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Mechanisms for the Formation of Super El Niños

Tim Li and Lin Chen
Department of Atmospheric Sciences, University of Hawaii at Manoa, HI

EXTENDED SUMMARY

Current operational models have difficulty in predicting the intensity of El Niños. To improve the El Niño forecast skill, it is critical to understand statistically significant precursory signals between regular and super El Niños. With the use of observed sea surface temperature (SST) and rainfall data and oceanic and atmospheric reanalysis datasets, El Niño events during 1958-2008 were separated into two groups, a super El Niño group (with Niño 3.4 index being greater than 2.5 standard deviation, hereafter S-group) and a regular El Niño group (with Niño 3.4 index being less than 2.0 standard deviation, hereafter R-group) (Chen *et al.* 2016). A composite analysis shows that during the El Niño onset phase (Apr-May) when the amplitude of the

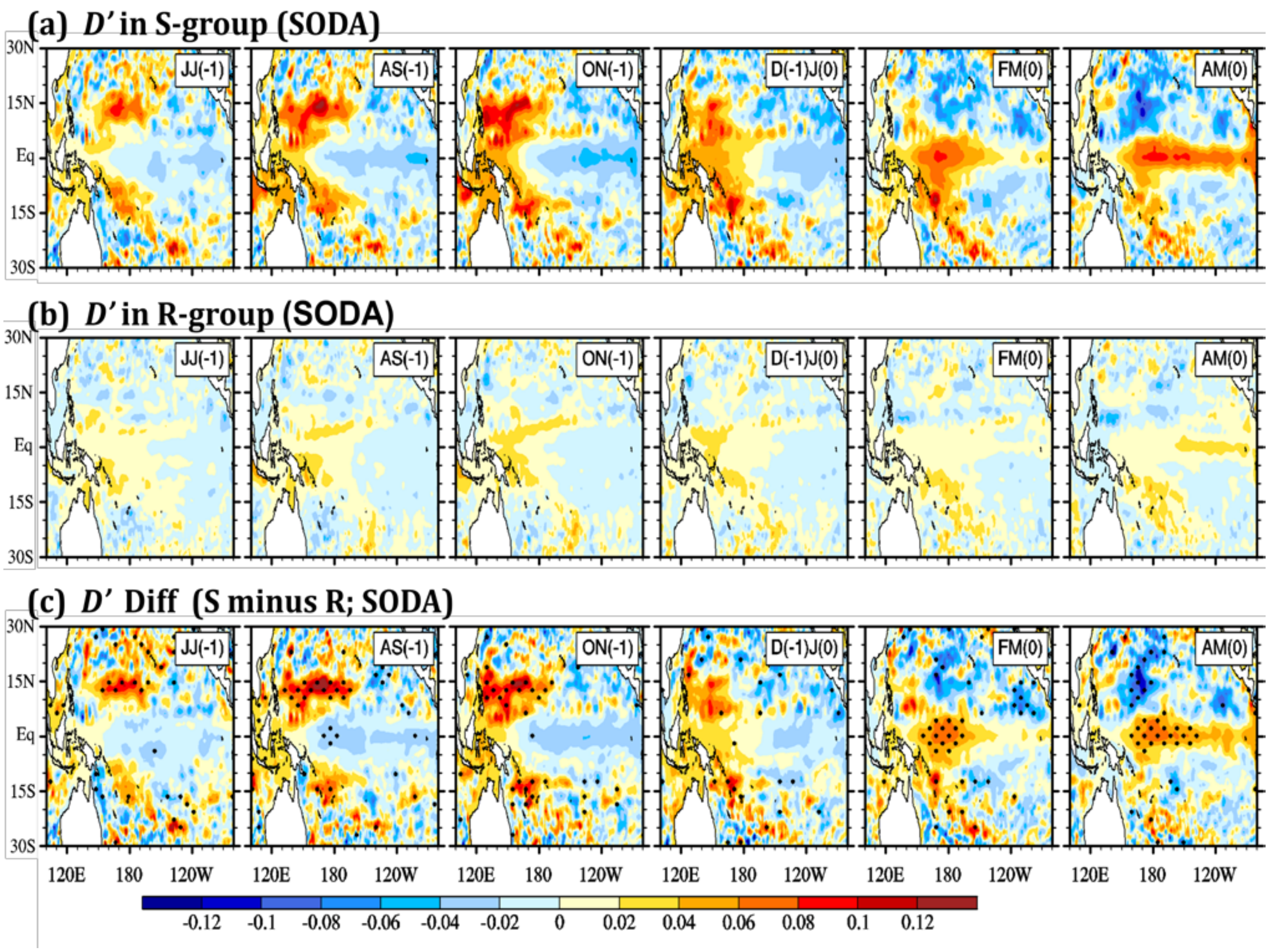

Fig. 1 Evolution of composite sea surface height anomaly (unit: m) for JJ[−1], AS[−1], ON[−1], D[−1]J[0], FM[0] and AM[0], derived from (a) S-group, (b) R-group and (c) the difference between S-group and R-group. The stippling in (c) indicates that the difference exceeds a 95% confidence level using a *t*-test. The ocean reanalysis dataset SODA was used. (From Chen *et al.* 2016)

Correspondence to: Tim Li, Department of Atmospheric Sciences, University of Hawaii at Manoa, HI.
E-mail: timli@hawaii.edu

eastern Pacific SST anomaly (SSTA) is still small in both the groups, a significantly larger positive SSTA tendency appears in S-group than in R-group. A mixed-layer heat budget analysis was further conducted, and the result indicated that the SSTA tendency difference arises primarily from the difference in anomalous advection of mean temperature by zonal current anomaly. The major factor controlling the zonal current anomaly is geostrophic current associated with oceanic thermocline depth anomaly (D').

To understand the cause of the D' difference during the onset phase, we investigated the evolution of D' from the pre-onset stage to the onset phase. Figure 1 shows the evolution of D' from June-July of the preceding year (denoted as year [-1]) to April-May of El Niño developing year (denoted as year [0]) in the S-group and R-group, as well as their difference (S minus R). A similar buildup of positive D' (which represents the upper ocean heat content anomaly) appeared in the western equatorial Pacific in both the S- and R- group (Fig. 1a–b). However, the signal of D' was much stronger in the S-group. Most important difference lies in the off-equatorial region from JJ[-1] to ON[-1]. A significantly larger positive D' anomaly appeared over the off-equatorial (10°N-20°N and 10°S-20°S) western Pacific region in S-group than in R-group (Fig. 1c). As the significantly different D' signals propagated westward as Rossby waves and were reflected in the western boundary, they contributed to distinctive differences in the magnitude of D' at the equator in FM[0] and AM[0], with a much larger positive D' in S-group than in R-group. Thus, the accumulation of deepened thermocline depth anomaly in the off-equatorial western Pacific in preceding months (JJAM[−1]) holds a key for the subsequent differences in the thermocline depth, zonal current and vertical velocity anomalies in later months (*i.e.*, FM[0] and AM[0]). The difference in D' was further caused by the difference in anomalous wind stress curl patterns in JJAS[-1] in the western Pacific, which were regulated by anomalous SST and precipitation fields over the Maritime Continent and western Pacific.

While a clear positive D' signal was seen in western Pacific during the onset phase of super El Niños in 1982 and 1997, such a precursory signal was not presented in the 2015 El Niño case (Chen *et al.* 2017). Figure 2 compares the evolutions of the Niño3 SSTA for 2015 El Niño (hereafter 2015EN) and traditional super El Niño (defined as ensemble average of 1982 and 1997 events, hereafter TR-super EN). Two marked differences are worth noting. Firstly, in contrast to TR-super EN that started from a cold episode in the preceding year, 2015EN was preceded by a weak warming event peaked in November 2014. In the preceding winter (November to ensuing February, *i.e.*, the pre-onset phase), the TR-super EN shows a warming tendency but 2015EN shows a cooling tendency. Secondly, in 2015EN a marked turnabout of the SSTA tendency (from negative to positive) happened around February 2015.

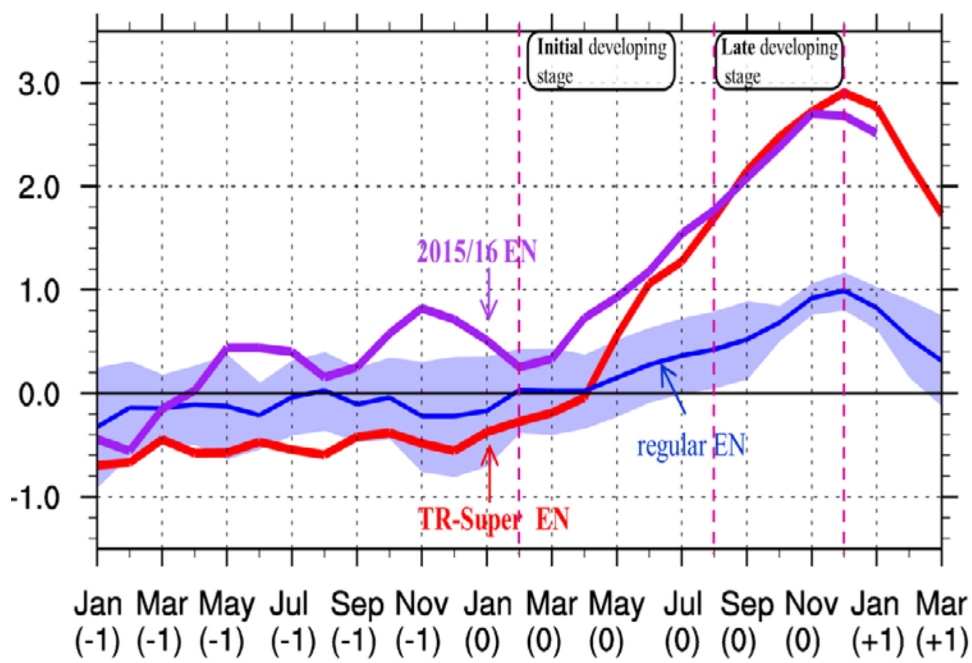

Fig. 2 Time evolution of Niño3 SSTA. Purple line indicates the 2015 El Niño, red line indicates the composite of traditional super El Niño events (*i.e.*, 1982 and 1997 events), and the blue line indicates the composite of regular El Niño events during 1980-2015 (including 1986/87, 1987/88, 1991/92, 1994/95, 2002/03, 2004/05, 2006/07 and 2009/10 El Niños). The light blue shading indicates the inter-case spread, estimated with the inter-case standard deviation of the regular El Niño events. (From Chen *et al.* 2017)

A mixed layer heat budget analysis indicated that the turnabout of the SSTA tendency in February 2015 was caused by the change of anomalous zonal advection associated with sudden built-up of positive *D′* over equatorial central Pacific. A further examination showed that the sudden increase of *D′* resulted from exceptionally strong westerly wind events (WWEs) in early 2015. An accumulated WWE index was introduced by Chen et al. (2017), and the result showed that this index attained the largest value in the past 37 years (*i.e.*, 1979-2015). Idealized ocean modeling experiments were further carried out to illustrate the important role of the WWEs in setting up the positive *D′* in early 2015.

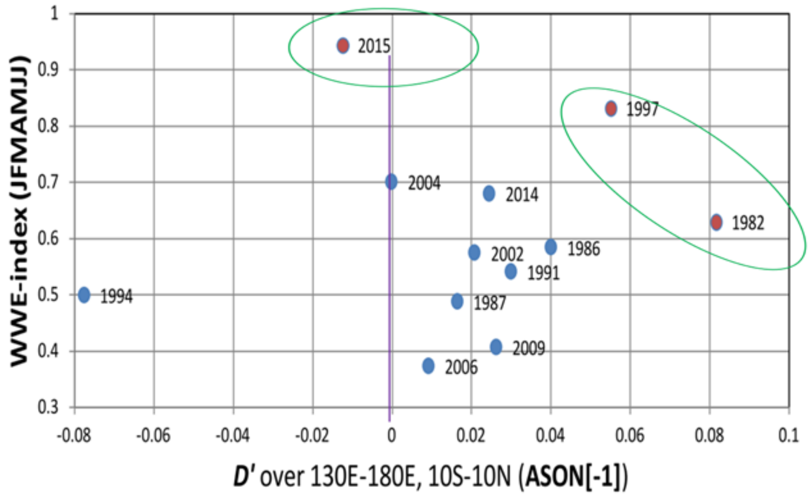

Fig. 3 Scatter diagram for each El Niño since 1979 as a function of precursory thermocline anomaly signal (horizontal axis) and an accumulated WWE index (vertical axis). Green circle indicates two distinctive regimes for super El Niño formation: exceptionally strong WWEs versus exceptional strong D' signal. (From Chen *et al.* 2017)

In summary, the occurrence of a series of exceptionally strong WWEs in early 2015 is the major driver to flare up a positive *D′* center over equatorial Pacific and cause the formation of the 2015 super El Niño. The unique developing characteristic breaks our traditional view of El Niño formation, which emphasized the off-equatorial thermocline recharging process. The result suggests that two routes may lead to super El Niño formation (Fig. 3). The first route is the occurrence of exceptionally strong positive precursory *D′* signal in off-equatorial western Pacific. The 1997 and 1982 events are such examples. The second route is the occurrence of exceptionally strong WWEs. The formation of 2015EN is such an example – while a precursory negative off-equatorial *D’* signal favored the occurrence of thermocline shoaling at the equator in subsequent months, such a discharging process was interrupted by the consecutive extremely strong WWEs. Thus the 2015 episode is a shining example showing how important WWEs are. They can turn around slow coupled dynamics and cause the generation of a super El Niño.

The works above have been published in referred journals (see references below).

Reference

Chen, L., T. Li, B. Wang, and L. Wang, 2017: Formation mechanism for 2015/16 super El Niño. *Scientific Reports*, **7**, doi:10.1038/s41598-017-02926-3.

Chen, L., T. Li, Swadhin K. Behera, and Takeshi Doi, 2016: Distinctive precursor air-sea signals between regular and super El Niños. *Adv. Atmos. Sci.*, **33**, 996-1004.