Atmosphere feedbacks during ENSO in GCMs

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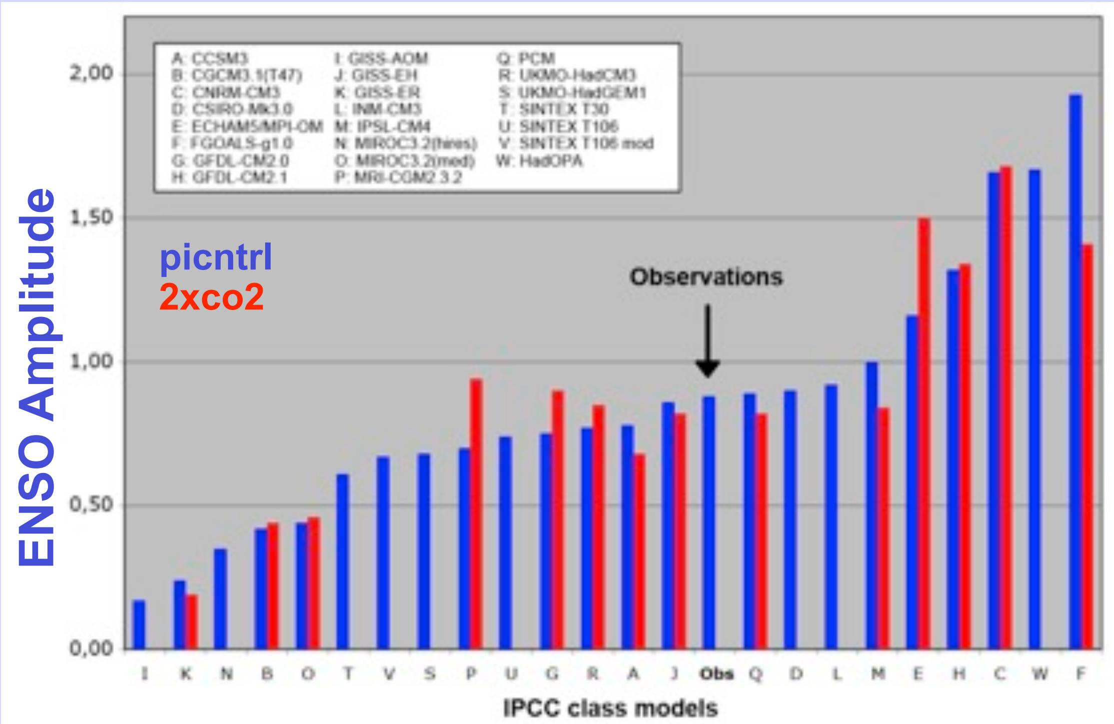
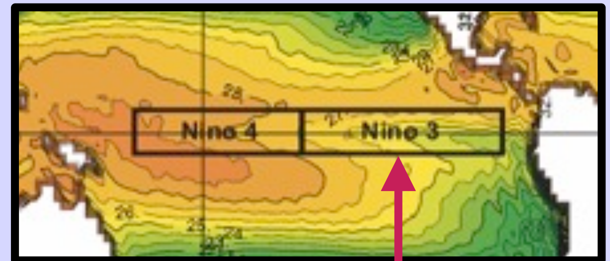
El Niño in coupled GCMs: too much diversity





Standard deviation SSTA (C)

ENSO amplitude in IPCC AR4 : much too large diversity !

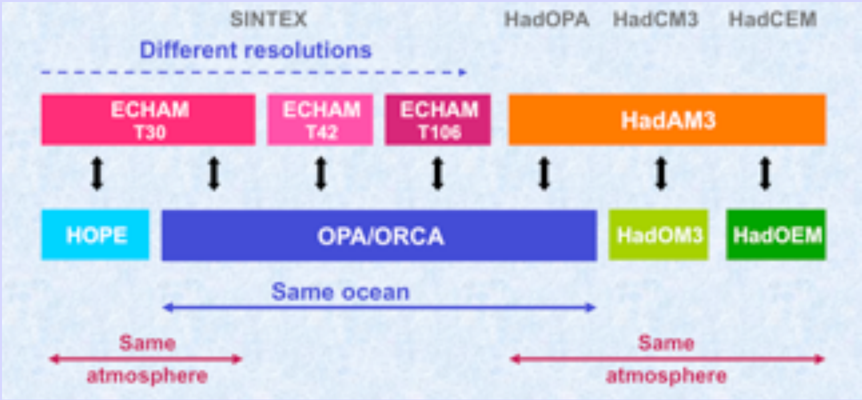
Model biases dominate over scenario

IPCC (2007)
Guilyardi et al. (BAMS 2009)
Collins et al. (NGEO 2010)

Atmosphere feedbacks during ENSO

Multi-model and sensitivity studies show that <u>AGCM has a dominant role</u>

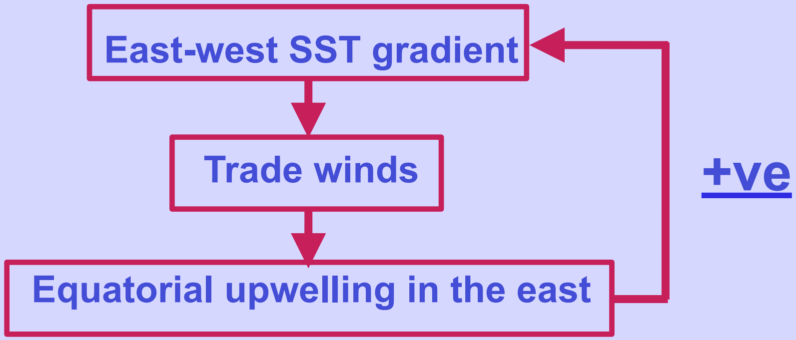
(e.g. Schneider 2002, Guilyardi et al. 2004, Kim et al. 2008, Neale et al. 2008, Sun et al. 2008, 2010...)



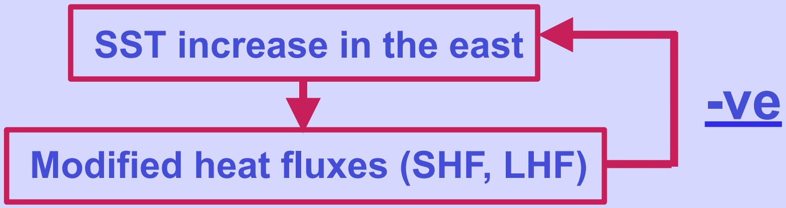
Guilyardi et al. (2004)

Two types of feedbacks:

Dynamical: Bjerknes feedback μ



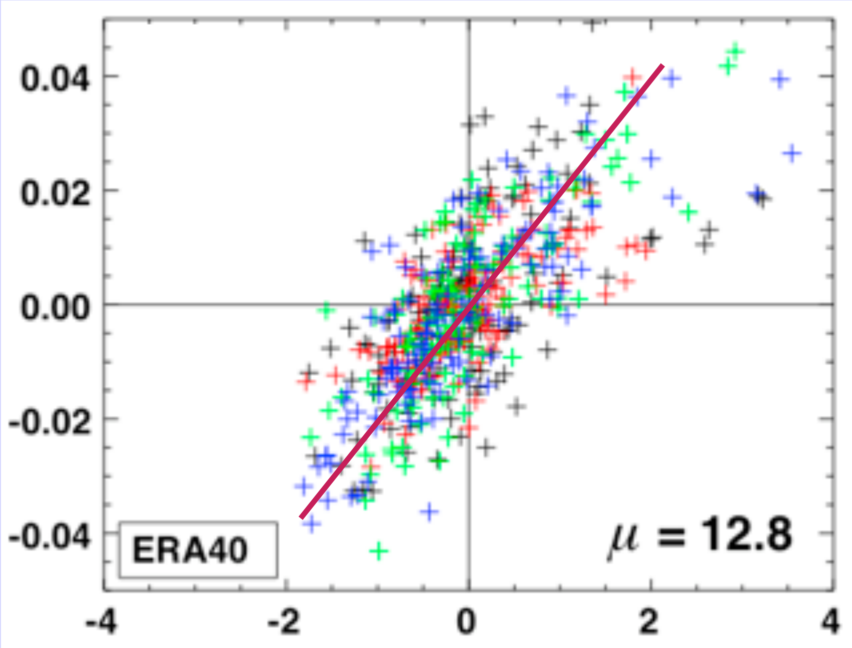
Heat flux feedback (response) α



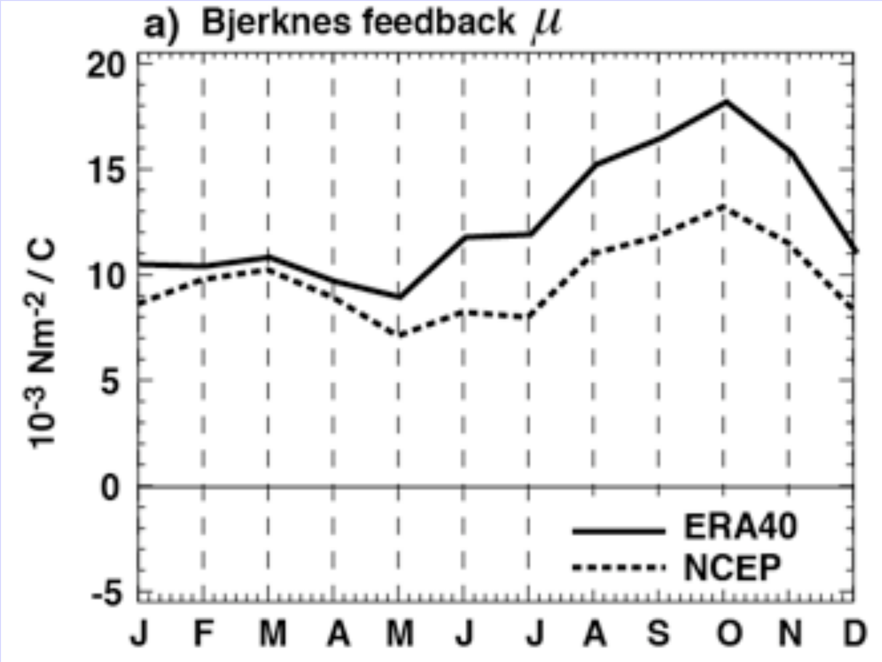
This talk: what for μ and α in model ENSO diversity ?

Evaluating the Bjerknes feedback μ

Niño 4 TauX anomaly



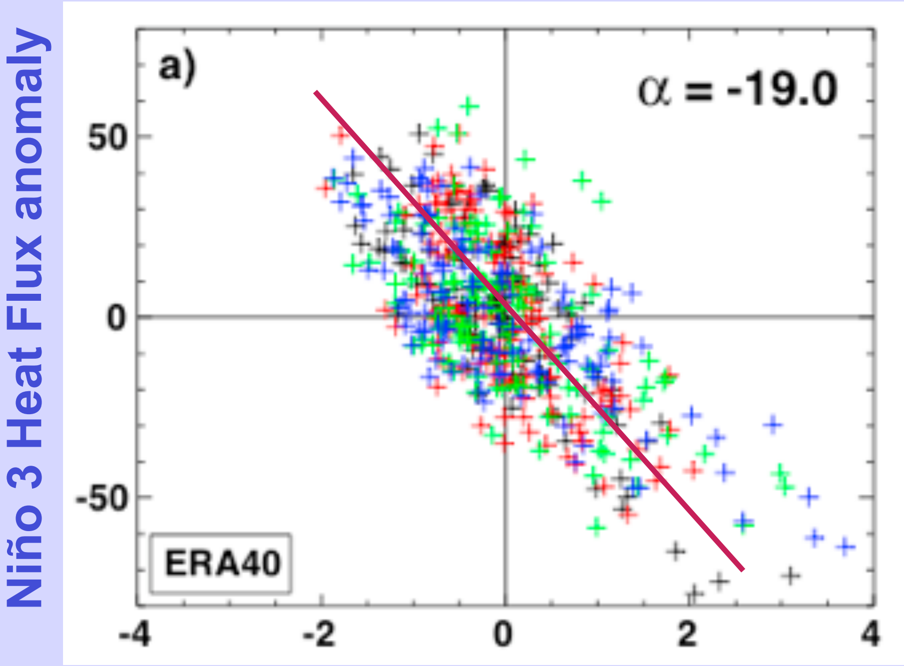
Niño 3 SST anomaly

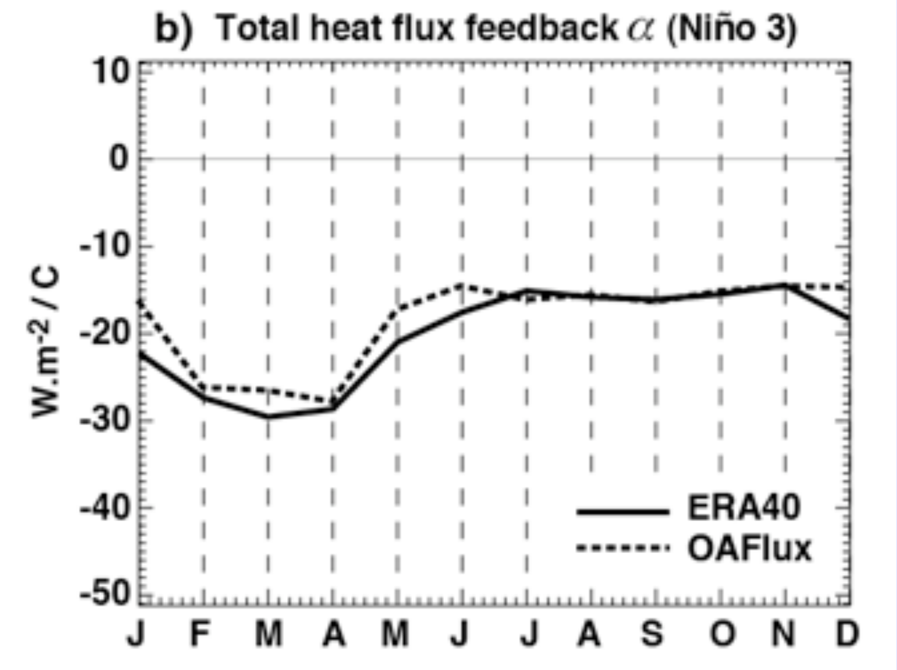


Seasonal evolution of μ

- Monthly variability = measure of seasonal phase lock
- Bjerknes amplification stronger in July-December
- Obs. values of μ vary from 10 to 15 (10^{-3} $N.m^{-2}$/C)

Evaluating the heat flux feedback α





- Defined as slope of heat flux QA = F(SSTA)
- α varies from -10 W.m^{-2}/C to -40 W.m^{-2}/C
- Damping stronger in January-May

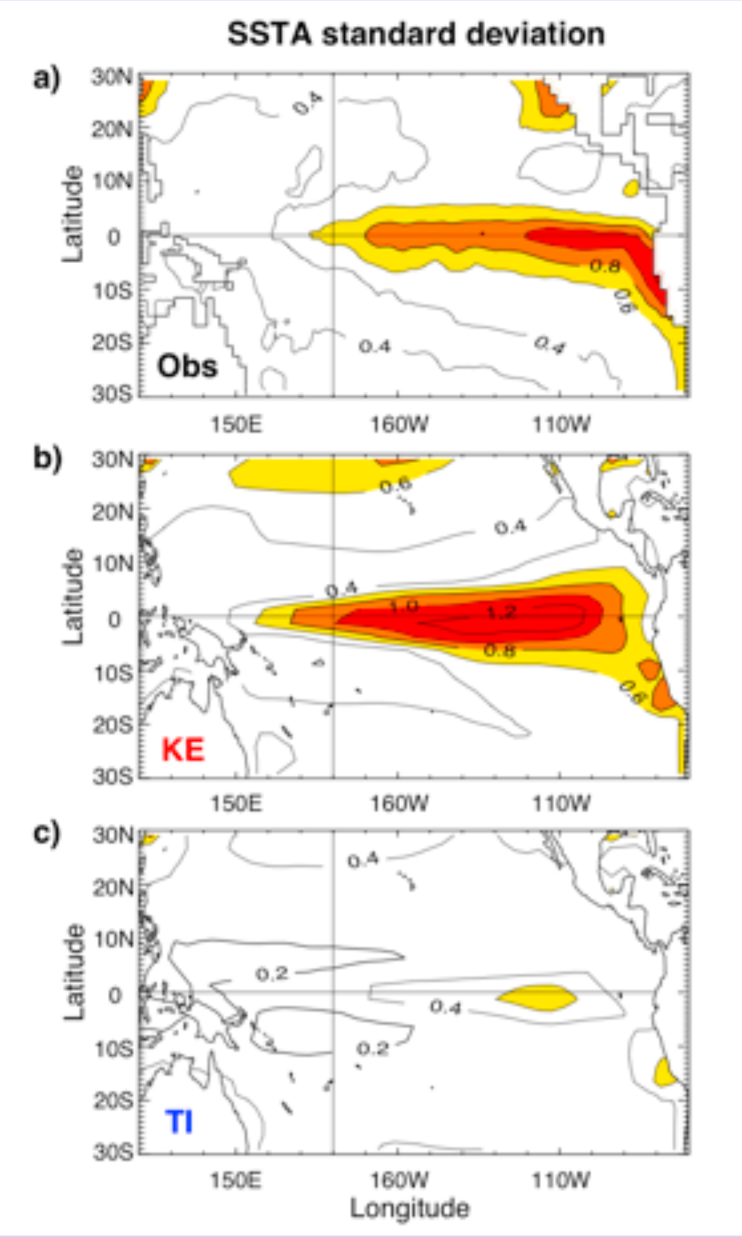
Impact of atmosphere convection scheme on ENSO

IPSL-CM4 model

Observations
(0.9 C) - HadiSST1.1

IPSL (KE)
Kerry Emanuel
(1.0 C) - in IPCC

IPSL/Tiedke (TI)
(0.3 C) – old scheme



ENSO has disappeared !

What role for α and μ ?

Guilyardi et al. (JClim 2009b)

Impact of deep convection scheme on atmosphere feedbacks during ENSO

	μ	α	El Niño Amplitude
Obs	~10	-18	0.9
KE	4	-5	1.0
TI	4	-20	0.3
	10^{-3} N.m^{-2}/C	*W.m^{-2}/C*	*^{o}C*

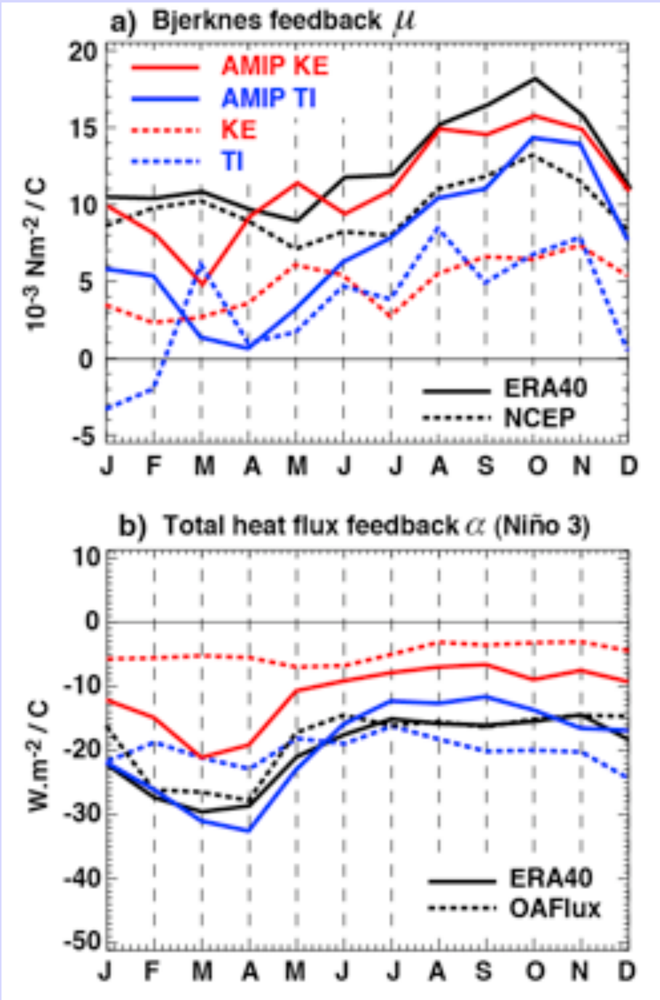
→ Error compensation !

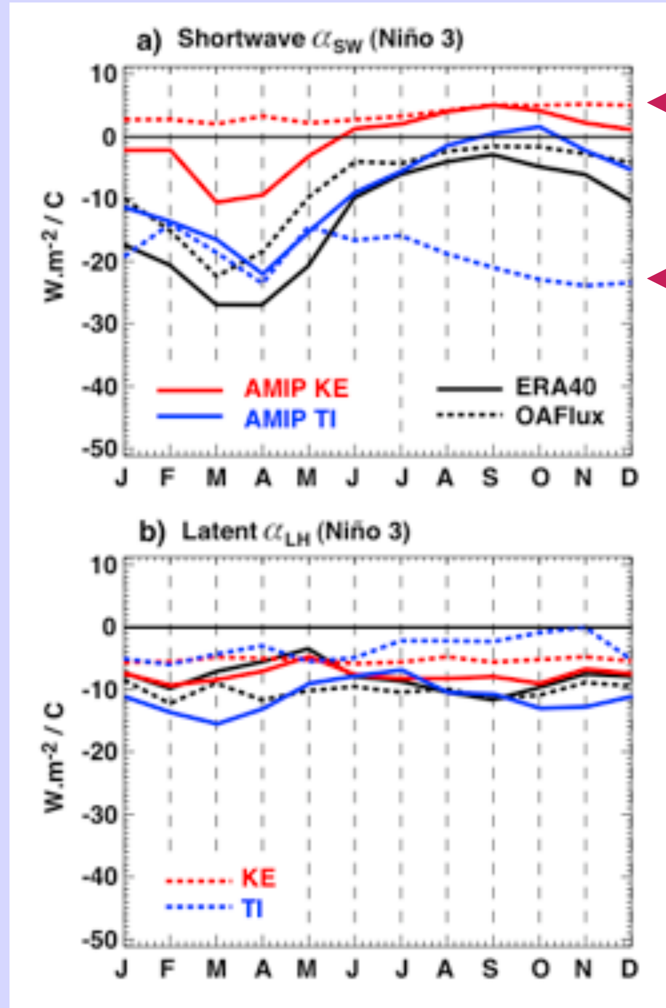
↓ **Too weak** (can improve with atmosphere resolution)

↓ **Due to shortwave feedback difference** (convection stronger in TI)

→ **Need to get the right ENSO amplitude for the right reasons !**

Seasonal evolution of feedbacks





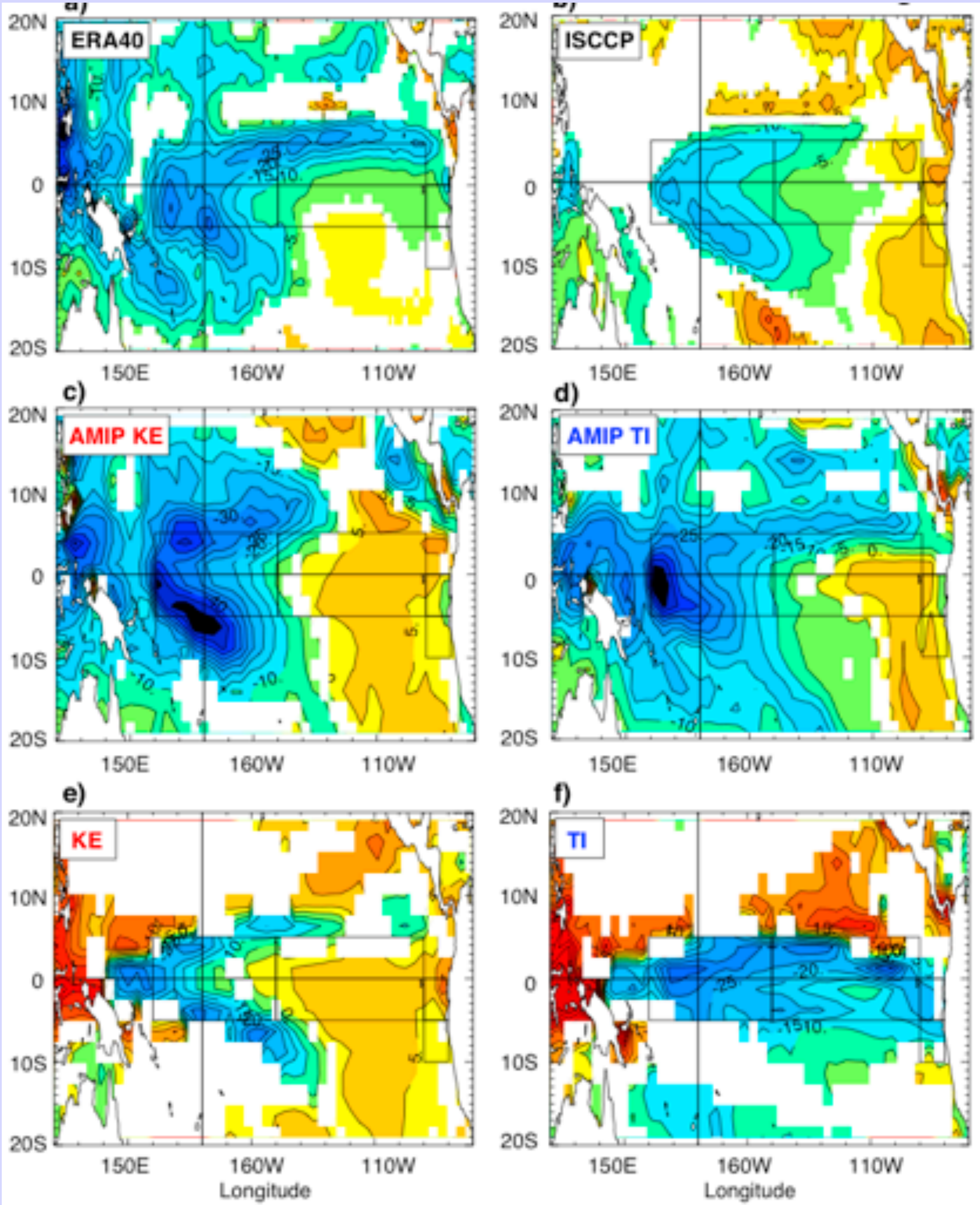
-25 W.m^{-2}/C

<=>

1^{o}C/month in SST cooling !!!

(MXL 50 m, SSTA of 2^{o}C)

- **Shortwave HF feedback α_{SW} in second half of year explains most of the difference**

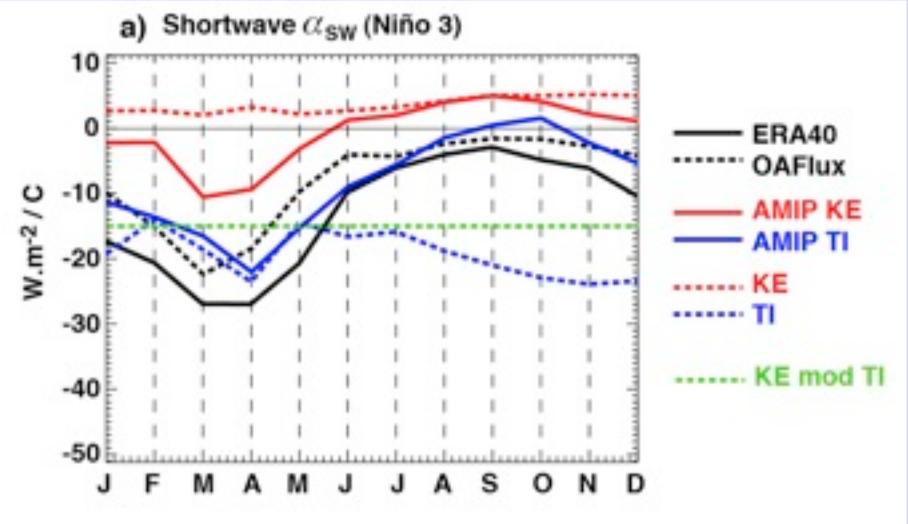


α_{SW} feedback distribution

- ***JASOND point-wise regression of SHF anomaly vs. SSTA** (correl. less than 0.2 blanked out)*
  - **Negative feedback (blue) = convective regime**
  - **Positive feedback (red/orange) = subsidence regime**
- **ERA40 has large errors in East Pacific** (Cronin et al. 2006)
- **AMIP KE closer to ISCCP**
- **AMIP TI has too strong convection**
- **In KE, subsidence/+ve α_{SW} invades central Pacific**
- **In TI, convection/-ve α_{SW} invades east Pacific**
- **Coupled vs. forced** (Yu & Kirtman 2007)

Can we suppress ENSO in KE ?

- Perform KE run with increased α_{SW}
  - Interannual Flux Correction:
    - $SHF_O = SHF_{SC}^{KE} + \alpha_{SW}^{mod} (SST_O - SST_{SC}^{KE})$
    - $\alpha_{SW}^{mod} = -15\ W.m^{-2}$
  - Mean state (SC) unchanged



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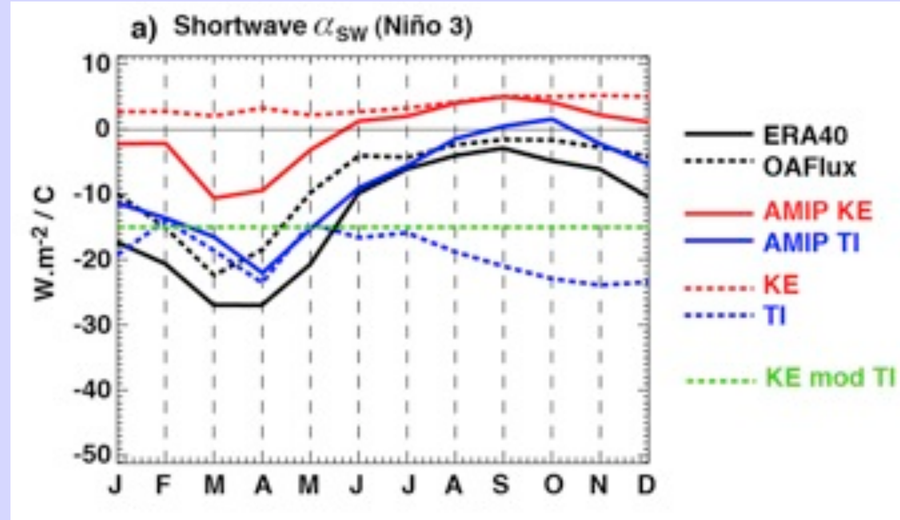
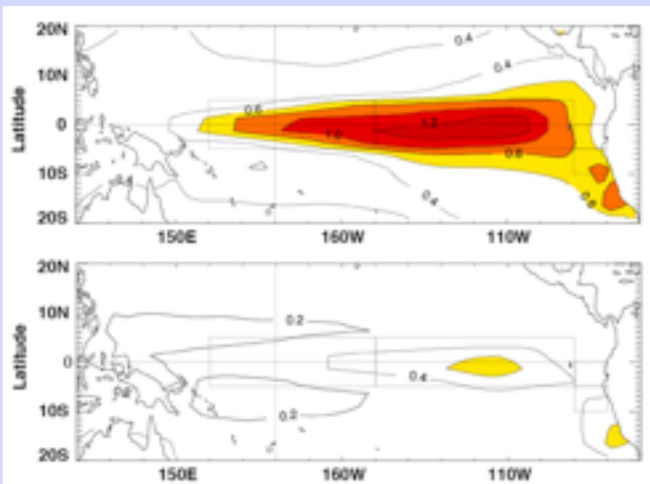


KE

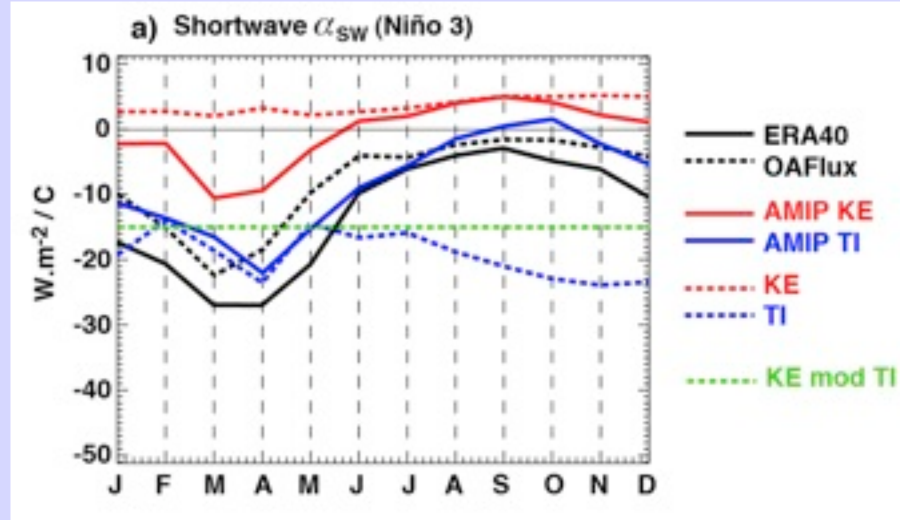
TI



KE mod TI

?

Can we suppress ENSO in KE ?



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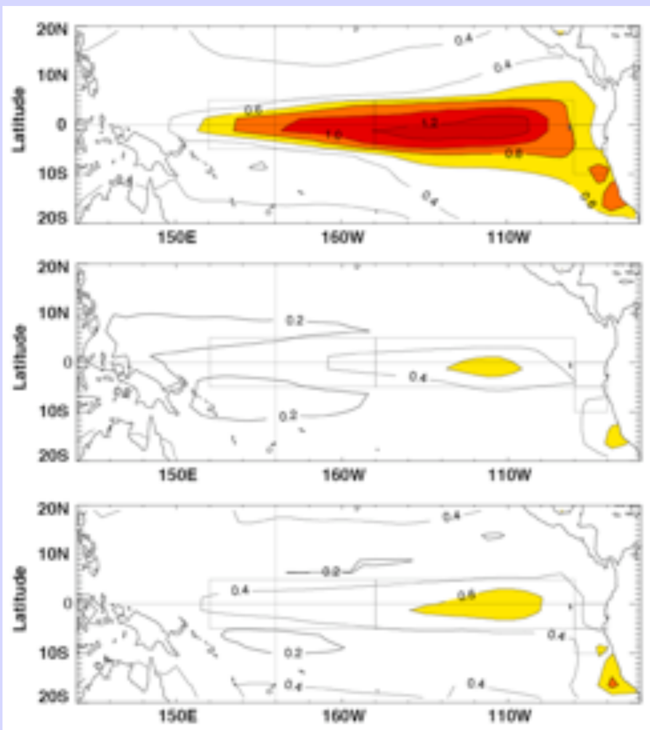
KE

TI

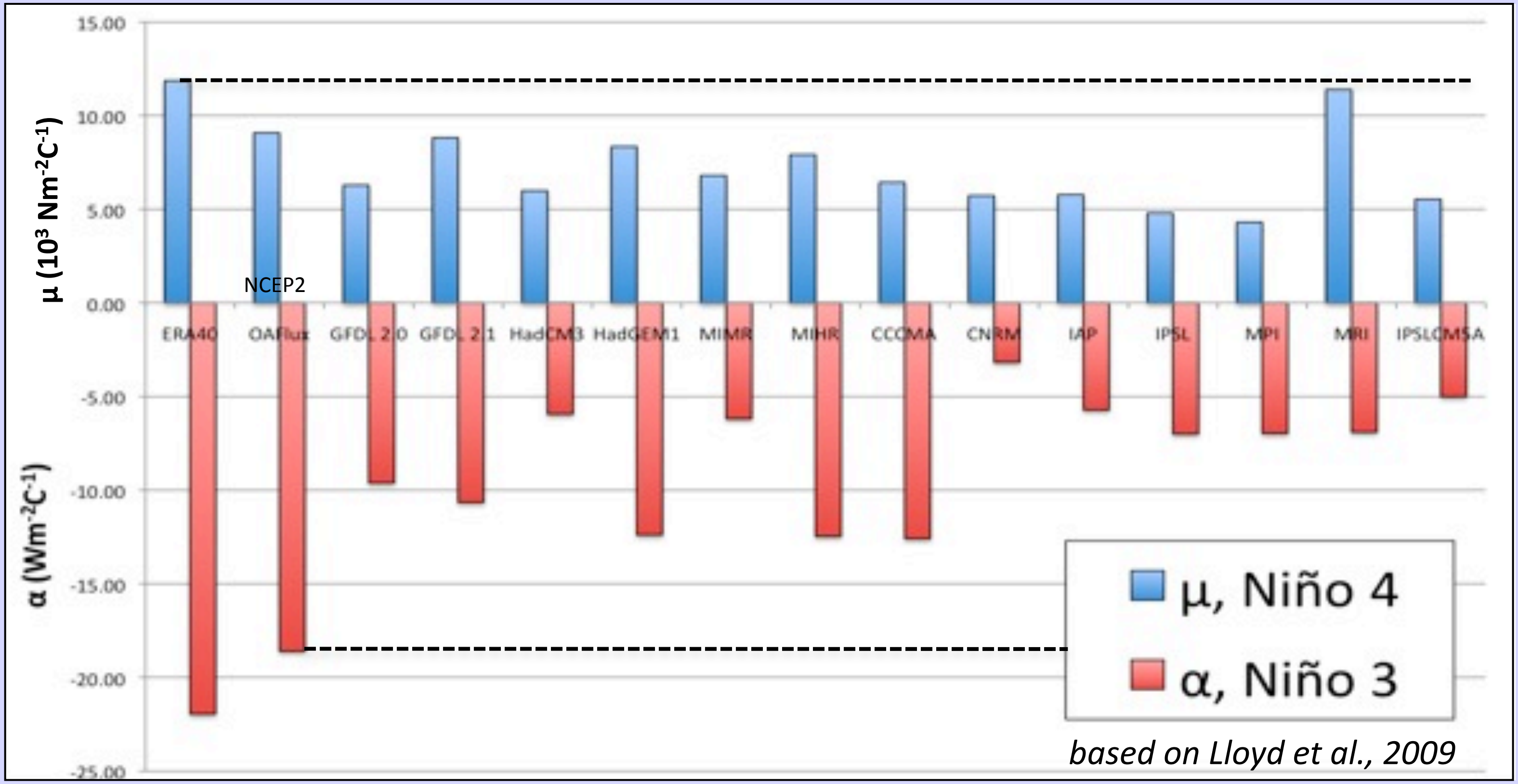
KE mod TI



	μ	α	El Niño Amplitude
Obs	~10	-18	0.9
KE	4	-5	1.0
TI	4	-20	0.3
KE mod TI	5	-21	0.4
	$10^{-3}\ N/m^2/C$	$W/m^2/C$	°C

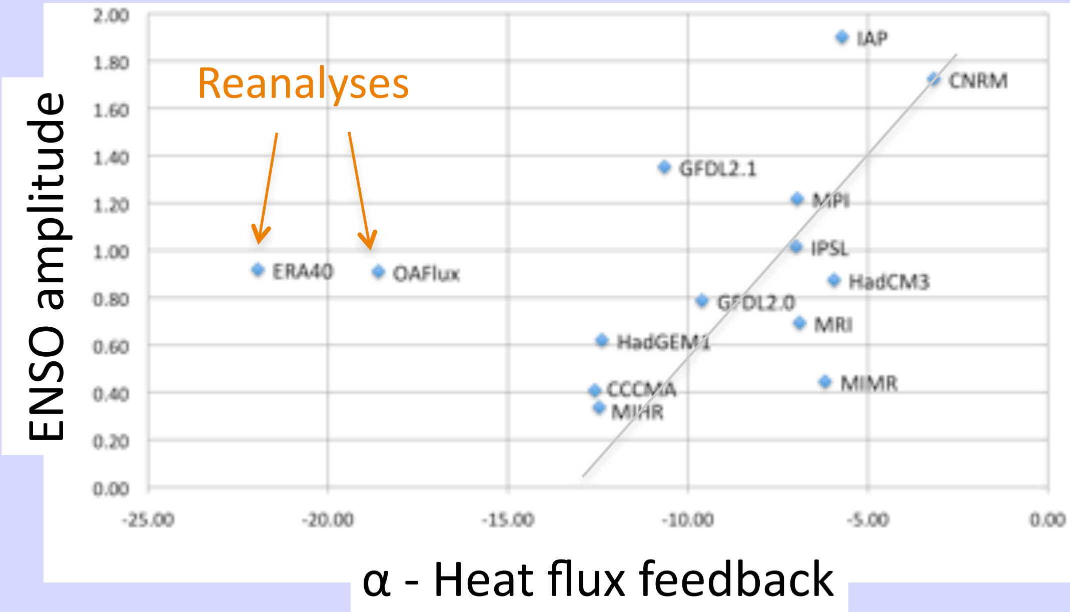
ENSO gone as well !

μ and α in the CMIP3 coupled simulations



- Models underestimate both μ and α with respect to the observed values => error compensation.

ENSO amplitude vs. α



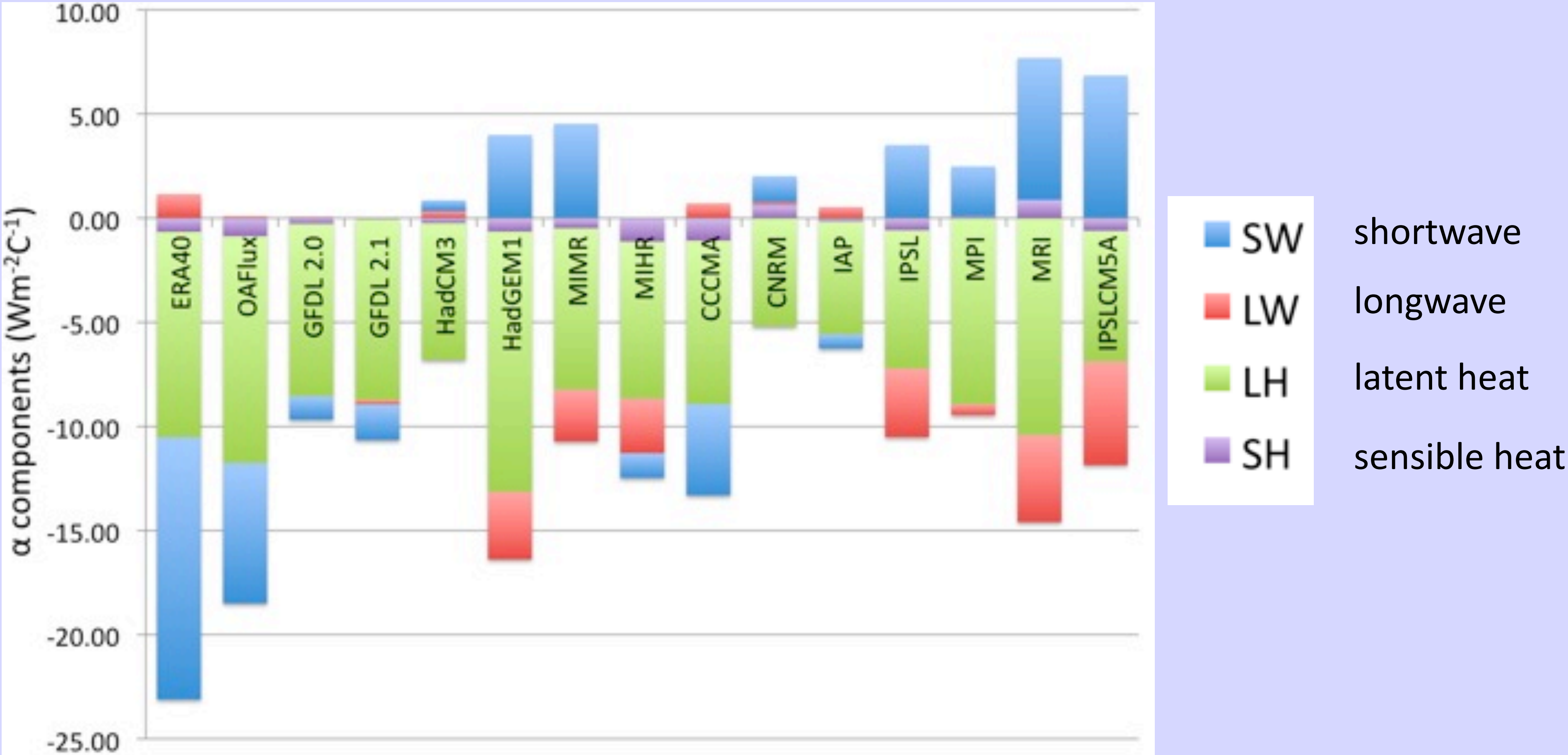
Models with stronger heat flux damping (more negative α) tend to exhibit weaker ENSO, and vice versa
(corr = 0.61, sig. at 0.05 level).

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

- Supported by Kim and Jin (2010,b), who apply BJ index to CMIP3 GCMs to show:

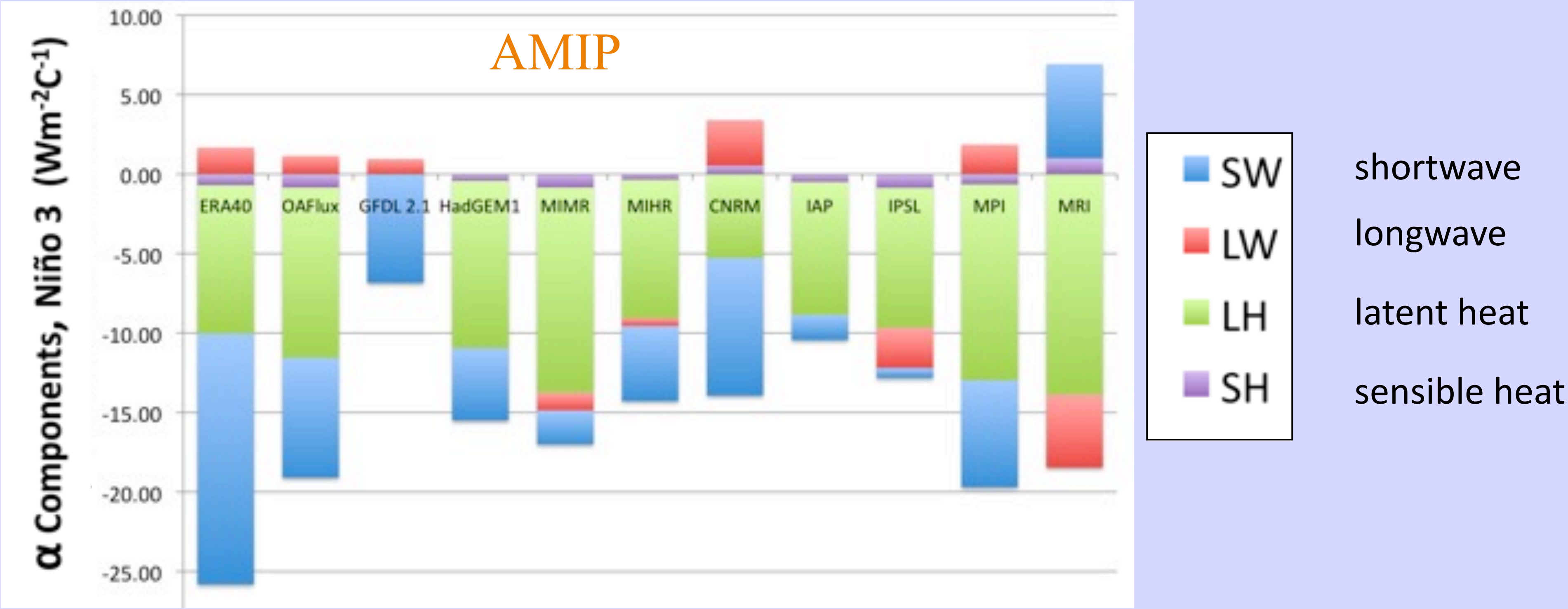
the "*diversity in ENSO stability [amplitude] is attributable to the large model-to-model difference in the* ***sensitivity of the oceanic response to wind forcing*** *and in the* ***atmospheric thermodynamic response to a SST anomaly***".

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})

AMIP heat flux components



- As in the coupled runs, the LH and SW feedbacks dominate.
- Improvements in α_{SW} explain most of the overall α improvement, but α_{SW} biases still dominate.

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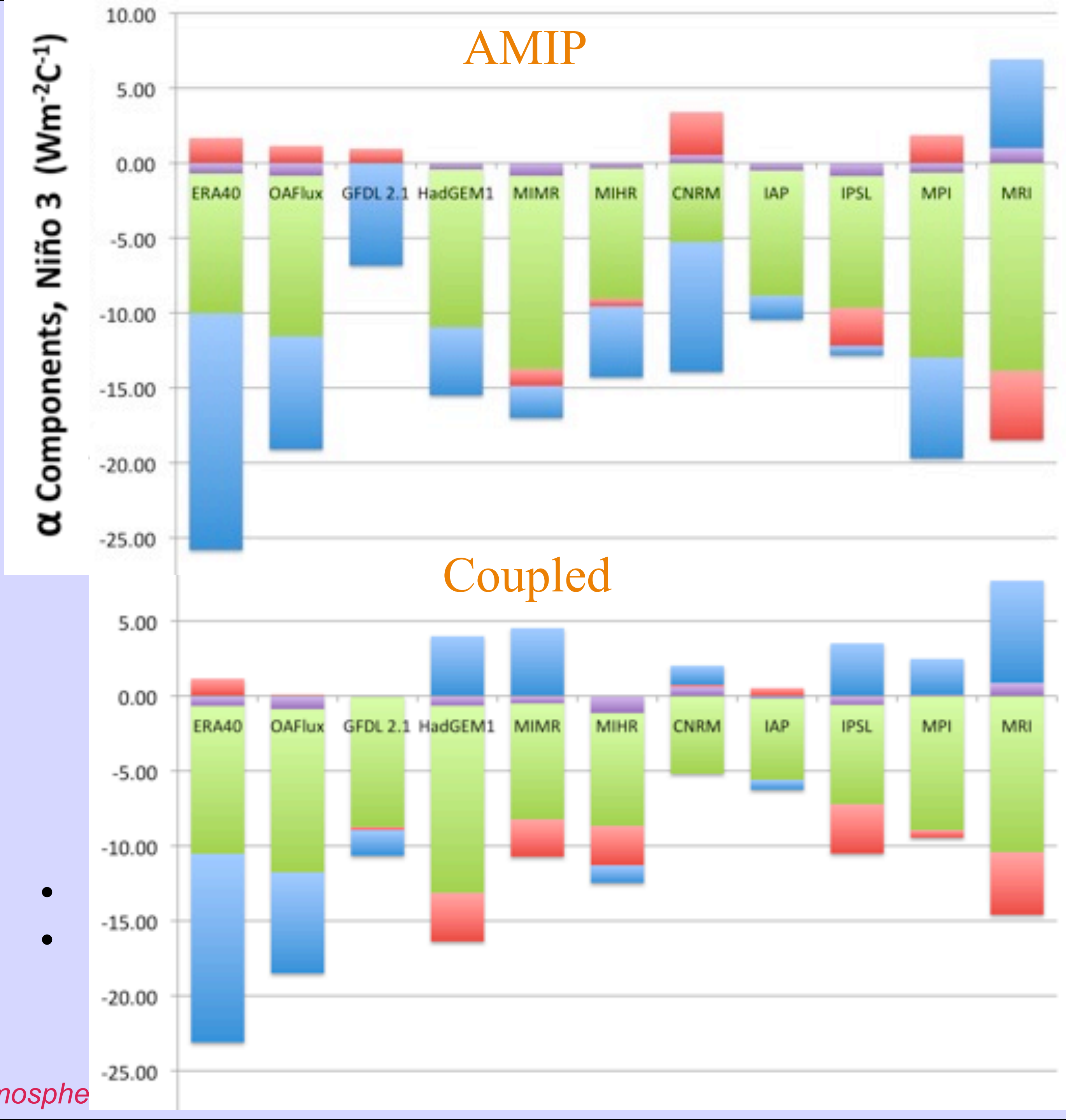


shortwave

longwave

latent heat

sensible heat

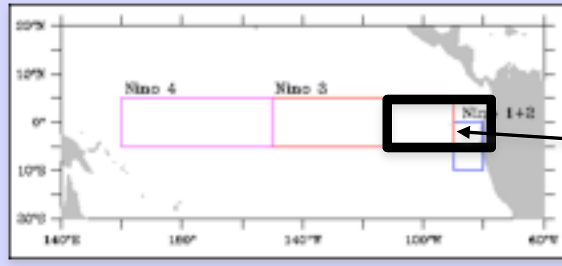
- e.
- ement, but α_{SW} biases

The α_{SW} Feedback Mechanism: Clouds

- No CFMIP in CMIP3 so we use TOA cloud radiative forcing (CRF) to infer cloud details:

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

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



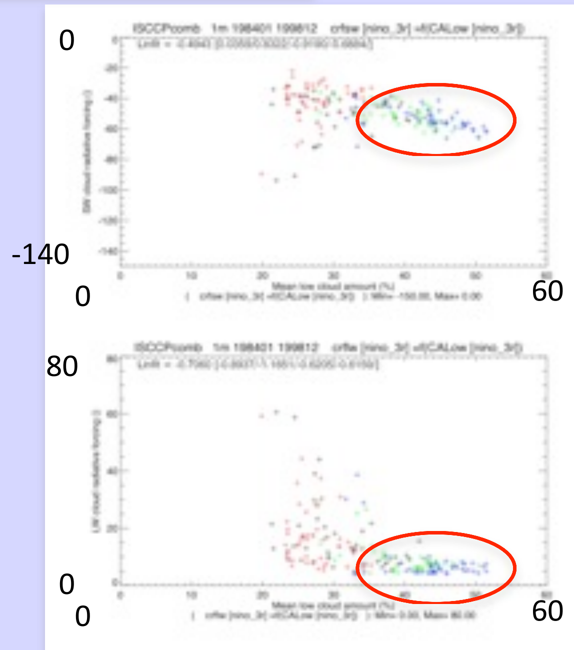
Niño 3r
5°N – 5°S
120°W – 90°W

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}

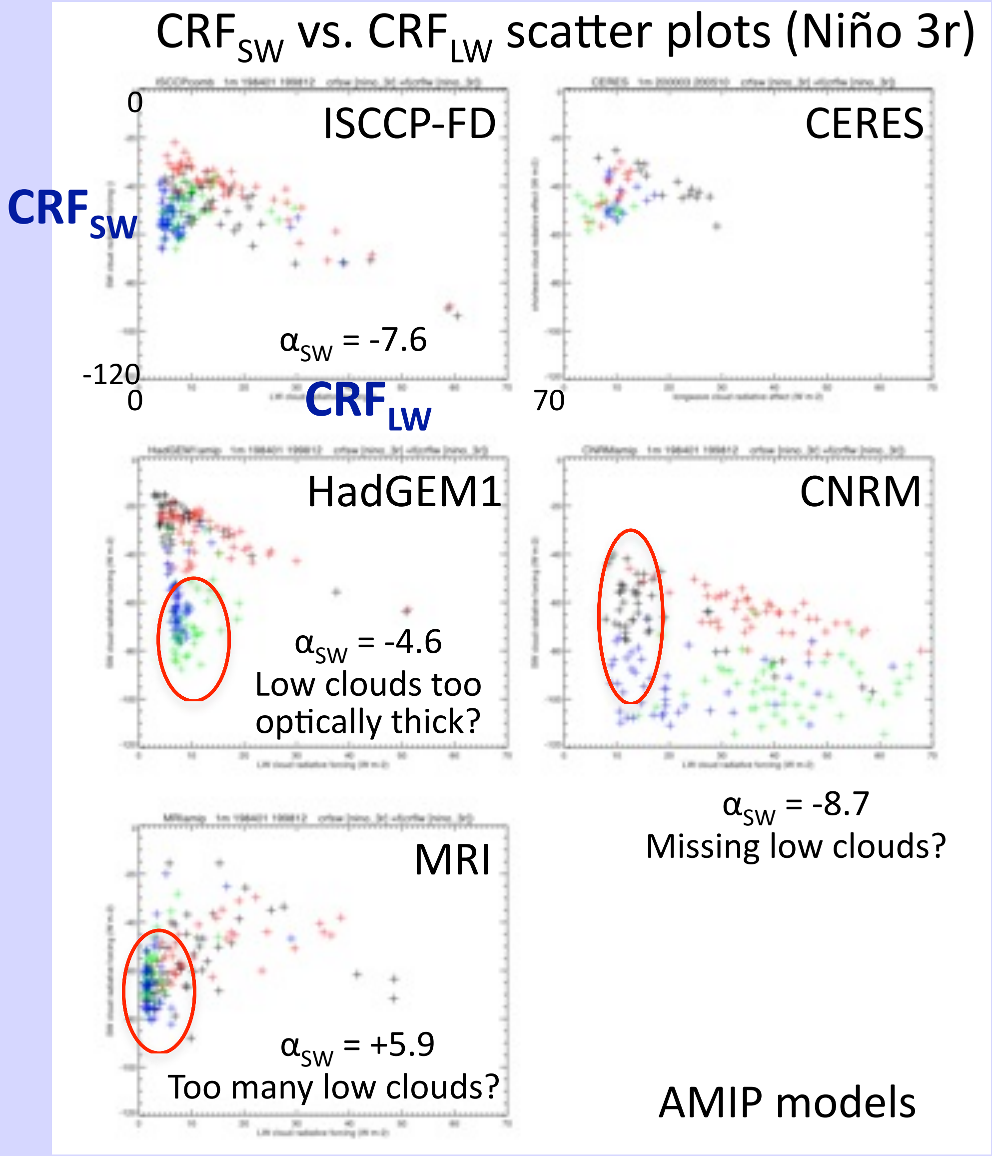
CRF_{LW}



ISCCP low cloud amount

The α_{SW} Feedback Mechanism: Clouds

- 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:** bias towards higher clouds? Explains strong negative α_{SW}?
- **MRI:** bias towards lower clouds? Explains positive α_{SW}?



A simple framework for unravelling α_{SW}

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

(1) (2) (3)

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

	(1) δω500/δSST	(2) δTCC/δω500	(3) δSW/δTCC
AMIP	-0.12	**0.84**	0.50
Coupled	-0.10	**0.82**	-0.19

AMIP

- corr(α_{SW}, $\delta TCC/\delta\omega_{500}$ x $\delta SW/\delta TCC$) = -0.97
- Cloud properties in eastern Pacific are the main source of AMIP α_{SW} errors

Coupled

- $\delta w_{500}/\delta SST$ main cause of Coupled/AMIP difference

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Summary

- **ENSO in IPCC-class GCMs:**
  - **significant progress in CMIP3 vs. previous generations**
  - **still major errors (too much diversity, structure, timing,...)**

AMIP

Coupled

Summary

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- **Atmosphere GCM is a dominant contributor:**
  - Dynamical +ve (μ) and heat flux -ve (α) feedbacks both likely to control ENSO properties in CGCMs
  - Both feedbacks are usually too weak in models
  - Convection scheme has direct impact on α_{SW} (TI vs. KE)
  - This is already seen in AMIP mode
  - Role of clouds dominant (EUCLIPSE)

AMIP

Coupled

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  - **Both feedbacks are usually too weak in models**
  - **Convection scheme has direct impact on α_{SW} (TI vs. KE)**
  - **This is already seen in AMIP mode**
  - **Role of clouds dominant (EUCLIPSE)**

- **α_{SW} analysis provides a framework to attribute errors**

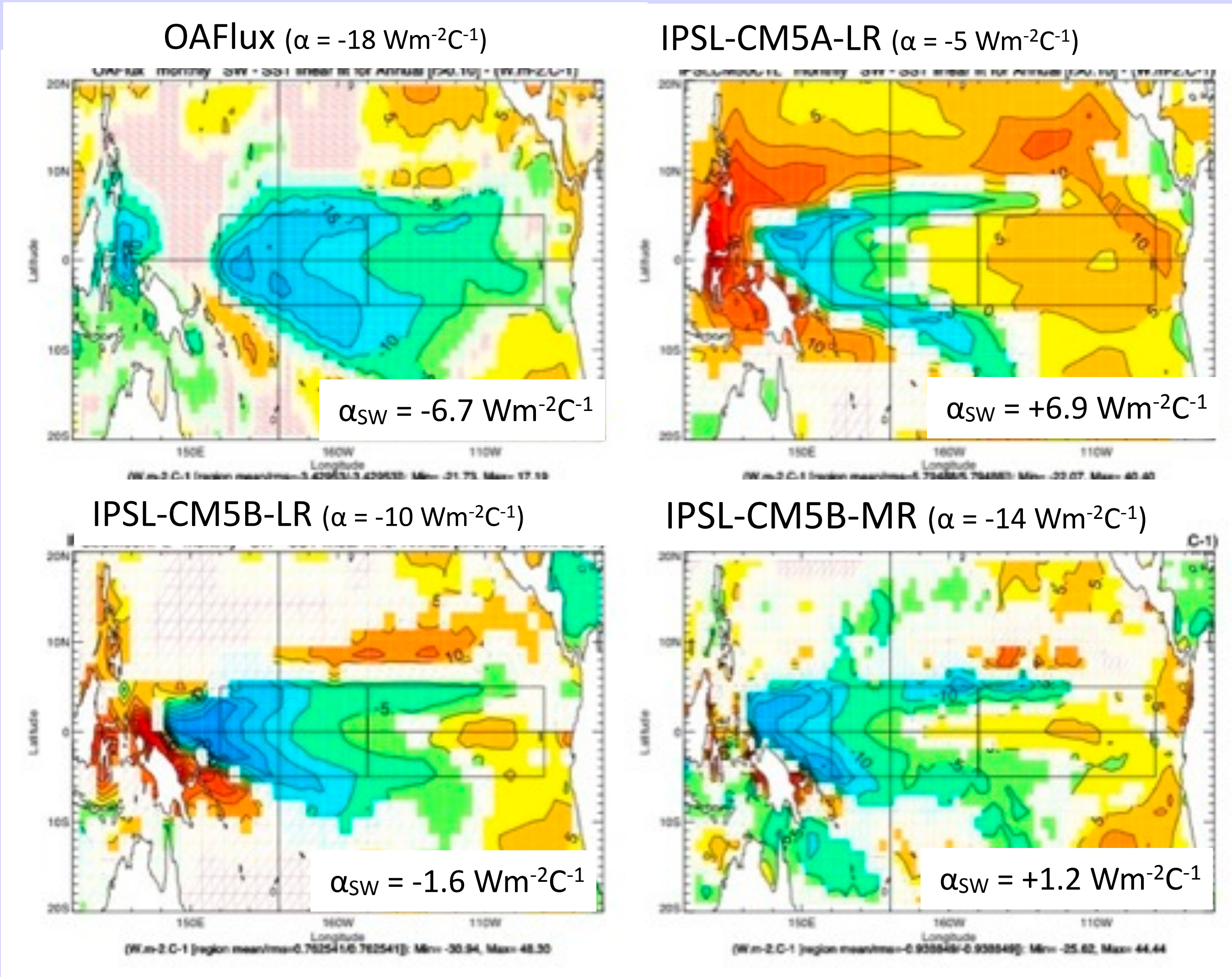
$$\frac{\partial SW}{\partial SST} = \underbrace{\frac{\partial \omega_{500}}{\partial SST} \times \underbrace{\frac{\partial TCC}{\partial \omega_{500}} \times \frac{\partial SW}{\partial TCC}}_{\text{AMIP}}}_{\text{Coupled}} \approx \alpha_{SW}$$

- **Caveat on non-local / non-linear part**

EUCLIPSE analysis plans for WP2

- Is ENSO better simulated in CMIP5 models (CLIVAR metrics)?
- Can we link improvement (if any) of modeled ENSO with atmospheric feedbacks representation? And can we understand the reason why?
  - Understand cloud-related mechanisms vs. dynamical
    - e.g. α_{SW}: understand the 3-way relationship: SST – Large-Scale Dynamics (ω_{500}) – Clouds (low-mid-high)
  - Explore links with other biases (double ITCZ, MJO errors,...)
  - Role of scale interactions, non-linearities (annual cycle, MJO, cyclones, convection threshold…)

Shortwave flux feedback in IPSL-CM5A and IPSL-CM5B

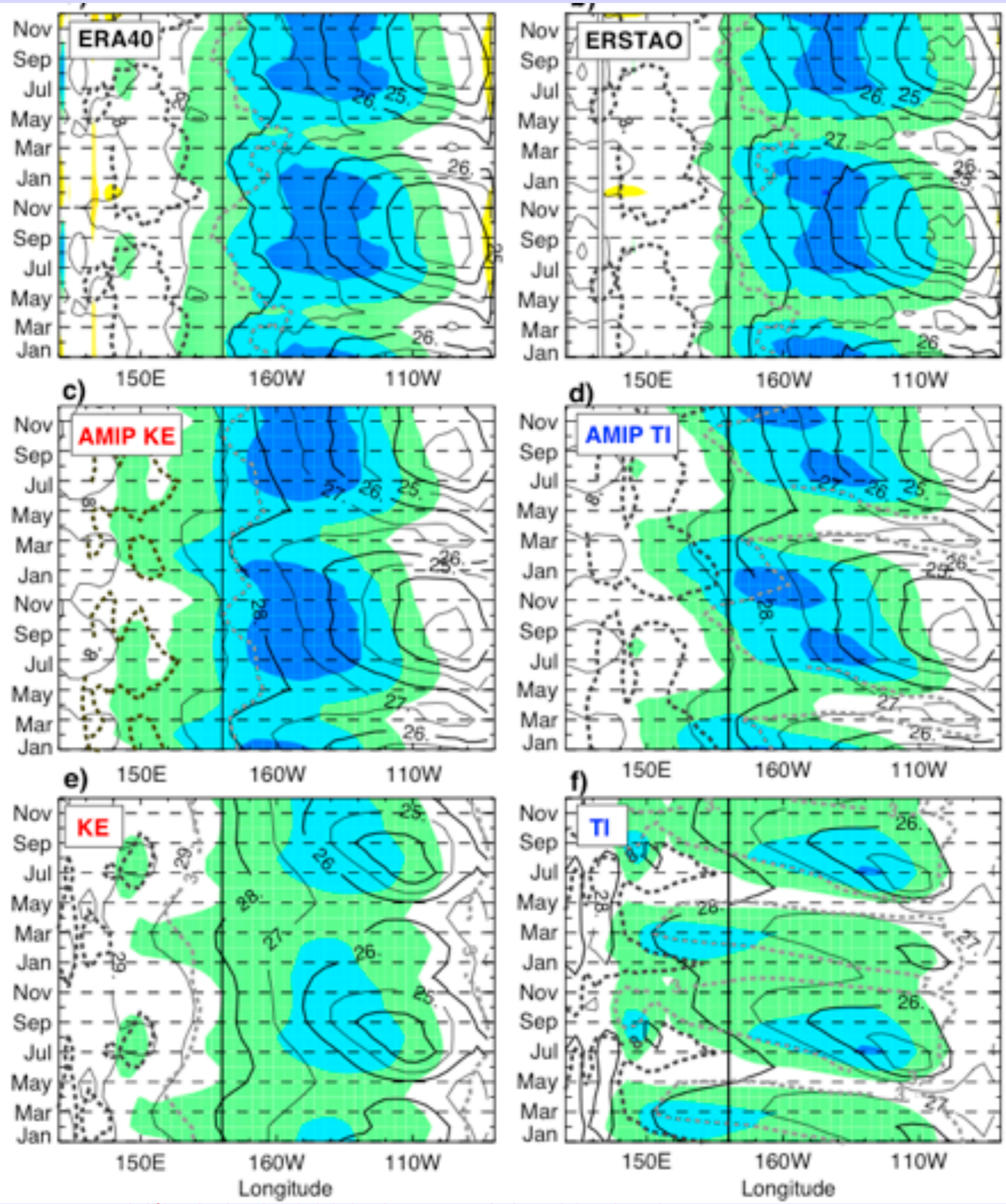


IPSL-CM5A has a stronger positive α_{SW} than any of the CMIP3 runs.

IPSL-CM5B (new atmosphere physics) shows considerable improvements

IPSL-CM4: α = -7 $Wm^{-2}C^{-1}$

α_{SW} = +3.5 $Wm^{-2}C^{-1}$



Mean seasonal cycle at Equator

- ***Wind stress (shading)***
- ***SST (solid contours)***
- ***Precipitation (3 and 8 mm/day dashed)***

- **AMIP KE performs rather well**
- **Convection in AMIP TI too strong and triggered early**

- **Biases amplified in coupled mode**
- **Semi-annual cycle in TI**
- **Similar errors than for ENSO**