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Understanding El Nino in ocean-atmosphere general circulation models: progress and challenges

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Understanding El Niño in coupled GCMs: progress and challenges

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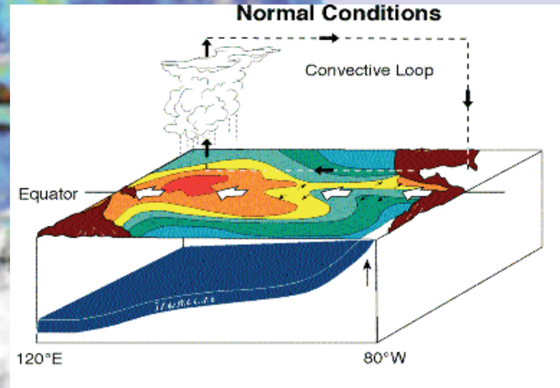
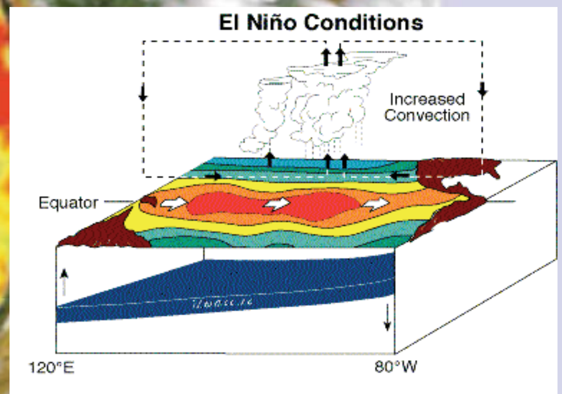
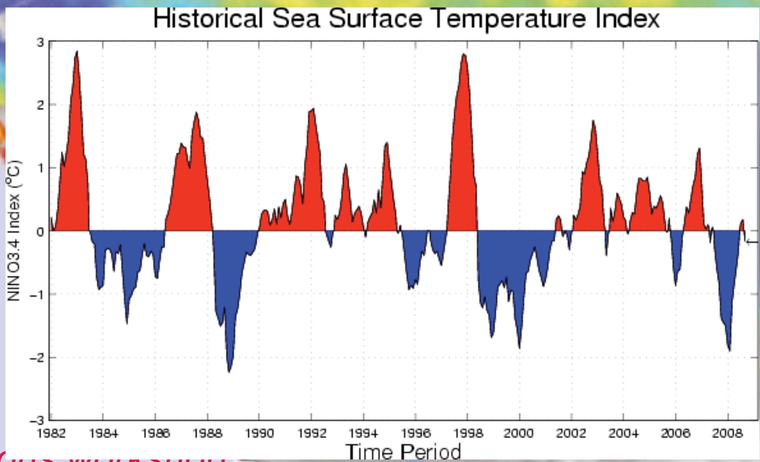
Conference on Teleconnections in the Atmosphere and Oceans, ICTP, Trieste, Nov. 2008

El Niño

Ocean-atmosphere coupled anomaly in the tropical Pacific







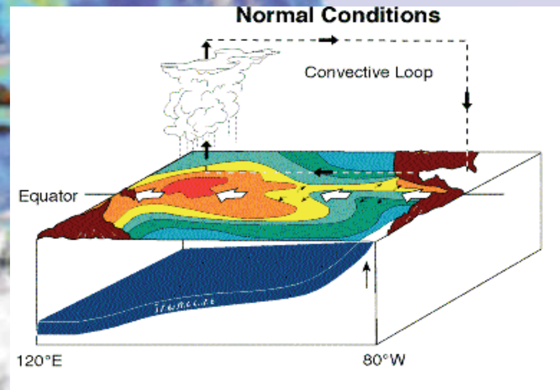
El Niño

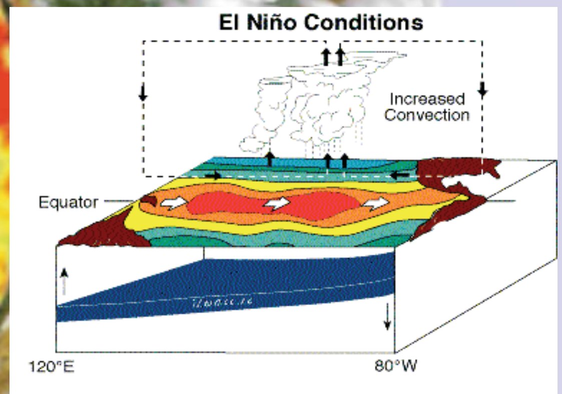
IPCC (2007)

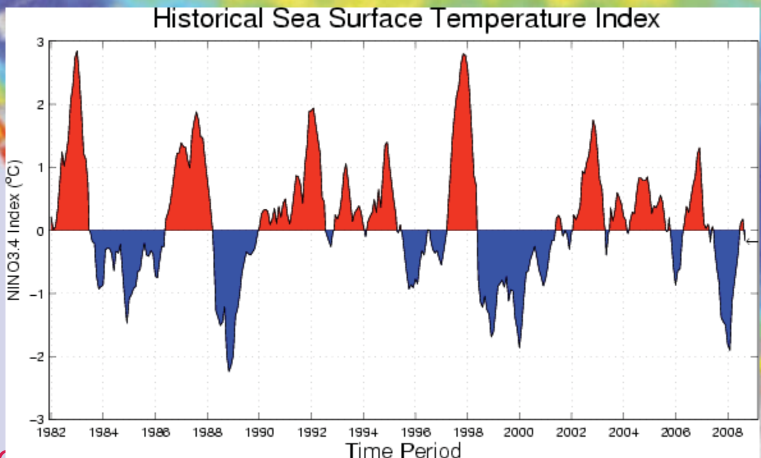
« All IPCC AR4 models show continued ENSO interannual variability in the future no matter what the change in average background conditions, but changes in ENSO interannual variability differ from model to model. Based on various assessments of the current multi-model archive, in which present-day El Niño events are now much better simulated than in the TAR, there is no consistent indication at this time of discernible future changes in ENSO amplitude or frequency. »

IPCC AR4 report, WG1, Chap. 10, Executive Summary

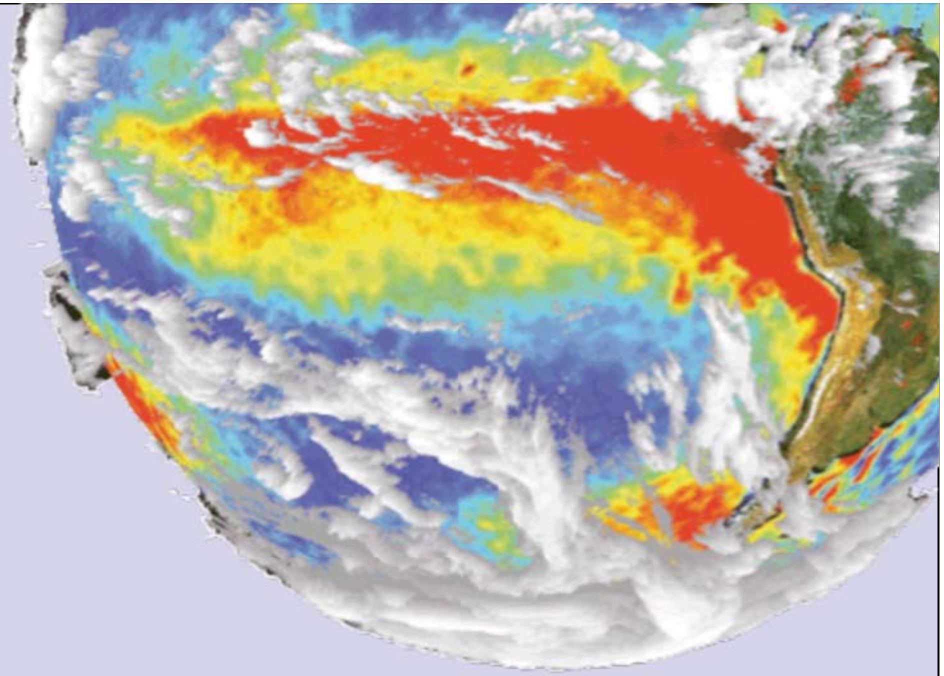
Ocean-atmosphere coupled anomaly in the tropical Pacific







Outline



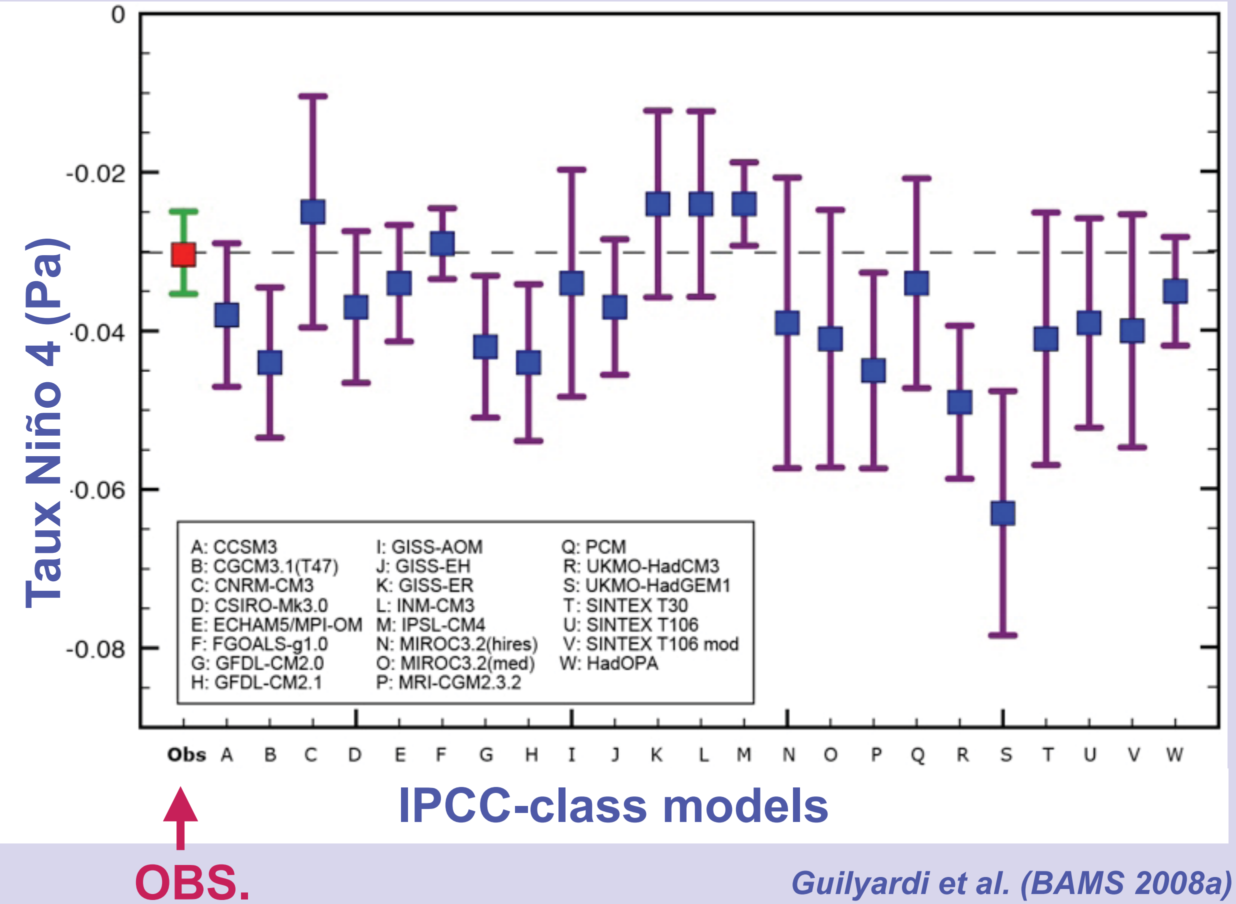
1. ENSO in coupled GCMs

2. Attributing ENSO errors

3. Community strategies to improve ENSO in models

El Niño in coupled GCMs – mean state

Zonal wind stress in central Pacific



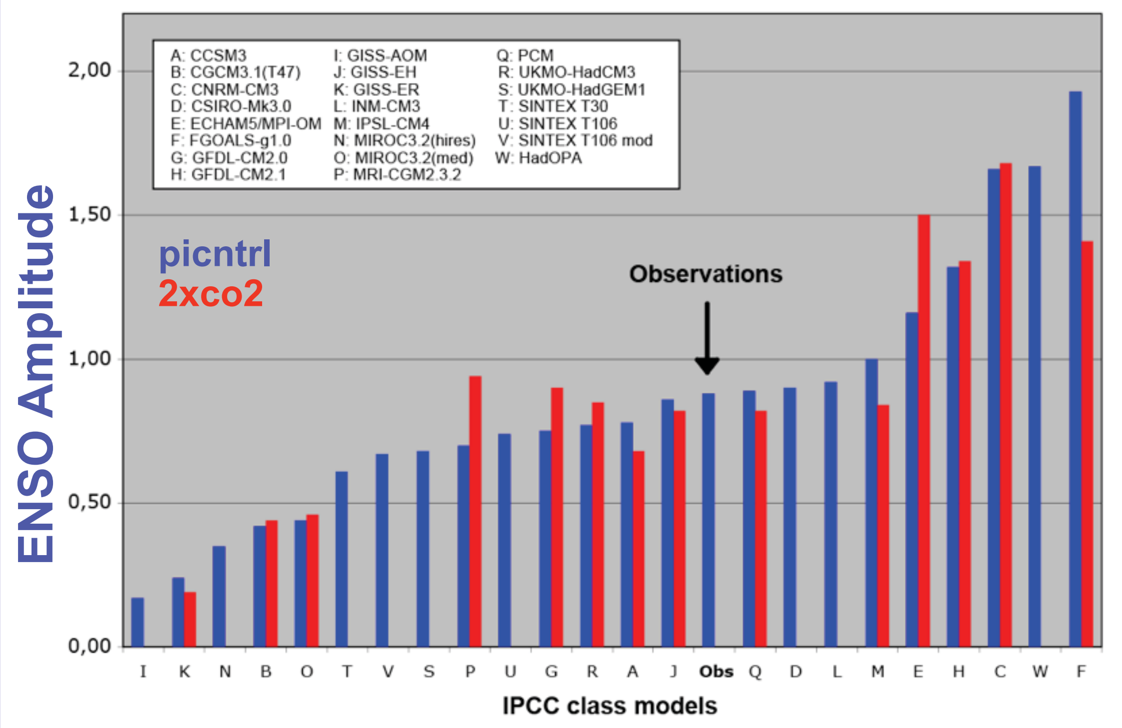
Guilyardi et al. (BAMS 2008a)

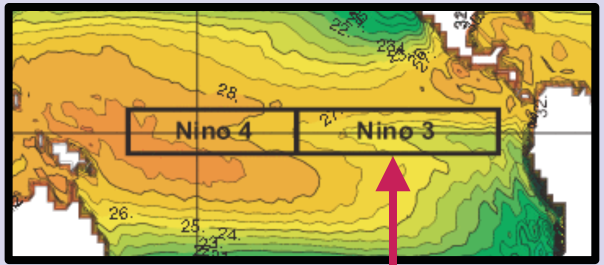
Trade winds too strong

Both mean and annual cycle

CMIP3 models used for IPCC AR4

El Niño in coupled GCMs - amplitude

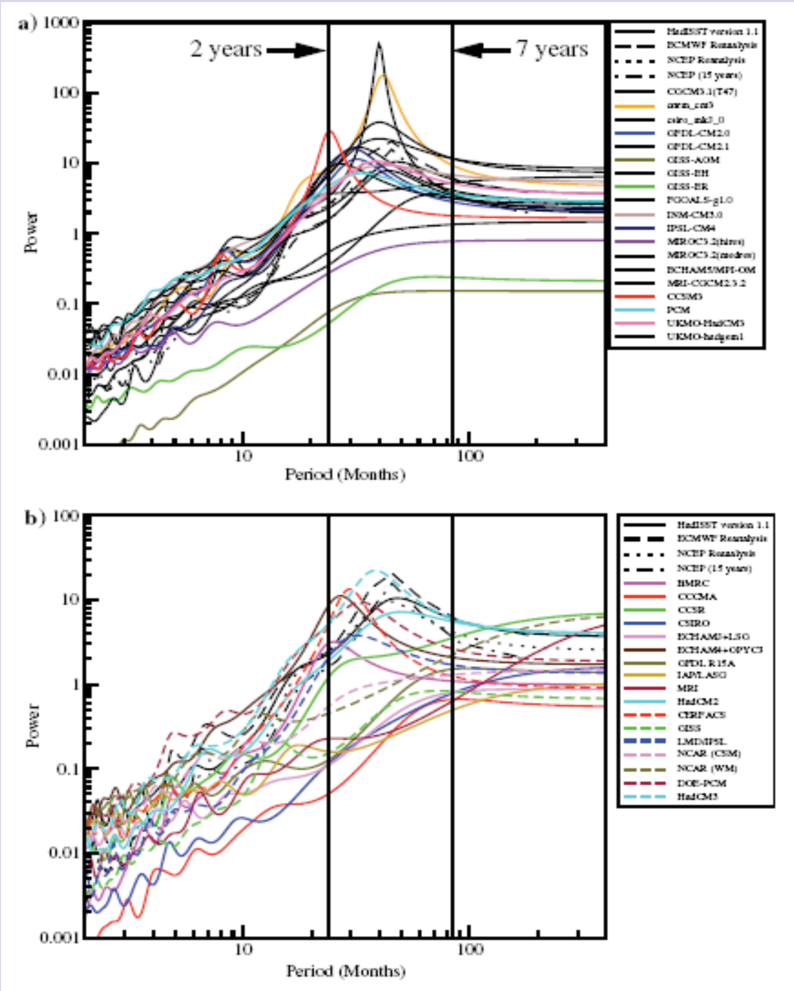




Standard deviation SSTA (C)

ENSO amplitude in IPCC AR4 : much too large diversity !

El Niño in coupled GCMs - frequency



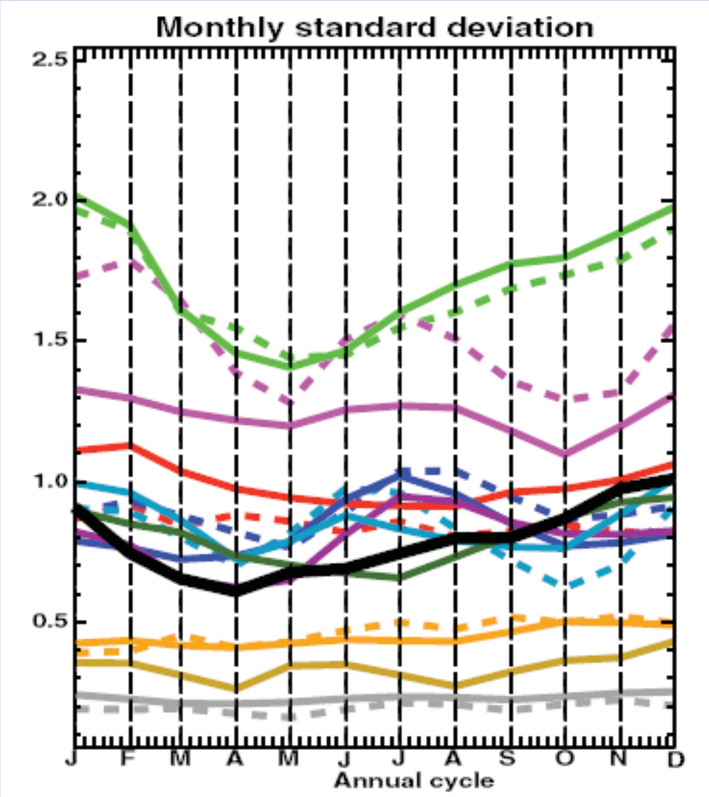
Maximum power of Niño3 SSTA spectra

IPCC AR4: improved towards low freq. but still large diversity

IPCC TAR: to high frequency

AchutaRao & Sperber (2006)

El Niño in coupled GCMs – seasonal phase lock



Subset of CMIP3 models

Monthly Niño3 SSTA std. dev.

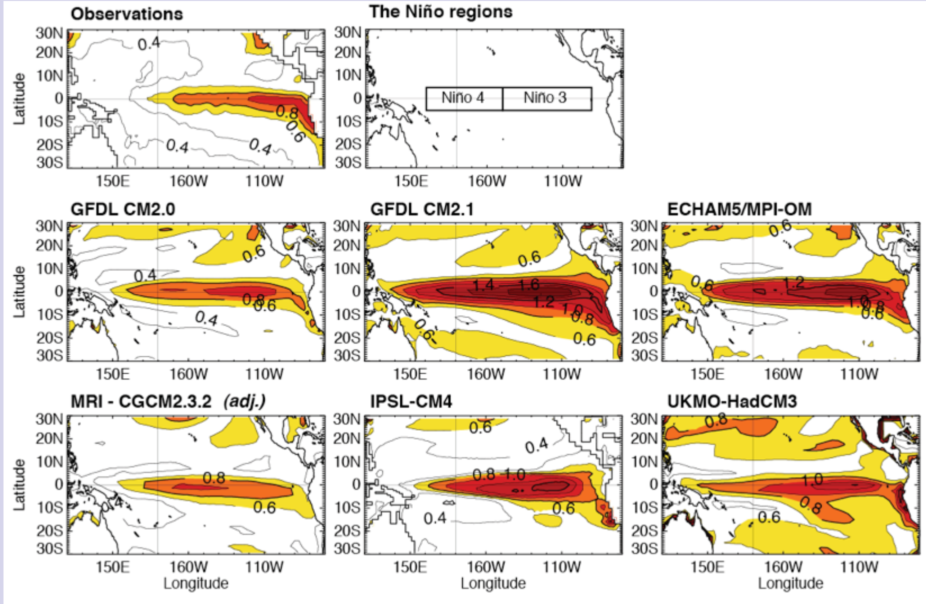
Observations

Half of the models do not display a seasonal phase lock

Even fewer models have the spring relaxation and the winter maximum

El Niño in coupled GCMs - structure and timing

SST standard deviation



Westward zonal extension

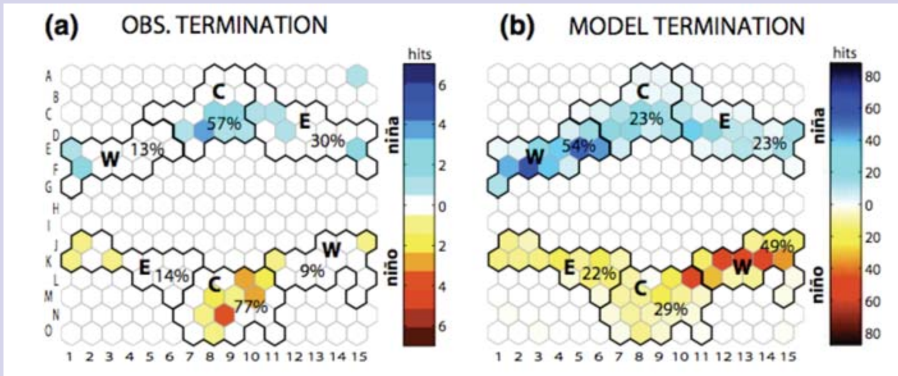
Too small meridional extension

With impacts on periodicity

(Capotondi et al. 2007)

Time sequence of El Niño/La Niña also has errors

e.g.: Model events terminate in West rather than in East Pacific

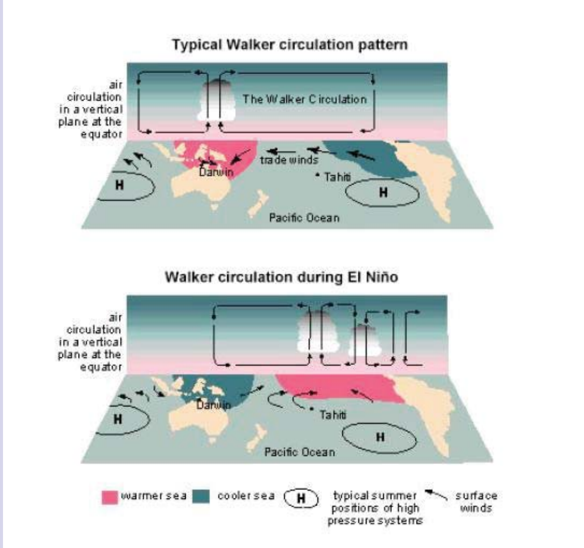


Leloup et al. 2008

El Niño in coupled GCMs - teleconnections

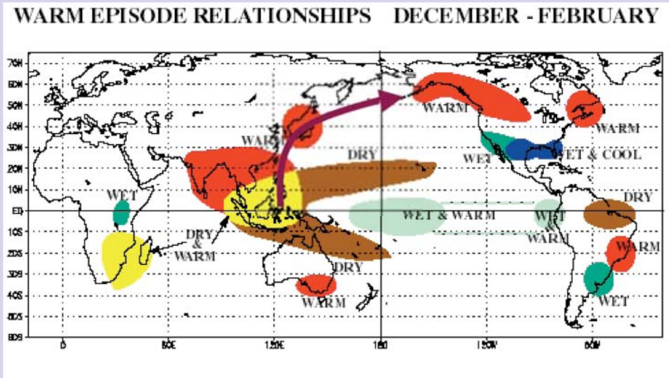
Tropical teleconnections:

- Well established
- Via modulation of Walker circulation and/or equatorial waves
- ENSO influence over-dominant in models (e.g. IO, *Saji et al. 2006*, WAM, *Joly et al. 2008*, SAM, *Annamalai et al. 2007, Cai et al. 2008*)



Extra-tropical teleconnections:

- Atmospheric bridge via Rossby wave train
- Still a debate on robustness (*Sterl et a. 2007*)



Much more during this workshop !

→ **Timing/amplitude/structure of events all key**

El Niño in coupled GCMs - summary

Clear improvement since ~15 years

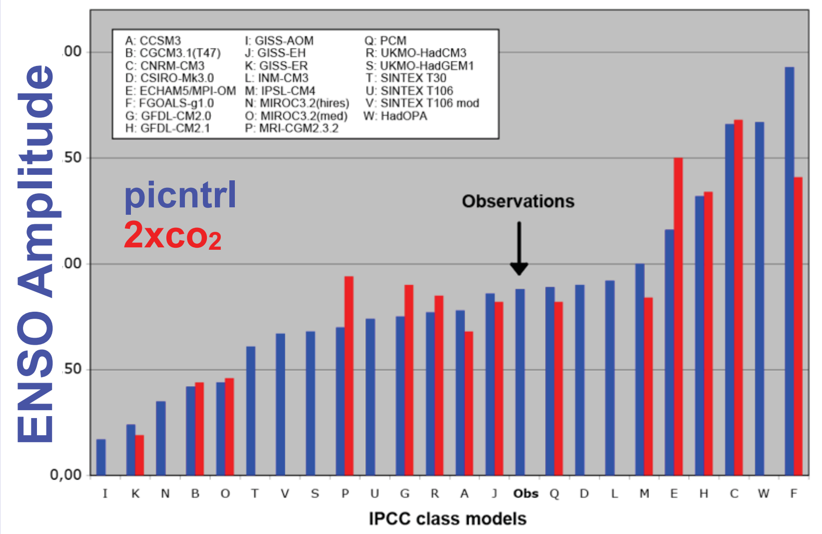
- some models get Mean *and* Annual cycle *and* ENSO right !

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

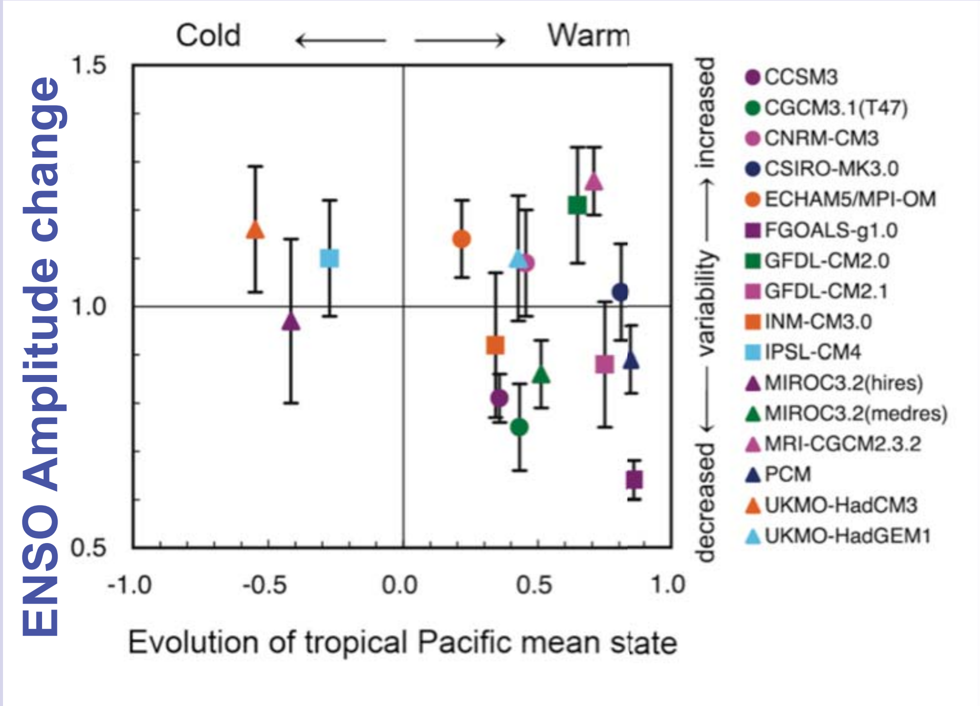
van Oldenborgh et al. (2005), Guilyardi (2006), Guilyardi et al. (2008a)

El Niño in a warming climate



Model biases dominate over scenario

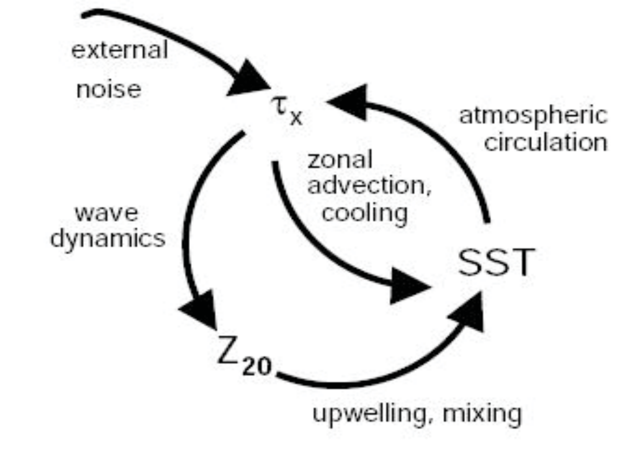
SRES A2 vs. pdcntrl



Evolution of mean state has little impact

IPCC (2007), Guilyardi et al. (2008a)

Attributing ENSO errors: physical mechanisms



van Oldenborgh al. 2005

Non linear processes:

- **NL dynamical heating (∇_xT + U in phase,** *An & Jin 2004***)**
- **"Multiplicative noise" - MJO** *(Lengaigne et al. 2004, Perez et al. 2005, Philip & van Oldenborgh 2007)*

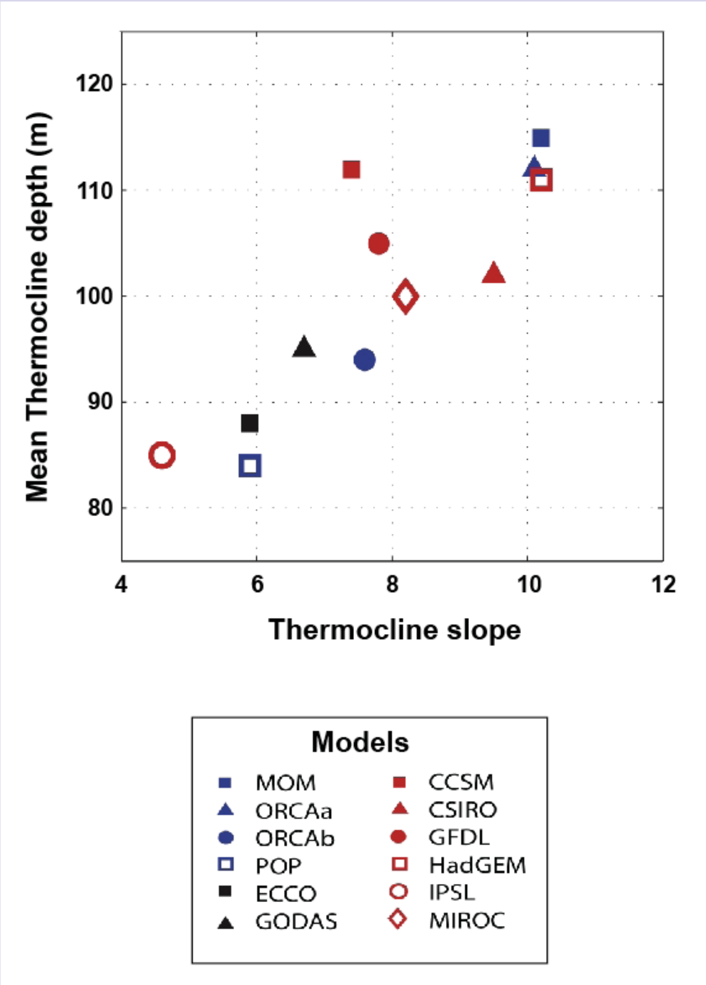
Atmosphere response to SSTA

- **Bjerknes wind stress feedback** (*van Oldenborgh al. 2005, Guilyardi 2006*)
- **Meridional response of wind stress** *(An & Wang 2000, Capotondi al. 2006, Merryfield 2006)*
- **Radiative and cloud feedbacks** *(Sun al. 2006, Bony al. 2006)*

Ocean response to τ and HF anomalies

- **Upwelling, mixing, ("thermocline feedback", "cold tongue dynamics")** *(Meehl al. 2001, Burgers & van Oldenborgh 2003)*
- **Zonal advection** *(Picaut al. 1997)*
- **Wave dynamics**
- **Energy Dissipation** *(Fedorov 2006)*

Attributing ENSO errors: the role of the ocean



Brown and Fedorov (2008)

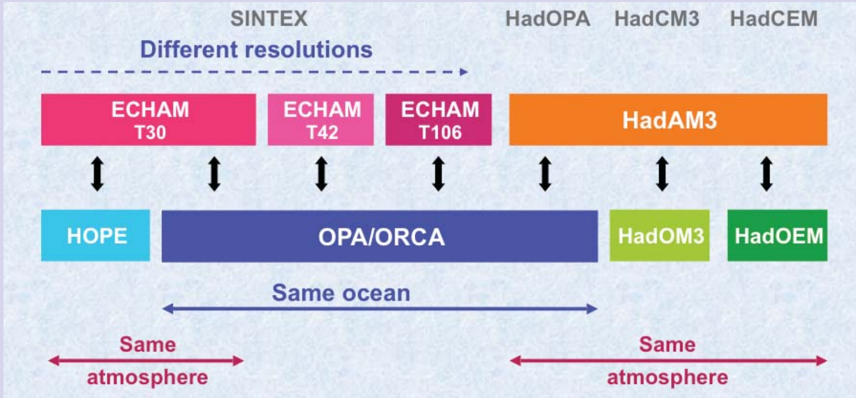
Thermocline feedback depends on thermocline properties

Coupled models show large diversity

Atmosphere feedbacks during ENSO

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

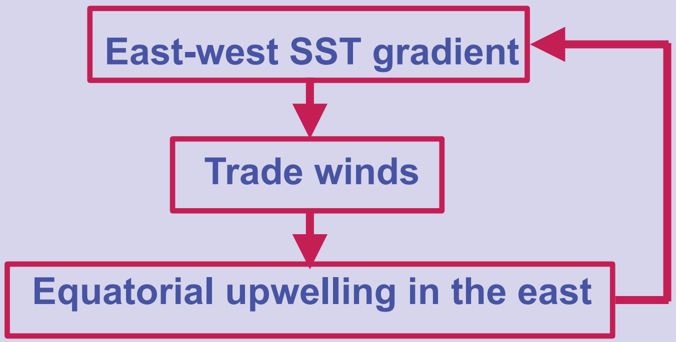
(e.g. Schneider 2002, Guilyardi et al. 2004, Kim et al. 2008, Neale et al. 2008, Sun et al. 2008,...)



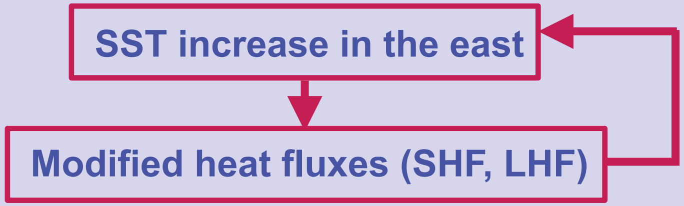
Guilyardi et al. (2004)

Two types of feedbacks:

Dynamical: Bjerknes feedback μ

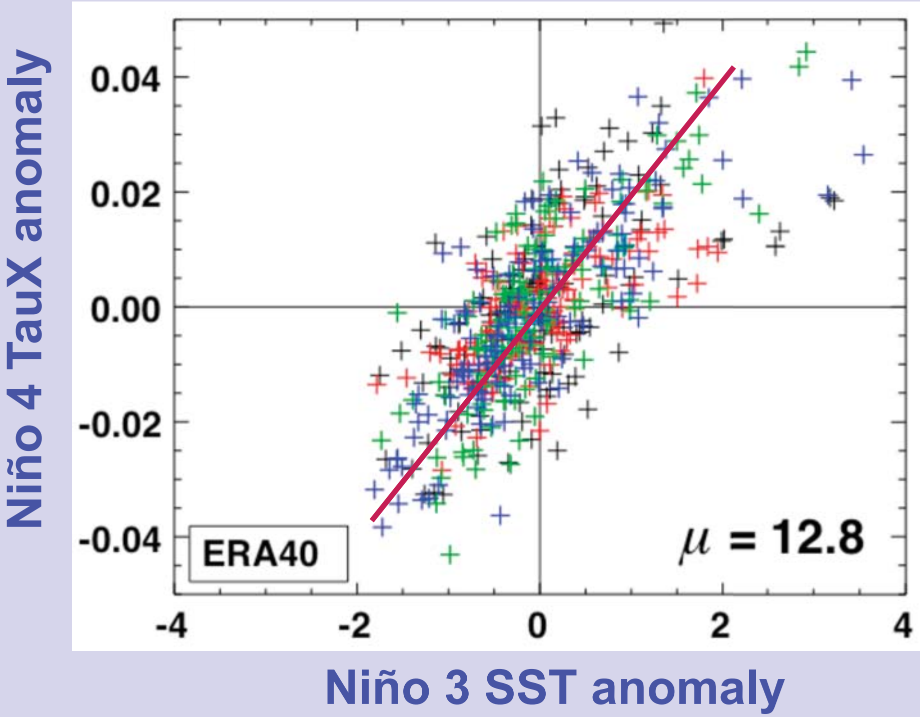


Heat flux feedback α

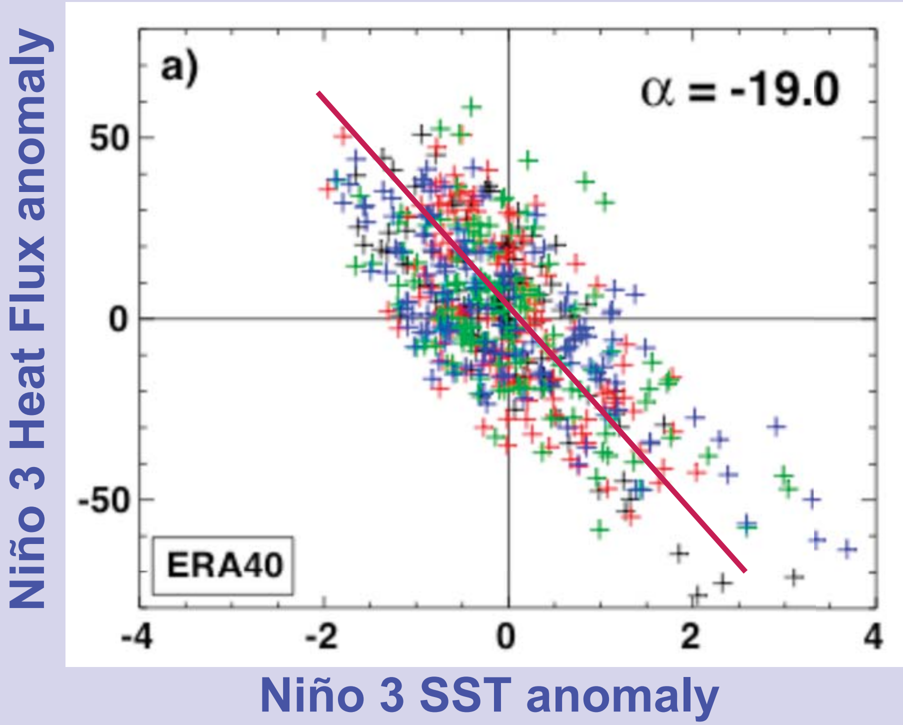


Evaluating the atmosphere feedbacks

Bjerknes feedback μ (+ve)



Heat Flux feedback α (-ve)



- Large diversity in coupled CGCMs
- Both feedbacks usually too weak

→ focus on one model

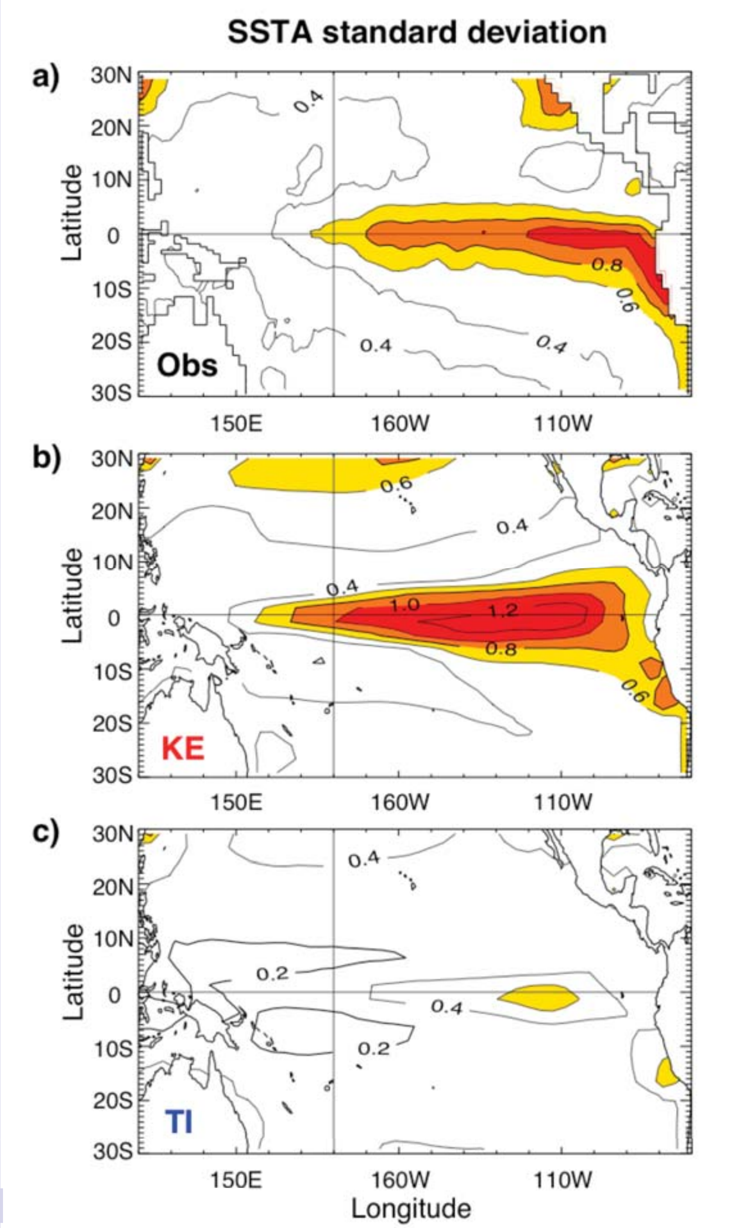
Impact of atmosphere convection scheme on ENSO

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. (2008b)

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 !

Community strategies to improve ENSO in models

The challenges lying ahead:

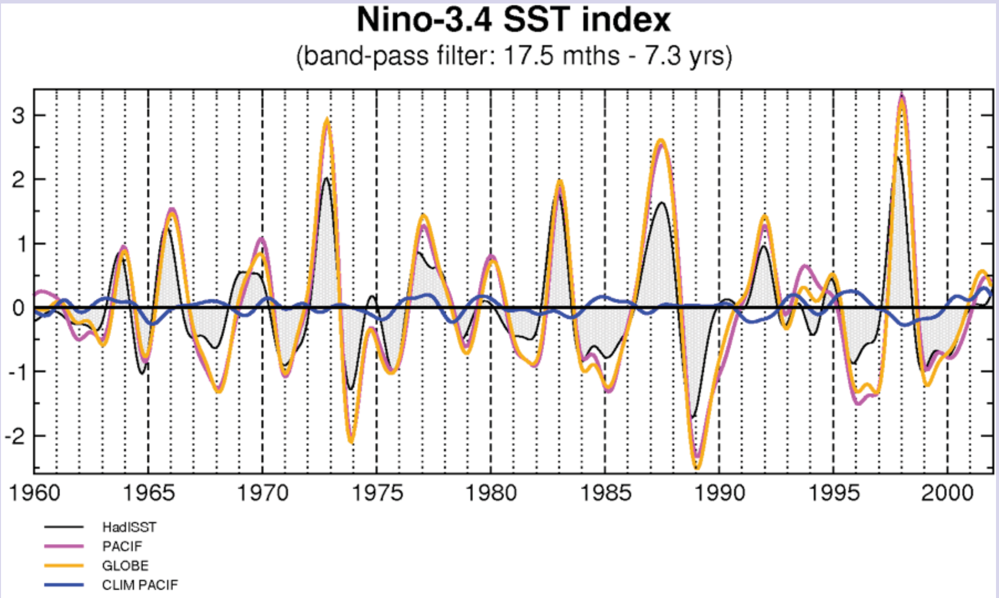
- **Improve the quality and utility of historical records**
- **Maintain present ENSO observing system into the future**
- **Continue promoting intercomparison studies (ENSO metrics)**
- **Isolate the main sources of model error, guided by theory, observations, and rigourous evaluation of the models, including tests in seasonal forecast mode**
- **Better understand the response of ENSO to climate change**
- **Better represent unresolved processes and coupled feedbacks.**

Guilyardi et al. (BAMS 2008a)

Community strategies to improve ENSO in models

Example: the Climate Forecast Historical Project (CFHP):

- initialise coupled system and perform hindcast ensembles
- identify mechanisms responsible for error growth
- (joins near term IPCC AR5 simulation strategy)



Black: HadISST

Orange: wind stress nudged to ERA40

Example of simple nudging for initialisation

Joly et al. 2008

Community strategies to improve ENSO in models

Example: the Climate Forecast Historical Project (CFHP):

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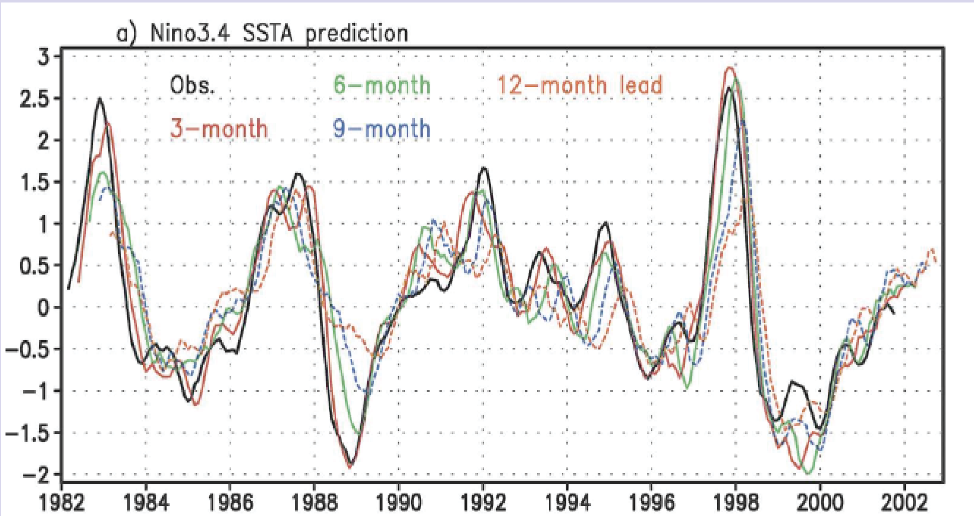


Example of simple nudging for initialisation

Luo al. 2004

Summary

- El Niño in IPCC-class GCMs:
  - significant progress in CMIP3 vs. previous generations
  - still major errors (too much diversity)

- Atmosphere GCM is a dominant contributor:
  - Dynamical +ve (μ) and heat flux -ve (α) feedbacks both likely to control El Niño properties in CGCMs
  - Both feedbacks are usually too weak in models
  - Convection scheme has direct impact on α
  - Atmosphere GCM horizontal resolution improves Bjerknes feedback μ

- New community strategies keys to make progress

Thank you !

BJ index for KE and TI

$$\frac{\partial\langle T\rangle}{\partial t} = 2I_{BJ}\langle T\rangle + F[h],$$

$$2I_{BJ} = -\left(\frac{\langle\bar{u}\rangle}{L_x} + \frac{\langle -2y\bar{v}\rangle}{L_y^2} + \frac{\langle H(\bar{w})\bar{w}\rangle}{H_m}\right) - \alpha$$
$$+ \mu_a\beta_u\left\langle -\frac{\partial\bar{T}}{\partial x}\right\rangle + \mu_a\beta_w\left\langle\frac{\partial\bar{T}}{\partial z}H(\bar{w})\right\rangle$$
$$+ \mu_a^*\beta_h\left\langle\frac{H(\bar{w})\bar{w}}{H_m}a\right\rangle,$$

$$\beta_u = \beta_{um} + \beta_{us}, \quad F = -\left\langle\frac{\partial\bar{T}}{\partial x}\right\rangle\beta_{uh} + \left\langle\frac{H(\bar{w})\bar{w}}{H_m}a\right\rangle.$$

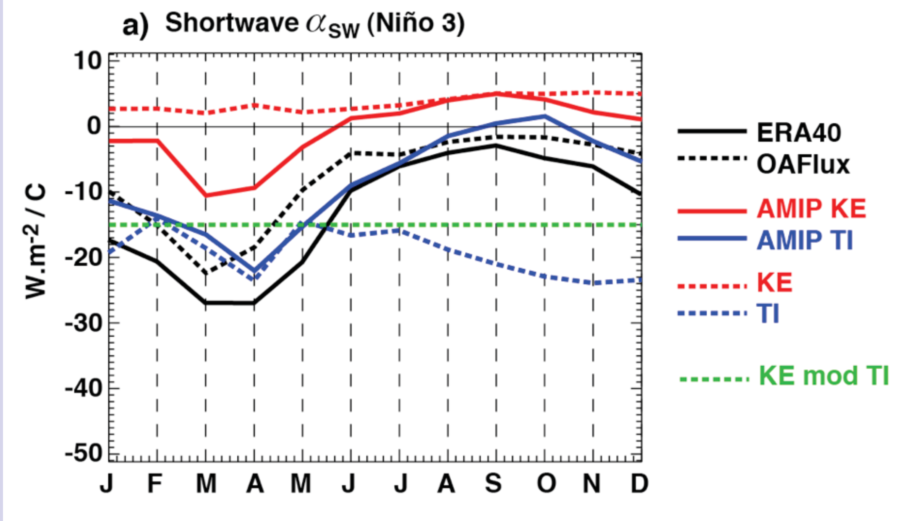
	Dynamic damping	Thermodynamic damping (α)	Ocean feedbacks	**BJ Index**
KE	-0.46	-0.45	1.02	**0.11**
TI	-0.61	-1.33	0.52	**-1.42**
Change (%)	-30%	-200%	-50%	

Table 1. The BJ Index and its components for KE and TI simulations. The ocean feedbacks sums the zonal advective feedback, the thermocline feedback and the Ekman feedback (see Jin et al. 2006 for details). Units are 1/Yr.

→ **Linear theory: α dominant factor in TI/KE difference**

Can we suppress ENSO in KE ?

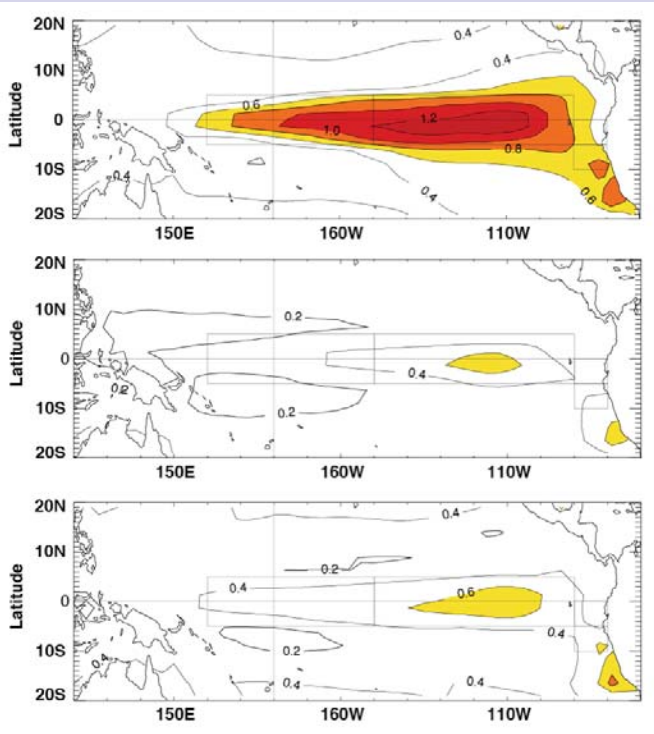
- **Perform KE run with increased α_{sw}**
  - **Interannual Flux Correction:**
    - **$SHF_O = SHF_{SC}^{KE} + \alpha_{sw}^{mod} (SST_O - SST_{SC}^{KE})$**
    - **α_{sw}^{mod} = -15 W.m^{-2}**
  - **Mean state (SC) unchanged**



KE

TI

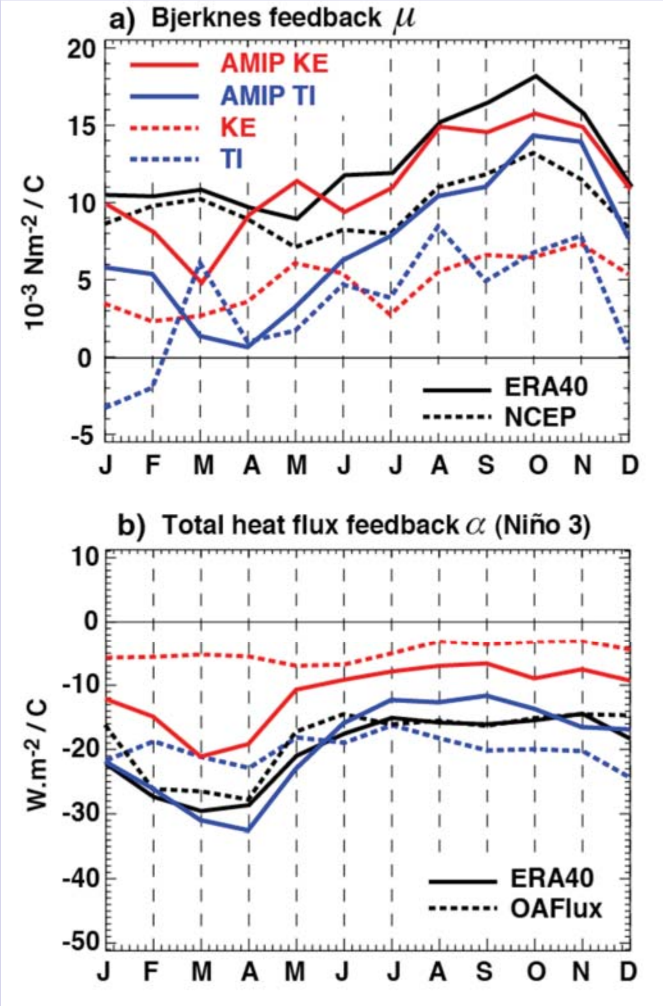
KE mod TI

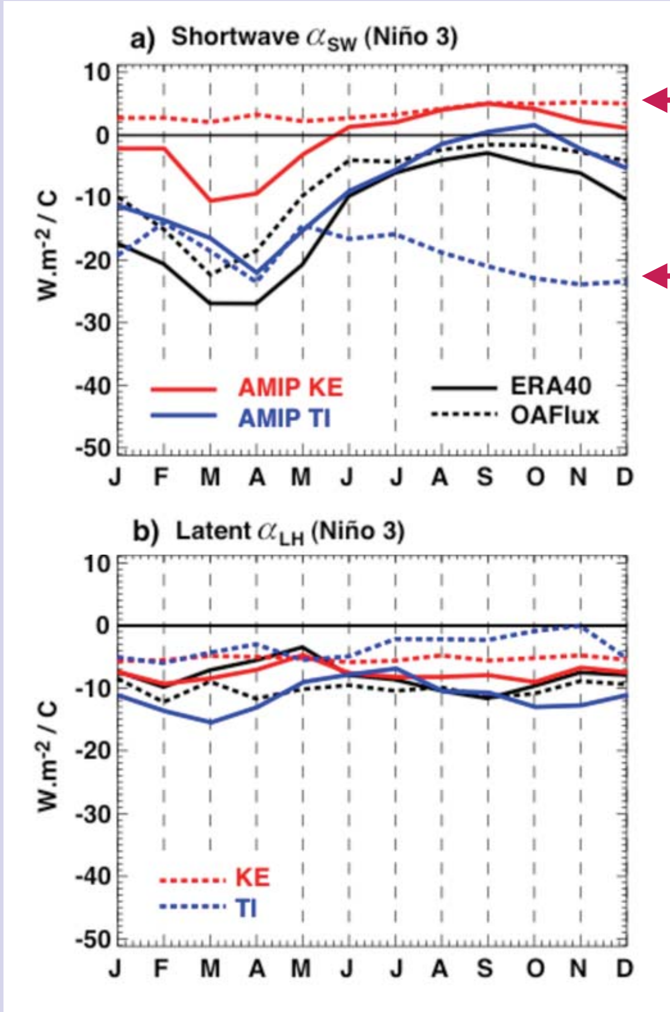


	μ	α	El Niño Amplitude
Obs	~10	-18	0.9
KE	4	-5	1.0
TI	4	-20	0.3
KE mod TI	5	-21	0.4
	10^{-3} N/m^2/C	*W/m^2/C*	*^{o}C*

ENSO gone as well !

Seasonal evolution of feedbacks





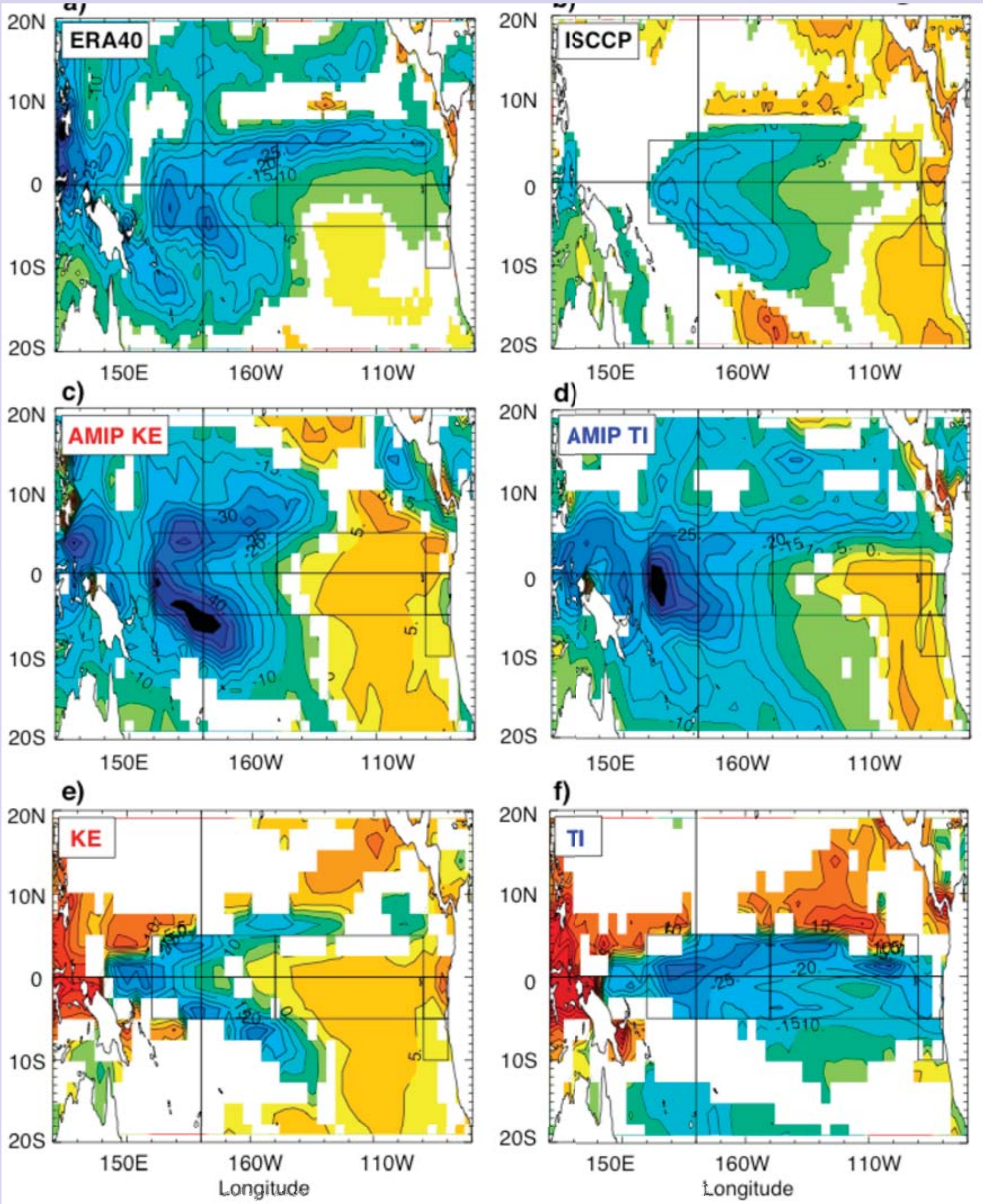
-25 W.m^{-2}/C

<=>

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



- ***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)