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The Mean and Beyond: Anomalous Bio-Physical Conditions Along the Northern California Current System

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I. Summary :

Oceanographic satellite-derived long-term series of Chlorophyll pigment concentration (CHL), Sea surface temperature (SST) and Wind stress (TAU), have been used to identify anomalous conditions along the Northern region (41.0°N – 48.5°N) of the California Current System (CCS). We find a strong local and latitudinal variability in the time series anomalies of CHL, SST and TAUv, where two latitudinal groups of variables identified northern and southern regions, with a dividing point near 44.0°N.

In the northern region, the alongshore component of wind stress is less upwelling-favorable, with a similar Spring Transition start date within the region. SST shows a well developed seasonality, except for a few strong anomalies occurring in early-1998 and mid-2005. High CHL concentrations predominate, especially at La Push (48.0°N) and the Columbia River (46.3°N) .

In the southern region, we find stronger upwelling-favorable wind conditions, increasing toward the equator. The SST pattern is strongly influenced by upwelling, decreasing summer temperatures at Crescent City (41.4°N) by 1-2°C, compared to the northern region. The CHL pigment concentrations are low, but their anomaly patterns show an increase from 1998 through 2005, which is associated to an increase in summer temperatures. The exception occurs in summer 2005 where an extended but late period of upwelling-favorable wind occurs.

I. Methodology :

Coincident 8-days composites of Chlorophyll pigment concentration (CHL), Sea surface temperature (SST), and the alongshore component of Wind Stress (TAUv), were used to generate time series for seven stations located from north to south: La Push, Columbia River, Lincoln City, Heceta Bank, Reedsport, Gold Beach, and Crescent City (Figure 1).

Data from September 1997 to June 2006 were used for CHL and SST, while TAUv comes from July 1999 to June 2006. The CHL concentration was derived from SeaWiFS (Sea Viewing Wide Field-of-View Sensor) at ~1.2 km resolution, while SST was obtained from the clearest (less that 50% of clouds) and warmest-pixel fields from NOAA (14-17) Advanced Very High Resolution Radiometer (AVHRR) at ~1.2 km resolution. The wind stress data (TAU) comes from QuikSCAT at a quarter degree resolution. Thus, the long term time series at each station were generated by averaging all the available data in a 0.25° (latitude) by 0.25° (longitude) box, centered 70km offshore (Figure 1).

The date of the Spring Transition was identified, to define the beginning of upwelling-favorable conditions. This point occurs between downwelling-favorable conditions (positive wind stress values) and upwelling-favorable conditions (negative wind stress values). It was defined as the mid-point between at least three consecutive positive and negative values.

The analyses at each station examined annual and interannual CHL, SST, and TAUv means, standard deviations and anomalies. The standardized anomalies for each parameter, were derived by scaling the individual values in the time series to quantify the strength of the anomalies, calculated as $z_i = (x_i - \mu) / \sigma$, where x_i is the measured value at each time, and μ and σ are the mean and the standard deviation values, respectively, for all observations $x_1, x_2 \ldots x_i$, in the time series at that point.

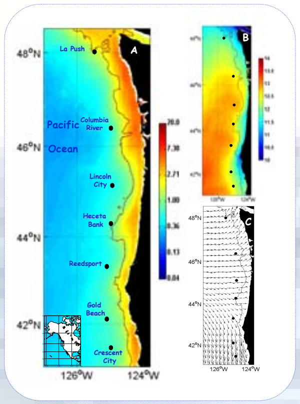

Figure 1. This figure shows the position of the seven stations along the northern CCS over satellite-derived mean fields of CHL (A, left), SST (B, top-right), and TAUv (C, bottom-right). The 200-m isobath is indicated by the single offshore contour.

(A): The 10-year mean CHL distribution shows a strong onshore/offshore pattern, with a maximum concentration near the coast, decreasing offshore. An inshore band is coincident with the 200 m isobaths and has highest CHL concentrations north of ~45°N.

(B): The coastal cold and oceanic warm temperatures characterize the 10-year mean distribution of SST, with coldest values occurring close to the coast around Cape Blanco (42.8°N) and north of Gray's Harbor (46.6°N), while warm offshore water occurs south of ~47°N.

(C): The 8-year mean of wind stress shows favorable downwelling conditions north of the Columbia River (~46.2°N), while south of ~45.0°N, the wind stress reverses and coastal upwelling favorable conditions occur (in the annual mean).

III. Latitudinal variability :

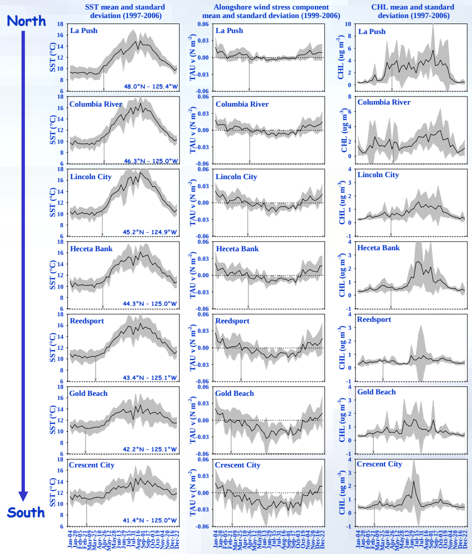

Figure 2. Along-shore variability in the local annual cycles of SST (left column), TAUv (central column), and CHL (right column, note the different Y-axes scales): mean seasonal cycle (black line) and standard deviation (gray region). The annual mean Spring Transition to upwelling conditions at each latitude is shown by perpendicular arrows in each plot.

S S T :

• Strong latitudinal gradient with large temperatures fluctuations along the central coast characterize the SST distribution.

• Lincoln City shows the largest SST range with mean values between 9.9° and 17.6°C.

• Crescent City shows the lowest fluctuations, with mean values between 10.8° and 14.3°C, due to the effect of stronger spring-summer upwelling.

T A U v :

• Upwelling-favorable conditions (negative stress values) start late in February at southern stations and move north, reaching the northern station in April.

• Downwelling-favorable conditions start first at La Push (October) and progressively move to the south.

• La Push shows the weakest and most homogeneous wind conditions, with the shortest upwelling-favorable period.

• The strongest upwelling-favorable conditions occurs at Crescent City, starting ~2 months earlier than La Push and ending ~1 month later.

• Crescent City also shows the strongest non-seasonal variability during upwelling-favorable conditions.

C H L :

• The CHL spatial distribution is predominantly composed of local variability.

• La Push (Reedsport) shows the highest (lowest) annual concentrations.

• Some of the stations show an early-spring and late-summer CHL peak, associated principally with light and nutrient availability, respectively.

IV. Spring transition variability:

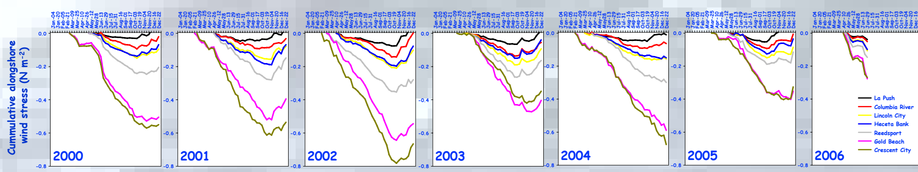

Figure 3. Inter & Intra annual cumulative alongshore wind stress. Here, the zero-crossing point corresponds to the initial date of the Spring transition. This transition point occurs between downwelling and upwelling-favorable conditions, and was derived as the mid-point between at least three consecutive positive and negative TAUv values.

• A propagation of the Spring transition occurs starting at Crescent City and moving north after a few weeks along this region. The exception occurs in 2006 where the delay between north and south stations is much reduced.

• The range of timing of the initial date of the Spring transition between 2000 and 2006 goes from late-February through mid-May.

• The starting point of the Fall-transition between 2000 and 2006 occurs from late-October to mid-January.

• Crescent City and Gold Beach show a strong cumulative negative alongshore wind stress which is associated with strong upwelling-favorable conditions.

• During 2002 and 2004 the extension of the upwelling-favorable conditions was longer than usual, preceding delayed Spring Transitions in 2003 and 2005.

• In 2004 the northern stations, from Heceta Bank to La Push, show weak cumulative alongshore wind stress, compared to other years.

• In 2005, Crescent City, Gold Beach and Reedsport show weak cumulative alongshore wind stress, compared to other years.

• In 2006 after the Spring transition, the cumulative alongshore wind stress shows two periods of strong upwelling-favorable conditions - a steeper negative slope than others years, during a short period of time during April, interrupted by a relaxation lasting a month, followed again by another strong increase in upwelling-favorable conditions.

V. Spatio-temporal anomalies :

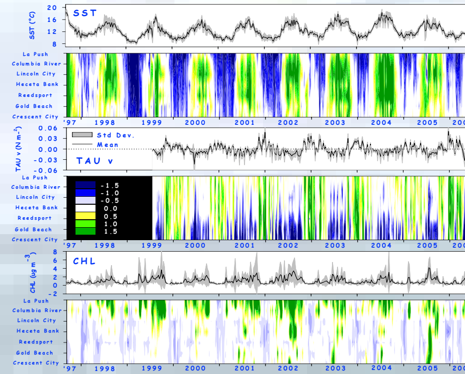

Figure 4. Latitudinal averages and standard deviations of each variable at each time (line plots with grey shading), along with spatial contours of standardized anomalies (color plots) for SST (top), TAUv (middle), and CHL (bottom). Blue and green represent strong negative and positive anomalies, respectively.

• Strong positive SST anomalies occur at all stations (usually stronger in the north) during late-1997, mid-1998, and during summers of 2002, 2003 and 2004, associated with large-scale anomalous conditions during El Niño 1997-1998, and more regional NE Pacific warm events.

• A strong negative SST anomaly was present at all the stations in early-1999 which is associated with a La Niña event.

• Warmer winter months were observed in 1997-1998, 2002-2003, 2003-2004, 2004-2005, and 2005-2006 associated with warmer conditions during the previous summer, especially south of Heceta Bank. There is a general pattern of warming during 2002-2005.

• Strong cold anomalies were observed in winter-spring of 1999 and 2000, associated with cooler conditions during the previous summer months. These anomalies are consistent with stronger negative anomalies in TAUv, and positive CHL peaks.

• During 2000 and 2005 the duration of upwelling-favorable conditions (spring-summer) is shorter than other years (no data to verify for 1999), which are consistent with cooler summer SST values during the same years.

• The upwelling-favorable conditions predominate south of Heceta Bank, which is consistent with the mean wind stress field for this region.

• High CHL concentrations occur at the northern stations, where strong positive values occur each year. However 1999 and 2002 shows the highest peaks during summer months, propagating from north to south.

• In 2005 a strong positive anomaly occurs with a propagation from south to north. This anomaly is consistent with a strong negative TAUv condition (upwelling-favorable conditions), and a negative SST anomaly.

• An early upwelling-favorable condition occurs at most of the stations early in spring of 2006.

V. CONCLUSIONS :

• Two latitudinal regions were identified along the northern CCS, with a dividing point near 44.0°N. These regions shown an important difference in the strength and duration of CHL, SST and TAUv seasonal variability.

• A north-south (south-north) Spring (Fall) transition propagation occurs along both regions.

• Strong events like El Niño, La Niña and regional NE Pacific events have an important influence on latitudinal variability, local seasonality, and Spring and Fall transition timing.

• Previous-year strength and duration of wind conditions has a strong effect on Spring and Fall transition delays. In 2006 the Spring transition occurs late at all the stations, and shows the shortest propagation timing range.

• Strong negative alongshore wind stress, low temperatures and increase in CHL shown a strong consistency in both latitudinal regions.

• A general warming pattern occurs between 2002 and 2005 in the study area, while an positive trend in CHL pigment concentration occurs between 1998 to 2005 at the southern region.

• Strong upwelling-favorable conditions occurs in 2002 and 2004, especially at the southern region, while in 2004 and 2005 the alongshore wind stress shows the largest and shortest range of annual anomalies, respectively.

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