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Remote Sensing of the NE Pacific: Retrospective and Concurrent Time Series Analysis Using Multiple Sensors on Multiple Scales

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Principal Investigator: Thomas, Andrew C.
Organization: University of Maine
Title:
Remote Sensing of the NE Pacific: Retrospective and Concurrent Time Series Analysis Using Multiple Sensors on Multiple Scales

Project Participants

Senior Personnel

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

Post-doc

Graduate Student

Name: Bosch, Jennifer
Worked for more than 160 Hours: Yes
Contribution to Project:
MSc thesis begun addressing one aspect of project goals

Undergraduate Student

Other Participant

Research Experience for Undergraduates

Organizational Partners

Oregon State University

Ocean Imaging

Other Collaborators or Contacts

Dr. P. Ted Strub, COAS Oregon State University, separately funded co-PI.
Dr. Jan Svejkovski, Ocean Imaging CA, separately funded co-PI.
Dr. Mary Elena Carr, NASA Jet Propulsion Laboratory, Pasadena CA. Dr. Carr was funded separately to carry out ocean color research on eastern boundary current systems. A useful collaboration involving sharing of data and processing tasks reduced effort on both parts and resulted in a series of manuscripts (discussed later).
Jose Luis Blanco, now a PhD candidate at Old Dominion University. Mr. Blanco was the chief hydrographer for Institut Fomento Pesquero (IFOP) the Chilean fisheries institute located in Valparaiso. A collaboration on analysis of an extensive in situ data set on the northern Chilean coastal upwelling region resulted in a series of manuscripts.
Jorge Ossus, a biologist at (IFOP) the Chilean fisheries institute in Valparaiso collaborated on our efforts to document the oceanic effects of El Nino on the northern Chilean coastal upwelling region.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

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

Training and Development:

A graduate student has begun an MSc thesis at the University of Maine under the direction of the PI using partial funding provided by this grant.
Jennifer Bosch (MSc expected fall 2002) is using a high spatial resolution (1km) time series of SeaWiFS data over the Oregon / Northern California coast to calculate seasonal and interannual variability of chlorophyll in the GLOBEC target study region. Her specific interest is to contrast variability over Hecata Bank with that immediately north and south of the bank to highlight the effect of bathymetry. A preliminary presentation of her results was presented at the 2002 Ocean Sciences meeting in Honolulu.

Outreach Activities:

1) web site offers brief explanation of project and access to all satellite images used
2) interviews with radio and TV on use of SeaWiFS and satellite data to carry out oceanographic investigations

Journal Publications

Thomas, A.C., "Seasonal distributions of satellite-measured phytoplankton pigment concentration along the Chilean coast.", J. Geophys. Res., p. 25877, vol. 104, (1999). Published

Thomas A.C. and P.T. Strub,, "Cross-shelf phytoplankton pigment variability in the California Current.", Cont. Shelf Res., p. 1157, vol. 21, (2001). Published

Thomas A.C., J.L. Blanco, M.E. Carr, P.T. Strub and J. Ossus, "Satellite-measured chlorophyll and temperature variability off northern Chile during the 1996-1998 La Nina and El Nino", J. Geophy. Res., p. 899, vol. 106, (2001). Published

Thomas A.C., M.E. Carr and P. T. Strub, "Chlorophyll variability in eastern boundary currents", Geophys. Res. Lett., p. 3421, vol. 28, (2001). Published

Nixon, S.W. and A.C. Thomas, "On the size of the Peru Upwelling Ecosystem", Deep Sea Res. (1), p. 2521, vol. 48, (2001). Published

Blanco J.L., A.C. Thomas, M-E. Carr and P.T. Strub, "Seasonal climatology of hydrographic conditions in the upwelling region off northern Chile", J. Geophys. Res., p. 11451, vol. 106, (2001). Published

Blanco J.L., M-E. Carr, A.C. Thomas and P.T. Strub, "Hydrographic conditions off northern Chile during the 1996-1998 La Nina and El Nino", J. Geophys. Res., p. , vol. , (2002). Accepted

Carr M-E., P.T. Strub, A.C. Thomas and J.L. Blanco, "Evolution of 1996-1999 La Nina and El Nino conditions off the western coast of South America: a remote sensing perspective", J. Geophys. Res., p. , vol. , (2002). Accepted

Thomas A.C., P. T. Strub, M.E. Carr and R. Weatherbee, "Comparisons of chlorophyll variability between the four major global eastern boundary currents", Int. J. Rem. Sens., p. , vol. , (2002). Submitted

Books or Other One-time Publications

Web/Internet Site

URL(s):

wavy.umeoce.maine.edu

Description:

This is the URL for the Satellite Oceanography Data Lab at the University of Maine, School of Marine Sciences. A link from the front page here serves GLOBEC Ocean Color images for browsing.

Other Specific Products

Contributions

Contributions within Discipline:

1) This project provided the first detailed look at the upwelling-driven seasonality of pigment concentrations over the full latitudinal extent of the Peru-Chile region, allowing the community to view the manner in which historical CZCS data estimated these patterns.
2) The major cross-shelf seasonal and interannual variability of pigment concentrations measured by CZCS within the California Current were summarized and related to wind forcing.
3) The first direct and concurrent comparison of chlorophyll seasonal cycles over the full latitudinal extent of each of the global eastern boundary currents was published. This sets a background against which future variability can be measured.
4) A first climatology of hydrographic patterns in the upwelling zone off northern Chile was published. This allows direct comparison to the California Current system, it's northern hemisphere counterpart.
5) The hydrographic and satellite viewed anomalies associated with a major El Nino along the coast of Chile were published.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Funding from this grant partially supported 1 MSc student at the University of Maine. Funding for this student and another continues under the new NSF GLOBEC funding. In addition, this grant provided salary and training opportunity for 2 research associates working under the direction of the PI as satellite data analysts.

Contributions to Resources for Research and Education:

Funding from this grant purchased a UNIX work station which formed the backbone of an ocean remote sensing research laboratory. This money then leveraged external funding sources, including NASA, NOAA and local state sources, to increase the ocean remote sensing infrastructure at the University of Maine to the level outlined above in 'infrastructure'. This facility (described on our web site wavy.umeoce.maine.edu) has provided 2 undergraduates with undergraduate research projects and 5 additional undergraduates with part-time on-campus employment as data processing assistants, enhancing their training, exposure to science and overall undergraduate experience. In addition, the facility serves as a demonstration laboratory for a graduate-level School of Marine Sciences course entitled 'Satellite Oceanography' taught by the PI. This project contributed to the development of 3 separate databases of fully processed SeaWiFS images which are now made available to the entire community and especially other GLOBEC scientists. These databases are 1) daily, 4km resolution California Current time series, 2) daily, 4km resolution Gulf of Alaska time series and 3) daily, 1km resolution Pacific Northwest region SeaWiFS time series.

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Any Book

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

Final Report OCE-9711919

Activities

Remote sensing of the NE Pacific: Retrospective and concurrent time series analysis using multiple sensors on multiple scales

This grant has been completed, including a 1 year no-cost extension. The grant was a multi-institution, multi-PI effort, involving P. Ted Strub at COAS Oregon State University and Jan Svejkovski of Ocean Imaging in Solana Beach CA, under which each institution was funded separately. This report covers that portion for which Andrew Thomas, University of Maine was responsible. Separate Final Reports will be (have been?) submitted by each of the other co-PIs. The research effort initiated under this grant is continuing and being expanded upon under another NSF grant, OCE-0000899. Both of these grants are part of the multi-institution US GLOBEC program to study the mechanisms and ramifications of climate change in the oceanic regime of the Northeast Pacific and its affect on key target species. Goals include comparison of the NE Pacific upwelling system to other similar upwelling systems.

As originally proposed, the goals of this research were to process, archive and analyze environmental data from a number of satellite sensors and other sources in order to characterize and quantify the dominant modes of variability in surface transports, temperature and phytoplankton pigment concentrations in the NE Pacific. Encompassed within this overall goal was one of the U.S. GLOBEC objectives of comparing this variability to that observed in other upwelling regimes.

Activities
A major effort within this research project was to "acquire, process, quality control, archive and make electronically available" satellite fields of surface temperature, altimeter, winds and ocean color from various sensors. The multiple PIs on this project took responsibility for various aspects. Reported here are only those related to ocean color data for which the University of Maine was specifically responsible. Other aspects are reported separately in Final Reports by the co-PIs. A central focus of this original GLOBEC Pilot Study was the acquisition and analysis of retrospective data which would provide context and background for future (now present) GLOBEC field and model studies.

These activities are complete and are briefly outlined below.
Data acquisition and serving
The relevant retrospective ocean color data set available to the project was Coastal Zone Color Scanner data. The complete CZCS mission (1978-1986) Level 2, 4km resolution, daily CZCS scenes were acquired from the GSFC DAAC covering the NE Pacific as well as the SE Pacific (the Peru-Chile coastal upwelling region). Code was developed within the NASA ocean color processing software product (SEADAS) to ingest and remap these data to a standard projection. Remapped and standardized fields of CZCS pigment were then made available to the community (and my co-PIs) via anonymous ftp site.

With the launch and availability of SeaWiFS data, a mail delivery of DAT tapes (now replaced by FTP transfer) of Level 1a data via subscription service from the DAAC was initiated. This remains the ocean color (SeaWiFS) data stream for the project. The project acquired and processed SeaWiFS data the NE and SE Pacific from the beginning of the mission (September 1997) up to the present. This provides daily coverage at 4 km resolution. We have divided our products into 3 regions, the California Current, the Gulf of Alaska and the Peru-Chile Current region. IDL and SEADAS code was developed to ingest full orbit swaths, subset and remap these regions to standard projections and archive them as HDF files. These data are proprietary (OrbComm) and cannot be made freely available via the web. These data are, however, made available to licensed research investigators and the GLOBEC community via anonymous ftp from the University of Maine. In addition, a web based browse utility has been set up at U. Maine (wavy.umeoce.maine.edu) which allows users to view the daily scenes from We are currently (under present NSF GLOBEC funding) in the process of merging the SeaWiFS data serving tools with those already in place to handle AVHRR SST data at COAS Oregon State University. In addition to the 4km basin scale SeaWiFS products we produce, Scott Pegau's group at Oregon State also processes and remaps the 1km data SeaWiFS LAC data over the northern California, Oregon, Washington coasts. These data are transferred to the University of Maine for archiving and distribution. These provide higher spatial resolution coverage of one of the GLOBEC target study areas.

Computer / Computational Infrastructure

A significant component of the project was the development, testing and implementation of acquisition, processing and archiving code built around SEADAS to handle the anticipated SeaWiFS ocean color data stream and database. SEADAS processing, remapping and subsetting scripts were developed during the first year and continue to be modified and upgraded. This NSF funding purchased a UNIX workstation and an IDL license. Leveraging the NSF funding, additional CPU and hardware for data backup and processing have been acquired over the past 3 years under separate funding and configured into the satellite data laboratory at U.Maine. At present the Satellite Oceanography Data Laboratory houses 2 parallel RAID disk systems and a SCSI disk farm with a combined on-line disk storage capacity of approximately 1 terabyte, 5 UNIX and 2 LINUX based workstations networked to 5 PCs, dual DLT drives and dual DAT drives for back-up and archiving and assorted printers. We currently maintain 9 IDL licenses.

Final Report OCE-9711919

Findings

Remote sensing of the NE Pacific: Retrospective and concurrent time series analysis using multiple sensors on multiple scales

(publications resulting from this funding in bold, full bibliographic references given in "RESULTS" section)

Retrospective analysis: CZCS data coverage of the eastern Pacific.
Earlier work by ourselves (Thomas et al. J. Geophy. Res. 1994) suggested that large scale seasonal cycles of pigment were not in phase with annual wind forcing along major portions of the South American Pacific coast. This differed from the established picture of the California Current (Strub et al., J Geophys Res. 1990 and Thomas and Strub, J Geophys Res. 1990). However, the 1994 analysis was done with an earlier CZCS dataset, making use of climatological (1978-86) monthly means and 20km spatial resolution. The nature of this dataset made it impossible to separate interannual variability and aliasing due to missing data from seasonal variability. Under this NSF funding, the daily, 4km CZCS time series was examined to 1) test the validity of the 1994 result using a higher time/space resolution product and 2) to quantify higher resolution seasonal and latitudinal variability through the Peru-Chile upwelling region. Results of this analysis were published in **Thomas, J. Geophys. Res. 1999**. Results showed that the 1994 result was not unduly bias by the climatological averaging and/or interannual variability that could be separated in the 4km daily data, but that only 3 years (1979, 1981, 1983) have sufficient coverage to attempt a reconstruction of the annual cycle. The effect of missing data could not be addressed. The seasonal cycle evident in these data remained out of phase with local wind forcing over many latitudes. Of note was the fact that coastal SST deficit, an indication of upwelling strength calculated from NOAA AVHRR data was NOT out of phase with the wind forcing. This fact as well as the extensive missing data in the CZCS time series continued to cause doubt in the interpretation of South American CZCS data. Never-the-less, the results provided greater spatial resolution of seasonality and cross-shelf phytoplankton patterns along the entire continent than were available in 1994. These show very weak cross-shelf structure off northern Chile and much stronger cross-shelf structure off Peru and Central Chile. A distinct bio-physical boundary zone at approximately 33^{o}S separates increased cross-shelf pigment extensions to the south from a narrower coastal zone to the north.

Retrospective analysis of available ocean color data in the North Pacific focused on the California Current region. Earlier work had documented the large-scale overall seasonal and interannual patterns of CZCS pigment in the California Current using an older version of the CZCS atmospheric correction algorithm known to produce erroneous chlorophyll retrievals at large solar zenith angles (Strub et al. 1990, J. Geophys. Res.). No overview of pigment variability in the California Current had been attempted using CZCS data from a new algorithm with reduced atmospheric problems. We combined this analysis with a new focus on cross-shelf pigment structure. Results of this analysis were published in **Thomas and Strub, Cont. Shelf Res. 2001**. We calculate and quantify the cross-shelf pigment structure within 6 regions of the California Current from the Pacific Northwest to the southern tip of Baja, showing mean

seasonal cycles and the magnitude of interannual variability for the period 1979-1983. Winter measurements (November-February) remained suspect and were not evaluated. These data provide a background against which future SeaWiFS data and GLOBEC field measurements can be compared. We showed that minimum cross-shelf extension of elevated pigment concentrations are in March, and maximum in April-May with another sub-maximum in fall in September. Amplitude of this patterns was maximum off northern California and minimum off northern Baja. The effect of the 1983 El Nino is the strongest signal in the interannual variability, manifest as a strong reduction in cross-shelf pigment extensions and concentrations in the zone 50-150 km offshore. Very nearshore concentrations were not affected. This trend was weakest in the Pacific Northwest region. Correlations of cross-shelf pigment pattern to wind forcing (both alongshore wind stress and wind mixing) showed maximum values when wind forcing leads pigment concentrations by 1 or 2 10day periods (our averaging period). Strongest correlations were in the region off the southern Oregon and Northern California coast, weaker correlations were found off Baja and off the Washington, northern Oregon coasts. A calculation of pigment-wind correlations which excluded the 1983 El Nino period showed higher correlations suggesting that connections of pigment structure to wind forcing is stronger during non-El Nino years or that the El Nino pigment anomalies are not associated with concomitant wind anomalies.

Existing climatologies (e.g. Levitus) of oceanographic properties which cover the South American upwelling system do not have the spatial resolution to resolve details of the actual upwelling near the coast. Collaboration with Jose Luis Blanco of the Chilean fisheries institute resulted in a 30 time series of hydrographic data from the northern coast of Chile (18-24^{o}S). These were formed into seasonal climatological means to document the mean annual cycle of both surface and subsurface hydrography. These data not only establish the climatology against which interannual variability can be measured, but also allow direct comparisons to existing climatologies of the analogous northern hemisphere counterpart in the California Current. This hydrographic climatology, along with climatologies of coastal wind, SST and sea level were published in **Blanco et al. J. Geophys Res. 2001a**. The data show that upwelling occurs year-round at these latitudes, strongest in summer and weakest in winter. Surface flow is equatorward, while subsurface flow is poleward throughout the year, strongest in an undercurrent near the coast. Even within this latitude range, we document meridional gradients. One of the striking differences between the Chilean upwelling system and that off California is the difference in salinity fields. Off California, low salinities are a surface feature located offshore often traceable to the Columbia River discharge. Off Chile, low salinity water masses at middepth means that cold temperatures and low salinities are a characteristic of the actual upwelling zone nearshore.

The climatology manuscript was followed by 3 other manuscripts which use the hydrographic climatology as a basis for documenting the ramifications of the 1997-98 El Nino along the coast of South America. **Thomas et al., J. Geophys. Res. 2001**, calculated the SeaWiFS chlorophyll fields associated with the El Nino period off northern Chile showing that 1) chlorophyll cross-shelf structure over the period closely follows that of SST, apparently modulated by SST frontal structure 2) the maximum in El Nino hydrographic anomalies in December 1998 was associated with minimum chlorophyll concentrations and cross-shelf extent and 3) the annual cycle in 1997-98 was clearly different from that of the year following and that seen by the OCTS sensor in the previous year. This manuscript also published a figure showing 4 years of monthly vertical

profiles of temperature off northern Chile which clearly show the timing, extent and magnitude of the temperature anomalies associated with the 1997-98 El Nino. Details of the hydrographic anomalies associated with the El Nino event were published in **Blanco et al., 2002**. The highlight of these data were the distinct pulses of El Nino signal which arrived off northern Chile in May and December of 1997 associated with strong anomalous poleward surface flow. **Carr et al., 2002** quantify the large-scale view of El Nino along the South American coast using satellite data.

Nixon and Thomas Deep-Sea Res. (I) 2001 used thresholds of chlorophyll concentration from SeaWiFS data and correlations between annual primary production and fishery yield to estimate the size of the Peru upwelling system. Both measures were consistent, estimating the size of the region to be 220 x 10^3 km^2 , allowing us to suggest that a number of previously published estimates of the size of the Peruvian productive region are not good estimates.

A preliminary view of large-scale seasonal and interannual variability of chlorophyll, as viewed with the first 2 years of SeaWiFS data, in the 4 eastern boundary currents (California, Canary, Peru-Chile, Benguela) was presented at the 2000 Oceans from Space Conference in Venice and has been submitted for publication in Int. J. Rem. Sens. (**Thomas et al., Int. J. Rem. Sens. 2002**). A comparison of the seasonal cycle of chlorophyll in each of the 4 EBC regions of the global ocean was published in **Thomas et al., Geophys. Res. Lett. 2001**. Here we show that the first 3 years of SeaWiFS data are very similar to the seasonal climatology calculated from CZCS data over the 2 northern hemisphere EBC regions (California and Canary Currents). Distinct differences, however, are apparent in both southern hemisphere regions (Peru-Chile and Benguela) where CZCS data are very sparse. We show that seasonal patterns of chlorophyll within 100km of the coast are in phase (or lag slightly) with that of wind forcing over extensive latitudinal ranges of all 4 EBC regions. These data show that the sparse data from ZCS over the southern hemisphere regions results in a bias view of seasonality. We also show that despite these problems, the overall latitudinal profile of mean annual chlorophyll in the 4 EBC regions estimated by the CZCS is very similar to that of SeaWiFS.

Opportunities for Training and Development

A graduate student has begun an MSc thesis at the University of Maine under the direction of the PI using partial funding provided by this grant.

Jennifer Bosch (MSc expected fall 2002) is using a high spatial resolution (1km) time series of SeaWiFS data over the Oregon / Northern California coast to calculate seasonal and interannual variability of chlorophyll in the GLOBEC target study region. Her specific interest is to contrast variability over Hecata Bank with that immediately north and south of the bank to highlight the effect of bathymetry. A preliminary presentation of her results was presented at the 2002 Ocean Sciences meeting in Honolulu.