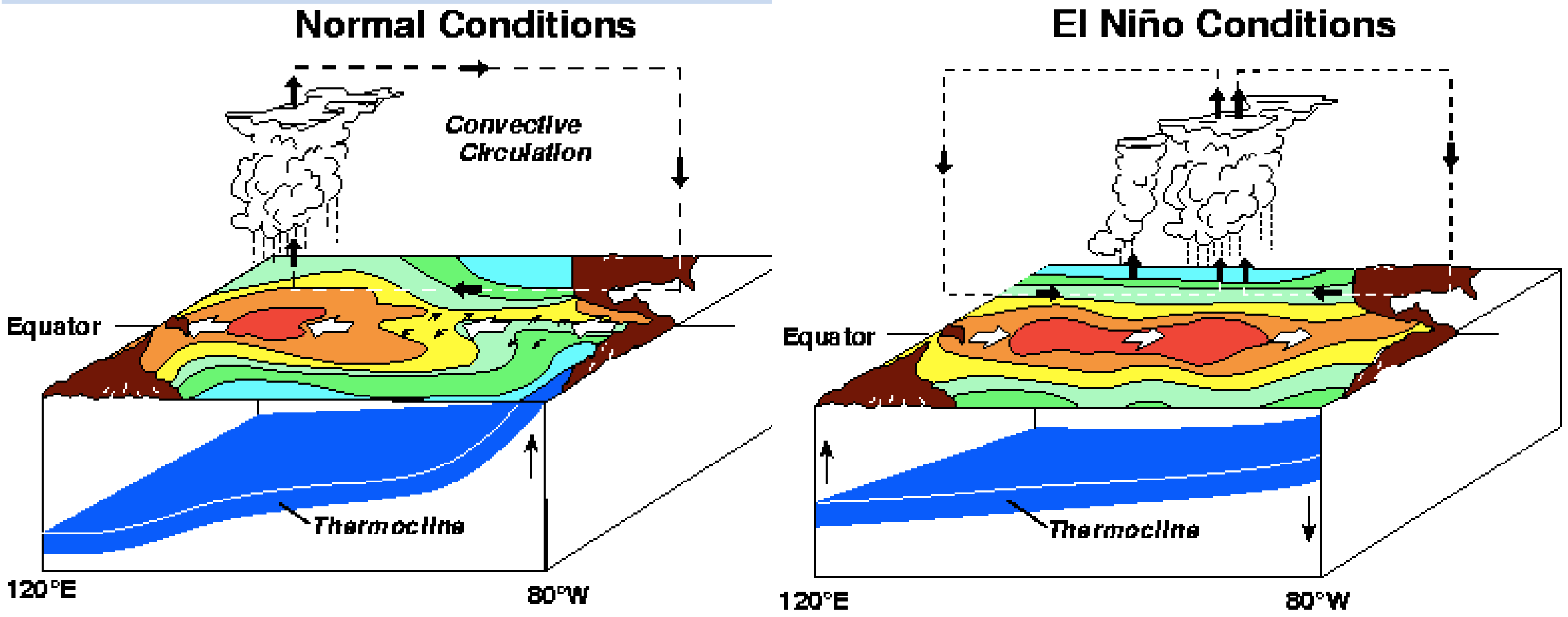
The Role of Atmosphere Feedbacks During ENSO in the CMIP3 Models.

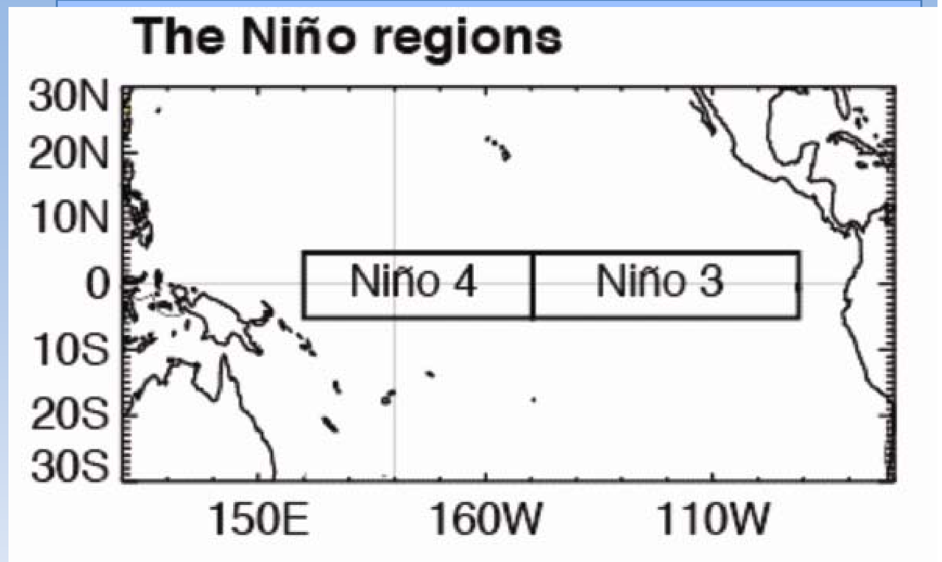
Investigating the heat flux feedback

EUCLIPSE Kick-Off Meeting, 27/09/10

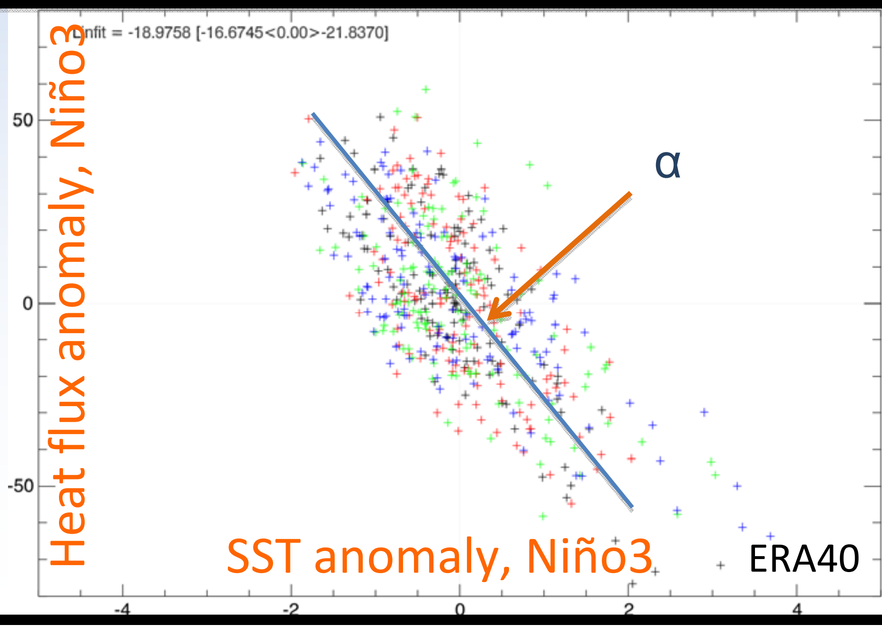


Two ENSO-relevant atmosphere feedbacks

- Dynamical feedback
- $\tau_x' = \mu SST'$
- Positive Bjerknes feedback: amplification
- Calculate by regressing wind stress anomaly against Niño 3 SST anomaly and average over Niño 4

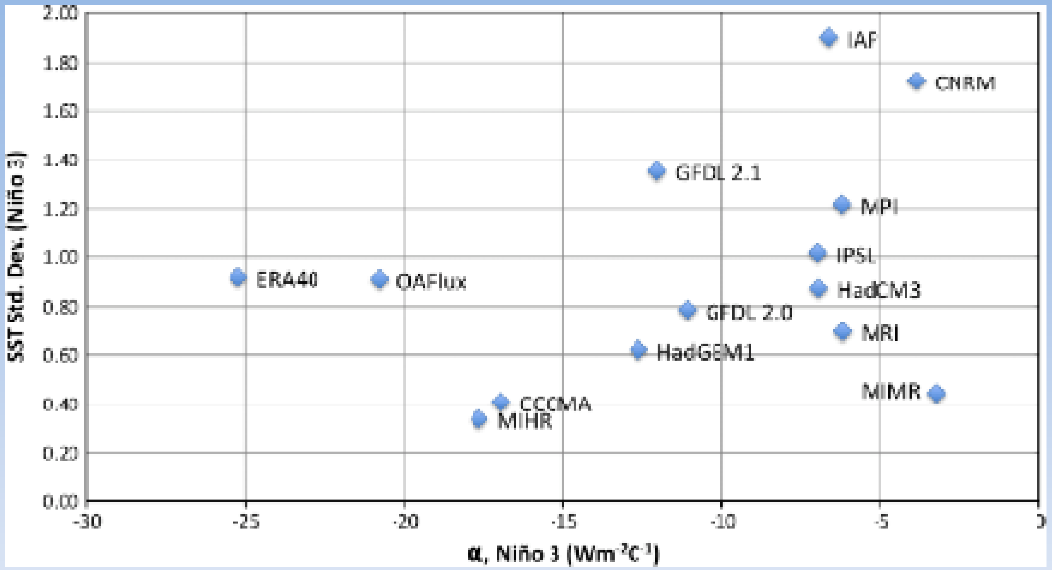


- Heat flux feedback
- $Q' = \alpha SST'$
- Negative thermodynamical feedback: damping
- Calculate by regressing heat flux anomaly against local SST anomaly and average over Niño 3



α in the CMIP3 Coupled Models…

- The heat flux feedback, α, is underestimated by all coupled models and exhibits a positive relationship with ENSO amplitude:



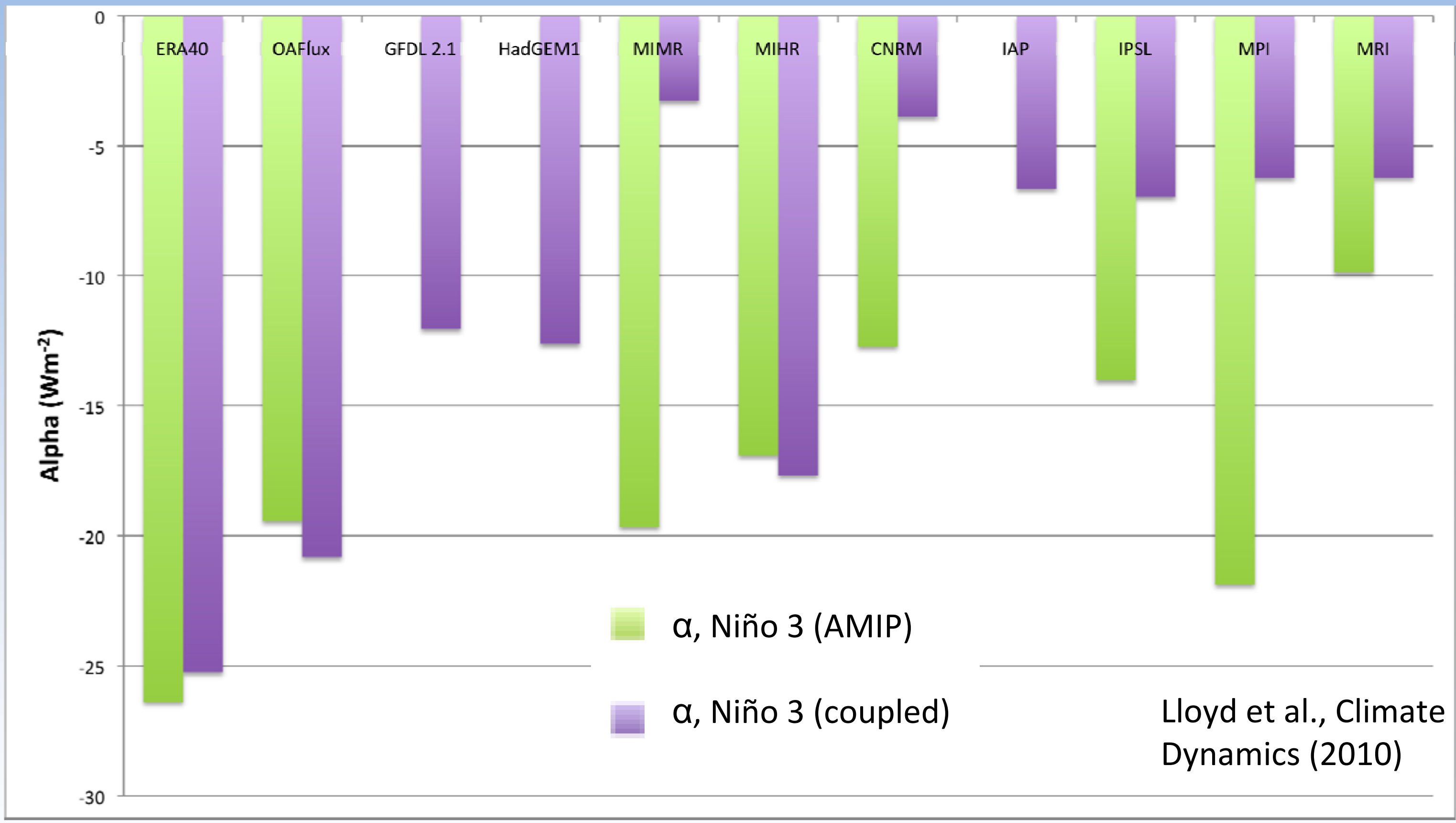
ENSO amplitude vs. α (Lloyd et al., 2009)

Kim and Jin (Clim. Dyn., 2010): 'BJ index' used to analyse the ENSO stability in CMIP3 GCMs. Conclude that: *"…diversity in ENSO stability 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****"*.

Need to understand α diversity…use **AMIP** simulations to isolate atmospheric response.

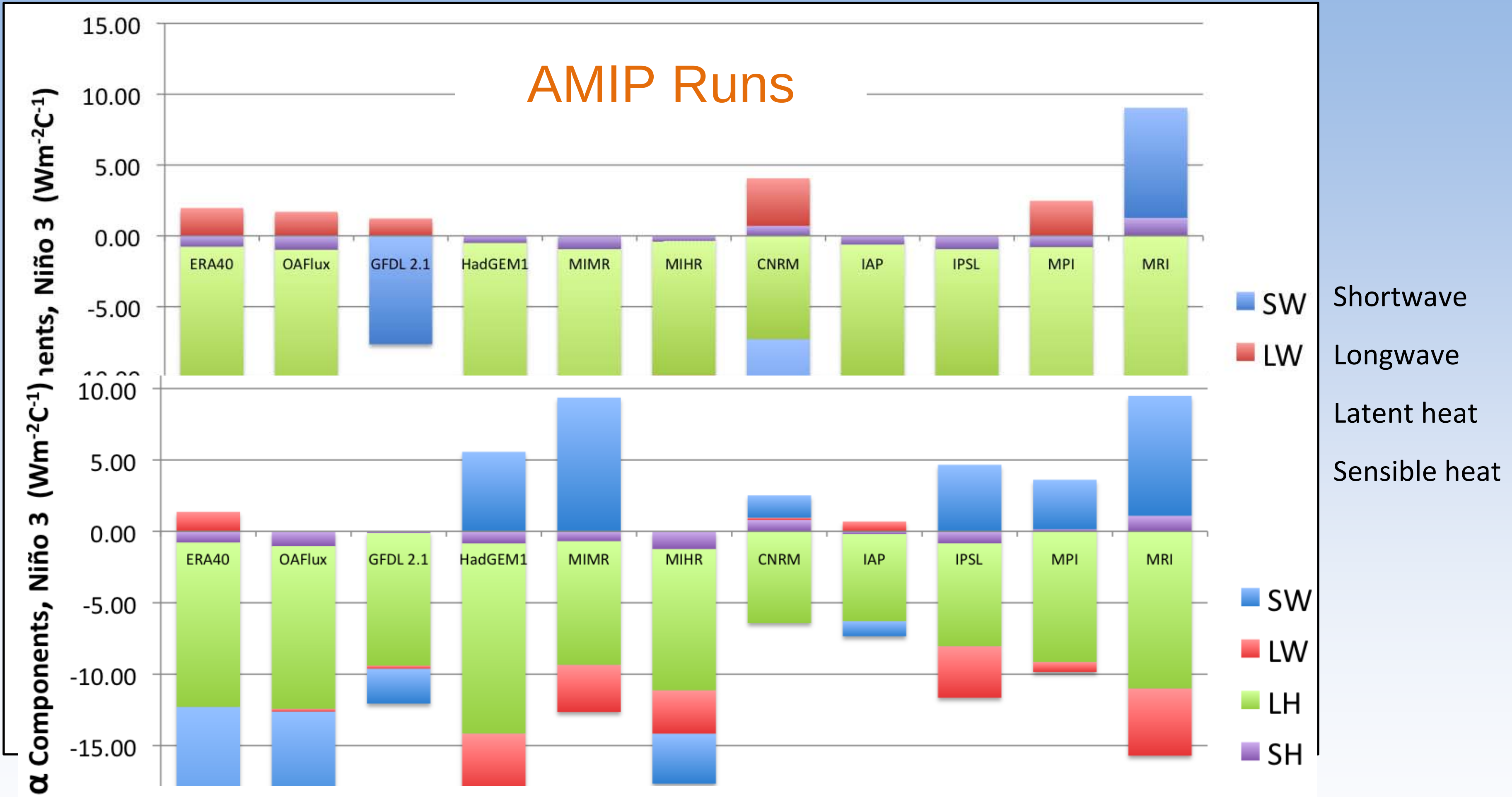
Comparing α in the AMIP and Coupled Runs…

- α feedback calculated in the 6 AMIP runs (1980-1998) with all available fields…



- The α feedback is improved in AMIP runs compared to coupled runs…
- What is the reason for this? Look at individual heat flux components…

AMIP Heat Flux Components

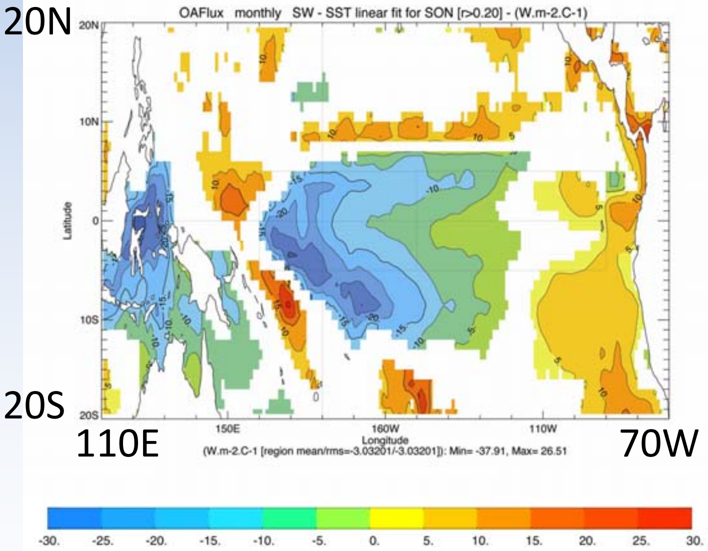


- Improvements in α_{SW} explain most of the improvement in the overall α
- But α_{SW} still main source of α error in AMIP runs

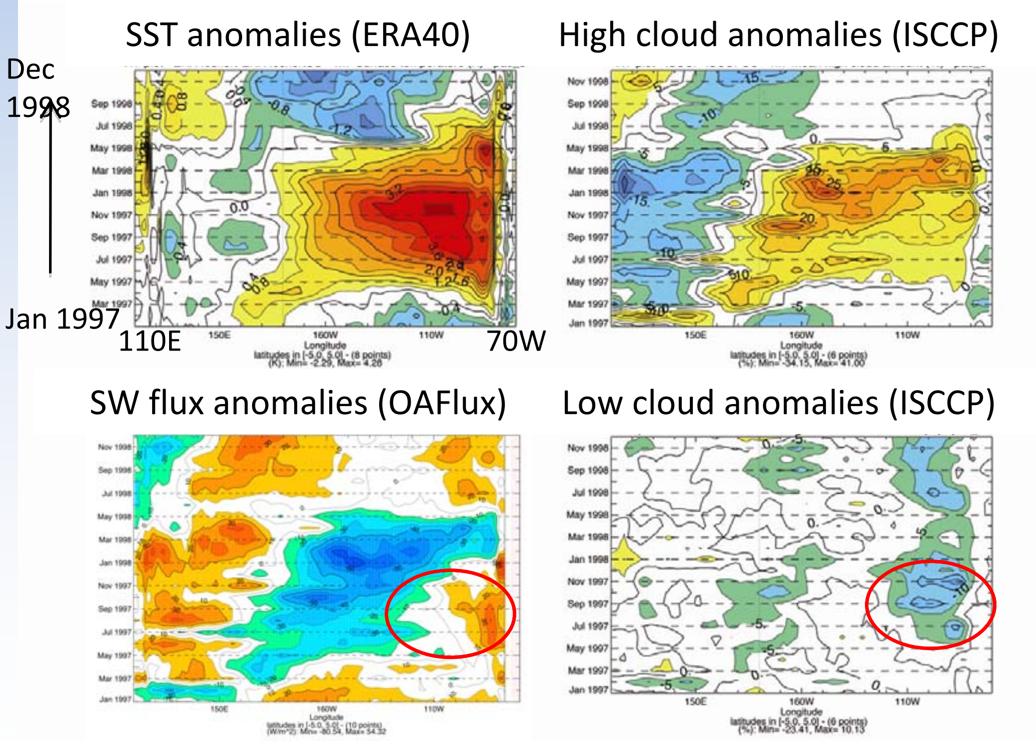
The α_{SW} Feedback Mechanism (obs)

- In observations, two different shortwave feedback responses…negative feedback in high cloud, convective regimes (Ramanathan & Collins, 1991) positive feedback in low cloud, subsidence regimes (Park & Leovy, 2004).

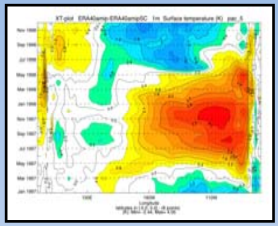
Spatial map of α_{SW} (OAFlux, SON)



Hovmöllers of 1997-98 El Niño



α_{SW} Feedback Mechanism: 1997-98 El Niño (AMIP runs)

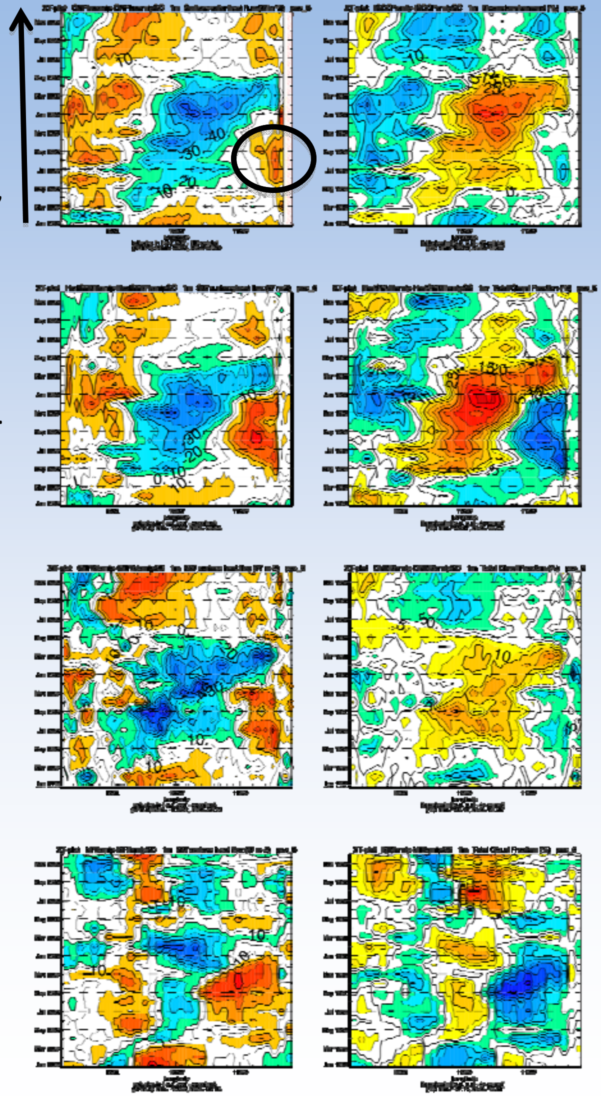


SST

SW flux | Cloud cover

Dec 1998

Jan 1997



	α_{SW} ($Wm^{-2}C^{-1}$)
Obs	-8.9 (OAFlux) -17.1 (ERA40)
HadGEM1	-5.6
CNRM	-9.5
MRI	7.8

Unravelling the α_{SW} feedback

- Split up α_{SW} into three responses:

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

(1) (2) (3)

(SW = shortwave flux, ω_{500} = vertical velocity at 500hPa, TCC = total cloud cover)

(1) dynamical response to SST

(2) cloud response to dynamics

(3) SW flux response to clouds.

- Calculate each response by linear regression of monthly values in Niño 3
- Which of these responses is most important for α_{SW} biases in the AMIP and coupled runs?

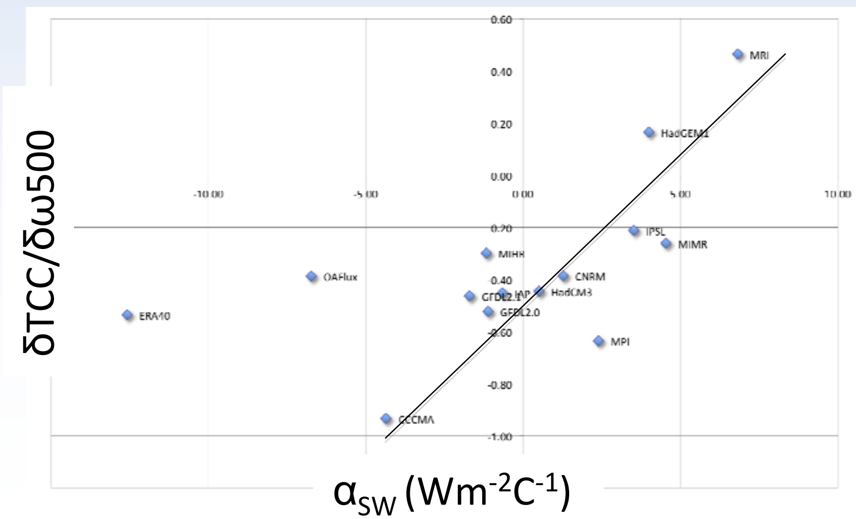
Unravelling the α_{SW} feedback

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

(1) (2) (3)

Correlations between the model α_{SW} values and each of the responses:

	(1)	(2)	(3) δSW/δTCC
AMIP	0.21	**0.73**	0.64
Coupled	0.28	**0.60**	0.12



- Cloud response to dynamics in E. Pacific appears to be the main source of α_{SW} errors. Region of subsidence…agrees with Bony & Dufresne (2005).

- Still to be understood: what causes the varied cloud response?

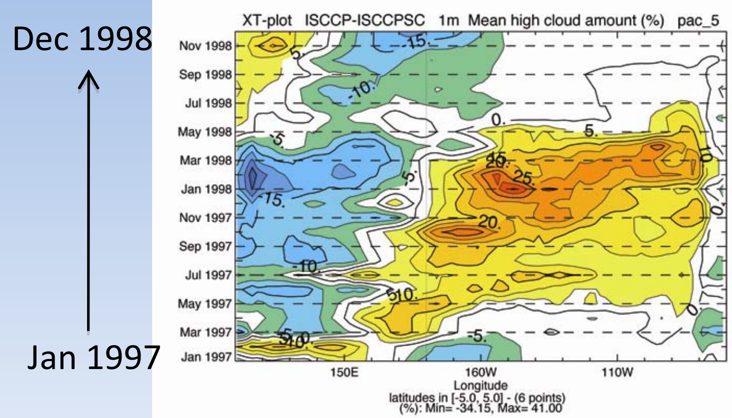
Summary

- The α heat flux feedback is one of the main sources of ENSO amplitude errors in present-day GCMs.
- The strength of α is underestimated by the coupled simulations and most AMIP simulations.
- α_{SW} is the primary source of model errors in the overall α feedback. Biases in the AMIP and coupled SW flux feedbacks are linked to the cloud response to dynamics (δTCC/δω500).
- An improved α feedback (and ENSO?!) can only be obtained by reducing the model cloud feedback biases in the East Pacific.

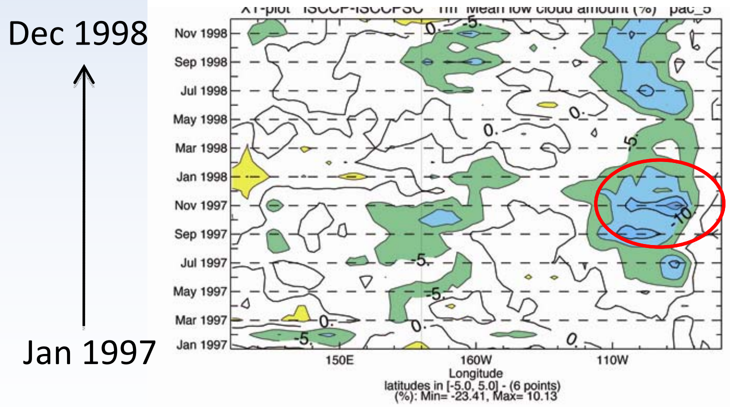
The α_{SW} Feedback Mechanism: Clouds (1)

- During 1997-98 El Niño, high cloud cover increases, low cloud cover decreases
- Explains region of reduced total cloud cover (and positive feedback) in East Pacific

High cloud anomalies (ISCCP)



Low cloud anomalies (ISCCP)



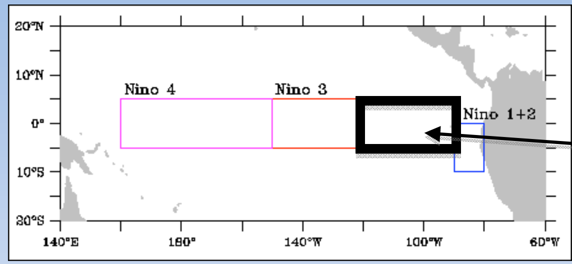
- How do the models simulate these two regimes?
- Unfortunately, no separate high/low-level cloud cover data supplied for models…

The α_{SW} Feedback Mechanism: Clouds (2)

- …so we use TOA cloud radiative forcing (CRF) to infer cloud details:

$CRF_{SW} = SW_{clear\text{-}sky} – SW_{all\text{-}sky}$

$CRF_{LW} = LW_{clear\text{-}sky} – LW_{all\text{-}sky}$



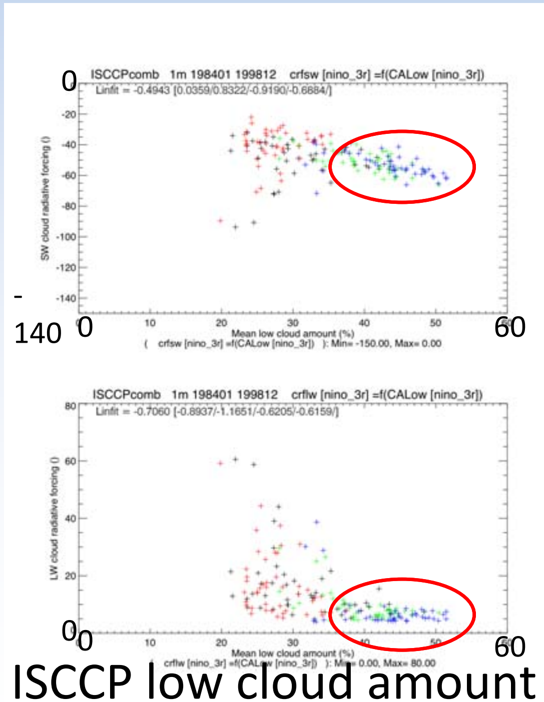
Niño 3r
5°N – 5°S
120°W – 90°W

Cloud radiative forcing of low clouds in ISCCP

- CRF_{SW} typically -40 to -60 Wm^{-2} (depends on optical thickness)
- Low clouds have small positive CRF_{LW} < 10 Wm^{-2}
- Blue/green points = JASOND

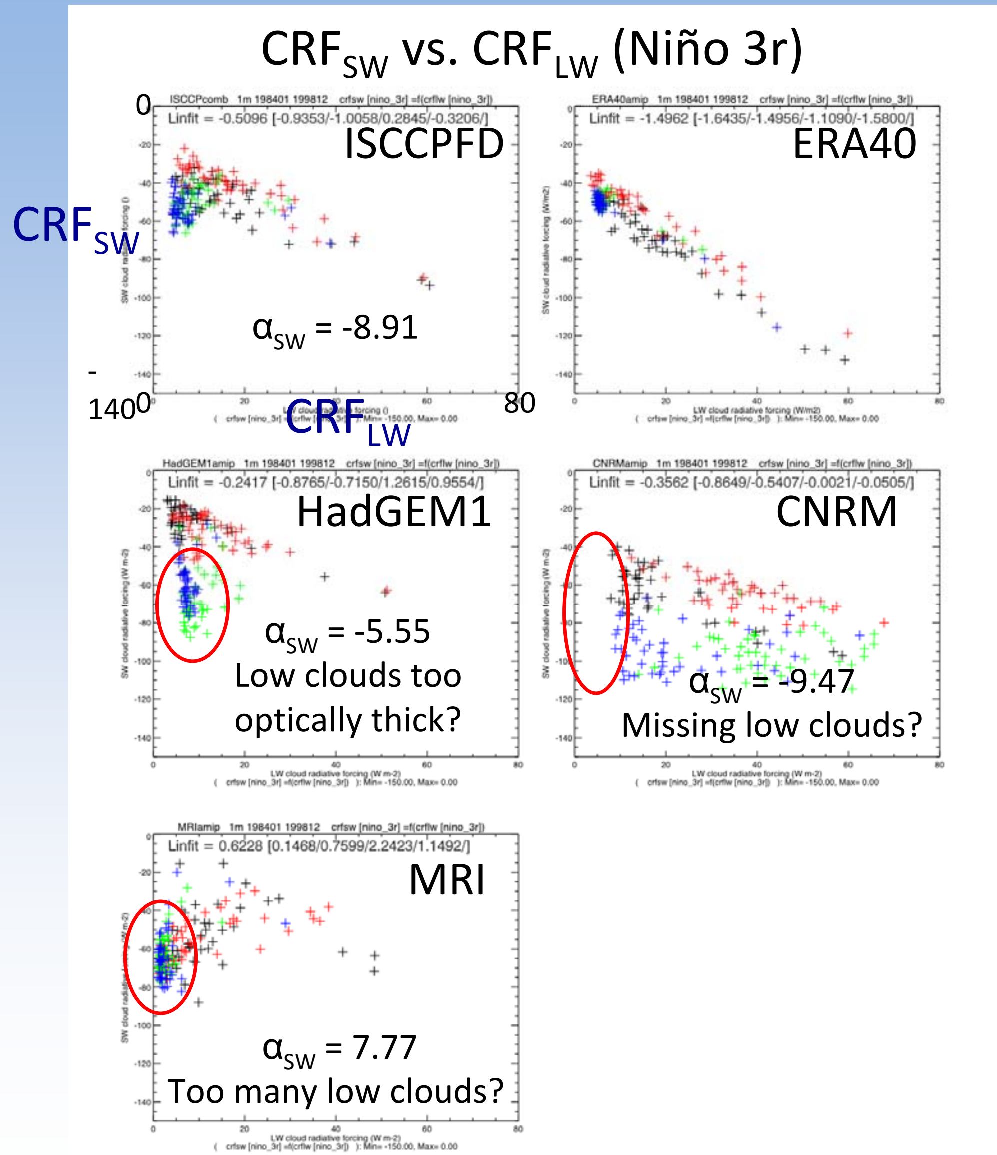
CRF_{SW}

CRF_{LW}

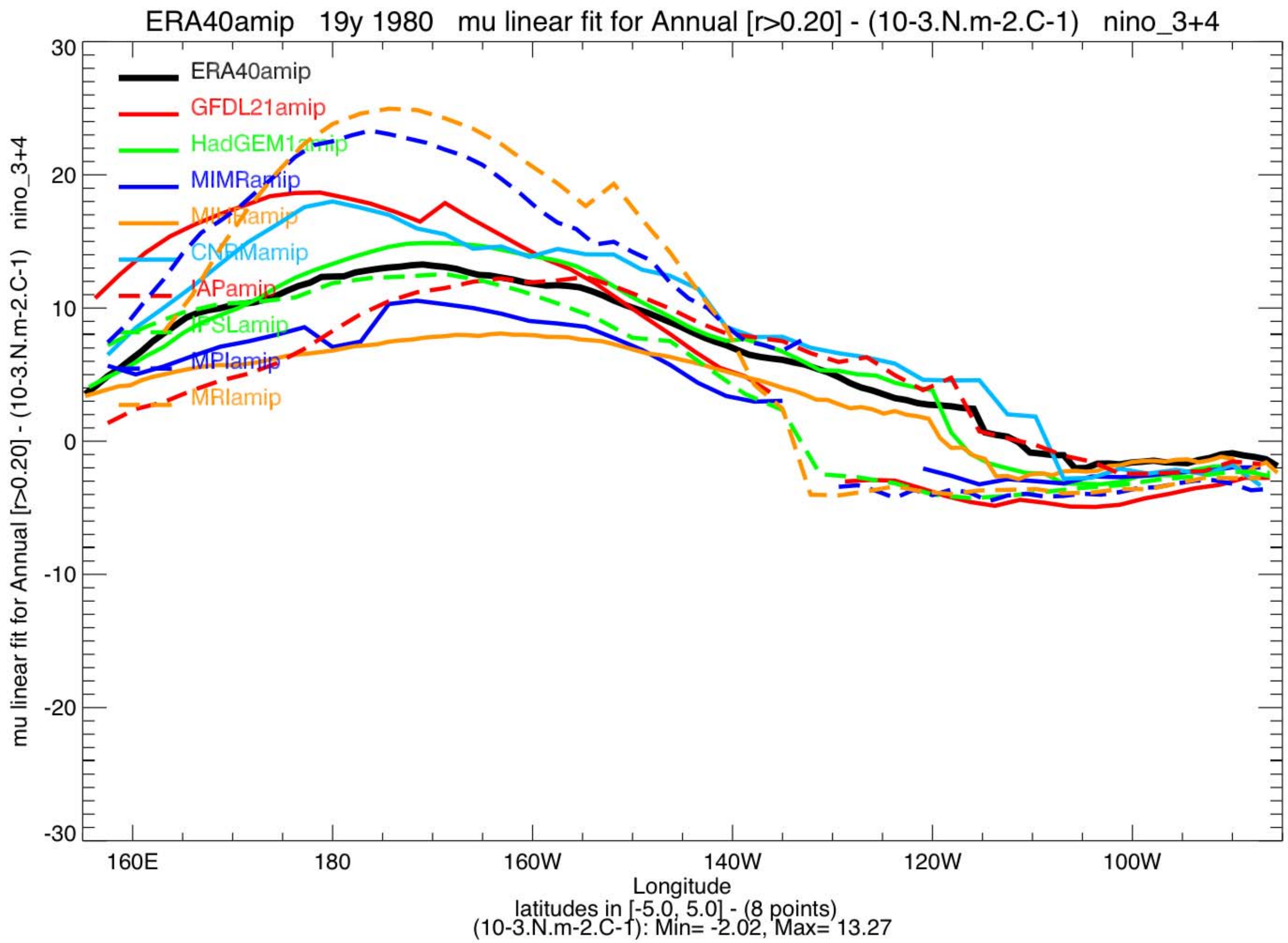


The α_{SW} Feedback Mechanism: Clouds (3)

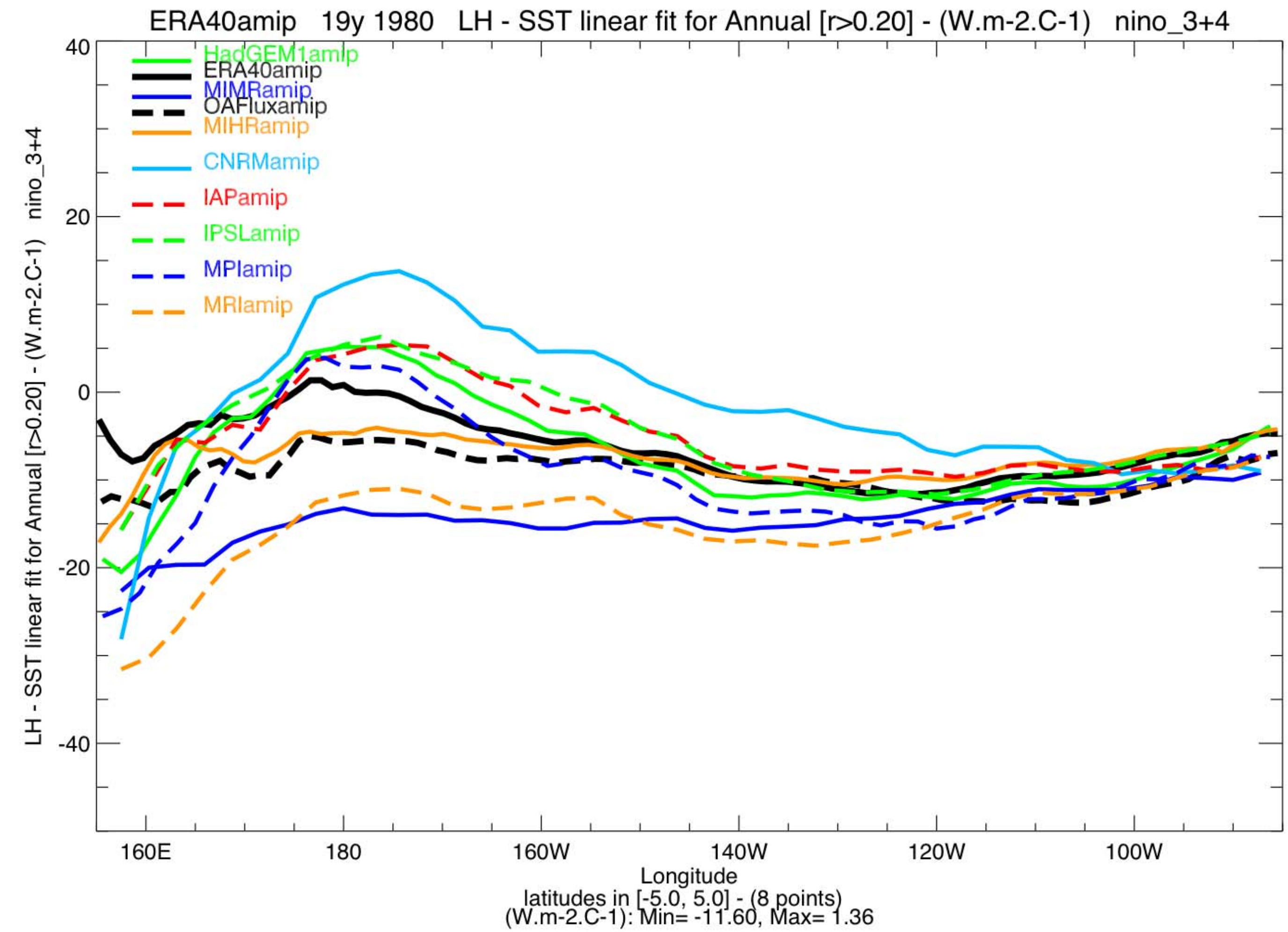
- Low clouds positioned close to y-axis (low CRF_{LW})
- Models have errors in both low cloud amount and optical thickness.
- **HadGEM1:** low clouds too optically thick? Explains weaker α_{SW}?
- **CNRM:** not enough low clouds? Explains strong negative α_{SW}?
- **MRI:** too many low clouds? Explains positive α_{SW}?



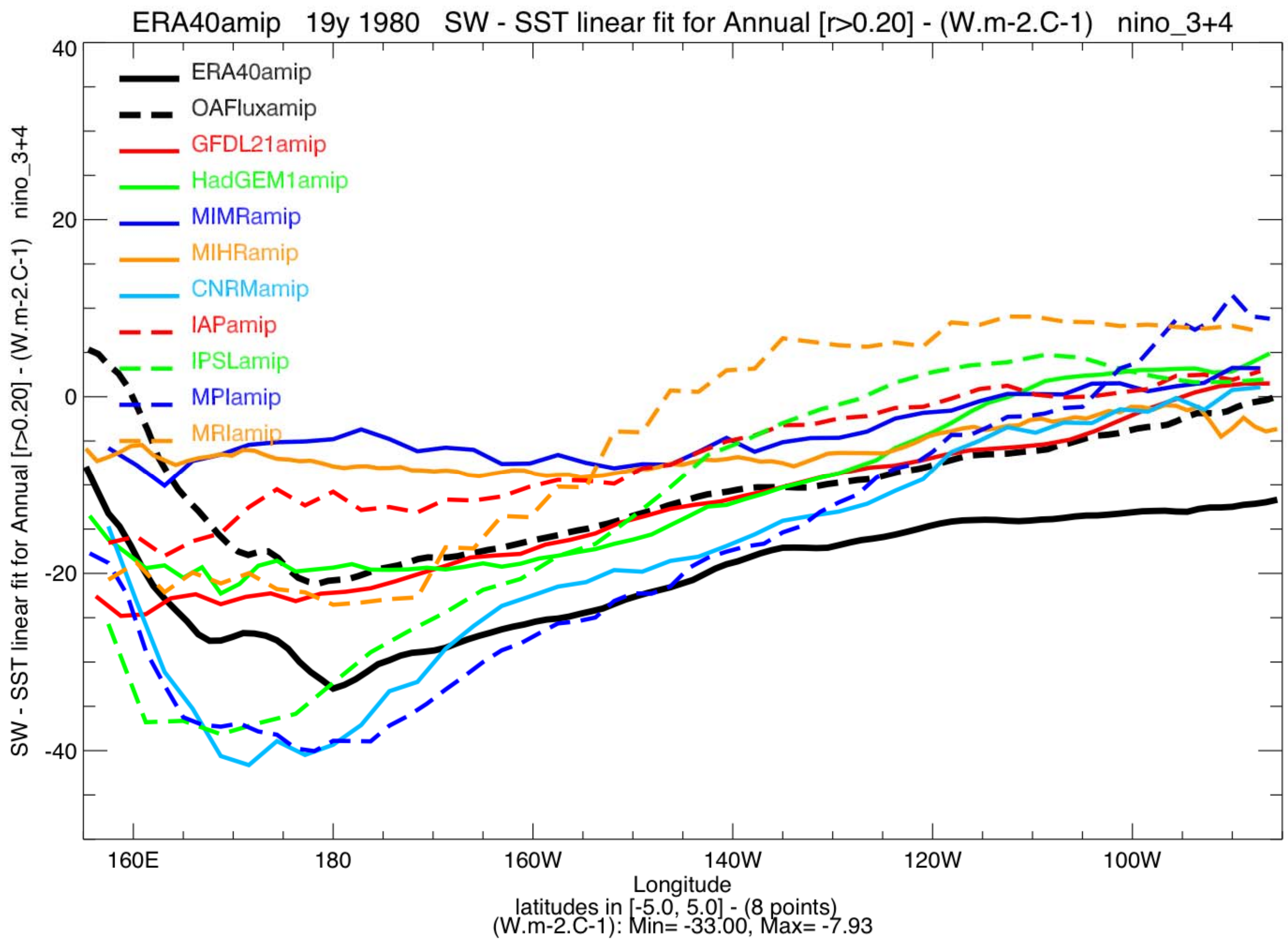
τ_x-SST regression as function of longitude



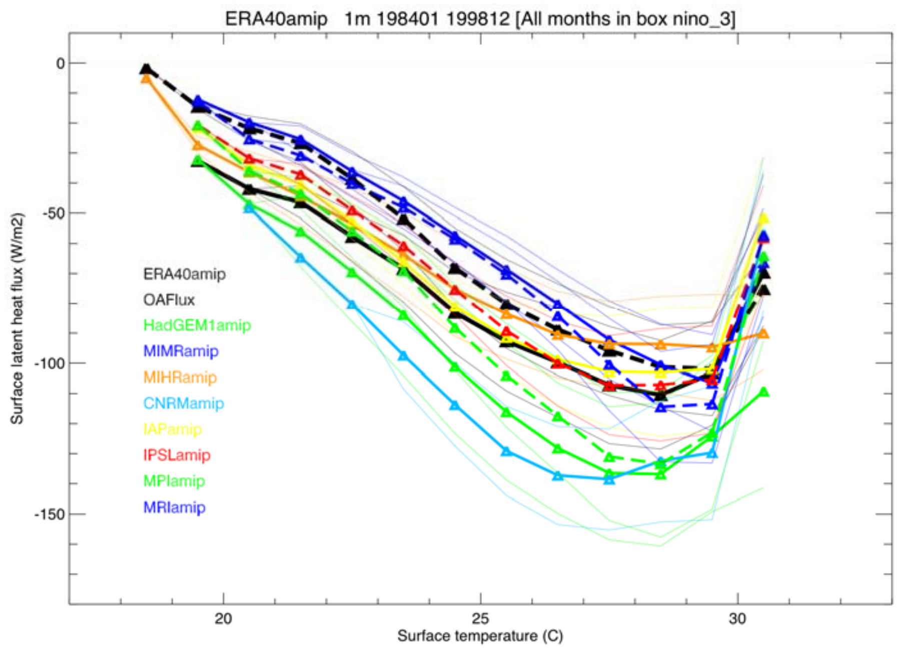
LH-SST regression as function of longitude



SW-SST regression as function of longitude

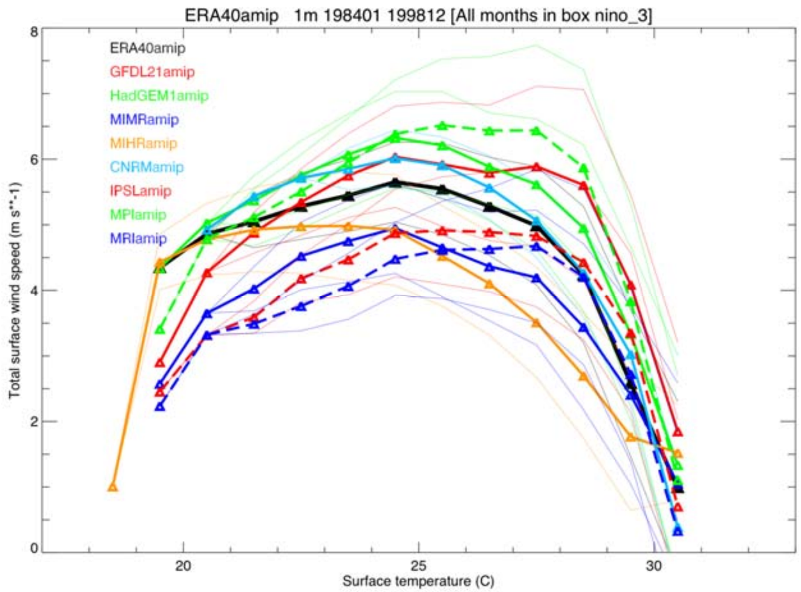


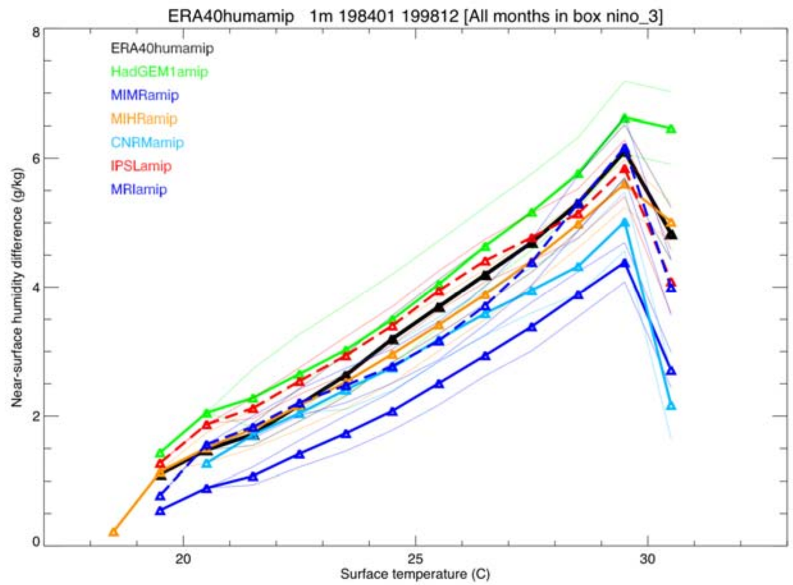
Latent heat flux binned by SST



Near-surf humidity diff.

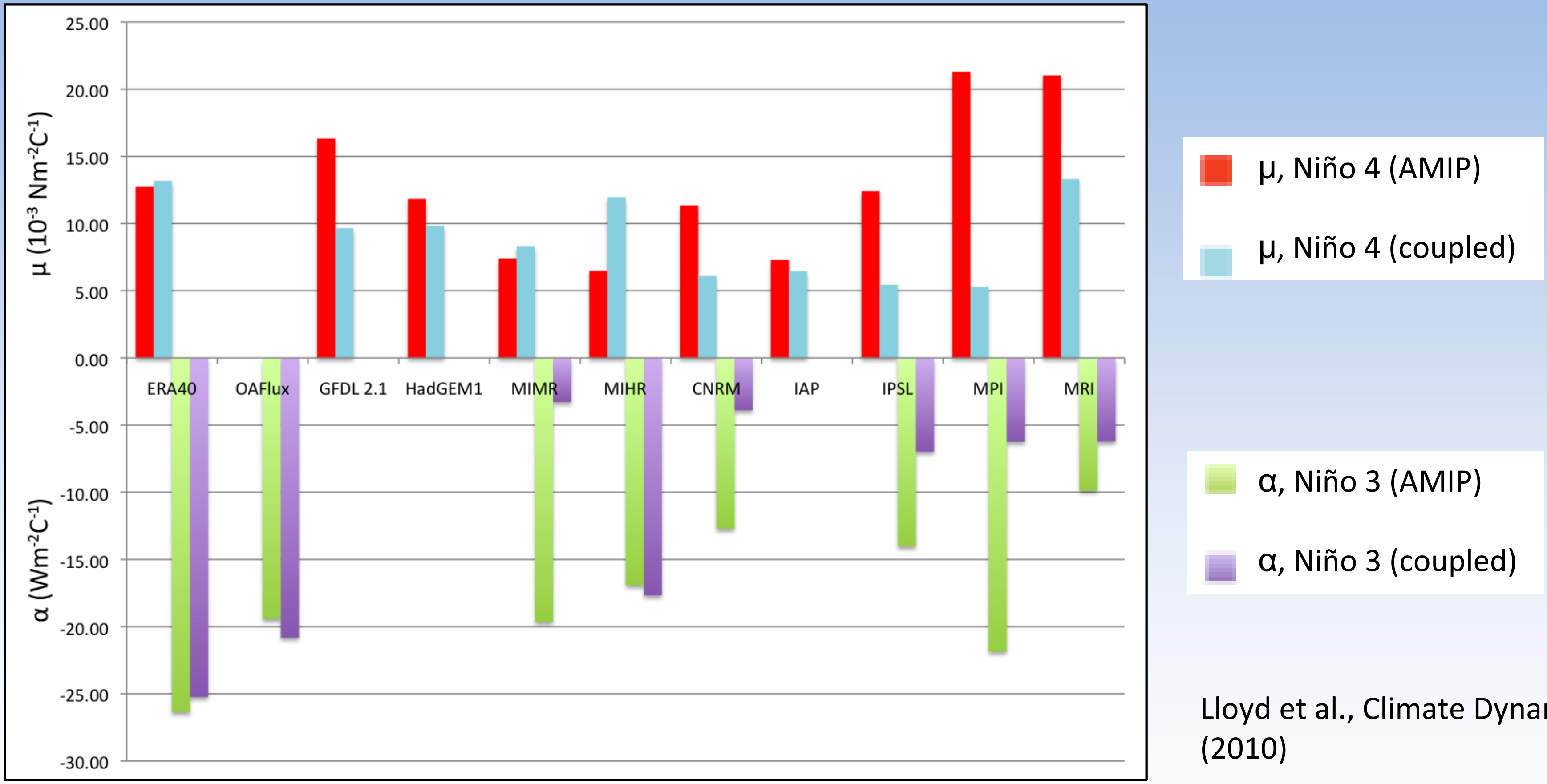
Wind speed





Comparing the Feedbacks in AMIP and Coupled Runs

- Both feedbacks are improved in AMIP runs compared to coupled runs…



Lloyd et al., Climate Dynamics (2010)

- *μ* is usually stronger and closer to observations
- α is a stronger negative feedback in all but one model