SIMPLE TEST OF CLOUD BASED EMERGENT CONSTRAINTS FOR CLIMATE SENSITIVITY

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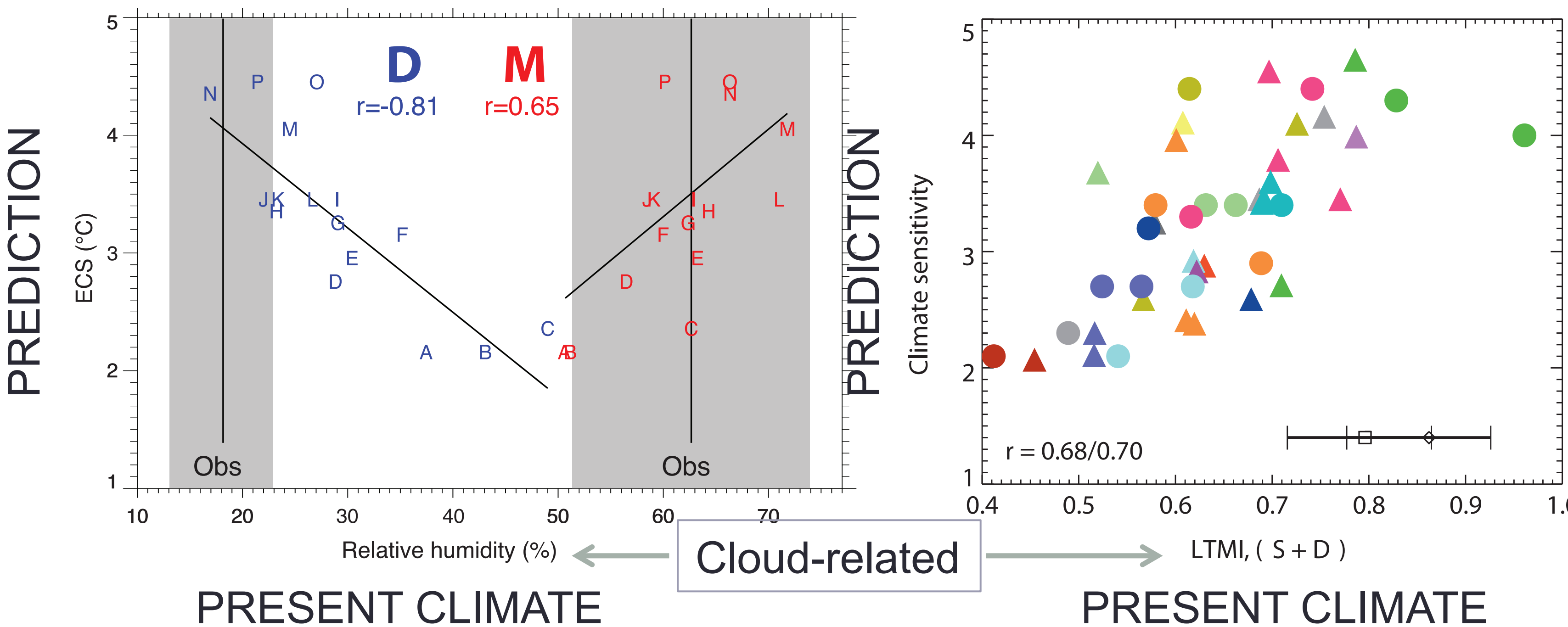
Motivation



Modified from Fasullo and Trenberth, 2012

Modified from Sherwood et al., 2014

Test

Emergent constraints should translate to other on ensembles.

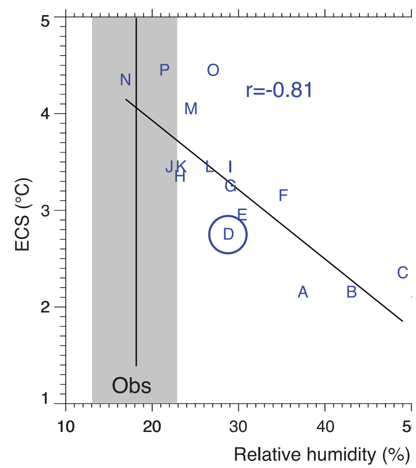
1. More or newer multi-model ensembles (MME)
   - E.g. CMIP5 applied to Fasullo and Trenberth 2012

2. Perturbed physics single model ensemble (SME)

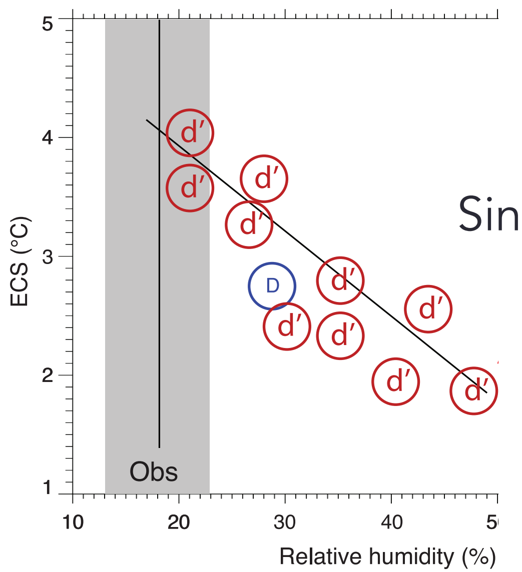
   - A different type of test than MME's: parametric, rather than structural diversity

   - We construct the sample

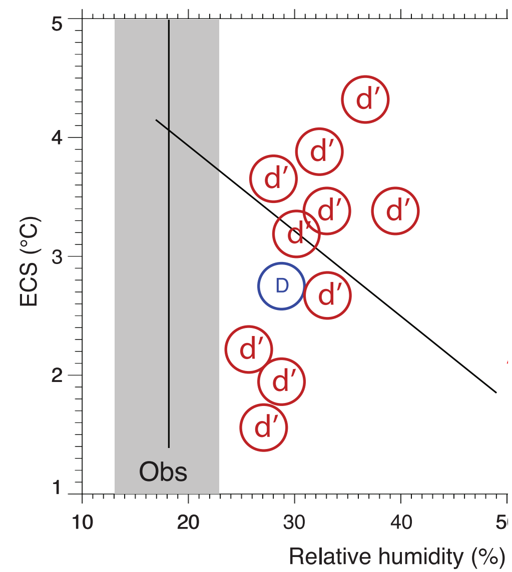
Test



Multi-model ensemble



Single model ensemble



Pass

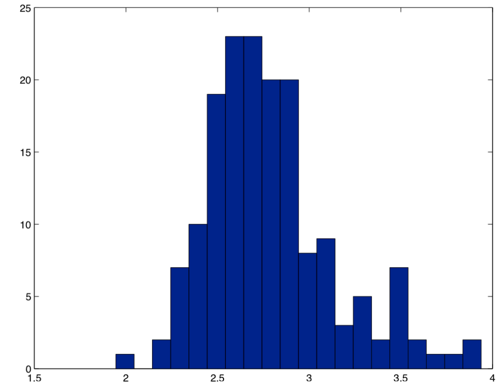
Fail

Modified from Fasullo and Trenberth, 2012

Single model ensemble details

- CAM3, 15 convection/cloud parameters perturbed
- Bayesian inference to calculate the joint posterior probability distribution for the parameters, given observations
  - 3364 4-yr simulations with prescribed SST. (update from Jackson et al., 2008)
  - VFSA Sampler accepts/rejects as it steps through parameter-space
- Interpretation: each perturbed physics member COULD have been CAM3
  - All 1800 models in posterior distribution outperform the default CAM3 according to NCAR Taylor metrics
- 165 samples of the posterior: slab ocean, climatology and 2x$C0_2$.

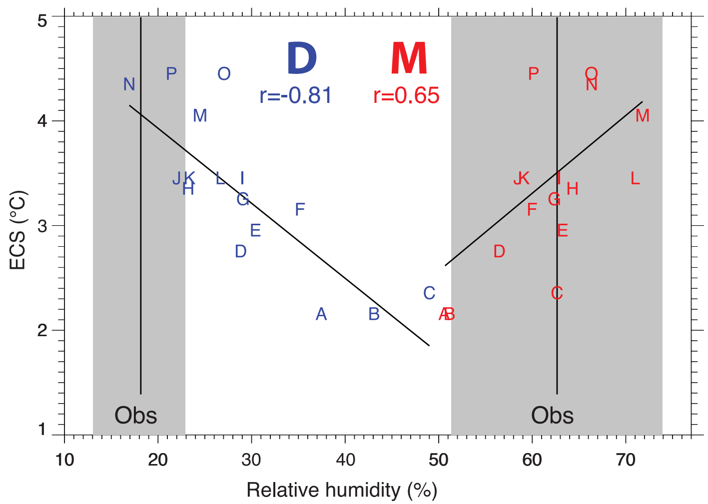
2.7



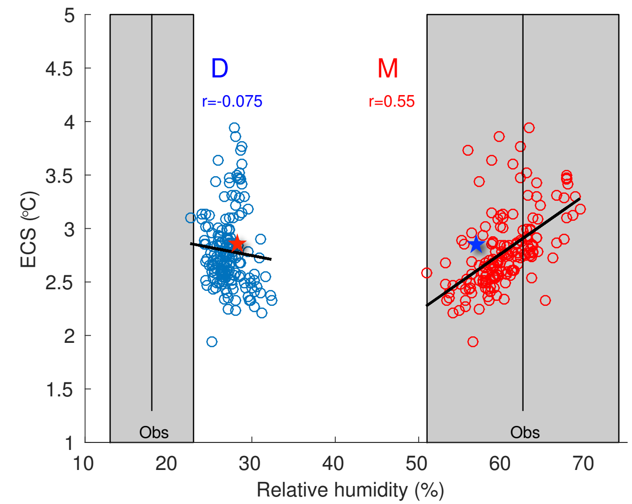
Change in Temperature

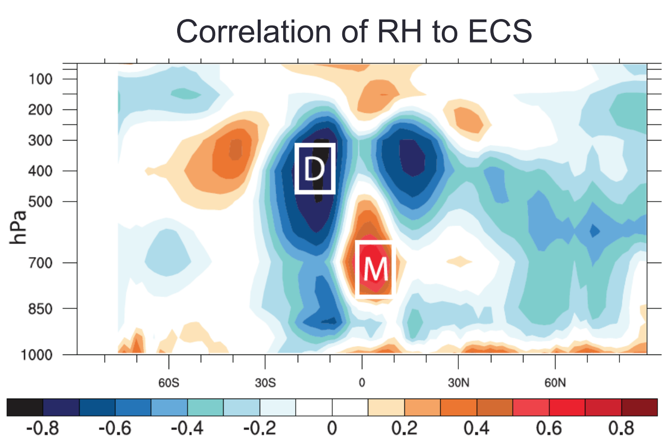
Results: Fasullo and Trenberth

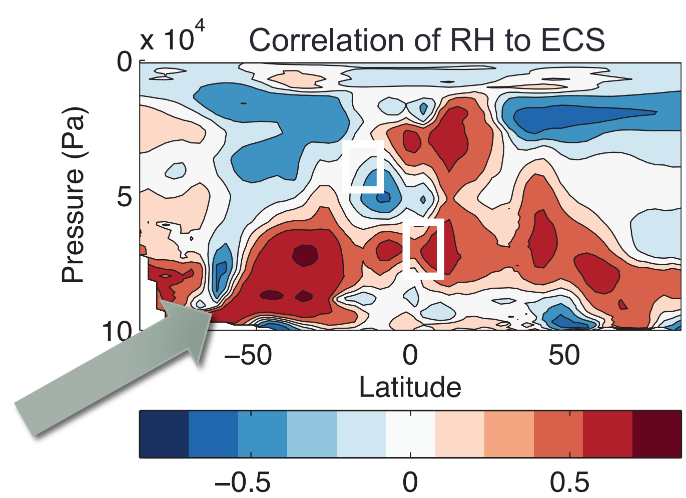
CMIP3 multi-model ensemble (Fasullo and Trenberth, 2012)



CAM 3 single model ensemble







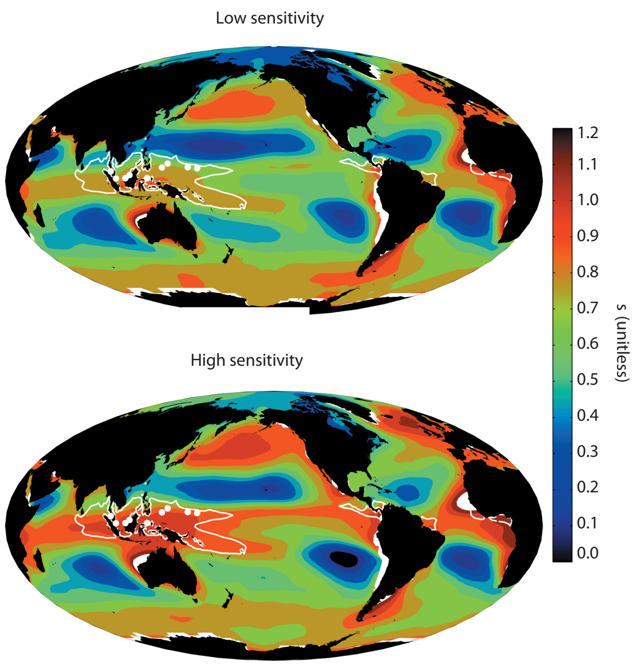
Results: Sherwood et al. LTMI

CMIP3/5 multi-model ensemble

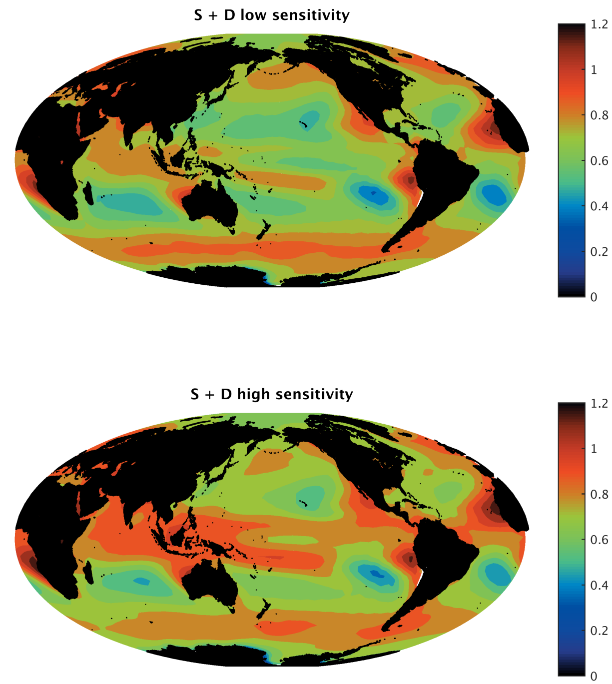
CAM 3 single model ensemble

Low sensitivity

High sensitivity



Sherwood et al., 2014

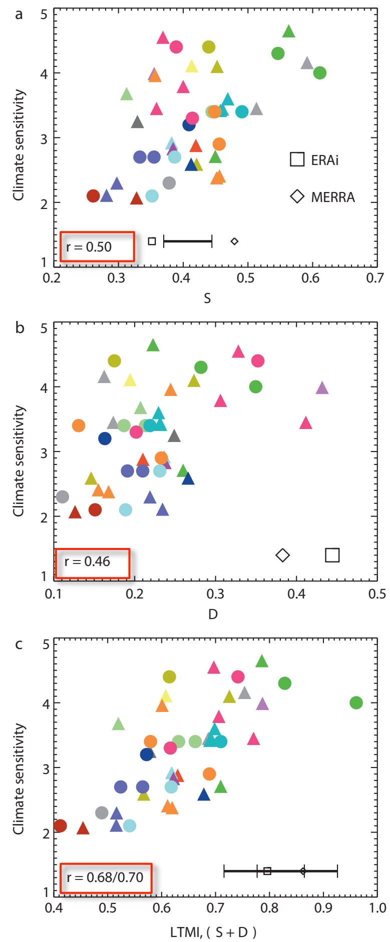


Results: Sherwood et al. continued

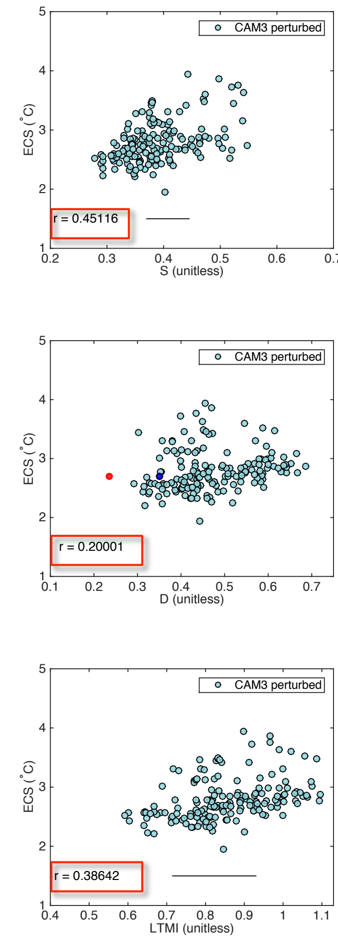
$$S \equiv \frac{\Delta R_{700-850}}{100\%} - \frac{\Delta T_{700-850}}{9^\circ K}$$

$$D \equiv \frac{\langle \Delta H(\Delta) H(-\omega_1) \rangle}{\langle -\omega_2 H(-\omega_2) \rangle}$$

$$LTMI = S + D$$



Sherwood et al., 2014



CAM3 single-model ensemble

Results

- Relationships between metric and prediction are qualitatively supported in the single model ensemble.
  - Correlations exist and are in the right direction.

Interpretation

Where does the weak signal come from?

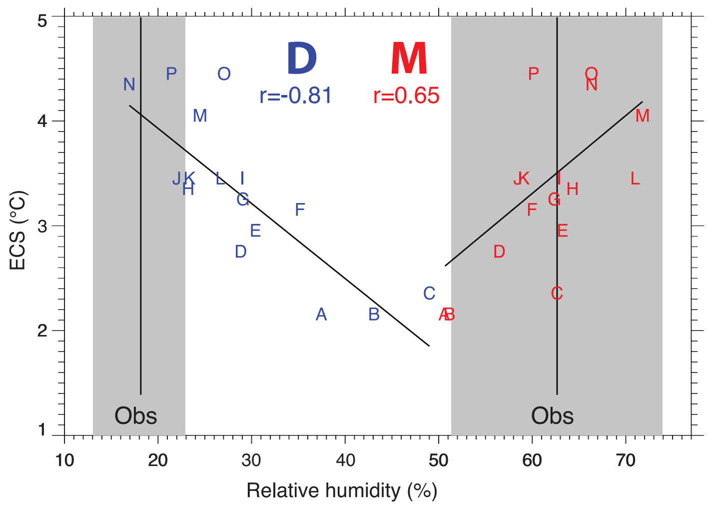
- Chance?
  No.
- Calibration encouraging nonphysical correlations ?
  Can't rule it out.

or

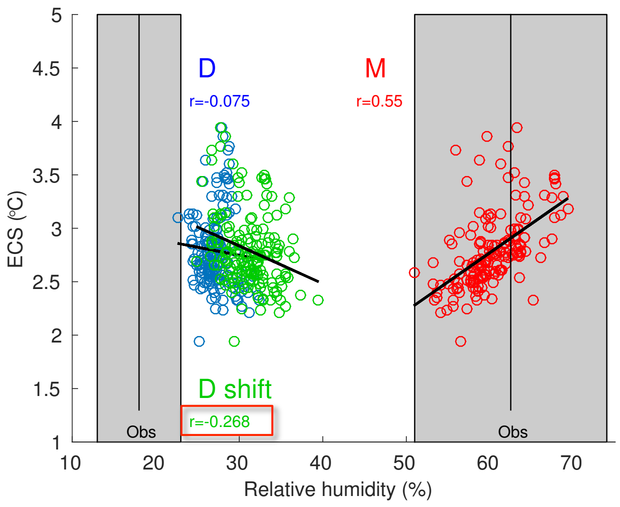
- Physical mechanisms – perhaps
  But the mechanism is not as important in CAM3

Mechanism relevance

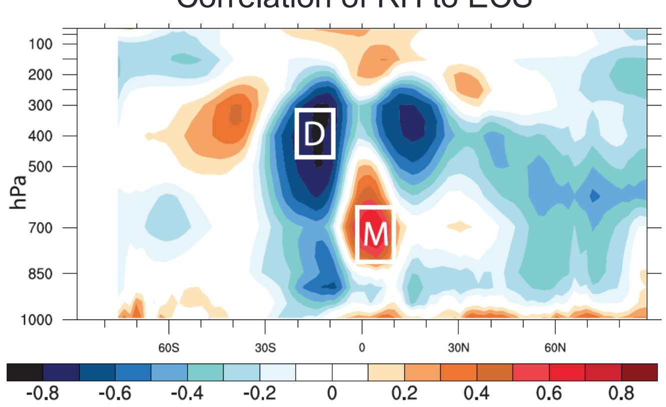
CMIP3 multi-model ensemble (Fasullo and Trenberth, 2012)

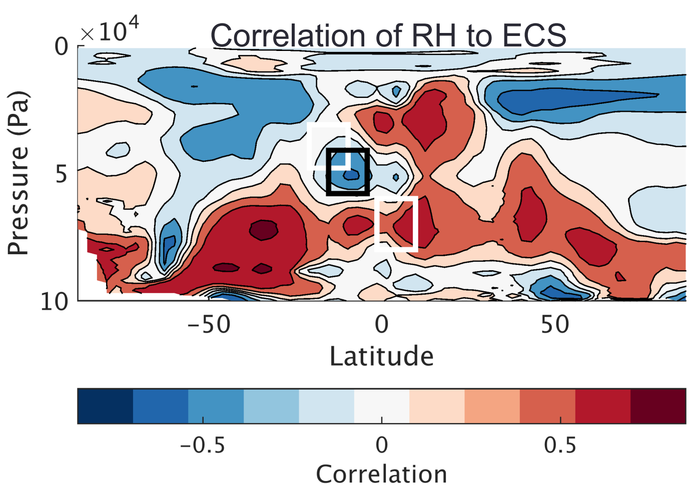


CAM 3 single model ensemble



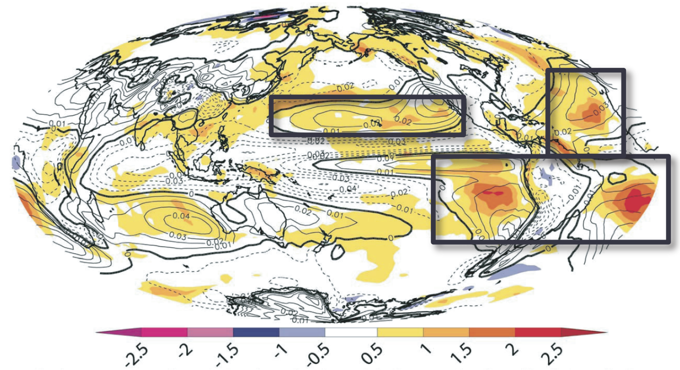
Correlation of RH to ECS





Related to CAM cloud feedbacks?

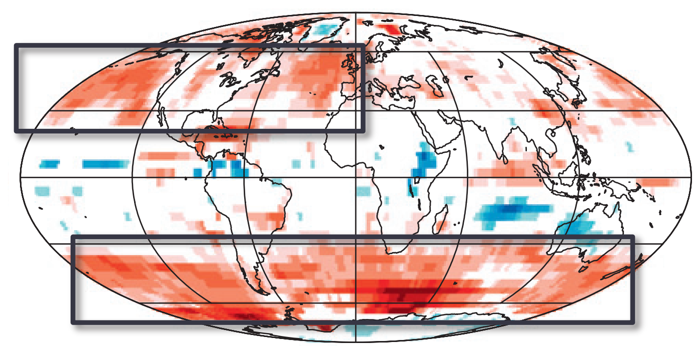
Shading: regression between local net cloud feedback at a point and global mean net cloud feedback in the CMIP3 ensemble.



Modified from Soden and Vecchi, 2011

Shading: regression between local net cloud feedback and global climate sensitivity in a perturbed physics CAM4/5 single model ensemble.
Gettelman et al., 2013

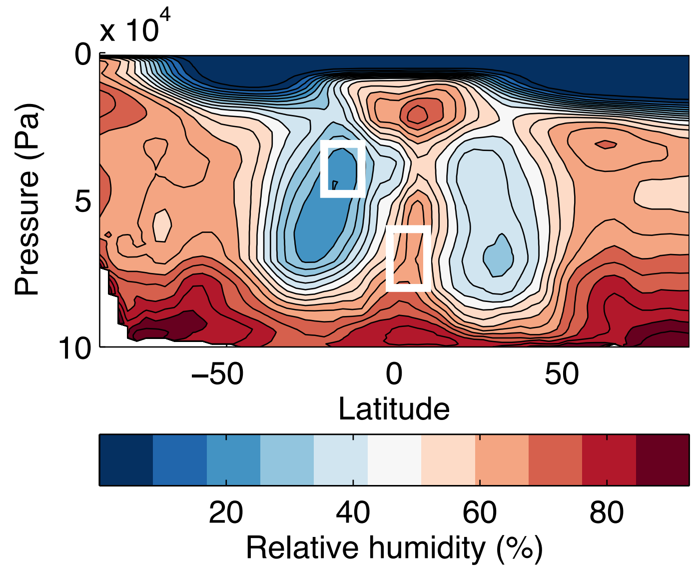
Decrease in low cloud fraction



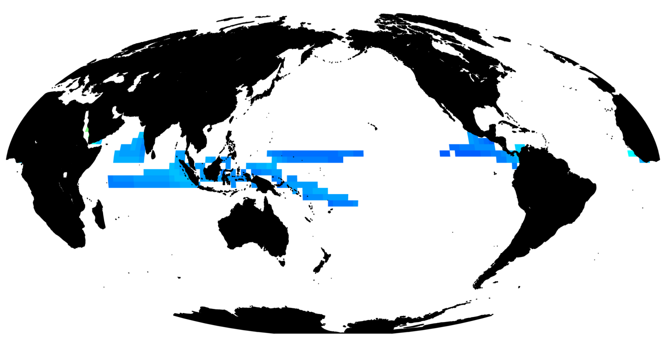
Regression Slope ($Wm^{-2}K^{-2}$)

Modified from Gettelman et al., 2013

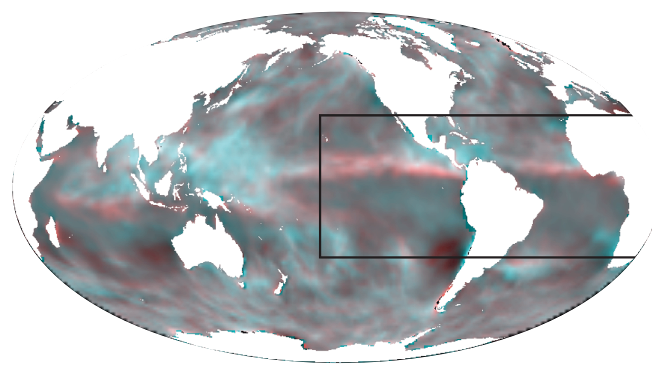
Constraint spatial domains



Fasullo and Trenberth domain



Sherwood “S” domain



Sherwood “D” domain

Modified from Sherwood et al., 2014

Discussion

- Cloud feedbacks from outside the tropics, e.g. the storm tracks, may affect global cloud feedback **independent** of cloud feedbacks in the tropics, particularly in CAM.

- Independent constraints for Independent feedbacks and their mechanisms.

References

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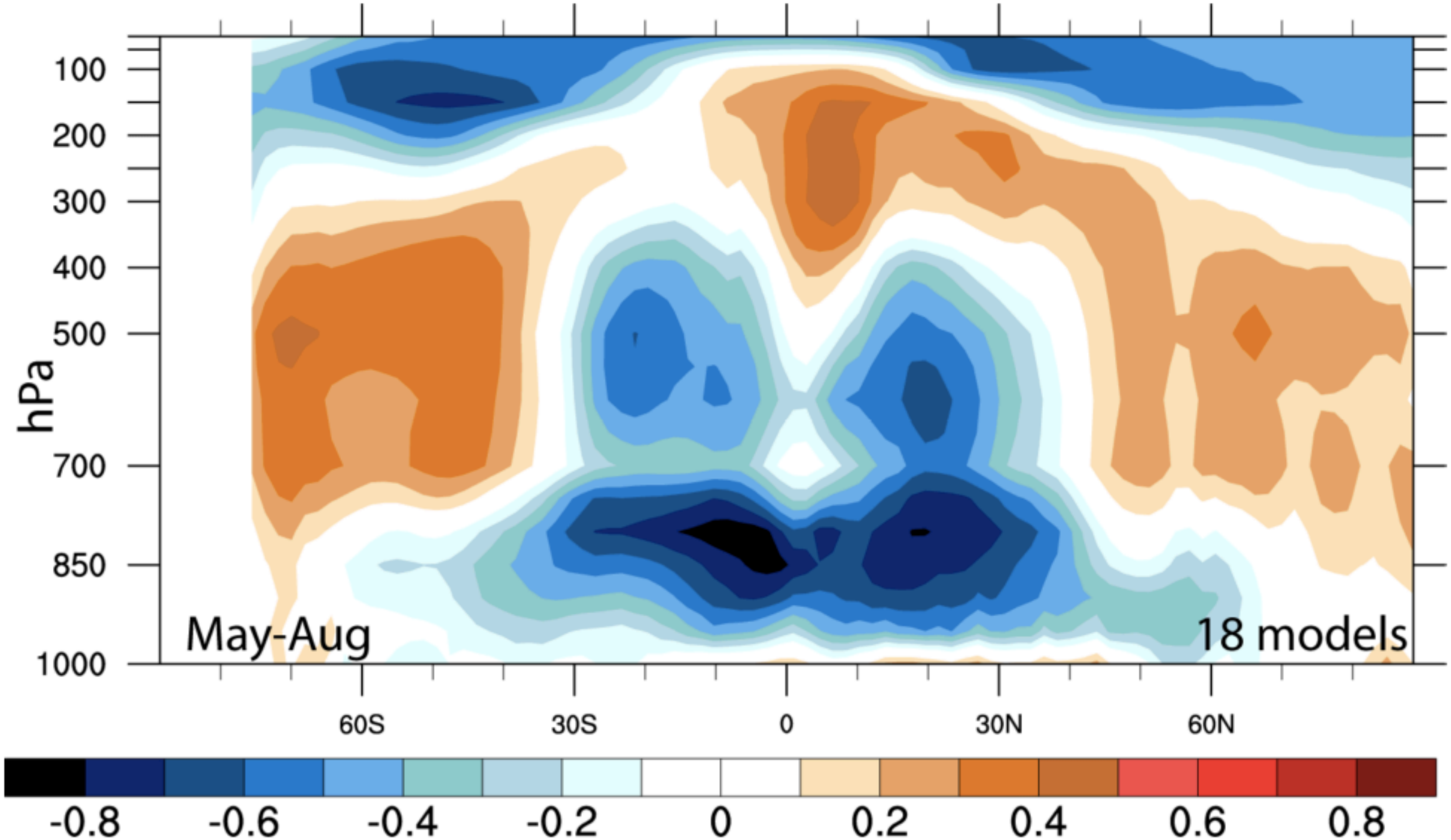

100
200
300
400
500
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850
1000
hPa
May-Aug
18 models
60S
30S
0
30N
60N
-0.8
-0.6
-0.4
-0.2
0
0.2
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0.8

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UTIG

Test

Apply emergent constraints to CAM3 single model ensemble with slab ocean and 15 perturbed cloud and convection parameters (Jackson et al., 2008).

- MCMC and a global skill metric to select 165 plausible perturbed models
- Control (present day climate)
- 2x$C0_2$ to equilibrium
  - ECS from 1.95°C to 3.94°C, mean 2.79°C

Future work

1. Calculate cloud feedbacks in CAM5-SOM single model ensemble.

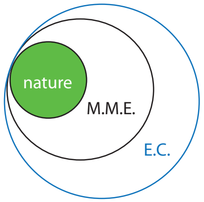
2. Calculate a covariance matrix of shortwave cloud feedbacks populated by both the single model ensemble and CMIP5.

3. Where different regimes of feedbacks covary, investigate a constraint.

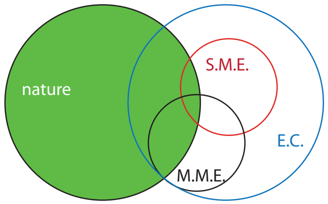
4. Individual constraints for the leading EOF's of cloud feedback.
   - Correlation is a start. A physical mechanism is a must (Caldwell et al., 2014).

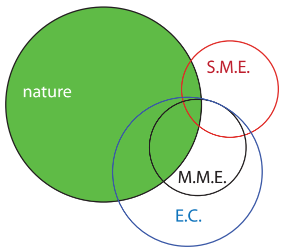
Constraints and model diversity

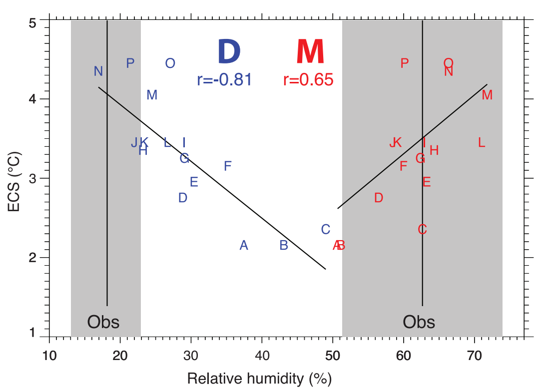
- Philosophy of the proposed emergent constraints is that nature is “contained” within the multi-model ensemble.



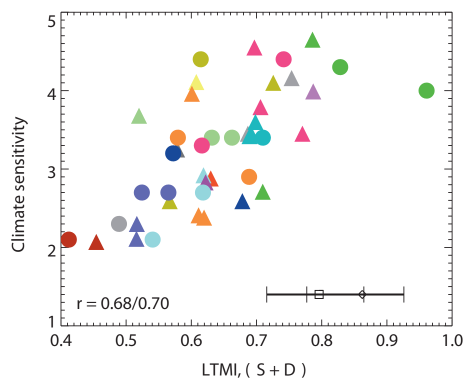
- Instead, ensembles could be a subset of nature, and the proposed emergent constraints may only apply over that subset.







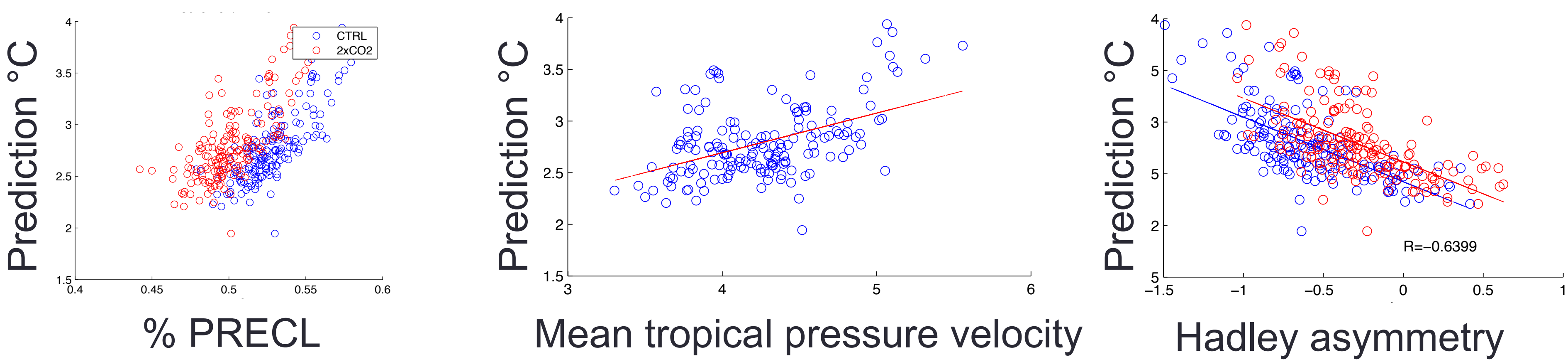
Modified from Fasullo and Trenberth, 2012



Modified from Sherwood et al., 2014

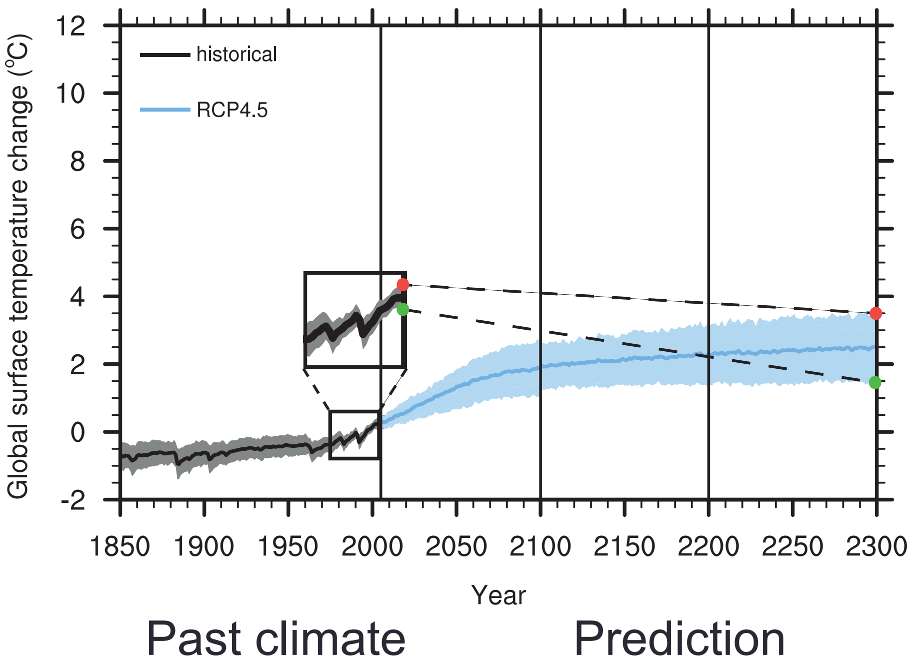
Caution: correlations abound

- Correlations between the base state and climate sensitivity are abundant.
  - Caldwell et al., 2014 data mine 40,000 in CMIP5
- Rather than emergent constraints, these relationships could reflect
  - structural similarity
  - shared biases between models
  - interconnectivity of climate processes, e.g. sea ice
- Misinterpreting a correlation as an emergent constraint could misguide model development, observational campaigns, and assessment of uncertainty in prediction.



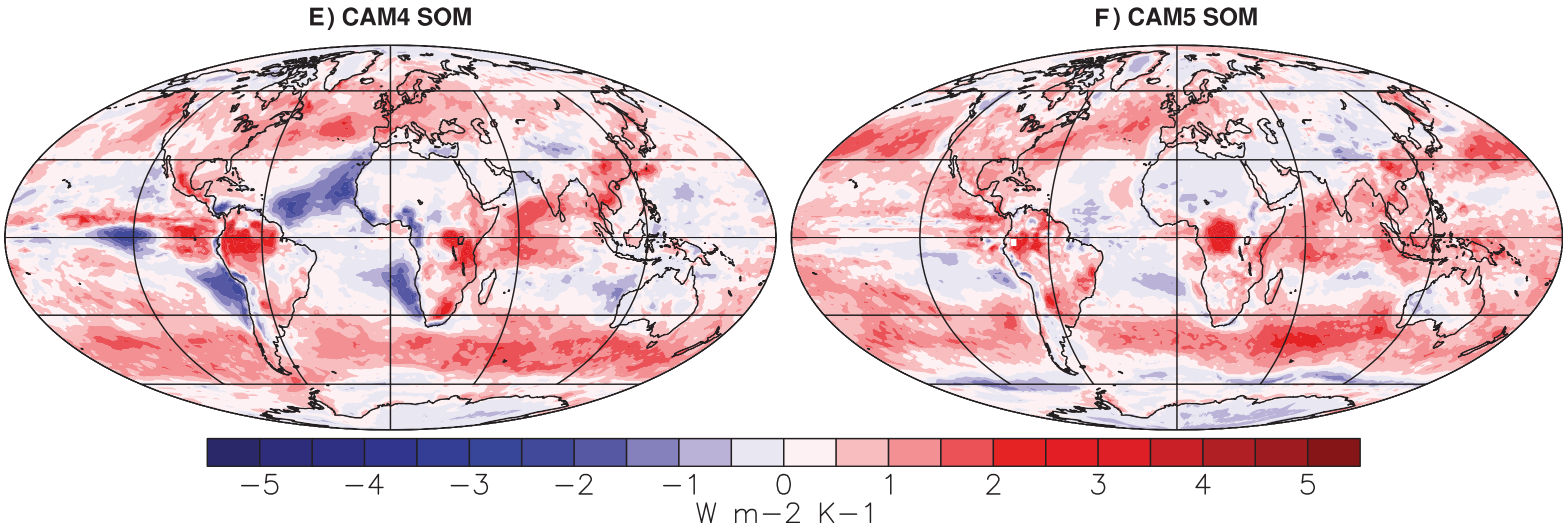
Why do we need an emergent constraint?

- "Global skill" metrics of past and present performance are unrelated to prediction of climate sensitivity.
- Predictions of the future (e.g. climate sensitivity) cannot be evaluated or weighted.
- Modelers do not know which biases to work on, and observationalists do not know what data to collect to improve prediction--besides "everything."



Modified from Collins et al., 2013

CAM4/5 NET CLOUD FEEDBACK

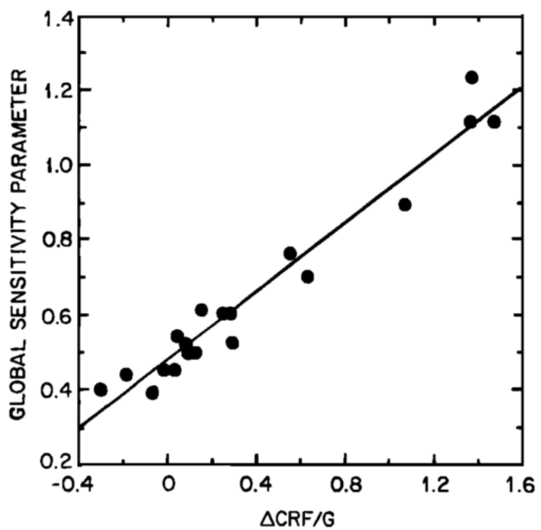


Gettelman et al., 2012

Modeling Details

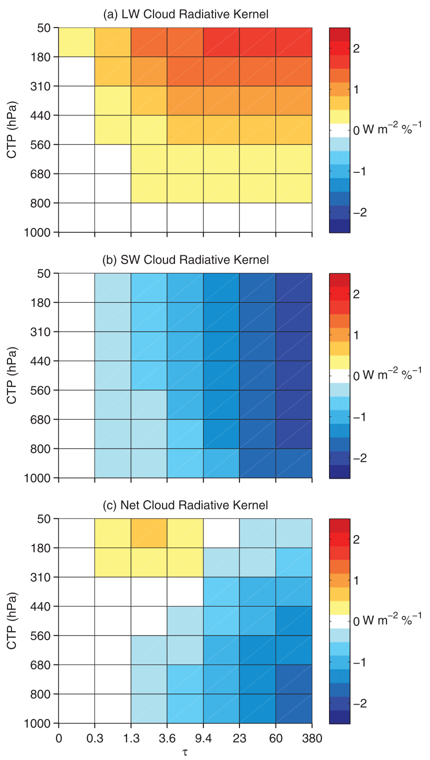
- Single model ensemble
  - CAM5-SE (Community Atmosphere Model 5, Spectral Element) ne30 resolution
  - Slab ocean
  - Cloud simulator
  - 5+ perturbed parameters
  - Steps:
    1. Short calibration runs (screening perturbed models)
       - 10-year integrations, present day forcing (10 years for slab ocean adjustment)
       - Compare to observations
       - Adjust parameters according to likelihood (MECS)
    2. Forward runs for climatology
       - Subset of 20 calibrated runs
       - Restart where calibration left off; integrate to year 60 with present day forcing to establish climatology (years 20-50)
    3. 2xCO_2 runs
       - Instantaneous doubling of CO_2
       - Integrate 60 years; climatology from years 30-60
- Cloud feedback calculation
  - Kernel (Zelinka et al., 2012)
- Ensemble control during calibration
  - MECS (Multiple Ensemble Control System)
- Supercomputer
  - Stampede at TACC (Texas Advanced Computing Center)

Cloud feedback dominates radiative changes



19 GCM's:
K m^2 W^{-1} vs. ΔCRF G^{-1}

Cess et al., 1990



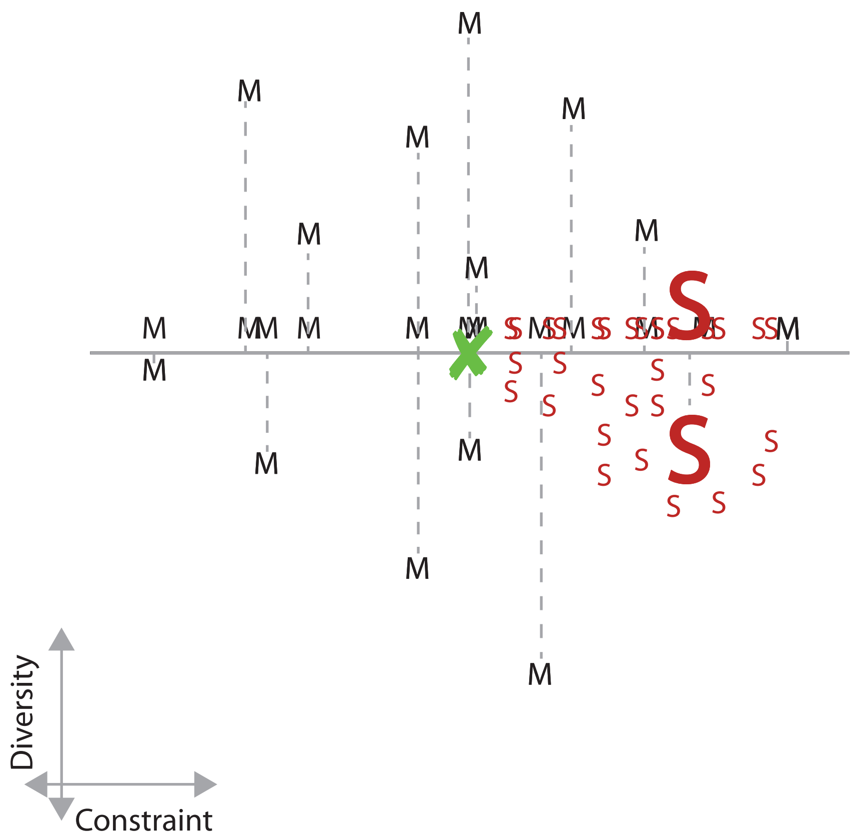
Zelinka et al., 2012

Appendix – Previous work

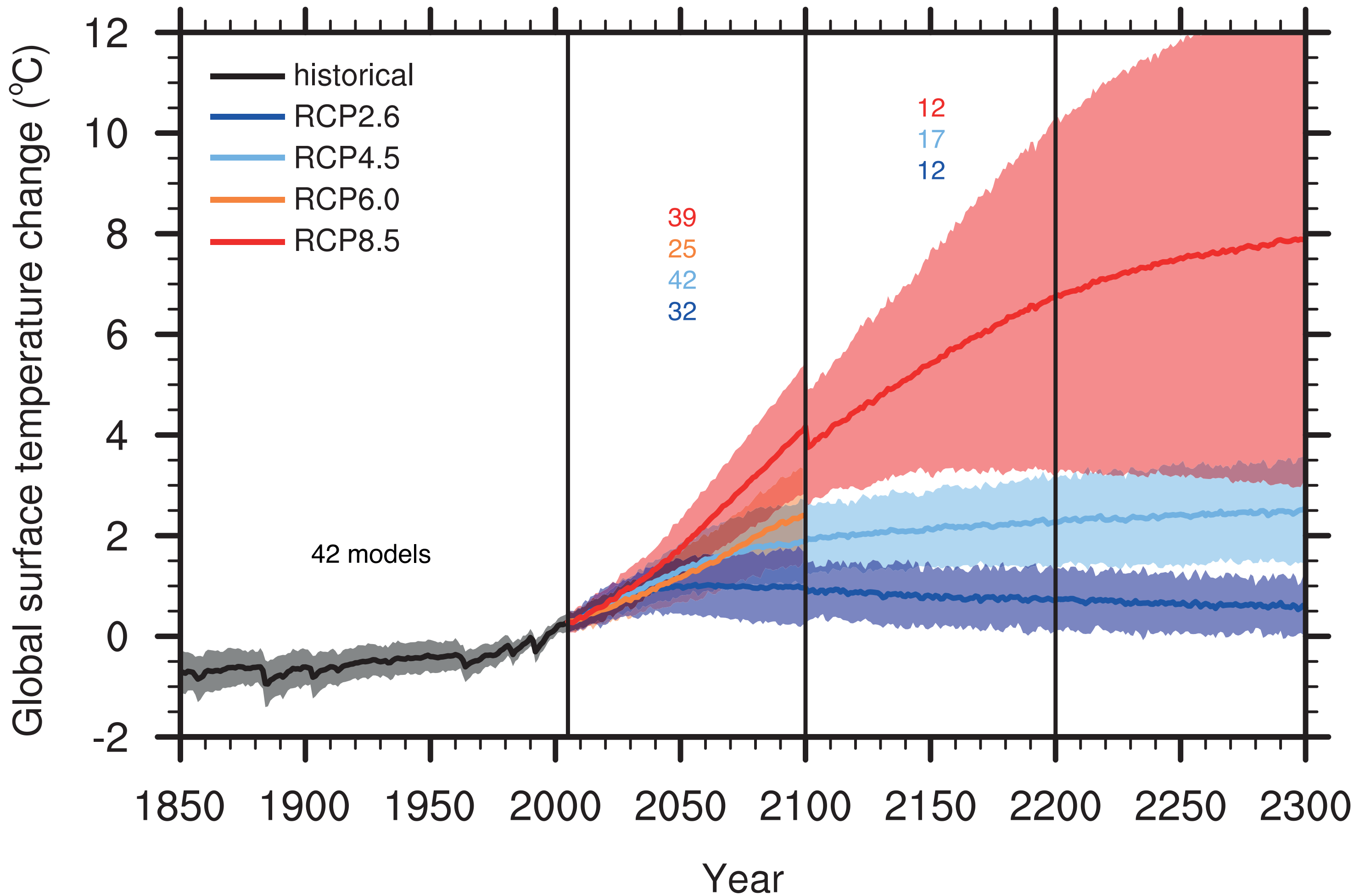
- LLNL ensemble (no radiative balance but lots of params in CAM3,4)
- KLOCKE

Test

How can we test emergent constraints?

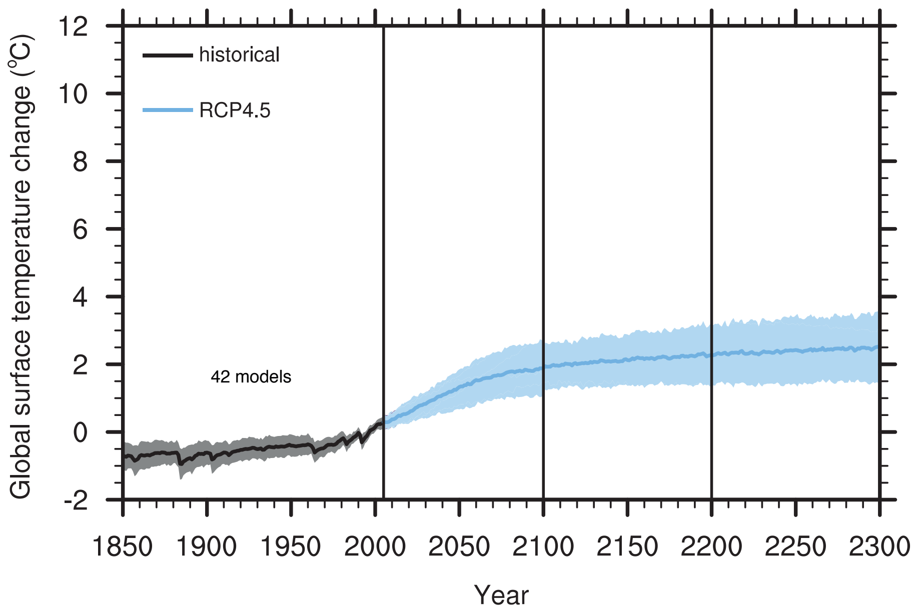


Problem: How sensitive is the climate?



Collins et al., 2013

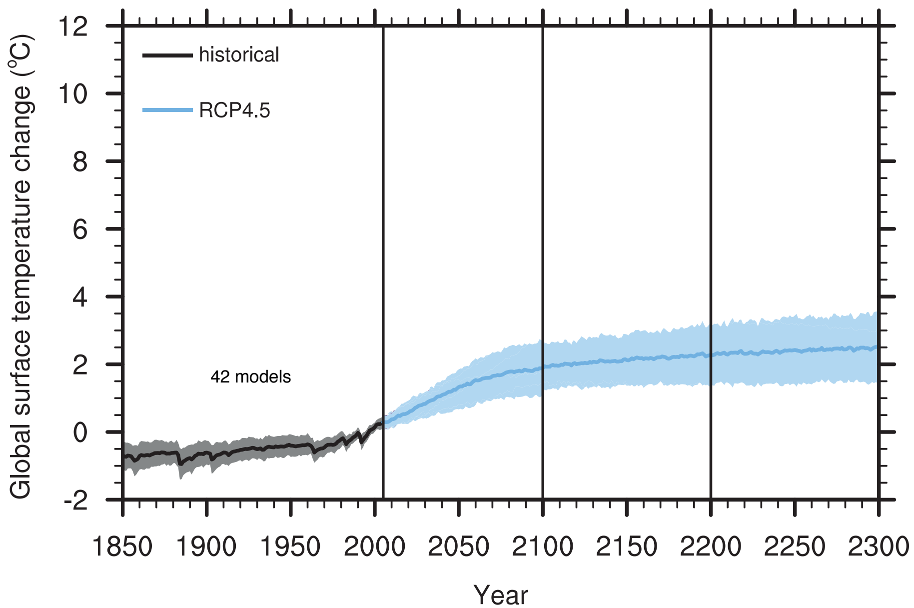
Model predictive spread: causes



Modified from Collins et al., 2013

- For a given forcing:
  - Structural differences between different models
  - Parametric differences between models
  - Natural variability
- Compensating structural and parametric errors exist in past and present due to tuning; errors compensate differently in prediction.

Predictive spread: interpretation



Modified from Collins et al., 2013

- For a given forcing, spread is used as a proxy for the uncertainty of the climate response.
- Different cloud feedbacks between models account for a large portion of this spread.

Appendix: Single model ensemble calibration

- CAM5 with perturbed convection/cloud parameters
- Unique calibration
- Gaussian Markov Random Field (GMRF)
  - Accounts for field and space dependencies when scaling the difference between model and data

$$\mathbf{C}^{-1} \approx \mathbf{S}^{-1} \bigotimes (\alpha\mathbf{I} + (1-\alpha)\mathbf{Q}).$$

$$\log p(\mathbf{d}|\mathbf{m}) = [\mathbf{d}-\mathbf{m}]^T \mathbf{C}^{-1} [\mathbf{d}-\mathbf{m}]$$

- S= spatially averaged grid point covariance between observed fields
- Q=precision matrix, representing spatial covariance within observed fields

- Current and previous generations of CAM have unique cloud feedbacks.

Appendix

$$ppd(m \mid d) = \frac{p(m)p(d \mid m)}{\int p(m)p(d \mid m)dm}.$$