The role of the atmosphere during ENSO
a CLIVAR/CMIP perspective

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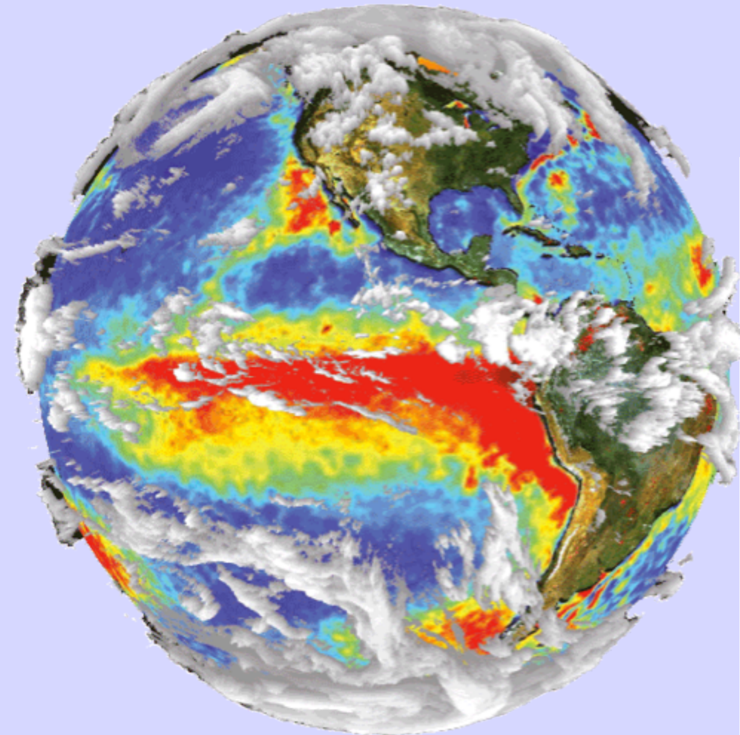


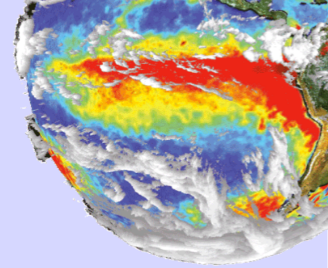
Outline:

- An evolving paradigm: linear atmosphere to main driver of variability
- Atmosphere heat flux feedbacks in GCMs
- Progress & challenges in ENSO modelling

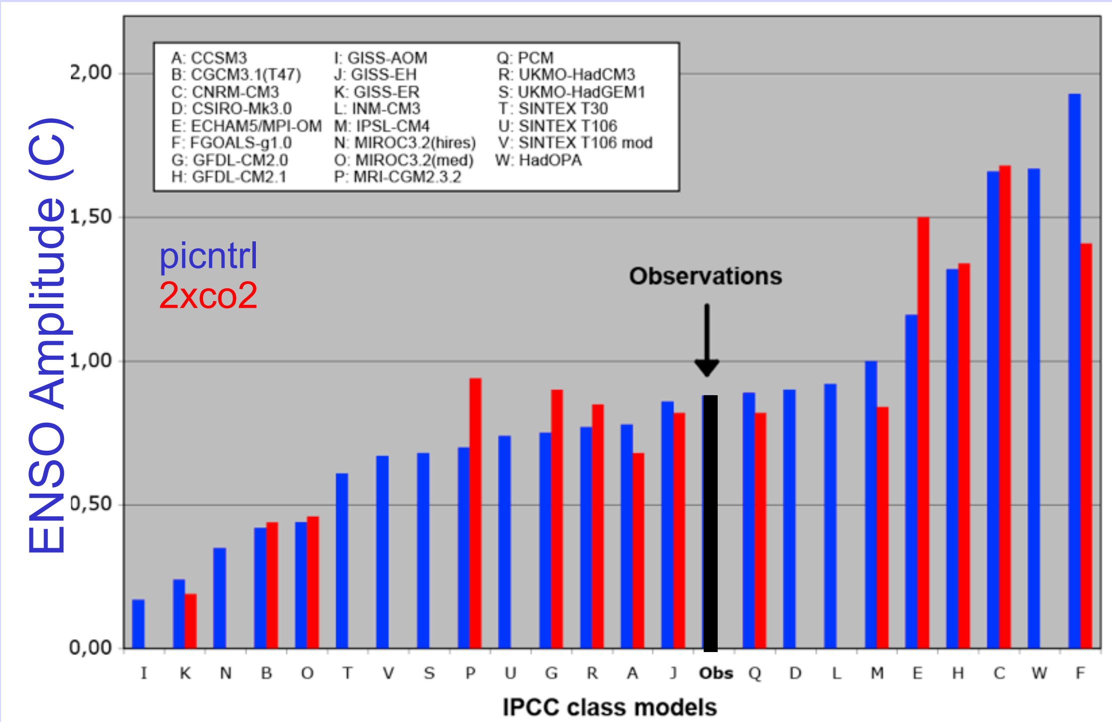
Thanks to Hugo Bellenger, James Lloyd, Pascale Braconnot, Andrew Wittenberg, Fei-Fei Jin, and many others

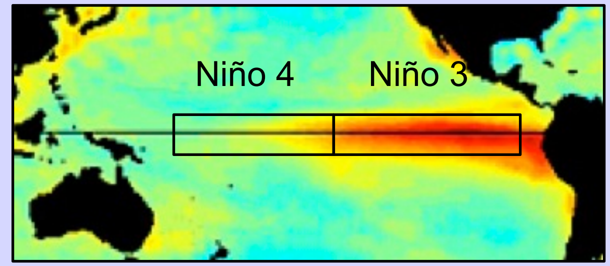
WCRP Open Science Conference, Denver, Oct 2011

ENSO in CMIP3



Standard deviation SSTA in east Pacific





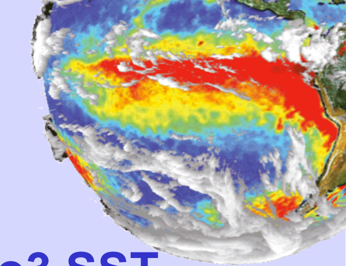
ENSO amplitude in CMIP3 : much too large diversity

Model errors dominate over scenario signal

Source of these errors ?

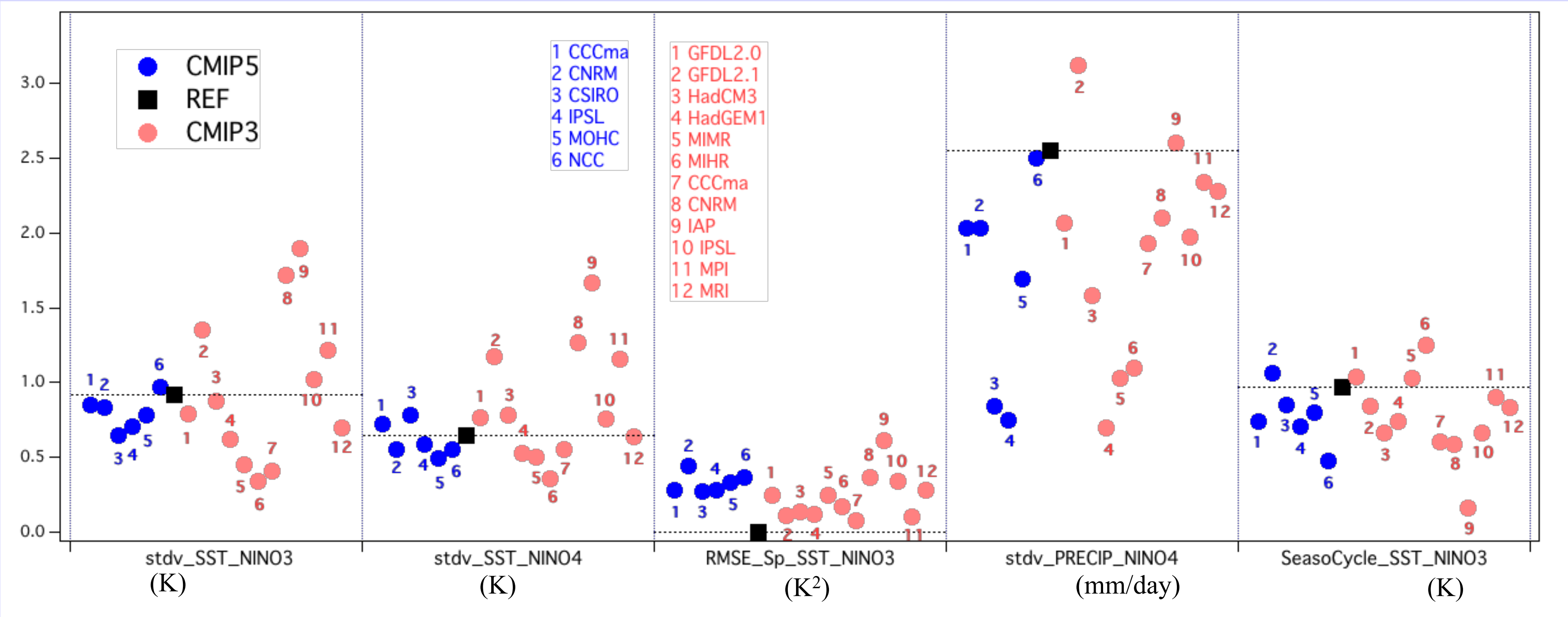
IPCC (Meehl et al. 2007)
Guilyardi et al. (BAMS 2009)
Collins et al. (NGEO 2010)

Preliminary assessment of ENSO in CMIP5 using Pacific Panel CLIVAR Metrics



Std dev

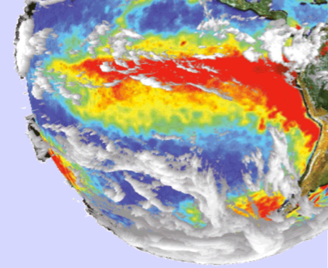
Niño3 SSTA | **Niño4 SSTA** | **Spectra RMS** | **Niño4 Precip Std dev** | **Niño3 SST annual cycle**



- **Some improvement of Niño3 and 4 interannual SST variability** (TBC)
- **No clear trend for ENSO spectra, precipitation response and SST annual cycle**
- **What role for the atmosphere ?**

Caveat: only 6 CMIP5 models

E. Guilyardi - Role of atmosphere in ENSO - WCRP OSC, Denver Oct 2011



Role of atmosphere during ENSO

From a linear atmosphere to the driver of variability

1 - Classical theory:

Dynamical positive Bjerknes feedback: μ

Negative heat flux feedback: α (SHF, LHF)

e.g.: the BJ coupled-stability index for ENSO I_{BJ}

Mean advection and upwelling (damping)

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

$$2I_{BJ} = -\left(\frac{\langle\bar{u}\rangle}{L_x} + \frac{\langle -2y\bar{v}\rangle}{L_y^2} + \frac{\langle H(\bar{w})\bar{w}\rangle}{H_m}\right) - \alpha$$

$$+ \mu_a\beta_u\left\langle -\frac{\partial\bar{T}}{\partial x}\right\rangle + \mu_a\beta_w\left\langle\frac{\partial\bar{T}}{\partial z}H(\bar{w})\right\rangle$$

$$+ \mu_a^*\beta_h\left\langle\frac{H(\bar{w})\bar{w}}{H_m}a\right\rangle,$$

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

Zonal advection feedback

Ekman pumping feedback

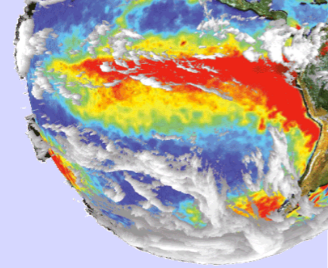
Thermocline feedback

α: atmosphere heat flux feedback (local linear)

μ: Bjerknes feedback or linear "coupling strength"

Jin et al. (2006), Kim et al. (2010)

Linear stability analysis of recharged oscillator SST equation



Role of atmosphere during ENSO

From a linear atmosphere to the driver of variability

2 - <u>Dominant role of AGCM in coupled AOGCMs</u>

OGCM only modifies the amplitude

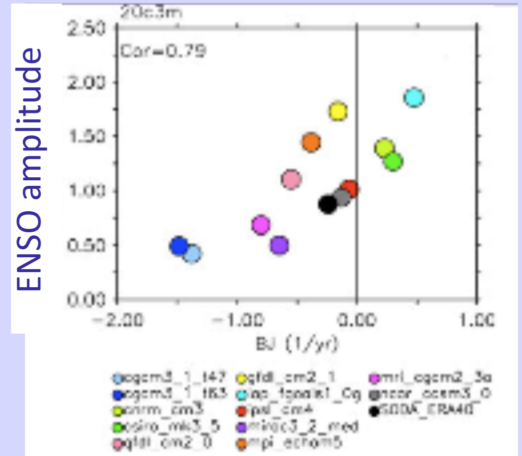
(Schneider 2002, Guilyardi et al. 2004, 2009, Kim et al. 2008, Neale et al. 2008, Sun et al. 2008, 2010)

e.g.: apply BJ Index to the CMIP3 GCMs:

- **BJ Index a good measure of ENSO amplitude**
- α **major contributor to ENSO amplitude errors**

Kim and Jin (2010)

BJ Index

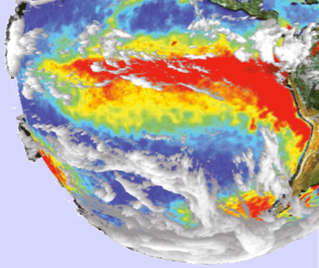


3 - <u>The Southern Oscillation is an atmosphere mode</u>

- **Slab ocean El Niño, thermally coupled Walker mode (TCW)**
- **Mechanisms: MM, WES, cloud shortwave feedbacks, extra tropics forcing**
- **Ocean role: amplify signal and 2-7 years power spectra in east Pacific**

(Kitoh al 1999, Vimont et al. 2003, Chang et al. 2007, Dommenget 2010, Alexander et al. 2010, Terray 2011, Clement al. 2011)

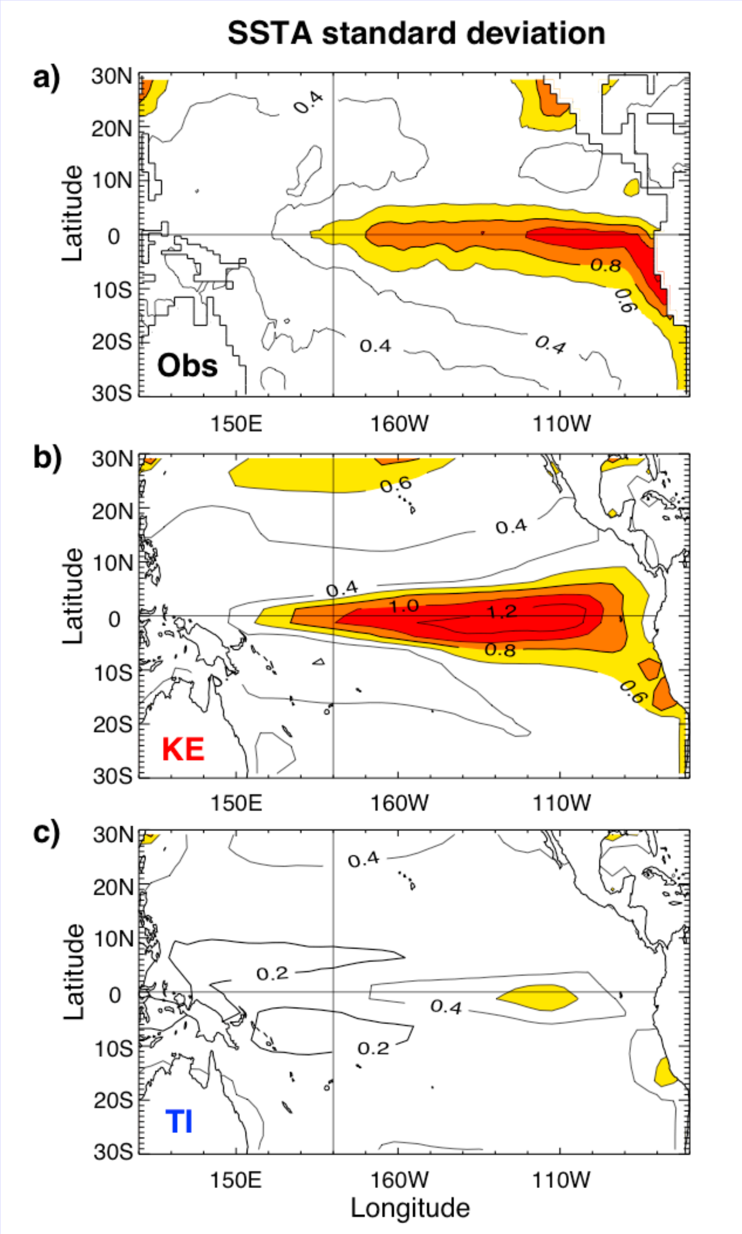
Impact of atmosphere convection scheme on ENSO



Observations
(0.9 C) - HadiSST1.1

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

IPSL/Tiedke (TI)
(0.3 C) – old scheme



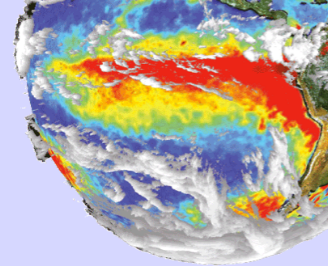
IPSL-CM4 model

ENSO has disappeared !

What role for α and μ?

Guilyardi et al. (2009b)

Impact of atmosphere convection scheme on ENSO in the IPSL-CM4 model

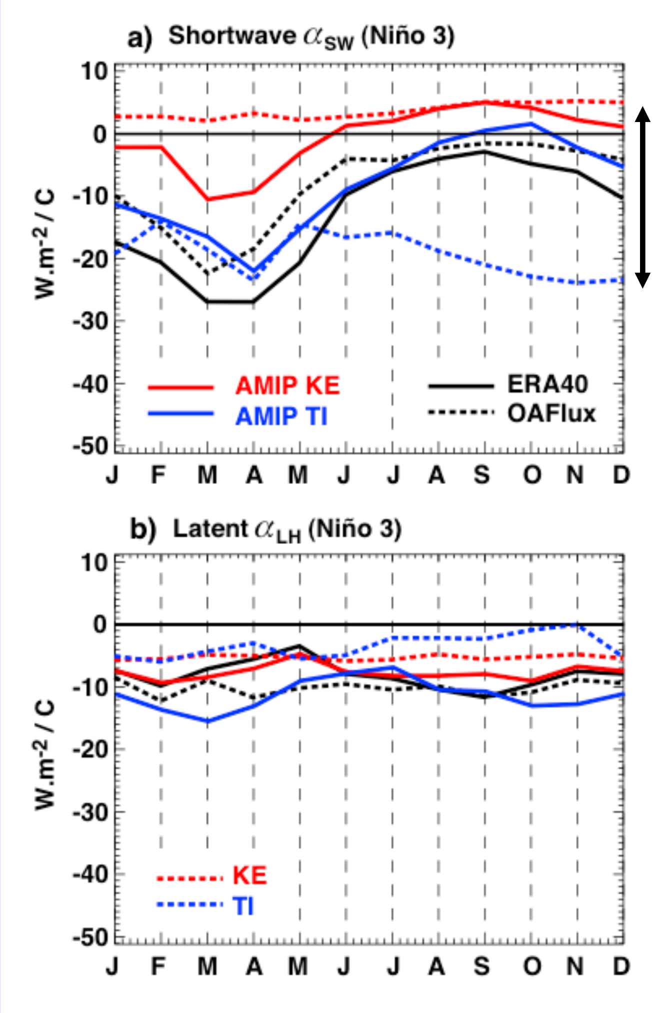


	μ	α	ENSO
Obs	~10/12	-18	0.9
KE	4	-5	1.0
TI	4	-20	0.3
	10^{-3} N.m^{-2}/C	W.m^{-2}/C	°C

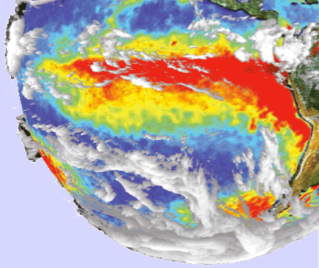
- **Due to shortwave feedback difference second half of the year**
- **KE: error compensation**

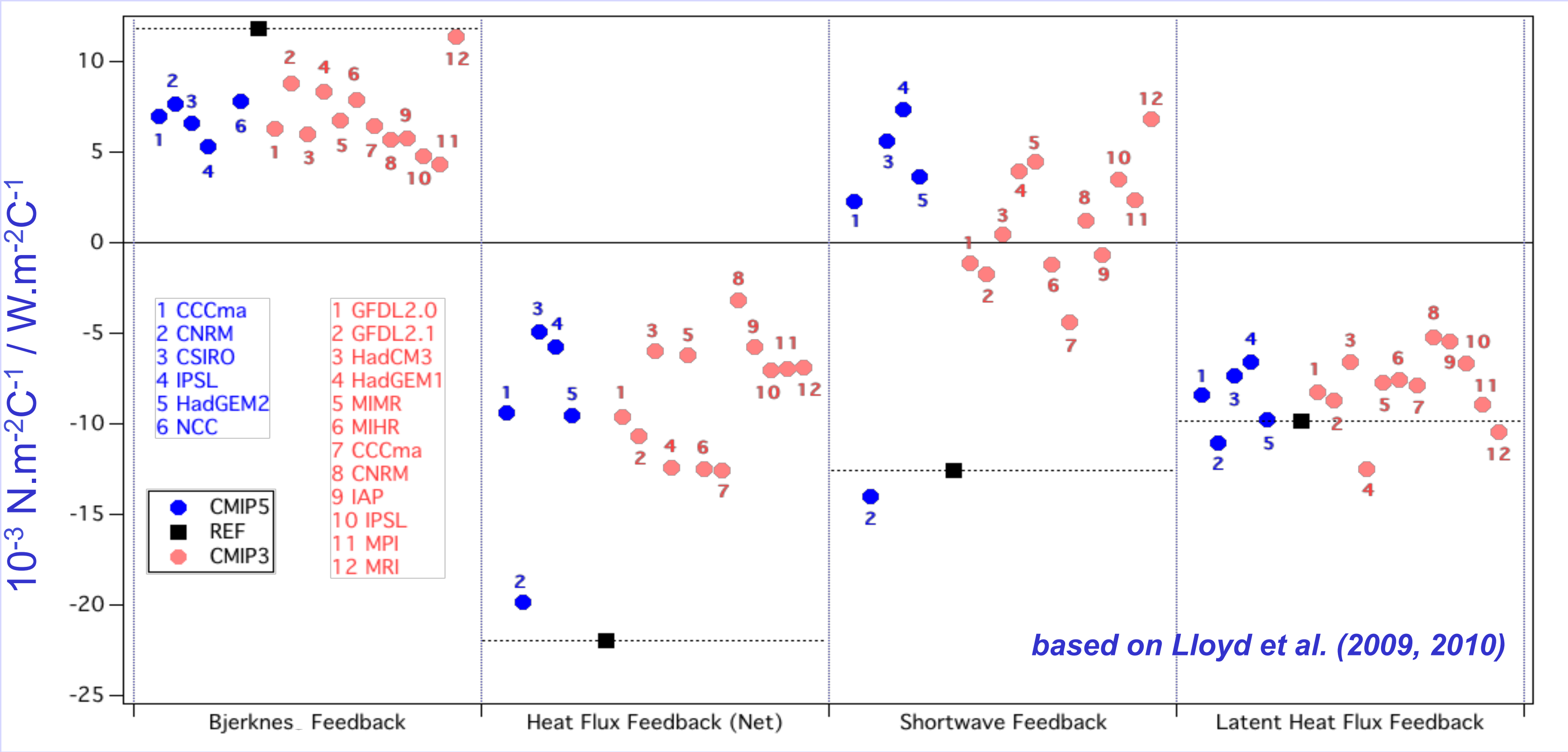
→ **α_{SW} sensitive to atmosphere convection scheme in IPSL-CM4**

Annual cycle of α_{SW} and α_{LH}



Atmosphere feedbacks in CMIP3/CMIP5

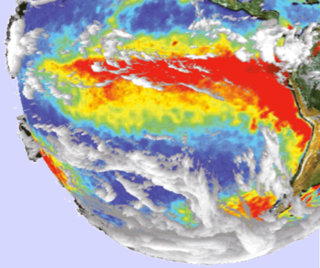


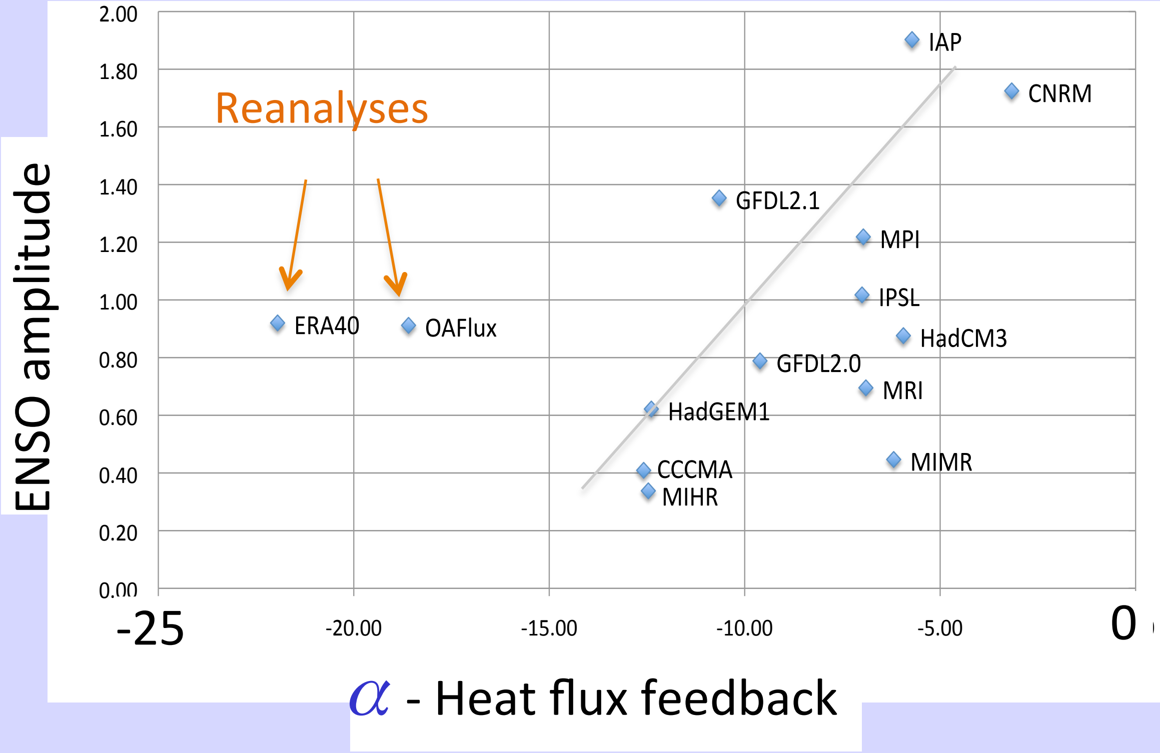


Models underestimate both μ and α (error compensation)

Shortwave feedback α_{SW} also main source of errors and diversity

ENSO amplitude vs. α



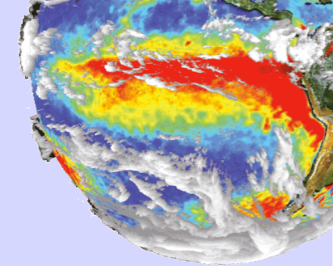


Inverse relationship

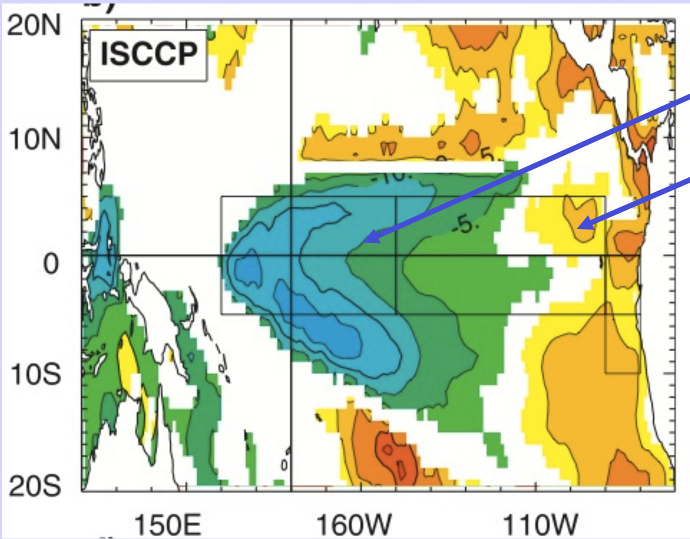
(corr = 0.61, sig. at 0.05 level)

- **α is an important contributor to model ENSO amplitude biases**
  - cf. Kim and Jin (2010) using BJ index
- **No relationship found between μ and ENSO amplitude**
  - Bjerknes feedback not central to (EN)SO ! (TCW, *Clement et al. 2011*)

Source of α_{SW} errors



α_{SW} map (ISCCP)



Convective regime $\alpha_{SW} < 0$

Subsidence regime $\alpha_{SW} > 0$

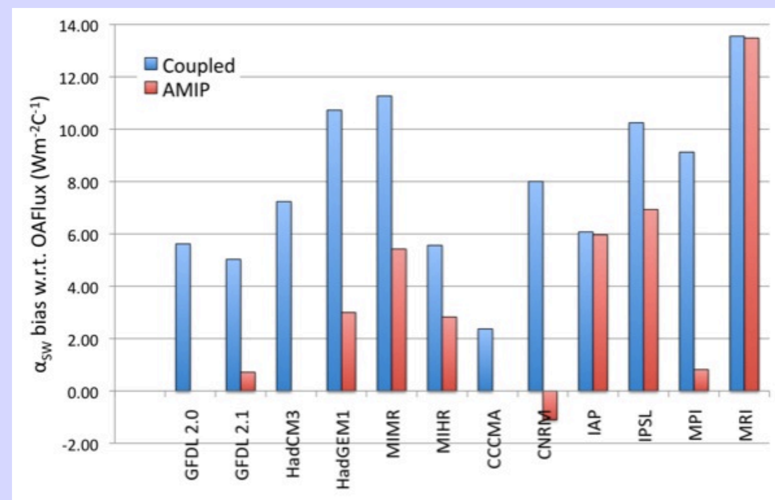
Both co-exist in Niño3

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

AMIP

Coupled

α_{SW} errors wrt OAFlux

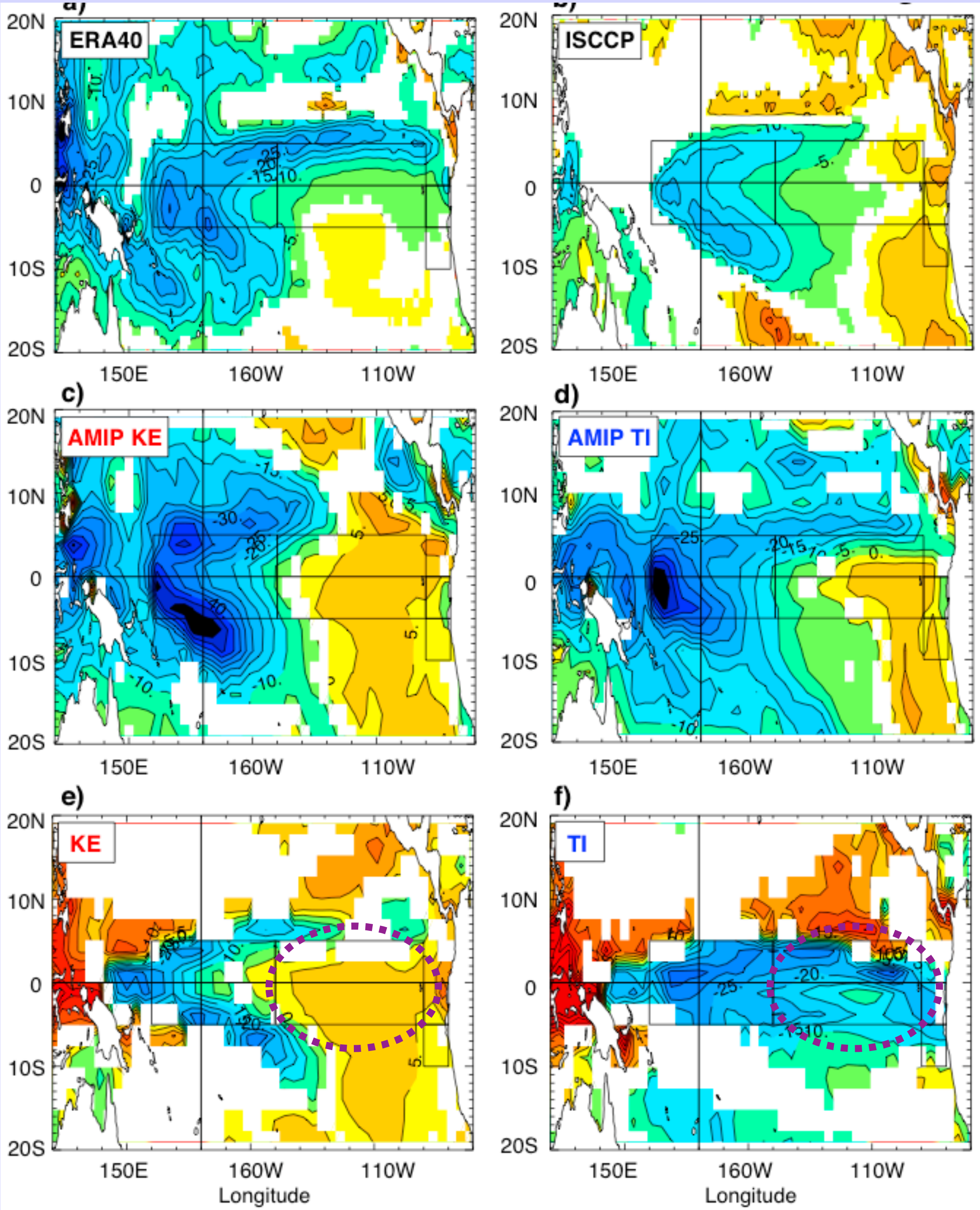


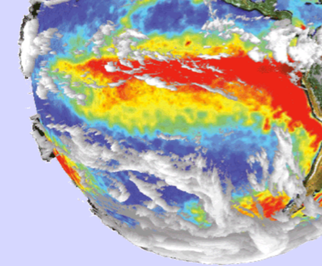
- α_{SW} error have their origin in the AGCM
  - cloud response to dynamics
  - (low) cloud properties

- When coupled, the dynamics also plays a role (SST drift)

Lloyd et al. (2011)

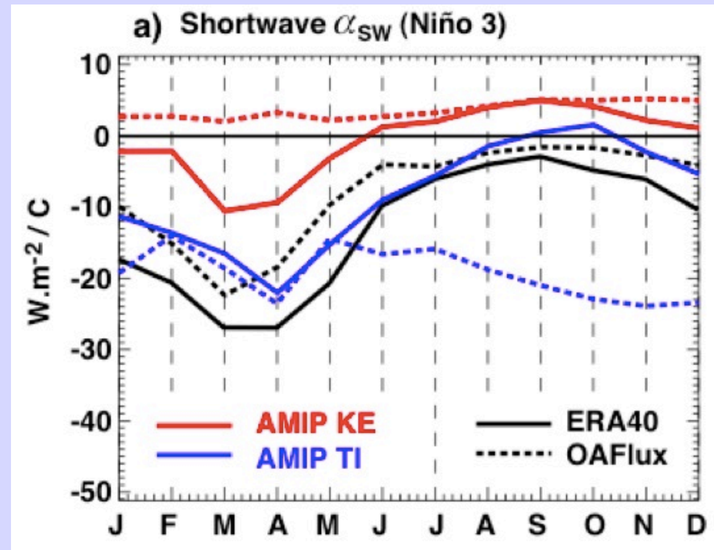
α_{SW} feedback





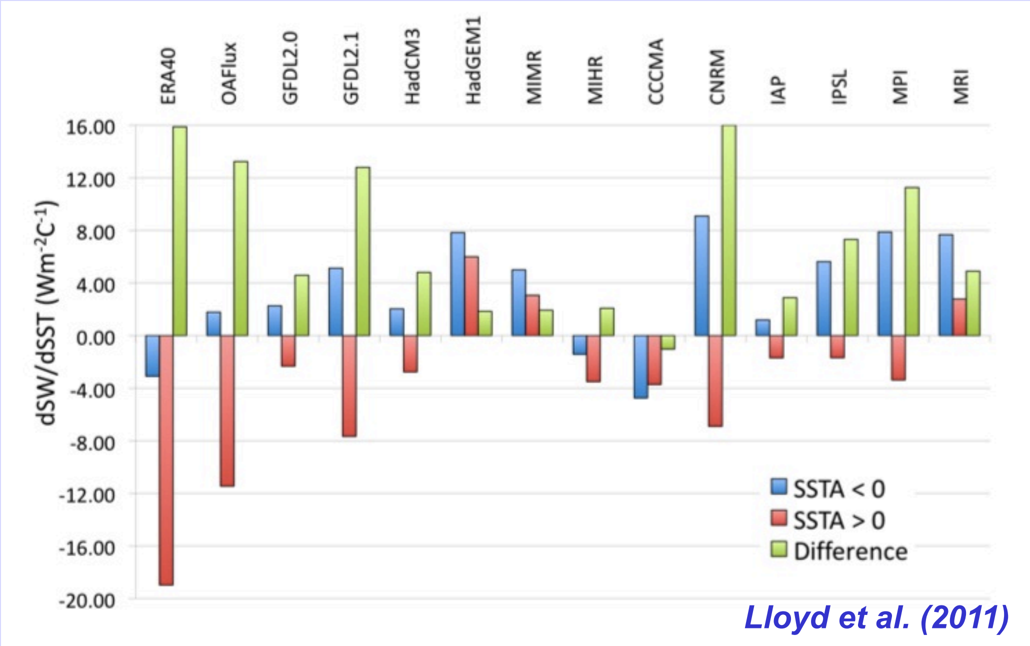
Observations and ERA40

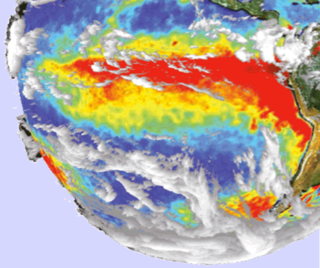
AMIP



KE and TI IPSL-CM4 models

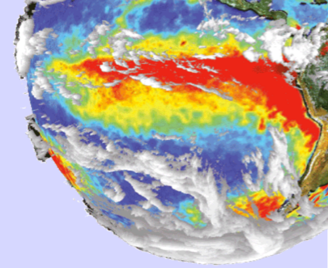
Non-linearities in α_{SW} in East Pacific



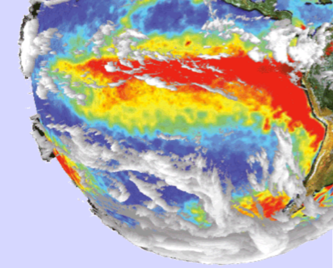


- **Theory assumes linear α whereas strong α_{SW} non-linearities in re-analysis**
  - due to the weaker dynamical (ω_{500}) response to SSTA < 0
- **Models differ considerably in their simulation of this non-linearity**
  - due to errors in the dynamical response to SSTA > 0

Summary

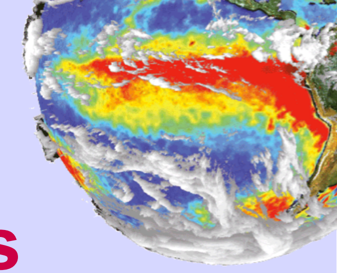


- **The atmosphere controls ENSO properties in AOGCMs**
  - Latent heat flux feedback well captured
  - Bjerknes feedback too weak but unrelated to ENSO amplitude
  - Danger of error compensations: process-based evaluation
- **Shortwave heat flux feedback α_{SW} is the key**
  - The convective and subsidence regimes have to be captured
  - And their spatial and temporal structure
  - Most CMIP5 models still fail at representing α_{SW}
  - Role of non-linearities
- **Why this dominant role of the atmosphere ?**
  - Limitations from AGCMs systematic errors (dynamics, clouds)
  - But also new physically-based evidence of this dominant role
  - Time to revisit ENSO theory ?



Key workshop findings

- The **basic physical properties of ENSO are now well simulated** by a growing number of CGCMs;
- The **detailed properties** of individual events (El Niño, La Niña) and their **subtle flavours still present a challenge for CGCMs**;
- The **parameterisation of the atmospheric convection** (and its interaction with the resolved flow and other parameterised processes) plays a critical role in the ENSO performance of CGCMs;
- **Model diagnostics of ENSO behaviour and the underlying mechanisms are improving**, guided by theory and availability of quality decade and longer-duration data sets;
- Mature approaches to **bridging ENSO theoretical frameworks and CGCM** results are now available;
- **ENSO prediction and simulation is far from being solved**



Recommendation and research priorities

- **Reducing mean state biases in CGCMs** (e.g. equatorial cold tongue extension, intensity of trade winds, double ITCZ, properties and extent of tropical clouds)
- **Understanding:**
  - Causes for **El Niño and La Niña inter-event diversity**;
  - Causes for **low-frequency modulation of ENSO** ("El Paso");
  - How **mid-latitudes and other tropical regions may influence ENSO**;
  - How **ENSO may change under global warming** including quantifying and reducing uncertainty in projections;
- **Coordinate CMIP5 ENSO analysis**; further develop process-based ENSO metrics as methods to understand ENSO in CGCMs;
- Further **bring together the different communities of experts** needed to make significant progress in the representation of ENSO in CGCMs.

(summary in press in BAMS)