Assessing Intraseasonal to Interannual Variability of Upwelling-Favorable Coastal Winds off Central Chile

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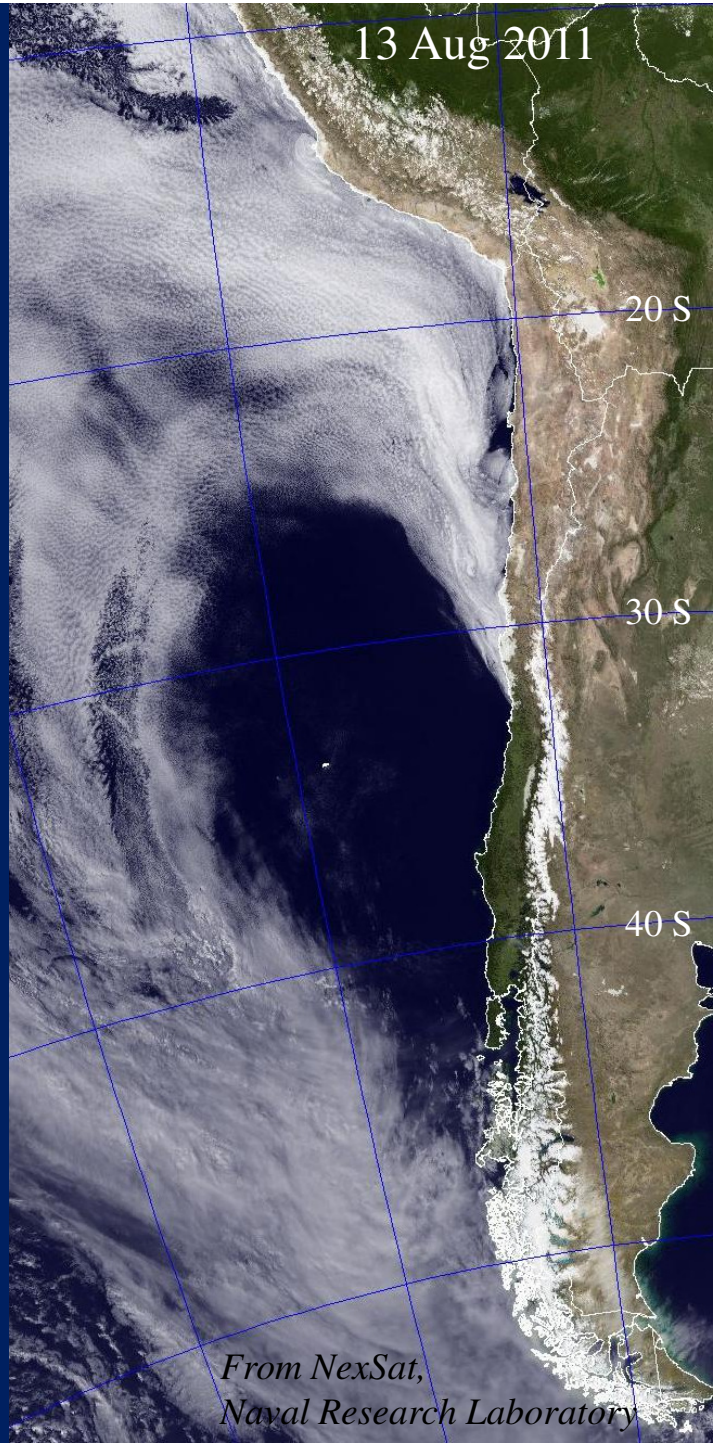
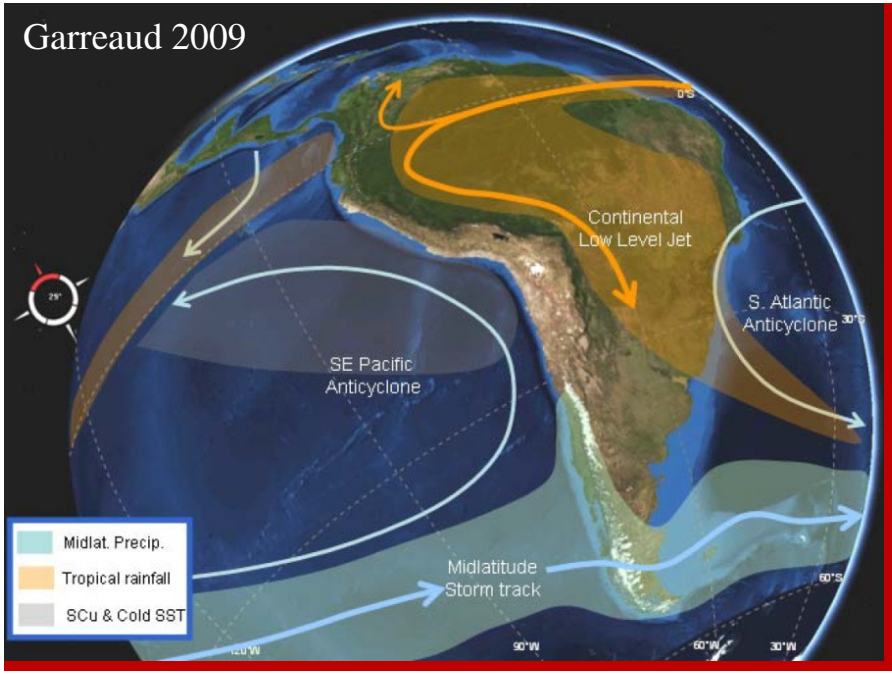
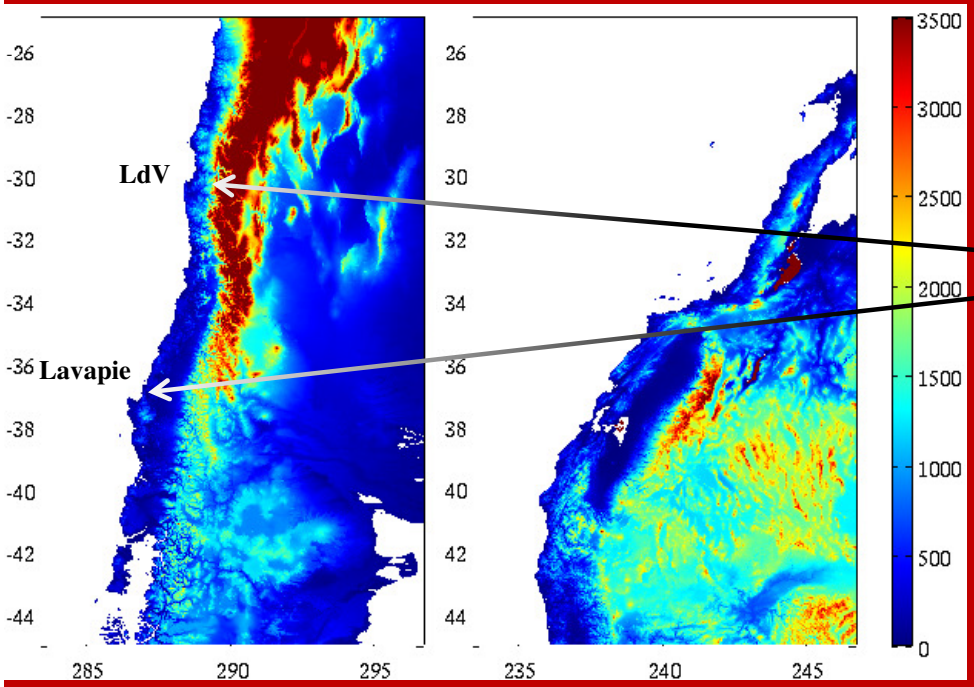
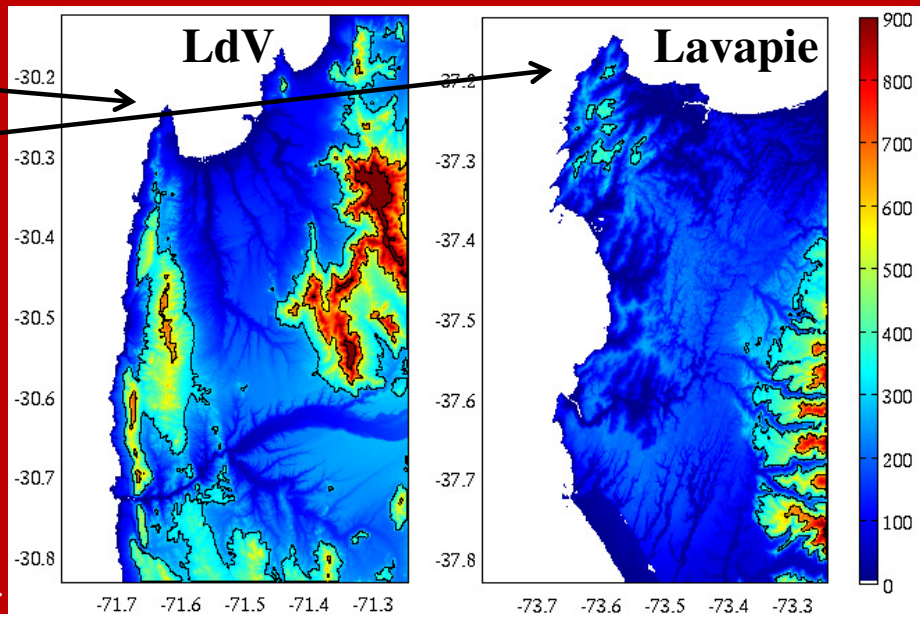




General Features

- Region dominated by southeast Pacific anticyclone most of the year driving the coastal upwelling-favorable equatorward wind.
- Midlatitude storm tracks to the south.
- Major upwelling points at Lavapie and Lengua de Vaca (LdV) in central Chile and Pisco in Peru.

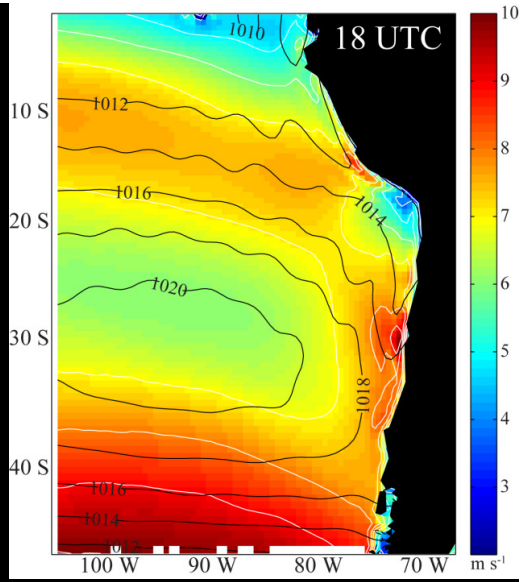




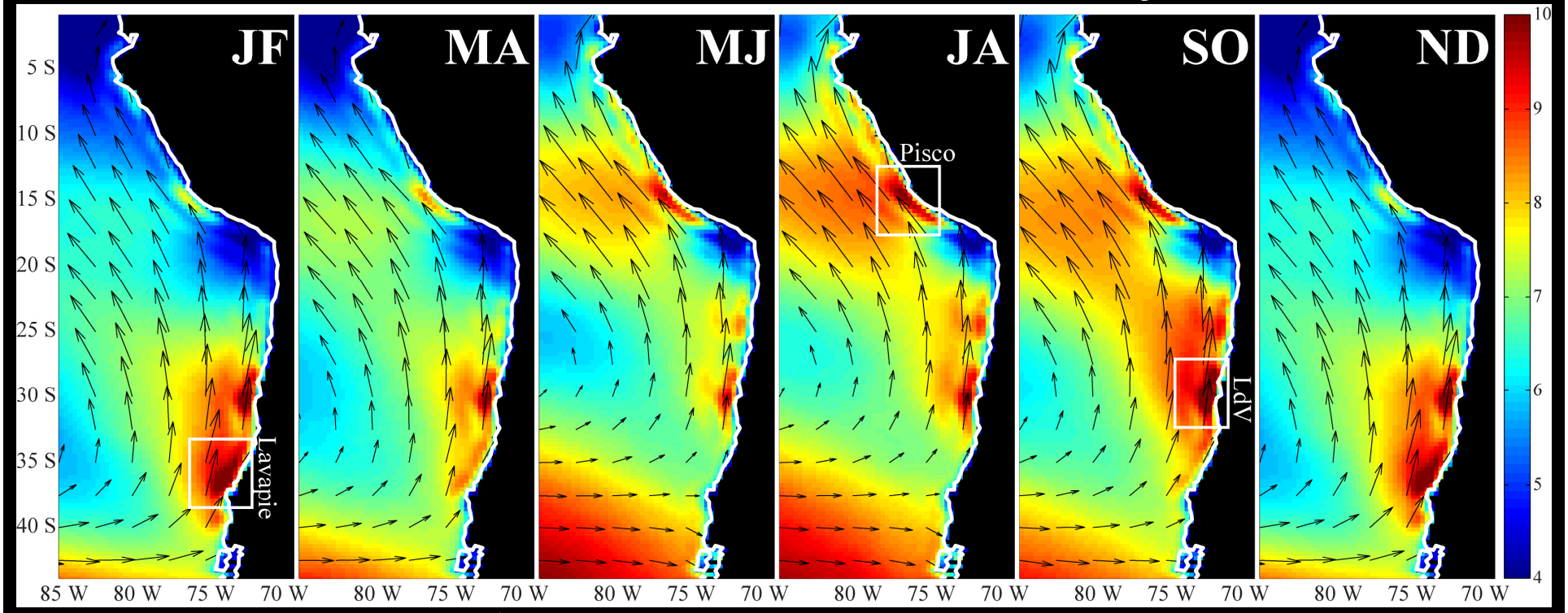
Above: Elevation (m) using 900m resolution.
Right: Elevation (m) using 90 m resolution with contours every 300 m.

10-m Wind Features

- Data from the Climate Forecast System Reanalysis (CFSR) with a maximum of 0.313° resolution and is available every 6 hours 1979-2010 (Saha et al. 2010).
- Three main upwelling centers
  - Pisco (Peru)
  - Lengua de Vaca (LdV)
  - Lavapie



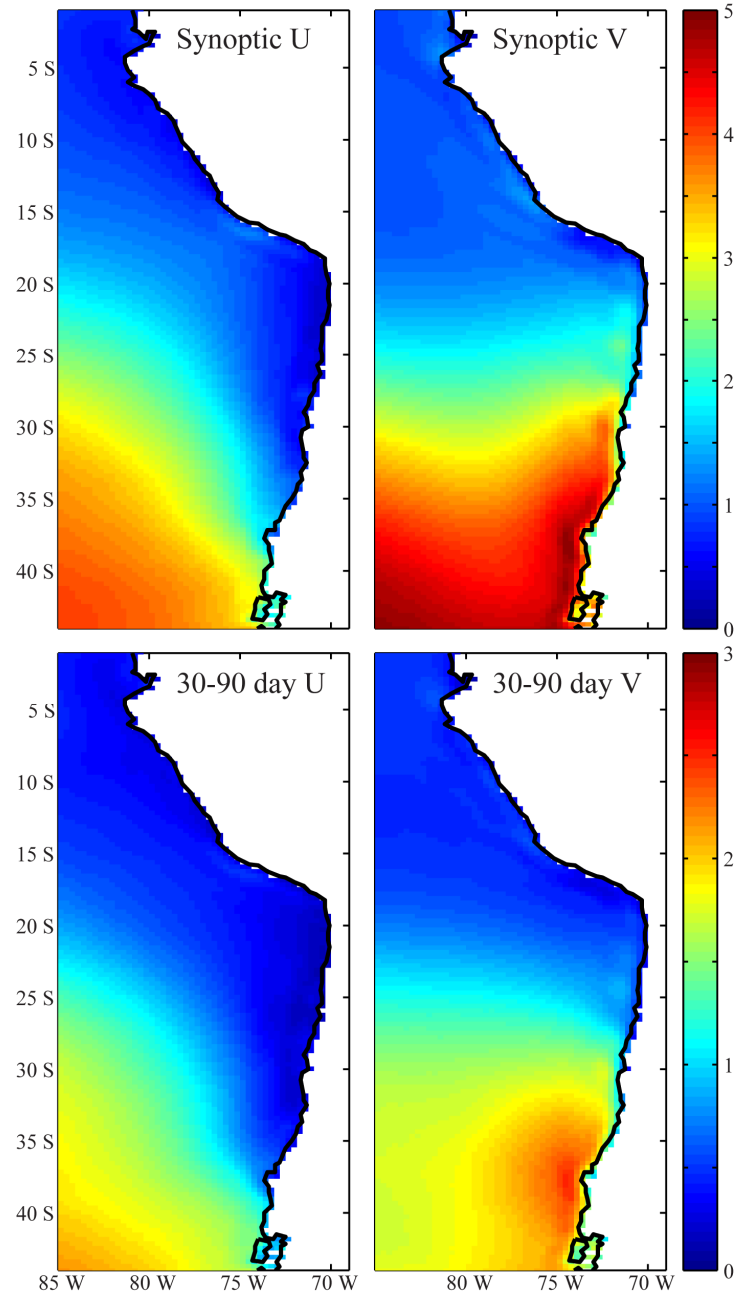
Above: Mean SLP (hPa, contours) and 10-m wind speed (m s^{-1}, color) over 1979-2010.



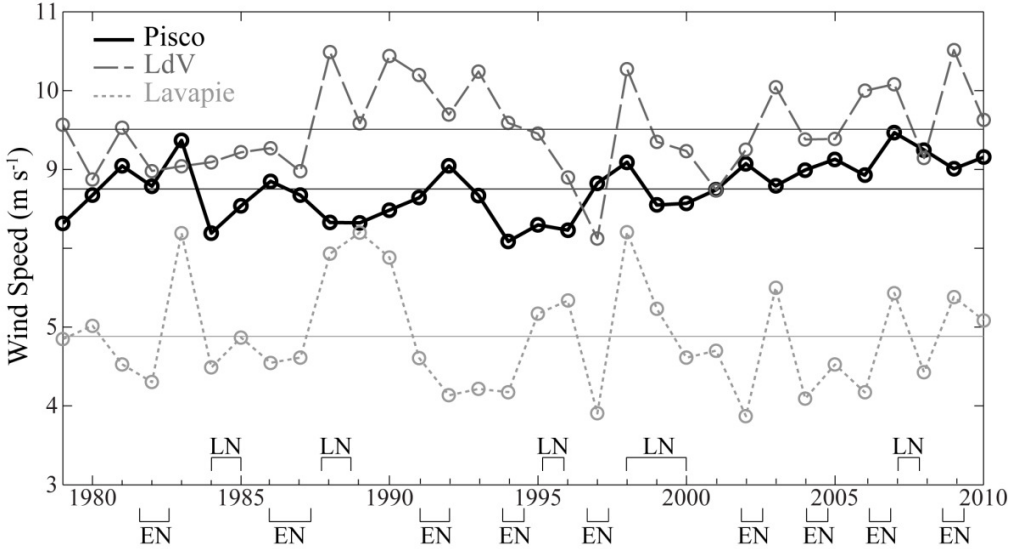
Above: Mean 10-m wind speed (m s^{-1}) and vectors at 18 UTC over two-month periods from 1979-2010 from the CFSR.

Variability

- Calculated for each component of the 10-m wind at each point using the time series of 6-hourly data from 1979-2010.
- Applied a bandpass filter that keeps specified frequencies and calculated its standard deviation.
- Synoptic variability (2-16 days)
  - Coastal impact clear as meridional wind is channeled northward and little variability in the zonal component (blocking).
- Intraseasonal variability (30-90 days).
  - Largest variability centered on Lavapie (about half of synoptic standard deviation)
- Annual variability has some influence by ENSO.



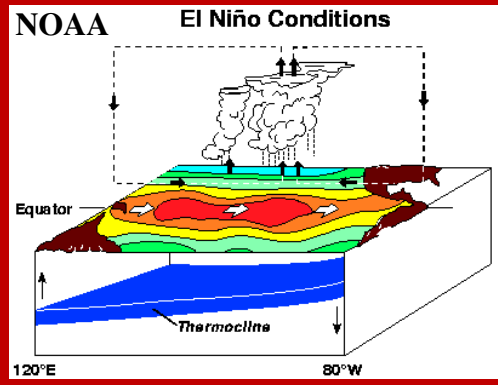
Standard deviation of (top) synoptic and (bottom) 30-90 day band-passed 10-m (left) zonal and (right) meridional wind speed (m s^{-1}, color) for the period 1979-2010.



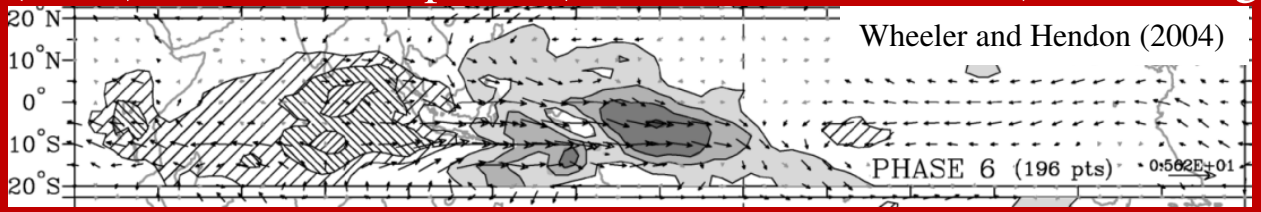
Mean alongshore wind (m s^{-1}) over the entire year at Pisco (solid), LdV (dashed), and Lavapie (dotted). El Niño (EN) and La Niña (LN) are indicated below. Mean indicated by the horizontal line. Note the break in scale of the vertical axis between LdV and Lavapie.

Important Oscillations

- **El Niño Southern Oscillation (ENSO)**
  - Anomalous ocean state in equatorial Pacific Ocean.
  - *Index used*: Bivariate ENSO Timeseries (Smith and Sardeshmukh 2000)

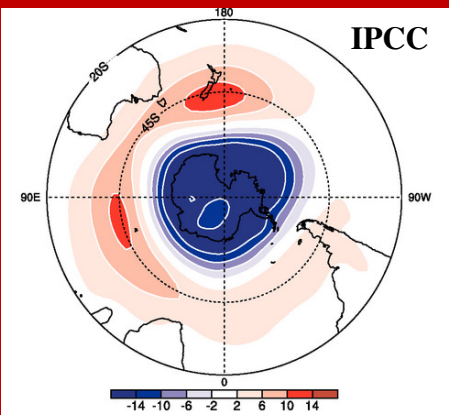


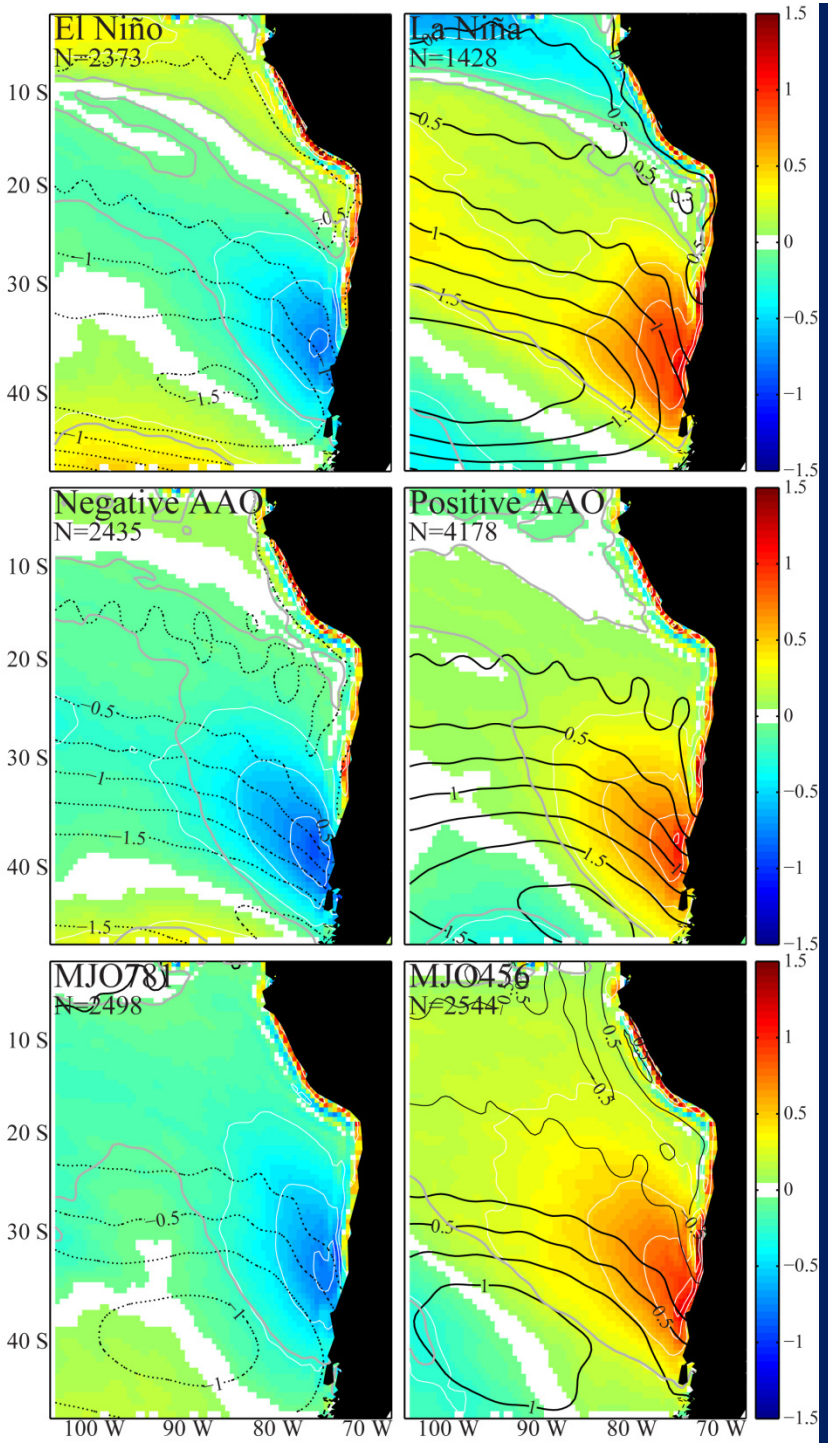
- **Madden Julian Oscillation (MJO)**
  - Planetary scale, eastward moving regions of enhanced or suppressed tropical rainfall, primarily over the Indian and Pacific Oceans.
  - *Index used*: Multivariate MJO index by Wheeler and Hendon (2004) that includes phase (location of convection) and strength.



Wheeler and Hendon (2004)

- **Antarctic Oscillation (AAO) or Southern Annular Mode (SAM)**
  - Low-frequency mode of atmospheric variability in the southern hemisphere characterized by vacillations in the zonal wind.
  - *Index used*: Daily Southern Hemisphere Annular Mode Index (Nan and Li 2003)
    - Difference of the normalized zonal mean SLP between 40-70°S.

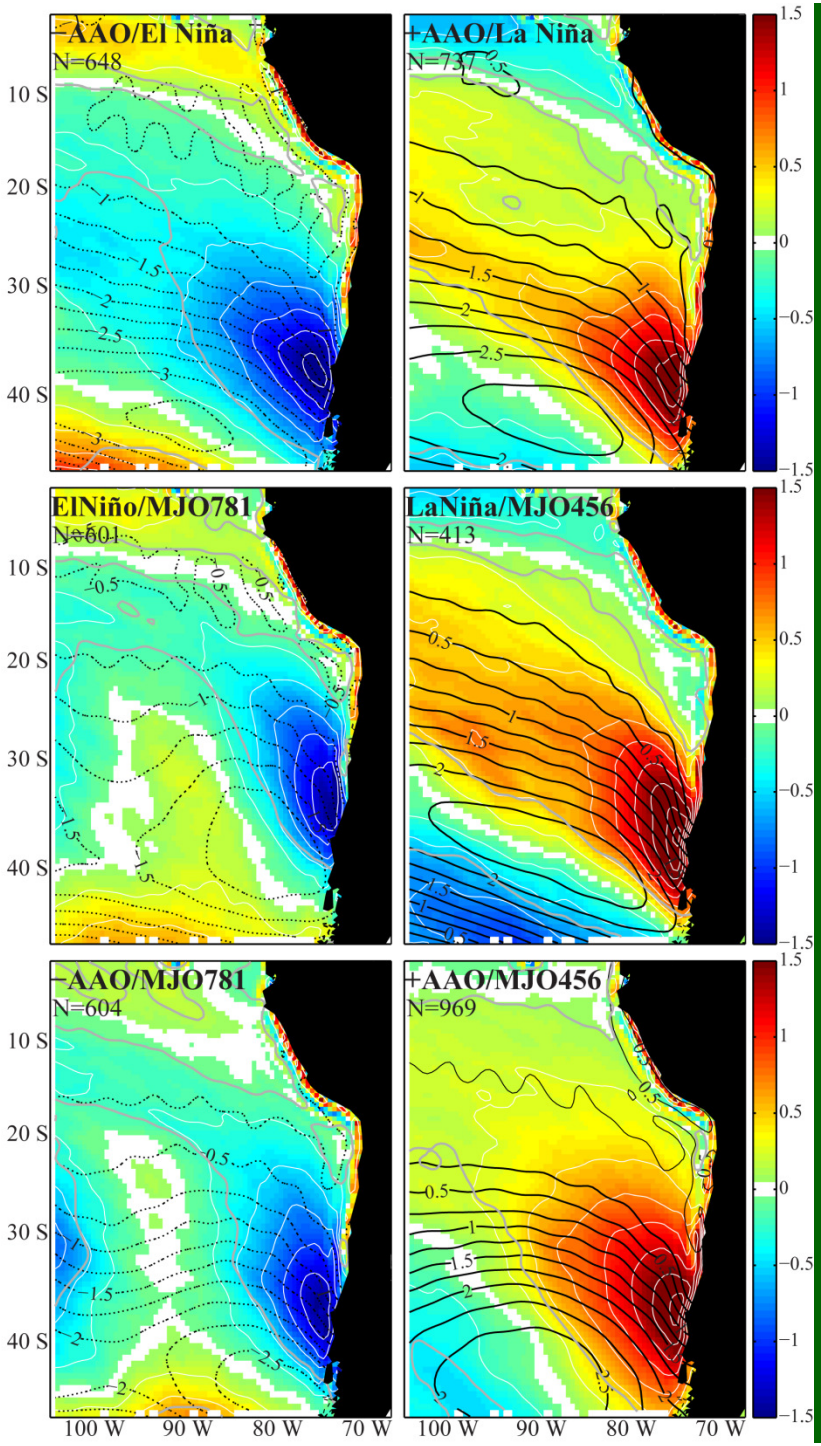




Composited Anomalies

- Composites of daily anomaly of meridional wind and sea level pressure (SLP) over all days based on each index
  - Composites over each season yield about the same.
- Changes in each oscillation impacts the general circulation and thus the SE Pacific anticyclone.
  - 1-1.5 hPa anomaly
- Alongshore wind (v) anomalies greatest off of Lavapie.
- Stronger upwelling favorable wind for:
  - La Niña
  - Positive AAO
  - MJO phase 456 (convection over 120 E).
- Average maximum anomalies in wind are ~1 m s^{-1}.

Left: Composites of SLP (hPa, contours) and meridional wind (m s^{-1}, color) anomalies according to index. Significant changes to wind at the 99% level indicated by gray line. N is the number of days in each composite.



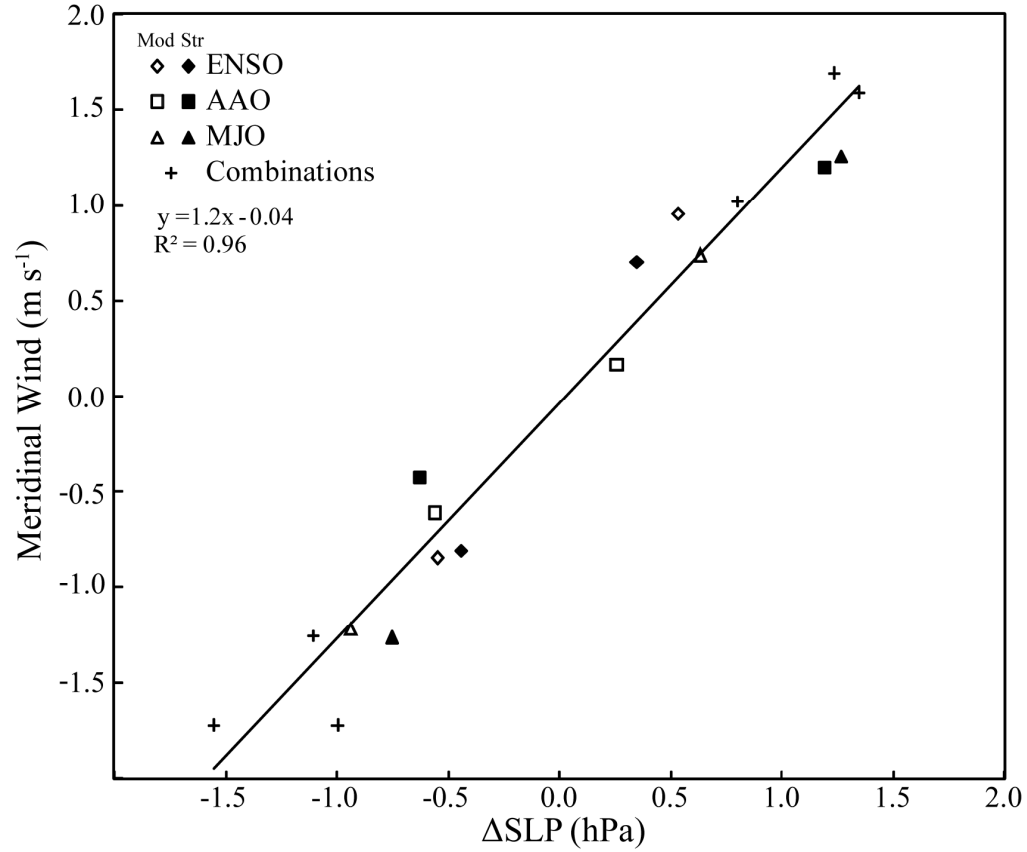
Combined Indices

- The three indices are considered to be independent (Pohl, et al. 2010).
  - (Still apparently some debate)
- Additive (constructive or deconstructive) behavior of the composites selected on more than one index.
- Intensification of the anomalies for favorable indices (constructive, shown on left).
- Cancellation of anomalies for opposing indices (deconstructive, not shown)
- Average maximum anomalies are now ~2 m s^{-1}.

Left: Composites of SLP (hPa, contours) and meridional wind (m s^{-1}, color) anomalies according to index. Significant changes to vwnd at the 99% level indicated by gray line. N is the number of days in each composite.

Forcing of Alongshore Wind

- Linear relationship between meridional pressure gradient force and alongshore wind holds with the different states of the oscillation as shown in Muñoz and Garreaud (2005) and with monthly mean data in Garreaud and Falvey (2009).
- When separated between the moderate and strong cases, the difference is not large. Attributed to large variability.



Anomaly of meridional wind (m s^{-1}) at 35°S 75°W with anomaly in the meridional gradient of SLP (hPa) along 75°W from 28°S to 38°S (positive to the north) with a line of best linear fit.

Summary

- Synoptic variability is the greatest along the coast, while 30-90 day variability is about half as large and centered on Lavapie (37°S).
- Three major oscillations in the general circulation impact the region: ENSO, AAO, and MJO. Each contribute to changes in the southeast Pacific anticyclone.
- Composites of meridional wind and sea level pressure (SLP) for each index reveal significant anomalies centered on Lavapie.
  - Maximum anomalies of ±1 m s^{-1} for each index alone.
  - Maximum anomalies of ±2 m s^{-1} for combined favorable or unfavorable states in the oscillation.
- Linear relationship between the changes in the meridional SLP gradient and meridional wind.
  - Moderate and strong definitions do not seem to yield consistently stronger anomalies.

References

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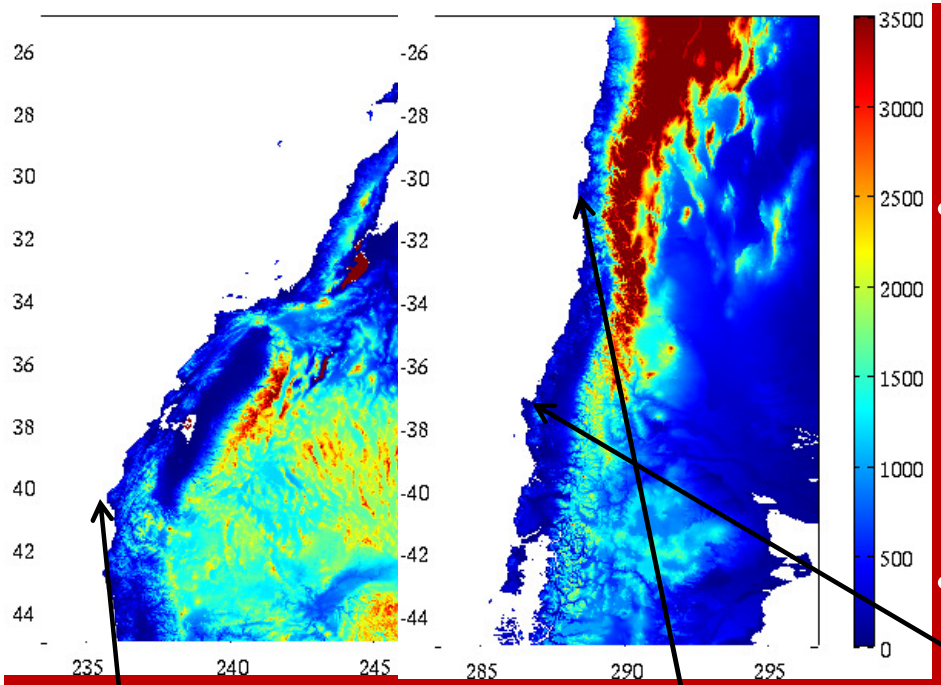
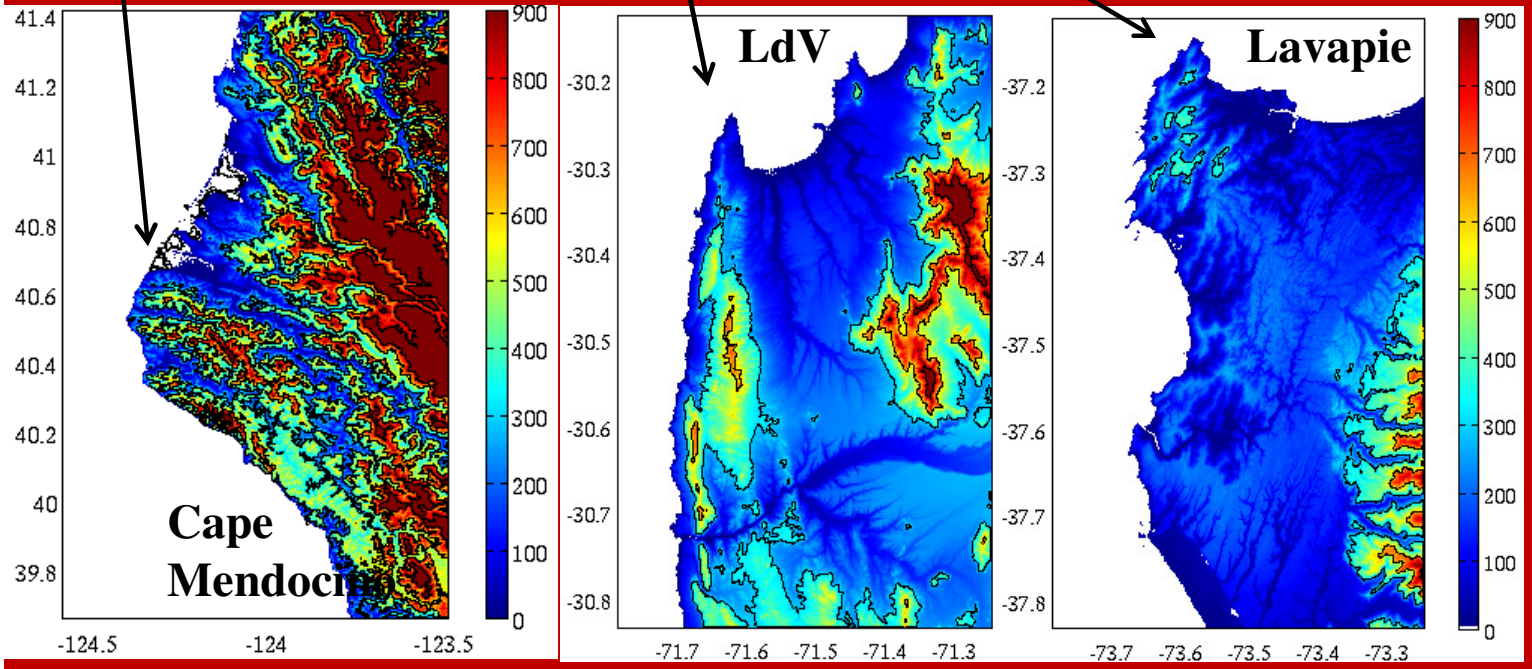
Upwelling Centers

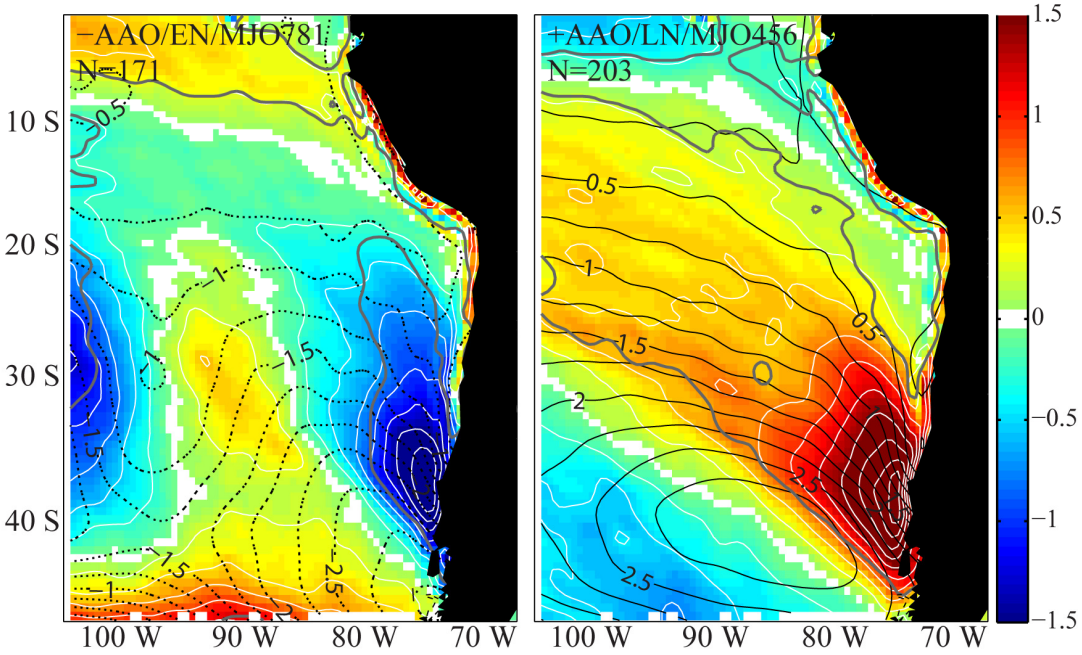
- Fairly high elevations that taper from south to north with two major capes that are centers of enhanced upwelling.
  - Lengua de Vaca (LdV) has a coastal ridge of up to 700 m
  - Lavapie has considerably lower terrain <300 m in most parts.
- The high winds occur at lower latitudes than their counterparts in California.



Elevation (m) using 900m resolution.



Elevation (m) using 90 m resolution with contours every 300 m.



Composites of sea level pressure (hPa, contours) and meridional wind (m s^{-1}, color) anomalies binned according to index. N is the number of days in each composite.

All three favorable or unfavorable

- Even stronger anomalies….
- Smaller region statistically significant (fewer samples)