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Ocean carbon cycle feedbacks in the tropics from CMIP5 models

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Norwegian Centre of Excellence

17th Annual CESM Workshop
Breckenridge, 18-21 June, 2012

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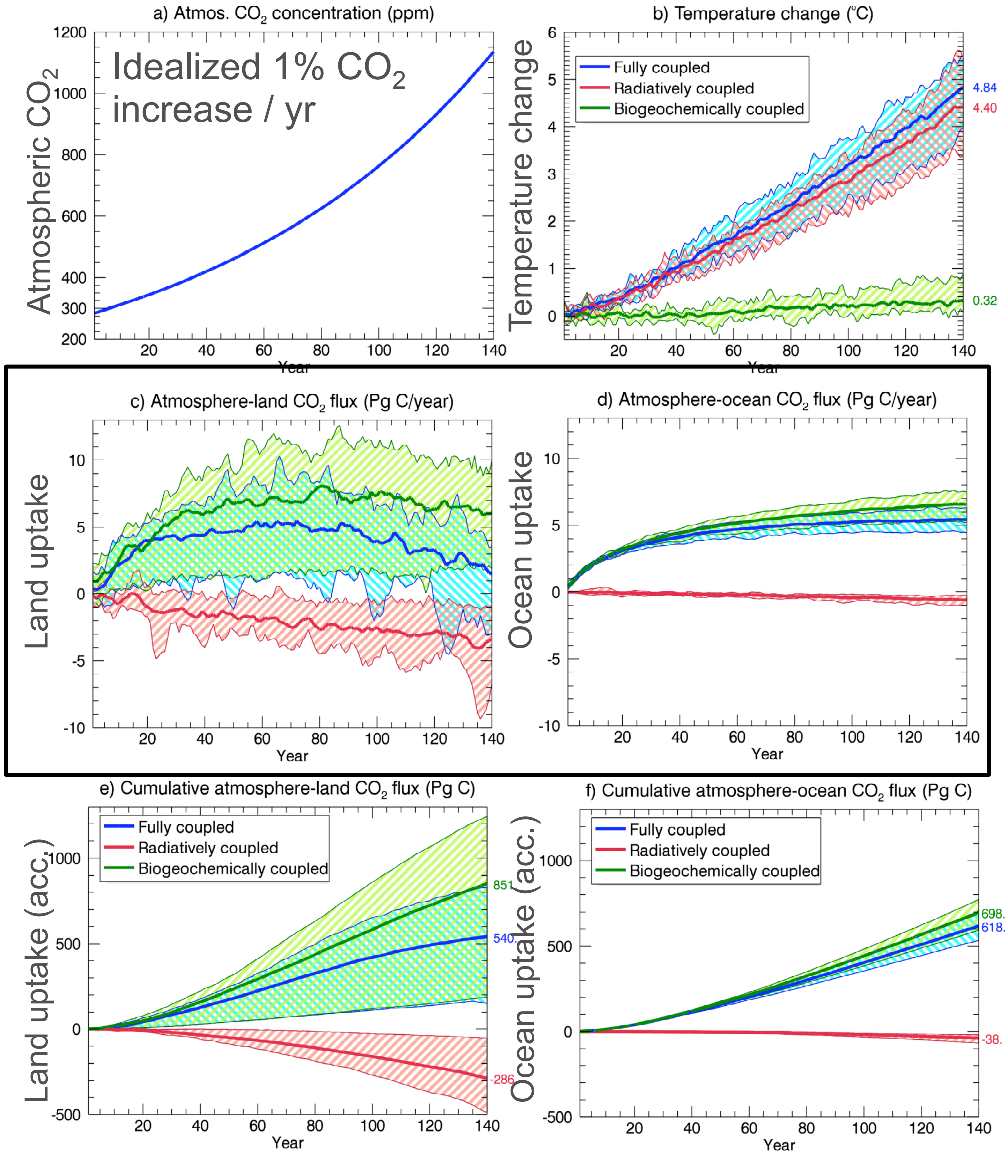
Feedbacks simulated by CMIP5 models (Arora et al.)



The positive feedback is predominantly due to change in surface temperature.

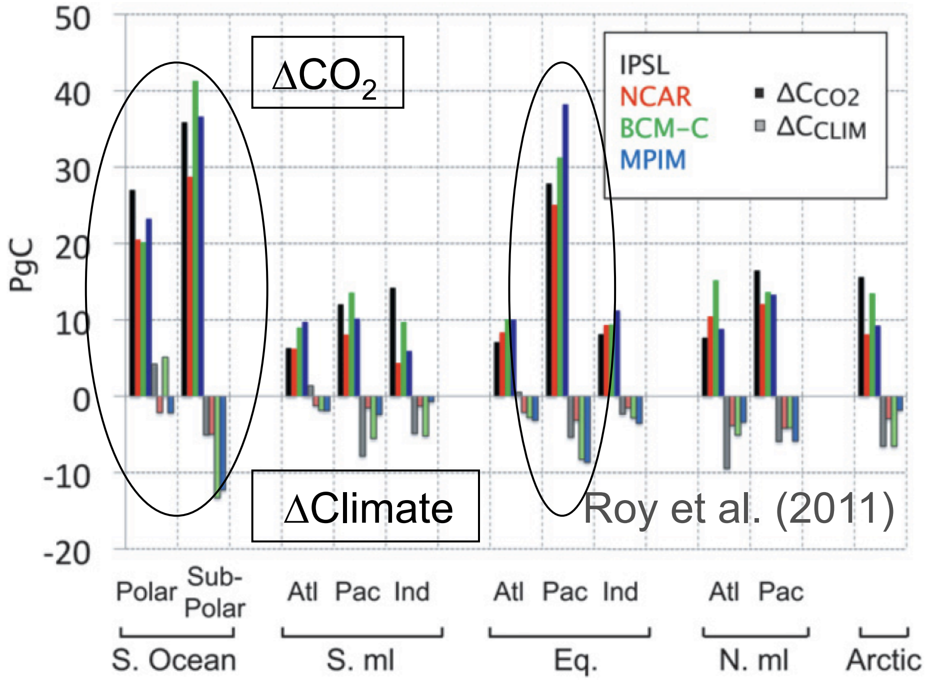
Ocean: Thermodynamic change lead to change in solubility, buffer capacity, and change in overturning.

Land: Change in terrestrial respiration largely responsible for reduced net uptake.

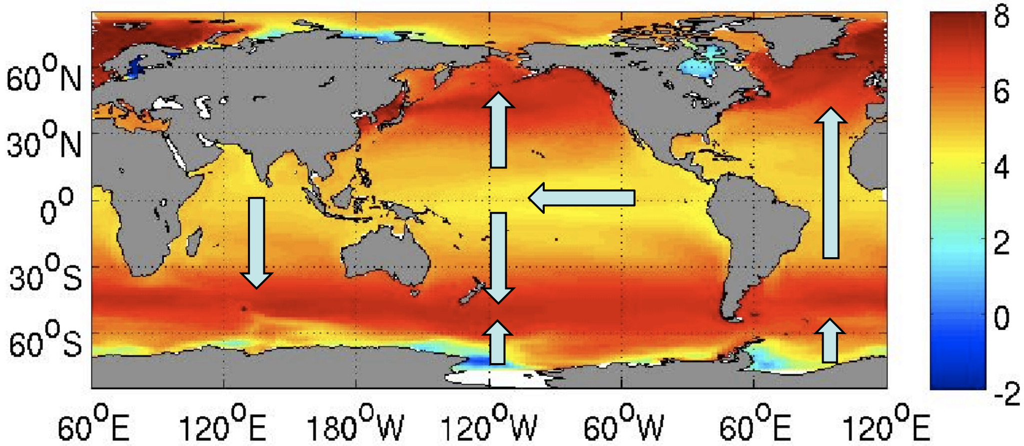
Fully coupled
Radiatively coupled (+)
Biogeochemically coupled (-)

List of models (8): BCC-CSM1-1, CanESM2, IPSL-CM5A-LR, MIROC-ESM, HadGEM2-ES, MPI-ESM-LR, Uvic ESM2.9, and NorESM-ME

Significance of future feedback in the equatorial Pacific



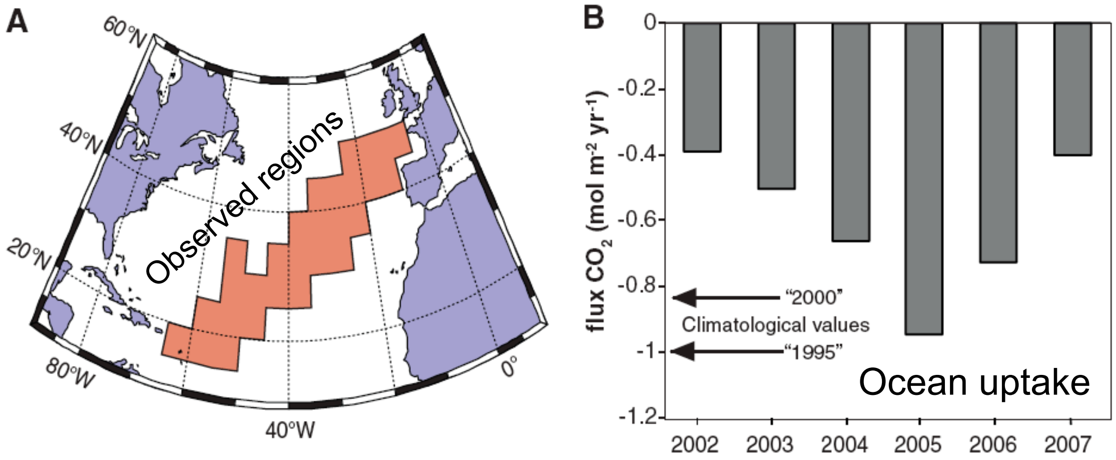
Accumulated (2010-2099) regional oceanic CO_2 uptake due to **change in atmospheric CO_2 (solid-colors)** and **change in climate (shaded-colors)**.

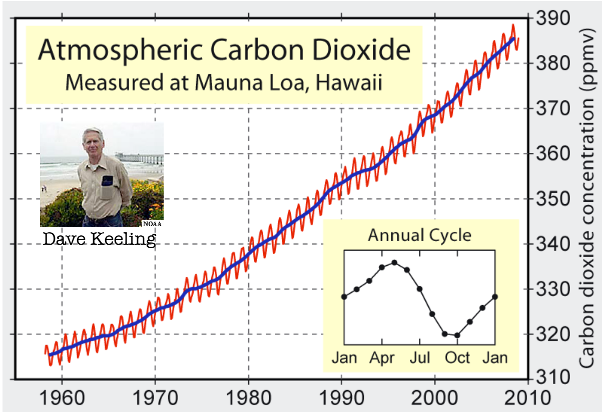


Simulated **change in Revelle Factor** due to anthropogenic CO_2 uptake by end of 21st century.

The **Revelle Factor** describes how the partial pressure of CO_2 in seawater changes to a given change in DIC (Sabine et al., 2004).

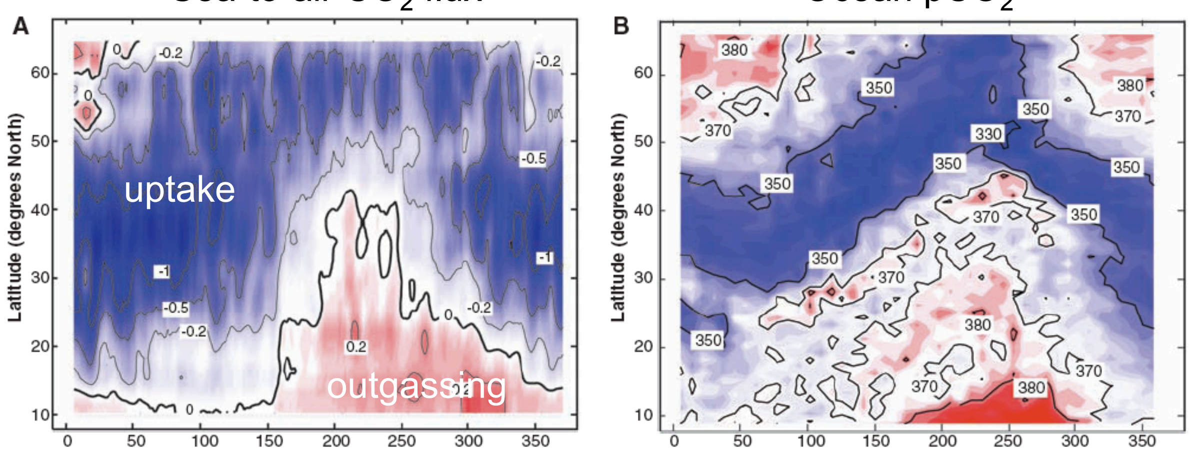
Climate-carbon cycle fluctuation in the North Atlantic





Sea-to-air CO_2 flux

Ocean pCO_2



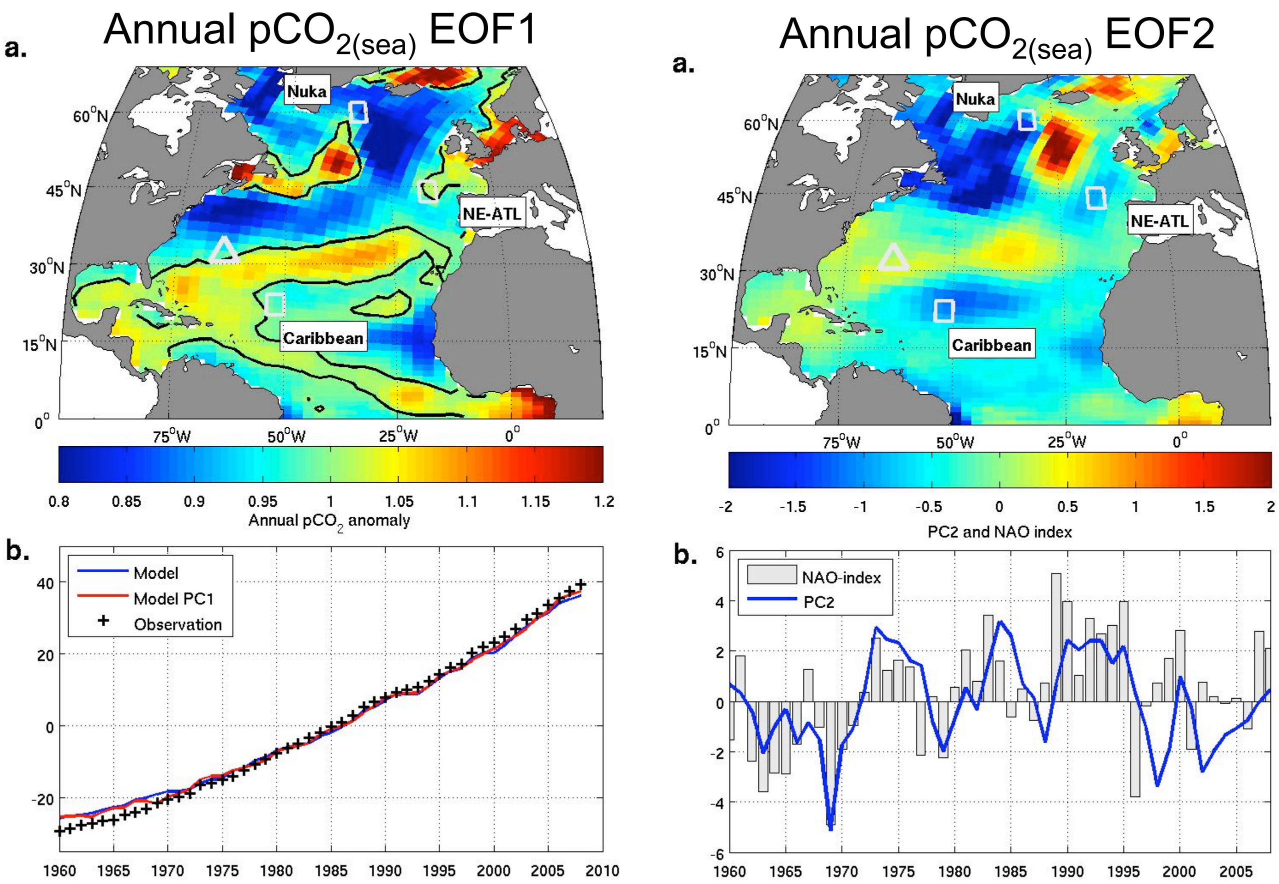
Julian day in 2005

Julian day in 2005

Observational-based study indicates substantial variability (in space and time) in the oceanic CO2 uptake in the North Atlantic

Watson et al. (2009)

Climate-carbon cycle fluctuation in the North Atlantic

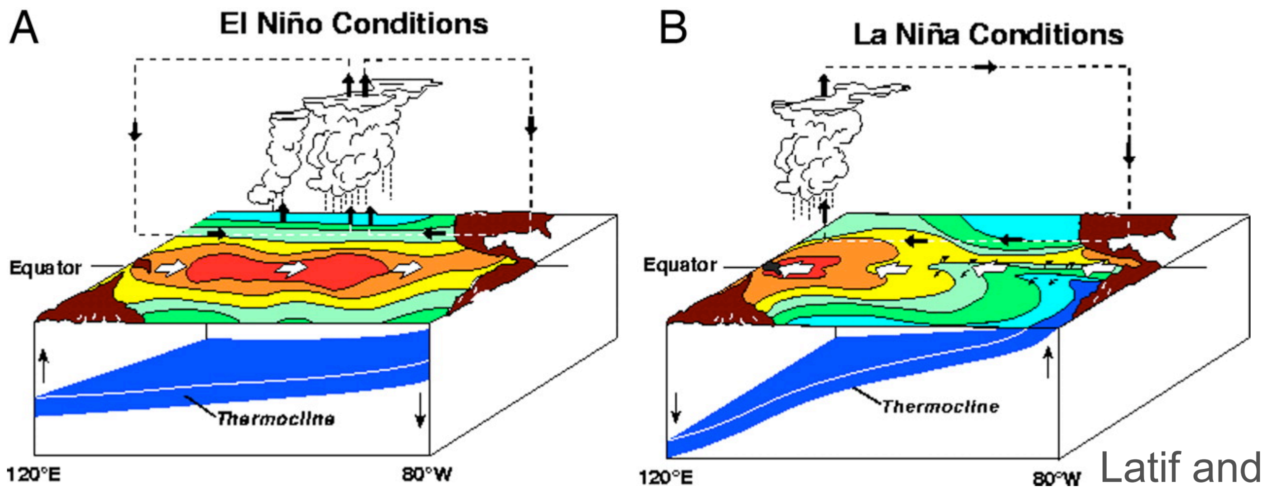


Modeling study using a coupled physical-biogeochemical ocean model forced by observed atmospheric variability in the North Atlantic. The study indicates that while over a long term, the atmospheric CO_2 control the oceanic uptake, over shorter interannual period, the NAO variability regulates the oceanic uptake.

Tjiputra et al. (2012)

Questions to address

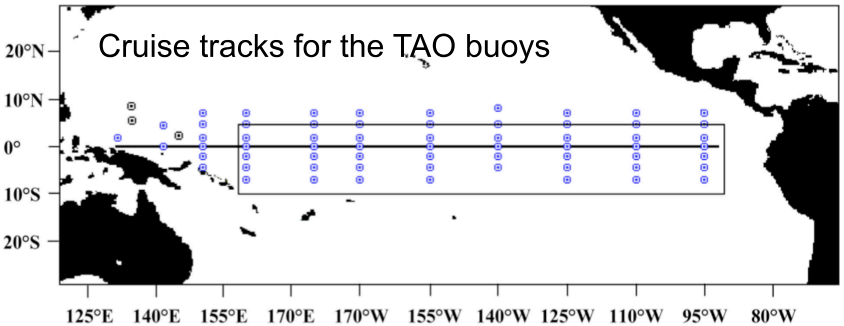
- How well do the CMIP5 models simulate the observed mean climate state and dominant variability in equatorial Pacific?
  - El-Nino Southern Oscillation (ENSO) is the strongest natural interannual climate signal.

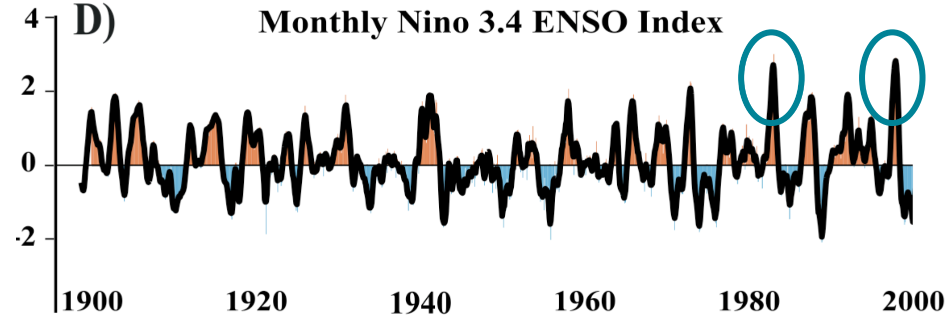


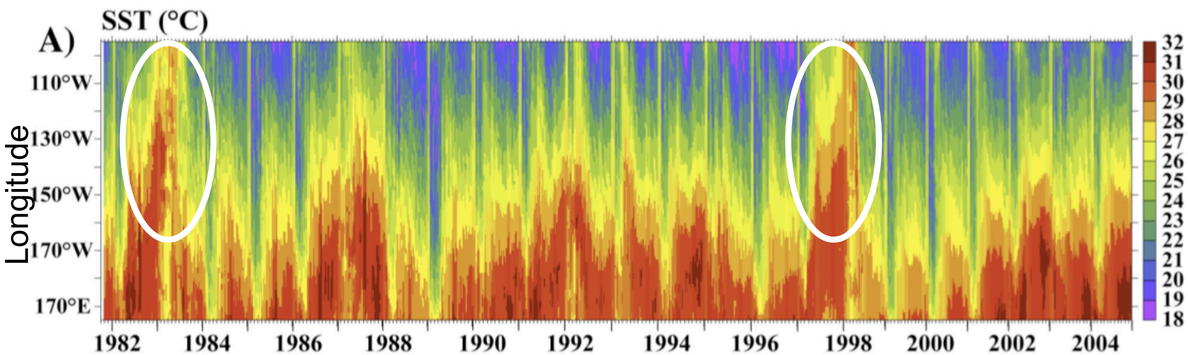
Latif and Keenlyside (2009)

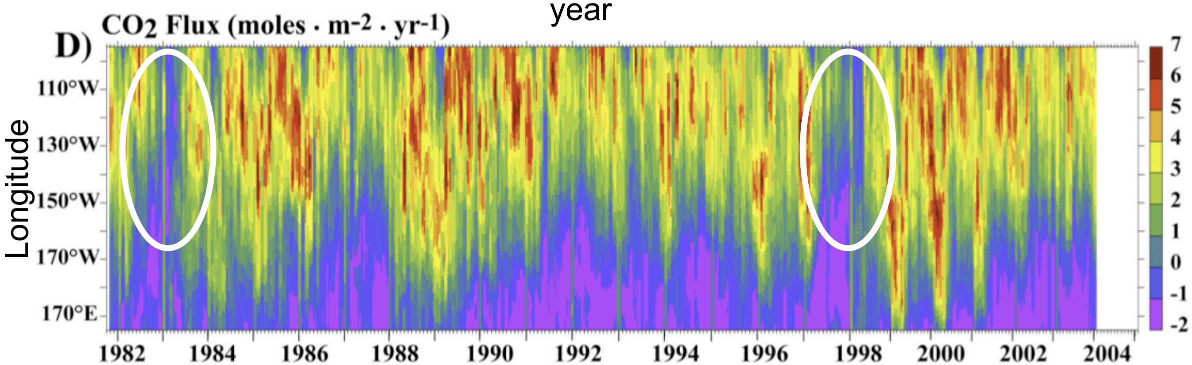
- Does the simulated global carbon cycle respond accordingly to climate variability as observed?
- How the climate carbon cycle interaction change in the future?

Observed ocean CO_2 flux variability in the Equatorial Pacific









- El-Nino ➔ Less outgassing
- La-Nina ➔ more outgassing
- Regulated by surface DIC convergence (vertical upwelling and meridional advection)
- Weak influences from biological production and temperature solubility effect

Feely et al. (2006)

CMIP5 Earth System Models

NorESM-ME (Bjerknes Centre, UiB, UiO)
ATM (CAM4-Oslo, ~1.9ºx2.5º, L26), OCN (MICOM, ~1º, L53)
Land CC: CLM4, Ocean CC: HAMOCC5

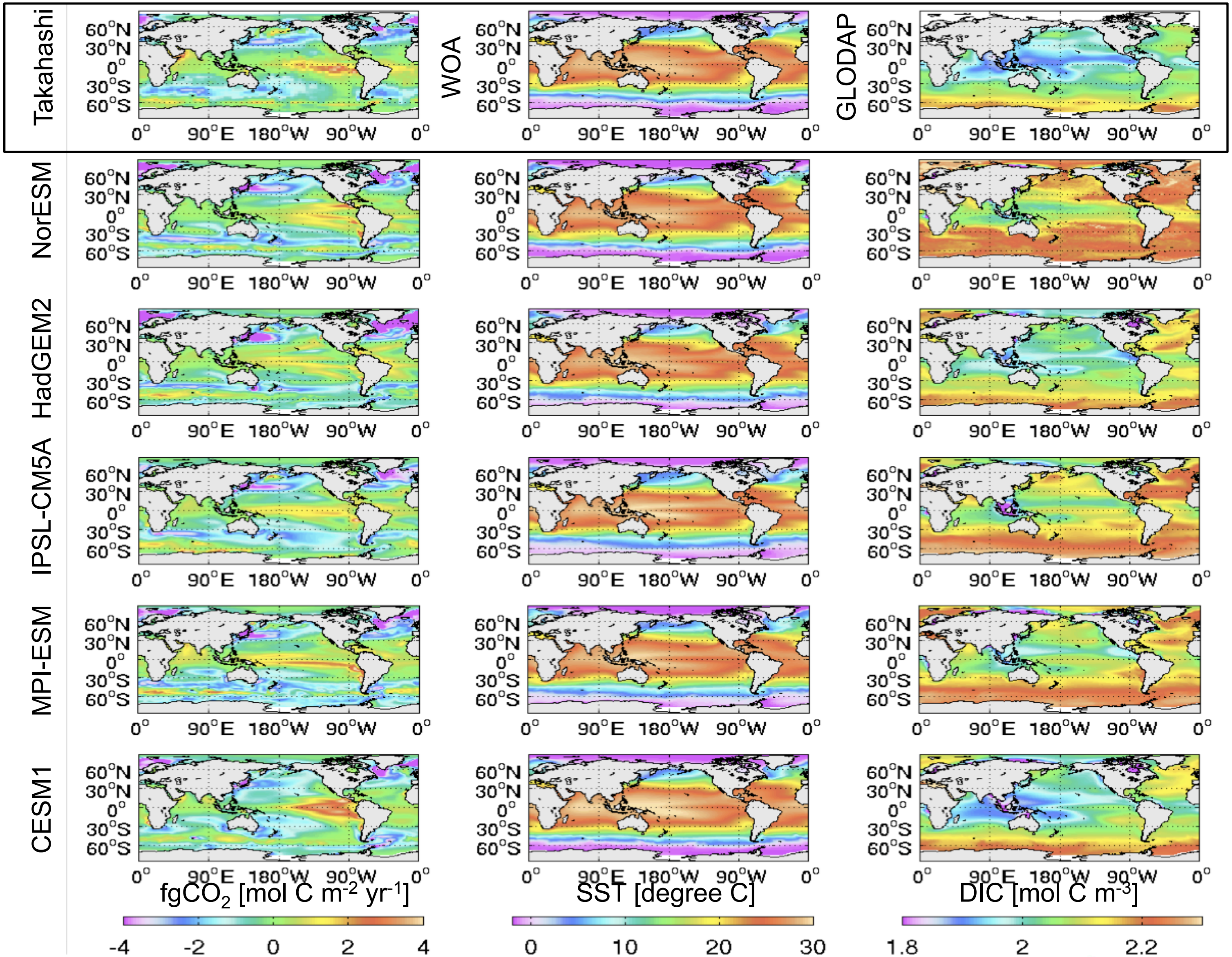
HadGEM2-ES (Met Office, Hadley Centre)
Atmospheric (~1.6º, L38), Ocean (~1º, L40)
Land CC: Jules, Ocean CC: Diat-HadOCC

IPSL-CM5-LR (Institut Pierre Simon Laplace)
Atmospheric (~3.75ºx1.9º, L39), Ocean(~2º, L31)
Land CC: ORCHIDEE, Ocean CC: PISCES

MPI-ESM-LR (Max Planck Institute)
ATM (ECHAM5, ~1.9º, L47), OCN (MPI-OM, ~1.5º, L47)
Land-CC: JSBACH, Ocean-CC: HAMOCC5

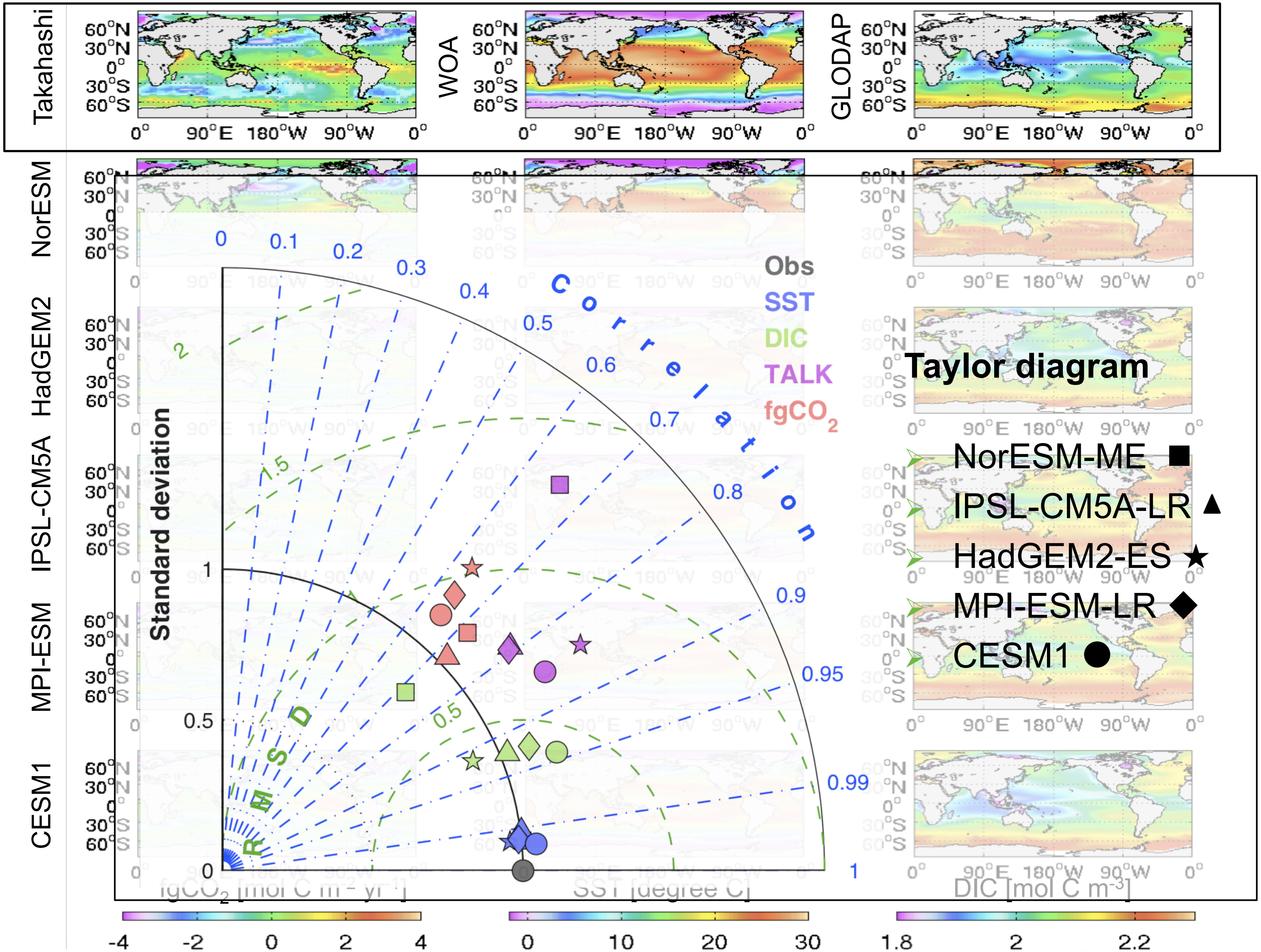
CESM1 (National Center for Atmospheric Research)
ATM (CAM4, ~1.9ºx2.5º, L26), OCN (POP, ~1º)
Land CC: CLM4, Ocean CC: BEC

CMIP5 simulated global mean surface CO_2 fluxes, SST, and DIC



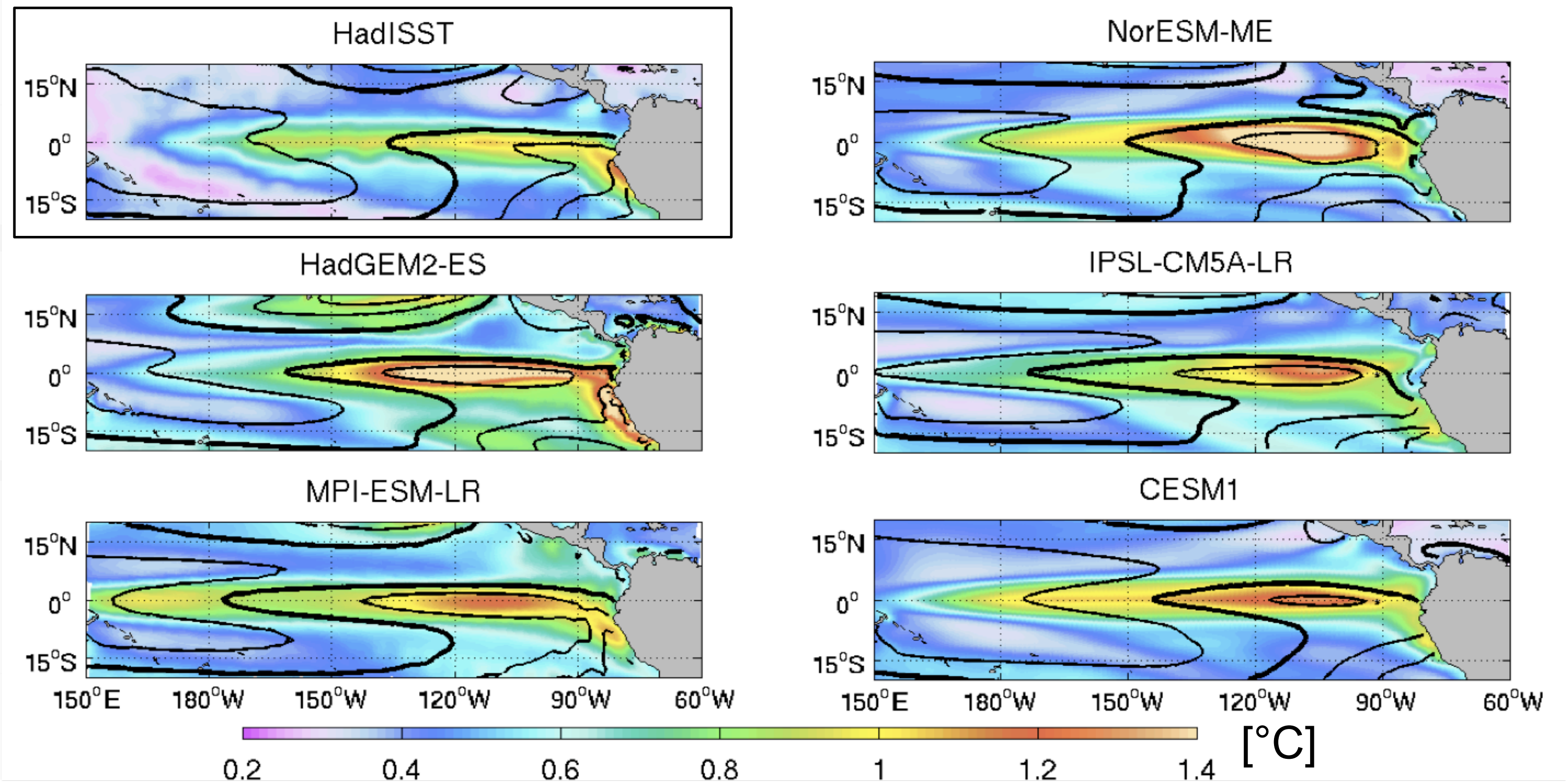
Historical (1995-2005)

CMIP5 simulated global mean surface CO_2 fluxes, SST, DIC, and TALK



Historical (1995-2005)

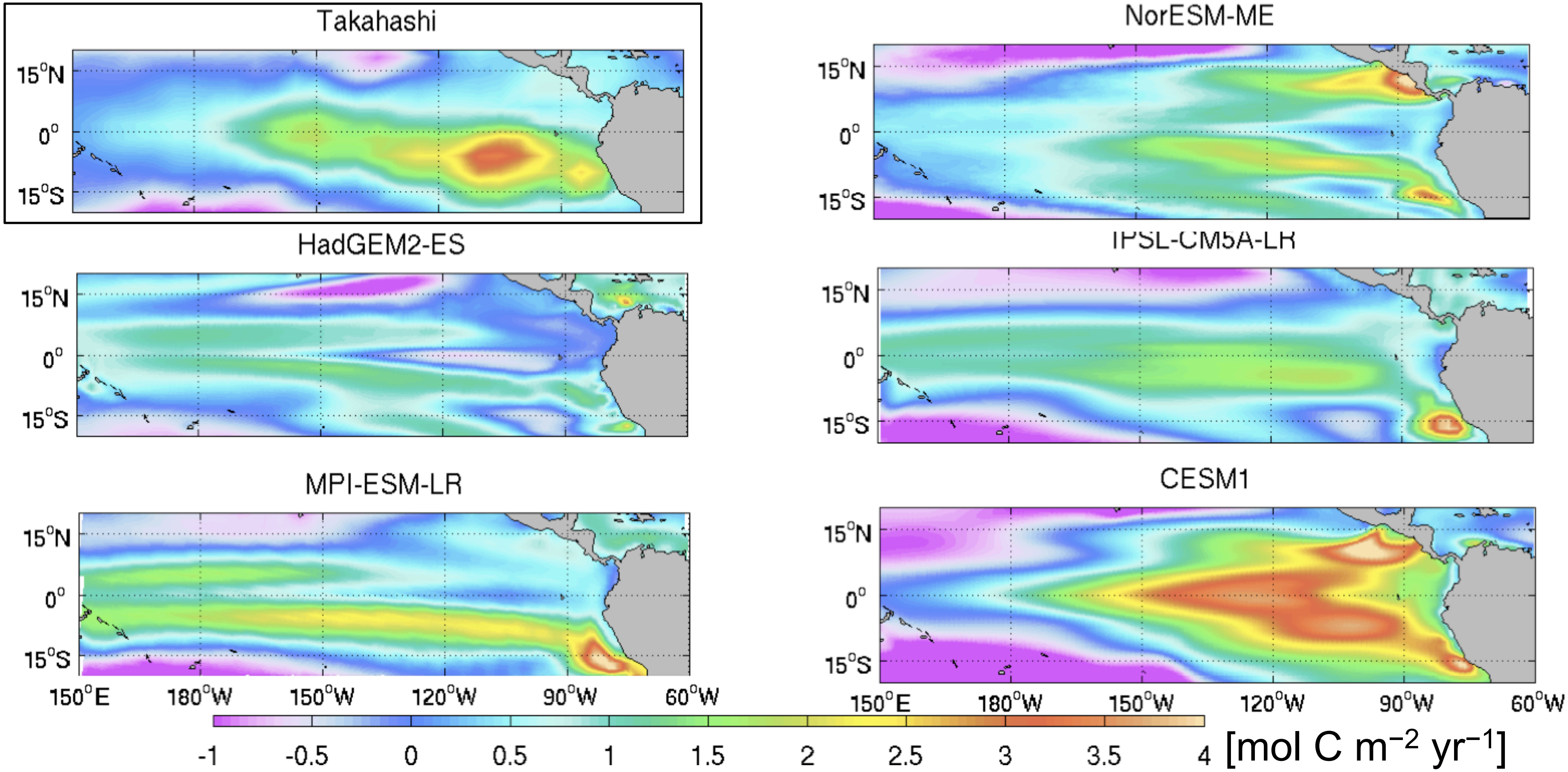
Mean and deviation of equatorial Pacific SST



Maps of (contour-lines) annual mean SST computed from historical simulation from January 1870 to December 2005.
The contour lines are in 2°C intervals and the **thick contour lines** represent the 26°C isotherms. The colors are standard deviation of seasonally-detrended monthly SST [°C].
Observation are taken from HadISST data over the same period.

historical

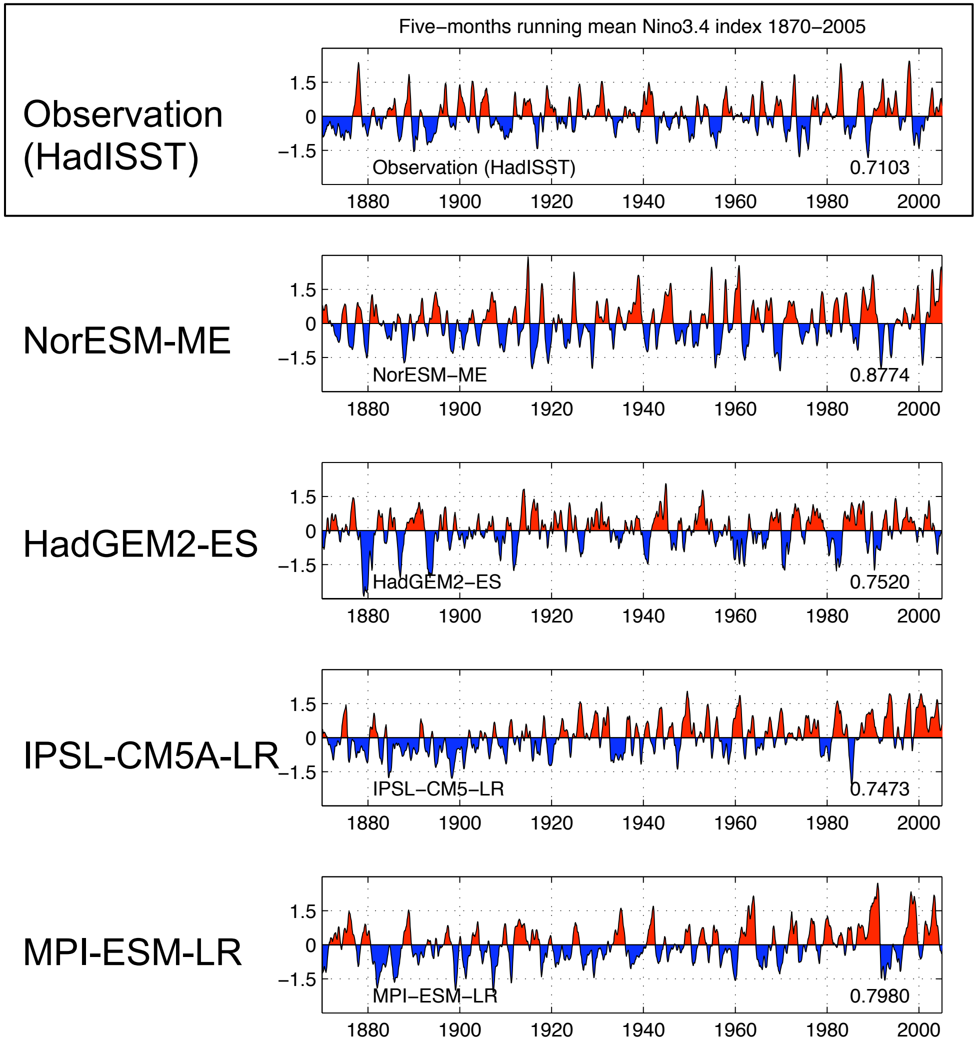
Mean of equatorial Pacific CO_2 flux

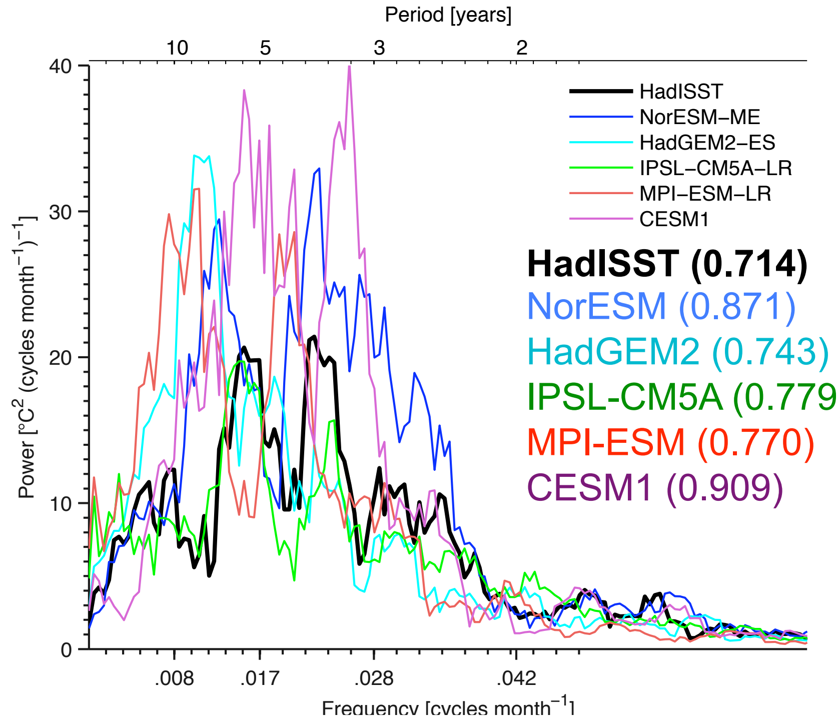


Maps of annual mean sea-to-air CO_2 flux (in [mol C m^{-2} yr^{-1}] units) from the observation [Takahashi et al., 2009] and as simulated by the models in the equatorial Pacific. Model values are computed from monthly CO_2 flux from January 1995 to December 2005 of historical simulation.

historical

Nino3.4 index variability





- Consistent 3-6 years intervals.
- The Hadley model only simulates one spectrum peak at around 7 years.
- All suggest higher amplitudes than observed.

Historical

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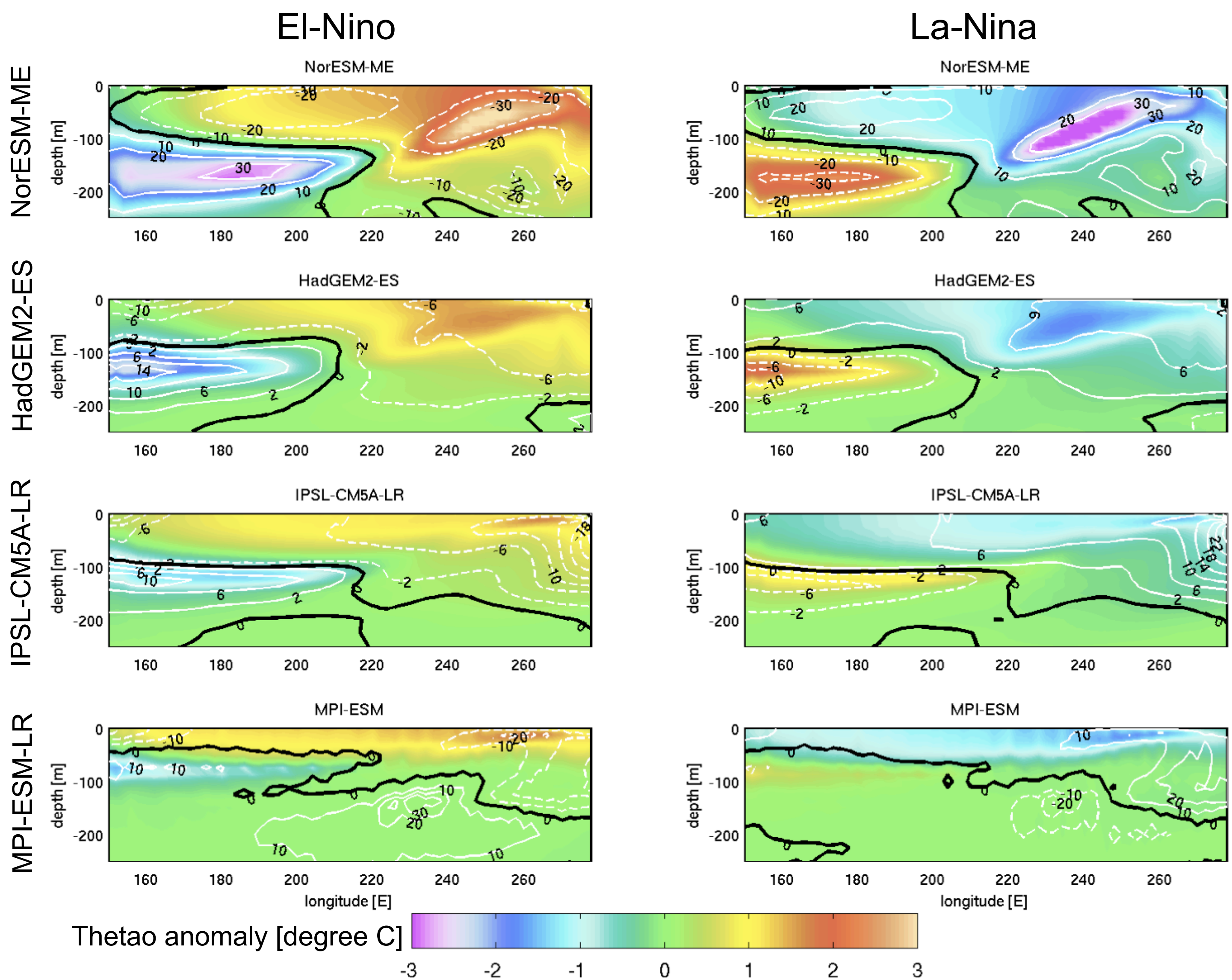
Vertical temperature and DIC profiles



Anomalies

Colors:

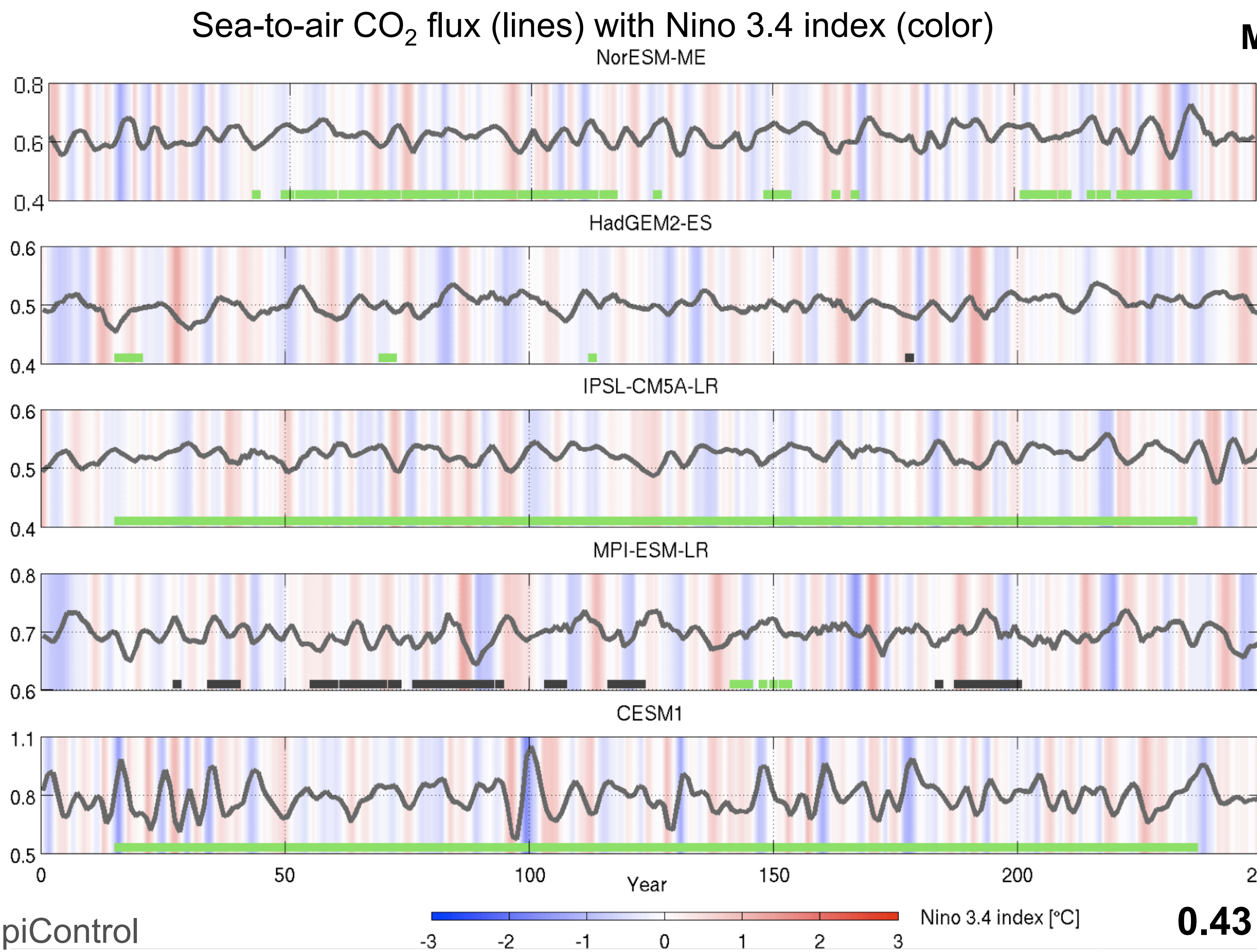
Potential temperature [°C]

Contours:

Dissolved Inorganic Carbon [μmol C L^{-1}]

250-yrs piControl

Simulated relationships between ENSO and sea-air CO_2 flux



Mean CO_2 flux [Pg C/yr]

0.62±0.05

0.50±0.02

0.52±0.02

0.70±0.03

0.79±0.12

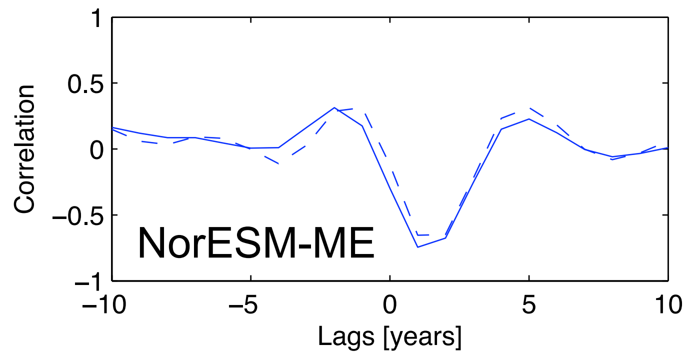
0.43 (Takahashi)

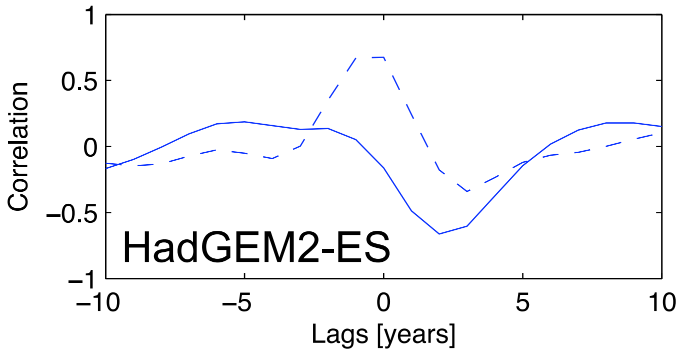
piControl

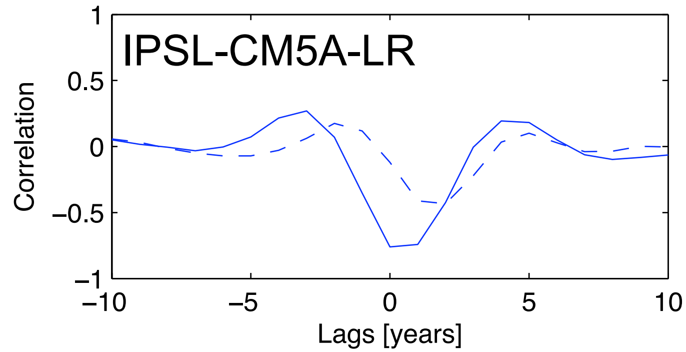
Simulated relationships between ENSO and sea-air CO_2 flux

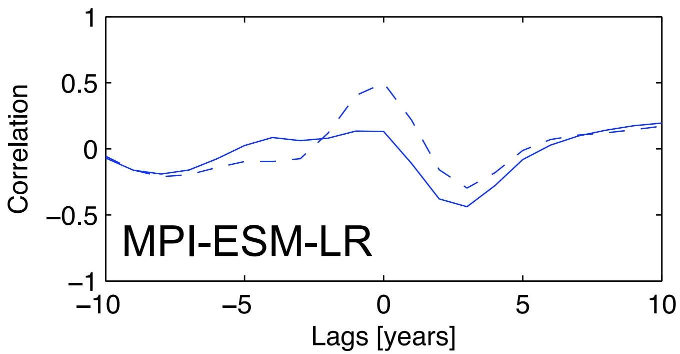
Cross correlation of annual (solid-lines) sea-to-air CO_2 flux and (dashed-lines) surface pCO_2 in the equatorial Pacific Ocean with Nino 3.4 index over the 250-years of preindustrial control simulations.

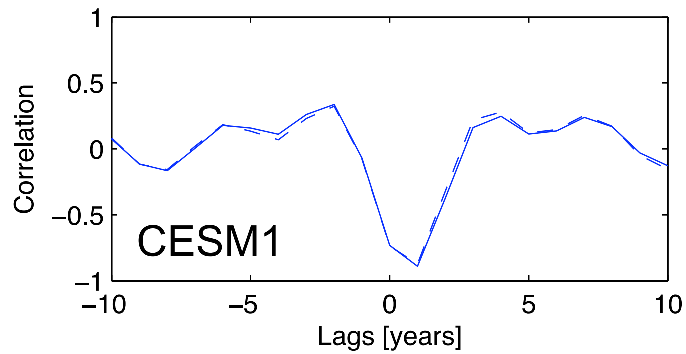
Positive lags ➔ Nino 3.4 index is leading.









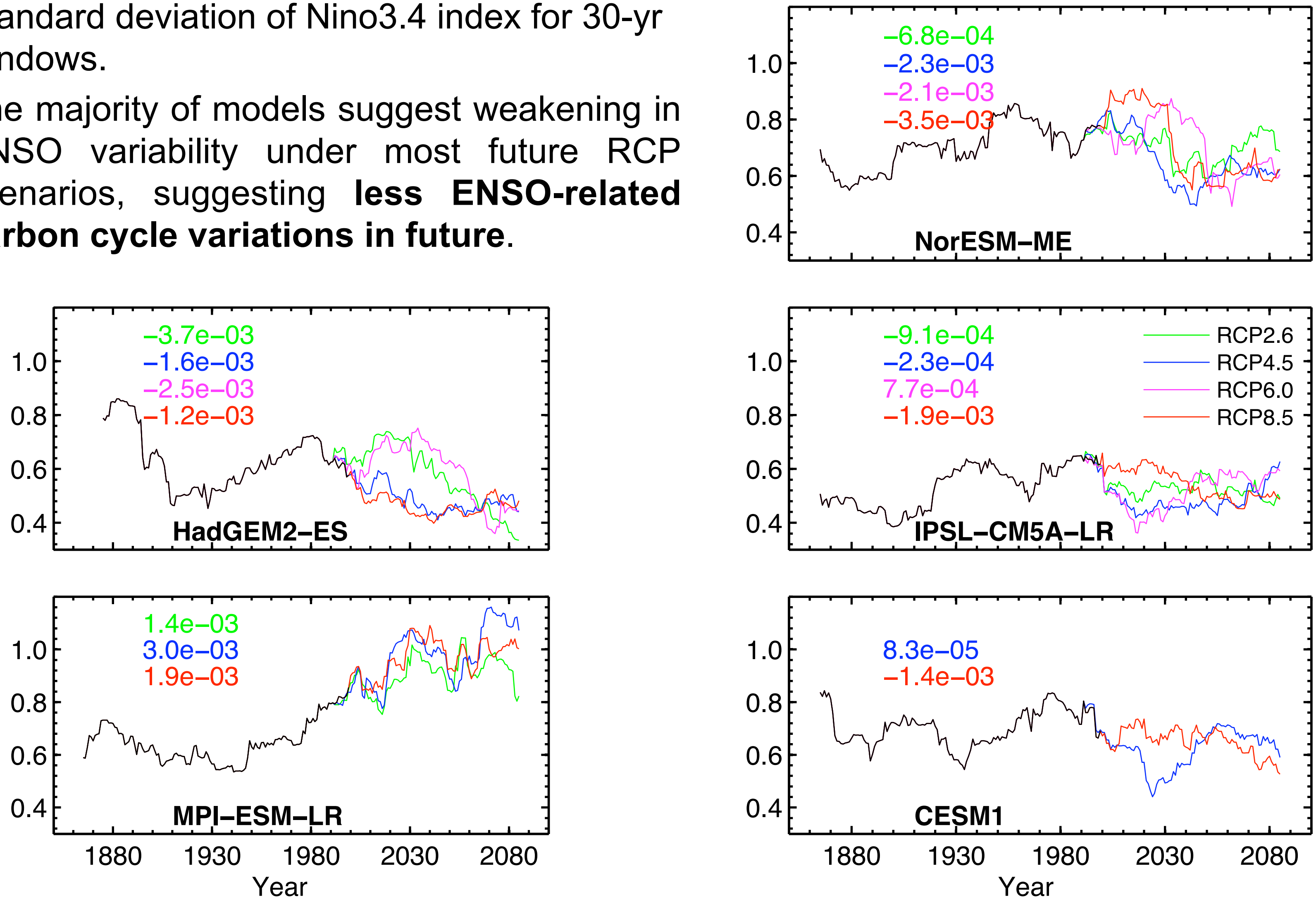


piControl

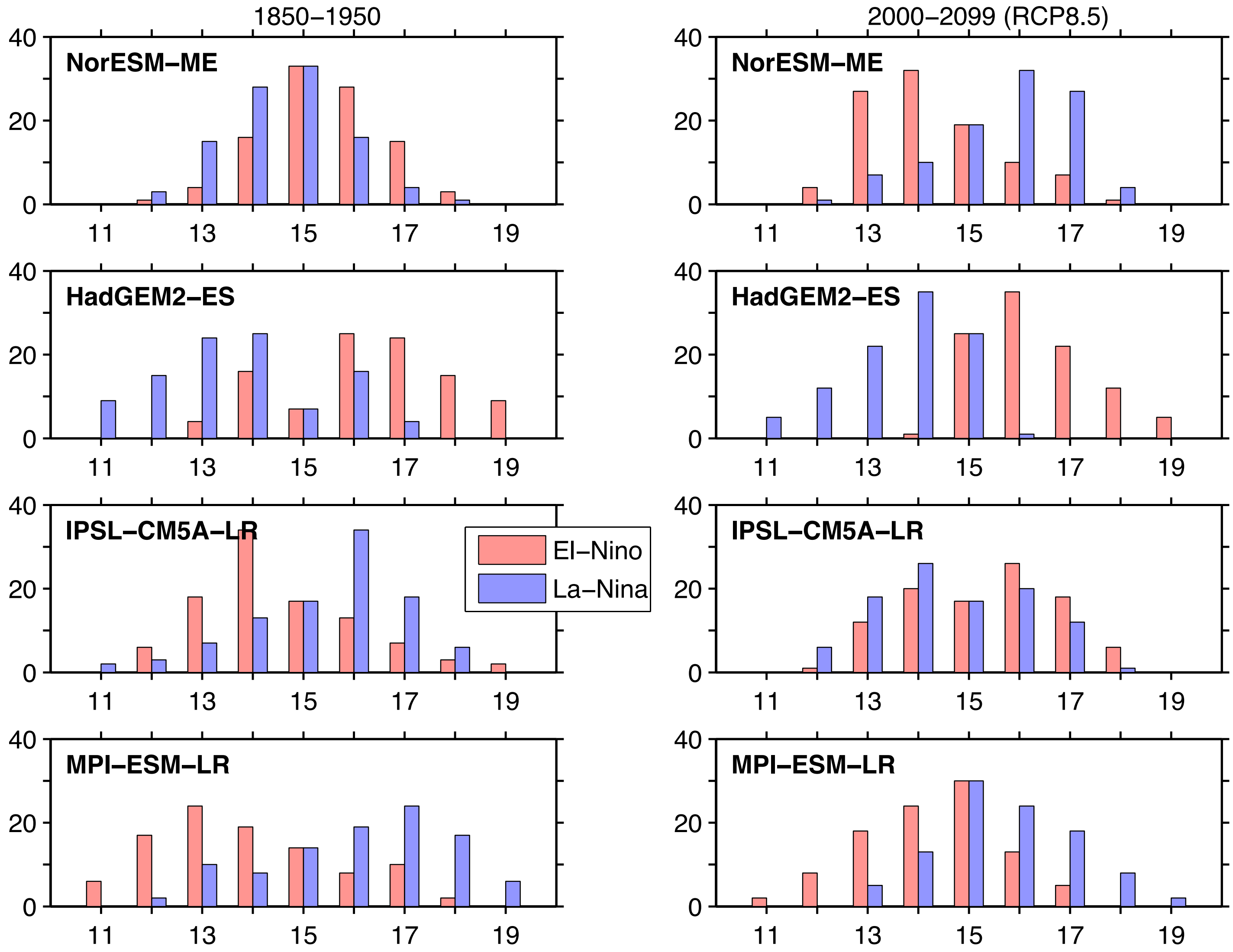
Simulated ENSO change in the 21st century

Standard deviation of Nino3.4 index for 30-yr windows.

The majority of models suggest weakening in ENSO variability under most future RCP scenarios, suggesting **less ENSO-related carbon cycle variations in future**.



Simulated mean ENSO change in the 21st century



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Long term mean state change in the equatorial Pacific

- All models simulate persistent future increase in SST, which translates to decrease in CO_2 solubility.
- Increase in stratification lead to reduced biological production in all models, hence decrease biological pump rate (10-20%).
- If consistent with AR4 in simulating decrease of AMOC, the export of carbon through westward advection to the Indian Ocean might be reduced, leading to relatively higher surface pCO_2
- Therefore, over longer term, the positive climate-carbon cycle feedback in the equatorial Pacific is expected.

Summary

- CMIP5 models are consistent in simulating global positive climate-carbon cycle feedback under high CO_2 world in the future.
- Five models studied here produce quite realistic Nino3.4 index variability.
- The climate-carbon cycle interaction in the equatorial Pacific is also well simulated by most of the models.
- Discrepancies in the interannual climate-carbon cycle fluctuations are mostly due to different representative of the ecosystem modules.
- Weakening of ENSO variability under future global warming scenarios are suggested by the majority models, suggesting less role of CO_2 flux to ENSO variations in the future.
- Over long time-scale, feedbacks due to change in SST, ocean circulation, and biological production will dominate.
- The land is known to have the opposite carbon cycle variability associated with ENSO, thus full analysis from both land and ocean carbon cycle will be necessary.