Importance of Central Pacific Meridional Heat Advection to the Development of ENSO

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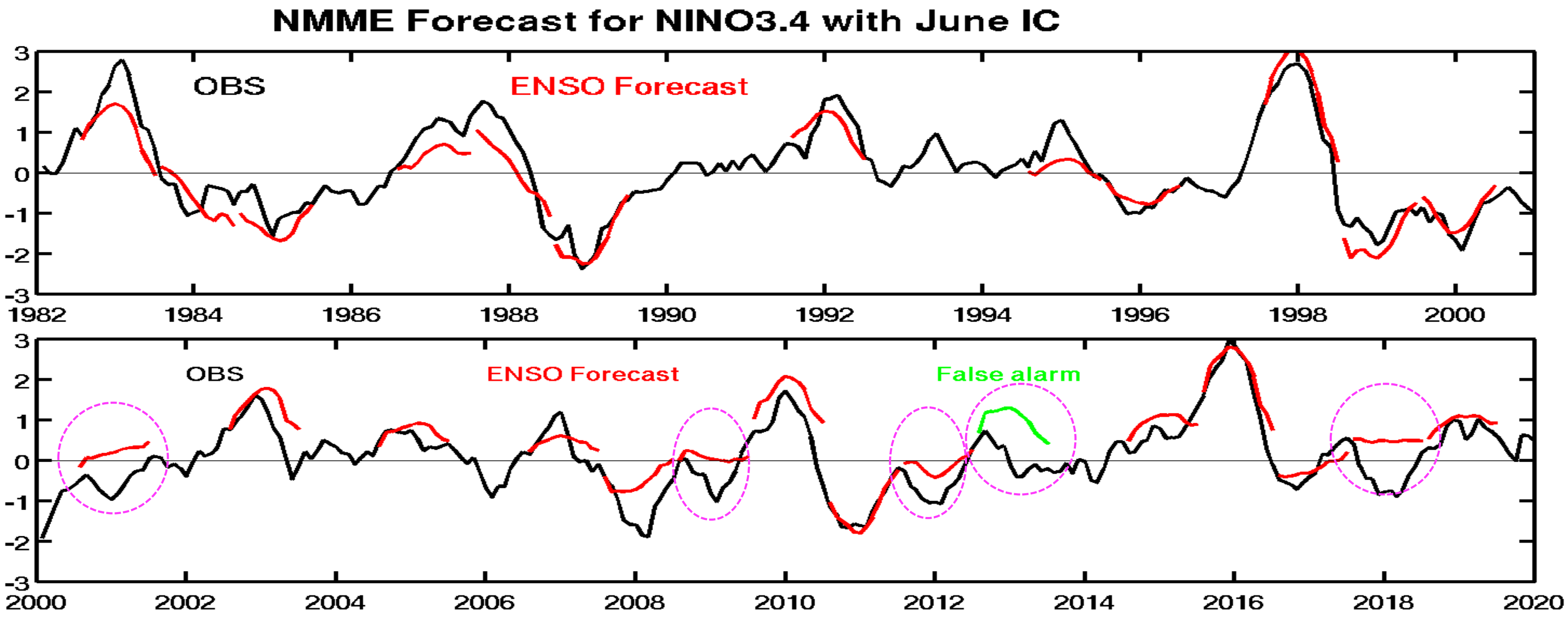
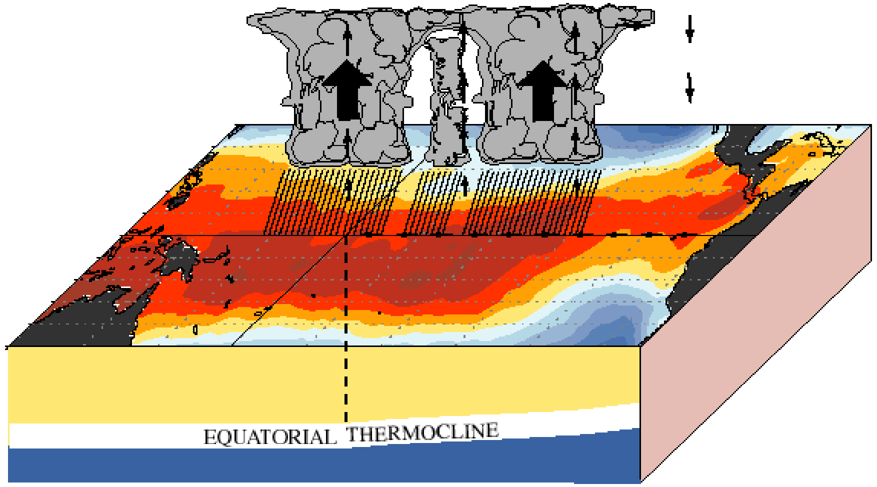
Challenge in Seasonal ENSO Predictions



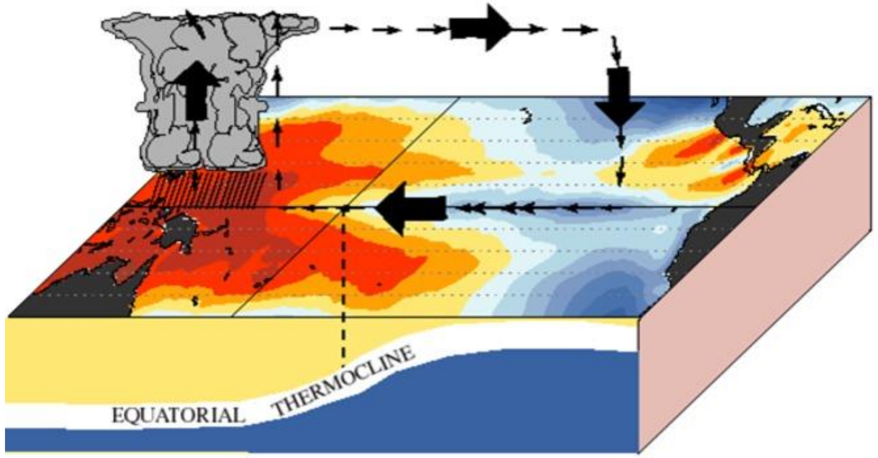
- Decrease in ENSO forecast skill from dynamical models since the 21th Century (Wang et al, 2010;Barnston et al. 2012,2017; Su et al. 2014)

Important Role of Equatorial Subsurface Temperature in ENSO Onset

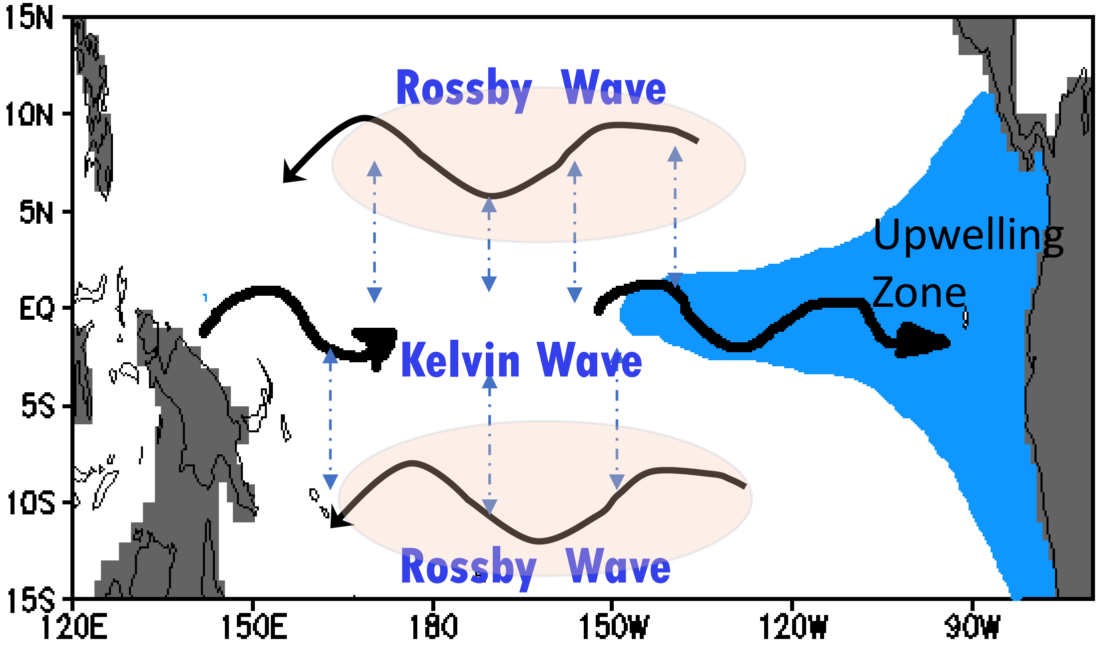
El Niño



La Niña



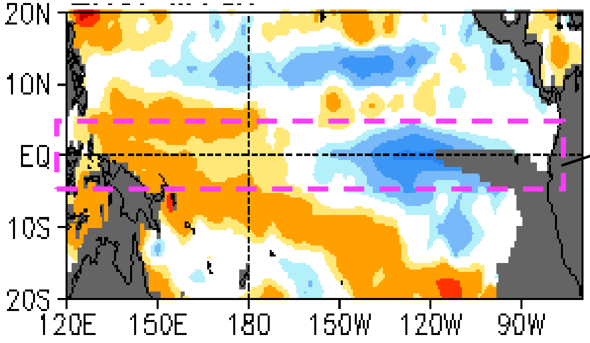
(Adapted from NOAA/NCEP/CPC)

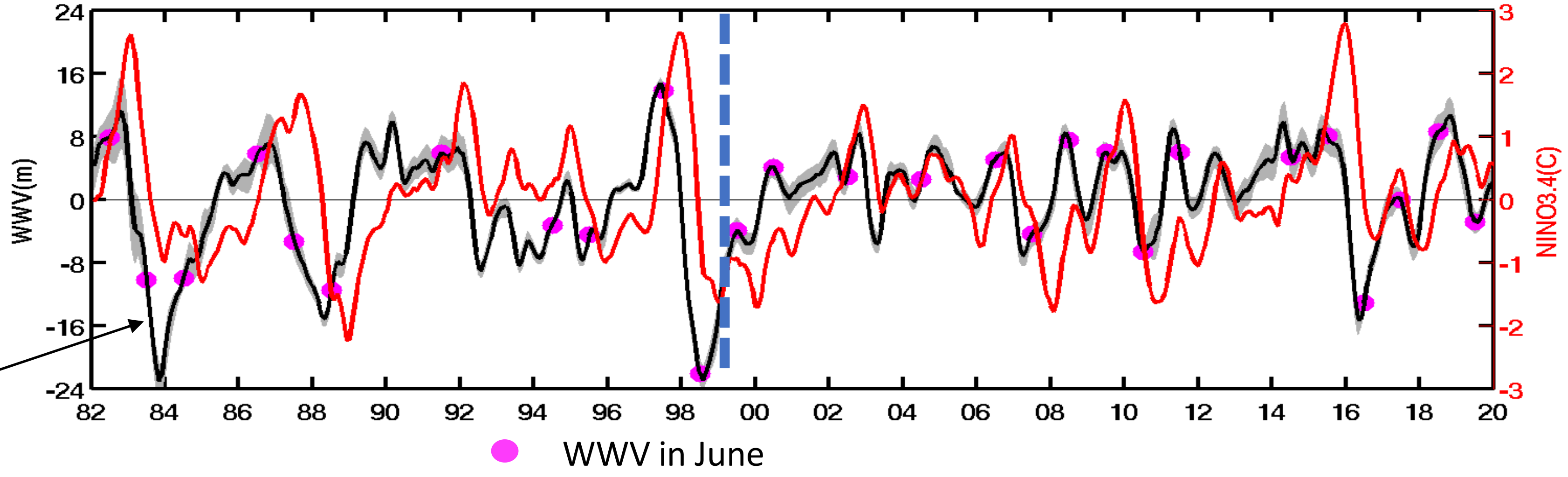


- Ocean waves are key processes to modulate equatorial thermocline variations
- Low-frequency oceanic adjustment (Delayed Oscillator, Suarez and Schopf 1988; Recharge-discharge theory, Jin 1997)
- High-frequency wind forcing (MJO, WWB,extra-tropical teleconnections and etc.)

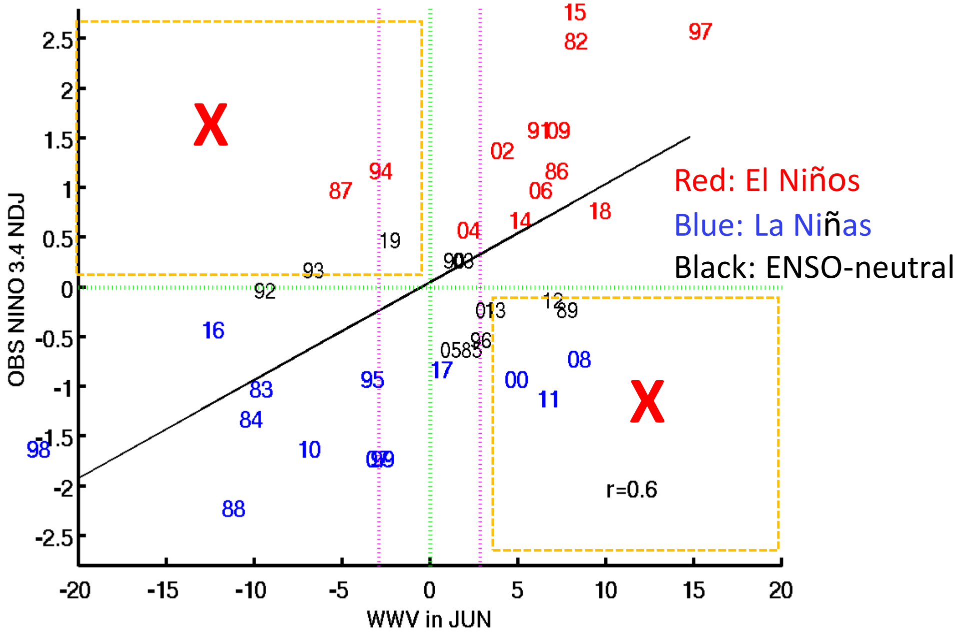
Oceanic ENSO Precursor: Warm Water Volume (WWV)

D20 Anomaly





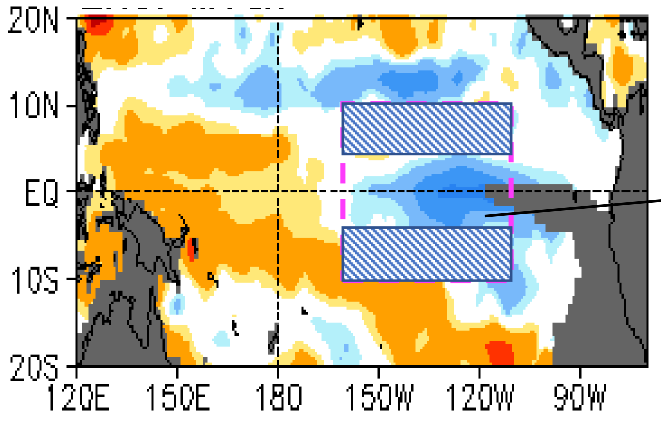
WWV:D20a in [120ºE-80ºW, 5ºS-5º (Meinen and McPhaden,2000)



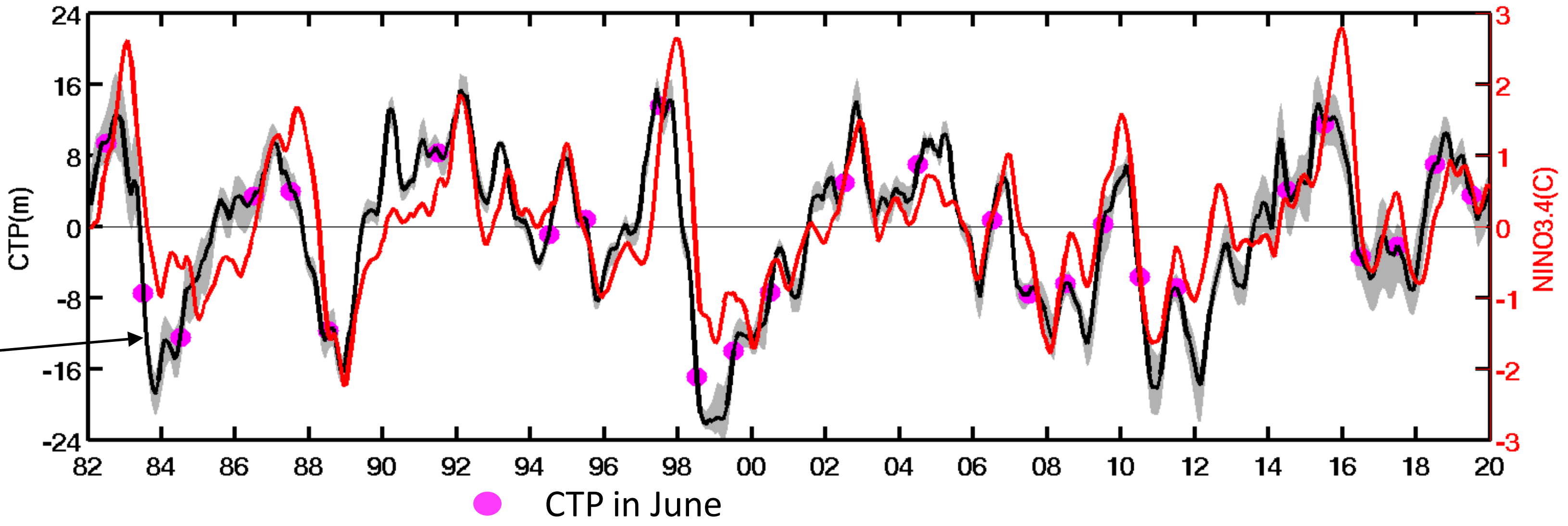
- WWV-ENSO linkage are often explained by the recharge-discharge theory.
- Breakdown of WWV/SST ENSO occurred after the late 1990s (McPhaden 2012).
- High frequent wind forcing plays a more important role than oceanic adjustment process, leading to a shorter WWV/SST lead time in the post-2000 period (Neske and McGregor 2018).

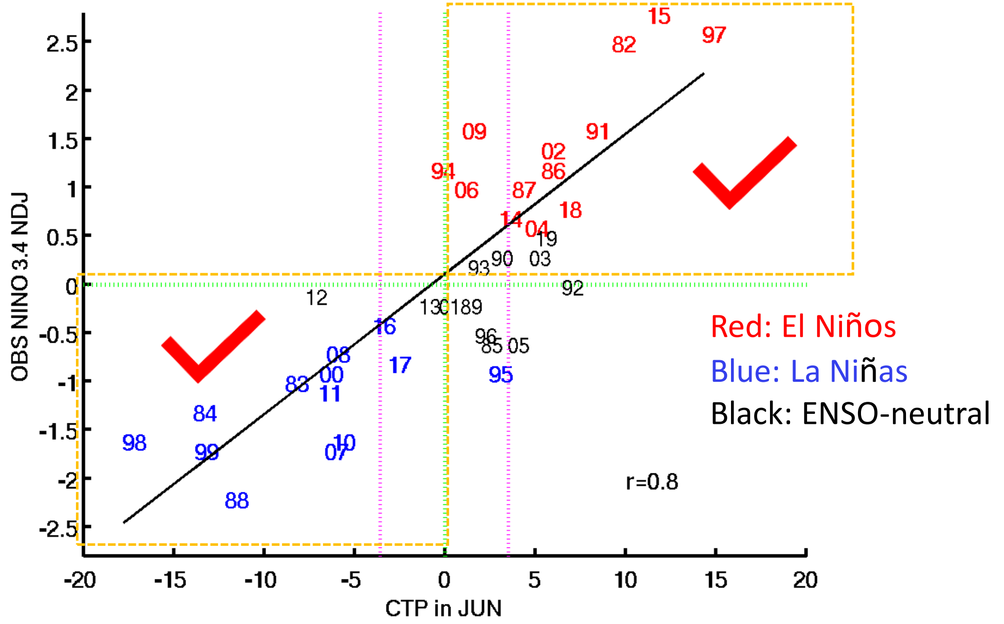
Oceanic ENSO Precursor: Central Tropical Pacific (CTP)

D20 Anomaly



CTP:D20a in [160°W-110°W, 10°S-10°N] (Wen et al. 2014)



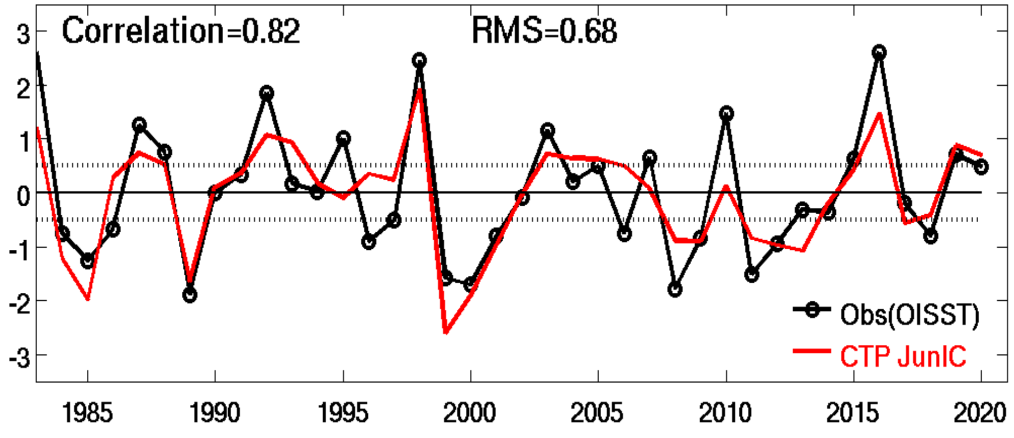


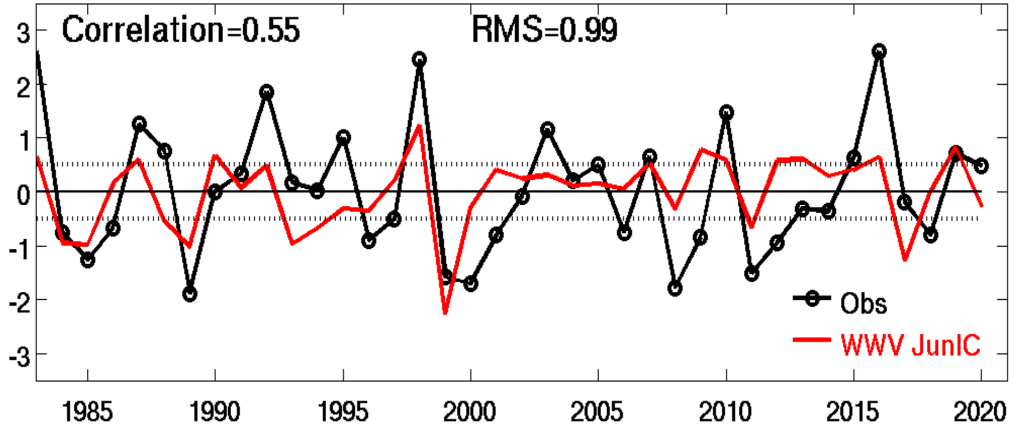
- CTP has a higher correlation with SST ENSO during the whole period.
- Subsurface conditions in off-equatorial regions are important for ENSO onset (Zhang et al. 2013;Wen et al. 2014)

Prediction Skill Comparison : WWV . VS. CTP

Univariate regression model

NINO3.4 NDJ Predictions

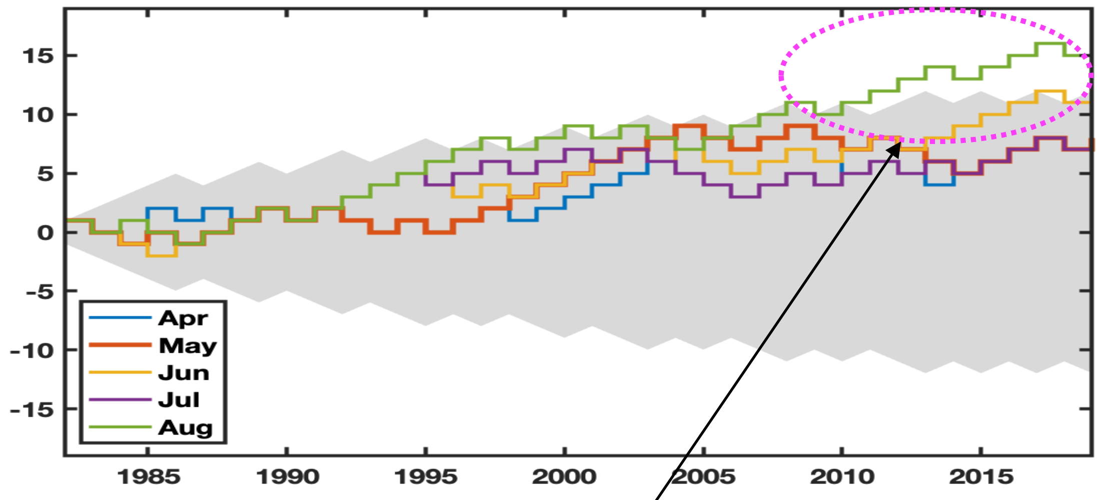




Leave-one-year-out cross validation

Significance test: Random walk diagram

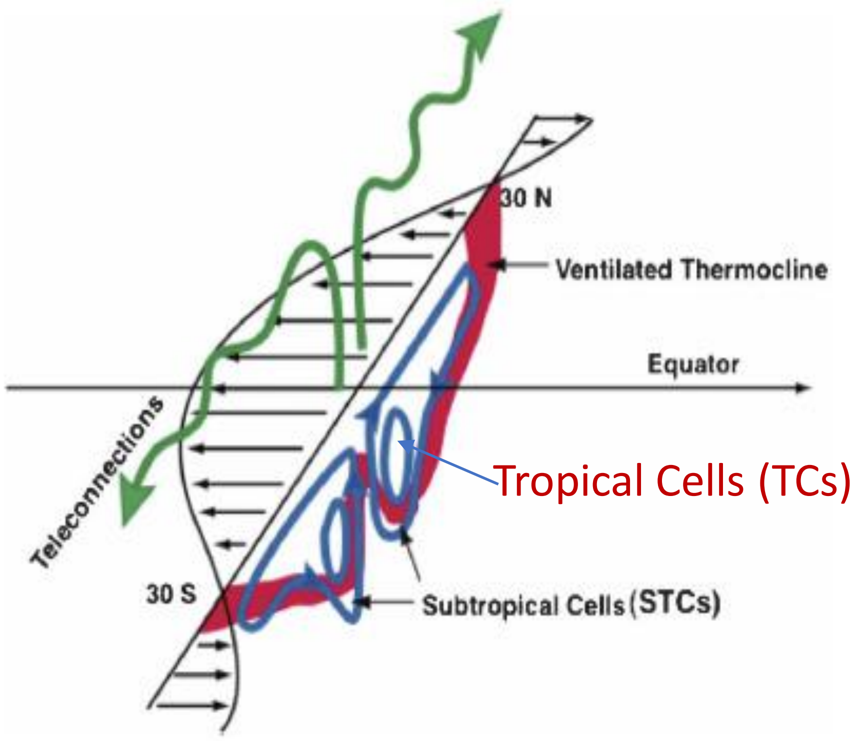
(Delsole and Tippett, 2016)



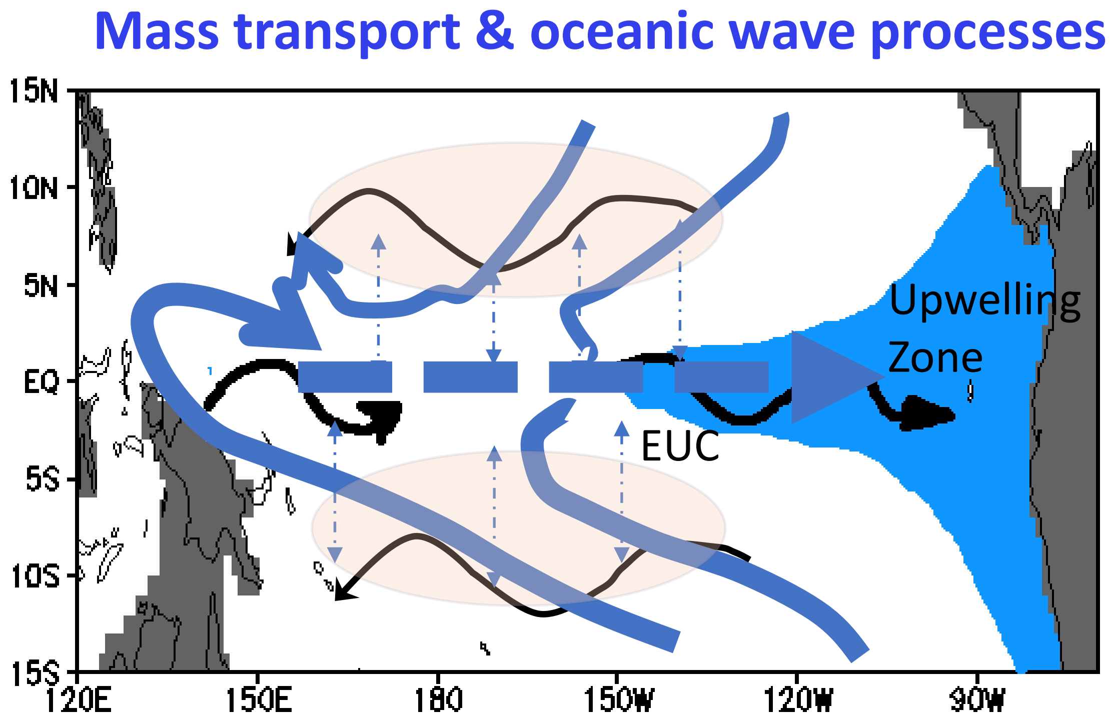
Deviation beyond positive gray cone: CTP skill is higher than WWV with 95% significance

- CTP index offers greater predictive skill than WWV after late 1990s, highlighting the importance of off-equatorial preconditions.

Thermocline Mass Transport and ENSO



(Adapted from Chang et al. 2006)



- Subtropical water mass transport can modulate the equatorial thermocline variations via oceanic pathways on decadal time scales (Kleeman et al. 1999).
- Western thermocline variations can modulate CE Pacific thermocline via zonal advection by equatorial undercurrent (Ballester et al. 2016; Lu et al. 2017).
- *Processes contributing to the linkage between off-equatorial and equatorial thermocline variations on seasonal time scale are not clear.*

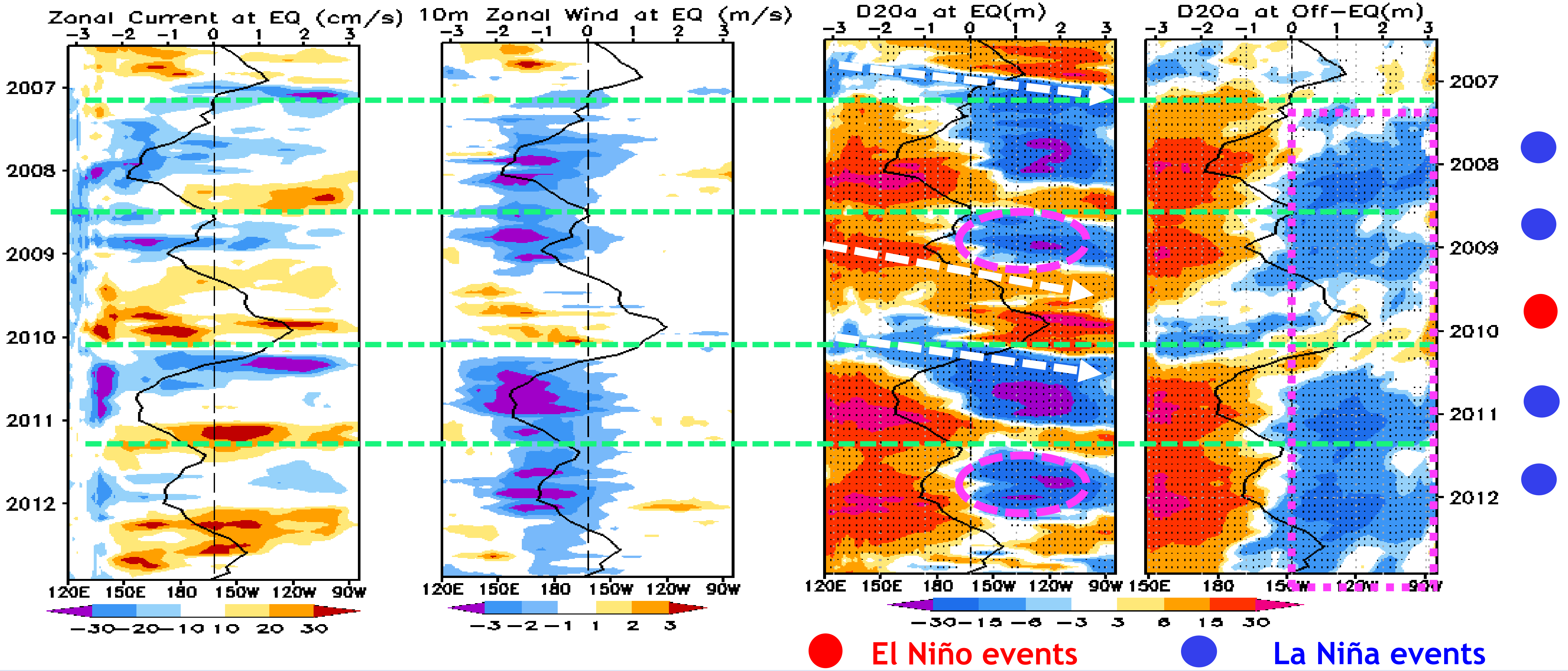
Questions:

- How do the **off-equatorial thermocline anomalies** influence the equatorial thermocline variations(**TCs related)**?
- What are the **physical mechanisms** leading to differences in predictive potential between CTP and WWV? Are such differences related to a **specific type of ENSO**?

Data sets:

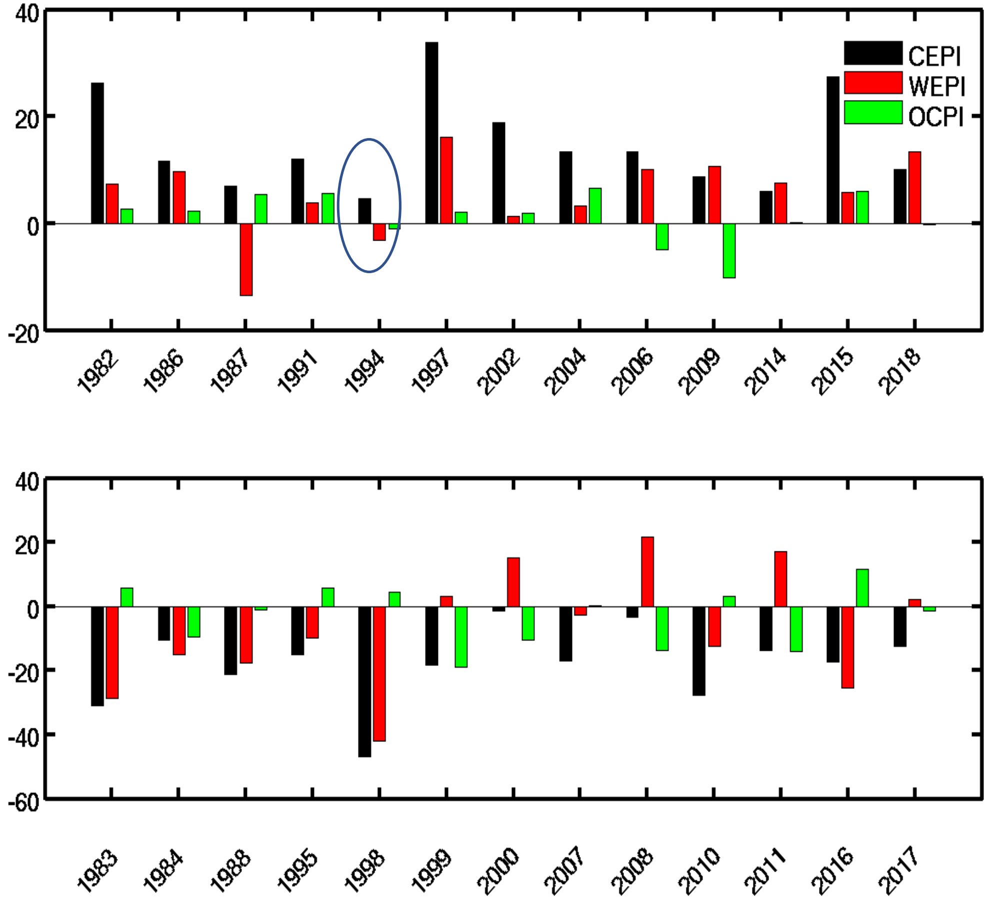
- Depth of 20℃ (D20) from Six operational ocean reanalysis (ORA) products (*GODAS,BOM,JMA,ECMWF S5,NASA,GFDL*)
- Monthly NCEP OISST
- Monthly Surface current analysis from Ocean Surface Current Analysis-Real Time (OSCAR)
- 10-meter monthly zonal wind from ERI-Interim
- NMME monthly SST predictions
  (*CanCM4i, CFSv2, GEM_NEMO,GFDL, GFDL_FLOR, NASA_GEOS5v2,NCAR_CCSM4*)
- GODAS subsurface temperature and currents to conduct heat budget analysis
- ENSO events are identified when Nino3.4 met a threshold of +/- 0.5℃ for a minimum of 5 consecutive overlapping seasons
- Analysis period:1982-2019

Potential Factors Contributing to ENSO Onset



- Central Equatorial (CE) D20 variations play the primary role in triggering ENSO onset , and surface wind & current further enhance SST tendency.
- CE D20 anomalies has clear western Pacific origin (2007,2010 La Niñas, 2009 El Niño).
- CE D20 fluctuations are closely connected with off-equatorial D20 variations(2008 and 2011 La Niñas).

Two Types of ENSO



CEPI: D20 anom in [160° W-110°W, 2°S-2°N] for Jul-Sep

WEPI: D20 anom in 160°E-160°W,2°S-2°N] for Mar-May

OCPI: D20 anom in [160°W-110°W, 6°N-10°N/10°S-6°S] for Mar-May

Two types ENSO based on spatial connections of d20 anom. in the C.E. Pac with surrounding regions.

- ***Western Equatorial Pacific(WEP) ENSO***

  ---- Same phase WEPI and CEPI & WEPI > OCPI

- ***Off-equatorial central Pacific (OCP) ENSO***

  ---- Same phase OCPI and CEPI & OCPI > WEPI

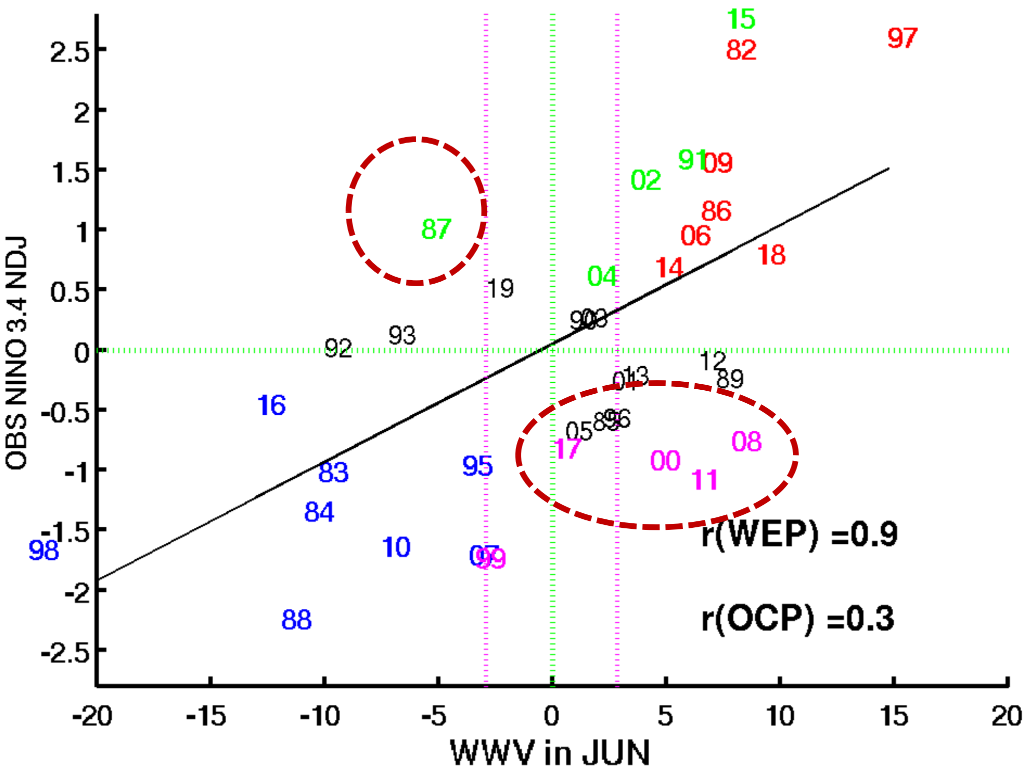
WEP (15 events)		OCP (10 events)	
El Niño	La Niña	El Niño	La Niña
1982	1983	1987	1999
1986	1984	1991	2000
1997	1988	2002	2008
2006	1995	2004	2011
2009	1998	2015	2017
2014	2007		
2018	2010		
	2016		

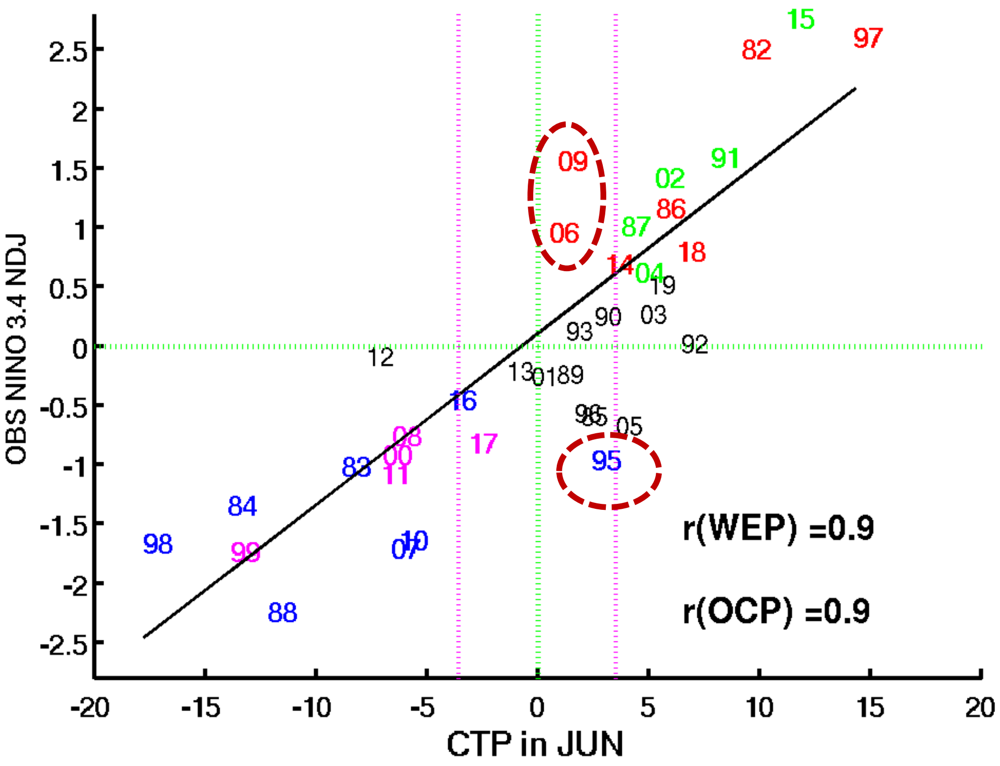
Impact of ENSO Types on CTP & WWV Skills

Red : WEP El Niño
Blue: WEP La Niña

Green: OCP El Niño
Blue: OCP La Niña

Black: ENSO-neutral

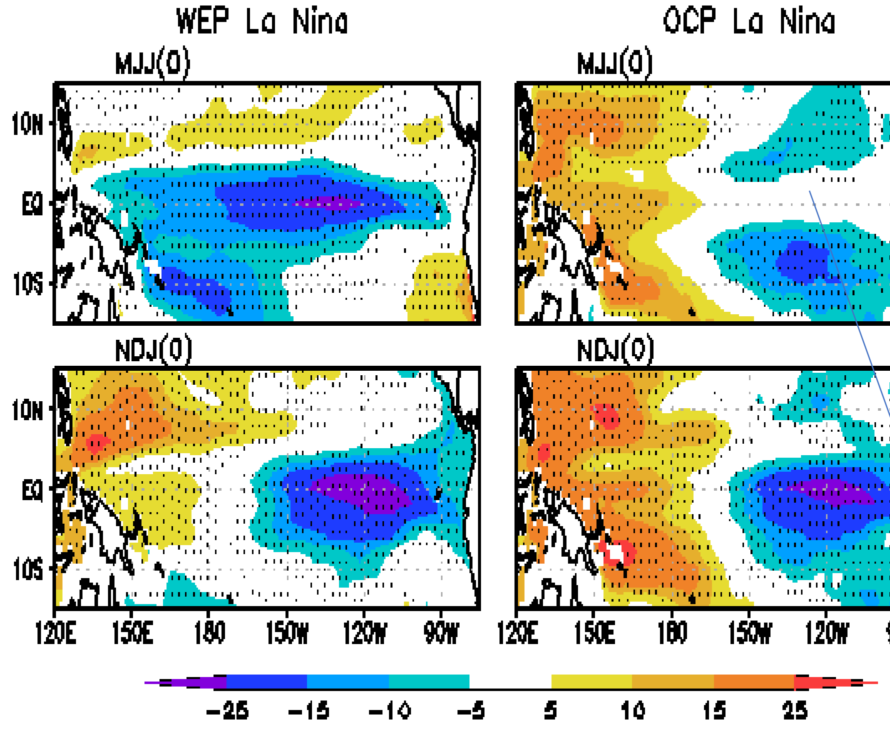




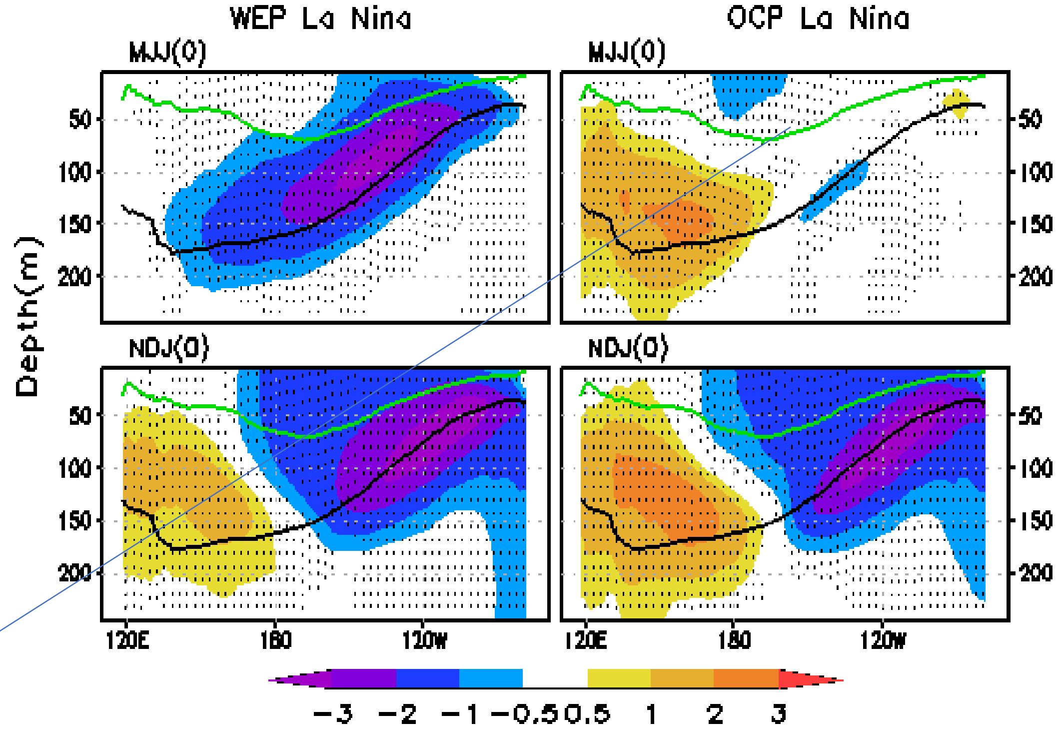
- Positive (negative) WWV precedes all WEP El Niños (La Niñas) , while the correlation drops substantially for the OCP ENSO.
- CTP is a very good precursor for OCP type events.

Characteristics of two types of ENSO : La Niña case

D20 Anomaly



Temperature Anomaly at Eq

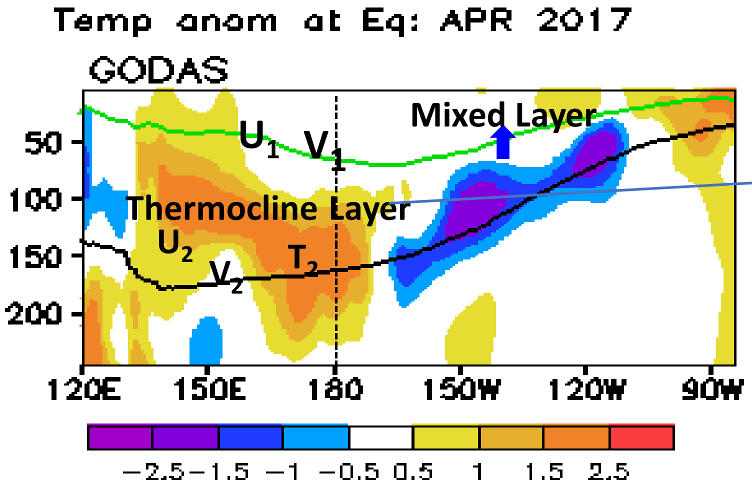


Off-equatorial origin

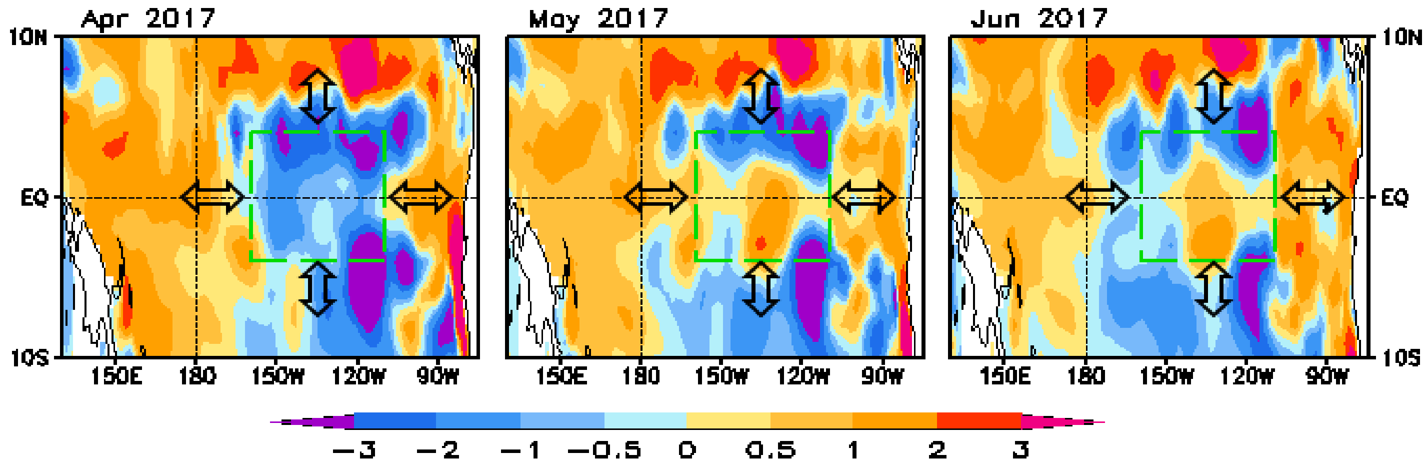
Depth of Mixed layer

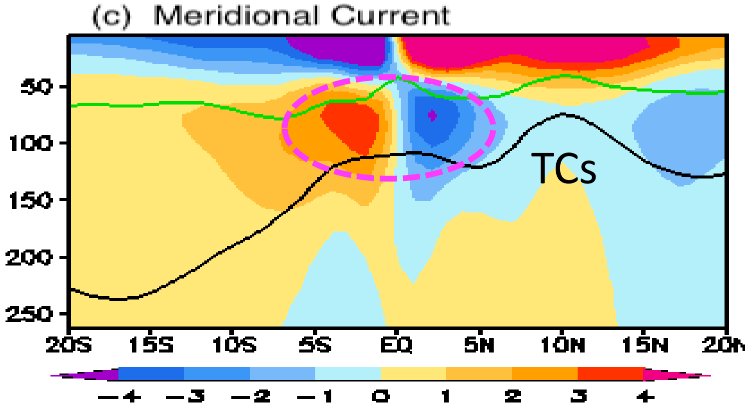
Depth of 20°C (D20)

Heat Budget Analysis

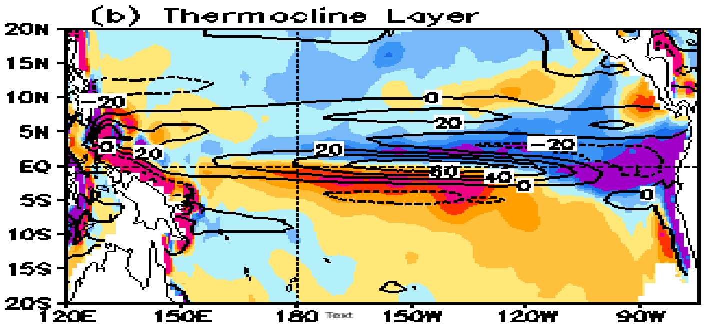


Thermocline temperature anomalies (T_2)





Equatorward maximum of TCs is about 3cm/s:
~1.5 months per degree of latitude

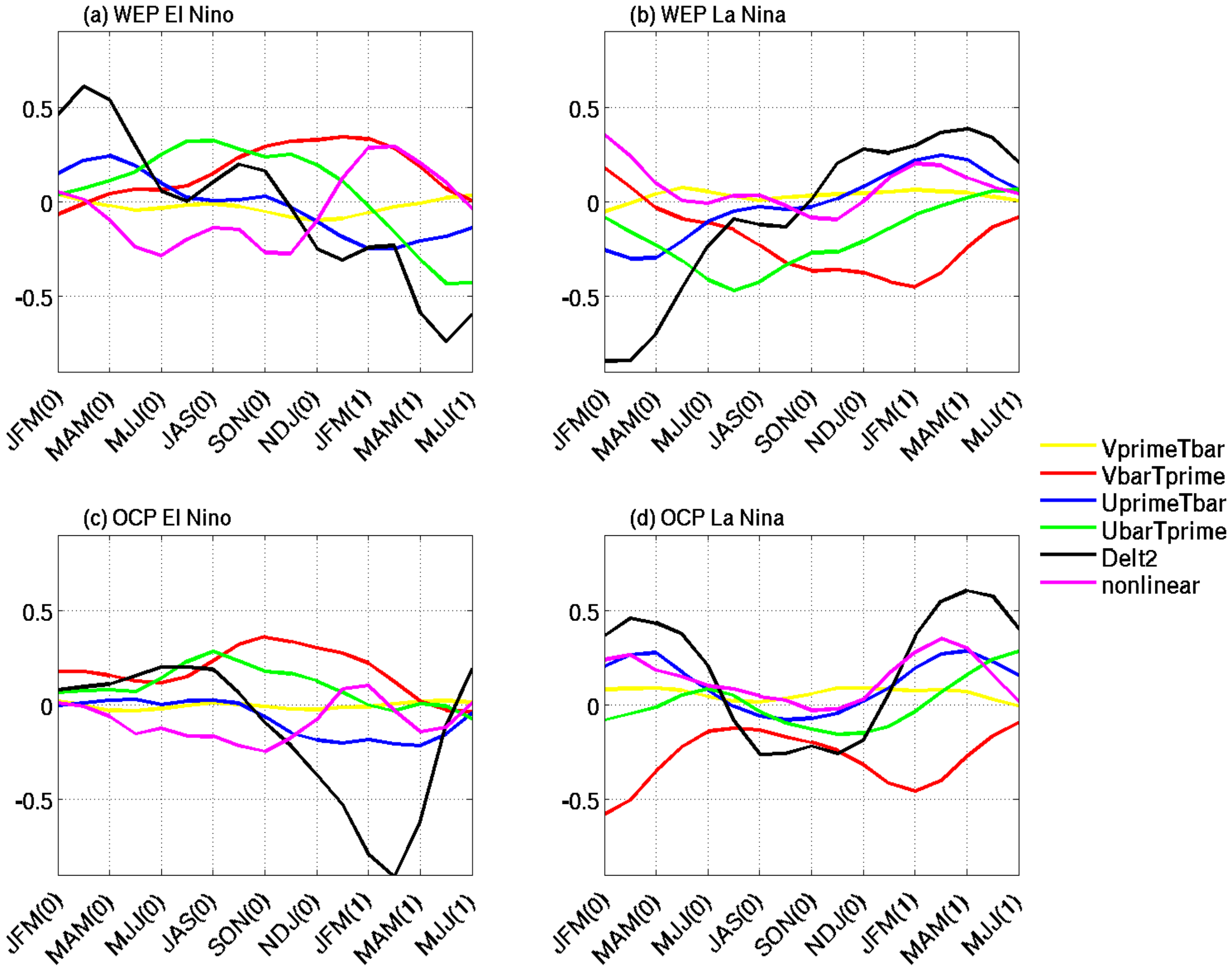


$$\frac{\partial T_2}{\partial t} = -\frac{\partial U_2(T_2 - T_m)}{\partial x} - \frac{\partial V_2(T_2 - T_m)}{\partial y} + residual$$

$$U_2(T_2 - T_m) = U_2'\overline{(T_2 - T_m)} + \overline{U_2}\,(T_2 - T_m)' + U_2'(T_2 - T_m)'$$

$$V_2(T_2 - T_m) = V_2'\overline{(T_2 - T_m)} + \overline{V_2}\,(T_2 - T_m)' + V_2'(T_2 - T_m)'$$

Heat Budget Analysis

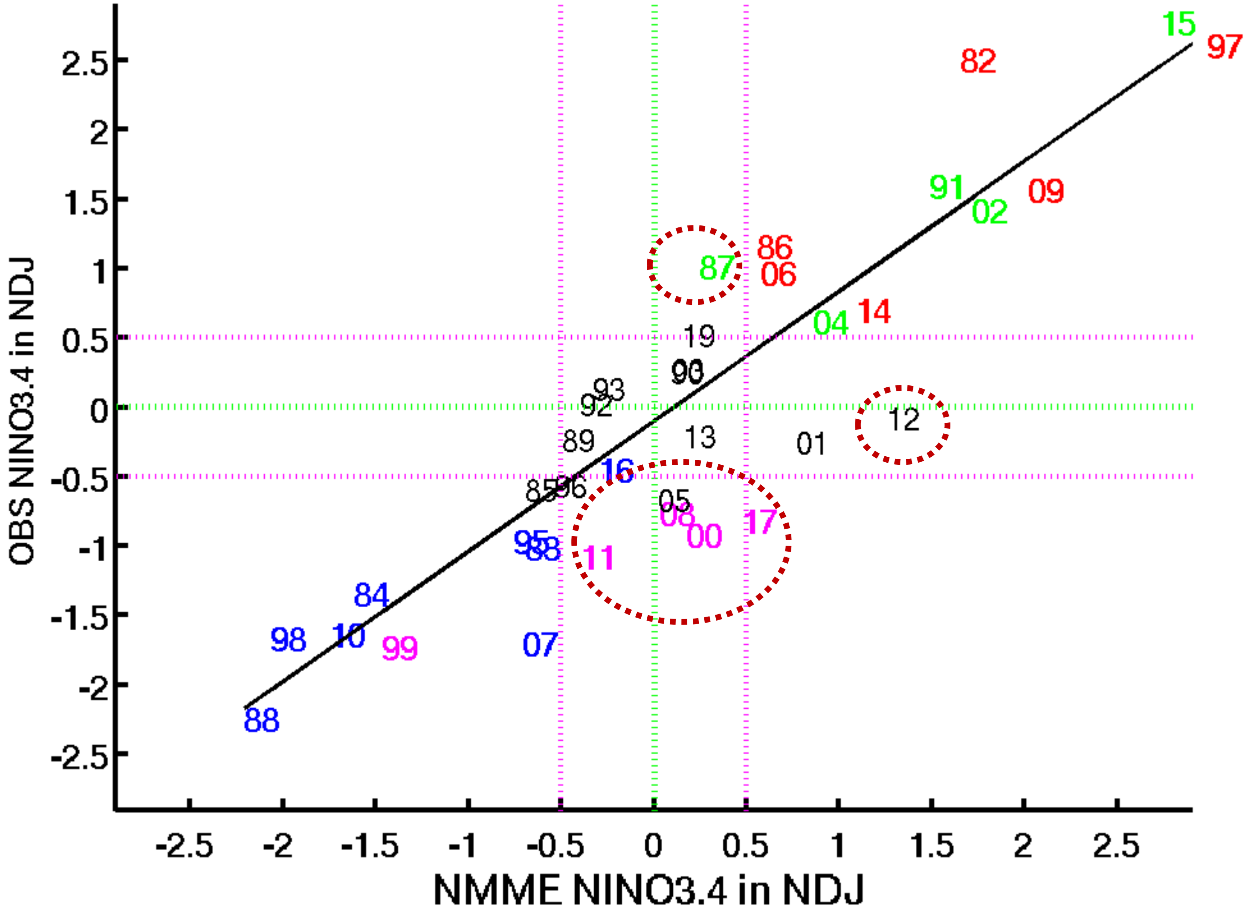


- For the WEP ENSO, zonal advection ($U_2'\overline{(T_2 - T_m)}, \overline{U_2}\,(T_2 - T_m)'$) plays an important role in modulating temperature tendency.
- For the OCP ENSO, $\overline{V_2}\,(T_2 - T_m)'$ plays the primary role in modulating temperature tendency.

Summaries:

- ENSO events can be classified into two categories based on their spatial and temperature connection between the central equatorial thermocline variations and surrounding regions (**WEP .VS OCP type ENSO**).
- WWV has very high correlation with SST WEP ENSO with six-month lead, while correlation drops substantially for the OCP ENSO.
- CTP has a very robust lead correlation with the OCP ENSO, highlighting the importance of off-equatorial subsurface preconditions in the central Pacific on ENSO onset.
- Off-equatorial thermocline temperature anomalies carried equatorward by the mean meridional currents play an important role in modulating the central equatorial thermocline variations.

Implication for Dynamical Model Skill Improvement



Red : WEP El Niño
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Green: OCP El Niño
Blue: OCP La Niña

Black: ENSO-neutral

- NMME accurately predict ENSO conditions for all WEP type ENSOs.
- NMME failed to predict 50% of OCP type ENSOs (1987 El Niño and 2000, 2008,2011,2017 La Niña events).