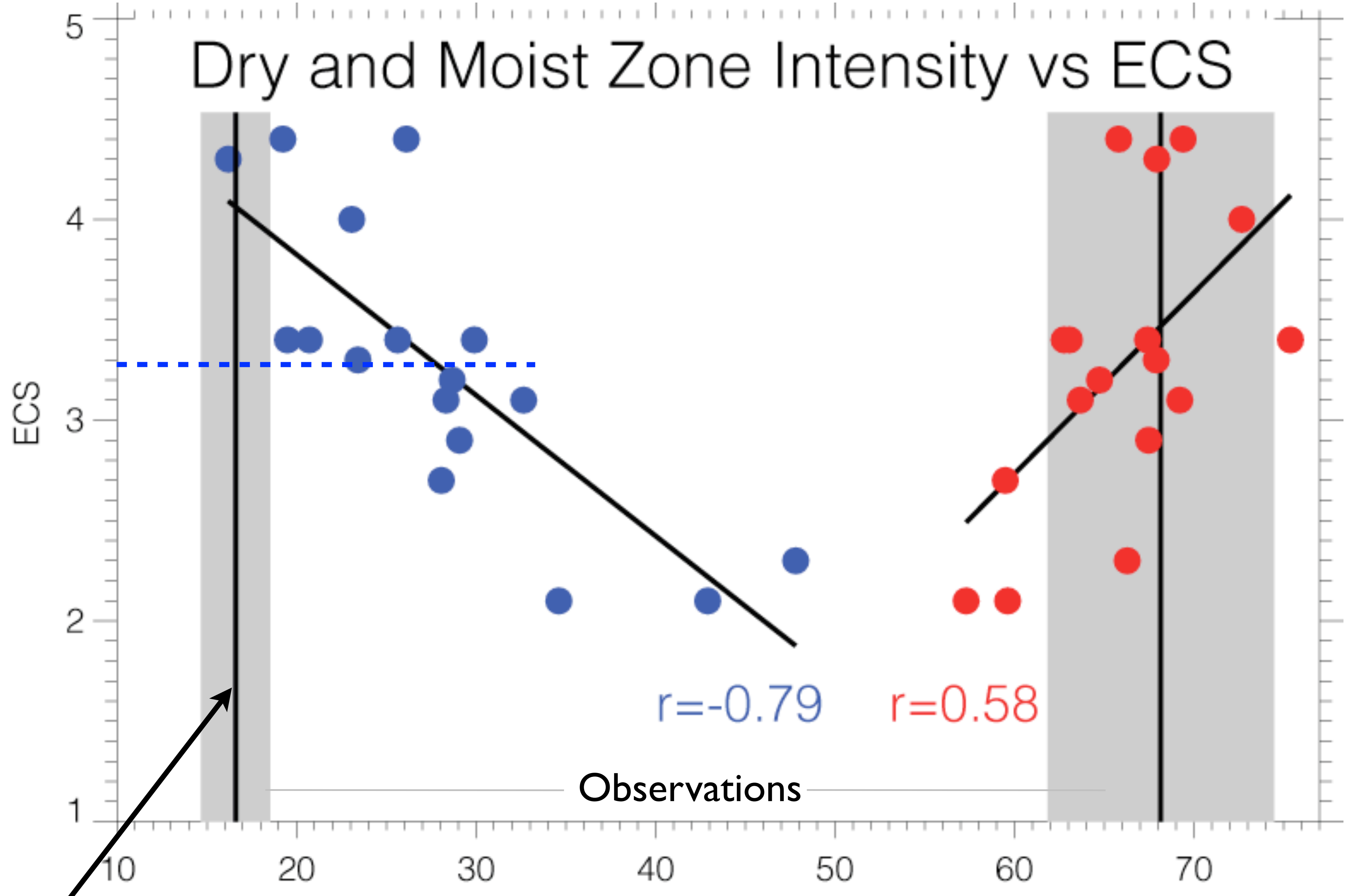
- implied strong relationship between present day dry zone and SW cloud feedback.

Zonal Structure of Correlations: 0-30S



- strong tie to subsident branch of major monsoon circulations suggested: Indian/Asian, North American/ITCZ, African - interrupted by SPCZ near the dateline.

Model Spread >> Uncertainty in Obs



- dry zone exhibits an exceptionally strong relationship with sensitivity and low observational uncertainty. Excludes models with S < 3.3.

Does this approach pass the earlier stated criteria?

- physical tie to contrasting SW feedbacks under climate change in a warming-normalized framework: **Yes, clouds are parameterized based on RH.**

- focus on processes at low latitudes where the area-integrated energy imbalance is dominant: **Yes the processes is central to the subtropical energy budget**.

- explain variance not just at a statistically significant threshold but at a large % of total variance explained: **Yes, correlation of about ~-0.8. > 50% of variance explained.**

- be physically consistent with the notion of a forced response in clouds (not coupled e.g. ENSO): **Yes, the seasonal cycle is forced by changes in solar insolation.**

To Do: Need to further document the mechanism by which this influences sensitivity. Is this process indicative of how models handle intensification of the dry zones? their poleward expansion? both? tied to low clouds?

Summary

- **Process-based analyses are likely to be key** in efforts to reduce uncertainty in climate sensitivity. Reduction of bias is not sufficient.

- **Representation of the subtropical dry zones in models is poor** yet their expansion is fundamental to cloud feedbacks and climate change.

- **Subsident teleconnections linking deep convective domains to the subtropics are likely to be central to existing dry zone biases.**

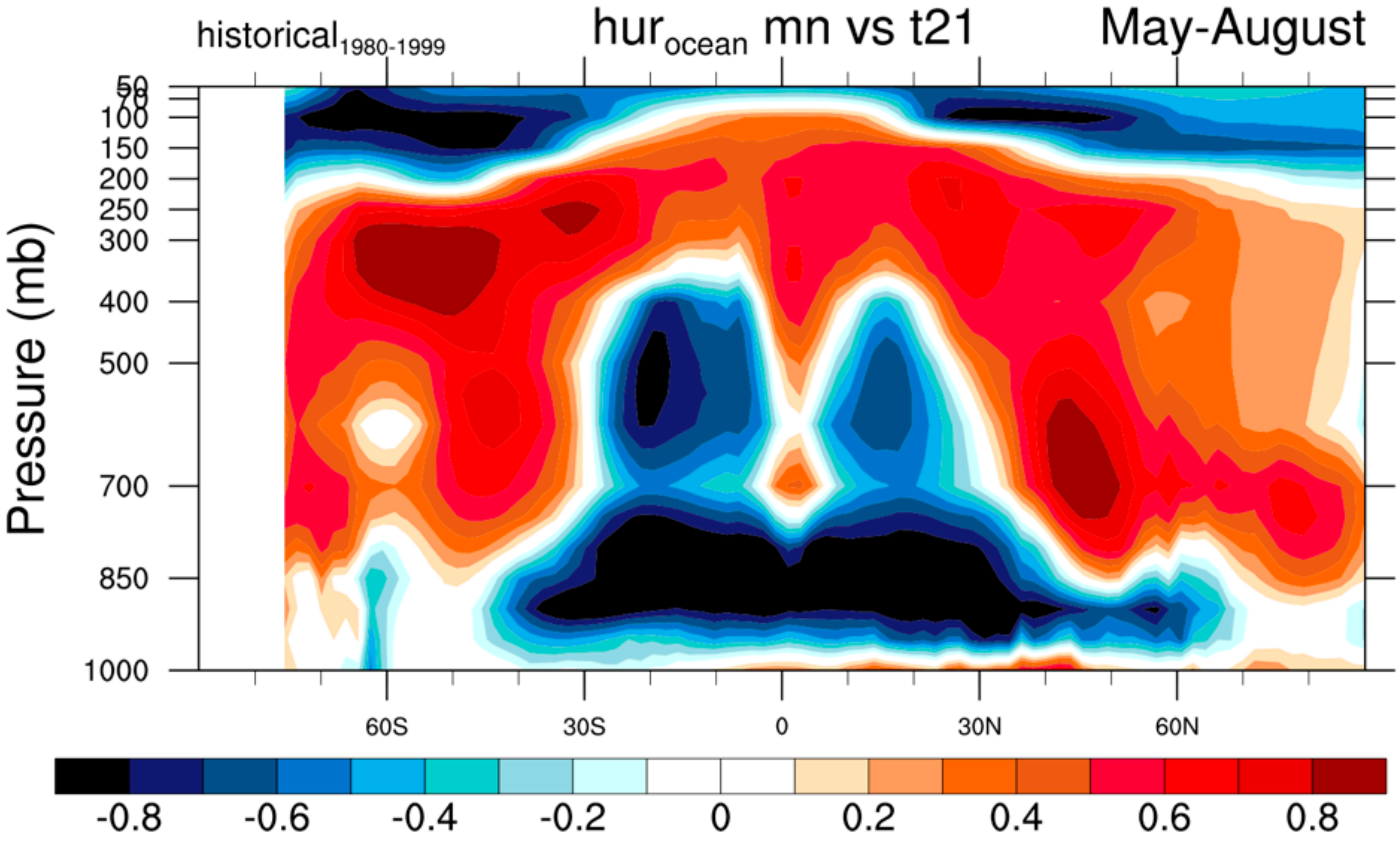
- **Seasonal dry zone intensity is strong indicator of model sensitivity** in CMIP3 and CMIP5. Observations represent a strong constraint.

- Work detailing the precise mechanisms by which current biases relate to future trends remains ongoing.

- **There is a strong and broader need to improve these aspects of models** related to climate extremes and impacts apart from the sensitivity problem.

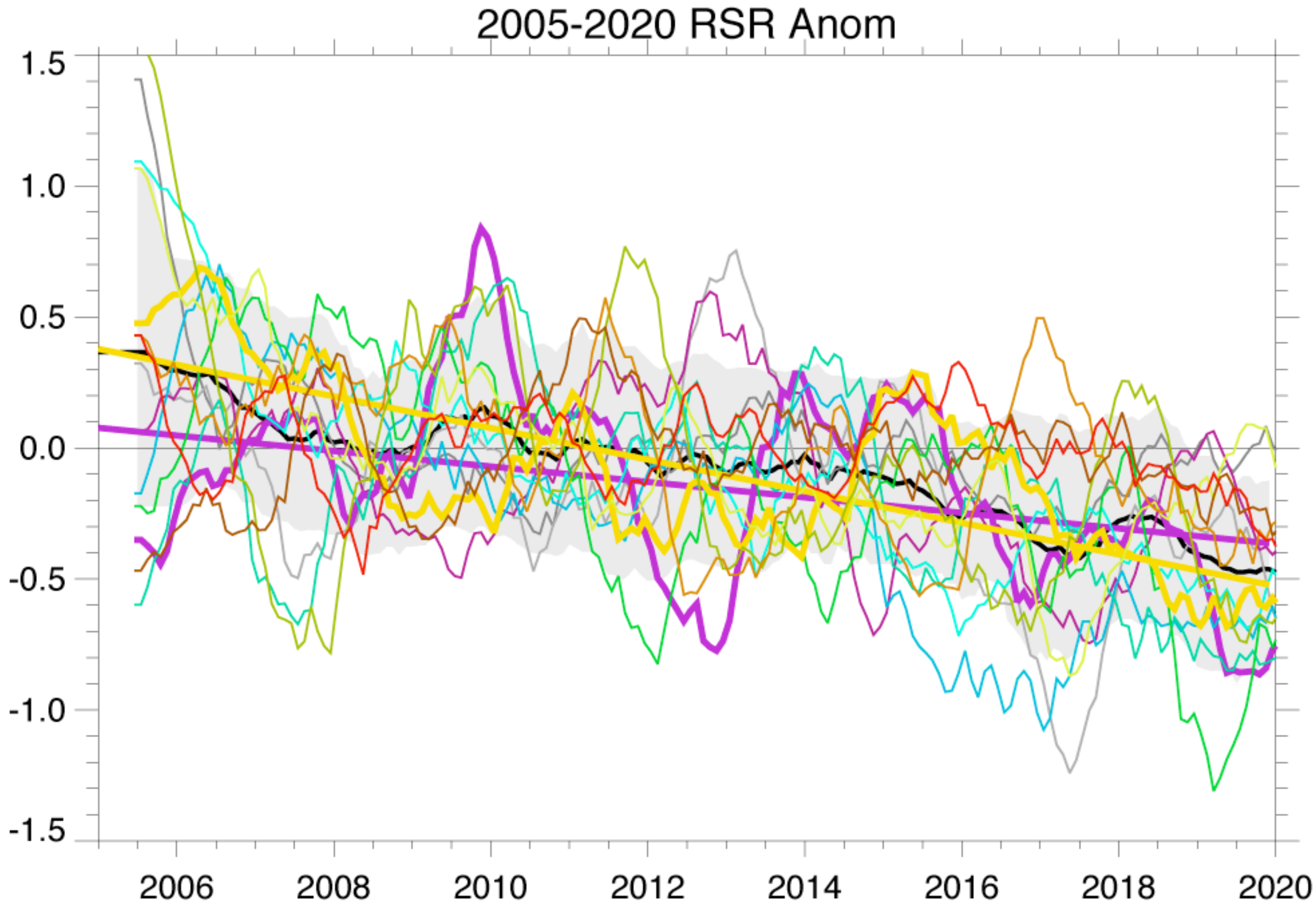
HUR vs T_{21} in CMIP5

- Similar suggested connection between deep convective and subsident domains.
- Stronger lower troposphere layer relationships.



10 models

How long a satellite record to we need to resolve the forced response from internal variability?



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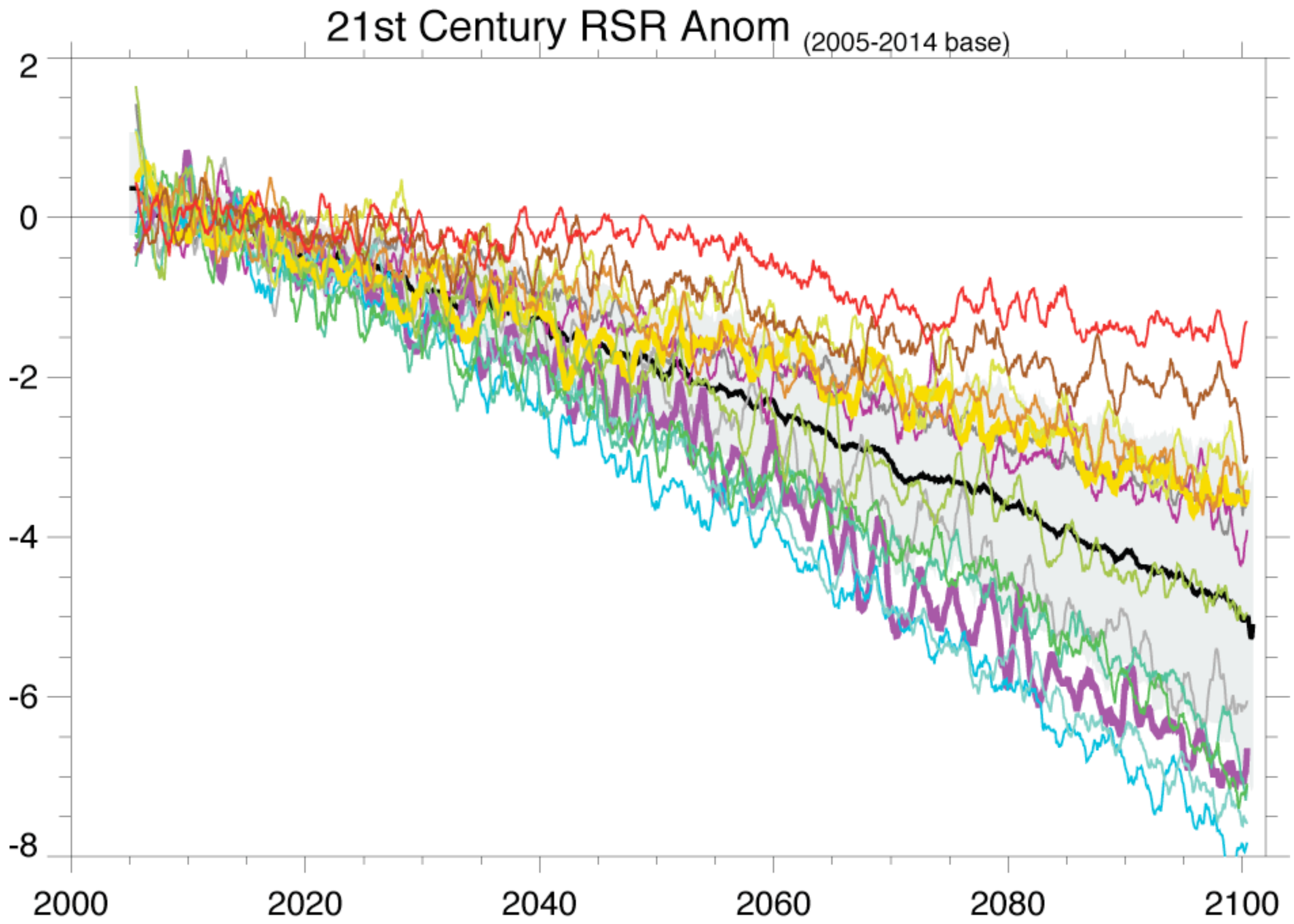
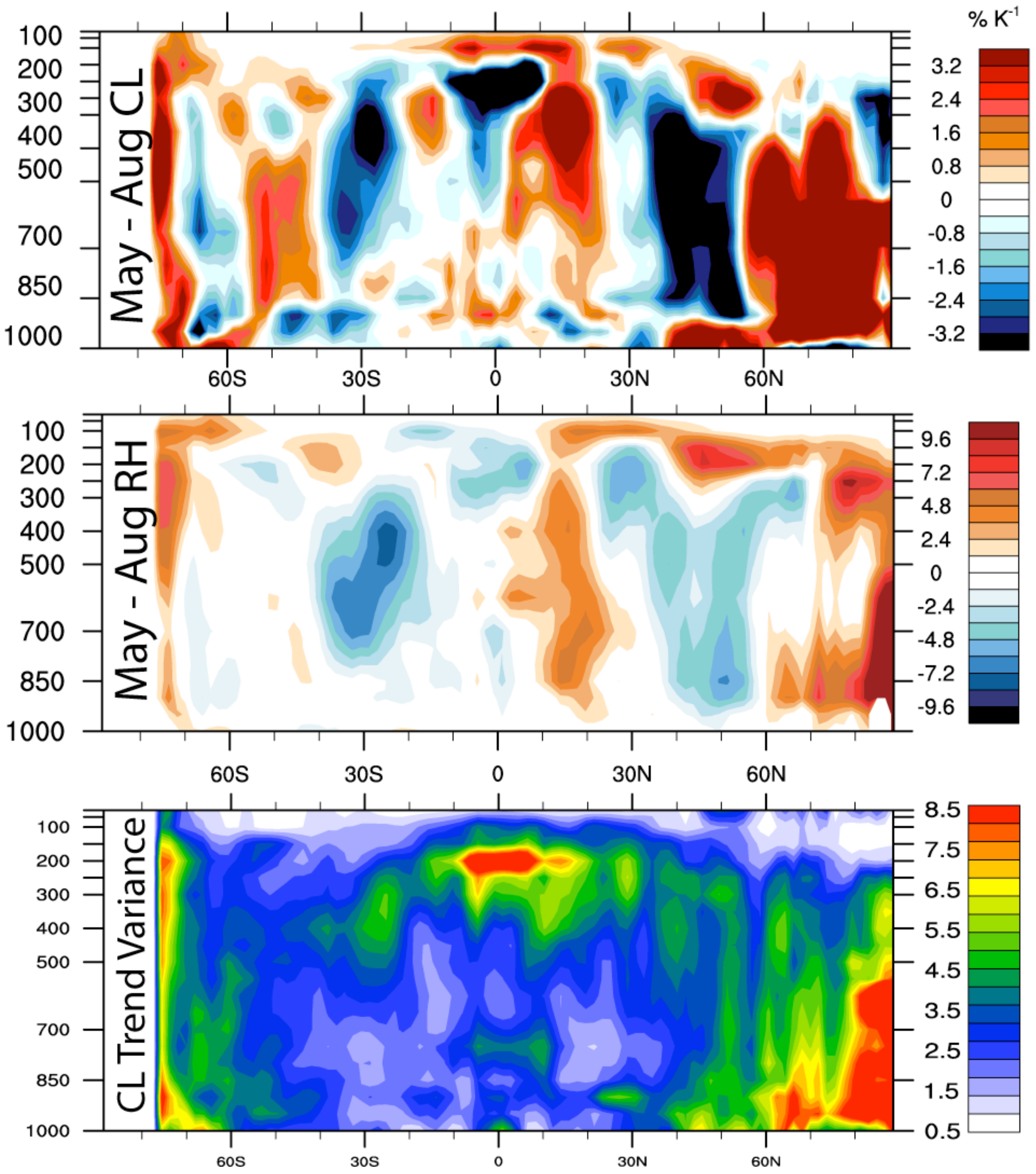
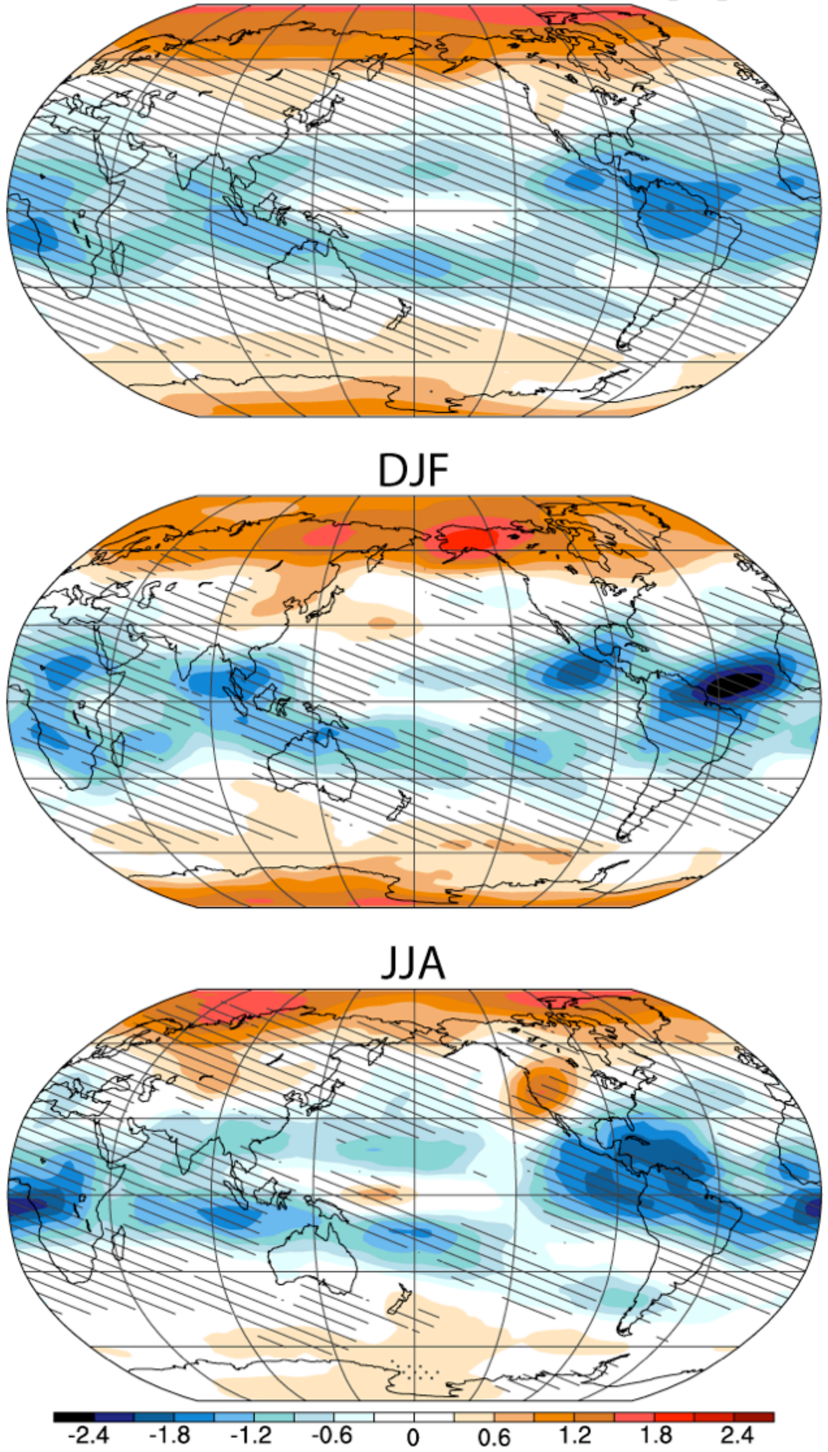


Seasonality of Trends

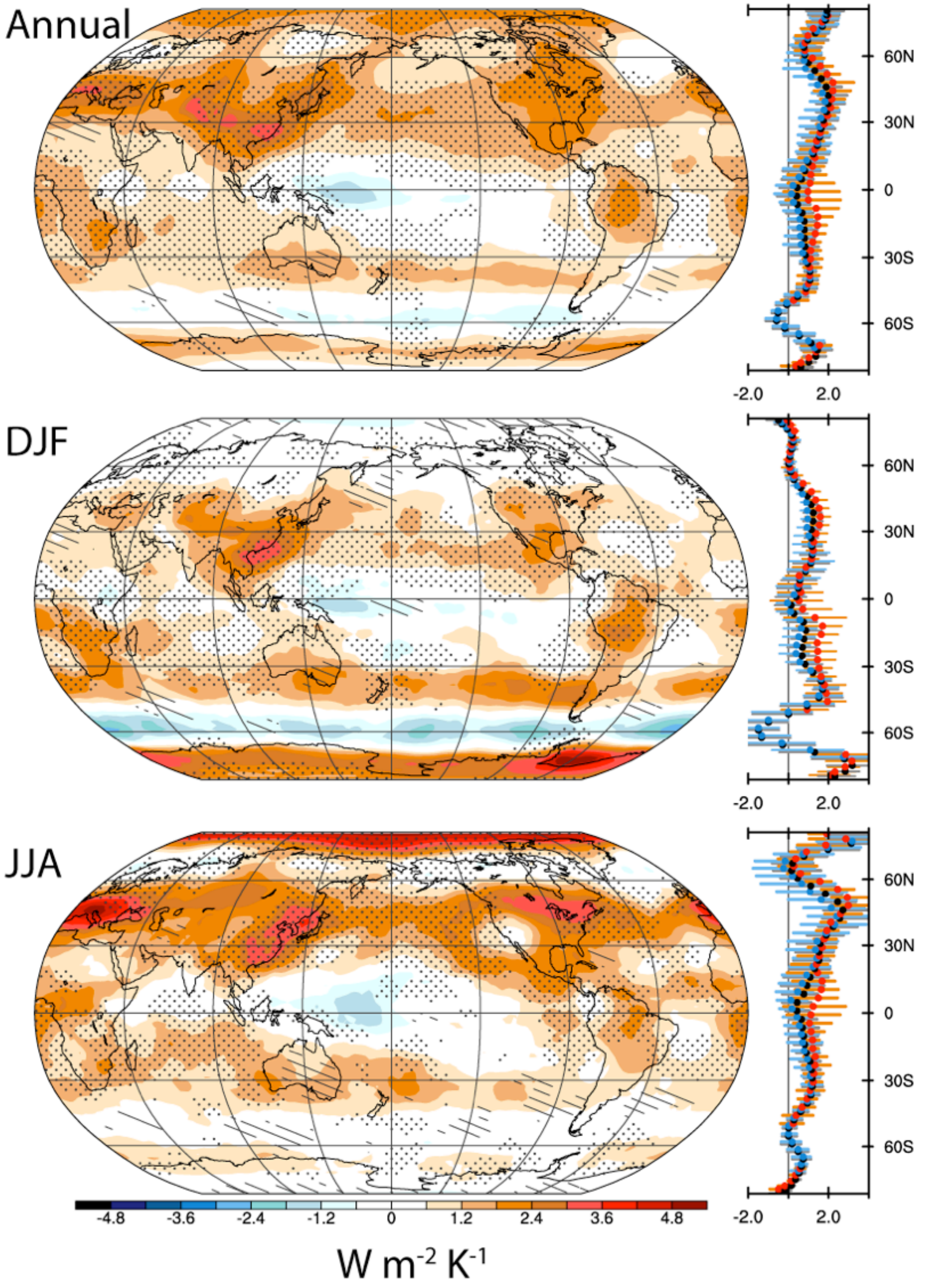

May - Aug Trends: High-Low Sensitivity Models

Trends in RH / ASR



21st Century Trend: RH 300 mb

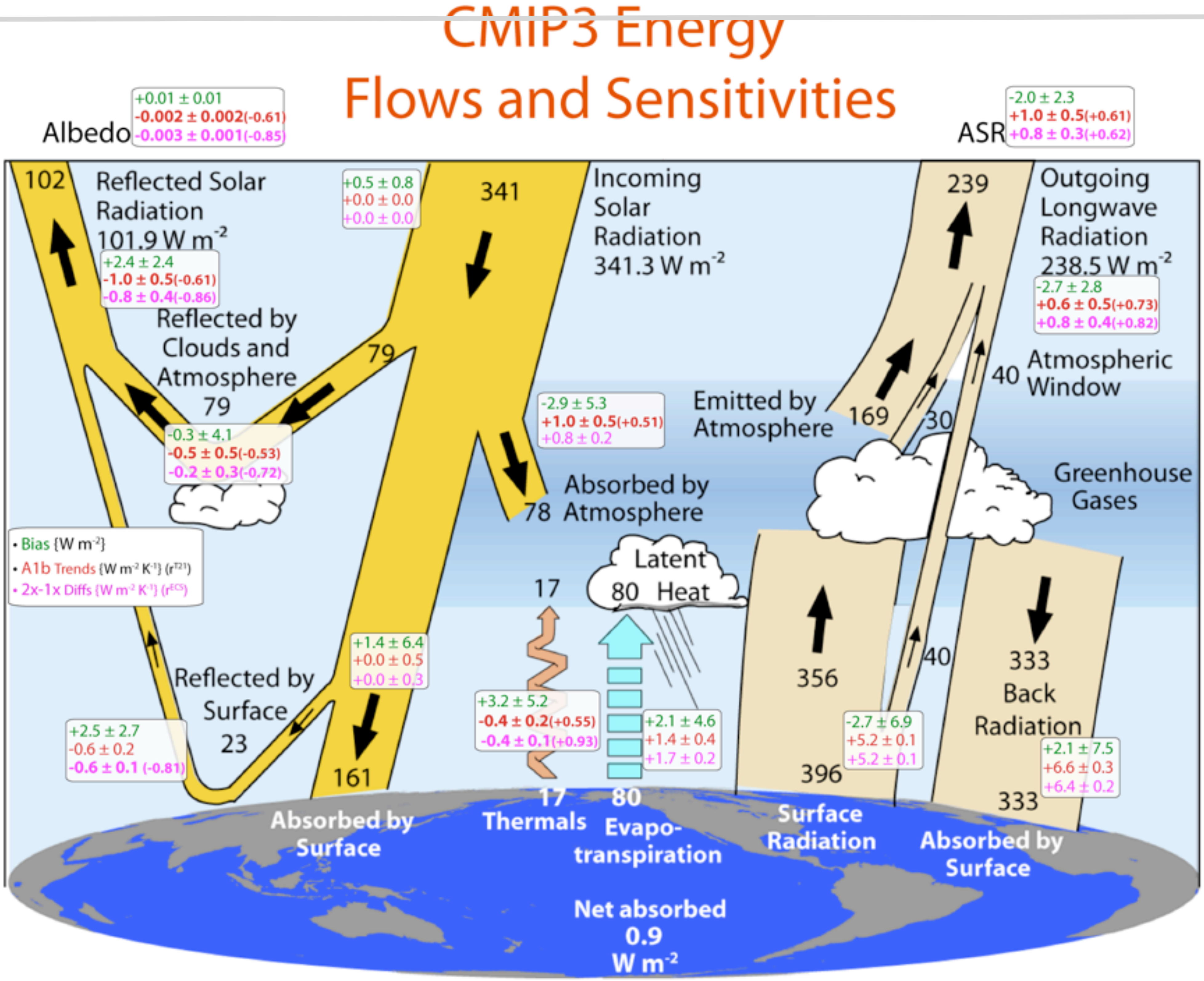
Annual Mean [%]



Absorbed Solar Radiation

21st Century Warming-Normalized Trends

But How to Select a Process? CMIP3 Biases / Trends



Latitudinal Structure of Energy Imbalance