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U.S.-GLOBEC: NEP Phase IIIb-CGOA: A synthesis of climate-forced variability on mesoscale structure in the CGOA with direct comparisons to the CCS

Andrew C. Thomas
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Final Report for Period: 03/2009 - 02/2010 **Submitted on:** 03/05/2010

Principal Investigator: Thomas, Andrew C. **Award ID:** 0535386

Organization: University of Maine

Submitted By:

Thomas, Andrew - Principal Investigator

Title:

U.S.-GLOBEC: NEP Phase IIIb-CGOA: A synthesis of climate-forced variability on mesoscale structure in the CGOA with direct comparisons to the CCS

Project Participants

Senior Personnel

Name: Thomas, Andrew

Worked for more than 160 Hours: Yes

Contribution to Project:

Principal investigator

Name: Mendelssohn, Roy

Worked for more than 160 Hours: Yes

Contribution to Project:

This is a collaborative proposal with Oregon State University and NOAA Southwest Fisheries Science Center. Mendelssohn's funding did not come through the University of Maine.

Name: Schwing, Franklin

Worked for more than 160 Hours: Yes

Contribution to Project:

This is a collaborative proposal with Oregon State University and NOAA Southwest Fisheries Science Center. Schwing's funding did not come through the University of Maine.

Name: Strub, P. Ted

Worked for more than 160 Hours: Yes

Contribution to Project:

This is a collaborative proposal with COAS Oregon State U. and NOAA SFSC. Strub's funding did not come through the University of Maine.

Name: Bograd, Steven

Worked for more than 160 Hours: Yes

Contribution to Project:

This is a collaborative proposal with Oregon State University and NOAA Southwest Fisheries Science Center. Bograd's funding did not come through the University of Maine.

Post-doc

Name: Henson, Stephanie

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Stephanie Henson carried out investigations of event-scale variability and time/space patterns of non-seasonal chlorophyll and eddy variability in the California Current and Gulf of Alaska. She was primarily supported by NSF grant 0531289 (Thomas), but received some support from this award (0535386). She has since moved, first to Princeton and now on to Southampton in the UK.

Graduate Student

Undergraduate Student

Technician, Programmer

Name: Brickley, Peter

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Peter Brickley is a data analyst / research associate working on the satellite data streams and North Pacific data analysis under my supervision. His work has been strongly supported by this grant in 2006, 2007 and 2008. In Sept 2008, he took a 9-month teaching sabbatical at Maine Maritime Academy and has since taken a job in the private sector working in ocean forecasting.

Name: Weatherbee, Ryan

Worked for more than 160 Hours: Yes

Contribution to Project:

Ryan is a data analyst / research associate who assists with IDL code for the satellite data analysis under my supervision. His involvement with the project was minimal over the first 2 years, but has increased since Dr. Brickley left.

Name: James, Corinne

Worked for more than 160 Hours: Yes

Contribution to Project:

On the combined CGOA and CCS projects, she has been the primary data analyst (Faculty Research Assistant), with funding from the CCS side.
This is a collaborative proposal with Oregon State U and NOAA PFEL. James is at OSU and her funding did not come through the University of Maine.

Name: Venegas, Roberto

Worked for more than 160 Hours: Yes

Contribution to Project:

On the CGOA and CCS projects, he was first a graduate student and then a Faculty Research Assistant. Venegas is at Oregon State and his funding did not come through the University of Maine.

Other Participant

Research Experience for Undergraduates

Organizational Partners

Institute of Ocean Sciences

NOAA

NOAA/NESDIS CoastWatch: David Foley

NOAA/NMFS Frank Schwing, Steven Bograd, Roy Mendelssohn, Daniel Palacios
These people are our collaborators at NOAA ERD.

NOAA NMFS Newport: Dr. Bill Peterson

Georgia Institute of Technology

Funded through a different and more recent NSF grant, collaborations with Manu DiLorenzo at GaTech have begun, many focussed on aspects of Gulf of Alaska variability relevant to this project.

University of Washington

Collaborations / interactions with Drs. Julie Keister and Al Herman

Other Collaborators or Contacts

Julie Keister - Now faculty at University of Washington, collaborates on aspects of biological variability in the North East Pacific.

Activities and Findings

Research and Education Activities:

This proposal is one component of a larger research effort involving co-PIs at NOAA NMFS in Pacific Grove CA and Oregon State University.

Final Reports will be submitted separately by each of these institutions.
Efforts at U Maine are primarily focused on investigations of satellite-derived biological variability in the Gulf of Alaska and its linkages to physical forcing, with comparisons to the California Current. A core component of the effort is acquisition, processing, QC and both analysis and serving of SeaWiFS chlorophyll fields to both this project and the GLOBEC community. Data sets are made available via the Oregon State GLOBEC server.

Presentations on the analyses of Gulf of Alaska and California Current ecosystem variability resulting either wholly or partially from this funding to U Maine have been made at:

Ocean Sciences Meeting, Portland OR (Feb 2010)
Eastern Pacific Oceanographic Conference, Sidney, British Columbia (Sept 2009)
Ocean University of China, Qingdao, China, (July 2009)
Chinese Academy of Sciences, Qingdao, China (July 2009)
University of South Florida: School of Marine Sciences, departmental seminar (February, 2009)
Penn State University: Dept of Meteorology, departmental seminar (January, 2009)
Eastern Pacific Oceanographic Conference, Fallen Leaf Lake, CA (Sept 2008)
International Symposium on Eastern Boundary Upwelling Systems, Las Palmas Spain, (June 2008)
Ocean Sciences Meeting, Orlando, FL (March 2008)
Eastern Pacific Oceanographic Conference, Leavenworth, WA (Sept 2007)
NE Pacific GLOBEC Science Team Meeting, Seattle WA (Sept 2007)
PICES Conference, Victoria BC, (Nov 2007)
Eastern Pacific Oceanographic Conference, Mt Hood, OR (Sept 2006)
PICES Conference, Honolulu HI, (April 2006)

These presentations were all by Andrew Thomas.

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Two Research Associates at the University of Maine (Dr. Peter Brickley and Ryan Weatherbee) received training and experience in geophysical data analysis and aspects of statistical analysis.
Stephanie Henson used her post doc experience to learn new approaches to analysis of time/space data sets, including the Okubo-Weiss eddy definitions in altimeter data and wavelet analysis applied to SeaWiFS ocean color data of the California Current.

Outreach Activities:

Journal Publications

Henson, S.A. and A.C. Thomas, "Interannual variability in timing of seasonal chlorophyll increases in the California Current", J. Geophys. Res., p. , vol. 112, (2007). Published, 10.1029/2006JC003960

Henson, S.A. and A.C. Thomas, "Phytoplankton scales of variability in the California Current system: Latitudinal variability", J. Geophys. Res., p. , vol. 112, (2007). Published, 10.1029/ 2006JC004040

Henson, S.A. and A.C. Thomas, "Phytoplankton scales of variability in the California Current system: Interannual and cross-shelf variability", J. Geophys. Res., p. , vol. 112, (2007). Published, 10.1029/ 2006JC004039

Legaard, K. and A.C. Thomas, "Spatial patterns of intraseasonal variability of chlorophyll and sea surface temperature in the California Current.", J. Geophys. Res., p. , vol. 112, (2007). Published, 10.1029/2007JC004097

Crawford, W.R., P.J. Brickley, and A.C. Thomas, "Eddy Transport into a Cyclonic Gyre: An Example in the Gulf of Alaska", Progr. in Oceanography, p. 287, vol. 75, (2007). Published,

Venegas, R., P.T. Strub, E. Beier, R. Letelier, A.C. Thomas, T.Cowles, C. James, L. Soto-Mardones, C. Cabrera, "Satellite-derived variability in chlorophyll, wind stress, sea surface height, and temperature in the northern California Current System", J. Geophys. Res., p. , vol. 113, (2008). Published, 10.1029/2007JC004481

Theil, M. et al., "The Humboldt Current system of northern-central Chile: Oceanographic processes, ecological interactions and socioeconomic feedback.", Oceanogr. Mar. Biol. Ann Rev, p. 195, vol. 45, (2007). Published,

Henson S.A. and A.C. Thomas, "A Census of oceanic anticyclonic eddies in the Gulf of Alaska", Deep Sea Research, p. 163-176, vol. 55, (2008). Published,

Thomas, A.C., P. Brickley and R. Weatherbee, "Interannual variability in chlorophyll concentrations in the Humboldt and California Current Systems", Progress in Oceanography, p. 386, vol. 83, (2009). Published,

Rubao Ji,*, Martin Edwards, David L. Mackas, Jeffery A. Runge, Andrew C. Thomas, "Marine plankton phenology and life history in a changing climate: Current research and future directions", J. Plankton Res., p. , vol. , (2010). Submitted,

Di Lorenzo, E; Fiechter, J; Schneider, N; Bracco, A; Miller, AJ; Franks, PJS; Bograd, SJ; Moore, AM; Thomas, AC; Crawford, W; Pena, A; Hermann, AJ, "Nutrient and salinity decadal variations in the central and eastern North Pacific", GEOPHYSICAL RESEARCH LETTERS, p. , vol. 36, (2009). Published, 10.1029/2009GL03826

Books or Other One-time Publications

Web/Internet Site

URL(s):

www.seasurface.umaine.edu

Description:

This site describes research activities at the U.Maine satellite data lab, lists publications and also has a server to show satellite data products for the Gulf of Alaska and California Current

Other Specific Products

Product Type:

Data or databases

Product Description:

Time series of SeaWiFS 4km and 1km satellite chlorophyll products covering the Gulf of Alaska and the California Current.
Time series of altimeter height fields over the Gulf of Alaska and California Current.

Sharing Information:

These data sets are made available through the Oregon State University GLOBEC data server, will soon also be available though the NOAA PFEG LAS and as available as pictures at our own web site (www.seasurface.umaine.edu).

Contributions

Contributions within Discipline:

Two related manuscripts by Henson and Thomas use wavelet analysis to isolate dominant temporal variability patterns in chlorophyll time series in the California Current. Application of wavelet techniques to biological ocean data is still relatively new. This approach allows isolation and identification of the actual periods at which time-varying components are important. We approach the issue as both cross-shelf and latitudinal summaries. Among the significant findings is evidence that some basin scale forcing processes (the PDO) are more closely linked to California Current chlorophyll VARIABILITY than anomalies in concentration.

A third manuscript by Henson and Thomas revisits the chlorophyll response to an episodic event in the annual cycle; the spring transition (first investigated by Thomas and Strub in 1989 using CZCS data, JGR 1989). Here, we are able to bring 8 years of SeaWiFS chlorophyll data, high resolution wind products, and improved in situ data to the problem. Results show a transition from upwelling control at lower latitudes in the coastal region to an interaction between wind mixing and light limitation at higher latitudes.

Crawford et al highlight the role of eddies in controlling overall chlorophyll concentrations and patterns of variability in the Gulf of Alaska.

Legaard and Thomas quantify intraseasonal (less than 4 month time scales)surface temperature and chlorophyll variability in the California Current, using a semi-variogram approach. These statistical tools allow an improved extraction of the signal compared to frequency-based approaches, for gappy, semi-non-stationary time series. Maps quantifying results show the impacts of upwelling area, the main California Current jet and offshore low-variability regions.

Theil et al (including Thomas) review current understanding of the role of large scale circulation, upwelling and wind forcing in controlling upwelling and its impact on the Northern Chile coastal planktonic and benthic ecosystem. This is then viewed in light of societal impacts.

Venegas et al (including Thomas and Strub) use multidisciplinary satellite data to view variability in the physical - biological linkages in the northern California Current Systems.

Henson and Thomas use a time series of AVISO altimeter height fields and an objective technique to identify and extract eddy structures from these data to provide a census across 15 years of Gulf of Alaska eddy activity.

Thomas, Brickley and Weatherbee use the available 10 year time series of satellite chlorophyll to quantify the time/latitude interannual variability in chlorophyll in the 2 major Pacific eastern boundary current upwelling systems. The extent to which these are correlated to basin scale forcing (El Nino, PDO, NPGO) and local forcing (upwelling-favorable wind) is presented.

Ji et al. review the current status of oceanic plankton phenology research and present possible future directions

For details and figures, please see actual publications. All are available as PDFs on my web site (www.seasurface.umaine.edu). Abstracts are attached under FINDINGS.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Stephanie Henson was a Post Doc carrying out research within this project. The opportunities afforded by this multi-institute and multi-disciplinary project are unsurpassed and Stephanie has excelled in synthesizing results from the large data sets. In 2008, she moved to Jorge Sarmiento's group at Princeton and in 2009 to a position at Southampton in the UK.

Dr. Peter Brickley received funding as a Research Associate working under the direction of Andrew Thomas, processing and analyzing Gulf of Alaska and California Current satellite data. He contributed to a series of manuscripts.

Contributions to Resources for Research and Education:

All data are made available to the community through our own web site (www.seasurface.umaine.edu) and the COAS OSU web site that serves as the GLOBEC NEP home site.

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Activities and Findings: Any Outreach Activities

Any Book

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

Any Conference

As a final summary of findings, I attach abstracts from the following recent papers that are wholly or partly funded by this grant. I make PDFs of all published work is made available to the community on my web site (www.seasurface.umaine.edu).

Di Lorenzo E., Fiechter J., Schneider N., Franks P. J. S., Bograd S. J., Moore A. M., **Thomas A.C.**, Crawford W., Peña A. and Hermann A.. ***2009.*** Nutrient and salinity decadal variations in the central and eastern North Pacific. Geophysical Research Letters. 36, L14601, doi:10.1029/2009GL038261

Long-term timeseries of upper ocean salinity and subsurface nutrients collected in the Alaskan Gyre along Line-P exhibit significant low-frequency variations that are shown to be in phase with variations recorded in the California Current System by the California Cooperative Fisheries Investigation (CalCOFI). We present evidence that these variations are associated with the North Pacific Gyre Oscillation (NPGO) -- a climate mode of variability that tracks changes in strength of the central and eastern branches of the North Pacific gyres and of the Kuroshio-Oyashio Extension (KOE). The NPGO emerges as the leading mode of decadal variability for salinity and nutrients. We reconstruct the spatial expressions of the salinity and nutrient modes over the Northeast Pacific using a regional ocean model hindcast from 1950-2004. These modes exhibit a large-scale coherent pattern that adequately predicts the in phase relationship between the Alaskan Gyre and California Current datasets. The patterns of nutrient and salinity variability are distinct and similar to their respective mean distributions. The structure of the nutrient mode is characterized by higher values along the Northeast Pacific boundary during the positive phase of the NPGO while the salinity mode exhibit positive salinity anomalies in the Alaskan gyre and California Current region, and negative anomalies in the subtropical gyre. These findings suggests that similar to temperature and sea surface height, the salinity and nutrient fields also exhibit coherent patterns of variability that are connected with basin scale climate fluctuations.

Thomas, A.C., P. Brickley and R. Weatherbee. ***2009***. Interannual variability in chlorophyll concentrations in the Humboldt and California Current Systems. Progress in Oceanography. 83, 386-392

SeaWiFS data provide the first systematic comparison of ten years (1997-2007) of chlorophyll interannual variability over the California (CCS) and Humboldt (HCS) Current Systems. Dominant signals are adjacent to the coast in the wind-driven upwelling zone. Maximum anomalies in both systems are negative signals during the 1997-98 El Niño that persist into 1999 at most latitudes. Thereafter, anomalies primarily appear to be associated with shifts in phenology, with those in the CCS stronger than those of the HSC. Prominent signals in the CCS are positive anomalies in 2001-2002 at latitudes > 35^{o}N and < 30^{o}N, and in 2005-06 from ~ 30-45^{o}N that persist at latitudes > 40^{o}N into 2007. In the HCS, latitudinally extensive positive events occur in austral summers of 2002-03, 2003-04. Relationships of chlorophyll anomalies to forcing are explored through correlations to local upwelling anomalies and three indices of Pacific Ocean basin-scale variability, the Multivariate El Niño Index (MEI), the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). These show that each system has strong latitudinal regionality in linkage to forcing. At higher latitudes, correlations follow expected relationships of increased (decreased) chlorophyll with positive upwelling and NPGO (MEI and PDO). At specific latitudes, notably the Southern California Bight and off Peru, where circulation and/or chlorophyll phenology differ from canonical EBUS patterns, correlations weaken or oppose those expected. Correlations excluding the El Niño period remain similar in the CCS but substantially changed in the HCS, indicating much stronger domination of El Niño conditions on HCS anomaly relationships over this 10-year period.

Henson, S.A. and **A.C. Thomas.** ***2008.*** A census of eddies in the Gulf of Alaska. Deep Sea Res. *Deep Sea Res.*, 55, 163-176..

In the Gulf of Alaska, mesoscale eddies play an important role in promoting off-shelf transport of heat, nutrients and biological populations into the HNLC water of the northeast Pacific Ocean. However, the spatial and temporal distribution of these eddies and their characteristics have not been substantially described. Here we apply an objective method (Okubo-Weiss parameter) for identifying and tracking eddies to fifteen years (October 1992-2006) of satellite sea level anomaly data. The parameter allows the spatial and temporal variability in eddy activity to be defined, providing the first systematic census of anticyclonic eddies in the region. Eddies are generated principally on the eastern side of the basin and propagate either westward (Haida eddies) or along the western GOA shelf break (Alaskan Stream eddies). Seasonal maps of eddy density show fewest eddies in winter, maximum in spring/summer. The Haida and Alaskan Stream eddy corridors are clearly defined, as is an 'eddy desert' in the southwest of the basin, where the probability of an eddy being identified is zero. Maps of eddy trajectories for each year show substantial interannual variability in number and propagation paths. Greatest eddy activity occurs in 1994, 1997/98 and 2004. Fewest eddies occur in 1996 and in the period from 1999 through 2002. Interannual variability in eddy characteristics (magnitude, propagation speed, diameter and duration) is assessed for the basin as a whole, and separately for the Alaskan Stream, Haida and Sitka/Yakutat formation regions. In general, Alaskan Stream eddies are more numerous, larger and more intense than Haida eddies. Periods of increased eddy activity do not necessarily correspond to El Niño events, but are associated with anomalous downwelling wind conditions along the continental margin.

Crawford, W.R., P.J. Brickley, and **A.C. Thomas,** ***2007.*** Eddy Transport into a Cyclonic Gyre: An Example in the Gulf of Alaska, *Prog. in Oceanogr.*, 75, 287-303.

The HNLC waters of the Gulf of Alaska normally receive too little iron for primary productivity to draw down macro nutrients in surface waters, even in spring and summer. SeaWiFS observations of chlorophyll north of 54N in pelagic waters (>500 m depth) of the gulf found that, on average, more than half of all surface chlorophyll was inside the 4 cm contours of anticyclonic mesoscale eddies (the ratio approaches 80% in spring months), yet these contours enclosed only 10% of the total surface area of pelagic waters in the gulf. Therefore, eddies dominate the chlorophyll and phytoplankton distribution in surface pelagic waters. We outline several eddy processes that enhance primary productivity. Eddies near the continental margin entrain nutrient – (and Fe) – rich and chlorophyll-rich coastal waters into their outer rings, advecting these waters into the basin interior to directly increase phytoplankton populations there. In addition, eddies carry excess nutrients and iron in their core waters into pelagic regions as they propagate away from the continental margin. As these anticyclonic eddies decay, their depressed isopycnals relax upward, injecting nutrients up toward the surface layer. We propose that this transport brings iron and macro-nutrients toward the surface mixed layer, where they are available for windforced mixing to bring them to surface. These mesoscale eddies decay slowly, but steadily, perhaps providing a relatively regular upward supply of macro-nutrients and iron toward euphotic layers. They might behave as isolated oases of enhanced marine productivity in an otherwise iron-poor basin. We note that much of this productivity might be near or just below the base of the surface mixed layer, and therefore poorly sampled by satellites. It is possible, then, that eddies enrich phytoplankton populations to a greater extent than noted from satellite surface observations only.

Theil, M. et al. ***2007***. The Humboldt Current system of northern-central Chile: Oceanographic processes, ecological interactions and socioeconomic feedback. *Oceanogr. Mar. Biol. Ann Rev.* 45: 195-345.

The Humboldt Current System (HCS) is one of the most productive marine ecosystems on earth, characterized by a predominant northward flow of surface waters of subantarctic origin and by strong upwelling of cool nutrient-rich subsurface waters of equatorial origin. Along the coast of northern and central Chile, upwelling is localised and its occurrence changes from being mostly continuous (aseasonal) in northern Chile to a more seasonal pattern in southern-central Chile. Several important upwelling centres along the Chilean coast are interspersed with long stretches of coast without or with sporadic and less intense upwelling. Large-scale climatic phenomena (El Niño Southern Oscillation, ENSO) are superimposed onto this regional pattern, which results in a high spatiotemporal heterogeneity, complicating the prediction of ecological processes along the Chilean coast. This limited predictability becomes particularly critical in light of increasing human activities during the past decades, at present mainly in the form of exploitation of renewable resources (fish, invertebrates and macroalgae). This review examines current knowledge of ecological processes in the HCS of northern and central Chile, with a particular focus on oceanographic factors and the influence of human activities, and further suggests conservation strategies for this high-priority large marine ecosystem. Along the Chilean coast, the injection of nutrients into surface waters through upwelling events results in extremely high primary production. This fuels zooplankton and fish production over extensive areas, which also supports higher trophic levels, including large populations of seabirds and marine mammals. Pelagic fisheries, typically concentrated near main upwelling centers (20–22S, 32–34S, 36–38S), take an important share of the fish production, thereby affecting trophic interactions in the HCS. Interestingly, El Niño (EN) events in northern Chile do not appear to cause a dramatic decline in primary or zooplankton production but rather a shift in species composition, which affects trophic efficiency of and interactions among higher-level consumers. The low oxygen concentrations in subsurface waters of the HCS (oxygen minimum zone, OMZ) influence predator-prey interactions in the plankton by preventing some species from migrating to deeper waters. The OMZ also has a strong effect on the bathymetric distribution of sublittoral soft-bottom communities along the Chilean coast. The few long-term studies available from sublittoral soft-bottom communities in northern and central Chile suggest that temporal dynamics in abundance and community composition are driven by interannual phenomena (EN and the extent and intensity of the OMZ) rather than by intra-annual (seasonal) patterns. Macrobenthic communities within the OMZ are often dominated in biomass by sulphide-oxidising, mat-forming bacteria. Though the contribution of these microbial communities to the total primary production of the system and their function in structuring OMZ communities is still scarcely known, they presumably play a key role, also in sustaining large populations of economically valuable crustaceans. Sublittoral hard bottoms in shallow waters are dominated by macroalgae and suspension-feeder reefs, which concentrate planktonic resources (nutrients and suspended matter) and channel them into benthic food webs. These communities persist for many years and local extinctions appear to be mainly driven by large-scale events such as EN, which causes direct mortality of benthic organisms due to lack of nutrients/food, high water temperatures, or burial under terrigenous sediments from river runoff. Historic extinctions in combination with local conditions (e.g., vicinity to upwelling centres or substratum availability) produce a heterogeneous distribution pattern of benthic communities, which is also reflected in the diffuse biogeographic limits along the coast of northern-central Chile. Studies of population connectivity suggest that species with highly mobile planktonic dispersal stages maintain relatively continuous populations throughout most of the HCS, while populations of species with limited planktonic dispersal appear to feature high genetic structure over small spatial scales. The population dynamics of most species in the HCS are further influenced by geographic variation in propagule production (apparently caused by local differences in primary production), by temporal variation in recruit supply (caused by upwelling events, frontal systems and eddies), and topographically driven propagule retention (behind headlands, in bay systems and upwelling shadows). Adults as well as larval stages show a wide range of different physiological, ecological and reproductive adaptations. This diversity in life-history strategies in combination with the high variability in environmental conditions (currents, food availability, predation risk, environmental stress) causes strong fluctuations in stocks of both planktonic and benthic resources. At present, it remains difficult to predict many of these fluctuations, which poses particular challenges for the management of exploited resources and the conservation of biodiversity in the HCS. Farther offshore, the continental shelf and the deep-sea trenches off the Chilean coast play an important role in biogeochemical cycles, which may be highly sensitive to climatic change.

Henson, S.A. and **A.C. Thomas.** ***2007.*** Phytoplankton scales of variability in the California Current system: Interannual and cross-shelf variability. *J. Geophys. Res.*, 112, C07017, doi:10.1029/ 2006JC004039

In the California Current System, strong mesoscale variability associated with eddies and meanders of the coastal jet play an important role in the biological productivity of the area. To assess the dominant timescales of variability, a wavelet analysis is applied to almost nine years (October 1997 to July 2006) of 1-km-resolution, 5-day-averaged, SeaWiFS chlorophyll a (chl a) concentration data. The dominant periods of chlorophyll variance, and how these change in time, are quantified as a function of distance offshore. The maximum variance in chlorophyll occurs with a period of _100–200 days. A seasonal cycle in the timing of peak variance is revealed, with maxima in spring/summer close to shore (20 km) and in autumn/winter 200 km offshore. Interannual variability in the magnitude of chlorophyll variance shows maxima in 1999, 2001, 2002, and 2005. There is a very strong out-of-phase correspondence between the time series of chlorophyll variance and the Pacific Decadal Oscillation (PDO) index. We hypothesize that positive PDO conditions, which reflect weak winds and poor upwelling conditions, result in reduced mesoscale variability in the coastal region, and a subsequent decrease in chlorophyll variance. Although the chlorophyll variance responds to basin-scale forcing, chlorophyll biomass does not necessarily correspond to the phase of the PDO, suggesting that it is influenced more by local-scale processes. The mesoscale variability in the system may be as important as the chl a biomass in determining the potential productivity of higher trophic levels.

Henson, S.A. and **A.C. Thomas.** ***2007.*** Phytoplankton scales of variability in the California Current system: Latitudinal variability *J. Geophys. Res.*, 112, C07018, doi:10.1029/2006JC004040.

The California Current System encompasses a southward flowing current which is perturbed by ubiquitous mesoscale variability. The extent to which latitudinal patterns of physical variability are reflected in the distribution of biological parameters is poorly known. To investigate the latitudinal distribution of chlorophyll variance, a wavelet analysis is applied to nearly 9 years (October 1997 to July 2006) of 1-km-resolution SeaWiFS chlorophyll concentration data at 5-day resolution. Peaks in the latitudinal distribution of chlorophyll variance coincide with features of the coastal topography. Maxima in variance are located offshore of Vancouver Island and downstream of Heceta Bank, Cape Blanco, Point Arena, and possibly Point Conception. An analysis of dominant wavelengths in the chlorophyll data reveals a transfer of energy into smaller scales is generated in the vicinity of the coastal capes. The latitudinal distribution of variance in sea level anomaly corresponds closely to the chlorophyll variance in the nearshore region (<100 km offshore), suggesting that the same processes determine the distribution of both. Farther offshore, there is no correspondence between latitudinal patterns of sea level anomaly and chlorophyll variance. This likely represents a transition from physical to biological control of the phytoplankton distribution.

Henson, S.A. and **A.C. Thomas.** ***2007.*** Interannual variability in timing of seasonal chlorophyll increases in the California Current. *J. Geophys. Res.*, 112, doi:10.1029/2006JC003960.

In the California Current System the spring transition from poleward to equatorward alongshore wind stress heralds the beginning of upwelling-favorable conditions. The phytoplankton response to this transition is investigated using 8 years (1998–2005) of daily, 4-km resolution, SeaWiFS chlorophyll a concentration data. Cluster analysis of the chlorophyll a time series at each location is used to separate the inshore upwelling region from offshore and oligotrophic areas. An objective method for estimating the timing of bloom initiation is used to construct a map of the mean bloom start date. Interannual variability in bloom timing and magnitude is investigated in four regions: 45–50N, 40–45N, 35–40N and 20–35N. Daily satellite derived wind data (QuikSCAT) allow the timing of the first episode of persistently upwelling favorable winds to be estimated. Bloom initiation generally coincides with the onset of upwelling winds (±15 days). South of 35N, where winds are southward year-round, the timing of increased chlorophyll concentration corresponds closely to timing of the seasonal increase in upwelling intensity. A 1-D model and satellite derived photosynthetically available radiation data are used to estimate time series of depth-averaged irradiance. In the far north of the region (>46N) light is shown to limit phytoplankton growth in early spring. In 2005 the spring bloom in the northern regions (>35N) had a false start. A sharp increase in chl a in February quickly receded, and a sustained increase in biomass was delayed until July. We hypothesize that this resulted in a mismatch in timing of food availability to higher trophic levels.

Legaard, K. and **A.C. Thomas.** ***2007.*** Spatial patterns of intraseasonal variability of chlorophyll and sea surface temperature in the California Current. J. Geophys. Res., 112, doi:10.1029/2007JC004097.

Six years of daily satellite data are used to quantify and map intraseasonal variability of chlorophyll and SST in the California Current. We define intraseasonal variability as temporal variation remaining after removal of interannual variability and stationary seasonal cycles. Semivariograms are used to quantify the temporal structure of residual time series. Empirical orthogonal function (EOF) analyses of semivariograms calculated across the region isolate dominant scales and corresponding spatial patterns of intraseasonal variability. The mode 1 EOFs for both chlorophyll and SST semivariograms indicate a dominant timescale of _60 days. Spatial amplitudes and patterns of intraseasonal variance derived from mode 1 suggest dominant forcing of intraseasonal variability through distortion of large scale chlorophyll and SST gradients by mesoscale circulation. Intraseasonal SST variance is greatest off southern Baja and along southern Oregon and northern California. Chlorophyll variance is greatest over the shelf and slope, with elevated values closely confined to the Baja shelf and extending farthest from shore off California and the Pacific Northwest. Intraseasonal contributions to total SST variability are strongest near upwelling centers off southern Oregon and northern California, where seasonal contributions are weak. Intraseasonal variability accounts for the majority of total chlorophyll variance in most inshore areas save for southern Baja, where seasonal cycles dominate. Contributions of higher EOF modes to semivariogram structure indicate the degree to which intraseasonal variability is shifted to shorter timescales in certain areas. Comparisons of satellite-derived SST semivariograms to those calculated from co-located and concurrent buoy SST time series show similar features.

Venegas, R., P.T. Strub, E. Beier, R. Letelier, **A.C. Thomas**, T.Cowles, C. James, L. Soto-Mardones, C. Cabrera. ***2007.*** Satellite-derived variability in chlorophyll, wind stress, sea surface height, and temperature in the northern California Current System. *J. Geophys. Res.*, . 113, C03015, doi:10.1029/2007JC004481.

Satellite-derived data provide the temporal means, seasonal and non-seasonal variability of four physical and biological parameters off Oregon and Washington (41°-48.5 °N). Eight years of data (1998-2005) are available for surface chlorophyll concentrations, sea surface temperature and sea surface height, while six years of data (2000-2005) are available for surface wind stress. Strong cross-shelf and alongshore variability is apparent in the temporal mean and seasonal climatology of all four variables. Two latitudinal regions are identified, separated at 44°-46°N, where the coastal ocean experiences a change in the direction of the mean alongshore wind stress, is influenced by topographic features, and has differing exposure to the Columbia River Plume. All these factors may play a part in defining the distinct regimes in the northen and southern regions. Non-seasonal signals account for approximately 60-75% of the dynamical variables. An Empirical Orthogonal Function analysis shows stronger intra-annual variability for alongshore wind, coastal SST and surface chlorophyll, with stronger interannual variability for surface height. Interannual variability can be caused by distant forcing from equatorial (ENSO) and basin-scale changes in circulation, or by more localized changes in regional winds, all of which can be found in the time series. Correlations are mostly as expected for upwelling systems on intra-annual time scales. Correlations of the interannual time scales are complicated by residual quasi-annual signals, created by changes in the timing and strength of the seasonal cycles. Examination of the interannual time series, however, provides a convincing picture of the covariability of chlorophyll, surface temperature and surface height, with some evidence of regional wind forcing.