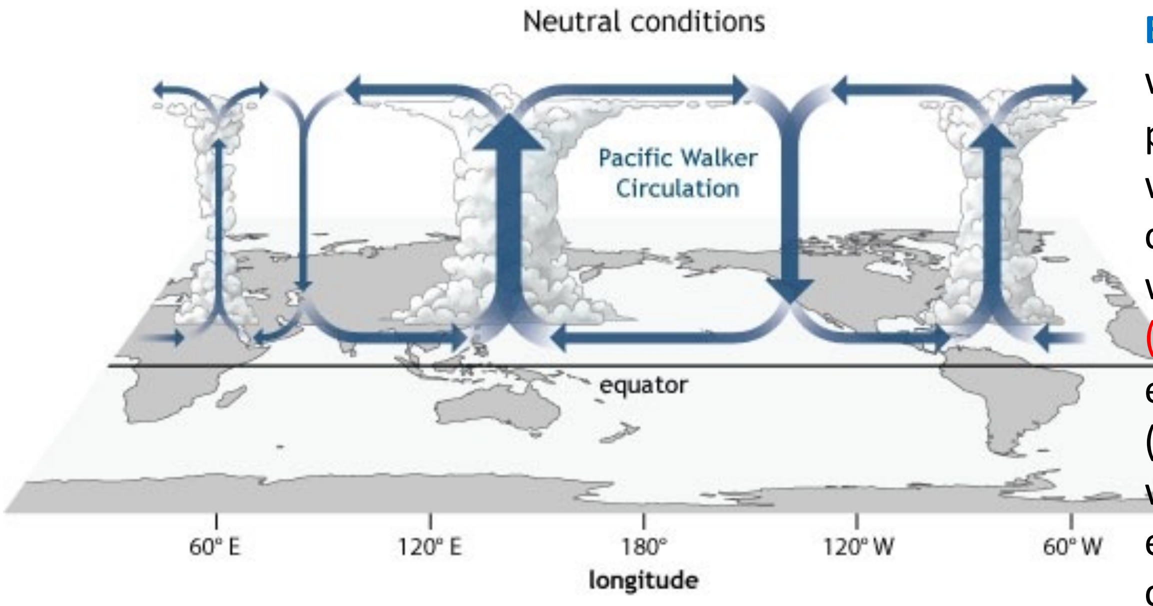
Topic #2: Tropical Variability and Analysis of the El Niño-Southern Oscillation (ENSO) Forcing in Observations and Models

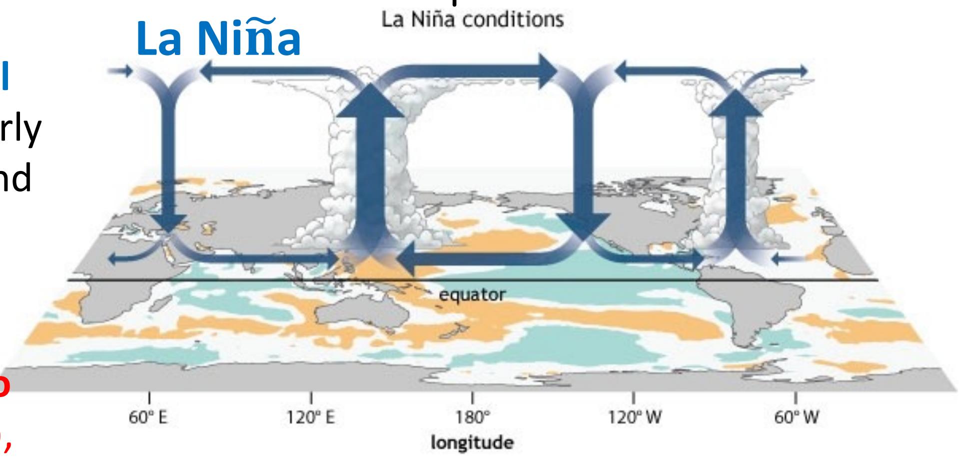
- **Introduction:** ENSO is a periodic variation in winds, Sea-Surface Temperatures (SSTs), and cloud/convection characteristics over the near equatorial central/eastern Pacific Ocean, with remote influences nearly globally (teleconnections). The irregular periodicity of ENSO (2-7 years) continues to provide challenges; during some years a full-fledged El Niño never develops even in the midst of anomalously warm waters. The shift in warm waters across the equatorial Pacific coincides with a shift in the large-scale-circulation, also known as the **Walker Circulation**, which results in a shift in the location of deep convection and maximum tropical precipitation.



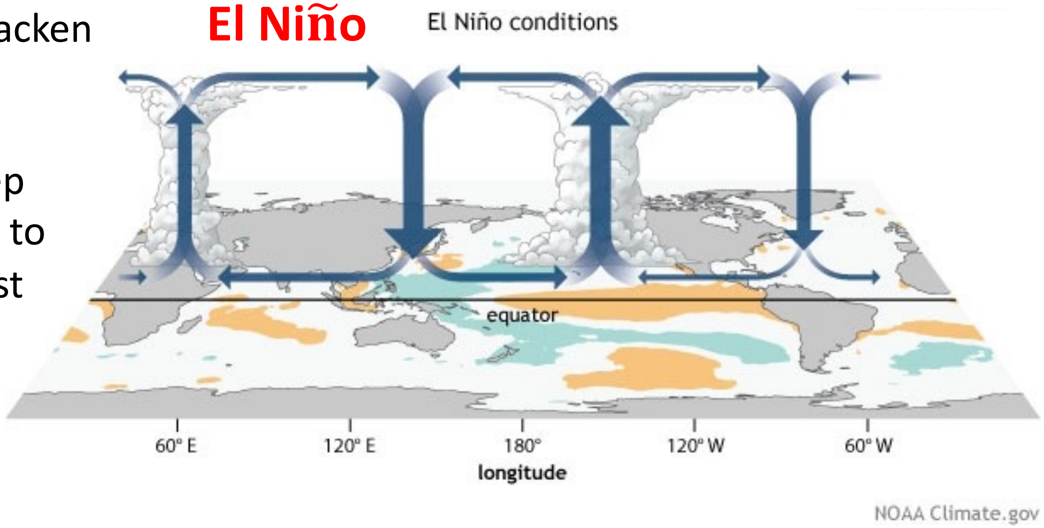
During **Neutral conditions (above)**, near-surface equatorial winds blow from eastern Pacific to western Pacific, with the highest SSTs found in the western Pacific, coincident with maximum deep convection and precipitation.

During La Niña **(cool ENSO phase),** easterly winds strengthen and push the warmest waters and deepest convection further west; during **El Niño** (warm ENSO phase), easterly winds slacken (and sometimes westerly winds emerge) and deep convection shifts to the central to east Pacific

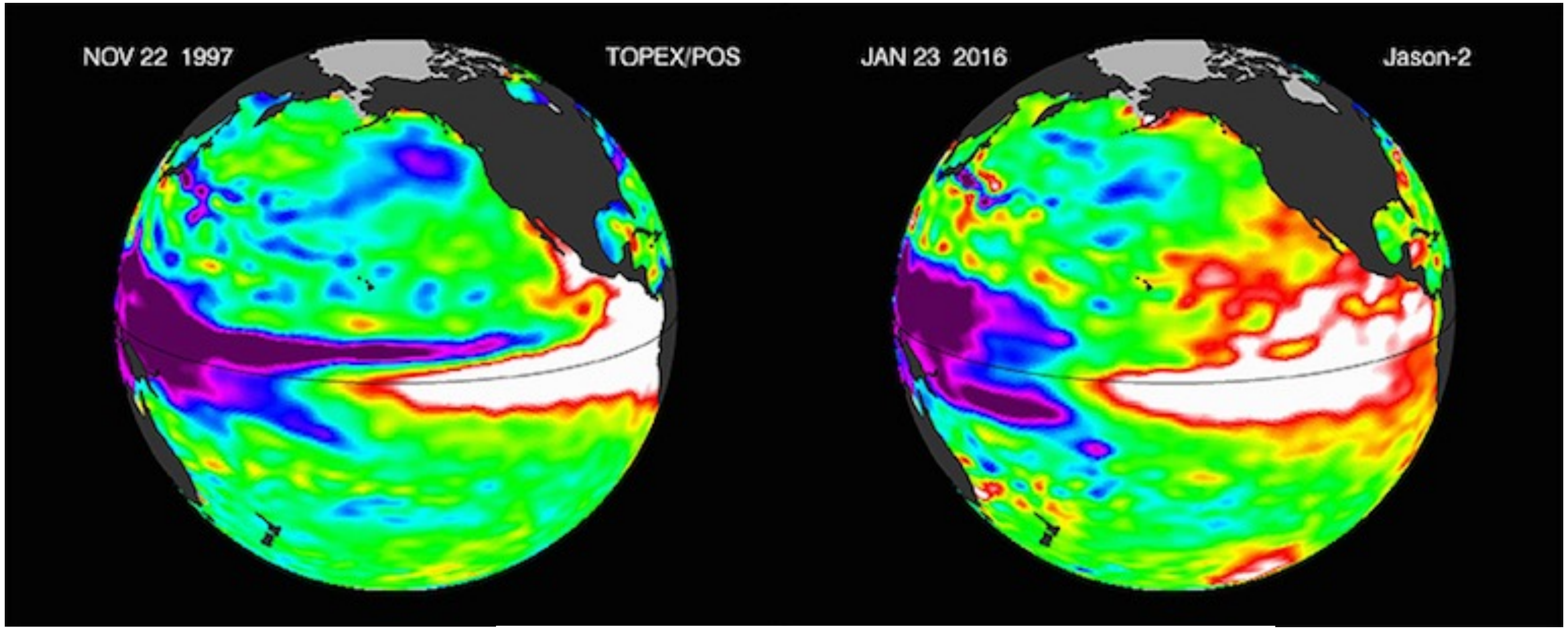
La Niña



El Niño



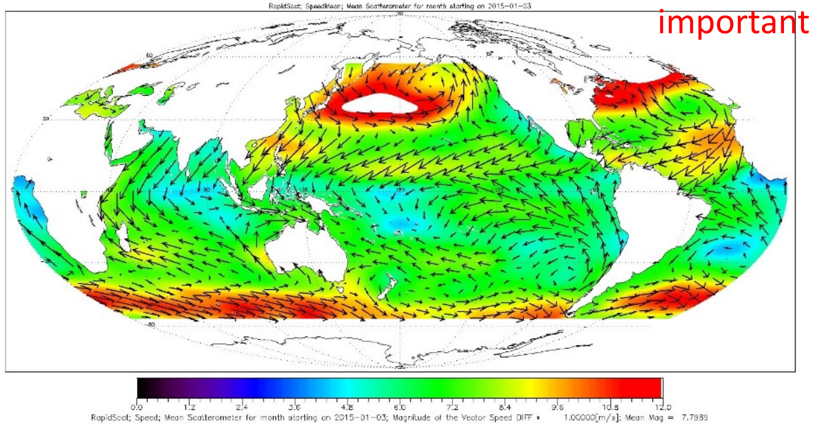
Comparison of Sea Surface Heights of a More Recent Strong El Niño Event (Right; 2015-16) with a Previous Strong Event (1997-1998)



Left - Source: NASA-JPL: Depicts altimeter images with increased anomalous sea-surface heights in reds and whites, reflecting higher surface temperatures

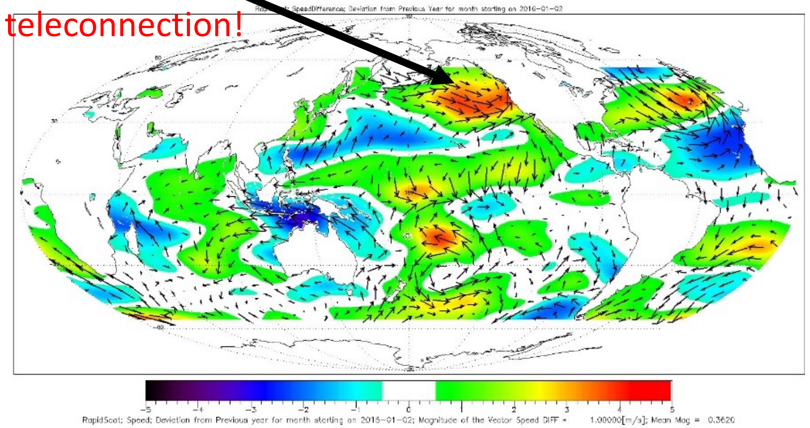
Below: Images from RapidScat, an International Space Station Based Scatterometer, a replacement for NASA's QuikScat

RapidScat
January 2015

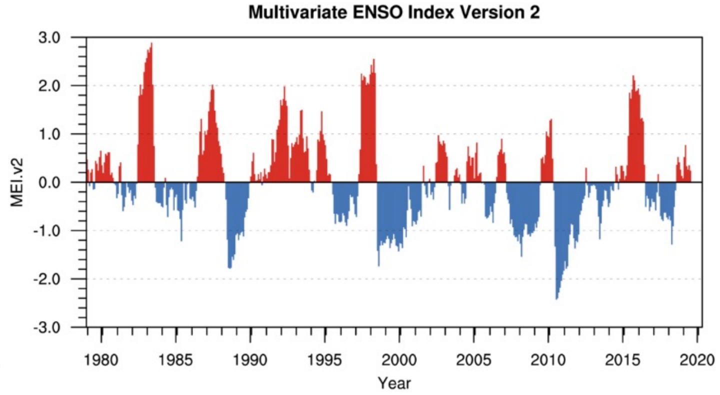


Note the shift in the West Coast storm track – an important teleconnection!

RapidScat
January 2016 Anomaly



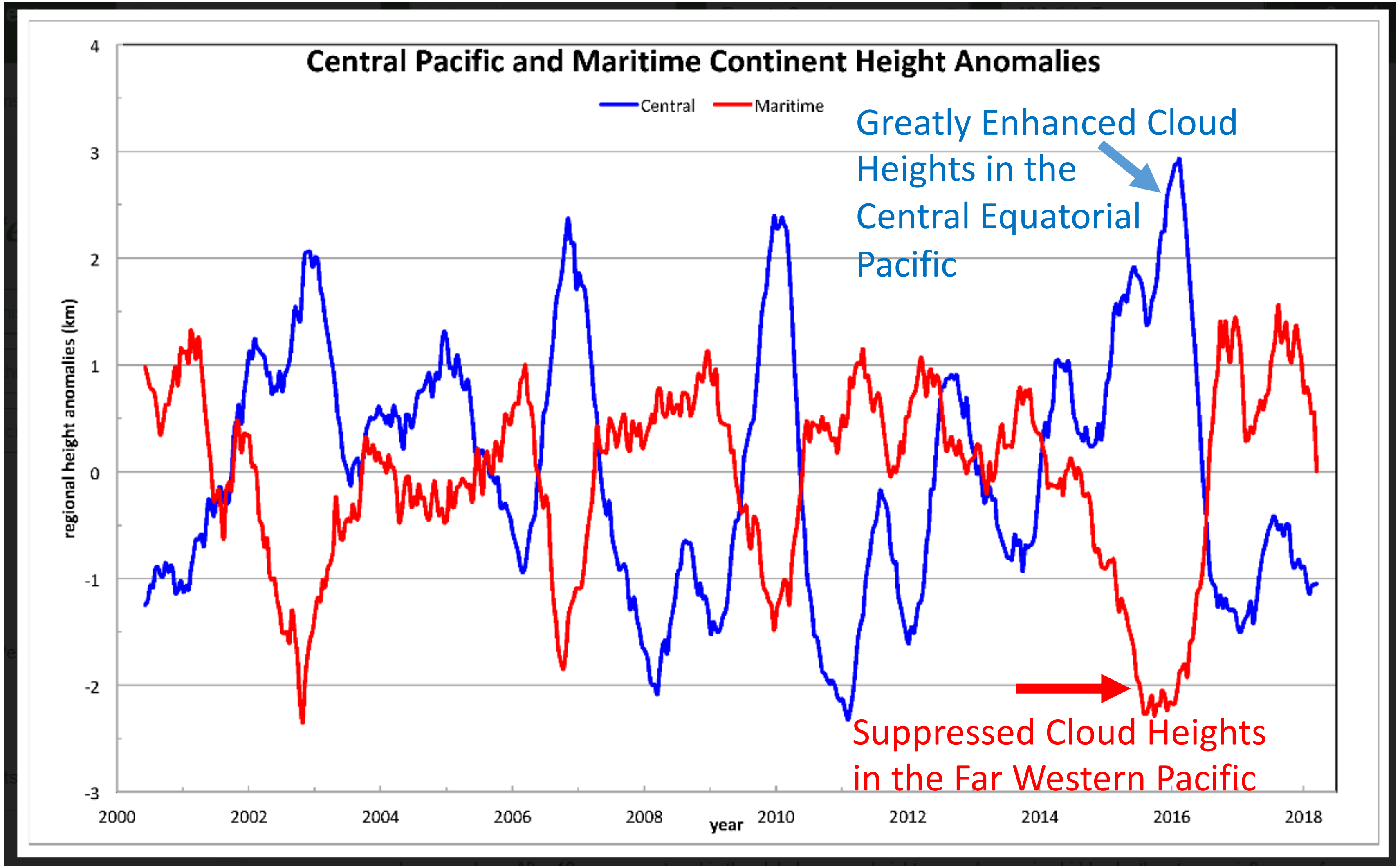
Below: Multivariate ENSO Time Series from 1979-2019, showing the periodicity of warm and cool ENSO events.



Time Series of Central Pacific and Maritime Continent Cloud Height Anomalies from MISR (Multi-angle Imaging SpectroRadiometer)

Figure Courtesy of Figure 5 from R. Davies (2018), *Remote Sensing:* “ENSO and Teleconnections Observed Using MISR Cloud Height Anomalies.”

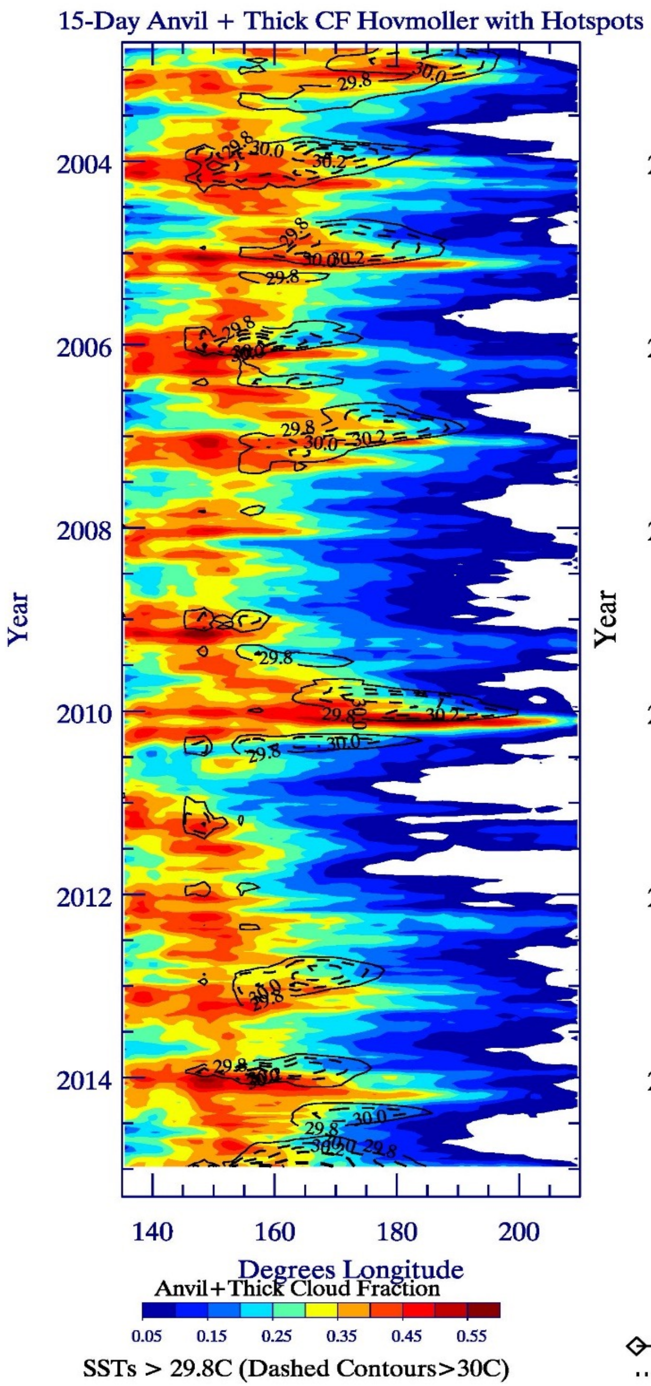
doi:10.3390/rs11010032

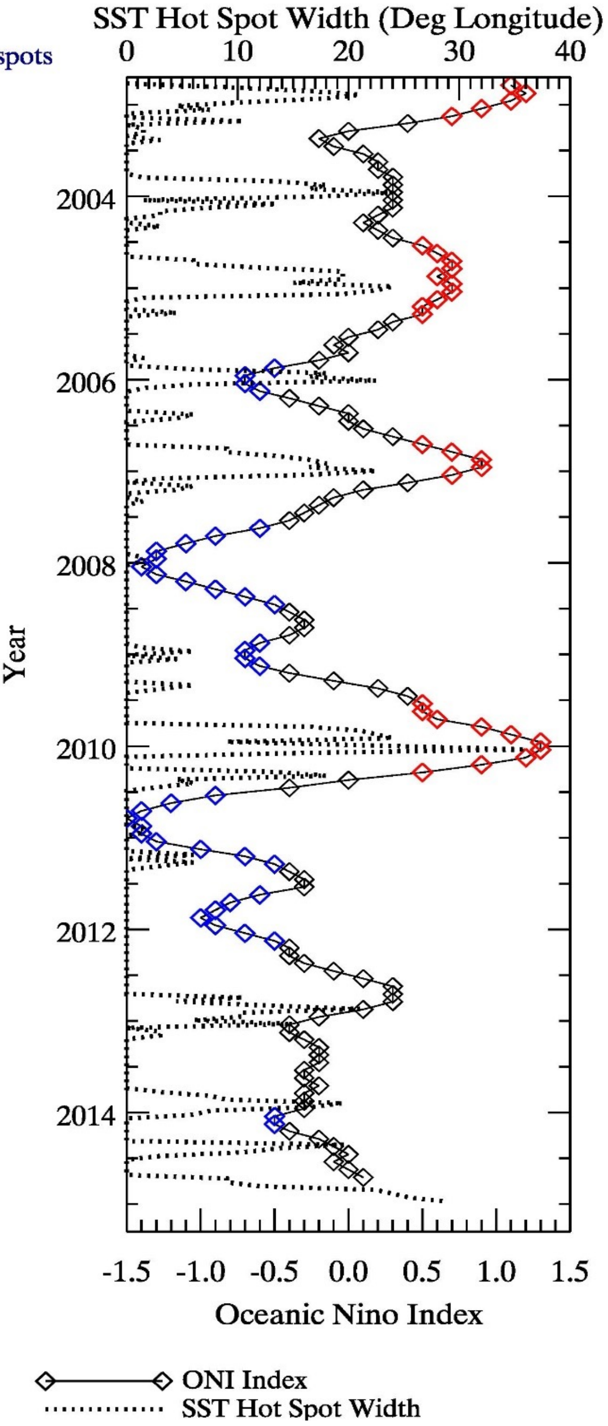


Analysis examining connections between high SSTs, referred to as SST hot spots (in this case, when the SST exceeds 30°C in a specified area for at least 15 days), and deep convection fraction from Aqua MODIS

Left plot: Hovmöller Diagram showing MODIS Anvil+Thick CF as a function of longitude (x-axis) and time (y-axis) from October 2002 – September 2014) (filled contours) and SSTs (unfilled contours, starting at 29.8°C, with each contour in 0.2° increments). Shows that SST hot spots tend to occur during austral summer (e.g. December/January) with maximum convection following closely behind. As hot spots grow in width, so does the width of convective features.

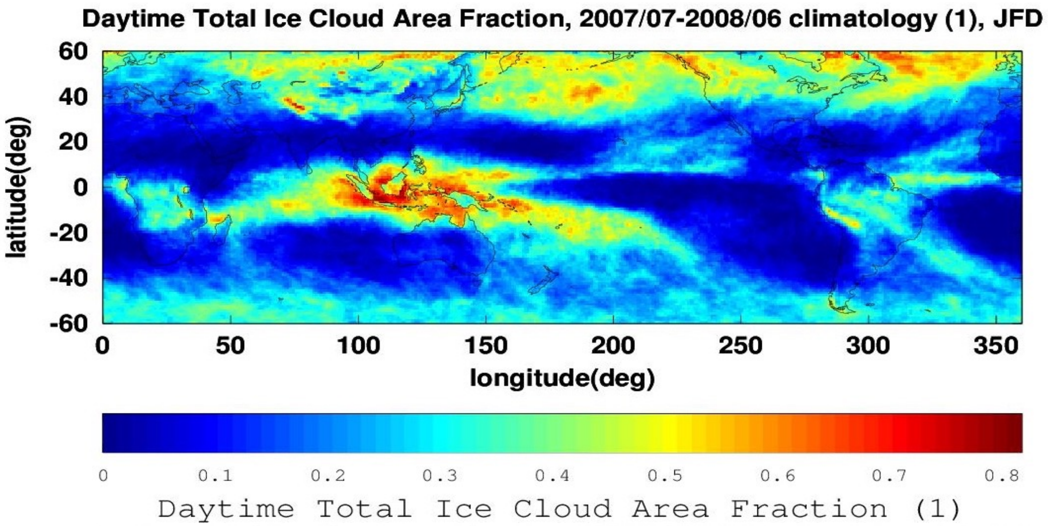
Right: Time series of Oceanic Niño Index (ONI), with red diamonds depicting **El Niño**, black **neutral conditions,** and blue diamonds **La Niña.** Thick dashed line shows width (° longitude) of the SST>30°C features with time.

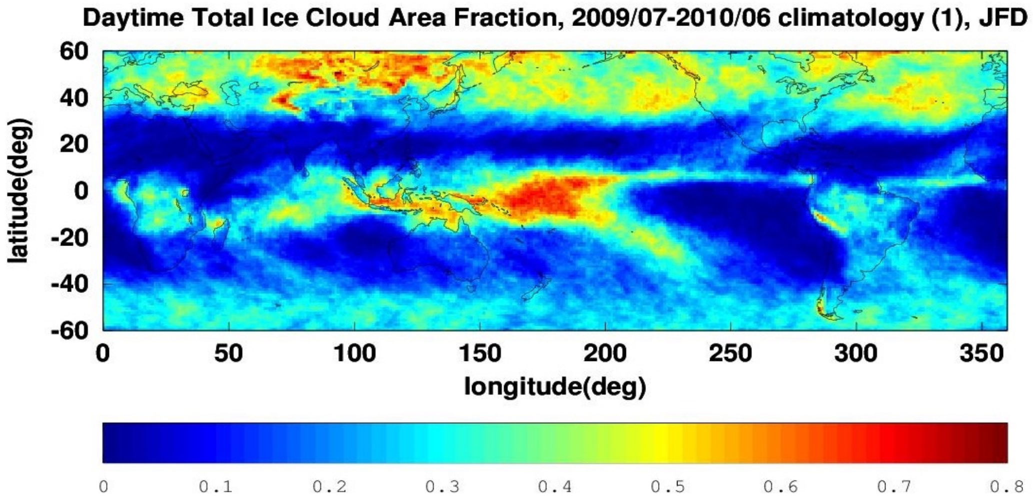




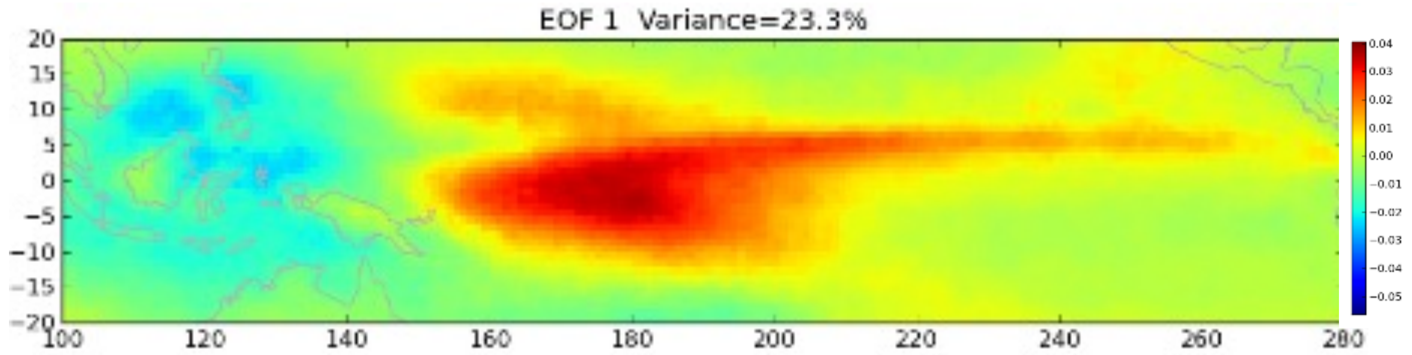
Using **2D-Map Service**: Total Daytime Ice Cloud Fraction from Terra MODIS Satellite During a Moderate La Niña (2007-2008) versus a Moderate El Niño (2009-2010):

*Notice eastward shift of ice clouds along equator during El Niño

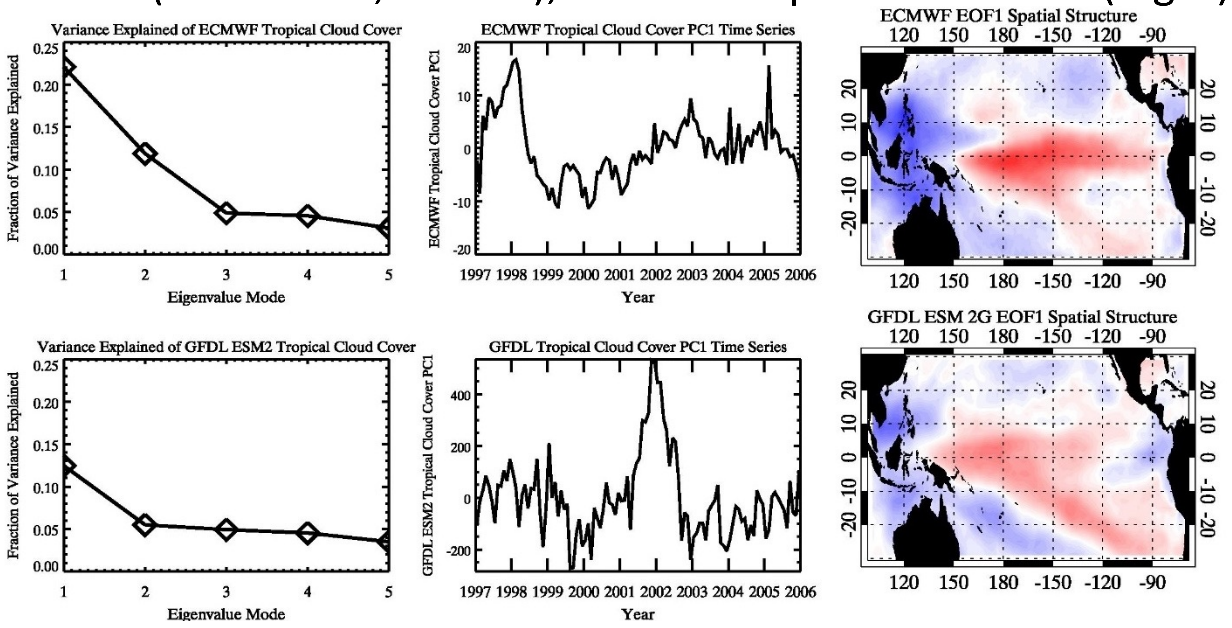




Empirical Orthogonal Function (EOF) Analysis of MODIS Total Ice Cloud Fraction (1st Mode) from 2000-2015

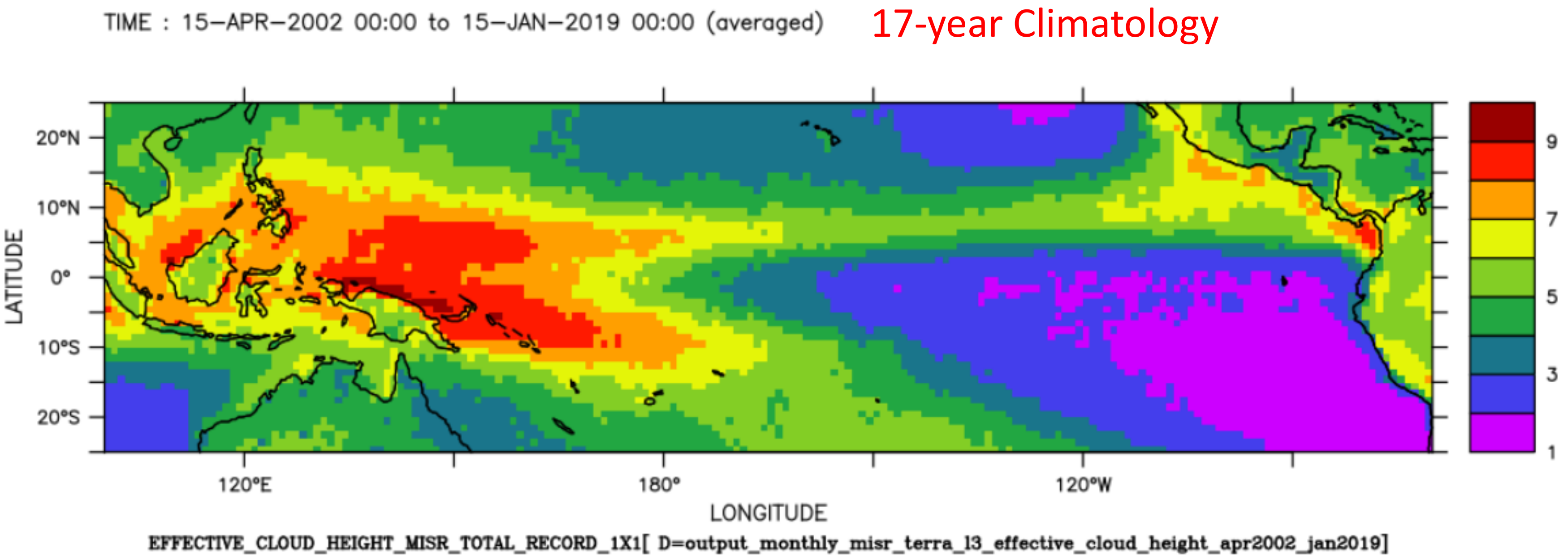


EOF Analysis of Total Cloud Cover of ECMWF-Interim and One Coupled Model, Showing Fraction of Variance Explained (Left), PC1 Time Series (1997-2005; middle), and EOF1 Spatial Structure (Right)

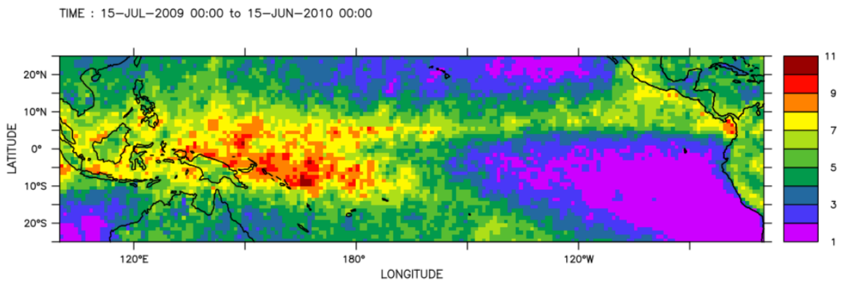


Using MISR Effective Cloud Top Heights to Assess Different ENSO seasons

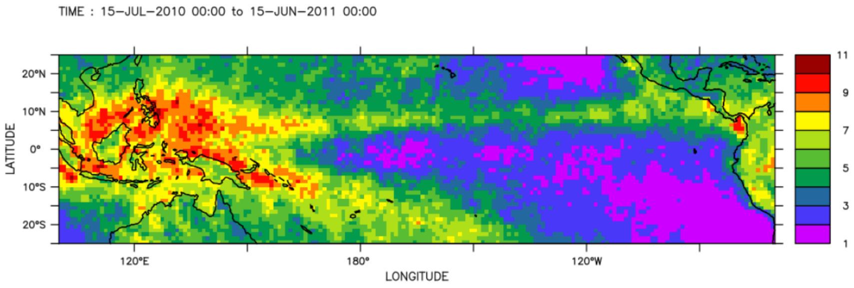
17-year Climatology



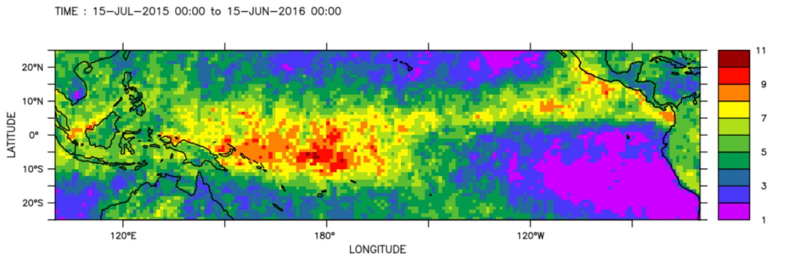
2009-2010 Warm ENSO



2010-2011 Cold ENSO

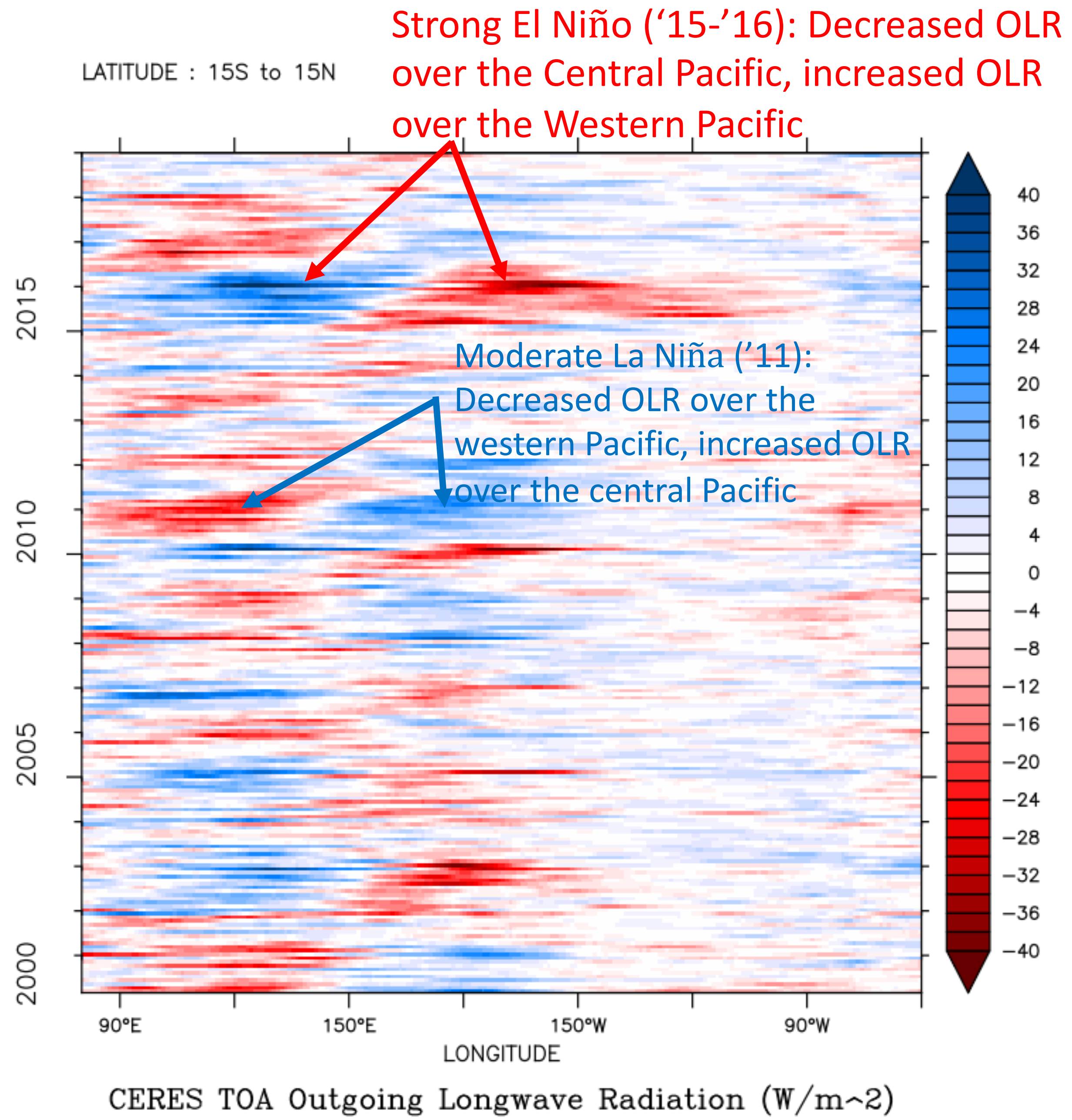


2015-2016 Strong Warm ENSO

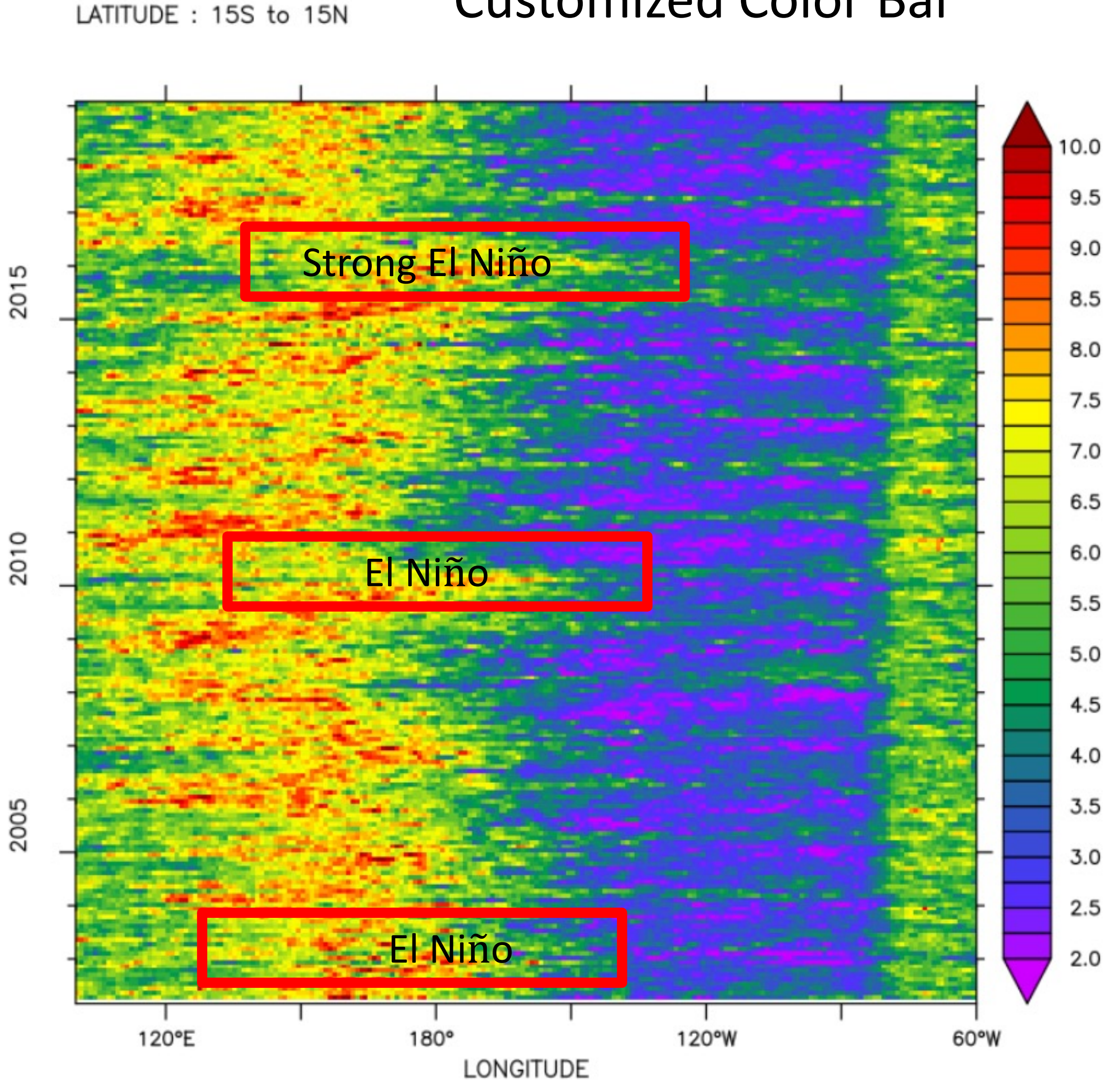


- Stronger East Pacific ITCZ during El Niño; convection right at equator occurs at and generally east of International Date Line (although not as far east during moderate or Central Pacific warm ENSOs such as 2009-2010
- During La Niña, shallow clouds extend further west to the Date Line

Hovmöller Diagram of CERES OLR with Customized Color Bar

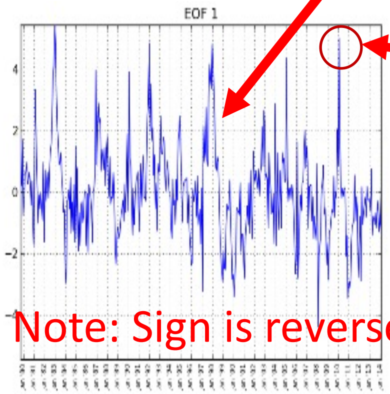


Hovmöller Diagram of MISR Effective Cloud Top Height with Customized Color Bar



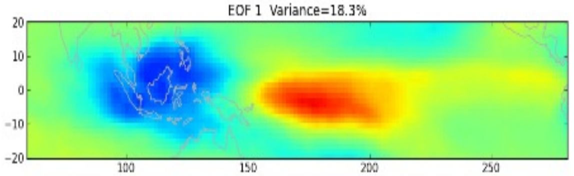
Has there been a trend in the strength of the Walker Circulation since 1979? The study, “Observational evidences of Walker circulation change over the last 30 years contrasting with GCM results” by Sohn et al. (2013) *(Climate Dynamics)*, suggests that there had been, at least through 2010 …

- Can these results be reconstructed, and what happens if we take the deep convection PC1 out through 2014?



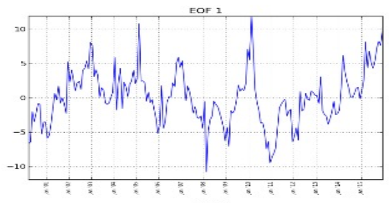
Note: Sign is reversed!

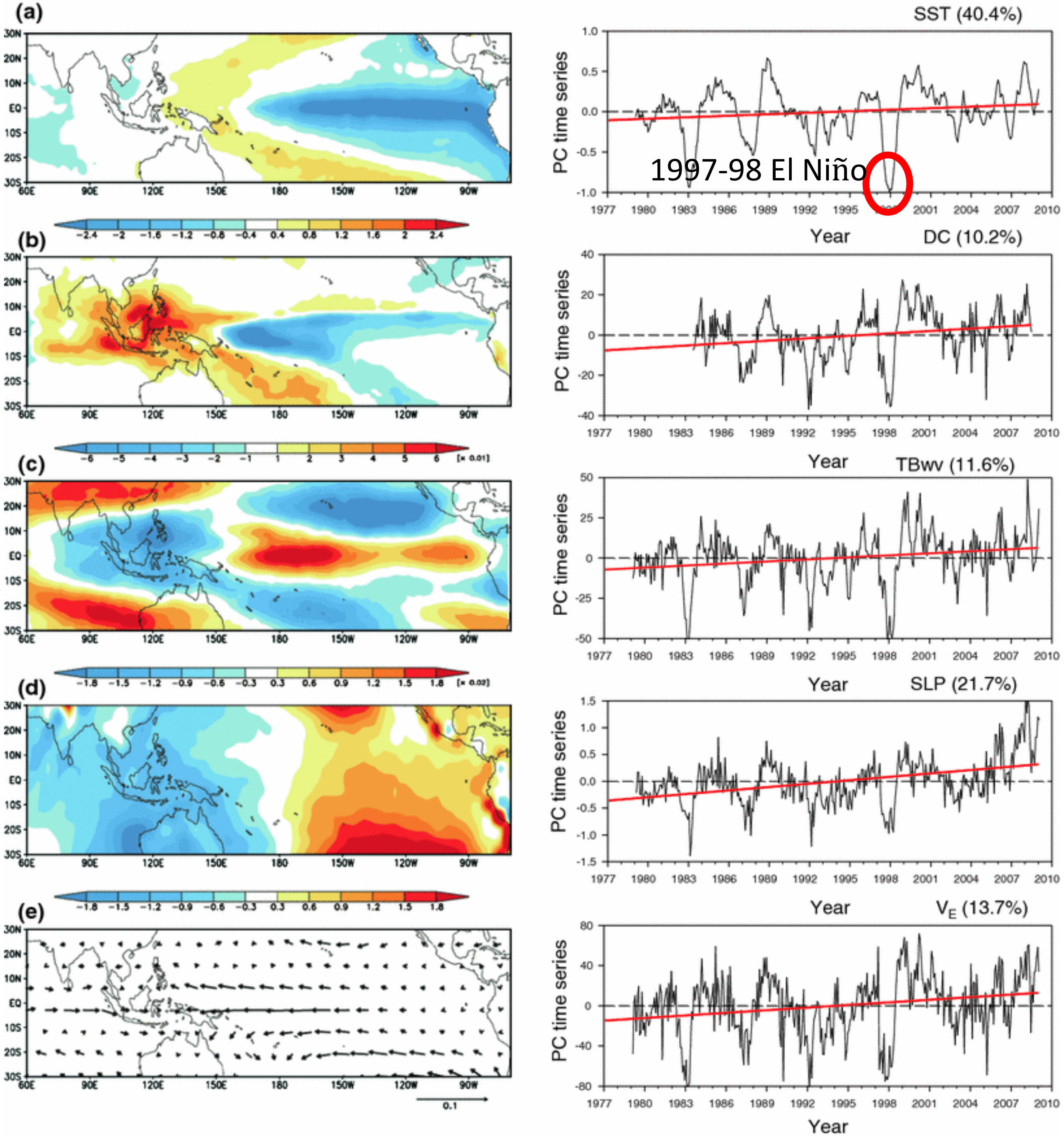
This peak corresponds moderate 2009/2010 El Nino!



Above: EOF1 of CF at 250 hPa

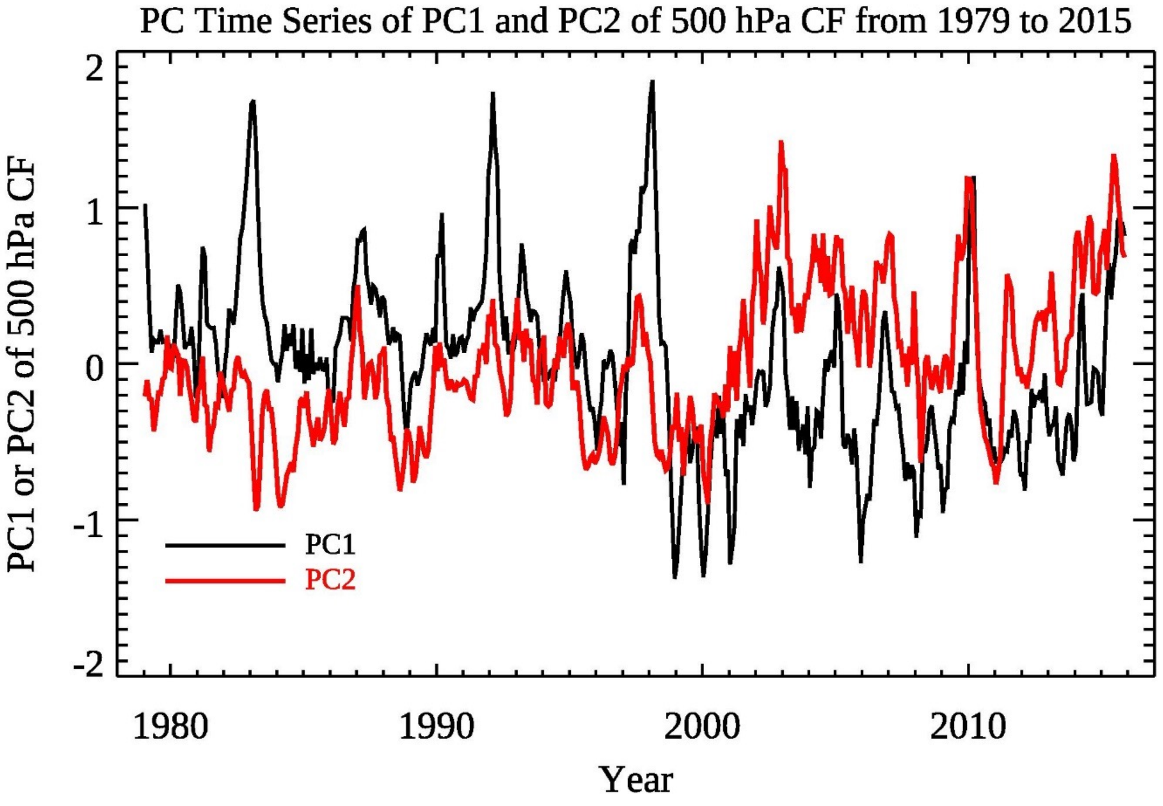
Right, lower: PC1 of MODIS Ice CF (through 2015) – showing early stages of strong warm ENSO at the end.

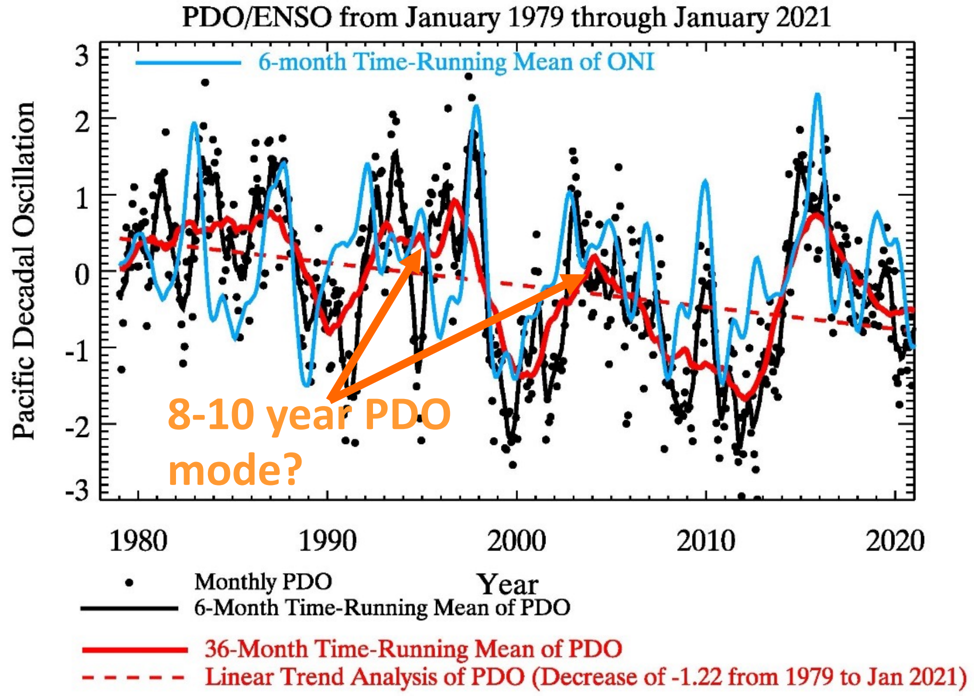


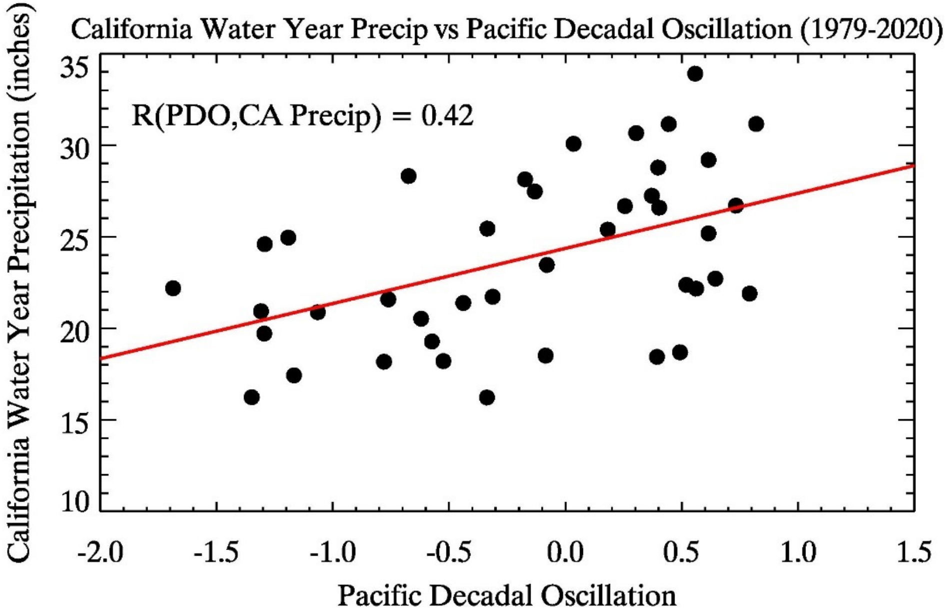


ENSO, the PDO (Pacific Decadal Oscillation), and Teleconnections

PC1 and PC2 Time Series of 500 hPa ERA-Interim
Positive PC1: El Niño (Black Curve),
Positive PC2: More of a "Central Pacific" ENSO (Red Curve)



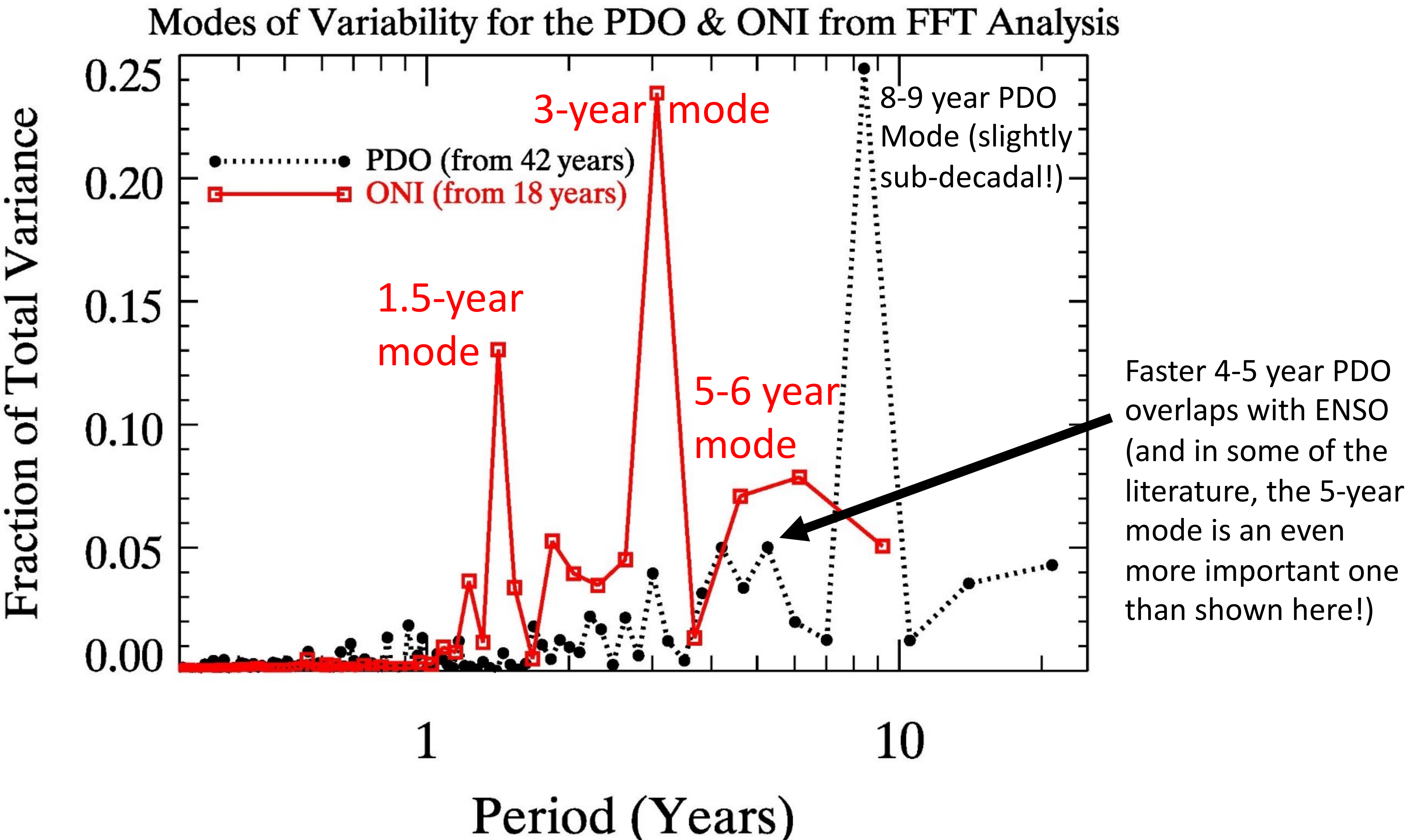




Top: PDO Time Series (and 6-month ONI), showing a rapid decline after strong warm 1997-1998 ENSO, and then a shift upwards prior to the strong 2015-2016 ENSO

Left Bottom: (Weak) Positive Correlation between PDO and California Precipitation

Temporal Modes of Variability of ENSO and PDO Using Fast Fourier Transform (FFT) Analysis



Topic #2: Datasets, Geographic Foci

- Topic: Tropical Variability and Analysis of the El Niño-Southern Oscillation Forcing in Observations and Models

- **Datasets**: ECMWF Sea-Surface Temperatures (SSTs), near surface winds, cloud fraction, MODIS cloud top temperature, cloud optical depth (τ), cirrus reflectance, and ice cloud fraction, MISR cloud properties and TOA cloud albedo, CERES TOA LW/SW/Net cloud forcing, and a subset of these variables from both historical coupled climate models (CMIP) and atmosphere-only climate models (AMIP models).

- **Geographic Foci:** The tropical/subtropical band, mostly between 30°S and 30°N, except further poleward to study possible teleconnections

Topic #2: Questions

1. Starting with ERA5 reanalysis and observational datasets, perform EOF analysis, beginning with a suggested domain of [100°:290°, 20°S:20°N], and examine the domain sensitivity. Identify moderate/strong El Niño and La Niña events from Principal Component (PC) Time Series, and compare with published results (e.g. NCEP/NOAA) of different indices (ONI, MEI). Describe the spatial structure of EOF1 (and possibly EOF2), and identify any geographical offsets of variables in terms of the Walker Circulation.
2. Can a lead-lag relationship be deduced between the u-wind and SST? If so, what does this suggest about the forcing/response of these two variables? How are anomalously strong westerly winds (e.g. westerly wind bursts) geographically related to SST? Consider using either EOF analysis or time series analysis, and zoom in around ENSO events to characterize.
3. Using CERES TOA LW Cloud Forcing, MODIS cloud top temperatures, and/or MISR effective cloud heights, examine the spatial/temporal response of cloud heights/convection as a function of ENSO. Explain in terms of the Stefan-Boltzmann Law, including the shift in the location and height of convection during El Niño events. Consider looking at time series from MISR (or MODIS) cloud heights in different locations of the Pacific, and/or constructing Hovmöller Diagrams. Can you demonstrate how the warm pool shifts eastward during warm ENSO events with cloud data alone? Can you deduce strength of warm/cold ENSO events from MISR/MODIS/CERES data? How do near-equatorial low clouds change as a function of ENSO? (consider MISR and/or MODIS low cloud data.)
4. Next, evaluate the ability to simulate ENSO from several of the available **historical coupled GCMs (CMIP data).** Utilize techniques described above, and characterize fidelity in terms of spatial structure, timing, etc. Are **AMIP** models more skillful? Before answering, think *a priori* why you think AMIP or CMIP models should be more skillful, and see if the results are consistent with your hypothesis. **Also:** Does the frequency of ENSO in models (e.g. consider the temporal modes of ENSO using FFT analysis) compare well with reanalysis data and/or observations?
5. Use ECMWF-Interim/ERA5 to divide the past ~40 years into decadal chunks. Describe location changes with time in terms of "Central" vs "Eastern" ENSO events; think also about PC1 and PC2 time series. Is precipitation off the U.S. West Coast related to the type of El Niño event? Also, think about the importance of the PDO. If possible, assess the historical context/strength of the 2015/2016 El Niño with ECMWF (with variables that are available). If analyzing the PDO, is there a role for having both indices (ENSO/PDO) in-phase in terms of enhancement of the West Coast precipitation signal in one direction or another? (You may consider splitting the West Coast into subregions, too – e.g. WA vs CA.)
6. There is now a greater than 50% chance among prognostications among seasonal forecasts from climate models that we may be approaching the third consecutive year of what type of ENSO? Based on the available data on the CMDA website, how many other times, if any, has this happened before in recent history? Are you able to relate longer-term trends or cycles in ENSO with recent drying over California or the southwestern U.S.? (Consider using California precipitation from https://wrcc.dri.edu/my/climate/tracker/CA, or data from any other west coast state from the WRCC site.)
7. Finally, determine if any longer-term, decadal trends are apparent in the PC1 Times Series of variables most relevant to describing the Walker Circulation. Consider saving data and doing a formal trend analysis offline, if time permits. What do you think may have caused any of these changes? Rely mostly on ERA5 data, but if any climate models have a longer time series, try evaluating those, too. Is there any evidence for a switch in trends in recent years contrary to the previous ~30-year trend toward a more La Niña state, or is the same long-term trend still apparent?

Contact Scientist: Dr. Terence Kubar (terry.kubar@jpl.nasa.gov)