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US-GLOBEC NEP Phase IIIa-CCS: Large-scale Influences on Mesoscale Structure in the CCS, A Synthesis of Climate-forced Variability in Coastal Ecosystems

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Project Participants

Senior Personnel

Name: Thomas, Andrew
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Henson, Stephanie
Worked for more than 160 Hours: Yes
Contribution to Project:
Dr. Henson's research program here at U.Maine was strongly focussed on this project.

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Oregon State University
This proposal is a Collaborative proposal with a separate award to U.Maine, Oregon State University and NOAA PFEL. PIs at all 3 institutions collaborate on the project.

NOAA-National Marine Fisheries Service

Other Collaborators or Contacts

Al Hermann, University of Washington
William Crawford, DFO IOS, British Columbia
David Mackas, DFO, IOS, British Columbia
Martin Theil, Universidad Catolica del Norte, Coquimbo, Chile
Vivian Montecino, Universidad de Chile, Santiago, Chile

Activities and Findings

Research and Education Activities:

Our work is focussed on analysis of variability in chlorophyll patterns in the California Current, especially in determining quantitative measures of its linkage to local and basin scale forcing, and the relationship between broad scale variability and mesoscale variability.
This is extended to include comparisons to the Humboldt Current System where possible.
We have acquired, processed and QCed the entire SeaWiFS ocean color data set over the California Current. These data, and a number of derived research products, are made available to the community.

We use multiple statistical tools to extract dominant time and space patterns of CHL variability from the image time of the California Current. These include EOFs, wavelet analyses, structure functions and clustering techniques.

Funded through separate channels, a graduate student, Kasey Legaard, participated in this project. Two papers resulting from his thesis contributed to the overall results of the research funded here.

Findings:

Previous annual reports outline specifics from each year.
For my summary of findings, below are versions of abstracts from papers that are all results of the funded work. PDFs of all published work is made available to the community on my web site (www.seasurface.umaine.edu).

Andrew C. Thomas and Peter Brickley, 2006, Satellite measurements of chlorophyll distribution during spring 2005 in the California Current. Geophys. Res. Letters. 33, L22S05, doi:10.1029/2006GL026588
Eight years of satellite data quantify spring 2005 surface chlorophyll-a (chl-a) anomalies in coastal areas of the California Current. Negative anomalies <_1.0 mg m_3 begin in March north of _47_N, spread south to 43_N in April and 40_N in May and June 2005, maximum (<_2.0 mg m_3) north of 45_N. Positive chlorophyll anomalies dominate from _40_N to 27_N during this period. Strongest negative wind stress and positive coastal surface temperature anomalies are located south of maximum chla anomalies, in the region of maximum climatological summer wind stress. Despite the magnitude of these wind anomalies, they remain upwelling-favorable and negative chl-a anomalies are in higher latitude regions of weaker wind anomalies, sufficient however, to prolong winter downwelling, delaying the onset of spring upwelling. In June, winds across the entire region become strongly upwelling favorable and by July, chl-a anomalies switch to positive.

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 Ni±o 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 û (and Fe) û 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 Ni±o 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 (20û22S, 32û34S, 36û38S), take an important share of the fish production, thereby affecting trophic interactions in the HCS. Interestingly, El Ni±o (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 _100û200 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 (1998û2005) 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: 45û50N, 40û45N, 35û40N and 20û35N. 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.

Training and Development:

This project serves as the primary funding source for a post doc,
Dr. Stephanie Henson. In addition to the research and publications she as carried out (see publications list), she has participated in presenting a graduate level course here at U.Maine, assisted in the preparation of proposals, and used the funding to attend numerous national meetings. Dr Henson has since moved to Princeton to work with Jorge Sarmiento.

This project was also a significant source of funding for Dr Peter Brickley, a Research Associate in the School of Marine Sciences here at U Maine, working under the direction of Dr Thomas. His primary tasks withn the project were processing and analysis of CHL image time series data.

Outreach Activities:

Our fully processed satellite data sets are made available to the public
over our web site at: www.seasurface.umaine.edu and also through the GLOBEC NE Pacific server at Oregon State University.

Journal Publications

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

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

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

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

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

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,

Thomas, AC; Brickley, P, "Satellite measurements of chlorophyll distribution during spring 2005 in the California Current", GEOPHYSICAL RESEARCH LETTERS, p. , vol. 33, (2006). Published, 10.1029/2006GL02658

Venegas, RM; Strub, PT; Beier, E; Letelier, R; Thomas, AC; Cowles, T; James, C; Soto-Mardones, L; Cabrera, C, "Satellite-derived variability in chlorophyll, wind stress, sea surface height, and temperature in the northern California Current System", JOURNAL OF GEOPHYSICAL RESEARCH-OCEANS, p. , vol. 113, (2008). Published, 10.1029/2007JC00448

Henson, SA; Thomas, AC, "A census of oceanic anticyclonic eddies in the Gulf of Alaska", DEEP-SEA RESEARCH PART I-OCEANOGRAPHIC RESEARCH PAPERS, p. 163, vol. 55, (2008). Published, 10.1016/j.dsr.2007.11.00

Books or Other One-time Publications

Mackas, D., P.T. Strub, A.C. Thomas, V. Montecino, " Eastern Ocean Boundaries Pan-Regional View", (2006). Book, Published
Editor(s): A.R. Robinson and K.H. Brink
Collection: The Sea
Bibliography: Harvard Press Ltd.

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

Our data sets extend the time period over which the community has a synoptic view of chlorophyll variability in the California Current.
These are made available to the community and and papers present preliminary views of the variability.
We present papers that further develop 2 relatively poorly explored approaches to quantifying variability in ocean biological studies, semivariograms (borrowed from geospatial statistics) and wavelet analysis (borrowed from signal processing).
We document a major time/space anomaly in CHL concentrations in the northern California Current in 2005, showing its linkage with delayed wind forcing in spring.
We also show that in certain cases, anomalies in the variability of chlorophyll is as important as anomalies in concentration with respect to linkages to basin-scale forcing.
Our results present views of use to modelers seeking to verify patterns, and to researchers working across multiple trophic levels.

Contributions to Other Disciplines:

Our results of chlorophyll variability have been used by the
top-predator ecologists to explore links between ocean variability and bird populations in the California Current. We also deliver our data and analyses to the fisheries ecologists for similar work.

Contributions to Human Resource Development:

Funding through this grant has enabled the continuing training and development of Dr. Stephanie Henson (post doc) as a biological oceanographer and researcher.
The funding also provides partial support for Dr. Peter Brickley, a Research Associate at the University of Maine.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Any Web/Internet Site

Any Product

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering