Modification of ENSO and ENSO-related Atmospheric Characteristics due to Future Climate Change

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Introduction

Under climate warming the characteristics of two ENSO types may change significantly, including amplitude, frequency and Central Pacific/Eastern Pacific El Niño ratio (Lee and McPhaden, 2010; Cai et al., 2014; Ham et al., 2015.). The warming occurs everywhere but at a faster rate in the eastern equatorial Pacific (Xie et al., 2010; Power et al., 2013), diminishing the zonal and meridional SST gradients. This Tropical Pacific warming shifts ENSO-related convection centers in the equatorial Pacific to the east, which may amplify the ENSO amplitude (Kim et al., 2011; Watanabe et al. 2012; Power et al., 2013). Along the equator the trades weaken, as required by the reduction in zonal SST gradient and associated Bjerknes feedback (Stevenson, 2012; Xiang et al., 2014). The weakening of the Walker circulation and the increased thermal stratification can play opposing roles in ENSO–mean climate interactions. Weaker upwelling in response to a weaker Walker circulation drives a reduction in thermocline-driven ocean heat flux convergence (i.e., thermocline feedback) and reduces the ENSO amplitude. A stronger zonal subsurface temperature gradient, associated with the increased thermal stratification, drives an increase in zonal-current-induced ocean heat flux convergence (i.e., zonal advection feedback) and increases the ENSO amplitude (DiNezio et a, 2012). Therefore several atmospheric and oceanic feedbacks related to ENSO are amplified and some are weakened after global warming, which explains the diverse changes in amplitude by the model simulation of ENSO. No consensus has been reached on El Nino changes among most models participating in CMIP5 (Power et al., 2013; Bellenger et al., 2014; Taschetto et al., 2014). Uncertainty still exists on how the relative frequency of the two types of El Niño might change in the future climate.
In current investigation the wider range of ENSO characteristics is considered as compare to previous studies, including sea surface temperature, atmosphere circulation, vertical velocity and precipitation. The modification of Central Pacific (CP) and Eastern Pacific (EP) El Niño is analyzed under two climate warming scenario (RCP 8.5 and RCP 2.6) and compared to the PiControl experiment with no radiative forcing.

Data

- **NCEP/NCAR Reanalysis**
- **HadISST**
- **23 coupled ocean-atmosphere general circulation models (CMIP5):**
ACCESS1-3, BNU-ESM, CanESM2, CCSM4, CESM1-CAM5, CMCC-CM, CNRM-CM5, CSIRO-Mk3, EC-EARTH, FIO-ESM, GFDL-CM3, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-CC, HadGEM2-ES, INM-CM4, IPSL-CM5A-MR, MIROC 5, MPI-ESM-LR, MPI-ESM-P, MRI-CGCM3, NorESM1-M.
- **Scenario: PiControl, RCP 2.6, RCP 8.5**
- **Parameters: SST, precipitation, U850, ω500 – monthly mean**

Method

Validation of CMIP5 models

- Simulation of the Eastern (EP) and Central (CP) Pacific El Niño (Takahashi et al., 2011)

Empirical orthogonal functions (EOFs) analysis of SST anomalies → PC1, PC2 (principal component of EOF 1, EOF 2) →
Eastern Pacific El Niño: $E = \frac{PC1 - PC2}{\sqrt{2}}$
Central Pacific El Niño: $C = \frac{PC1 + PC2}{\sqrt{2}}$

23 models → 16 models

- Simulation of frequency of EP and CP El Niño – power spectra of E, C-indices

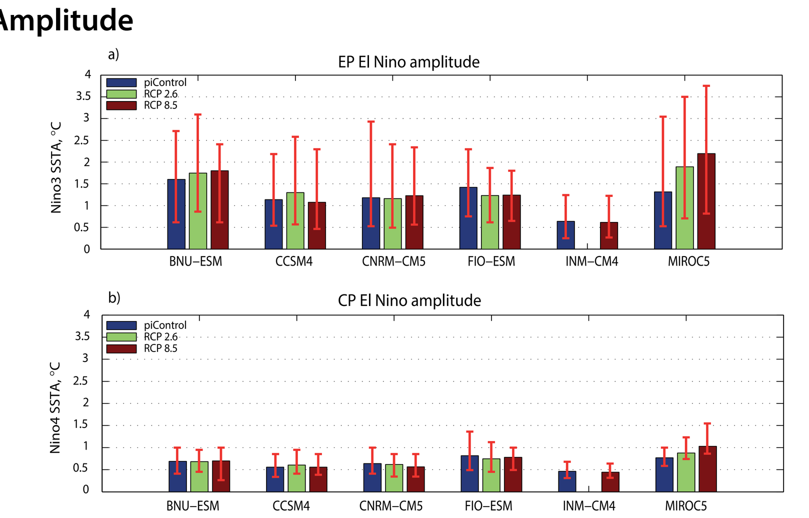
16 models → 6 models
(BNU-ESM, CCSM4, CNRM-CM5, FIO-ESM, INM-CM4, MIROC5)

Definition of the two types of El Niño

Correction of Nino 3 and Nino 4 regions for models (by EOF):
- Nino 3 index > threshold for EP El Nino → EP El Nino
- Nino 4 index > threshold for CP El Nino → CP El Nino

Modification of amplitude and frequency of ENSO

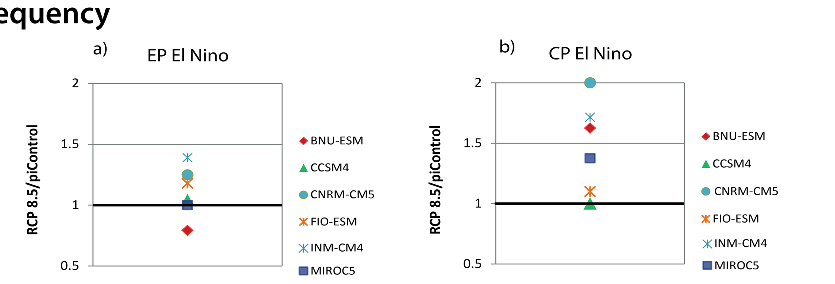
- **Amplitude**



The mean (column), maximal and minimal (red line) amplitude of Nino3 (a) and Nino4 (b) amplitude.

The mean amplitude of CP event is lower than EP in future as in modern climate. The maximal amplitude decreases with global warming for both types of El Niño.

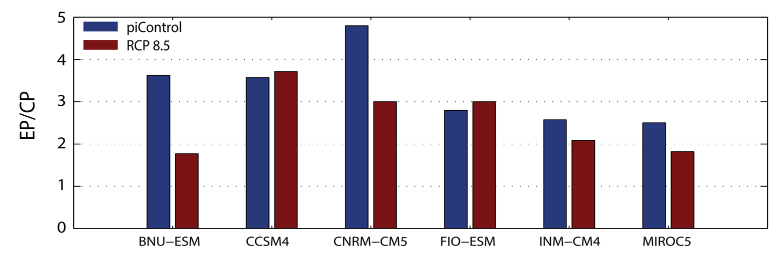
- **Frequency**



The ratio of El Niño event numbers in RCP 8.5 experiment to numbers in piControl experiment (100 model years): a) EP El Niño; b) CP El Niño.

The frequency of EP El Niño does not change significantly in RCP 8,5 experiment.
The model's estimate of CP frequency is contradictory but most models simulate the increasing of CP events number (up to doubling in CNRM-CM5).

- **The EP/CP ratio**

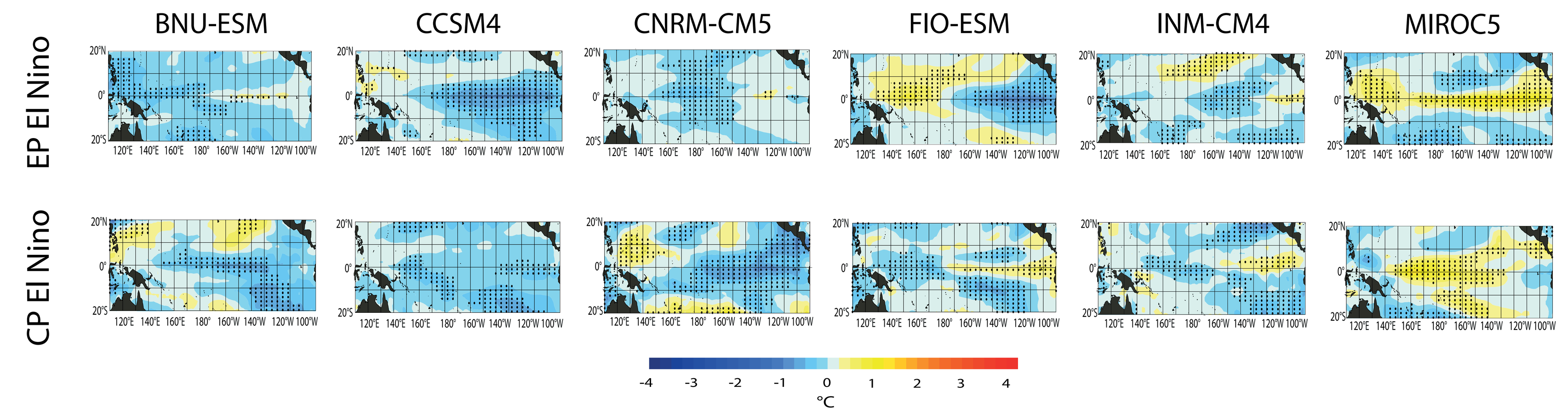


The ration of EP/ CP events in RCP 8.5 and piControl experiments

Several studies (Yeh et al., 2009; Lee and McPhaden, 2010) document the growth of CP events number associated with global warming. Our results demonstrates the increasing of CP and decreasing of EP events in warmer climate in accordance with previous investigations.

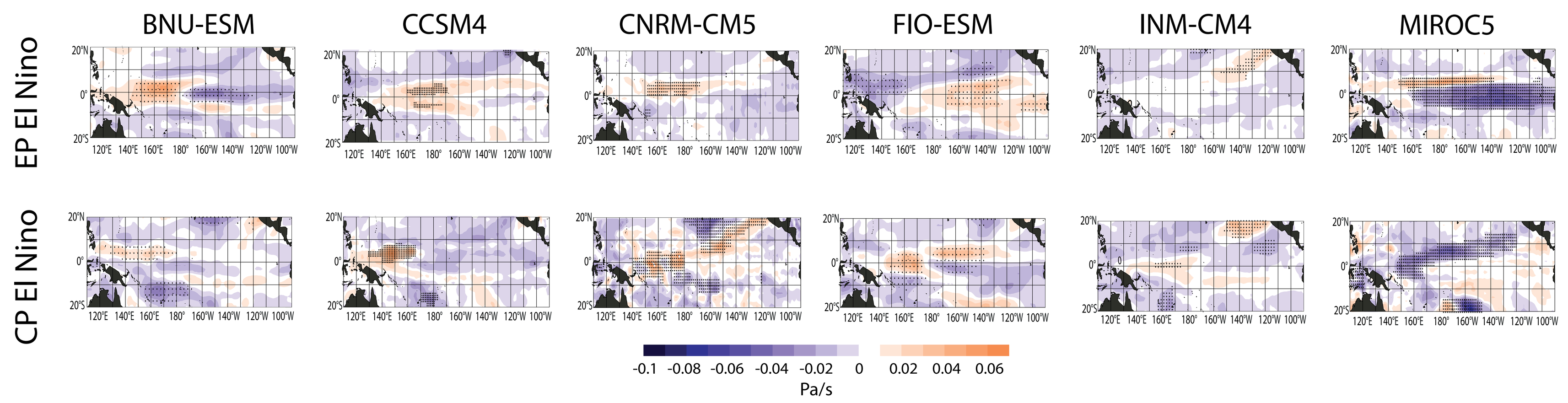
ENSO response to global warming (comparison of piControl and RCP 8.5 experiments)

- **SST (difference between RCP 8.5 and piControl experiment)**



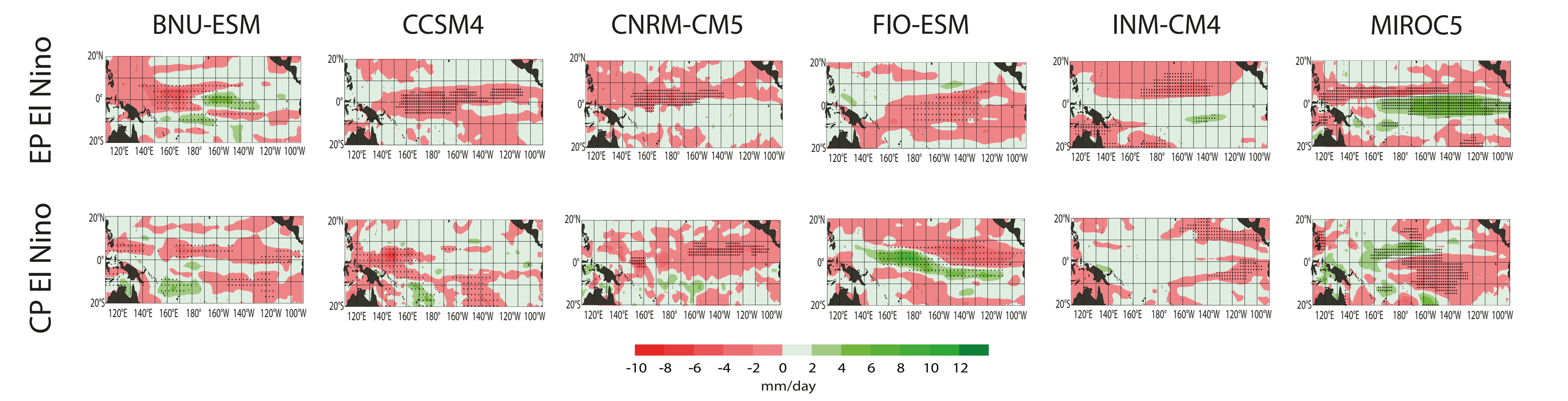
Most models demonstrates decreasing of SST anomalies associated to EP and CP El Niño in warmer climate, while the localization of SST extremes does not change. EP El Niño weakens stronger as compare to CP event. However MIROC5 documents intensification both of CP and EP events.

- **Vertical velocity (difference between RCP 8.5 and piControl experiment)**



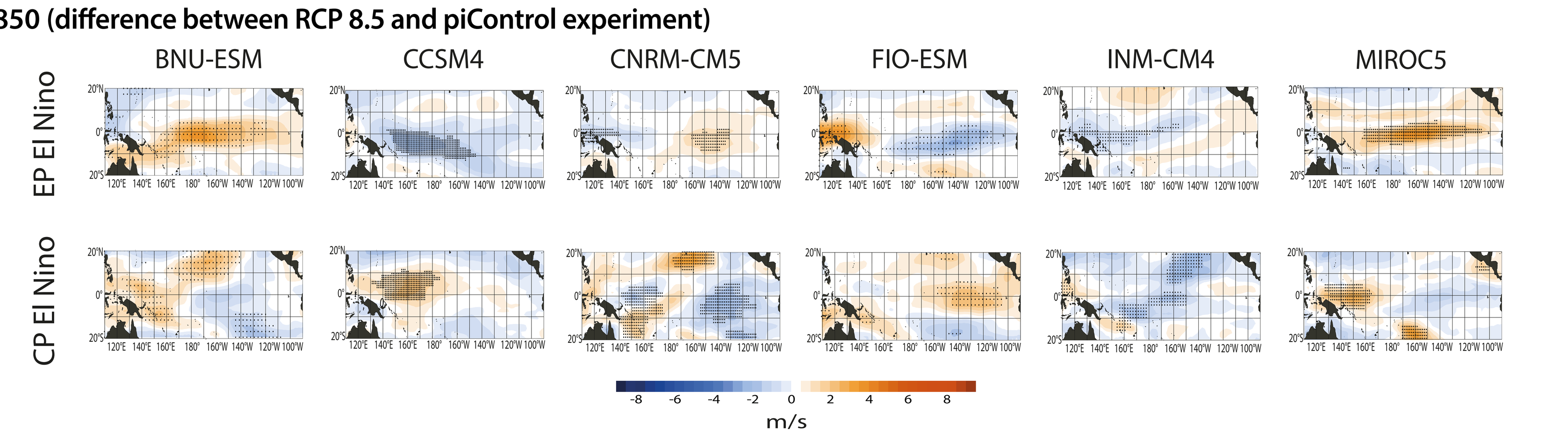
The SST changes involves modification of vertical circulation, however models demonstrates a strong diversity in estimates
In warmer climate:
- ascending motion decreases for both El Niño in CCSM4, CNRM-CM5 and FIO-ESM
- ascending motion intensifies over central and eastern Pacific during CP El Niño in FIO-ESM
- ascending motion intensifies over central and eastern Pacific during EP and over western Pacific during EP in MIROC5.

- **Precipitation (difference between RCP 8.5 and piControl experiment)**



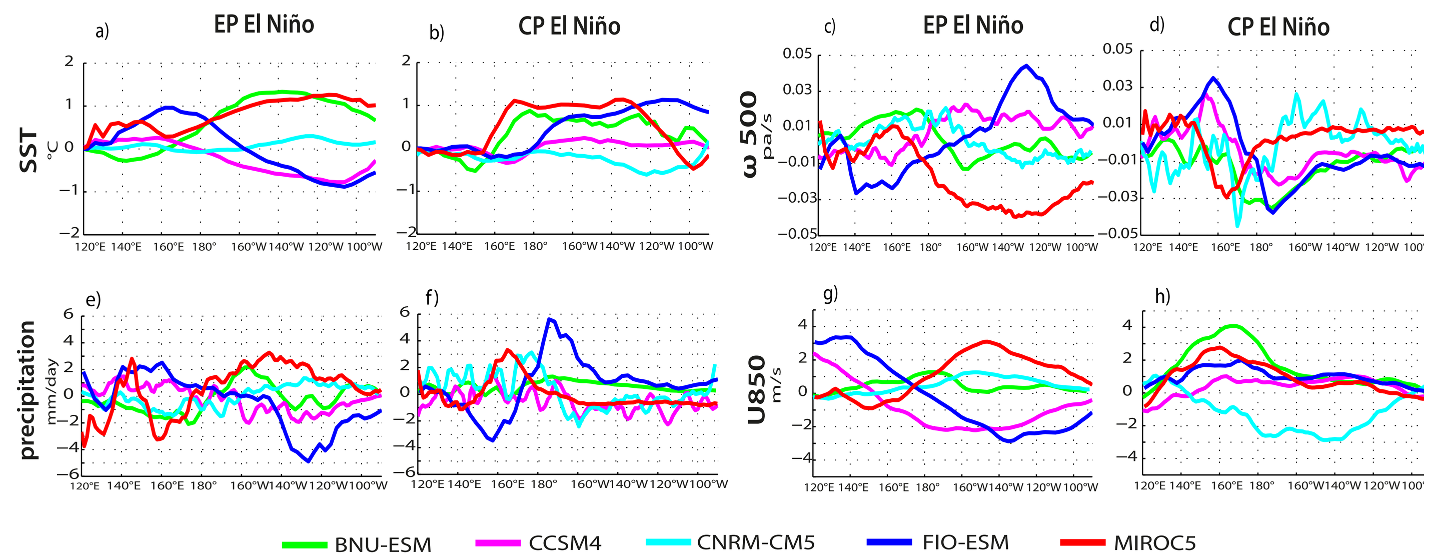
The changes of intensity and localization of vertical motion results in changes of deep convection and associated precipitation.
Most models simulate the decreasing of precipitation anomalies associated to ENSO in equatorial belt, except for MIROC5 which demonstrates the intensification of precipitation for both El Niño types.
In BNU-ESM the precipitation intensifies during EP event, in FIO-ESM during CP event.

- **U850 (difference between RCP 8.5 and piControl experiment)**



The anomalies of atmosphere circulation during El Niño modifies under climate warming in accordance with the SST changes.
The western wind anomalies during EP event are lower in FIO-ESM, CCSM4 and INM-CM4.
In opposite the westerlies intensify during CP in BNU-ESM and CCSM4.
MIROC5 simulates the stronger decreasing of trade winds in warmer climate as compare to PiControl experiment for both types of ENSO.

The sensitivity to intensity of radiation forcing
(experiments RCP 8.5 and RCP 2.6)



Difference of equatorially averaged (5N-5S) anomaies of SST (a,b), vertical velocity analogue (hPa/s^{-1}) at 500 hPa (c,d), precipitation (e,f) and zonal wind at 850 hPa (g,h) between RCP 8.5 and RCP 2.6 experiments for EP and CP El Nino. Period (2071-2100)

The modification of ENSO characteristics under global warming demonstrates significant sensitivity to the warming rate. However the models exhibit a large difference in estimates. The response of CP and EP events to the change of radiation forcing is also different. Most models simulate intensification of CP El Niño with growth of warming rate, while the response of EP event is uncertain.

Discussion and Conclusions

- Under climate warming associated with extreme scenario RCP 8.5 the occurrence of Eastern Pacific El Niño does not change significantly: CNRM-CM5, FIO-ESM and INM-CM4 models show an increase, BNU-ESM – decrease. Most of models demonstrate increasing frequency of Central Pacific El Niño in response to climate warming (except for the CCSM4 model).

- Model assessments of the El Niño intensity in future climates are rather sparse: most of the models demonstrate El Niño weakening under climate warming, to a lesser extent for Central Pacific El Niño. However, MIROC5 shows intensification of both types of El Niño.

- The EP/CP ratio depends on the intensity of radiation forcing: in RCP 2.6 the CP share in total number of cases diminishes, in RCP 8.5 – rises.

- ENSO sensitivity to the warming rate differs between the El Niño types: anomalies associated to the Central Pacific El Niño are enhanced with increasing radiation forcing, while Eastern Pacific El Niño does not demonstrate a clear trend.

The uncertainty in model's assessment of ENSO modification in warming climate may be constrained using paleo-climate comparisons (Schmidt et al., 2014). The «best» in paleoclimate simulation models may give more reliable estimates of El Niño changes (frequency, amplitude) in response to climate warming, and thus more reliably determine the vector of El Niño changes in a warmer future climate.

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