Change of ENSO characteristics in response to global warming

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1. Introduction

As the strongest interannual signal with global climate impacts, ENSO characteristics probably will change due to global warming *(Meehl et al. 2007)*. However, previous studies show ***controversial*** results about the change of ENSO characteristics *(Deng et al. 2010)*.

- **ENSO frequency**

a. increase: because of deepened equatorial zonally averaged thermocline *(Jin 1997; Wang and An 2002)*, increased upper ocean stratification *(Merryfield 2006)*, increased meridional temperature gradient on either side of equator *(Collins 2000)* or eastern tropical Pacific warming *(Timmermann et al. 1999; Cai et al. 2014)*.

b. decrease: because of reduced zonal gradient of thermocline depth in the tropical Pacific *(Fedorov and Philander 2001; Wittenberg 2002)*.

c. undistinguishable: because of so many amplifying and damping processes involved and their cancellations *(Collins et al. 2010)*.

- **ENSO magnitude**

a. increase: because of increased vertical temperature gradient in the thermocline region *(Timmermann et al. 1999; Collins 2000)*.

b. decrease: because of reduced time-mean zonal SST gradient *(Knuston et al. 1994, 1996)*.

c. undistinguishable: because of so many amplifying and damping processes involved and their cancellations *(Collins et al. 2010)*.

- **Ratio of CP-ENSO to EP-ENSO**

a. frequency: ***increase*** because of the flattening thermocline in the equatorial Pacific based on CMIP3 *(Yeh et al. 2009)*.

b. intensity: almost the ***same*** in the pre-industrial and historical simulations but ***increase*** in the RCP4.5 simulation based on CMIP5 *(Kim and Yu, 2012)*.

Questions: What changes of ENSO characteristics in response to global warming? And **Why?**

2. Data and Method

Reanalysis data: NOAA-CIRES20 v2c 2°×2° 1895.1-2014.12
HadISST1.1 1°×1°

Pre-global warming: 1895-1954 **Post-global warming: 1955-2014**

CESM 1.0.4 / EXPs	AGCM		OGCM		CO2
	Version	Resolution	Version	Resolution	Concentration
Control	CAM4	T31 L26 (3.75°×3.71°)	POP2	gx3v7 L60 (3.6°×1.6°)	367 ppmv
2×CO2	CAM4	T31 L26 (3.75°×3.71°)	POP2	gx3v7 L60 (3.6°×1.6°)	734 ppmv

Integration: from 0 to 1600 model year **Analysis: 1000-1600 model year**

Definition:

ENSO: niño3 index with at least 6 months larger than 2/3 of their standard deviation during the period from September to the next May

extreme ENSO: ENSO events with niño3 index larger than 1.5 times of its standard deviation

moderate ENSO: ENSO events with niño3 index less than 1.5 times of its standard deviation

3. Results

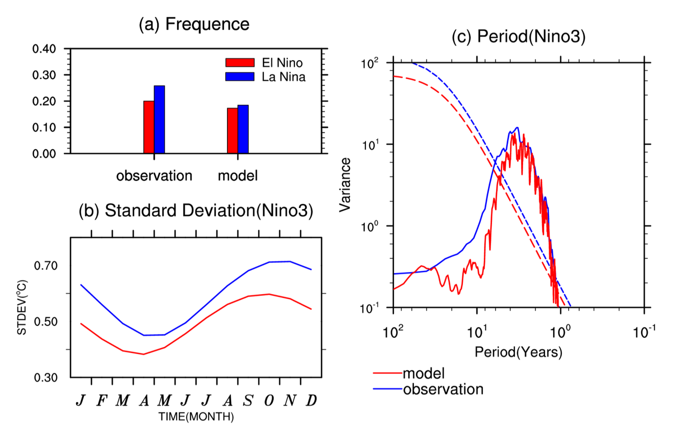


Fig 1: Frequency of ENSO (a), **standard deviation** (b) and **spectra** (c) of niño3 index for Obs (blue) and CESM (red).

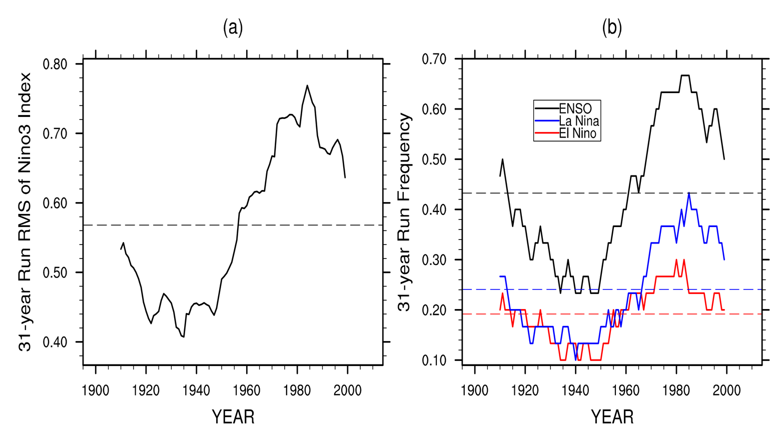
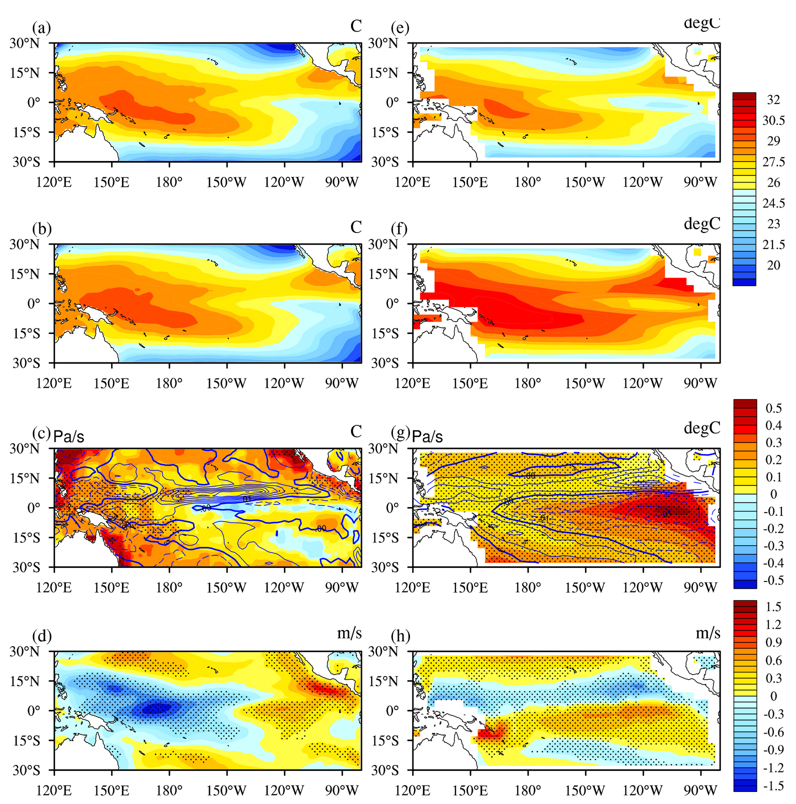


Fig 2: 31-year moving **standard deviation** of **niño3** index (a) and **ENSO frequency** (b) in Obs (1895-2014).

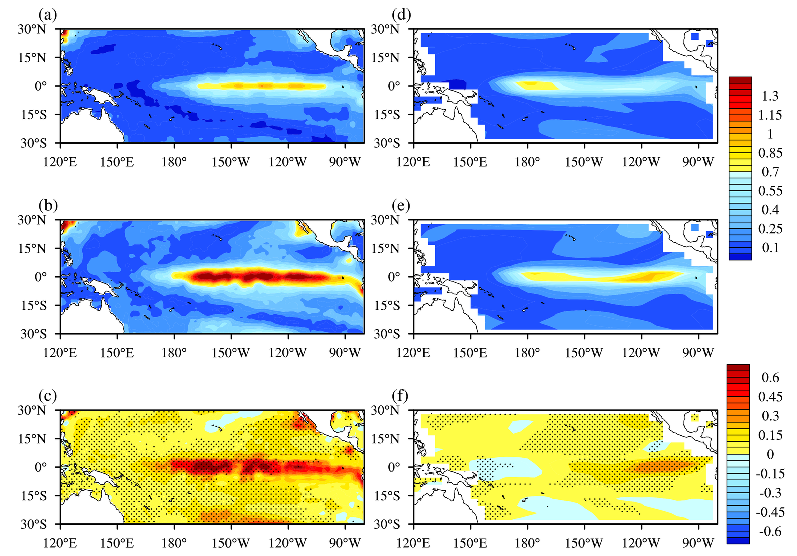
- CESM can well reproduce the observed ENSO characteristics in history.
- It's suitable to divide the whole Obs period into two equal epochs in 1955.



Observation CESM

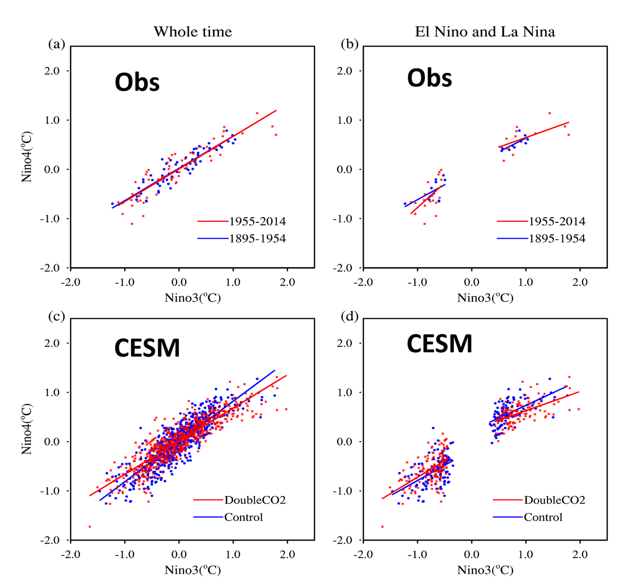
Fig 3: Climatologically averaged tropical Pacific **SST** (unit: °C) (a, b, e, f) for the periods of pre (a, e) and post (b, f) global warming, and the **differences of SST** (unit: °C) overlaid **500hPa ω** (unit: Pa/s)(c, g) and **1000 hPa zonal wind** (unit: m s^{-1}) (d, h) between post and pre global warming periods. (a-d) are derived from observations, and (e-h) are produced by CESM model. (a) and (b) represent the periods of 1895-1954 and 1955-2014, respectively, and (c) and (d) are their differences. (e) and (f) indicate the experiments of control run and double-CO2 run, respectively, and (g) and (h) are their differences. The black dots in (c, d, g, h) denote the significant differences at 0.1 significance level based on Student's t-test.

- **Obs:** La Niña-like warming, divergence in the tropical central Pacific.
- **CESM:** El Niño-like warming, enhanced westerly wind in the equatorial Pacific.



Observation CESM

Fig 4: Winter **SST variance** (unit: °C) in the tropical Pacific pre (a, d) and post (b, e) global warming and **their difference** (c, f). (a) and (b) represent the periods of 1895-1954 and 1955-2014, respectively, and (c) is their differences. (d) and (e) indicate the experiments of control run and double-CO2 run, respectively, and (f) is their differences. The black dots in (c, f) denote the significant differences at 0.1 significance level based on Student's t-test.



All years ENSO

Fig 5: Scatter diagram with linear fitting between winter **Niño3 and Niño4 indices** (unit: °C) in observation (a, b) and model (c, d). X, Y coordinates indicate Niño3 index and Niño4 index, respectively. Blue and red denote pre and post global warming, respectively.

- **Obs:** increased SST variance in the tropical central Pacific, more CP-La Niñas tend to occur due to the western Pacific background easterly wind anomaly.
- **CESM:** increased SST variance in the tropical eastern Pacific, more EP-El Niños tend to occur due to the tropical Pacific background westerly wind anomaly.

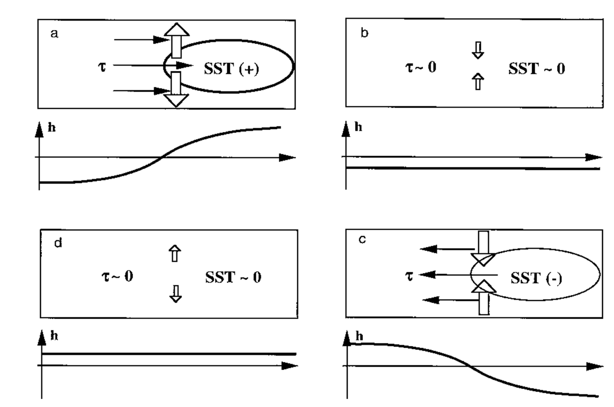


Fig 6: Schematic panels of the four phases of the recharge oscillation *(Jin 1997)*.

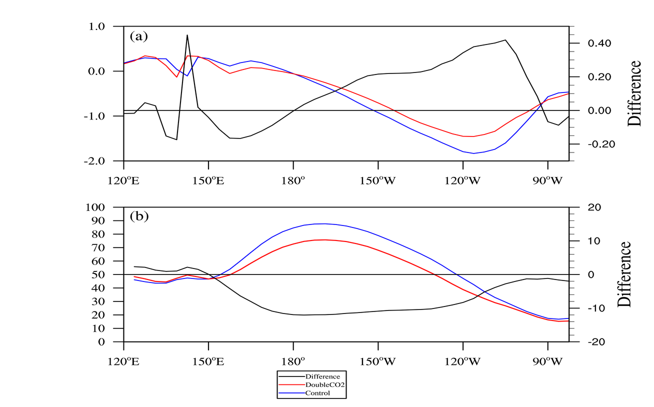


Fig 7: Zonal variations of **tropical upper ocean meridional temperature gradients** (unit: °C) (a) and **equatorial tropical thermocline depths** (5°N-5°S) (unit: m) (b) pre (blue) and post (red) global warming and their difference (black).

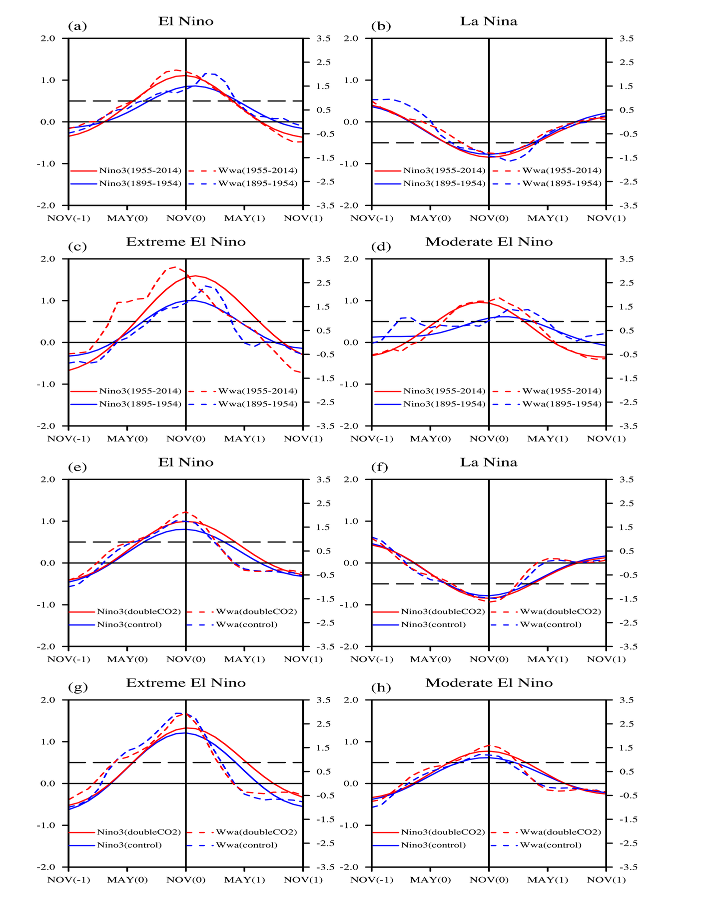


Fig 8: Evolvement of composite **Niño3 index** (solid line, unit: ° C) and western-central Pacific (155°E – 185°E; 5°N – 5°S) **zonal wind anomaly** (dashed line, unit: m s-1) in lifetime of El Niño (a, e), La Niña (b, f), extreme El Niño (c, g) and moderate El Niño (d, h) events. The left and right Y axes indicate Niño3 index and zonal wind anomaly, respectively, and the X axis represents the month, where -1, 0, and 1 denote the previous year, the current year and the next year of an ENSO event, respectively. (a-d) are derived from observations and (e-h) are produced by CESM model.

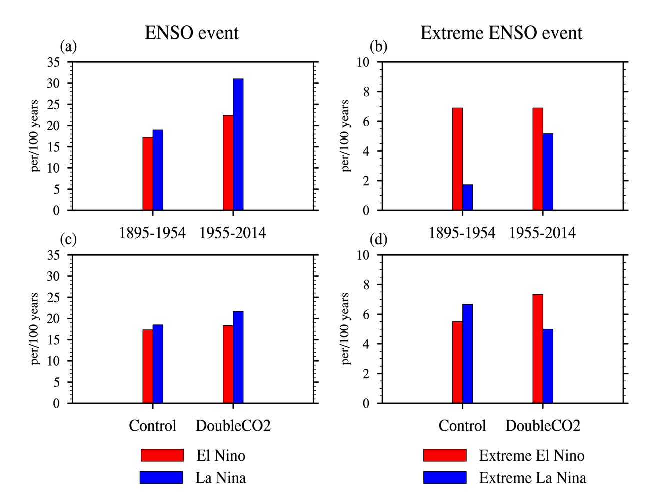


Fig 9: Frequency (unit: number/100-year) of occurrence of the all ENSO events (a, c) and the extreme ENSO events (b, d) pre and post global warming in observation (a, b) and model (c, d). Red and blue bars denote El Niño and La Niña events, respectively.

- Life time of El Niño, especially extreme El Niño is significantly extended because of *earlier outbreak of WWB*, and *slower Kelvin wave speed* due to shallower thermocline depth, and *weakening "discharge" rate* due to reduced equator and off- equator temperature gradient.
- Frequency of ENSO events greatly increases due to global warming, and many more extreme El Niño and La Niña events appear under the El Niño-like and the La Niña-like background warmings, respectively.

4. Summary

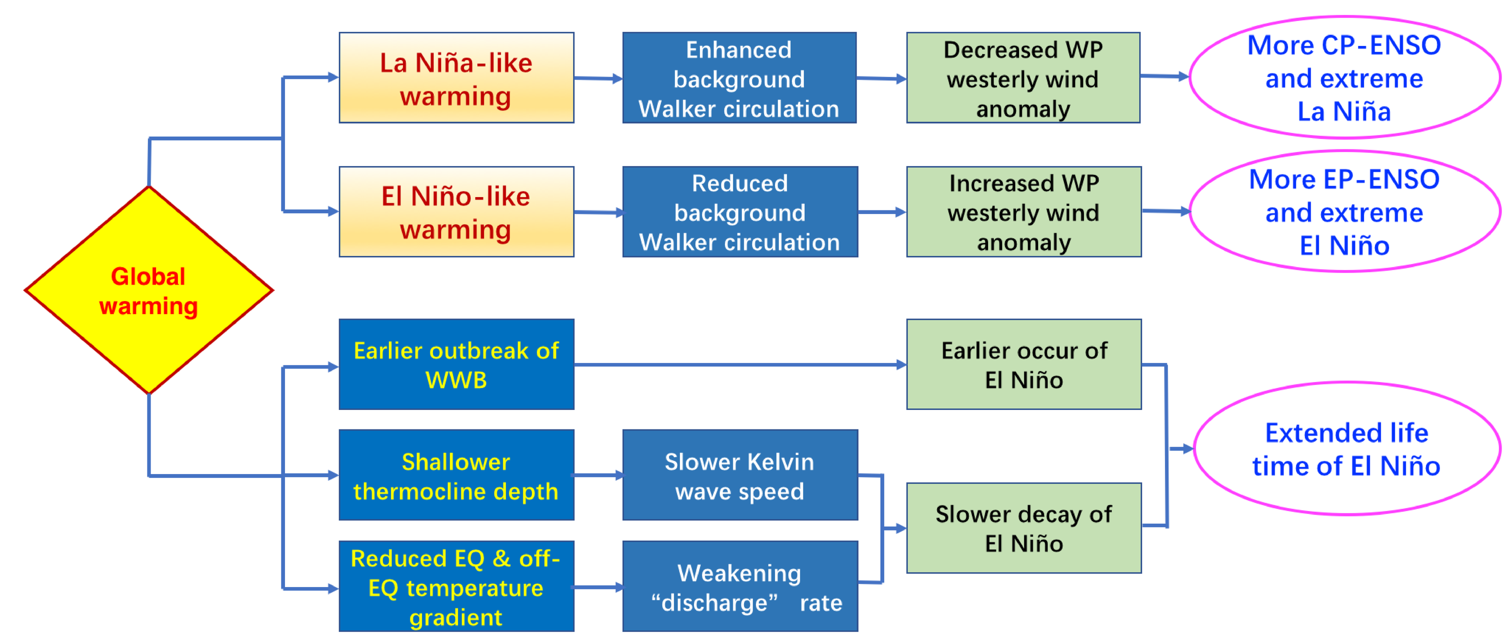


Fig 10: The schematic diagram of global warming caused ENSO changes.

5. Reference

Xia Y, **Sun X G**, Yan Y, et al. Change of ENSO characteristics in response to global warming (*in Chinese*). Chin Sci Bull, 2017, doi:10.1360/N972016-01225