Cause-effect Relations of California Niño/Niña

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Recent studies have identified the quasi-periodic SST anomalies off Baja California coast called California Niño/Niña. A novel method to analyze the cause-effect relations between two time series is applied in this study to examine the causality relation around the positive feedback that contributes to the development of California Niño/Niña suggested by Yuan and Yamagata (2014). The research concludes that California Niño/Niña triggers the ENSO and ENSO also makes California Niño/Niña anomalous. The results also show that of some climate models are incapable of simulating reality under certain circumstances.

Introduction to California Niño/Niña

Fairly recently, the realization of anomalous sea surface temperature (SST) off Baja California and California coast have led to the discovery of an intrinsic coastal atmosphere-ocean coupled phenomenon. Even though the existence of the anomalous SST in that area has long been recognized, it was categorized by many researchers under the realm of the ENSO (El Niño Southern Oscillation), because the ENSO can have an impact on the coastal warming/cooling anomalies via atmospheric teleconnection. However, Yuan and Yamagata (2014) pointed out uniqueness and independence of the SST anomalies and suggested that the anomalous SST named California Niño/Niña develop through a positive costal Bjerknes feedback.

To understand the intrinsic coastal SST anomalies, we need to first recognize the unique geographical characteristics of the coast of Baja California and California. The coast is famous for its high productivity because of the year-round equatorward surface wind blowing along the shore. The alongshore wind drives the offshore Ekman transport. To compensate this, the cold and nutritious water upwells from the deep ocean and increase the biological productivity of the Baja California-California coastal region. However, during the period of California Niño(Niña), the upwelling is significantly reduced(enhanced) and leads to the obvious decline(increase) of biomass of phytoplankton and zooplankton.

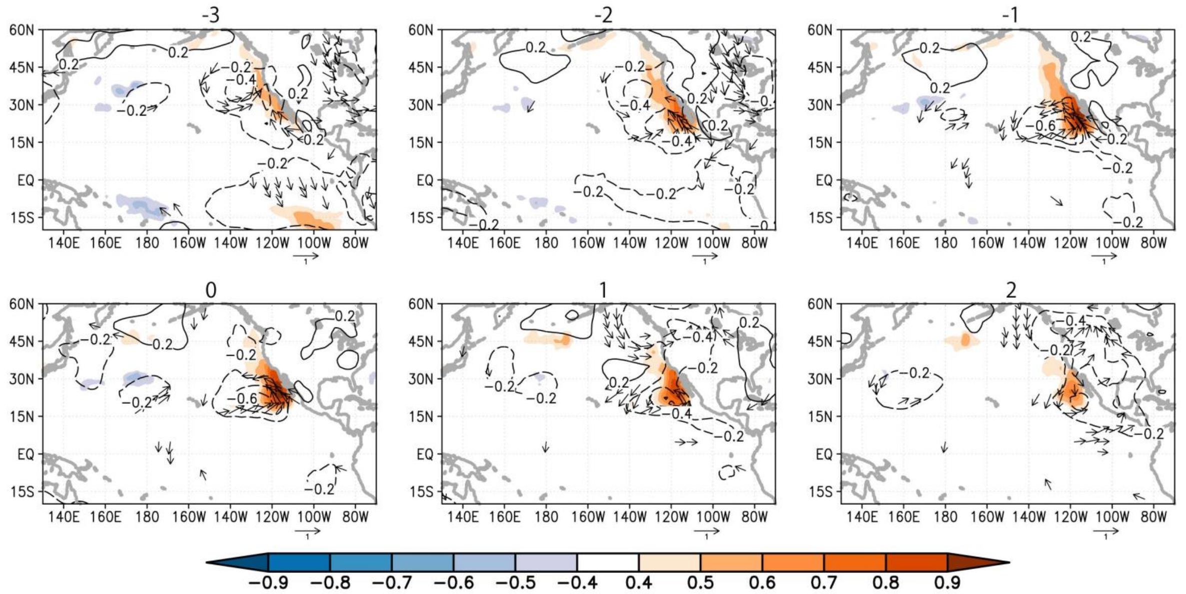

Figure 1. Lead-lag correlation coefficients of boreal summer California Niño SST, sea level pressure and 3-month-running mean anomalies in SST (shading), SLP (contour) and 10-meter-height wind (vector). Negative (positive) numbers in the top of each panel denote the months that the July-August-September California Niño/Niña indices lag (lead) and the correlation coefficients are calculated after linearly regressing out the simultaneous variations related to ENSO. Adioted from Yuan and Yamagata (2014).

How is the costal upwelling reduced/enhanced and how does California Niño/Niña develop? The development of California Niño can be decomposed into three different stages. First stage, anomalous sea level pressure (SLP) appears off the Baja California and California coast. In Figure 1, identifiable anomalous negative SLP anomalies emerge three months prior to the peak month of California Niño. The associated anomalous poleward wind counteracts the year-round equatorward wind. Second, because of the poleward wind anomalies, the coastal upwelling is reduced, and less cold water is transported to the surface. Finally, anomalously warm SST strengthens the negative SLP and stronger southerly wind anomalies are generated. These three stages form a full cycle of the positive air-sea coupled feedback.

Along with the coastal Bjerknes feedback, the SST-stratus cloud-shortwave radiation feedback may also contribute to the development. Since California Niño occurs in the sub-tropical latitudes (around 20N to 30N), where cool SST helps the stratification of cloud in planetary boundary layer. However, positive SST anomalies destabilize the stratification, and result in smaller amount of stratus cloud. Less stratus cloud allows more shortwave radiation to reach the sea surface, and contributes to further warming of the SST.

Introduction to Dr. Liang's analytical method

Although correlation coefficients are used to discuss the statistical relationships between two variables, they cannot explain causality. However, Liang (2014) suggested a new formalism to quantify the two unidirectional causalities between two dynamical events with corresponding time series given.

This formalism calculates the rate of information flow from one event to the other.

The crucial idea of Liang (2014) is to find the likelihood of two given time series. Mathematically speaking, likelihood is the hypothetical probability to predict the parameter when one knows the outcome of the event. Under this assumption, one may find the cause-effect relation using only time series:

$$T_{2\to 1} = \frac{C_{11}C_{12}C_{2,d1} - C_{12}^2 C_{1,d1}}{C_{11}^2 C_{22} - C_{11}C_{12}^2}$$

The $T_{2\to 1}$ value shows the impact from event 2 to event 1 by calculating the information flow. The C_{ij} values are the covariance between event i and j, and $C_{i,dj}$ values are the covariance between event i and the time derivative of event j:

$$C_{ij} = \overline{(X_i - \overline{X_i})(X_j - \overline{X_j})}$$

$$C_{i,dj} = \overline{(X_i - \overline{X_i})(\dot{X}_j - \overline{\dot{X}_j})}$$

Positive covariance means that X and Y have the same tendency, while negative covariance means that X and Y have the inverse tendency. Zero covariance means that X and Y are independent.

$$\forall X>E[X] \wedge Y>[Y],\ \exists\, cov(X,Y)>0$$

$$\forall X>E[X] \wedge Y<[Y],\ \exists\, cov(X,Y)<0$$

$$\forall P(A\cap B)=P(A)P(B),\ \exists\, cov(X,Y)=0$$

As Liang (2014) mentioned, a positive T value indicates that event 2 makes event 1 more anomalous while negative T indicates that event 2 make event 1 more stable, and T=0 means that event 2 does not influence event 1.

Liang (2014) applied the method to examine the causality between ENSO and Indian Ocean Dipole and obtained $T_{E\to I}$ = -6 and $T_{I\to E}$ = 16. He suggests that "El Niño and IOD are mutually causal, and the causality is asymmetric, with the one from the latter to the former larger than its counterpart. Moreover, the different signs indicate that El Niño tends to stabilize IOD, while IOD tends to make El Niño more uncertain". His research shows a potential usefulness of this method in climate research.

Data analysis

Since Dr. Liang's method was comparatively new to climate research, I applied this method to analyze the cause-effect relations about California Niño/Niña. The span of the time series is shorter by excluding the data before 1982, compare to Dr. Liang's research, to eliminate the effect of inaccuracy of data. First, to examine the causality between ENSO and California Niño/Niña, I used the time series of Niño3 index from the NOAA and the California Niño Index from the OISST, from January 1982 to December 2014, 396 months in total. The resultant T values are $T_{E\to C}$ = 4.26 and $T_{C\to E}$ = 6.84(both units are 10^{-3} nats/month). These T values indicate that the ENSO destabilizes California Niño, and California Niño also makes ENSO anomalous. This conclusion coincides with Feng et al (2014). SST anomalies off Baja California may serve as the precursor of some ENSO events.

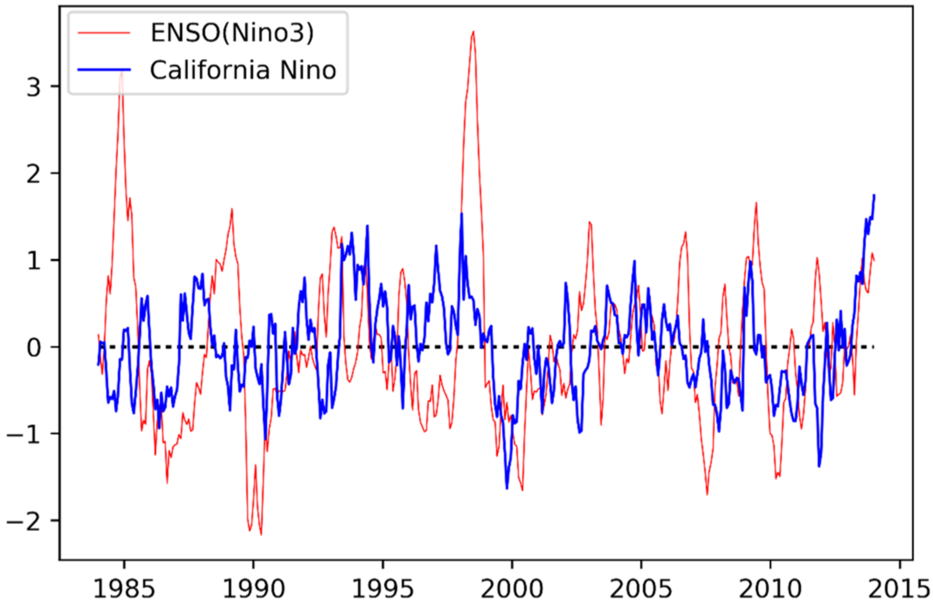

Figure 2. Niño3 index vs California Niño/Niña index. The monthly anomalies of the Niño 3 index (red line) and the California Niño index (blue line) from January 1982 to December 2014 (in ℃). The figure was plotted by Jupyter.

To investigate influence of alongshore wind to the SST anomalies off the Baja-California coast, the index of alongshore wind was computed from the JRA-55 (the Japanese 55-year Reanalysis) for the same time span.

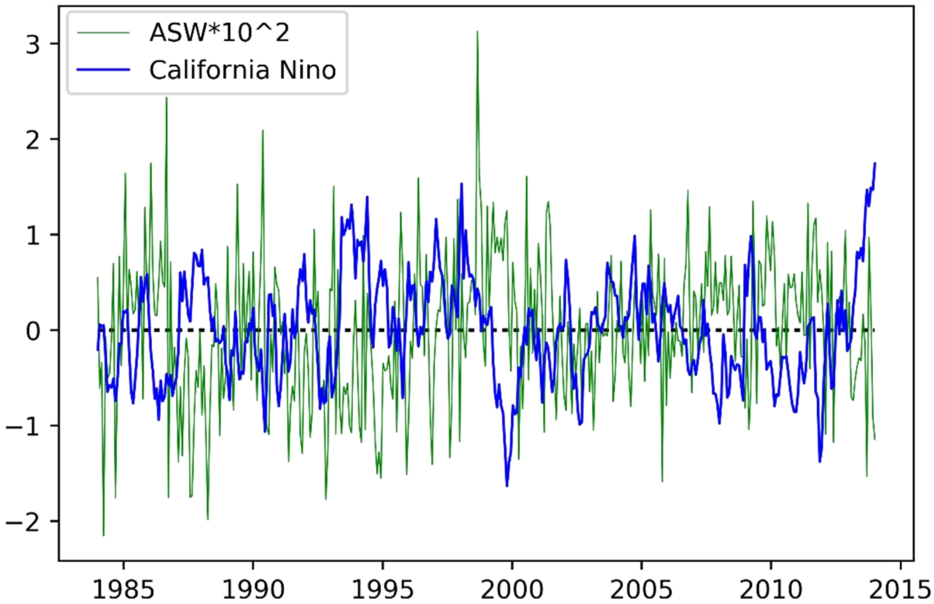

Figure 3. Alongshore wind index vs California Niño/Niña index. The monthly anomalies of the alongshore wind index of Baja California coast is in 10^{-2}m/s(green line) and the California Niño index in ℃ (blue line) from January 1982 to December 2014. The figure was plotted by Jupyter.

$T_{A \to C}$ = 44.03 and $T_{C \to A}$ = 9.93(both units are 10^-3 nats/month). Since both of the T values are positive, this supports Yuan and Yamagata (2014) who suggested a positive feedback involving SST and alongshore wind anomalies.

To check the causality between Califor-nia Niño and Stratus cloud, I used the stratus cloud index computed using the JRA-55 dur-ing the same time span .

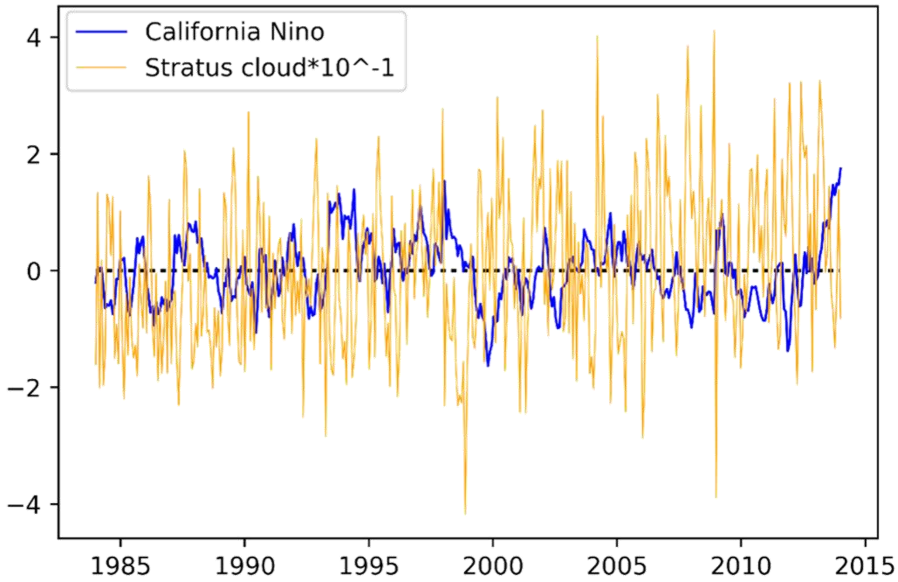

Figure 4. Stratus cloud index vs California Niño/Niña index. The monthly anomalies of the stratus cloud index in percentage*10^{-1} (yellow line) and the California Niño index in ℃ (blue line) from January 1982 to December 2014. The figure was plotted by Jupyter.

To check the causality between Califor-nia Niño and Stratus cloud, I used the stratus cloud index computed using the JRA-55 during the same time span. Although $T_{C \to S}$>0 shows that California Niño activates stratus cloud anomalies and $T_{S \to C}$<0 means stratus cloud anomalies stabilize California Niño, contradict with Yuan and Yamagata's hypothesis, since stratus cloud and SSTAs cannot form a positive feedback.

To examine the long-term change in the information flow over time I split the time series into two of the equal length and calculated the T values for the first 16 years and the last 16 years. The first period is from January 1982 to December 1997, and the second period is from January 1999 to December 2014; both the series contains 192 months of data.

Unit:10^-3 nats/month	JAN 1982-DEC 1997	JAN 1999-DEC 2014
$T_{E\to C}$	0.47	15.71 (3242%)
$T_{C\to E}$	1.13	30.80 (2625%)
$T_{A\to C}$	44.44	54.65 (23%)
$T_{C\to A}$	8.91	25.49 (186%)
$T_{S\to C}$	-10.87	-62.30 (473%)
$T_{C\to S}$	17.59	80.81 (359%)

Table 1. The rates of information flows between the three pairs of processes for two time periods. The percentages in the third column indicate the increase of T value in the 1999-2014 period from the 1982-1997 period. All T values are in 10^{-3} nats/month.

Surprisingly, all values increase over time while the percentage varies. The result suggests the casual relation strengthened in the second period. There are two possible reasons: rising greenhouse gas concentration or decadal oscillation. Since the positive phase of Pacific Decadal Oscillation took place between 1982 and 1998 and the negative phase took place between 1998 to 2014, the Pacific Decadal Oscillation may have influenced on the relations of the regional phenomenon since the observational data is very limited. I tried to verify if global warming can have an impact on the rates of information flows using two models from the CMIP5 (Coupled Model Intercomparison Project Phase 5) that performed the "1pctCO2" (1% per year increase in atmospheric CO2) experiment, namely MRI and ESM2 models. I calculated the T values between ENSO and California Niño for the first and last fifty years separately.

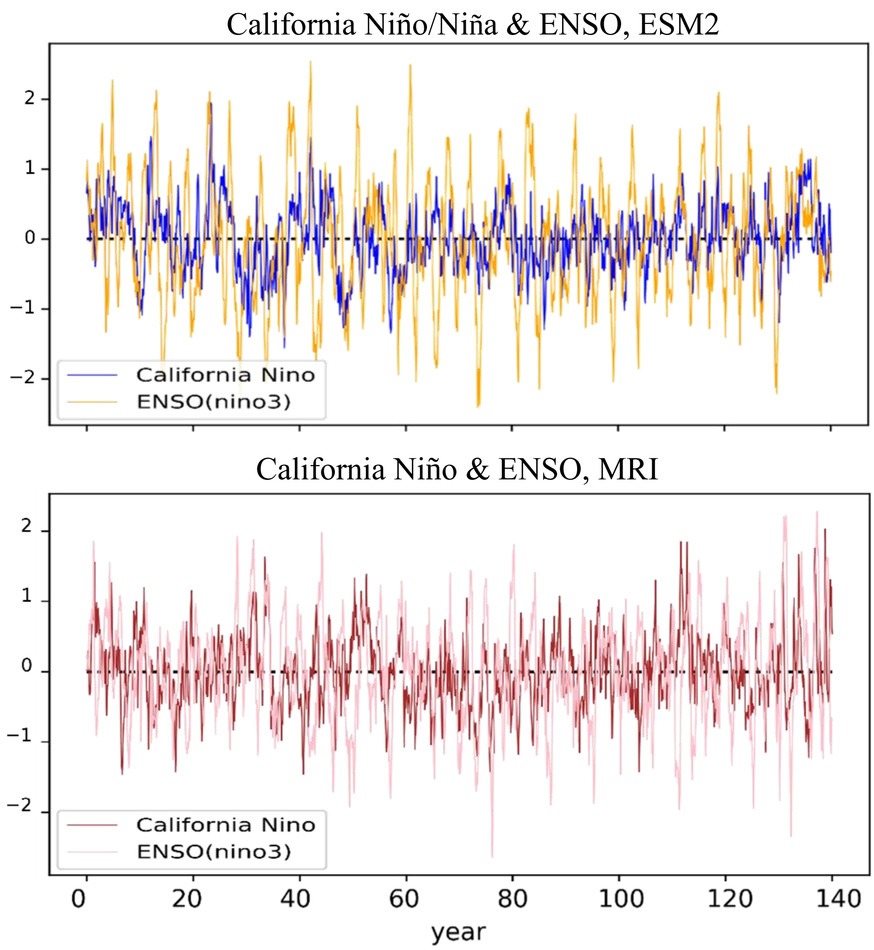

Figure 5 Results of 1pctCO2 experiment from ESM2 and MRI models. Time series of California Niño/Niña and ENSO indices from the 1pctCO2 experiment of ESM2 and MRI models. All monthly values in ℃. The figure was plotted by Jupyter.

Unit:10^-3 nats/month	**First 50 years**	**Last 50 years**
$T_{E\to C}$: MRI	0.81	-3.51
$T_{C\to E}$: MRI	5.54	9.79
$T_{E\to C}$: ESM2	11.90	32.71
$T_{C\to E}$: ESM2	-0.41	-6.08

Table 2. The rates of information flows between ENSO and California Niño/Niña calculated using outputs from the 1pctCO2 experiment of MRI and ESM2 models. All units in 10^{-3} nats/month.

In the MRI model, $T_{E\to C}$ in the first 50 years is much smaller than the observation and even changes its sign in the last 50 years.

In the ESM2 model, $T_{C\to E}$ for both periods are negative, which means California Niño stabilize the ENSO, which contradicts the conclusion from historical data. On the other hand $T_{E\to C}$ increases with global warming, suggesting that the destabilization of the California Niño by the ENSO in this model is enhanced in a warmer world.

Therefore, both models fail to simulate

the observed relation between California Niño and the ENSO. To have a better understanding to the cause-effect relation between them under the increasing CO2 concentration, we need to use models that can realistically simulate the observed relation.

Discussion

While applying the new method in meteorological analysis seems very logical, some intrinsic weaknesses and the lack of decipherment of this approach still holds researchers back from comprehending the full potential of the method. First weakness, as Liang (2014) mentioned, is that this method requires a large set of data. Even though there is no actual number of values that will grant that T value is accurate enough, the shortest period of time he applied his formula was 40 years or 480 months. In this study, I have used at least 196 values. This points to the importance of maintenance of observational network.

Also, Liang (2014) also does not offer a reverse proposition to verify the result. This weakness is partially because this method is purely statistical. Because the establishment of this approach is very recent, the study does not offer scientist any other related method to verify if the causality is true.

Moreover, since this method is a mathematical evaluation, the result cannot provide the dynamics hiding under the cause-effect relation. Statistical results need to be supported by dynamical considerations.

Another shortcoming is that there is no quantitative way to test whether the T value is significantly different from zero. The standard was from Dr. Liang's empirical experience between ENSO and IOD. Such statistical test may help us to explore the full potential of the present mathematical analysis.

References

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