The Role of Atmosphere Feedbacks During ENSO in the CMIP3 Models

+ IPSL-CM5A!

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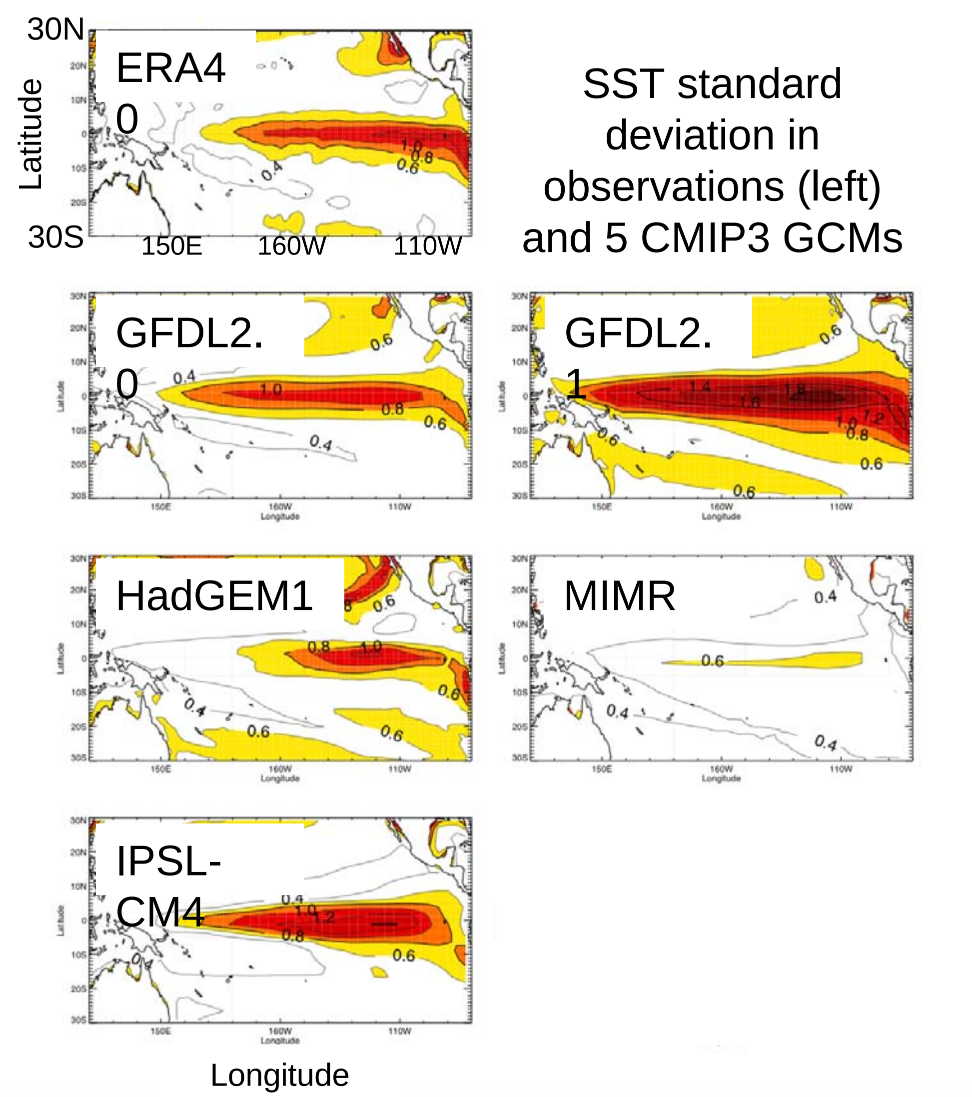
The Coming Storm – Winslow Homer (1901)

ENSO in present-day GCMs

- ENSO representation differs from model to model.
- No current model captures all ENSO features (i.e. period, amplitude, spatial structure).
- ENSO is overly weak in IPSL-CM5A



ENSO in GCMs: The Role of the Atmosphere

- Historically, ENSO has been an oceanographer's problem.

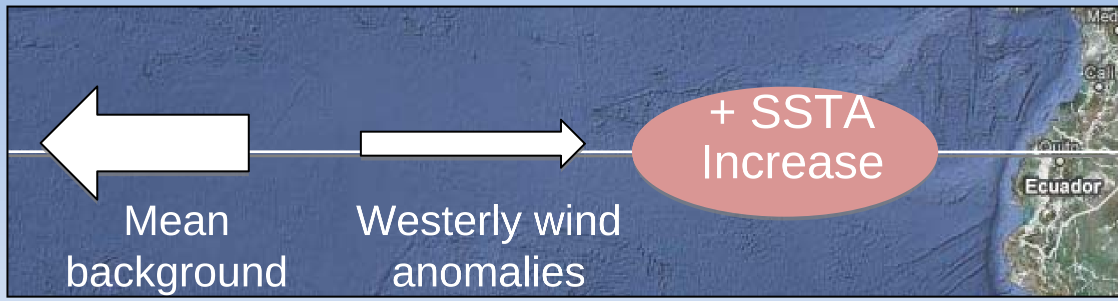
- But many recent GCM studies suggest that the atmosphere component plays a dominant role in determining ENSO properties (e.g. 'systematic modular approach': Guilyardi et al., 2004, Schneider et al., 2003)

- Altering the convection scheme has been found to have a large impact on ENSO (Kim et al., 2008, Neale et al., 2008, Wu et al., 2007, Guilyardi et al., 2009).

The μ (Bjerknes) positive feedback

Dynamical coupling between remote winds and SST

Equator

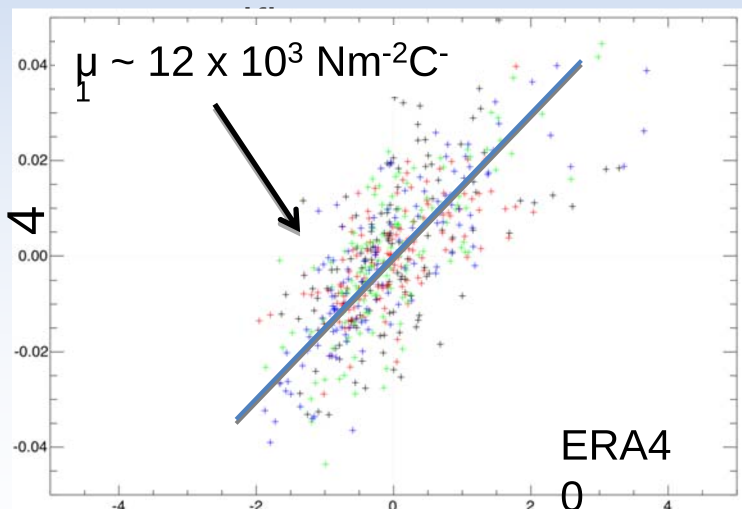


Central Pacific

East

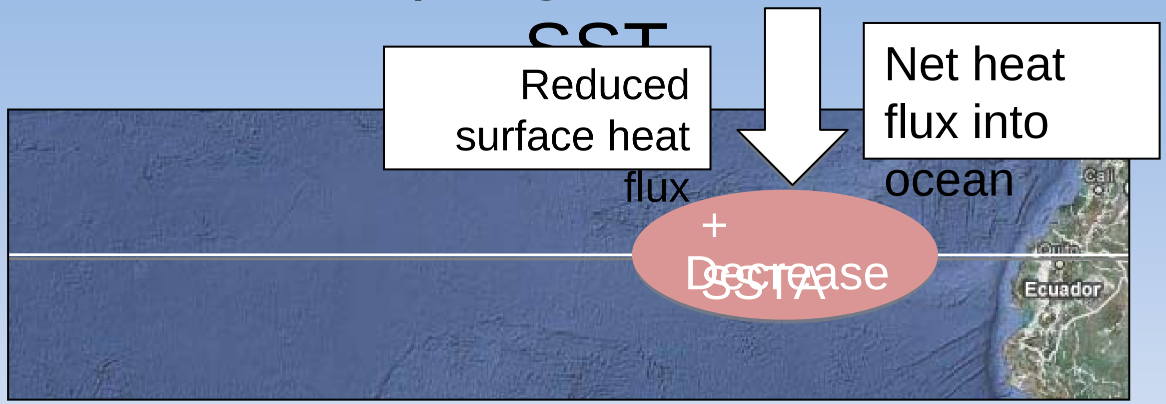
$\tau_x' = \mu SST'$

Calculate by regressing zonal surface wind stress anomaly (τ_x') against Niño 3 SST anomaly (SST') and average over Niño 4



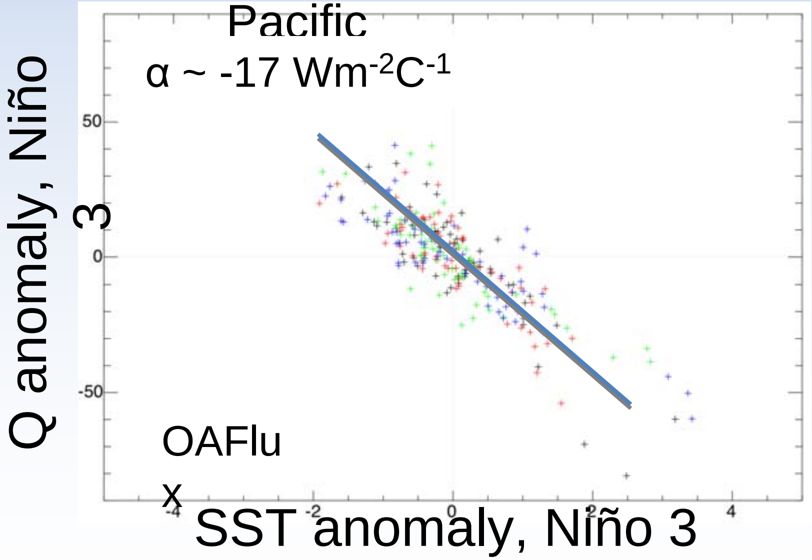
The α negative heat flux feedback

Thermodynamical coupling between net heat flux and SST



$Q' = \alpha SST'$

Calculate by regressing heat flux anomaly against local SST anomaly and average over Niño 3



Models and observations

- 12 'Coupled Model Intercomparison Project 3' (CMIP3) models
  + IPSL-CM5A (standard low resolution, atm: 2°x3.75°, ocean: 2°)

Model	Country
GFDL2.0	USA
GFDL2.1	USA
HadCM3	UK
HadGEM1	UK

Model	Country
MIMR	Japan
MIHR	Japan
CCCMA	Canada
CNRM	France

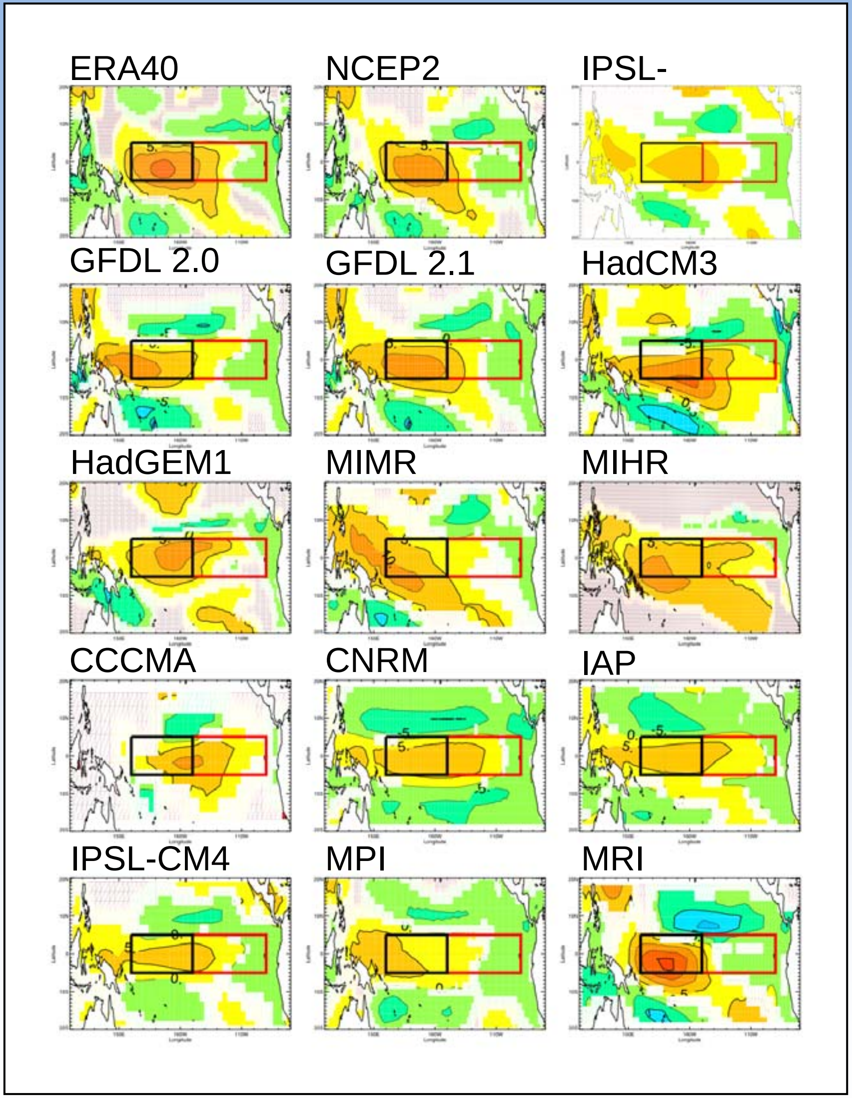
Model	Country
IAP	China
IPSL	France
MPI	Germany
MRI	Japan
+ IPSL-CM5A	France

- Look at pre-industrial (at least 100 years) and Atmospheric Model Intercomparison Project (AMIP, 1980-1998) runs.
- Reanalyses/observations used to assess models:

Product	Variables used	Years	Reference
ERA40	All	1958-2001	Uppala et al., 2005
OAFlux	Heat fluxes	1984-2004	Yu and Weller, 2007
NCEP2	Dynamical	1979-2009	Kanamitsu et al., 2002
ISCCP	Clouds/heat fluxes / CRF	1984-2001	Rossow et al., 1996

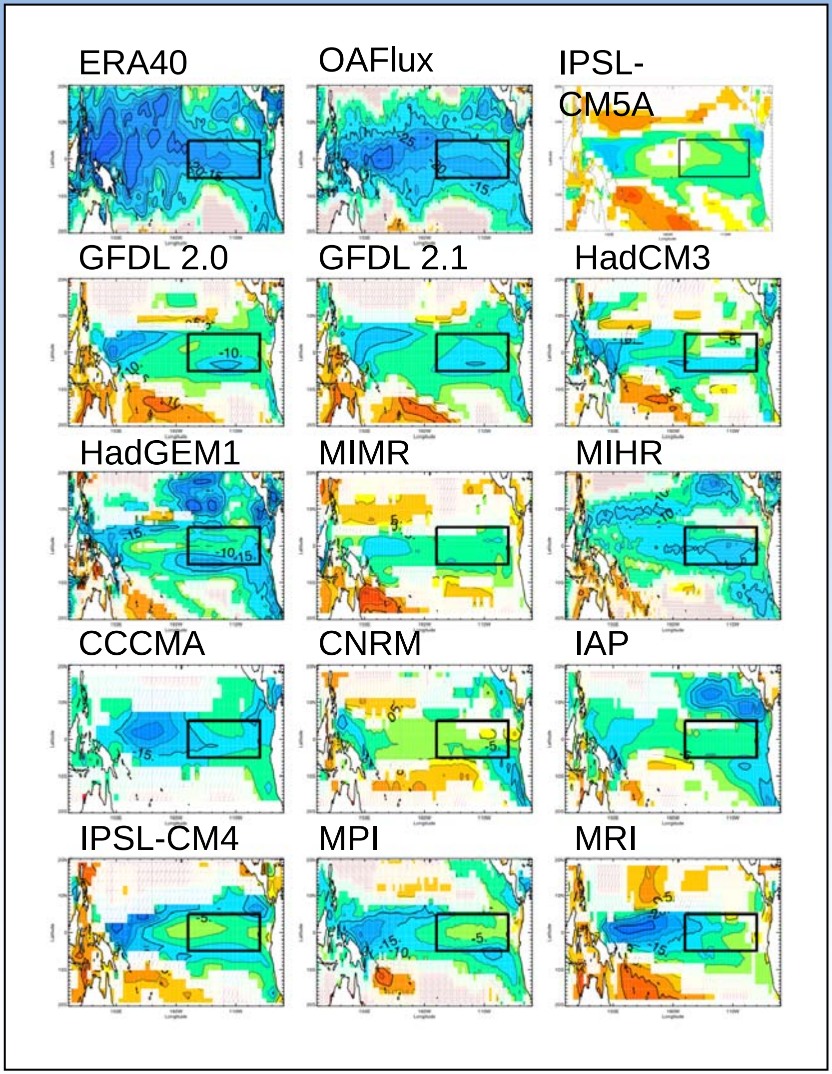
μ and α in the coupled runs

μ in the coupled simulations



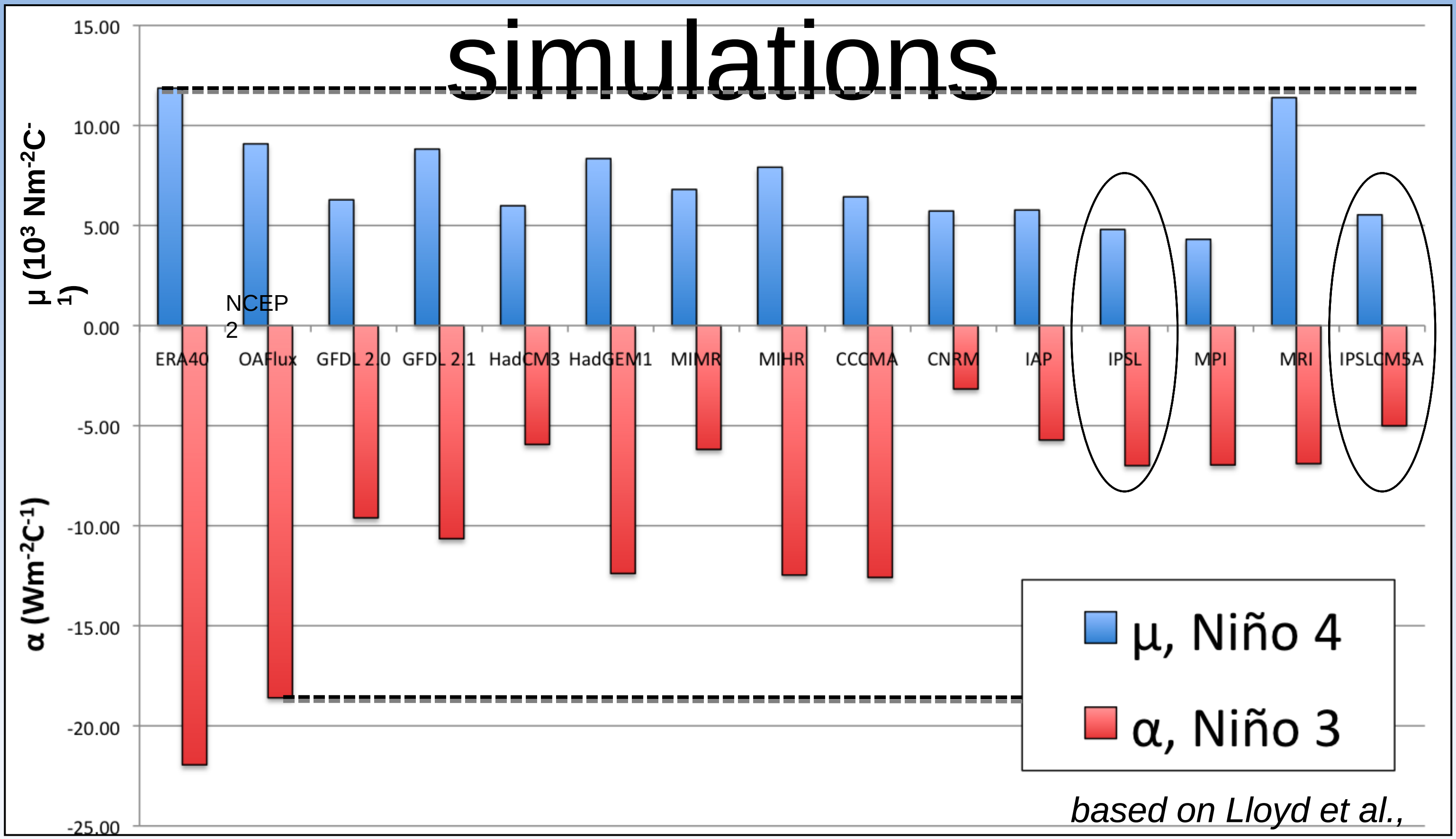
- Maximum wind stress response located to west of Niño 3 SST forcing in all models (Gill, 1980).
- CMIP3 models tend to underestimate the remote wind stress response.
- IPSL-CM5A does not improve on this - also has an underestimated μ feedback.

α in the coupled simulations



- Local heat flux feedback is negative in observations and models across most of tropical Pacific.
- CMIP3 models underestimate the heat flux feedback in Niño 3.
- IPSL-CM5A does not improve on this - also has an underestimated α feedback.

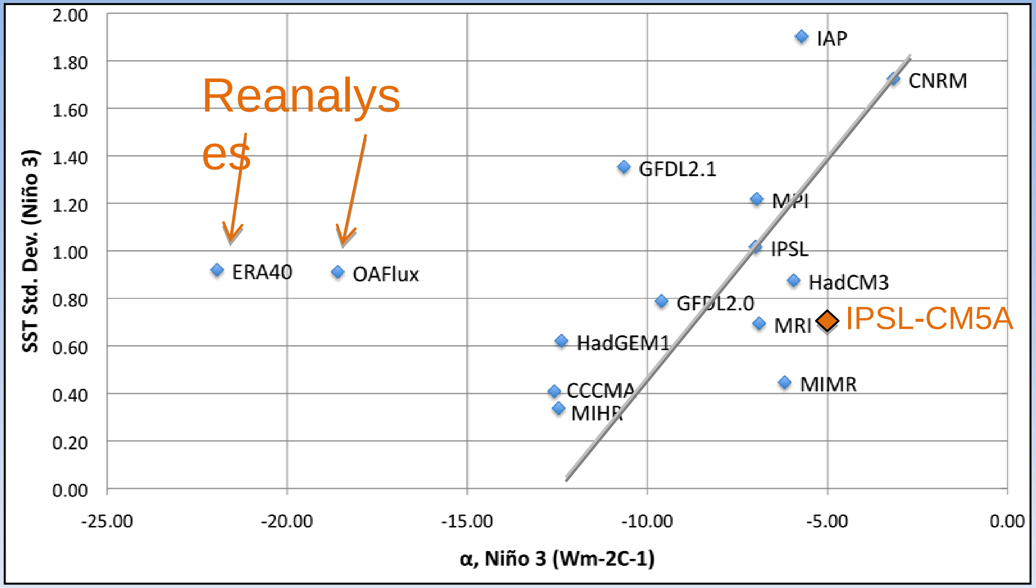
μ and α in the coupled simulations



based on Lloyd et al., 2009

- Models underestimate both μ and α with respect to the observed values => error compensation.
- ENSO is weaker in IPSL-CM5A compared to IPSL-CM4 despite stronger μ and weaker α! Due to changes in oceanic

ENSO amplitude vs. α

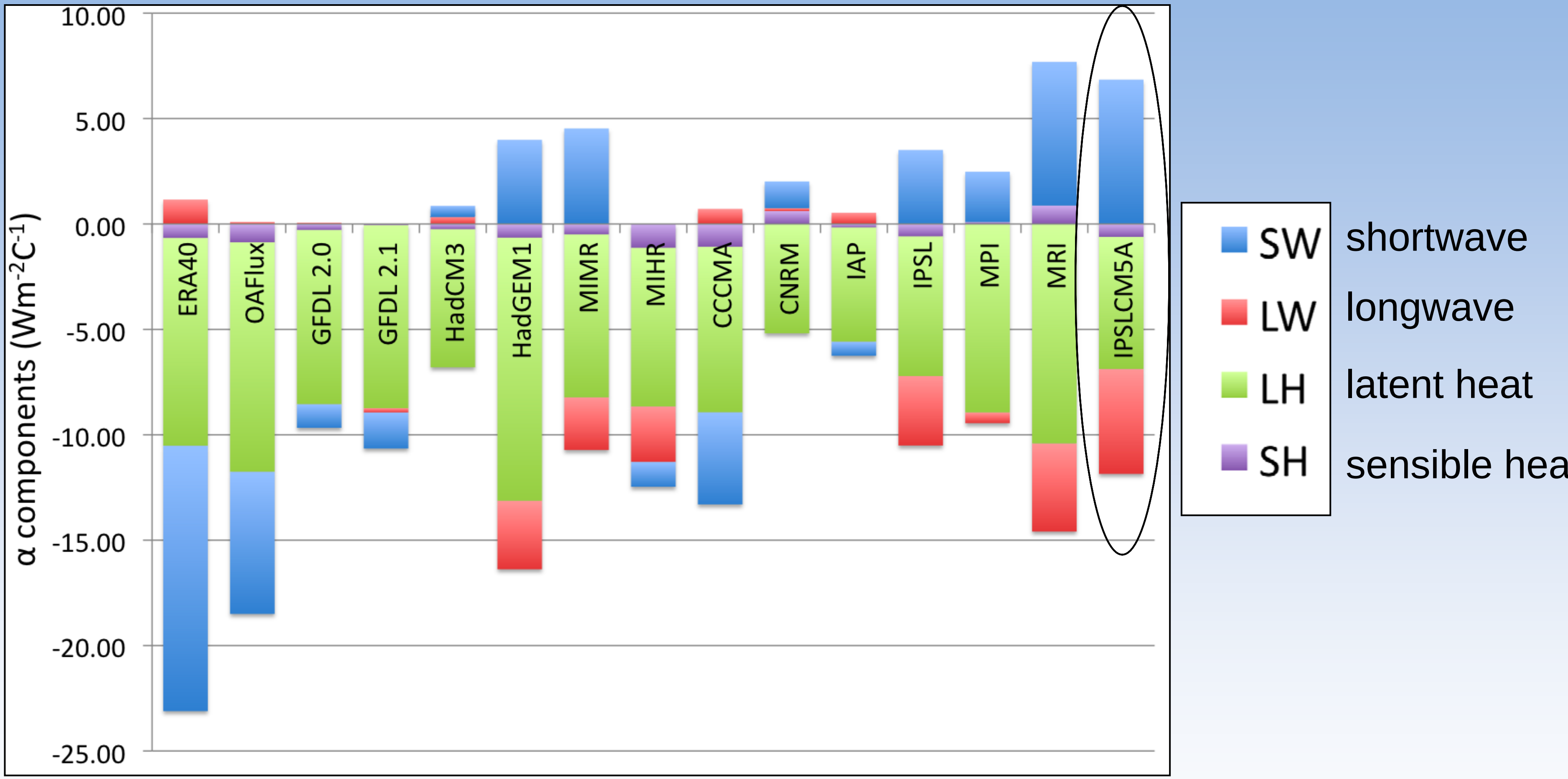


Models with stronger heat flux damping (more negative α) tend to exhibit weaker ENSO, and vice versa (corr = 0.61, sig. at 0.05 level).

- Suggests that α is an important contributor to model ENSO amplitude biases.
- On the other hand, no relationship found between μ and ENSO amplitude.
- t … Ms

the *"diversity in ENSO stability [amplitude] is attributable to the large model-to-model difference in the* ***sensitivity of the oceanic response to wind forcing*** *and in the* ***atmospheric thermodynamic response to a SST anomaly****".*

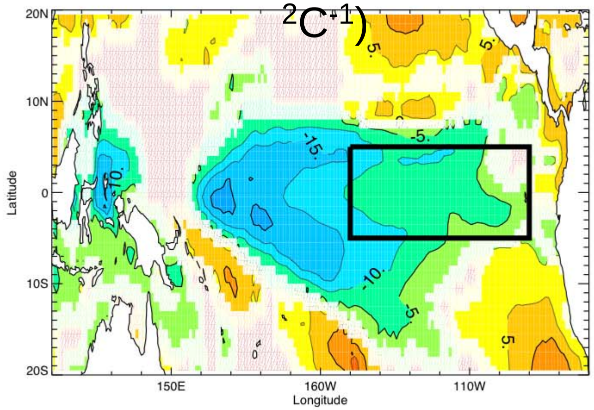
Breaking down the α feedback



- The net α feedback is dominated by the SW and LH components.
- Main cause of α biases is the SW component, α_{SW} (8 models have positive α_{SW}).
- IPSL-CM5A has the strongest positive α_{SW} and one of the weakest α_{LH} feedbacks!

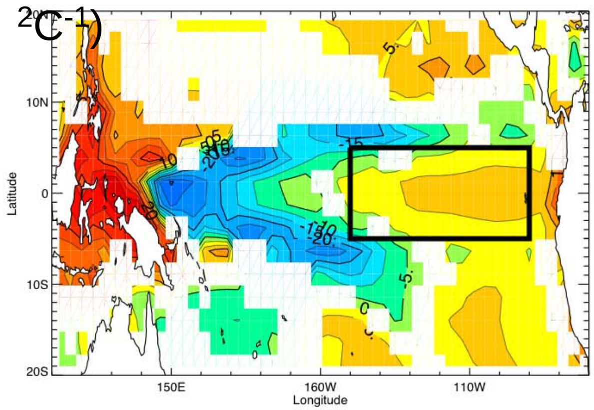
Shortwave flux feedback problems in IPSL-CM5A

OAFlux (α_{SW} = -6.7 $Wm^{-2}C^{-1}$)

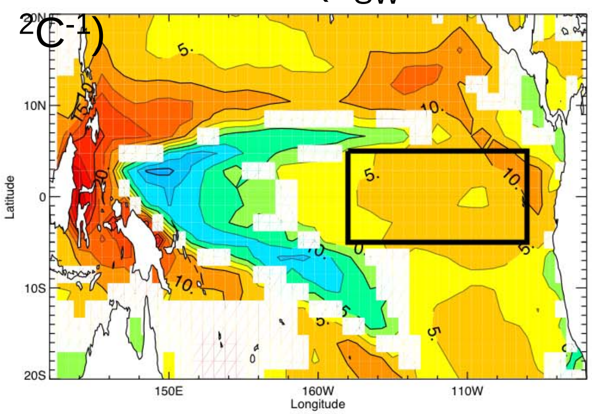


IPSL-CM5A has a stronger positive α_{SW} than any of the CMIP3 runs.

IPSL-CM4 (α_{SW} = +3.5 $Wm^{-2}C^{-1}$)



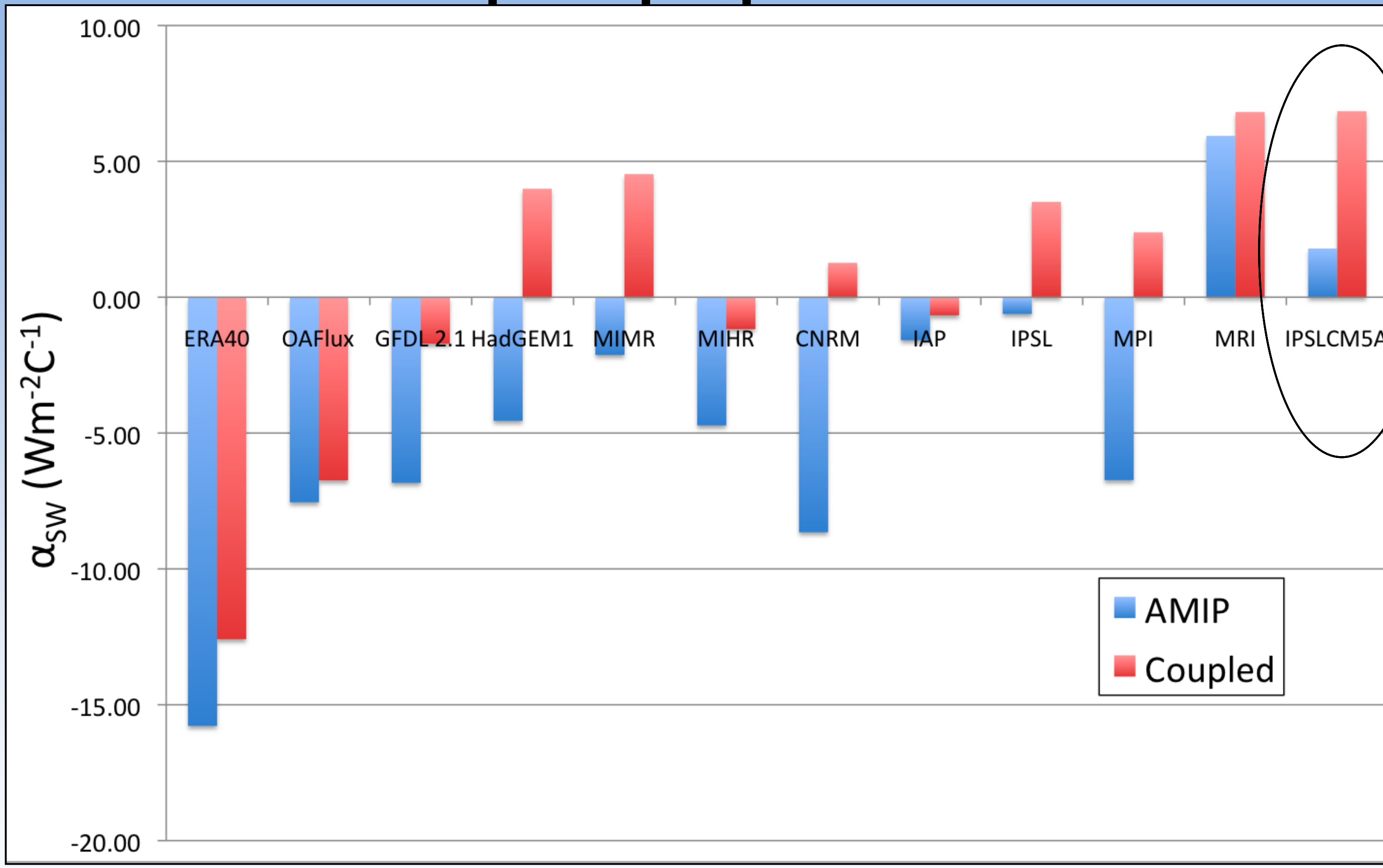
IPSL-CM5A (α_{SW} = +6.9 $Wm^{-2}C^{-1}$)



How can we understand the source of these errors?

- Diversity of events makes it difficult to compare modelled El Niños to observed events.
- Do biases have their source in the ocean or atmosphere model?
- Use AMIP simulations – isolate atmosphere, identical SST forcing.
- Shown here: diagnosing SW flux feedback errors.

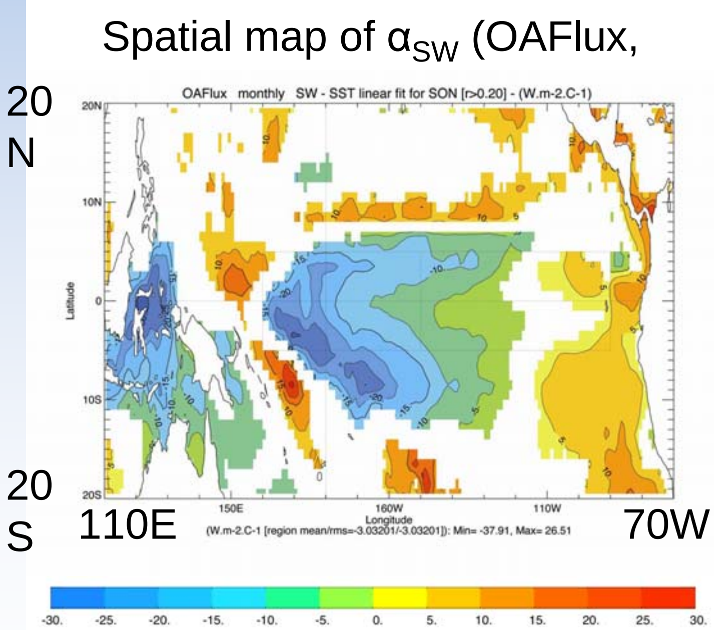
α_{SW} in the coupled and AMIP

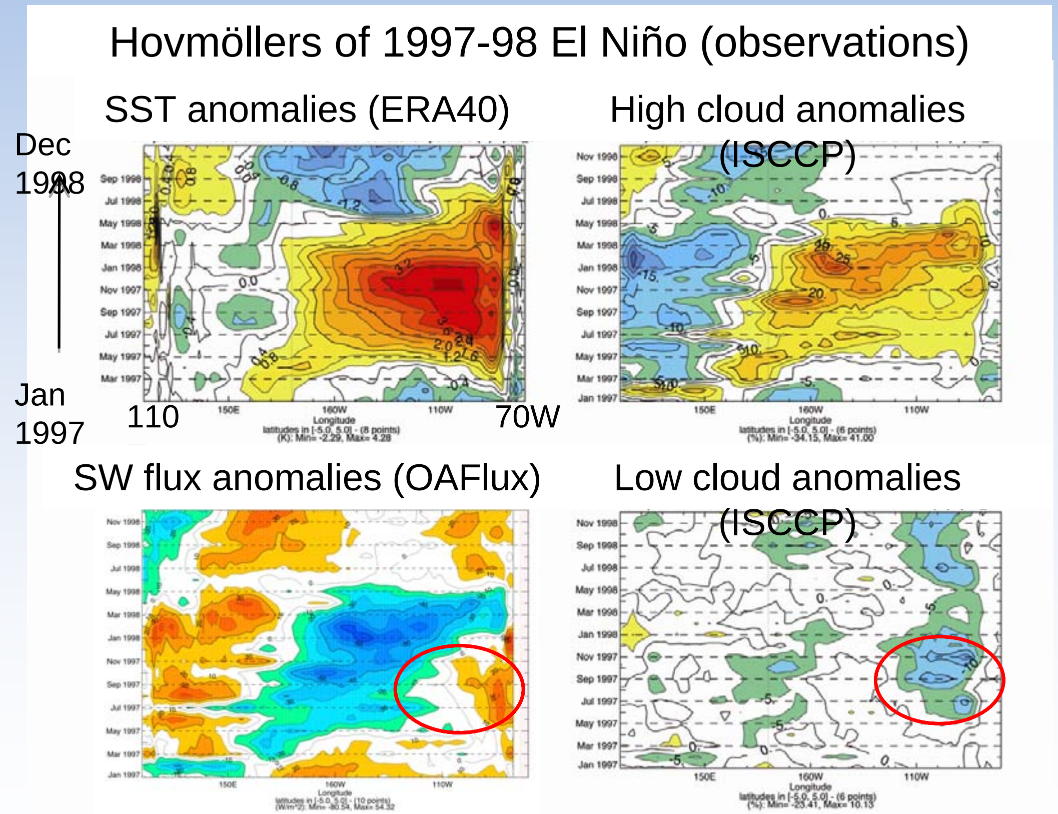


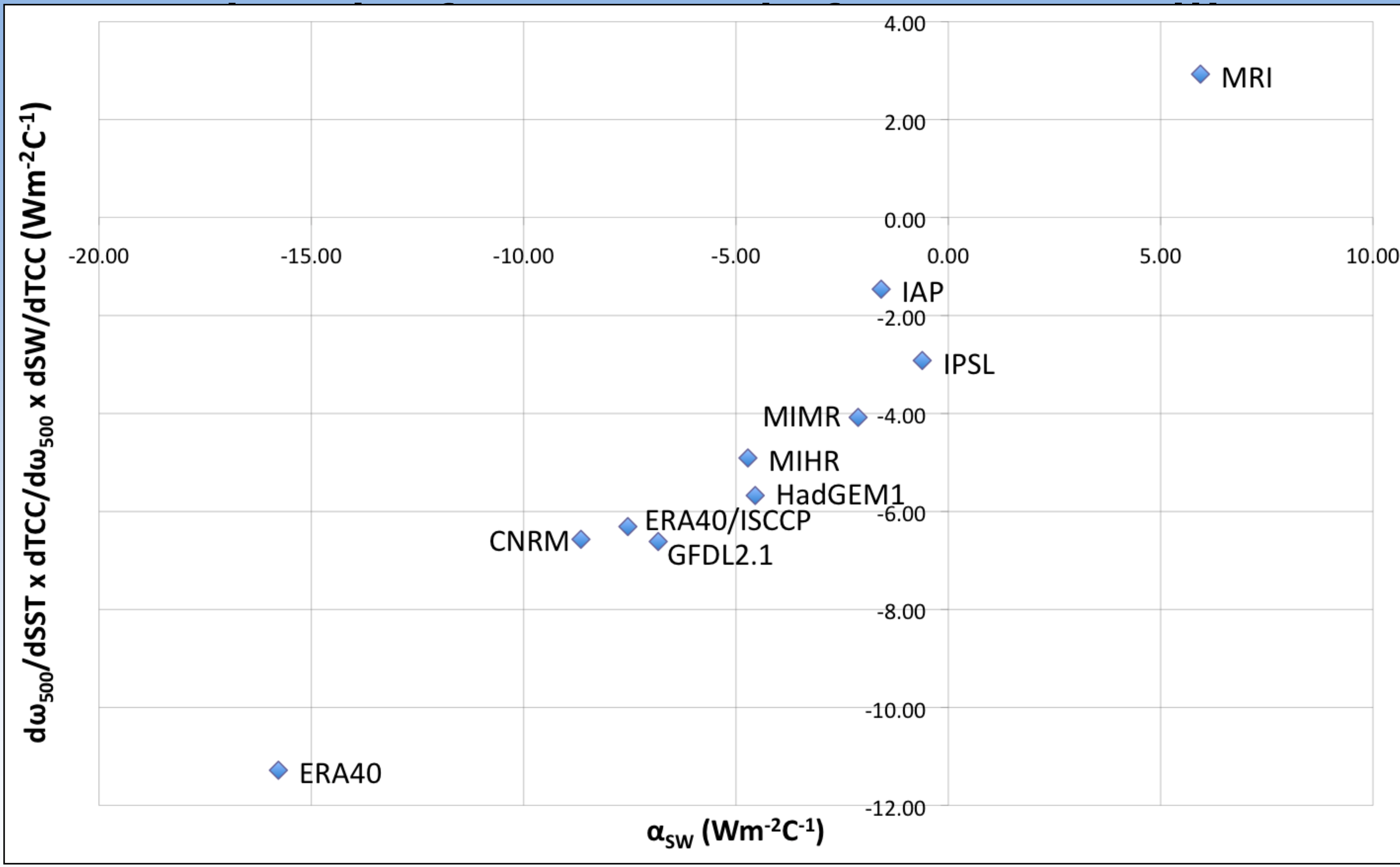
- The SW flux feedback, α_{SW}, is improved in all AMIP runs compared to the coupled values.
- However, MRI and IPSL-CM5A have a positive α_{SW} feedback in the AMIP runs…errors have their roots in the atmosphere model.

The α_{SW} feedback mechanism

- In observations, two SW flux responses…negative feedback in high cloud, convective regimes (Ramanathan & Collins, 1991), positive feedback in low cloud, subsidence regimes (Klein & Hartmann, 1993, Park & Leovy, 2004).







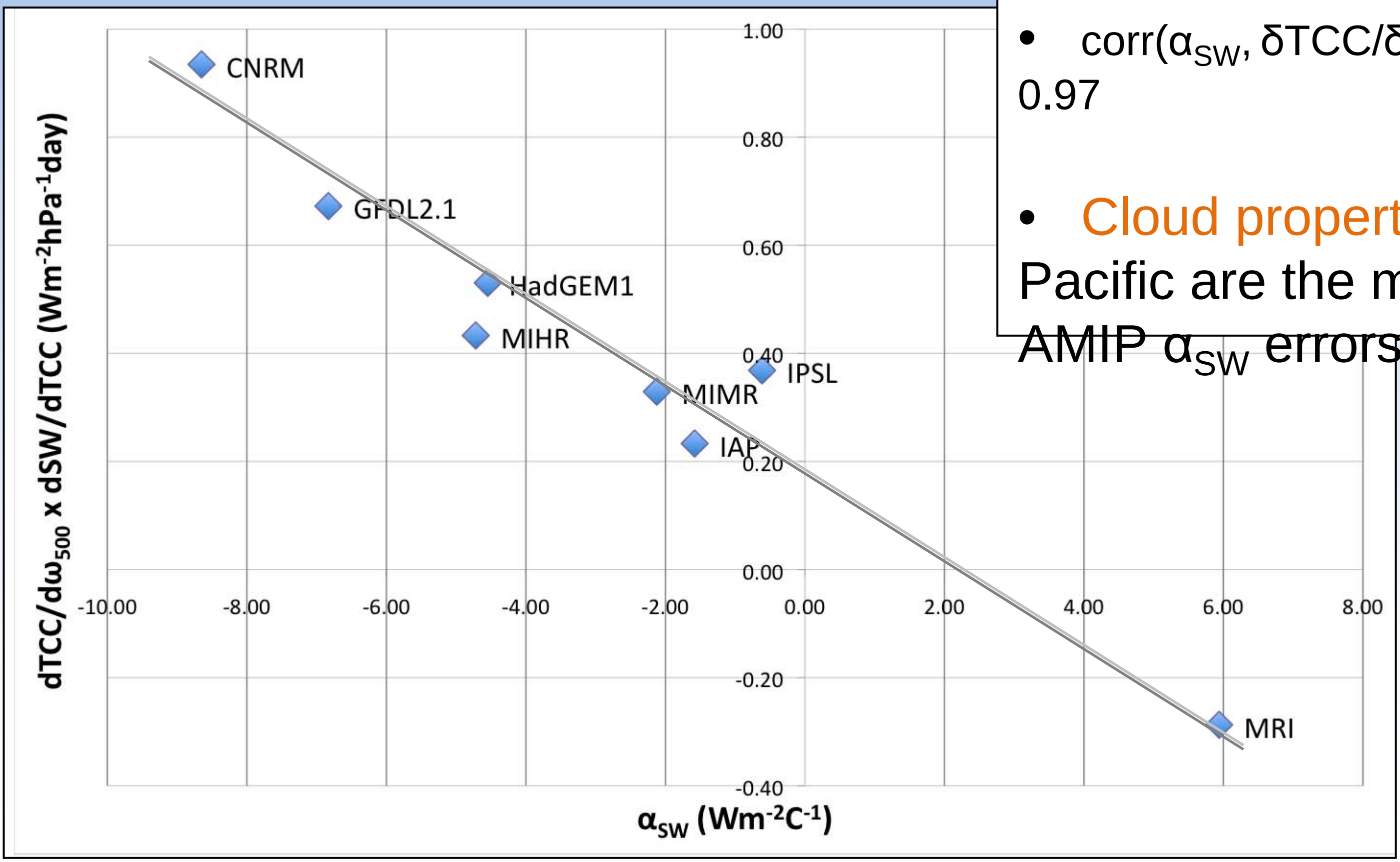
$$\frac{\partial SW}{\partial SST} = \boxed{\frac{\partial \omega_{500}}{\partial SST} \times \frac{\partial TCC}{\partial \omega_{500}} \times \frac{\partial SW}{\partial TCC}} \approx \boxed{\alpha_{SW}}$$

A simple framework for unravelling

$$\frac{\partial SW}{\partial SST} = \frac{\partial \omega_{500}}{\partial SST} \times \frac{\partial TCC}{\partial \omega_{500}} \times \frac{\partial SW}{\partial TCC} \approx \alpha_{SW}$$

α_{SW}

(1) (2) (3)



- corr(α_{SW}, δTCC/δω500 x δSW/δTCC) = -0.97
- Cloud properties in eastern Pacific are the main source of AMIP α_{SW} errors.

Summary and outlook

- As found in the CMIP3 models, the positive Bjerknes (μ) and negative heat flux (α) feedbacks are both underestimated in the standard IPSL-CM5A run (an error compensation).
- The underestimated heat flux feedback in IPSL-CM5A is mainly due to a positive SW flux feedback (α_{SW}). An underestimated LH flux feedback (α_{LH}) also contributes.
- A brief look at the IPSL-CM5A AMIP run shows that the large α_{SW} error has its roots in the atmosphere model.
- A 'feedback decomposition method' for diagnosing the α_{SW} errors is introduced.
- Other diagnostics, not described here, can be used to understand the α_{LH} biases.
- A full investigation of the oceanic feedbacks is also needed to understand the impact of the μ and α biases on the modelled ENSO (e.g. using the BJ index).