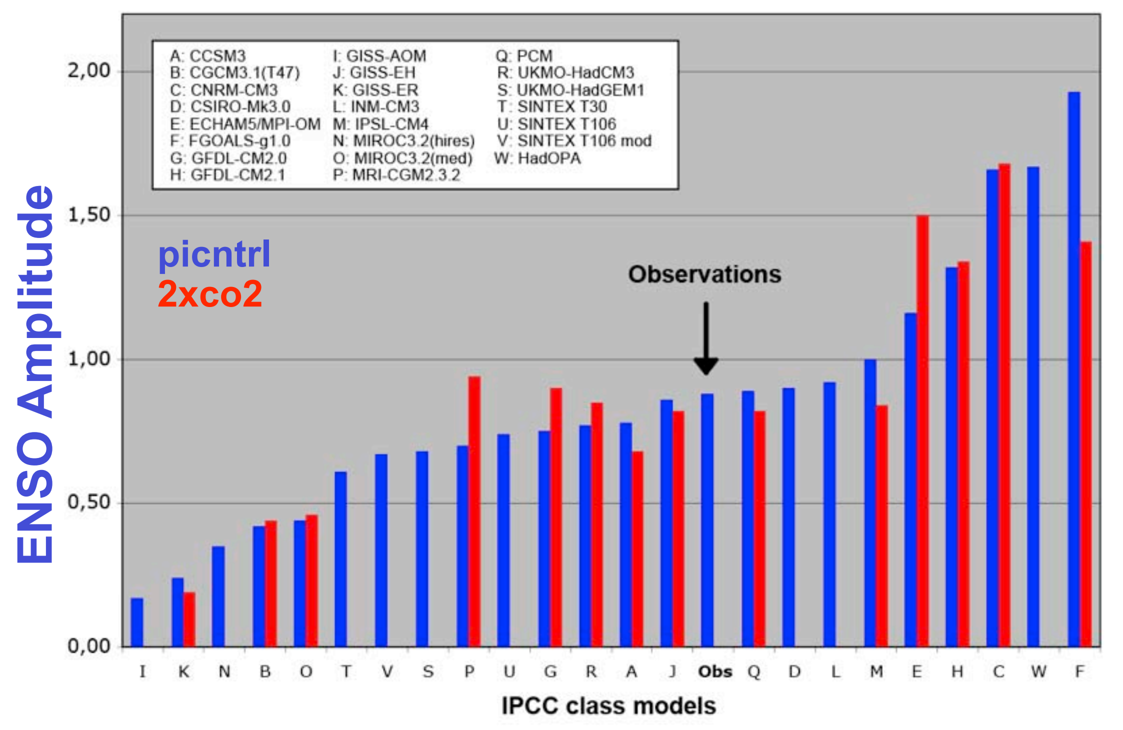
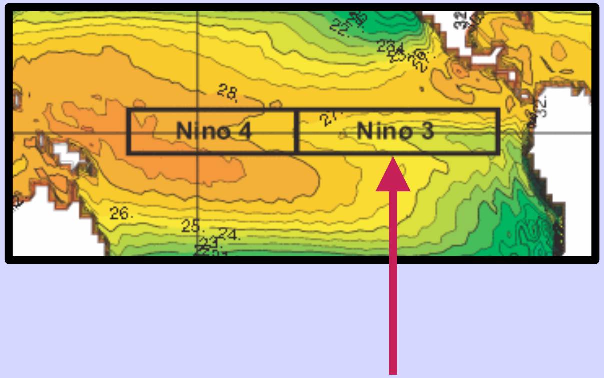
Atmosphere feedbacks during ENSO in a coupled GCM with a modified atmospheric convection scheme

Eric Guilyardi, Pascale Braconnot, Fei-Fei Jin,
Seon Tae Kim, Michel Kolasinski, Tim Li, Ionela Musat

Journées MissTerre - Mai 2009

El Niño in coupled GCMs - amplitude





Standard deviation SSTA (C)

ENSO amplitude in IPCC AR4 : much too large diversity !

Model biases dominate over scenario

El Niño in coupled GCMs - summary

Clear improvement since ~15 years

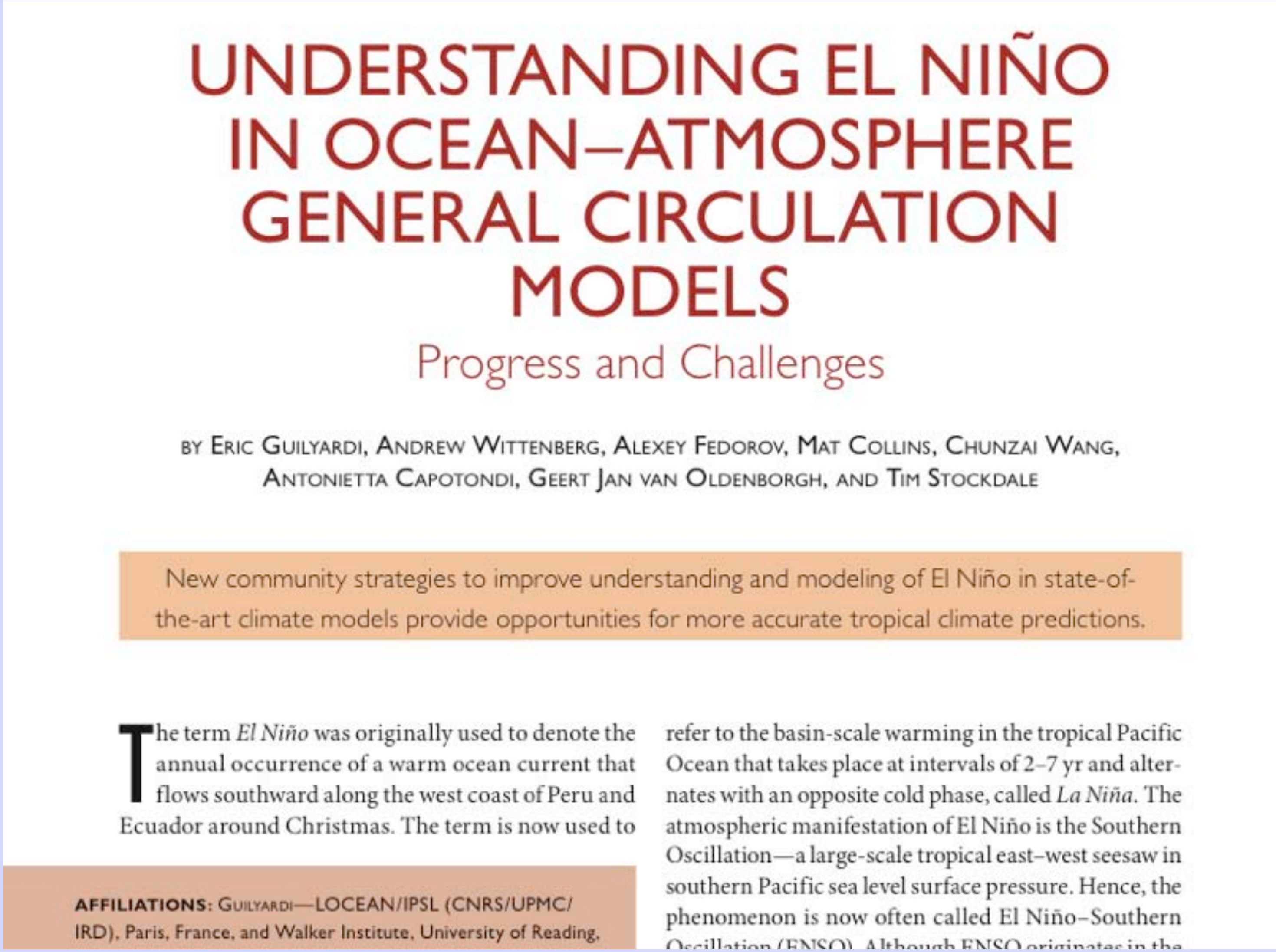
- **some models get Mean *and* Annual cycle *and* ENSO right !**

but:

- **Amplitude: models diversity much larger than (recent) observed diversity**
- **Frequency: progress towards low frequency/wider spectra but still errors**
- **SPL: very few models have the spring relaxation and the winter variability maximum**
- **Structure and timing: westward extension and narrowing around equator, issues with time sequence (onset, termination)**
- **Modes: very few model exhibits the diversity of observed ENSO modes; most are locked into a S-mode (coherent with too strong trade winds)**
- **Teleconnections: ENSO influence over-dominant**

van Oldenborgh et al. (2005), Guilyardi (2006), Guilyardi et al. (2009a)

Article de review



UNDERSTANDING EL NIÑO IN OCEAN–ATMOSPHERE GENERAL CIRCULATION MODELS

Progress and Challenges

BY ERIC GUILYARDI, ANDREW WITTENBERG, ALEXEY FEDOROV, MAT COLLINS, CHUNZAI WANG,
ANTONIETTA CAPOTONDI, GEERT JAN VAN OLDENBORGH, AND TIM STOCKDALE

New community strategies to improve understanding and modeling of El Niño in state-of-the-art climate models provide opportunities for more accurate tropical climate predictions.

The term *El Niño* was originally used to denote the annual occurrence of a warm ocean current that flows southward along the west coast of Peru and Ecuador around Christmas. The term is now used to refer to the basin-scale warming in the tropical Pacific Ocean that takes place at intervals of 2–7 yr and alternates with an opposite cold phase, called *La Niña*. The atmospheric manifestation of El Niño is the Southern Oscillation—a large-scale tropical east–west seesaw in southern Pacific sea level surface pressure. Hence, the phenomenon is now often called El Niño–Southern

AFFILIATIONS: GUILYARDI—LOCEAN/IPSL (CNRS/UPMC/IRD), Paris, France, and Walker Institute, University of Reading,

Bull. Amer. Met. Soc. (March 2009)

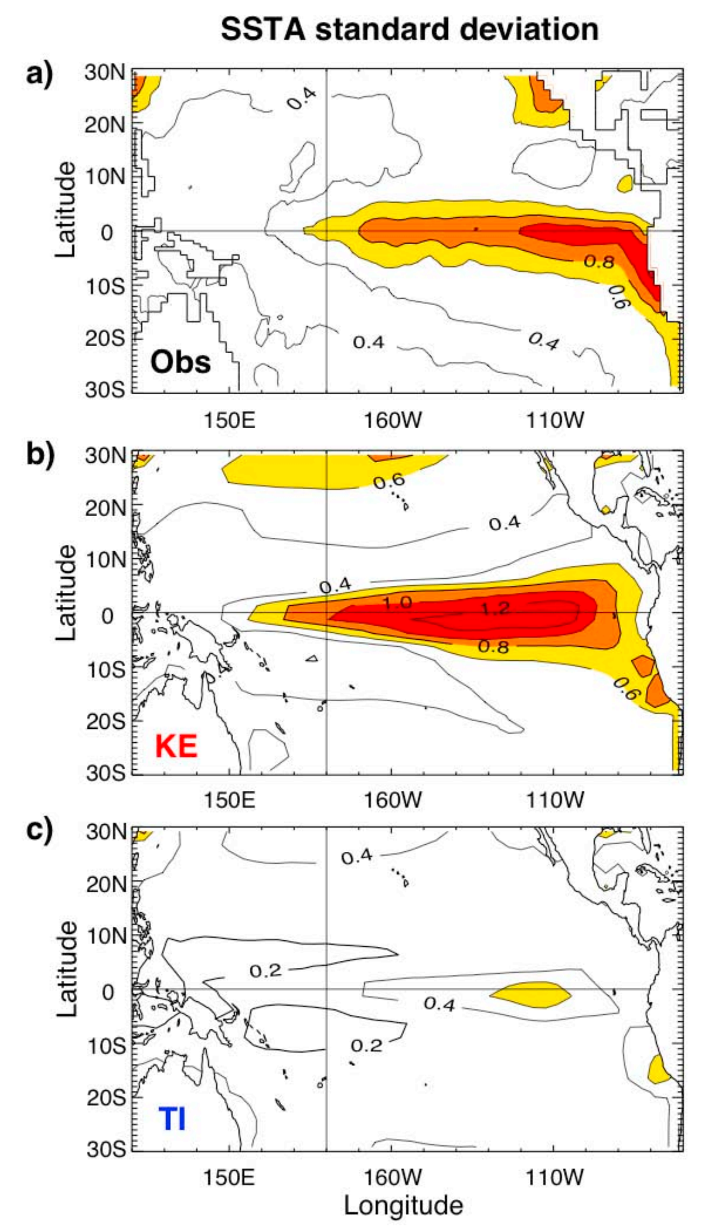
Impact of atmosphere convection scheme on ENSO

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

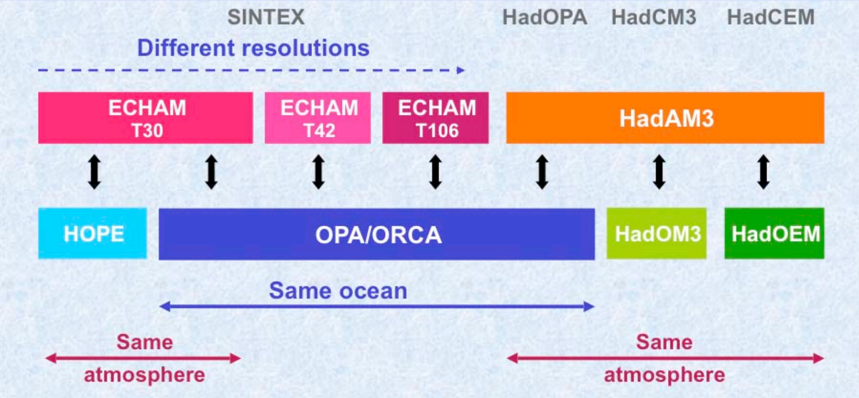


ENSO has disappeared !

Atmosphere feedbacks during ENSO

Multi-model and sensitivity studies show that AGCM has a dominant role

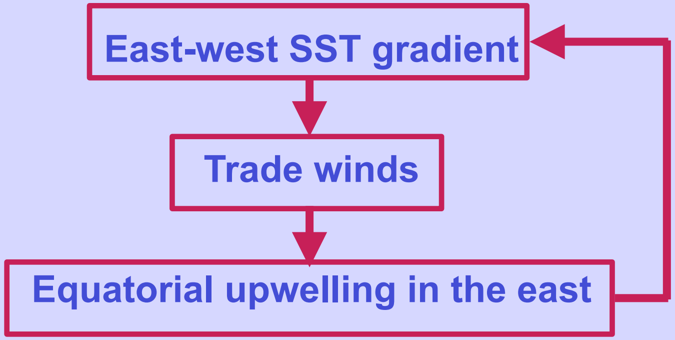
(e.g. Schneider 2002, Guilyardi et al. 2004, Kim et al. 2008, Neale et al. 2008, Sun et al. 2008,...)



Guilyardi et al. (2004)

Two types of feedbacks:

Dynamical: Bjerknes feedback μ



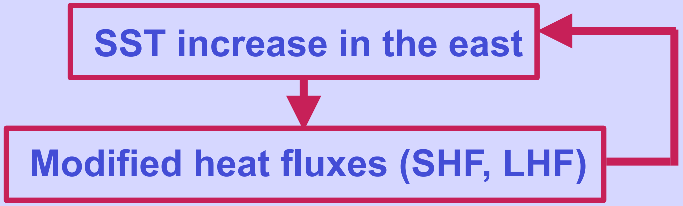
East-west SST gradient

Trade winds

Equatorial upwelling in the east

+ve

Heat flux feedback α

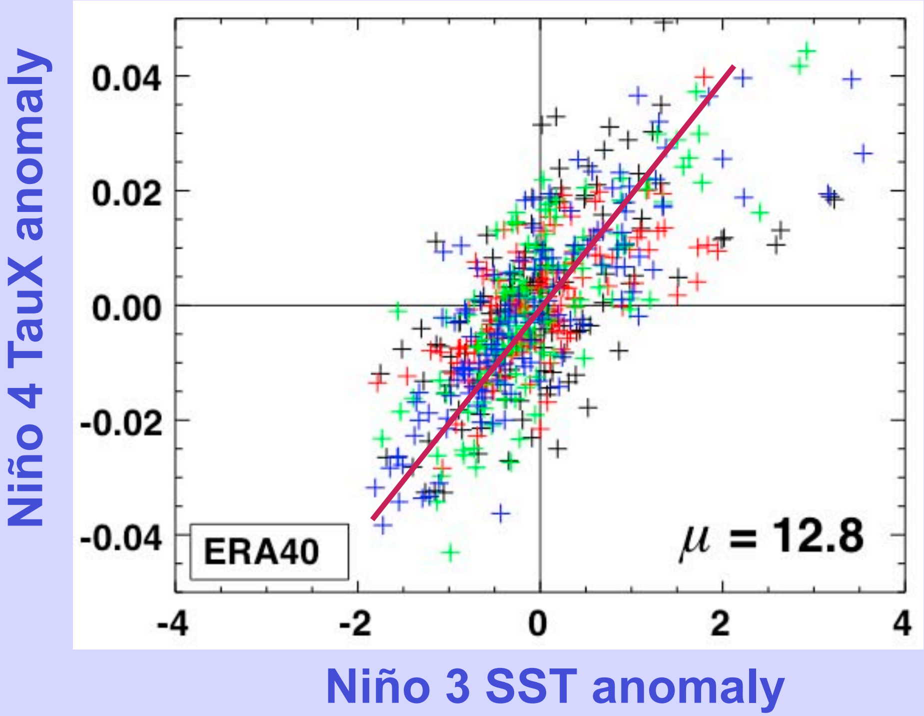


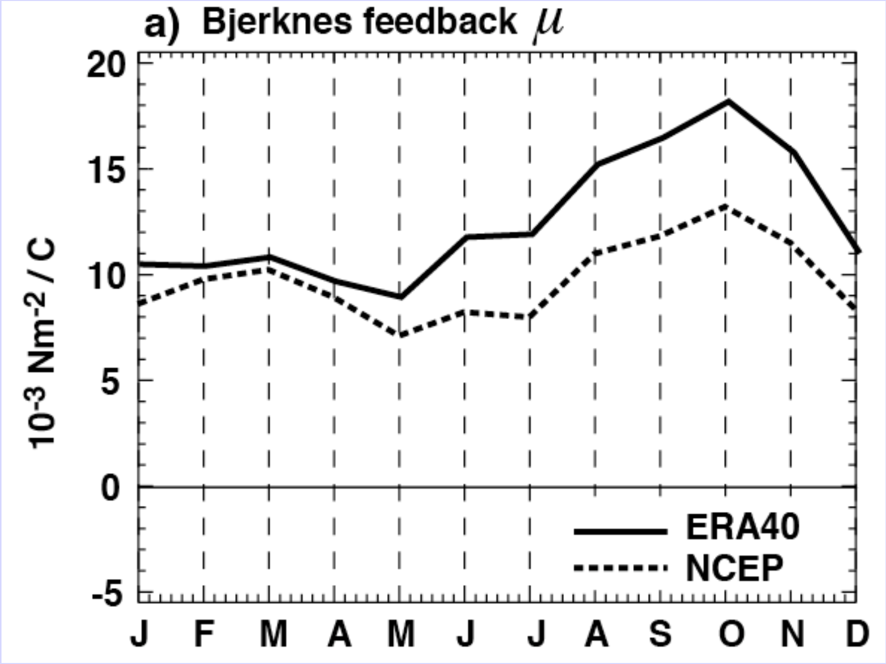
SST increase in the east

Modified heat fluxes (SHF, LHF)

-ve

Evaluating the Bjerknes feedback μ

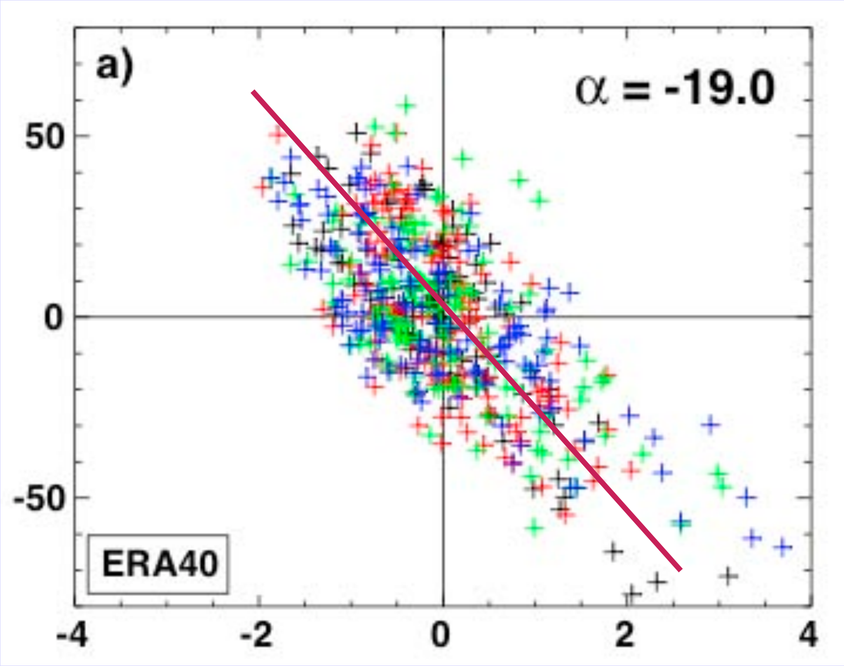




Seasonal evolution of μ

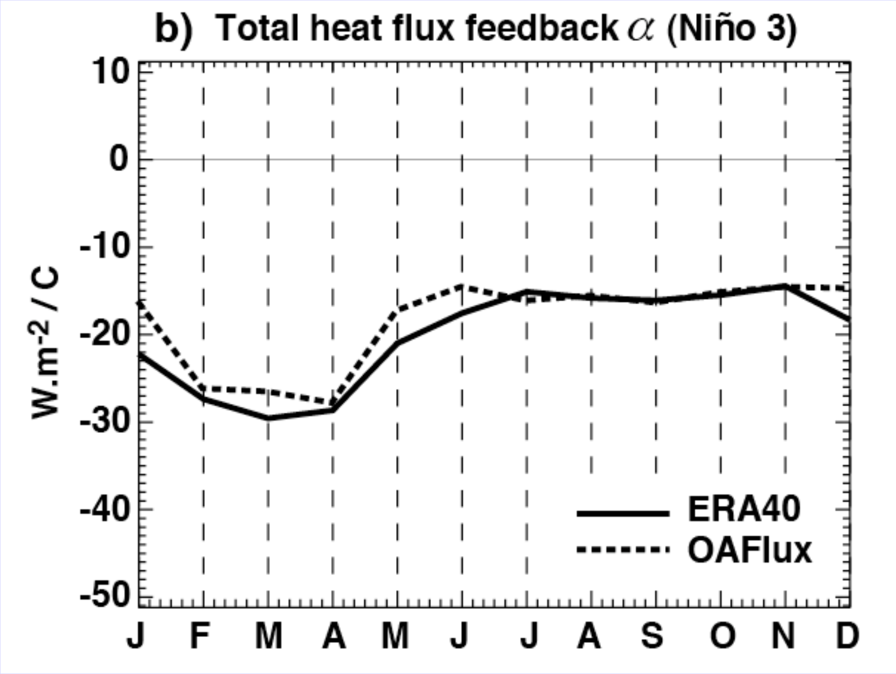
- Monthly variability = measure of seasonal phase lock
- Bjerknes amplification stronger in July-December
- Obs. values of μ vary from 10 to 15 (10^{-3} N.m^{-2}/C)

Evaluating the heat flux feedback α



Niño 3 Heat Flux anomaly

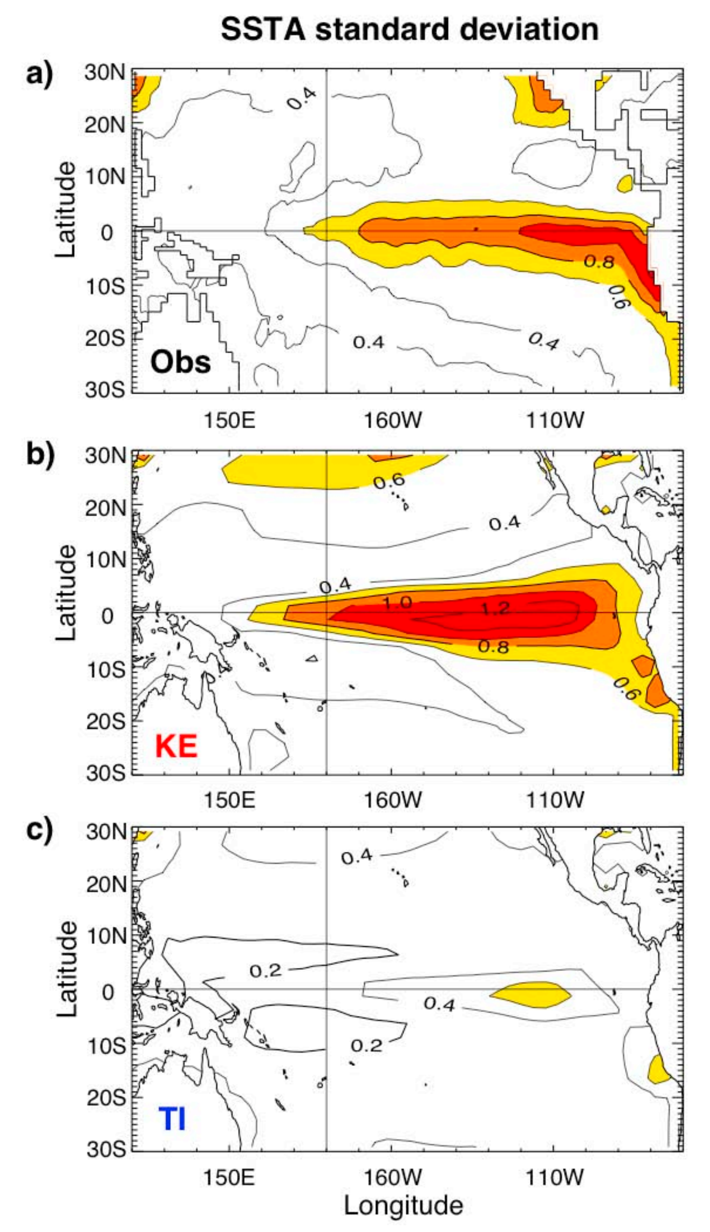
Niño 3 SST anomaly



- 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


SSTA standard deviation

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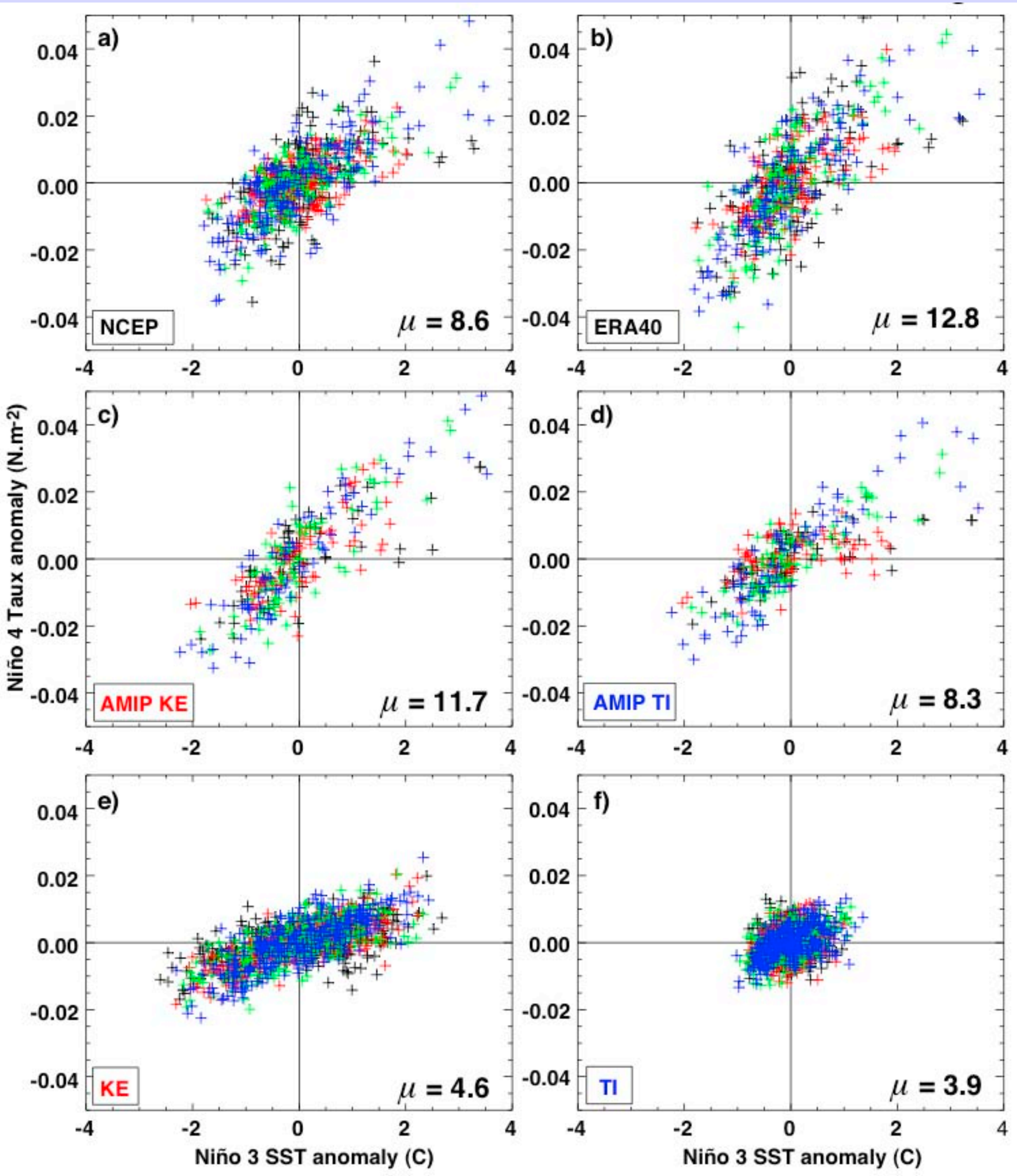
ENSO has disappeared !

What role for α and μ ?

Guilyardi et al. (2009b)

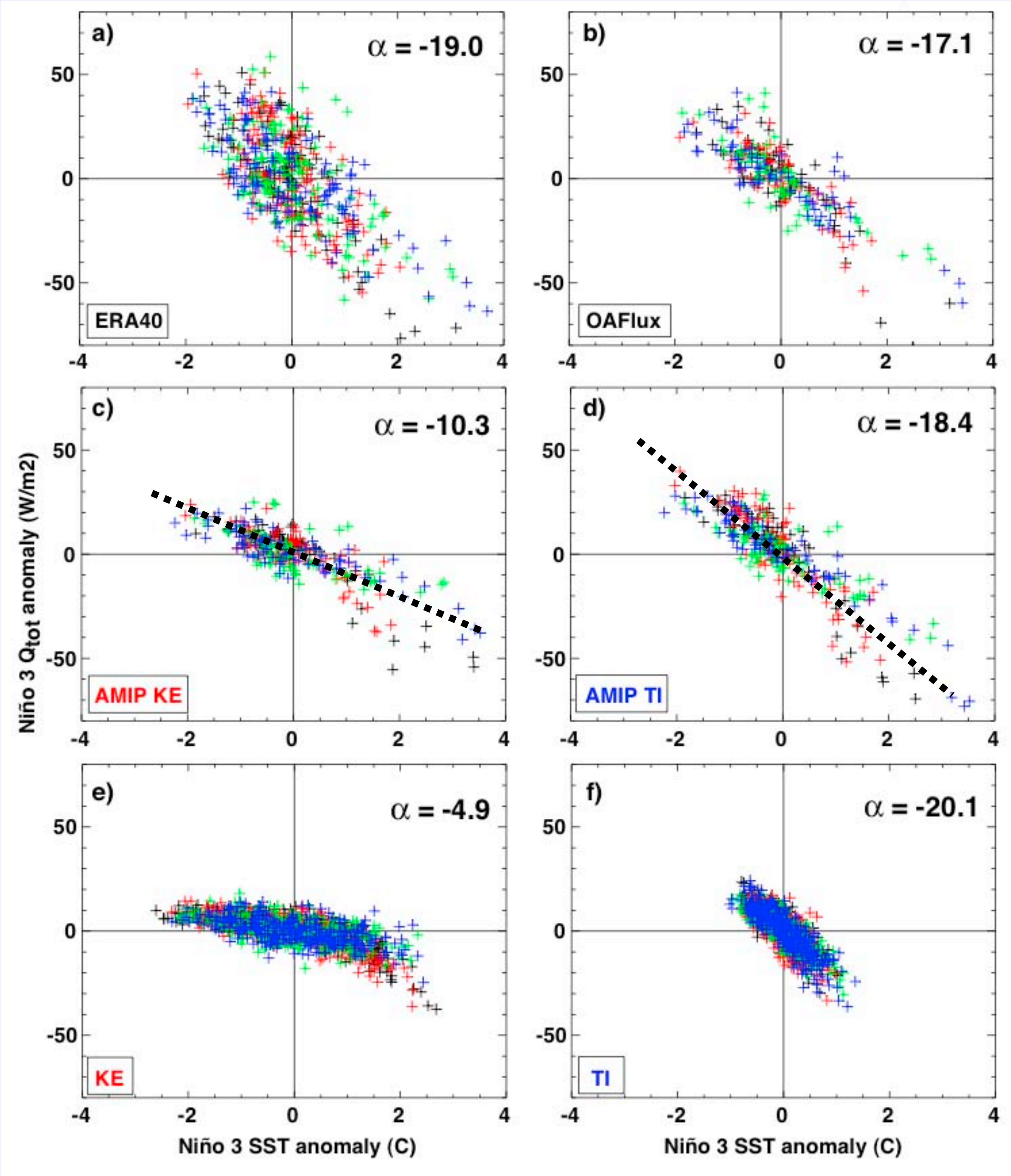
Bjerknes feedback μ



- **Bjerknes feedback in AMIP KE and AMIP TI similar and within re-analysis estimates**

- **Bjerknes feedback in KE = 1/3rd of that of AMIP KE**

Heat flux feedback α



- Heat flux feedback α in AMIP TI is ***double*** that of AMIP KE (and closer to re-analysis estimates)

- Heat flux feedback in KE = half of that of AMIP KE
- Value unchanged in TI

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	°C

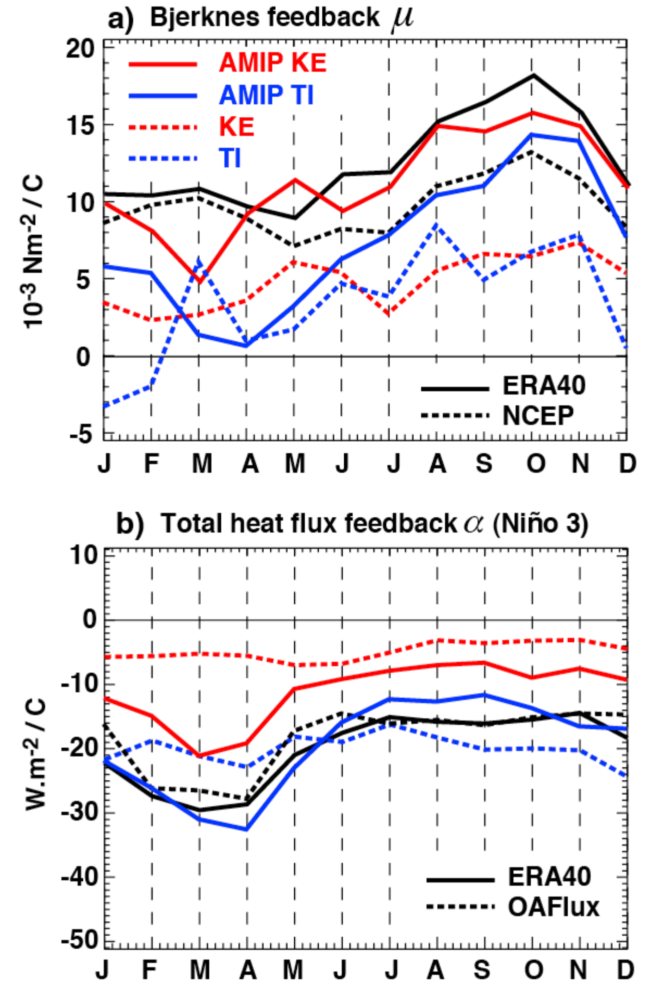
→ Error compensation !

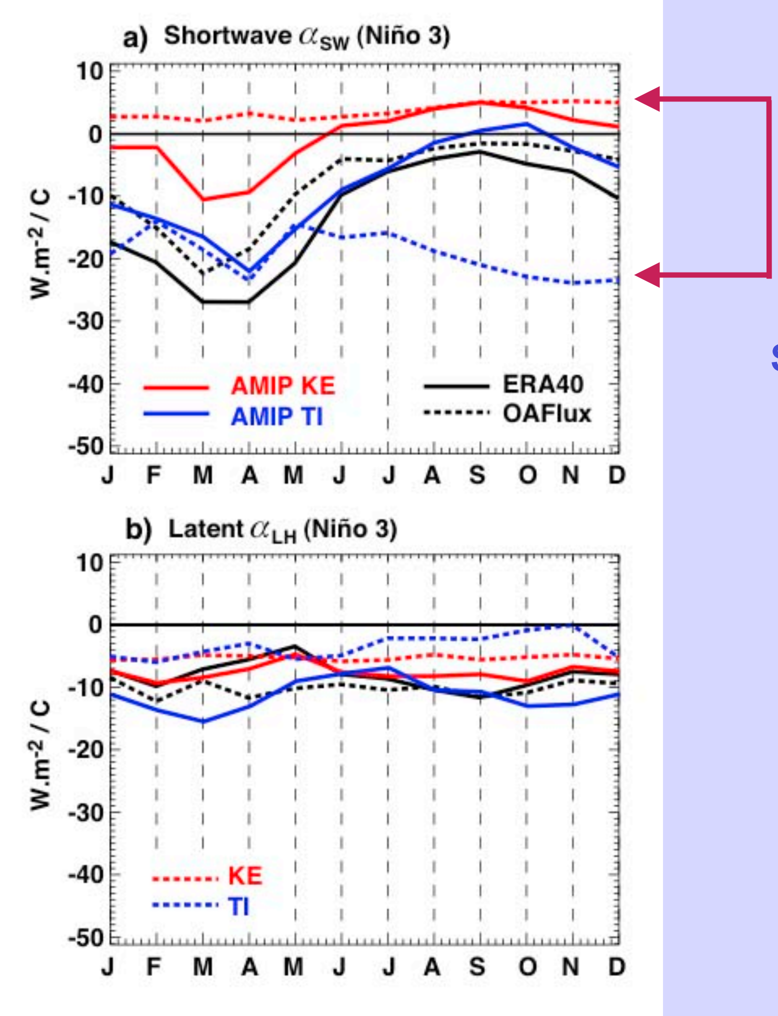
Too weak (improves with atmosphere resolution)

Due to shortwave feedback difference (convection too strong in TI)

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

Seasonal evolution of feedbacks





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

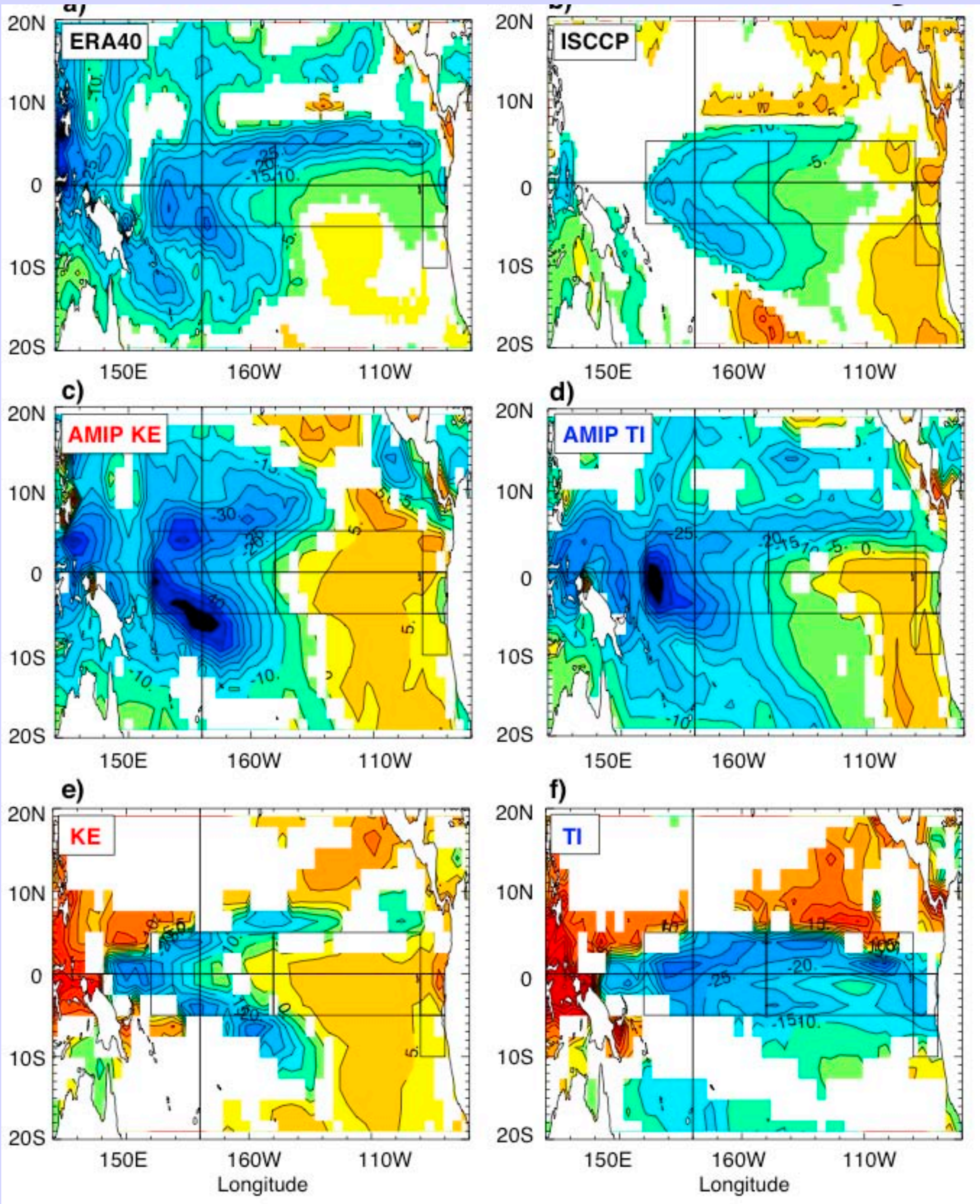
<=>

1°C/month in SST cooling !!!

(MXL 50 m, SSTA of 2°C)

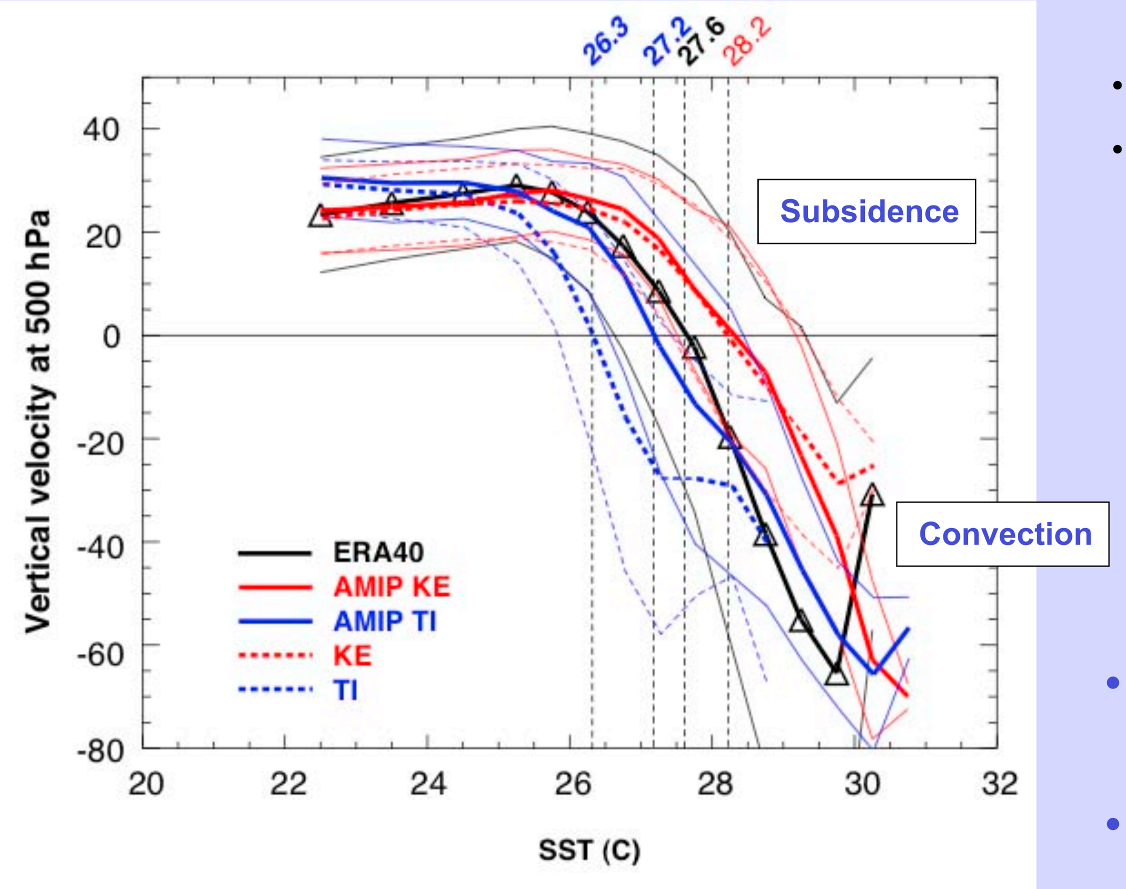
- **Shortwave HF feedback α_{SW} in second half of year explains most of the difference**

α_{SW} feedback distribution



- ***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)**

SST threshold for convection

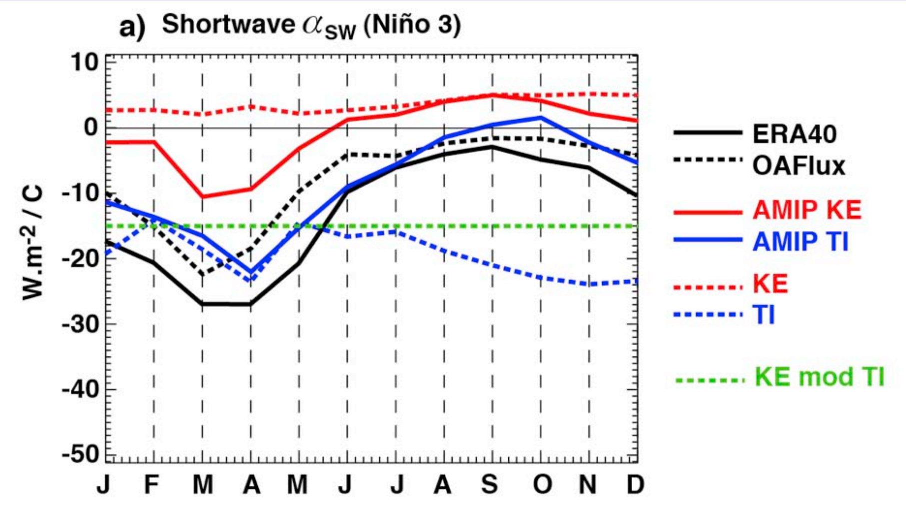


- *Bin vertical velocity at 500 hPa in SST bins*
- *Convective threshold when regime switches from subsidence to convection (Bony et al. 2004)*

- **AMIP KE threshold larger by 1°C / AMIP TI (same SST !)**
- **KE threshold unchanged**
- **TI threshold even lower: 2°C difference with KE !**

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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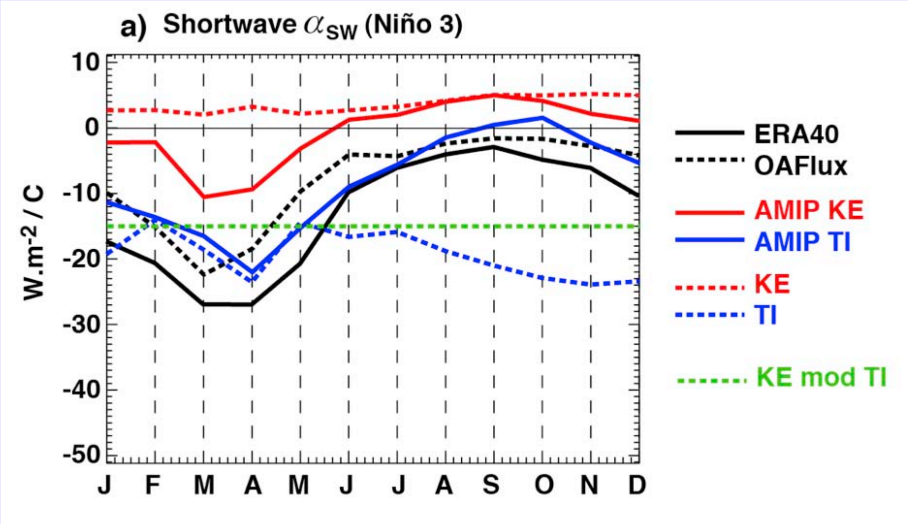

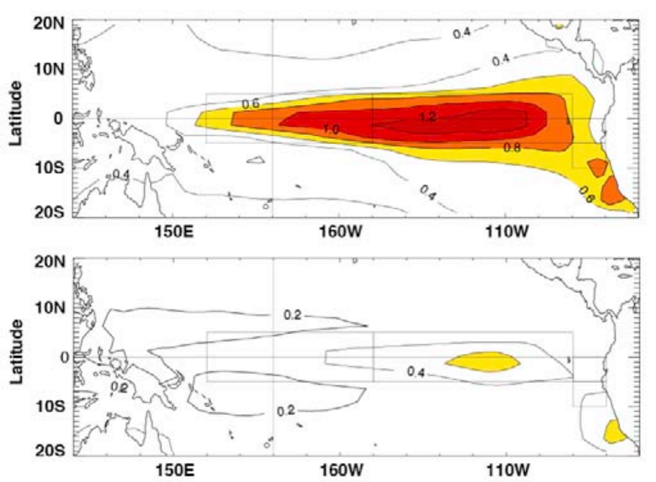

KE

TI

KE mod TI

?

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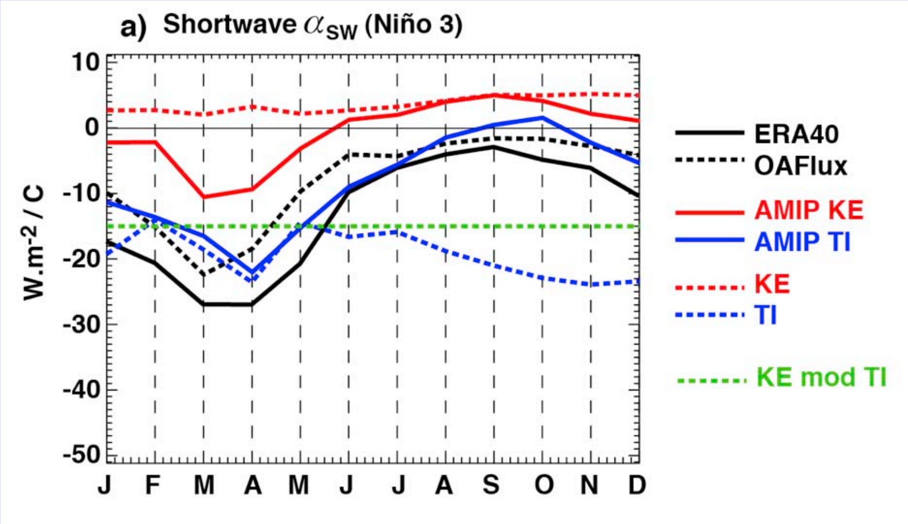

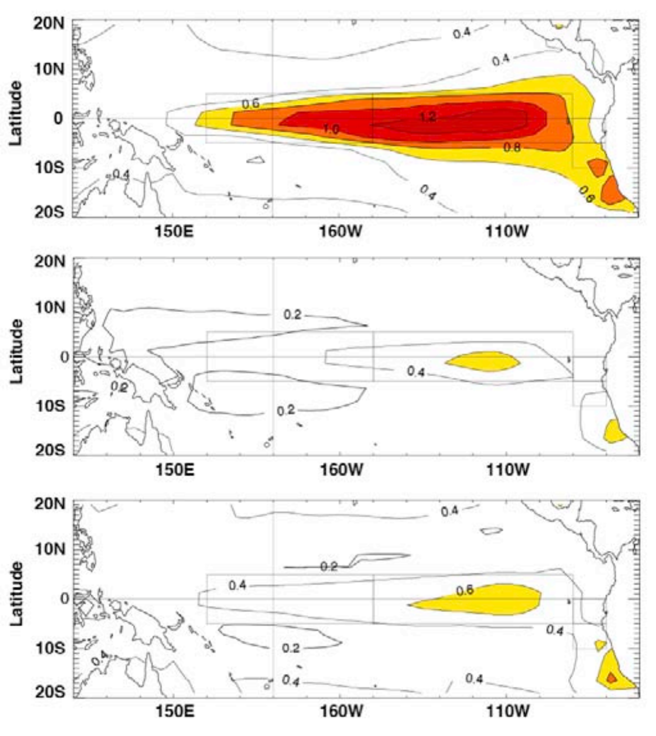

	μ	α	El Niño Amplitude
Obs	~10	-18	0.9
KE	4	-5	1.0
TI	4	-20	0.3
KE mod TI	5	-21	0.4
	10^{-3} N/m²/C	W/m²/C	°C

ENSO gone as well !

ENSO atmosphere feedbacks: what about μ ?

(Zonal x Merid.)	μ	α	El Niño Amplitude
Obs	12	-18	0.9
R97E (3.75 x 2.5)	3.9	-4.9	0.8
R99A (3.75 x 1.8)	4.4	-5.1	0.95
R149A (2.5 x 1.8)	6.2	-5.7	1.15
R1414A (2.5 x 1.2)	7.5	-4.3	1.13
R1914E (1.8 x 1.2)	7.8	-5	1.18
	10^{-3} N/m^2/C	*W/m^2/C*	*^{o}C*

Varying the horizontal atmosphere resolution in IPSL-CM4

AGCM resolution affects μ (but not α):

- Atmosphere grid can "see" ocean equatorial wave guide
- Added non-linearities in AGCM: better circulation (on/off convection behavior reduced,...)

Summary

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  - This is already seen in AMIP mode
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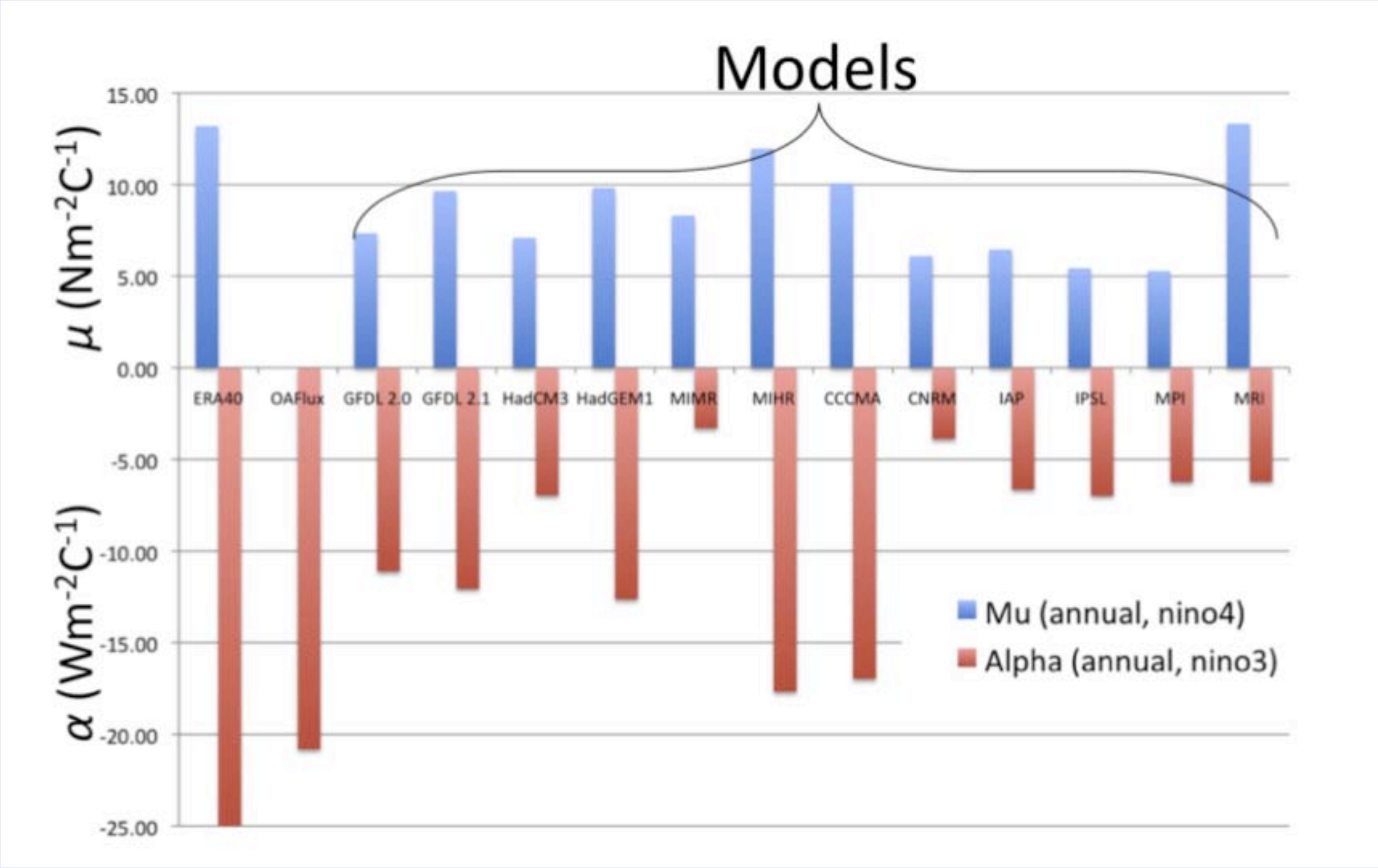
- Role of μ and α in CMIP3 models (PhD James Lloyd)

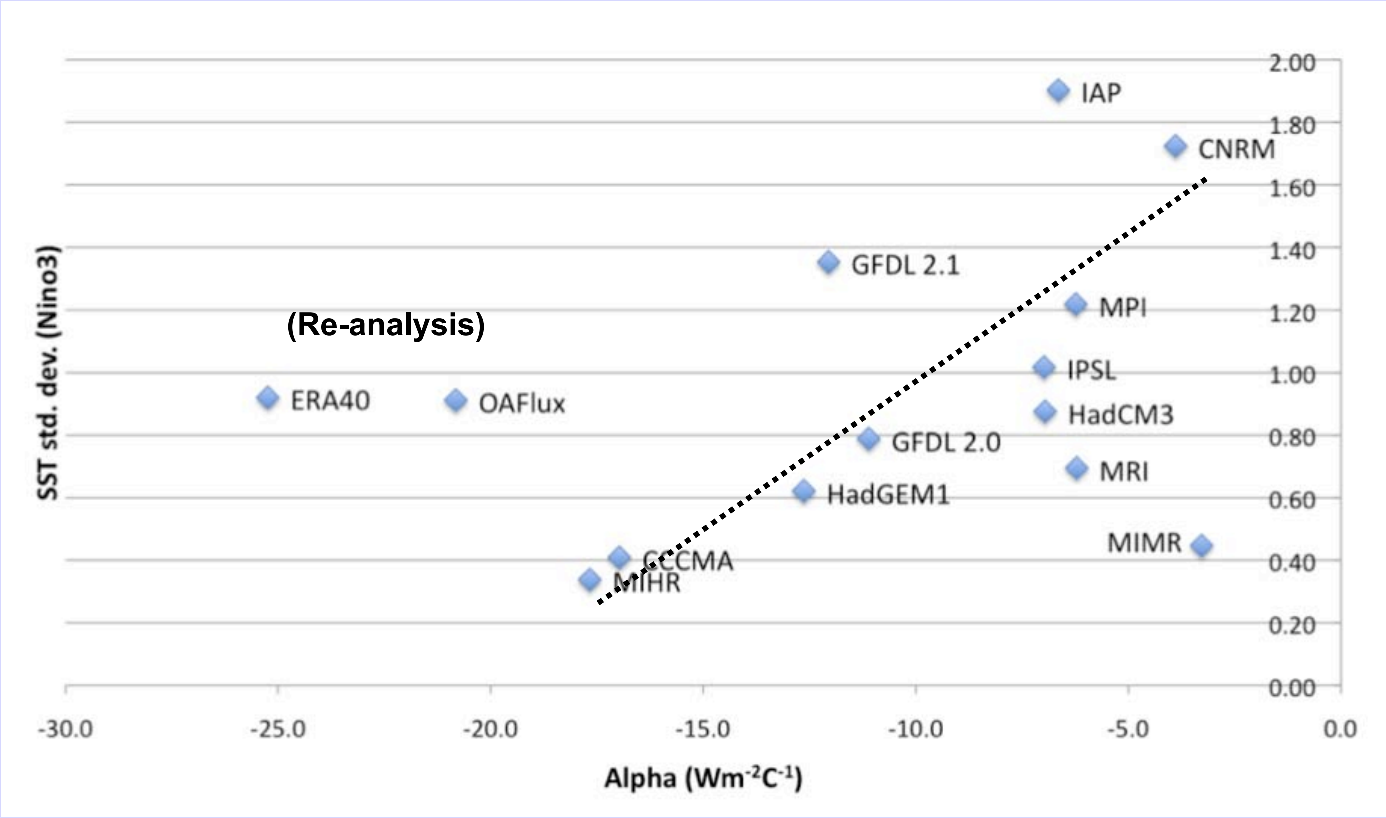
ENSO atmosphere feedbacks in CMIP3 models



Lloyd et al. 2009

Diversity of μ and α (both too weak)

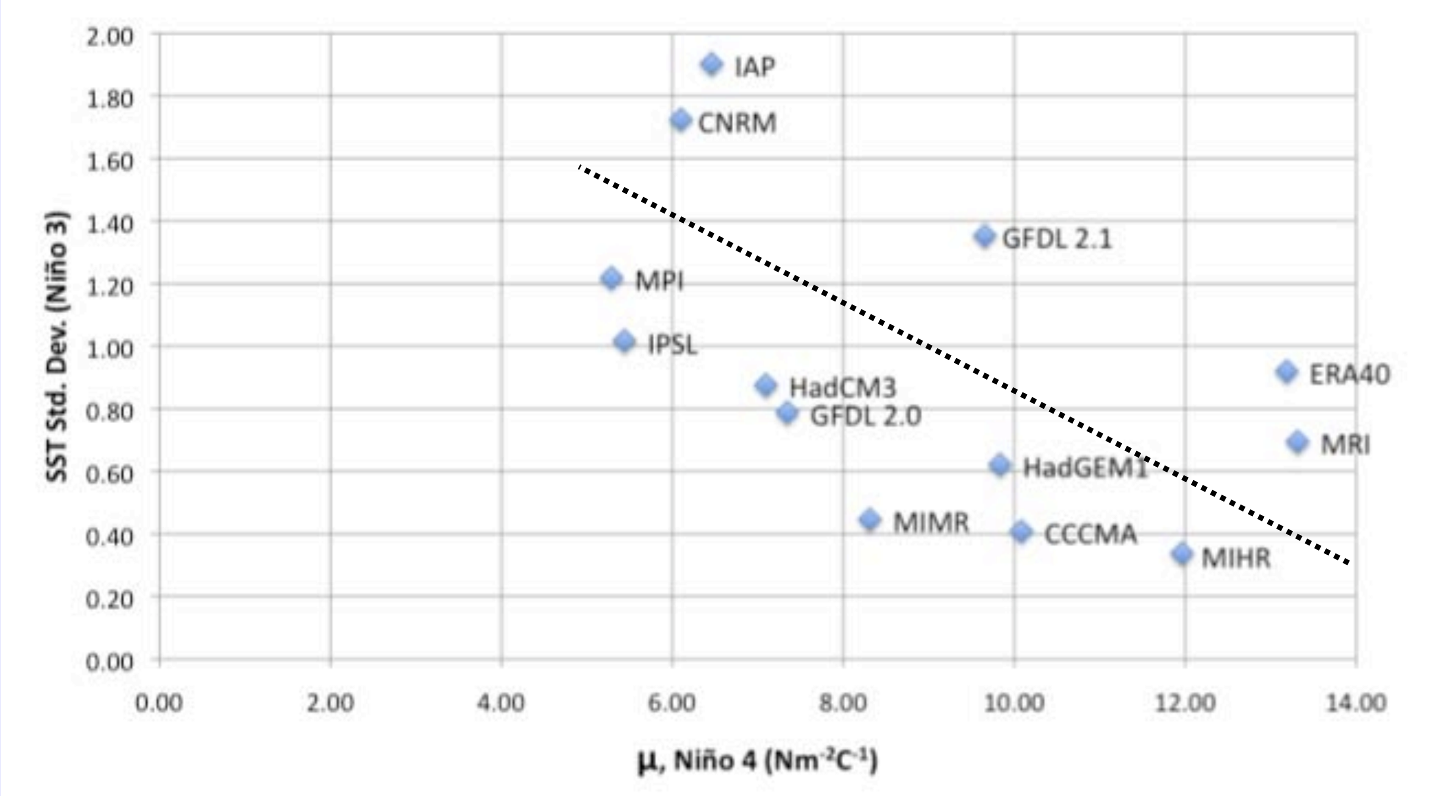
Relation between alpha and ENSO amplitude



Lloyd et al. 2009

Inverse relationship (expected)

Relation between μ and ENSO amplitude

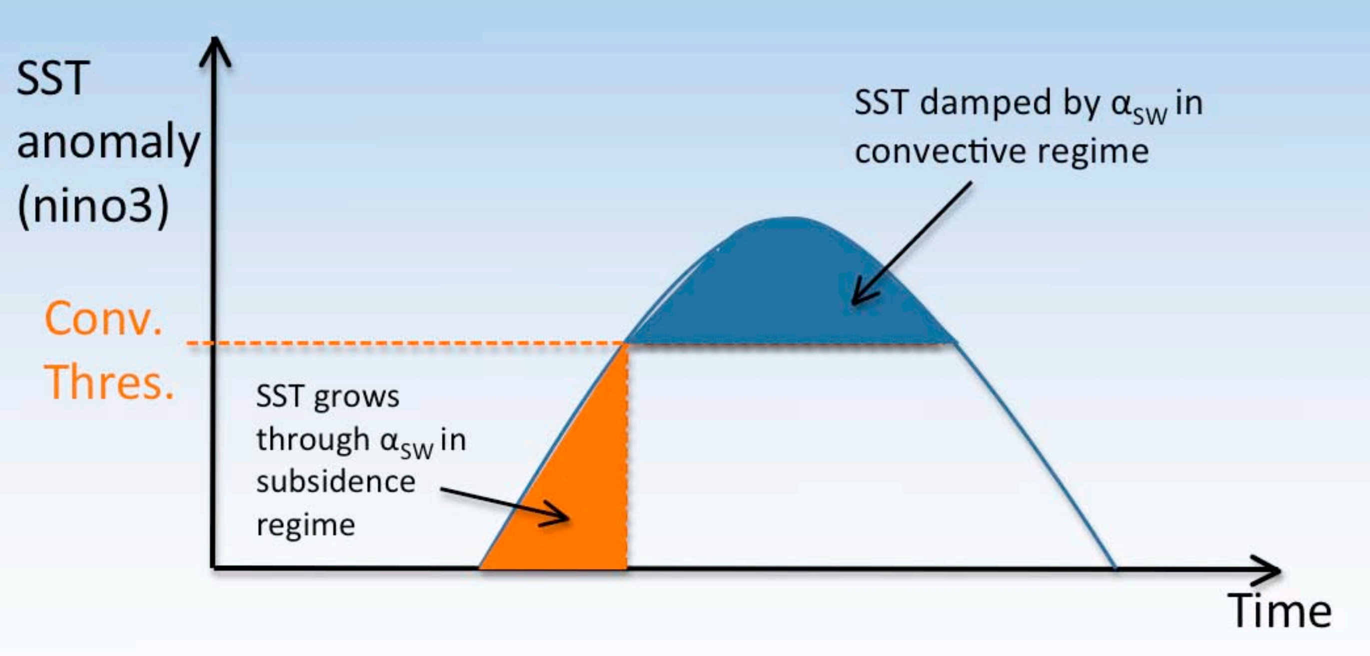


Lloyd et al. 2009

Inverse relationship (not expected !)

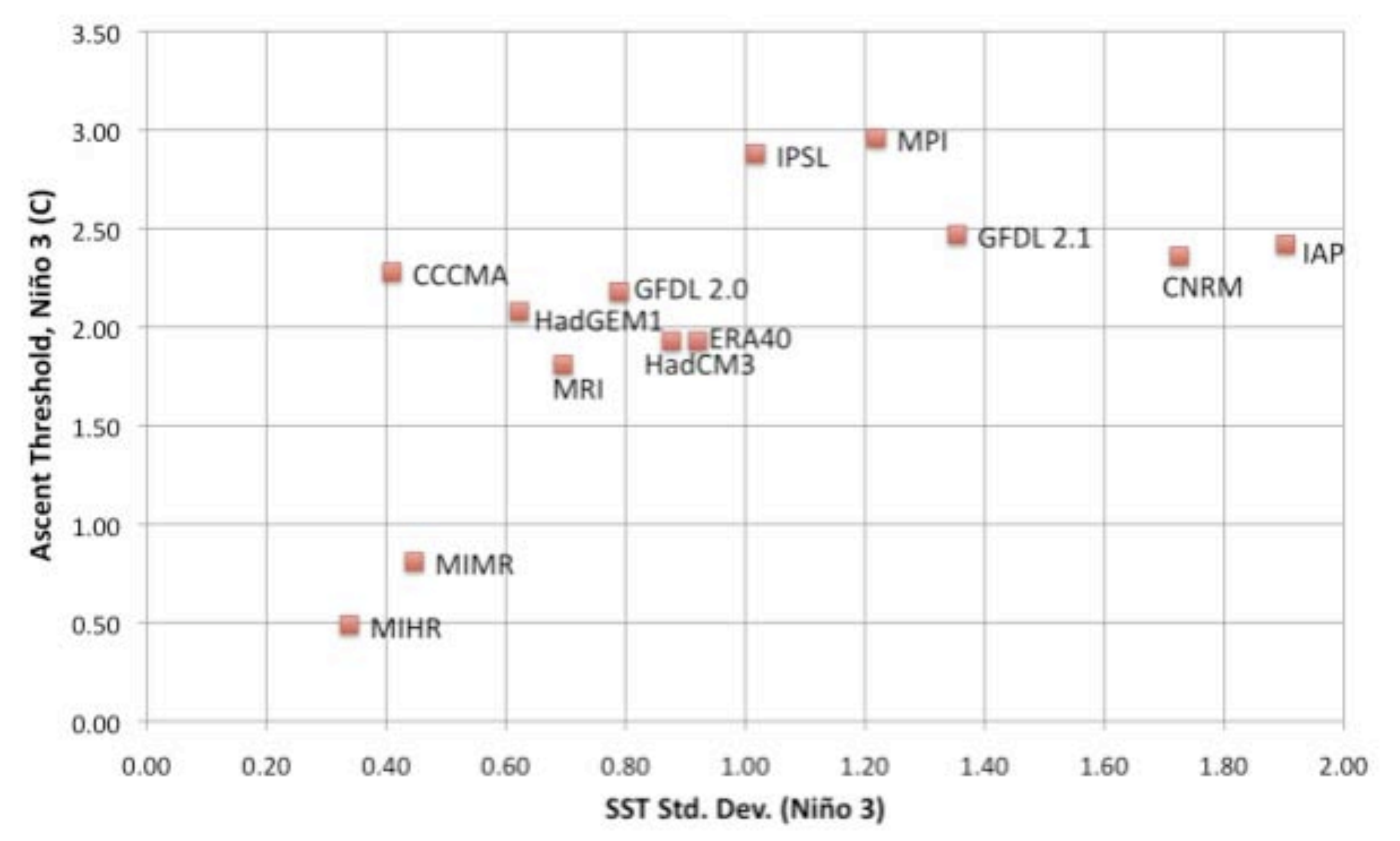
Impact of atmosphere convection scheme:

- Studies point to the key role of atmosphere convection on ENSO (Neale et al. 2008, Kim et al. 2008)
- One key mechanism (at least in IPSL-CM4) is the relative roles of convective vs. subsidence regimes during the amplification of ENSO
- ENSO amplitude is likely to depend on both the “ascent threshold” and the strength of the SW feedbacks



Courtesy James Lloyd

ENSO amplitude vs. ascent threshold



Lloyd et al. 2009

Positive correlation !

Next: understand details of physical mechanisms and links with models systematic errors