Variability in Mesoscale Physical Activity in the Northern California Current and its Effects on Biological Distributions

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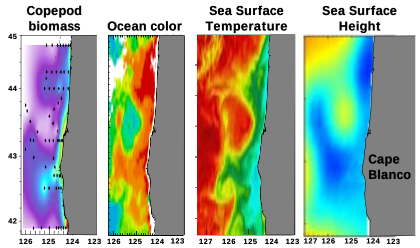
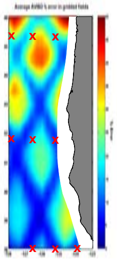
Introduction

Mesoscale circulation features contribute significantly to cross-shelf transport of biological production from nearshore areas to the deep sea. As part of the U.S. GLOBEC Northeast Pacific program, we are studying the linkage between mesoscale features and the distribution of chlorophyll and secondary production in upwelling areas of Oregon and northern California. Dynamic mesoscale physical features develop through the summer upwelling season in coastal areas of the California Current System and move offshore. The larger of these are generated in fairly predictable, topographically-controlled locations and persist from weeks to months.

In our study area, mesoscale activity and zooplankton biomass and distribution vary seasonally and interannually, with peak biomass typically coinciding with peak mesoscale physical activity (in late summer). Variation in the seasonal timing and magnitude of mesoscale activity can therefore affect cross-shelf transfer of biomass and hence can affect the overall productivity of the California Current System. Our goal in this presentation is to characterize the spatial and temporal variability in mesoscale circulation to further our understanding of the dominant mechanisms controlling biological distributions.



(Figure 1): August 2000: An example of the relationship between mesoscale circulation features and biological fields. Panels are (left to right) copepod biomass from net-tows during a U.S. GLOBEC cruise, chlorophyll *a* from SeaWiFS, sea surface temperature from the AVHRR, and sea surface height from AVISO.



Methods

Sea surface height (SSH) data and estimates of gridding error (**Figure 2**) come from AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic data) *http://www.aviso.oceanobs.com*):

- Weekly fields of gridded sea surface anomalies
- Oct 1992 to Dec 2004
- TOPEX/ERS/ENVISAT/and JASON altimeters (as available)
- SSH gridded over 6 weeks of data, weighted to the central date.

Specific locations for wavelet analysis were chosen by examining the average error in the gridded fields (**Figure 2**) and selecting locations with low temporally-averaged errors that were also well-spaced meridionally and zonally at similar distances from shore.

Figure 2. Gridding error in AVISO sea surface height anomaly fields averaged over the entire time series – expressed as % of total variance. X = locations chosen for wavelet analyses. Note that error is lowest along TOPEX ground tracks.

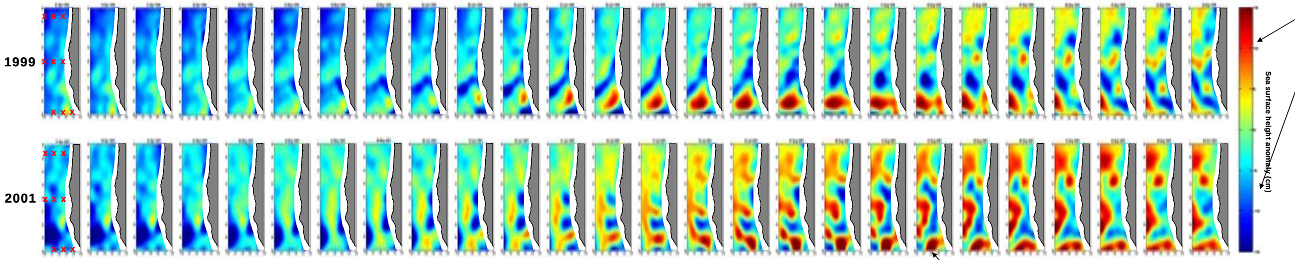
Wavelet analysis: Wavelet methods were based on Torrence and Compo (1998). The wavelet power spectrum is constructed by convolving the time series (X_n) with a scaled wavelet (ψ), to produce a matrix of N data points by *s* scale factors:

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \psi^* \left[\frac{(n'-n)\partial t}{s} \right]$$ and the power is defined as: $|W_n(s)|^2$

Here, we use the Morlet wavelet (with ω_0=6), which is comprised of a sine wave modified by a Gaussian: $$\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0 \eta} e^{-\eta^2/2}$$

The local wavelet power shown in figures is the square of the wavelet coefficients normalized by the variance of each time series. Significance was tested at each location by comparing the wavelet variance to a red-noise background spectrum defined by the variance and length of each individual time series.

Figure 3. Weekly images of sea surface height, April to September 1999 and 2001. x in first panels show locations of wavelet analyses.



Note the differences between years:

- In the north, mesoscale activity began later and was less energetic (weaker SSH gradients existed) in 1999 than 2001.
- Until mid-August 1999, activity was dominated by one large propagating feature whereas patterns of SSH were much more complex in 2001.

Wavelet Analysis

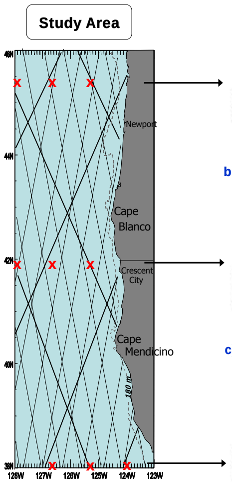


Figure 4. Study area showing locations for wavelet analyses (X) and ground tracks of TOPEX (thick lines) and ERS (thinner lines) altimeters.

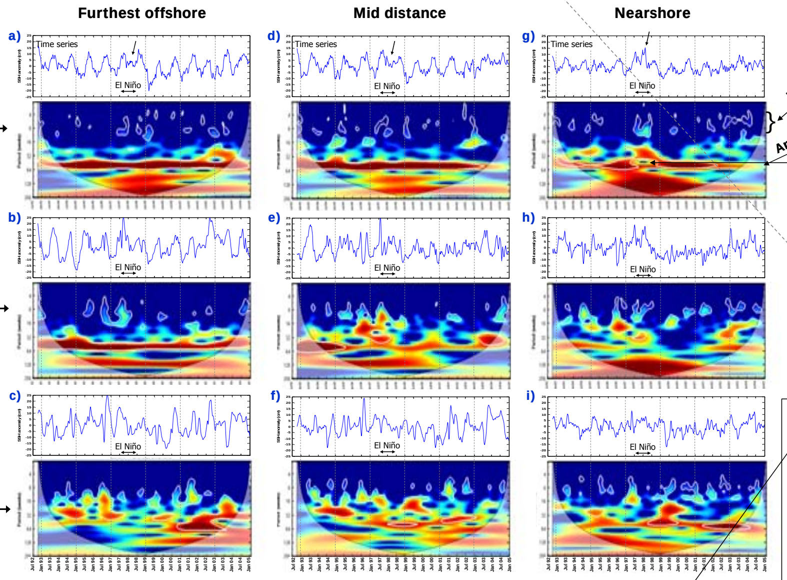


Figure 5. Time series (top panels) and wavelet power spectra (lower panels) from each of nine locations off Oregon and California. White contours enclose variance significantly higher than a red-noise background at the 95% level. The pale edge areas indicate the "cone of influence" (Torrence and Compo, 1998) where edge effects due to the length of the time series reduce the variance.

In the wavelet analyses, the annual period dominates the variance in the north (**Figure 5**: panels a, d, g) and offshore (panel b), but energy in the annual period decreases nearshore and to the south where shorter period variability dominates the signal.

Mesoscale variance is a dominate source of energy in our study area, second only to the annual cycle.

All locations show interannual variability in the mesoscale-frequency (4-12 week).
There is much less mesoscale energy north of the Capes compared to at and south of the Capes.

El Niño disrupted the annual SSH cycle:
the annual variance was significantly lower during the 1997/98 El Niño (seen as decreased energy in the annual band between ~July 1997 and July 1998 in panel g). SSH peaked in winter 1998 rather than declining as usual (time series in panel g) – a strong deviation from the norm. A similar decline in annual variance is seen at several locations, but is not as clear at more offshore locations where SSH typically exhibits minima in the spring rather than winter.

At several locations, variance was relatively low during the La Niña of ~1999-2002.

In the south, summer 2001 had very strong energy in the 4-12 week band that wasn't present to the north. That signal is from an eddy that can be seen moving offshore between late June and the end of September in the maps **Figure 3**.

4 to 12-week scale-average wavelet power time series

To examine fluctuations in power contained within a range of periods (scales), we scale-averaged across several periods at each time point and present the averaged power as a time series.

Because features propagate from nearshore to offshore at ~2-3 km/day in our study area (Strub and James, 2000 and see time series of SSH at top), we chose to analyze the 4-12 week periods (scales) as the periods of mesoscale circulation variability.

As in the wavelet power spectra (**Figure 5**), a relatively quiescent period following the El Niño is seen in the scale-averaged time series (again note the much smaller scaling of the northernmost time series).

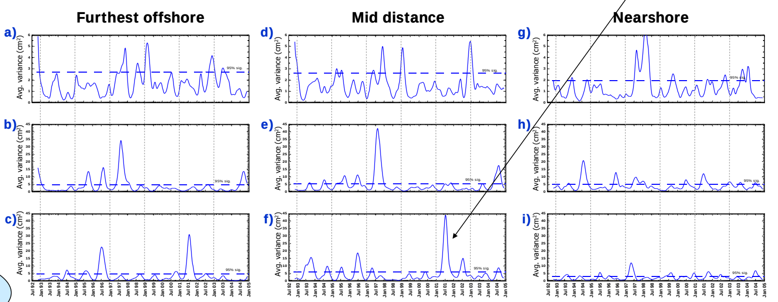


Figure 6. Time series of scale-averaged wavelet power across the 4-12 week periods. The narrow dashed line in each plot is the 95% confidence level calculated against a red noise background. ➤ Note that the y-axis is scaled to much lower variance in the northern locations compared to the southern locations.

Conclusions

- **Wavelet analyses successfully located temporal changes in periodicity in our SSH time series.**
- **We found statistically significant spatial and inter-annual variability in SSH variance.**
- **The dominant periods of variability in our study area differ spatially (Figure 5):**
  - **offshore and in the north, the variance in SSH is dominated by the annual cycle;**
  - **to the south and nearshore, the variance in shorter-duration signals dominates.**
- **Time series of the scale-averaged power (Figure 6) clearly illustrate the variability in mesoscale energy: mesoscale variability is much lower in the north than the south and was higher in the few years prior to the 1997/98 El Niño compared to during the La Niña.**

Recent progress

This poster was originally presented at the 2006 Ocean Sciences Meeting in Honolulu. Since then, we have made the following progress on this work including:

1) We have run these analyses using the gridded SSH data produced by Martin Saraceno which incorporates tide gauge data near the coast;
2) We extended our analyses to a broader area (35 - 49°N, 123 - 132°W) and examined more locations;
3) We developed a time series of the energy integrated over the area 37 - 43°N, between 1 - 3° from the coast. That time series serves as an index of the temporal variability in mesoscale energy in the northern California Current and is useful to compare to biological variability.

Acknowledgements

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References

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