Fisheries and Oceans Canada / PICES Symposium

Time Series of the Northeast Pacific: A symposium to mark the 50th anniversary of Line-P

July 5–8, 2006
Victoria, Canada

Fisheries and Oceans Canada / PICES Symposium

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Fisheries and Oceans Canada / PICES Symposium

Co-Convenors

Howard J. Freeland and Angelica Peña
Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, Canada

Steering Committee

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This focuses on general aspects of time series in the NE Pacific. It includes a review of the importance of long time series in the ocean and overviews of specific time series, such as CalCOFI, The Newport Line, The GAK time series and HOTS;

Theme 2: Physical, chemical and biological variability in NE Pacific time series

This focuses mostly on Line-P results, including presentations on the physical variability, plankton and biogeochemical cycles and ecosystem modelling;

Theme 3: Process studies in the NE Pacific

This focuses on process studies in the NE Pacific including discussion of the factors influencing gas exchange, the SERIES iron fertilization experiment, and the influence of eddies and mesoscale variability in the region.

Abstracts are sorted first by session and then alphabetically by presenter's last name. Presenters' names are in bold and underlined print. The Author Index lists all authors, including co-authors, in alphabetical order. Paper numbers and page numbers are also listed in the Index. Some abstracts in this collection have not been edited and have been printed in the condition that they were received.

Fisheries and Oceans Canada / PICES Symposium

Symposium Schedule

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11:30	A survey of Newport Line sampling *(Huyer)*	11:45	Comparison of Zooplankton time series *(Mackas)*	12:15	Lunch	
12:15	Lunch	12:30	Lunch	14:00	The SERIES experiment *(Levasseur)*	
14:00	A survey of GAK/Seward Line *(Weingartner)*	14:00	Ecosystem modelling *(Denman)*	14:45	Panel Discussion	
14:45	**Poster Session**	14:45	**Poster Session**			End of workshop
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				Evening Event – Bus to IOS and a buffet meal with slide show.		

Theme 1 Overview of time series of the NE Pacific

Wednesday, July 5, 2006 9:00–17:00

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09:30–10:15 **D.E. Harrison**
Importance of long time series worldwide: Why are we doing this? (T1-2773)

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10:45–11:30 **David M. Checkley**
A survey of CalCOFI sampling (T1-2761)

11:30–12:15 **Patricia A. Wheeler, Adriana Huyer and Robert L. Smith**
The Newport hydro line – Studies in the NE Pacific off the coast of Oregon (T1-2728)

12:15–14:00 *Lunch*

14:00–14:45 **Thomas Weingartner**
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16:15–17:00 **Ricardo M. Letelier and David M. Karl**
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Posters

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Ocean climate change off Oregon: A comparison of two epochs (T1-2730)

T1-2723 Oral

A review of the Line P Program

Frank A. **Whitney**

Institute of Ocean Sciences, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
E-mail: whitneyf@pac.dfo-mpo.gc.ca

In 1949, Ocean Station Papa (OSP) was first occupied as a site to assist meteorologists in predicting storms coming towards the North American coast. It was several years before oceanographers began to use the Weatherships as vessels of opportunity. In 1956, hydrographic casts, net tows and other measurements began at OSP. In 1959, the program expanded to include oceanographic surveys along the line between the mouth of Juan de Fuca Strait and OSP. When vessels were no longer required for weather forecasting, oceanographers reduced the frequency of observations along Line P to several surveys per year. With 50 years of reasonably good data from OSP and along Line P, we have a powerful data set with which to follow ocean variability. Surface warming, increasing stratification, reduced nutrient supply to the upper ocean, earlier maturation of spring zooplankton and decreased ventilation of the interior ocean are clearly discernible in these data.

T1-2773 Oral

Importance of long time series worldwide: Why are we doing this?

D.E. **Harrison**

NOAA/PMEL/OCRD, 7600 Sand Point Way NE, Seattle, WA 98115, U.S.A. E-mail: D.E.Harrison@noaa.gov

Some of the most important knowledge of the ocean has come from long term measurements at particular sites or from repeated measurements along sections. Because the spectrum of oceanic variability is so rich and contains lots of energy typically at both short/fast and long/slow ends of the wavenumber/frequency spectrum, sampling oceanic variability poses many challenges. Knowing accurately the time variability in even a few regimes around the world ocean is important, but very long records are needed if we are to be able to determine the difference between multi-decadal cycles and trends. Much effort is now going into design of effective repeat section observing efforts, which are also needed to gather information about basin scale variability of many variables.

Ultimately it is desired to pull information from all scales together into useful oceanic analyses, but the data sets themselves must always be useful. Examples from time series and repeat section efforts will be presented, and plans for ongoing and future efforts will be described.

T1-2761 Oral

A survey of CalCOFI sampling

David M. **Checkley**, Jr.

Integrative Oceanography Division, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093-0218, U.S.A. E-mail: dcheckley@ucsd.edu

The northern fishery for the California sardine (*Sardinops sagax*) collapsed in late 1945 and the formative California Cooperative Oceanic Fisheries Investigations was created in 1949. The goal of CalCOFI was to achieve an understanding of the dynamics of fish resources off California to enable their improved management. The triumvirate of scientists, industry, and managers assumed such understanding would arise only from an empirical investigation of ocean physics and biology. A monthly, grid-based survey was begun. Core measurements focused on hydrography (temperature, salinity, and pressure) and zooplankton, including the early life stages of fish. Over time, effort varied spatially and temporally. Gaps arose. The grid shrank. However, the core measurements continued. Since 1982, station sampling of dissolved oxygen, nutrients, chlorophyll *a* fluorescence, primary productivity and underway sampling of temperature, salinity, chlorophyll *a* fluorescence, and fish eggs have been added. Numerous ancillary programs cooperate with CalCOFI and significant augmentation has occurred with the NSF-funded California Current Ecosystem Long-Term Ecological Research program. Research by students and staff is vital to CalCOFI. As the time series has lengthened, the spectral window has broadened. Now, after 57 y, we are able to infer confidently about phenomena of time scales ~ 0.25–15y and, with less confidence, ~ 60 y, and spatial scales ~60–500 km horizontally and ~5–500m vertically, as well as large-scale trends. We have learned that the desired understanding must include processes at all these scales, and more. CalCOFI has become one of a few programs with data to infer about processes over this range of scales, now including climate change. In turn, the focus of CalCOFI has shifted from fish alone to the ecosystem and long-term change. Challenges include continuity, innovation, funding, and the need to provide results useful for management and policy.

T1-2728 Oral

The Newport hydro line – Studies in the NE Pacific off the coast of Oregon

Patricia A. Wheeler, Adriana **Huyer** and Robert L. Smith

College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 97331, U.S.A.
E-mail: pwheeler@coas.oregonstate.edu

Sampling of the Newport Hydrographic (NH) Line beyond the continental shelf began in 1961. The NH line extends along 44.65N from the central Oregon coast to 160 km offshore; about half lies over the continental margin. Regular seasonal sampling occurred during two periods: 1961–1971 through the TENOC program and 1997–2003 through the GLOBEC Northeast Pacific Long Term Observations Program (LTOP). During the intervening period (1972–1996) studies focusing on the Oregon shelf occasionally sampled the NH-line. In this paper we review the early studies, compare the TENOC and LTOP time series and discuss the NH results in a spatial context. LTOP included sampling during a strong El Niño (1997–1998), a La Niña (1998–2001), an intrusion of subarctic water (2001–2002), and an additional line at 41.9N in the windier region south of Cape Blanco. Satellite data (1998–2003) show the interannual and cross shelf variations in chlorophyll levels during the upwelling season and a smaller more variable (in timing) spring bloom for the NH-line. Seasonal averages of temperature, salinity and other characteristics along the NH-line show some significant differences between TENOC and LTOP summers: surface waters are warmer and fresher during LTOP; steric heights over the continental slope are higher; and subsurface waters near the shelf break are warmer but not fresher. The seasonal cycle appears less regular during LTOP than TENOC, and interannual variability is greater, especially in winter. During summer upwelling, the NH-line is warmer and fresher, with lower nutrients, thinner mixed layers and lower chlorophyll, than the line at 41.9N. Nutrients, chlorophyll and copepod biomass are similarly high during the summer upwelling season over the shelf along both lines. However, offshore, high chlorophyll pockets at depth and high copepod standing stocks at 41.9N illustrate additional effects of physical factors on the distributions of phytoplankton and copepods.

T1-2772 Oral

Ecosystem structure and function on the Gulf of Alaska shelf

Thomas **Weingartner**

Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 99775, U.S.A.
E-mail: weingart@ims.uaf.edu

This talk draws heavily on results from the Coastal Gulf of Alaska GLOBEC Program (1997 – 2004), which emphasized the northern Gulf of Alaska shelf and slope. The seasonally-varying Aleutian Low induces large annual cycles in air–sea heat exchange, runoff, and winds, which in conjunction with a complex shelf bathymetry and coastal orography, form the physical basis of this marine ecosystem. In aggregate, these parameters establish substantial cross- and along-shelf circulation and hydrographic gradients reflected in spatial and temporal differences in stratification, nutrient transport pathways, and the production, distribution, and community composition of phytoplankton, zooplankton, and fish. Cross-shelf variability in phytoplankton and zooplankton appear linked to freshwater dispersal processes and along- and cross-shelf transports. These influences are manifested in nutrient ratios, phytoplankton size distributions, and the greater abundance of *Neocalanus* in low-salinity waters and suggest bottom-up control. Pink salmon distribution and size may also be related to salinity variability, with greater fish abundance in low salinity, nearshore waters, but larger size juveniles in saltier, offshore waters.

Long term physical variability is manifested in fall–winter heat fluxes and runoff and is linked to variations in the Aleutian Low. Recent decades have witnessed a marked reduction in ocean cooling by the atmosphere and increasing runoff. The latter is correlated with alongshore baroclinic transport in winter and our results suggest that the transport has also increased since the mid-1970s. While the recent transport changes have been substantial, they do not appear to have exceeded those observed early in the 20th century. These changes affect biological production through changes in the onset of springtime stratification, along-shore transport in the Alaska Coastal Current, and possibly through iron availability via runoff and mesoscale processes. The talk concludes with speculations on how a warmer and wetter winter environment, as envisioned under global warming scenarios, might affect this ecosystem.

T1-2769 Oral

Biogeochemical inter-annual to decadal variability in the North Pacific Subtropical Gyre

Ricardo M. **Letelier**[1] and David M. Karl[2]

[1] College of Oceanic and Atmospheric Sciences, Oregon State University
[2] School of Ocean Earth Science and Technology, University of Hawaii

Over the past half century biogeochemical time-series records from marine pelagic environments have provided evidence of ecosystem responses to changes in climate patterns. For example, long-term records of water soluble reactive phosphorus (SRP) concentration in the North Pacific Subtropical Gyre (NPG) indicate that, during warm phases of the Pacific Decadal Oscillation (PDO), microbial assemblages are able to deplete SRP well below the concentrations observed during cold PDO phases. These observations, when combined with other physical and biological time-series data, suggest an increase in nitrogen fixation and the relative contribution of prokaryotic photoautotrophs to this ecosystem during warm PDO phases. However, the temporal extent of the available data does not allow assessing if these observed changes are reversible. Furthermore, changes in photoautotrophic assemblages, as detected though the variability in phytoplankton pigment data from the Hawaii Ocean Time-series (HOT) program indicate that the relative contribution of certain photoautotrophic eukaryotic taxa have varied over time without a clear concomitant alteration in the large scale physical forcing. In this presentation we will attempt to analyze the HOT data in the context of other time-series datasets collected in the Eastern North Pacific to evaluate the role that local and regional forcing may have in the observed biogeochemical variability and ecosystem structure.

T1-2727 Poster

The Continuous Plankton Recorder survey in the North Pacific

Sonia D. **Batten**[1] and David W. Welch[2]

[1] Sir Alister Hardy Foundation for Ocean Science, c/o 4737 Vista View Cr, Nanaimo, BC, V9V 1N8, Canada
E-mail: soba@sahfos.ac.uk

[2] Kintama Research Corporation, Centre for Shellfish Research, Malaspina University-College, 900-5th St., Nanaimo, BC, V9R 5S5, Canada

The first CPR deployed in the North Pacific was towed behind an oil tanker in summer 1997 as a pilot project and routine sampling began in 2000. There are currently 9 transects sampled between March and October each year on two routes that provide seasonal coverage of the offshore regions of the North Pacific. In addition to sampling the plankton we have also added other samplers where possible to record additional variables. The 6500 km trans-Pacific route has been well supplemented in this way and has had temperature, salinity, chlorophyll a (as fluorescence), and seabird and mammal observations recorded since summer 2002. Although the survey has some way to go before it can be compared to the Atlantic CPR survey (now in its 75th year) it is already showing that offshore plankton populations respond as rapidly as shelf plankton to climate variability. The first part of the CPR record since 2000 saw relatively cool conditions in the eastern Pacific before conditions warmed again in 2003, and we have recorded changes in the timing and distribution of zooplankton that correspond to surface ocean conditions. This poster describes the survey and research highlights to date.

T1-2743 Poster

Long-term trends in apparent oxygen utilization and Redfield ratios in the southern California Current System

Steven J. **Bograd**[1], Carmen G. Castro[2], Curt A. Collins[3], and Francisco P. Chavez[4]

[1] NOAA, Southwest Fisheries Science Center, Environmental Research Division, Pacific Grove, CA, 93950-2097, U.S.A. E-mail: steven.bograd@noaa.gov
[2] Instituto de Investigaciones Marinas, Consejo Superior de Investigaciones Cientificas, Vigo, Spain
[3] Department of Oceanography, Naval Postgraduate School, Monterey, CA, 93940, U.S.A.
[4] Monterey Bay Aquarium Research Institute, Moss Landing, CA, 95039, U.S.A.

We use historical hydrographic data from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program to explore the temporal variability of physical and chemical properties of slope waters impacted by the California Undercurrent (CUC) over the period 1984–2005. The upper water column (sigma-theta < 26.0) has experienced a strong warming trend, and is greatly impacted by El Niño events. At the depth of the CUC (sigma-theta = 26.4), there has been weaker interannual variability, but waters have become progressively warmer, saltier, and lower in oxygen content over the record, leading to a significant increase in apparent oxygen utilization. There have also been increasing trends in nitrate and phosphate in CUC waters over this period, although at different rates, leading to highly significant declines in the NO_3:PO_4 and SiO_4:NO_3 ratios. Several mechanisms for the observed trends were considered. The most likely cause is temporal variability in the properties of CUC source waters, and changes in net transport into the Southern California Bight. Significant changes in the oxygen content and nutrient composition of CUC waters, which are upwelled upstream, could have important implications for the California Current ecosystem. We also examine the CUC trends in the context of decadal variability in water properties throughout the southern California Current System, based on the CalCOFI 1949–2005 series of temperature, salinity, and dissolved oxygen measurements.

T1-2764 Poster

In situ marine primary production and net oxygen production determined from *in situ* O_2 measurements on a mooring and Seaglider in the subtropical Pacific at HOT

S. **Emerson**, D. Nicholson, C. Eriksen and C. Stump

P.O. Box 355351, School of Oceanography, University of Washington, Seattle, WA 98195, U.S.A.
E-mail: emerson@u.washington.edu

During the year 2005 we deployed oxygen and gas tension sensors on a mooring at the Hawaii Ocean Time Series (HOT) while a Seaglider with oxygen sensors surveyed the area measuring T, S, O_2 and chlorophyll in a "butterfly" pattern around the mooring. Diurnal oxygen changes in the euphotic zone from the moored oxygen sensor are a measure of gross biological oxygen production. Gross O_2 productivity determined in this way indicates biological activity at this location in the ocean is intermittent due to eddies and fronts that pass through the area. In the spring when eddies are usually present, the *in situ* gross primary production rates are up to seven times that determined by ^{14}C primary production, while they differ by 2–3 times during other times of the year. The difference between these tow measurements during the year may be due to an ecological separation of gross and ^{14}C primary production or it may indicate the ^{14}C primary production measurements are missing some part of the productivity during these intermittent events. The Seaglider surveys provide the measurements necessary to determine the net annual oxygen production in the euphotic zone, which is correlated via the Redfield Ratio with the net biological carbon export. The net biological oxygen production can be determined from the measured time rate of change, the biological O_2 flux to the atmosphere and the flux of oxygen across the pycnocline. The advantage of the *in situ* oxygen methods is that they capture the importance of intermittent productivity events, and because they are *in situ* determinations, they can be deployed in ocean areas where it is not possible to mount a ship-supported time series.

T1-2742 Poster

Satellite and buoy time series of the Gulf of Alaska

Jim F.R. **Gower**

Institute of Ocean Sciences, Box 6000, Sidney, B.C., V8L 4B2, Canada. E-mail: gowerj@pac.dfo-mpo.gc.ca

This paper presents examples of satellite data of the Gulf of Alaska, including the SeaWiFS water colour (chlorophyll and water brightness) time series, 1997 to 2006, and images from SeaWiFS, MODIS and MERIS of specific events, and time series of wind, waves and surface temperature from the Canadian and U.S. ODAS buoys. We also note that European and U.S. satellites will soon be launched to map surface salinity, which may provide a new window on the surface flow of fresh-water from land to ocean.

T1-2763 Poster

Constraining productivity and air–sea gas exchange with dissolved gases at the Hawaii Ocean Time-series

Roberta C. **Hamme**[1] and Steven R. Emerson[2]

[1] Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive #0244, La Jolla, CA, 92093-0244, U.S.A. E-mail: rhamme@ucsd.edu
[2] School of Oceanography, University of Washington, Box 355351, Seattle, WA, 98195-5351, U.S.A.

We measured profiles of dissolved O_2/Ar, N_2/Ar and Ne at station ALOHA (Hawaii Ocean Time-series) on eleven consecutive cruises from July 2000 to June 2001. Using a dynamic mixed layer model (PWP), we determined carbon export by the oxygen mass balance method from our measurements. Organic carbon export from the mixed layer calculated from our O_2/Ar measurements was 1.1 +/– 0.5 mol C/m^2/yr, with most of the error deriving from uncertainties in the parameterization of diffusive gas exchange with wind speed. Our estimates of carbon export from the zone beneath the mixed layer but still in the euphotic zone ranged from 0 to 0.6 mol C/m^2/yr as the rate of background diapycnal mixing was increased from 0.1 to 1.0 cm^2/s. The inert gas measurements constrain the flux of oxygen into the mixed layer from small, collapsing bubbles (injection) to be greater than or equal to the flux from larger bubbles (exchange), with mean estimates of the ratio in the range of 1–2. We also show that monthly observations of temperature and inert gases cannot constrain the rate of diapycnal mixing at this location, because of uncertainties in air–sea heat flux estimates, bubble dynamics, and horizontal processes. We conclude that the oxygen mass balance method has errors of about a factor of two in areas similar to the subtropical North Pacific, with the main uncertainties deriving from mixing rates and the parameterization of diffusive gas exchange.

T1-2737 Poster

Change and resilience in the species composition of subtropical North Pacific zooplankton communities: The Hawaii Ocean Time-series

Cecelia C.S. **Hannides**[1] and Michael R. Landry[2]

[1] Department of Oceanography, University of Hawaii at Manoa, 1000 Pope Road, Honolulu, HI, 96822, U.S.A. E-mail: sheridan@hawaii.edu

[2] Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093, U.S.A.

Zooplankton in the North Pacific subtropical gyre (NPSG) are dominated by larvaceans and small copepods from the Families Oithonidae, Oncaeidae, Clausocalanidae and Paracalanidae. Observations from the Hawaii Ocean Time-series (HOT) Station ALOHA (22°45′N, 158°W) indicate that the biomass of these NPSG zooplankton can vary on seasonal and multi-year timescales. In particular, the abundance of larvaceans and copepods from the Families Oithonidae and Paracalanidae increases in response to summertime blooms of diatoms and diazotrophic phytoplankton. We further explore the time-series of zooplankton species composition from Station ALOHA to understand the response of system dominants to inter-annual fluctuations in phytoplankton abundance, system productivity and ecosystem function at Station ALOHA. Fluctuations in abundance and biomass within the time-series can be contrasted with long-term resilience in the dominance structure of NPSG zooplankton.

T1-2744 Poster

Modeling the temperature–nitrate relationship in the California Current

Daniel M. **Palacios**[1,2], Steven J. Bograd[2], Franklin B. Schwing[2] and Roy Mendelssohn[2]

[1] Joint Institute for Marine and Atmospheric Research, University of Hawaii, 1000 Pope Road, Marine Sciences Building, Room 312, Honolulu, HI 96822, U.S.A. E-mail: daniel.palacios@noaa.gov

[2] NOAA, Southwest Fisheries Science Center, Environmental Research Division, 1352 Lighthouse Avenue, Pacific Grove, CA 93950-2097, U.S.A.

We have compiled over 30,000 nitrate, temperature, and salinity measurements for a region of the California Current System (CCS; 30–47°N) in the upper 0–200 m, within 0.5 degrees from the coast, and spanning the period 1959–2004. Sources of this data set include NOAA's World Ocean Database 2001, and a number of field programs such as CalCOFI, GLOBEC/LTOP, and COOP/WEST. This data set is used to develop statistical models to predict nitrate concentration, the major nutrient fueling biological production in this upwelling ecosystem, based on temperature, salinity, latitude, and the annual cycle as explanatory variables. Although global methods (*i.e.*, linear regression, including polynomial expansions) have been widely used to model the temperature–nitrate relationship, we use instead local methods (*i.e.*, generalized additive models, GAMs), which better capture biochemical processes in the water column as well as geographic variability due to local (*e.g.*, upwelling foci, riverine inputs) and regional processes (*e.g.*, watermass distributions). We apply this modeling approach to predict nitrate from a set of subsurface temperature time series at various locations within the CCS for the period 1950–1993. Further, we derive indicators that describe interannual variability in nitrate availability and potential primary production, relative to the strength of stratification in the water column.

T1-2730 Poster

Ocean climate change off Oregon: A comparison of two epochs

Robert L. **Smith**, J.H. Fleischbein, A. Huyer and P. M. Kosro

College of Oceanic and Atmospheric Sciences, Oregon State University, Ocean Admin. Bldg. 104, Corvallis, OR 97330, U.S.A. Email: rsmith@coas.oregonstate.edu

The Newport Hydrographic (NH) Line along 44.65 N off central Oregon was sampled seasonally during two epochs: 1961–1971 through the TENOC program and 1997–2003 through the GLOBEC Northeast Pacific Long Term Observations Program (LTOP); additional summer observations are available for 2004 and 2005. The inshore portion of this line, which lies over the continental margin, experiences strong seasonal variation. The seasonal cycle has rapid transitions in spring and fall, with relatively persistent regimes in summer and winter. This poster provides epoch-to-epoch comparisons for both summer and winter. The summer regime has coastal upwelling driven by southward wind, equatorward surface currents, and advection of low salinity waters from the Columbia River. The winter regime off Newport has strong vertical mixing, coastal downwelling, and poleward surface currents driven by northeastward winds. We show zonal sections of the summer and winter averages of temperature, salinity, and density for both TENOC and LTOP, as well as the spatial distributions of the differences between these epochs. Alongshore velocities are also compared, using geostrophic estimates for both TENOC and LTOP, and direct (ADCP) current measurements for LTOP. In summer, the near-surface layer (0–100 m) at most locations is significantly warmer, fresher and less dense during LTOP than TENOC; a subsurface region (150–300 m deep, 60–120 km offshore) is significantly warmer but not fresher. Deeper water (400–700 m), was significantly fresher during LTOP than TENOC, by a small amount (0.04 psu) that is consistent with deep freshening at Station P. Summer steric heights over the continental margin are significantly higher during LTOP than TENOC. Comparison of LTOP and TENOC winters shows that average temperatures at most locations were not significantly different, but that temperature variance of the surface layer was significantly higher during LTOP than TENOC, especially near the shelf-break.

Theme 2 Physical, chemical and biological variability in NE Pacific time series

Thursday, July 6, 2006 9:00–17:00

09:00–09:45 **Howard J. Freeland and Patrick F. Cummins**
Recent physical variability along Line-P, evidence and causes (T2-2746)

09:45–10:30 **Angelica Peña and Diana Varela**
Phytoplankton and upper ocean biogeochemical cycles along Line P in the NE subarctic Pacific (T2-2756)

10:30–11:00 *Coffee Break*

11:00–11:45 **David Timothy, C.S. Wong, Frank Whitney, Janet Barwell-Clarke and John Page**
Spatial and temporal trends in the flux of biogenic particles to deep waters of the subarctic Pacific Ocean (T2-2755)

11:45–12:30 **David L. Mackas**
Comparison of zooplankton time series (T2-2739)

12:30–14:00 *Lunch*

14:00–14:45 **Kenneth Denman, Angelica Peña and Bruce Frost**
Ecosystem modelling at Ocean station P: What have we learned about the Subarctic NE Pacific? (T2-2741)

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Posters

Jake Galbraith and William Crawford
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Michael S. Lipsen and Paul J. Harrison
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Adam H. Monahan and Kenneth L. Denman
Impacts of atmospheric variability on a coupled upper-ocean/ecosystem model of the subarctic Northeast Pacific (T2-2733)

Philippe D. Tortell, Nina Nemcek and Celine Gueguen
Real-time gas measurements in oceanic waters made by membrane inlet mass spectrometry (T2-2750)

Frank A. Whitney and Howard J. Freeland
Oxygen declines in the interior of the subarctic NE Pacific (T2-2722)

C.S. Wong, Liusen Xie and William Hsieh
Variation of nutrients and carbon caused by regime shift at Station P/Line-P in sub-arctic Northeast Pacific (T2-2729)

T2-2746 Oral

Recent physical variability along Line-P, evidence and causes

Howard **Freeland** and Patrick Cummins

Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
Email: FreelandHJ@pac.dfo-mpo.gc.ca

This talk will review the history of variability in physical parameters along Line-P from the inception of the Line-P program to the present, but focusing on recent variability. We will describe the recent history of changes in the circulation field and recent changes in the density field that may be related to changes in the wind stress distribution over the Gulf of Alaska. The presentation will then progress to describe the nature of the wind-driven ocean variability and, through modelling experiments, relate variations in wind forcing to the historical record of observed variability at Station P and, more broadly, over the Gulf of Alaska. Implications for predictability over the region will be discussed.

T2-2756 Oral

Phytoplankton and upper ocean biogeochemical cycles along Line P in the NE subarctic Pacific

Angelica **Peña**[1] and Diana Varela[2]

[1] Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
E-mail: penaa@pac.dfo-mpo.gc.ca
[2] Department of Biology and School of Earth and Ocean Sciences, University of Victoria, P.O. Box 3020, Station CSC, Victoria, BC, V8W 3N5, Canada

Line P includes a series of oceanographic stations along a transect between the southwest corner of Vancouver Island to Ocean Station Papa, in the NE Pacific. Sampling along the line began in 1959 with 5 stations and in the next few years stations were gradually added, until a transect of 13 sampling sites was established in 1964. Since then several programs including the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Fluxes Study (JGOFS) and the GLObal ECosystem project (GLOBEC) have carried out studies along this coastal–oceanic transect. This long time series of observations has provided valuable information on the spatial and temporal variability of the planktonic ecosystem of the NE subarctic Pacific. Specifically, significant inshore and offshore gradients in phytoplankton abundance, primary production, nutrient uptake and community structure have been found. Biological processes are substantially different along the line as illustrated, for example, by the lack of nitrate depletion and iron limitation at Ocean Station Papa, a High Nitrate Low Chlorophyll (HNLC) region, and by marked seasonal changes in nutrient and phytoplankton concentration at inshore sites. Moreover, the last decade of sampling along Line P has shown that ENSO events could be responsible for significant interannual variability in nutrient supply to surface waters and the position of the oceanic boundary between HNLC and nitrate depleted regions. We will focus on the identification of chemical, biological and physical processes regulating spatial and temporal variability of primary production and carbon fluxes along Line P, and will speculate on how changes in oceanic processes affect shelf/slope primary productivity.

T2-2755 Oral

Spatial and temporal trends in the flux of biogenic particles to deep waters of the subarctic Pacific Ocean

David **Timothy**, C.S. Wong, Frank Whitney, Janet Barwell-Clarke and John Page

Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
Email: TimothyD@pac.dfo-mpo.gc.ca

Sinking particles have been collected by sediment traps at Ocean Station Papa (OSP: 50° N, 145° W) in the subarctic northeast Pacific Ocean since 1982. Temporal coverage in waters of 1000 m or greater has been approximately 17 of the past 23 years. In 1989 this time series was augmented by sediment traps deployed at 200 m, providing approximately 50% temporal coverage over the past 16 years. The deep sediment-trap time series from OSP provides nearly a quarter-century record of temporal variability including ENSO forcing, while biogenic export from the mixed layer is inferred from record of the 200-m traps. Other deployments provide spatial coverage of the sinking flux throughout the subarctic Pacific Ocean. At a station north of OSP (55° N, 145° W), a conical sediment trap was moored at 3700 m from June, 1990, to September, 1992, and recorded fluxes in the centre of the oligotrophic Alaska Gyre. A sediment trap has been successfully collecting sinking particles in ~700 m of water at La Perouse Bank near the coast of Vancouver Island (48° N, 126° W) for about 15 of the past 20 years, and between 1995 and 1997, traps deployed in deep waters (2700 m to 3500 m) at three stations along line P (48°–50° N) have generated a record of fluxes for the transitional waters between the highly productive coasts and the Alaska Gyre. Also, sediment traps were moored in deep waters (4300 m to 5300 m) at three stations in the subarctic northwest Pacific Ocean from August, 1991, to June, 1992. These stations cover a large area between 45° N and 51° N, and between 177° W and 165° E. We will present the climatological average flux for each of these sediment-trap time series, allowing us to contrast export dynamics in these different oceanographic regimes.

T2-2739 Oral

Comparison of zooplankton time series

David L. **Mackas**

Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
Email: MackasD@pac.dfo-mpo.gc.ca

The subarctic and mid-latitude North Pacific and its marginal seas include several of the world's longest and richest marine zooplankton time series. Examples include: Ocean Station P/Line P (sampled semi-continuously 1958–1981, and seasonally since 1981); the "Odate" collection from the western margin of the Pacific (1951–present); CalCOFI/IMECOCAL in the California Current (1951–present); Vancouver Island and Oregon continental margins (1969–1973 and 1979–present); "Oshoro Maru" summer surveys of the oceanic subarctic Pacific and Bering Sea (mid 1950s to present along various lines); and Korean coastal regions (1965–present).

Many within-data-set analyses have been completed, mostly since the early 1990s. Their results document large amplitude interannual–decadal changes in total zooplankton biomass, community composition, and body size and life cycle timing within individual species. In this paper, I will review highlights of this early work. I will then describe plans and some initial results from what we hope will be the next big step (the mandate of SCOR Working Group 125): a global comparison among available zooplankton time series to quantify correlation time and space scales, and to test for evidence of possible global 'teleconnections', similar to those that have been documented for small pelagic fishes in boundary current regions.

T2-2741 Oral

Ecosystem modelling at Ocean Station P: What have we learned about the Subarctic NE Pacific?

Kenneth **Denman**[1,2], Angelica Peña[2] and Bruce Frost[3]

[1] Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada, University of Victoria, Box 1700, STN CSC, Victoria, BC, V8W 2Y2, Canada. E-mail: ken.denman@ec.gc.ca
[2] Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
[3] School of Oceanography, University of Washington, Campus Box 357940, Seattle, WA, 98195-7940, U.S.A.

The long time series of oceanographic measurements collected during the Line P – Ocean Station P programme has provided an invaluable background both for special intensive physical and ecological projects and for the development of first mixed layer and then ecological models. Modelling projects have been integral to the major cooperative ecological studies: the SUbarctic Pacific Ecosystem Research project (SUPER), the Joint Global Ocean Fluxes Study (JGOFS), the GLObal ECosystem project (GLOBEC) and most recently, the Surface Ocean Lower Atmosphere Study (SOLAS). We consider there to be two basic roles for models. First, a model is an integrative data analysis tool, pulling together observations of different facets of the marine ecosystem such that as a minimum they must be expressed in the same 'currency' or units. Second, a model captures mathematically our various 'conceptual models' of the marine ecosystem and subjects them to consistency tests, with each other and with the available observations. In this context, we explore how successive ecosystems models have aided in the development of our understanding of what has become recognized as the classic High Nitrate Low Chlorophyll (HNLC) region of the world ocean. Starting from the elegant model of Evans and Parslow (1985), we consider the progression in our understanding of why there is no clear spring bloom in the Subarctic NE Pacific and why the major macronutrient nitrate is never limiting at OSP – from the idea of overwintering macrozooplankton grazers controlling the bloom, to consideration of the role of microzooplankton, to consideration of the role of the micronutrient iron, to acceptance and evaluation of the multiple and coupled roles of grazing, iron, silicic acid and physical circulation, both vertical and horizontal. Finally, we ask the important questions: are these models robust enough to predict future conditions of the Subarctic NE Pacific marine ecosystem in a changing climate; or will we need to include additional compartments/processes or 'plankton functional types'; and what will happen to marine ecosystems as the oceans continue to become more acidic?

T2-2748 Oral

Co-variability in the Northeast Pacific: Sources of variability in the California Current and Gulf of Alaska ecosystems

F.B. **Schwing**[1], S.J. Bograd[1], R. Mendelssohn[1], P.T. Strub[2] and A. Thomas[3]

[1] NOAA Fisheries Service, Southwest Fisheries Science Center, Environmental Research Division, 1352 Lighthouse Avenue, Pacific Grove, CA 93950-2097, U.S.A. E-mail: franklin.schwing@noaa.gov
[2] College of Oceanic and Atmospheric Sciences, Oregon State University, 104 COAS Admin. Bldg., Corvallis, OR 97331-5503, U.S.A.
[3] School of Marine Sciences, University of Maine, 5741 Libby Hall, Orono, ME 04469-5741, U.S.A.

It is widely believed that there is an out-of-phase variation between transports in the California Current System (CCS) and coastal Gulf of Alaska (CGOA), which is reflected in the biological production of the two ecosystems. This idea is based on low-frequency fluctuations in coastal physical variables (*e.g.*, sea level) as well as fish stock abundances, most notably salmon. However, large-scale coastal chlorophyll variability in the two systems appears to have varied in phase in recent years, and the characteristic relationship of salmon and other fish is less clear. Does this signify a change in the regional response of the Northeast Pacific to global climate variability? Interactions of large-scale atmospheric forcing with regional processes and coastal features create distinct localized responses to global climate variability. Heat, momentum, and material transported by the North Pacific Current (NPC) enter both coastal ecosystems, so basin-scale climate-induced variations in the NPC may have downstream impacts on the CCS and CGOA. We use satellite data, model output, and *in situ* observations to contrast variability in the CCS and CGOA transport and ocean properties on seasonal to decadal time scales and its ecosystem impacts, in the context of variable climate forcing. Observations from Line-P are vital in validating other data sources and providing a continuous time series characterizing the CGOA source water. We also examine how decadal climate variability has fluctuated in the last century. These comparative analyses allow for a qualitative comparison of the regionally distinct responses of the CCS and CGOA to large-scale climate forcing.

T2-2758 Poster

Temperature and salinity along Line-P: Fifty years of observations

Jake **Galbraith**[1] and William Crawford[2]

[1] 1920 Haltain St. Victoria BC, V8R 2L5, Canada. E-mail: jake.galbraith@home.com
[2] Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney BC, V8L 4B2, Canada

Accurate profiles of ocean temperature and salinity have been collected along Line-P since the 1950s, forming the Line-P series that extends from coastal waters out 1420 kilometres into the Gulf of Alaska. Data along these stations were sampled from 1950s to 1981 by Canadian Department of Transport weatherships on their way from Victoria, Canada, to Ocean Station Papa at 50°N, 145°W. Canadian Fisheries and Oceans research vessels took over sampling in 1981 when the weatherships program ended. These cruises are now undertaken by the Canadian Coast Guard. Throughout these years the ocean measurements have been managed by scientists of the Pacific Biological Station in Nanaimo, BC, and then by scientists of Fisheries and Oceans Canada at the Institute of Ocean Sciences in Sidney, BC. We used archived measurements of temperature and salinity to compute climatology of the seasonal cycle of these properties, as well as seawater density, at standard depths along Line-P. From these we computed time series anomalies of temperature and salinity averaged over several depth layers along Line-P. Results are presented graphically as Hovmøller plots, extending in time from 1950 to 2005 and in distance from Station P1 to P26 (OSP). Major climate events such as the sudden warming in 1976/77 and cooling in 1997/98 are clearly present in these plots. Density differences between near-surface waters and the 100-m layer have increased over the past 50 years. Interestingly, the top 150 metres of the ocean along Line-P in 1999 to 2002 were as cold as ever observed previously, despite the general warming since 1950. Since 2001 the top 100 metres have been significantly fresher than the 50-year-average. These observations will continue (we hope) to be collected, and will form a significant contribution to ocean climate programs.

T2-2734 Poster

Modelling of dimethylsulfide dynamics in the NE Pacific

Yvonnick **Le Clainche**[1], Maurice Levasseur[1], Alain Vézina[2], Ken Denman[3], Nadja Steiner[4] and C.S. Wong[3]

[1] Université Laval, Québec-Océan, pavillon Alexandre-Vachon, Québec, QC, G1K 7P4, Canada. E-mail: yvonick.leclainche@giroq.ulaval.ca
[2] Fisheries and Ocean Canada, Bedford Institute of Oceanography, 1 Challenger Drive, Dartmouth, NS, B2Y 4A2, Canada
[3] Fisheries and Ocean Canada, Institute of Ocean Sciences, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
[4] Canadian Centre for Climate Modelling and Analysis, University of Victoria, P.O. Box 1700, Victoria, BC, V8W 2Y2, Canada

The subarctic Northeast Pacific is known as an oceanic High-Nutrient Low-Chlorophyll (HNLC) region characterized by little seasonal variability. In spite of the low biomass, the concentrations of the climate-active gas dimethylsulfide (DMS) may be extremely high (> 20 nM) in summer. Current parameterizations used in climate models do not reproduce these high DMS emissions. Causes for the high DMS levels, and their potential link with the Fe-limited conditions prevailing at Ocean Station Papa (OSP), were investigated during the C-SOLAS program. DMS observations at OSP and results from the Subarctic Ecosystem Response to Iron Enrichment Study (SERIES) conduced in July 2002 were used to develop a new ocean DMS production model for the NE Pacific. The model is based on an existing 7-component ecosystem model (2 size classes for both phytoplankton and zooplankton) with Fe limitation calibrated at OSP. Sulfur fluxes linked to DMS cycle were introduced in the model in parallel with the nitrogen fluxes. New parameterizations of DMS yield (efficiency of bacterial DMS conversion) and DMS photodegradation by UV light were defined. This biogeochemical model was coupled to a physical upper ocean turbulent model (GOTM; General Ocean Turbulent Model) and used to simulate mean seasonal cycle of marine DMS at OSP and to address the sensitivity to iron-induced changes in the biological cycling of DMS.

T2-2754 Poster

Variation of organic and inorganic carbon uptake along Line P in the NE subarctic Pacific during the 1998 El Niño and the 1999 La Niña as well as 2000

Michael S. **Lipsen** and P.J. Harrison

Earth and Ocean Sciences, University of British Columbia, 6270 University Blvd., Vancouver, BC, V6T 1Z4, Canada. E-mail: mlipsen@eos.ubc.ca

Presented in this study are the size fractionated chlorophyll *a*, coccolithophore cell numbers, and primary productivity (organic and inorganic) values along line P for the winter, spring, and late summer for the years 1998 to 2000. Our results agree with the earlier findings that show the inshore stations to follow the classical seasonal cycle of spring and late summer blooms controlled by macronutrient concentrations with varying algal cells dominating depending on the season. The offshore stations (including OSP) exhibited low seasonality in biomass with a moderate seasonality in primary production. These stations were always dominated small algal cells. The 1998 year displayed a strong El Niño signal with a shallowing of the mixed layer and low coastal biomass followed by higher biomass at the offshore stations. Conversely, 1999 showed a strong La Niña signal and followed a somewhat opposite pattern from 1998 (Whitney, 2000). Coccolithophore (dominated by *Emiliana huxleyi* in most but not all cases) cell numbers were higher in 1998 with cell numbers reaching 100 cells per ml near the coast in February, at OSP in June and at P16 in early September. 1999 showed much lower concentrations throughout the year. Coccolithophore concentrations in 2000 were even higher with a 7 fold increase at OSP in June and at P12 in late August. Calcification values did not clearly follow coccolithophore concentrations. Inorganic carbon uptake rates were highest in June 1998 with very low inorganic production in all of 1999. June of 2000 demonstrated values consistent with 1998 while August/September of 2000 showed the highest values of all three years near the surface from P16 to OSP. We will attempt to explain the effects of the El Niño and La Niña on the biomass and productivity along Line P in terms of their size fraction and calcite production.

T2-2733 Poster

Impacts of atmospheric variability on a coupled upper-ocean /ecosystem model of the subarctic Northeast Pacific

Adam H. **Monahan**[1] and Kenneth L. Denman[2,3]

[1] School of Earth and Ocean Sciences, University of Victoria, P.O. Box 3055 STN CSC Victoria, BC, V8W 3P6, Canada. E-mail: monahana@uvic.ca
[2] Canadian Centre for Climate Modelling and Analysis, University of Victoria, P.O. Box 1700, STN CSC, Victoria, BC, V8W 2Y2, Canada
[3] Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada

Previous studies of coupled upper-ocean/planktonic ecosystem dynamics have considered models forced by observed atmospheric variability or by smooth annual and diurnal cycles. The second approach has the drawback that environmental variability is ubiquitous in the climate system, and may have a nontrivial impact on the (nonlinear) dynamics of the system, while the first approach is limited by the fact that observed time series are generally too short to obtain statistically robust characterisations of variability. In the present study, an empirical stochastic model of high-frequency atmospheric variability is estimated from long term observations at Ocean Station Papa in the subarctic Northeast Pacific. This empirical model is used to produce 1000-year realisations of atmospheric variability which are used to drive a coupled upper-ocean/ecosystem model. It is found that fluctuations in atmospheric forcing do not have a qualitative impact on most aspects of the dynamics of the ecosystem when primary production is limited by iron availability, although pronounced interannual variability in diatom abundance is simulated (even in the absence of episodic iron fertilisation). In contrast, the impacts of atmospheric variability are considerably more significant when phytoplankton growth is limited by nitrogen availability. Furthermore, the high-frequency variability in atmospheric forcing produces regions in parameter space in which the system alternates between iron and nitrogen limitation on interannual to interdecadal timescales. Both the mean and variability of export production are found to be significantly larger in the nitrogen-limited regime than in the iron-limited regime.

T2-2750 Poster

Real-time gas measurements in oceanic waters made by membrane inlet mass spectrometry

Philippe. D. **Tortell**, Nina Nemcek and Celine Gueguen

Dept. of Earth and Ocean Sciences, University of British Columbia, 6270 University Blvd. Vancouver, BC, V6T 1Z4, Canada. E-mail: ptortell@eos.ubc.ca

Dissolved gases provide powerful tracers of physical and biogeochemical processes in the oceans, particularly when multiple gases are measured simultaneously. For example, O_2 / Ar ratios can be used to examine net biological oxygen cycling independently of temperature and salinity effects, while N_2 / Ar ratios can be used to trace bubble mediated bubble exchange. Over the past few years, we have developed a ship-board method for high frequency dissolved gas analysis using membrane inlet mass spectrometry (MIMS). This method enables multiple gas species (CO_2, O_2, N_2, Ar, DMS) to be measured several times per minute with an accuracy and precision that is comparable to other existing techniques. Application of MIMS on a number of cruises to the Subarctic Pacific, Bering Sea and Ross Sea has revealed very fine-scale variability in all gases. Concentrations of DMS are particularly variable with large changes observed over sub-km spatial scales that are impossible to resolve using conventional methods. In all regions thus far studied, CO_2 and O_2 / Ar display a strong anti-correlation (reflecting the imprint of photosynthesis and respiration), and their distribution is related to both temperature and chlorophyll *a* (*i.e.* phytoplankton biomass). In contrast, DMS concentrations are often poorly correlated to other gases and physical parameters. However, this gas appears to covary with chlorophyll *a* levels, and the chl*a* / mixed layer depth ratio as observed in previous studies. We propose to integrate MIMS measurements into the future Line P program to better characterize the spatial and temporal variable of dissolved gases in the NE Pacific. This work will provide new constraints on a number of biogeochemical process (*e.g.* primary production, CO_2 fluxes, air–sea gas exchange), and provide much needed data on the distribution of DMS.

T2-2722 Poster

Oxygen declines in the interior of the subarctic NE Pacific

Frank A. **Whitney** and Howard J. Freeland

Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
E-mail: whitneyf@pac.dfo-mpo.gc.ca

A common result of ocean surveys over the past 20 years in the North Pacific has been the observance of oxygen declines in subarctic waters, especially on isopycnal surfaces between 26.5 and 27.0. The 50 year record of this trend at Ocean Station Papa shows there are periods of net oxygen utilization and periods of net ventilation. In particular, the period between 1994 and 2003 saw a persistent decline in oxygen concentrations in the interior ocean. A weak reoxygenation period has been seen in 2005, perhaps in response to a period of winter ventilation in 2002 off the Japanese coast. The implications on both periods of oxygen decline and the long term trend towards lower oxygen is discussed with regard to potential impacts on NE Pacific coastal ecosystems.

T2-2729 Poster

Variation of nutrients and carbon caused by regime shift at Station P /Line P in sub-arctic Northeast Pacific

C.S. **Wong**[1], Liusen Xie[1] and William Hsieh[2]

[1] Climate Chemistry Laboratory, Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, 9860 W. Saanich Rd., Sidney, BC, V8L 4B2, Canada. E-mail: WongCS@pac.dfo-mpo.gc.ca

[2] Dept. of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Rd., Vancouver, BC, V6T 1Z4, Canada

Using time series data collected at Station P (50°N, 145°W) and stations along Line P, long-term changes in 8 oceanographic and chemical components of sea surface temperature (SST), salinity, oxygen, phosphate (PO_4), silicate (SiO_4), nitrate (NO_3), dissolved inorganic carbon (DIC), and apparent oxygen utilisation (AOU) are examined. Results show that these components are affected by regime shifts. This is marked by a "step change" of anomalies for nutrients and carbon in sub-arctic Pacific occurring during the 1976–77 and 1988–89 regime shifts. The response of nutrients and carbon to regime shift was more intensive in 1977 than in 1989. The anomalies of salinity, PO_4, SiO_4, NO_3, oxygen and DIC show positive signals from 1950–1976 and negative from 1976-1996. The change of components through the 1976–77 regime shift is significant (marked as a sign change). Compared to the shift in 1976–77, the variation of the nutrients and carbon in 1989 is relative weak and indicates only magnitude change. In the sub-arctic Pacific, the effect of La Niña on nutrients and carbon is larger that the effect exerted by El Niño. The variation in characteristics of nutrients and carbon is increasing continually and reached a peak after several El Niño events. Strong La Niña events (*e.g.*, 1989) caused a sudden decrease of nutrients and carbon. Two regime shifts (1976–77 and 1988–89) occurred just after two strong La Niña events in 1975–76 and 1988–1989. The reasons are found in the atmospheric system and wind variation. Upwelling plays an important role. The change in nutrients and carbon produced by regime shifts is more severe in coastal regions than in the open ocean. By combining effects on the coasts and the open-ocean, the variations of nutrients and carbon in 1976–77 and 1988–89 are the same in magnitude.

Theme 3 Process studies in the NE Pacific

Friday, July 7, 2006 9:00–

09:00–09:45 **Svein Vagle**
Factors influencing gas exchange: Observations and modelling (T3-2757)

09:45–10:30 **Jay T. Cullen**
The importance of trace metal nutrients for marine phytoplankton and bacteria along Line-P (T3-2768)

10:30–11:30 ***Poster Session***

11:30–12:15 **William Crawford, Hiroji Onishi, Hiromichi Ueno and Frank Whitney**
Influence of eddies and mesoscale variability in the Gulf of Alaska (T3-2747)

12:15–14:00 *Lunch*

14:00–14:45 **Maurice Levasseur, Paul Harrison, Phillip Boyd, Atsushi Tsuda, C.S. Wong, Michael Scarratt, Anissa Merzouk, Sonia Michaud, Yvonnick Le Clainche and Richard Rivkin**
SERIES – A test for the iron–climate hypothesis in the NE Subarctic Pacific (T3-2735)

14:45– ***Panel Discussion***

Posters

Meghan Cronin and Christopher Sabine
KEO, a time series reference site in the Kuroshio Extension recirculation gyre (T3-2740)

Michael Dagg, Hongbin Liu and Suzanne Strom
Neocalanus spp. and food web structure in the HNLC Gulf of Alaska (T3-2745)

Rana W. El-Sabaawi and Paul J. Harrison
Interactive effects of irradiance and temperature on the photosynthetic physiology of the pennate diatom *Pseudo-nitzschia granii* (Bacillariophyceae) isolated from Ocean Station P (T3-2736)

Wm. Keith Johnson, C.S. Wong, Nes Sutherland, Jun Nishioka and Shigenobo Takeda
Iron distributions, enhancement, and transport in the Gulf of Alaska (T3-2752)

Tairu Salami
West African weather systems in the development of tropical cyclones (T3-2759)

Nadja Steiner, Ken Denman, Svein Vagle, Norm McFarlane and Larry Solheim
Simulating Canadian SOLAS experiments at OSP with a 1-D coupled atmosphere–ocean–biogeochemical model (T3-2731)

Hiroji Onishi, Hiromichi Ueno and William R. Crawford
Effects of warm eddies on temperature inversions in the Gulf of Alaska (T3-2726)

Hiromichi Ueno, Eitarou Oka, Toshio Suga, Hiroji Onishi and Dean Roemmich
Seasonal and interannual variability of temperature inversions in the NE Pacific (T3-2725)

Patricia A. Wheeler and Jennifer Jarrell Wetz
Biogeochemical characteristics of coastal phytoplankton blooms (T3-2738)

Michael S. Wetz, Burke Hales, Zanna Chase, Patricia A. Wheeler and Michael M. Whitney
Riverine input of macronutrients, iron, and organic matter to the coastal ocean off Oregon, U.S.A., during the winter (T3-2732)

T3-2757 Oral

Factors influencing gas exchange: Observations and modelling

Svein **Vagle**

Ocean Sciences Division, Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada. E-mail: vagles@pac.dfo-mpo.gc.ca

Knowledge of mechanisms underlying air–sea exchange is essential to create realistic numerical simulations of biogeochemical and physical processes and feedbacks within the context of changing forcing and climate change. To address this it is necessary to execute intensive process studies combined with remote sensing and modelling. The international SOLAS (Surface Ocean Lower Atmosphere Study) Implementation Plan states that air–sea exchange experiments should take place in areas where there is a significant flux of climate relevant gases and where the "auxiliary" forcing can be separated from wind forcing. In particular it is important to investigate the role of surfactants, fetch, precipitation, wave field and bubbles.

Since September 2002 we have been collecting N_2, O_2, pCO_2, temperature, salinity, fluorescence, PAR, wind speed, precipitation rates, bubble concentrations and bubble penetration depths, and advection in the upper ocean boundary layer approximately every 2 hours at several depths from approximately 20m to 100m on a mooring at Ocean Station Papa (OSP). This data set in addition to the historical data set available for OSP combined with ship based measurements and mooring servicing opportunities available through the Line P program, makes this process study quite unique.

Here we discuss some of the factors influencing open ocean gas exchange by using available mooring data and some state of the art modelling. (This work is supported by CFCAS, NSERC, and DFO.)

T3-2768 Oral

The importance of trace metal nutrients for marine phytoplankton and bacteria along Line-P

Jay T. **Cullen**

School of Earth and Ocean Sciences, University of Victoria, P.O. Box 3055 STN CSC, Victoria, BC, V8W 3P6, Canada. E-mail: jcullen@uvic.ca

Our understanding of the biogeochemistry of trace metals has grown significantly over the last 30 years owing, in part, to seminal work carried out along Line-P. Trace nutrients, despite concentrations that are 6 to 9 orders of magnitude lower than the inorganic macro nutrients (C, N and P) can control the marine biogeochemical cycling of carbon and nitrogen through the hydrosphere. Early work in the Alaskan gyre helped to shape the "Iron Hypothesis" where the availability of iron was posited to be the main control on rates of marine carbon fixation and nitrogen acquisition in high nutrient–low chlorophyll areas of the world ocean. As part of the Line-P program studies of trace metal distributions, chemical speciation and investigations of the physiological ecology of heterotrophic and autotrophic microbes have greatly improved our understanding of the interactions between trace metals, microbes and ocean biogeochemical cycles. Indeed, continuing work along Line-P will probe the importance of metal–metal interactions and the co-limitation of microbial growth by metals and other substrates for modulating the community composition and determining the fate of climatologically active gases in ocean surface waters. The history and past successes of the Line-P program represent a clear challenge to marine biogeochemists whose goal is to determine the nature of the interactions between trace metal nutrients, microbial ecology, and the transformations of carbon and nitrogen at the ocean margins.

T3-2747 Oral

Influence of eddies and mesoscale variability in the Gulf of Alaska

William **Crawford**[1], Hiroji Onishi[2], Hiromichi Ueno[3] and Frank Whitney[1]

[1] Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada
Email: crawfordb@pac.dfo-mpo.gc.ca
[2] Division of Marine Bioresource and Environmental Science, Graduate School of Fisheries Science, Hokkaido University, 3-1-1 Minato-cho, Hakodate, 041-8611, Japan
[3] Institute of Observational Research for Global Change, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima-cho Yokosuka, 237-0061, Japan

Satellite and ship-based observations of mesoscale eddies demonstrate their significant impact on cross-shelf exchange of heat, fresh water, macro- and micro-nutrients, phytoplankton and zooplankton. These observations track shelf features into the adjacent deep-sea waters and influx of offshore waters onto the shelf. Coastally generated mesoscale eddies generally hold fresher and warmer coastal waters in the upper 500 metres than are present at similar depths in the Gulf of Alaska. Sub-surface waters of eddies carry higher concentrations of iron and macro-nutrients than observed in surrounding waters of similar density. Eddy features are also examined in data records of Argo floats launched into the gulf in this century. Argo profilers sense salinity and temperature to high accuracy from 2000 metres up to the surface every 10 days, and many Argo floats have been launched into Haida Eddies that form in the Pacific Ocean off the northwest coast of Canada. Warm sub-surface water in eddies creates a temperature inversion in and below the halocline in the gulf that can be used to determine the presence and impact of these eddies. This region of the halocline, also denoted a mesothermal layer, lies at depths where the vertical temperature gradient is small and the salt gradient determines the density profile. Observations of dynamic heights at surface and in subsurface layers suggest eddies are able to deflect the eastward flow of the North Pacific Current toward the north, with significant impact on coastal ecosystems. Eddies may also stir and diffuse waters along the sub-polar front in the northeast Gulf of Alaska, and provide micro- and macro-nutrients into the euphotic zone as they decay. There is evidence that occasional mid-gulf plankton blooms are supported in eddy centres, due to nutrient enrichment, when no blooms appear in surrounding waters.

T3-2735 Oral

SERIES – A test for the iron–climate hypothesis in the NE Subarctic Pacific

Maurice **Levasseur**[1], Paul Harrison[2], Phillip Boyd[3], Atsushi Tsuda[4], C.S. Wong[5], Michael Scarratt[6], Anissa Merzouk[1], Sonia Michaud[6], Yvonnick Le Clainche[1] and Richard Rivkin[7]

[1] Université Laval, Département de biologie (Québec-Océan), Pavillon Alexandre-Vachon, QC, G1K 7P4, Canada. E-mail : maurice.levasseur@bio.ulaval.ca
[2] Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
[3] NIWA Centre for Chemical and Physical Oceanography, Department of Chemistry, University of Otago, Dunedin, New Zealand
[4] Ocean Research Institute, University of Tokyo, Nakano, Tokyo, Japan
[5] Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada
[6] Fisheries and Oceans Canada, Maurice Lamontagne Institute, Mont-Joli, QC, Canada
[7] Memorial University of Newfoundland, St-John's, NL, Canada

Episodes of elevated iron supply to the ocean over geological timescales resulting in enhanced algal productivity are hypothesized to alter global climate by increasing both sequestration of biogenic carbon to the Deep Ocean and cloud albedo *via* the formation of algal-derived sulfur aerosols. In support of this hypothesis, several mesoscale iron-enrichments conducted during the last 10 years in iron-limited oceanic regions have shown increased algal growth and uptake of atmospheric CO_2 in surface waters, and up to fivefold increase in the concentrations of dimethylsulfide (DMS), a biogenic gas that produces sulfur aerosols. In July 2002, we conducted a large scale iron fertilization experiment (Subarctic Ecosystem Response to Iron Enrichment Study – SERIES) in the Northeast Pacific as part of the Canadian SOLAS Program (Surface Ocean – Lower Atmosphere Study) in order to determine the influence of this limiting micronutrient on the dynamics of climate relevant gases. The addition of iron resulted in an important increase in phytoplankton biomass and a moderate increase in carbon sequestration. In contrast with previous experiments, the iron fertilization resulted in a decrease in DMS concentrations. The decrease in DMS levels coincided with an increase in bacterial production and a marked shift in the bacterial metabolism of dimethylsulfoniopropionate (DMSP), the algal precursor of DMS. Iron-enrichment resulted thus in both a low efficiency of carbon export and a reduction in DMS concentrations, leading to conditions that would not mitigate greenhouse warming. Causes and consequences of this unexpected response will be discussed during this talk.

T3-2740 Poster

KEO, a time series reference site in the Kuroshio Extension recirculation gyre

Meghan **Cronin** and Chris Sabine

NOAA Pacific Marine Environmental Laboratory, 7600 Sand Point Way, Seattle, WA 98115, USA.
E-mail: Meghan.F.Cronin@noaa.gov

A surface mooring, the Kuroshio Extension Observatory (KEO), was deployed in June 2004 in the Kuroshio Extension recirculation gyre at 32.3N, 144.5E as a component of the global network of OceanSITES time series reference sites and as a component of the Kuroshio Extension System Study (KESS) process study. In this presentation, we use the KEO mooring data to assess air–sea heat flux estimates from numerical weather prediction reanalysis products. In addition, KEO data are combined with KESS data to analysis of the upper ocean heat budget at the KEO site and determine the processes involved in changes in the recirculation gyre's heat content. A similar type of mooring with additional biogeochemical sensor enhancements has been proposed to be deployed at station P in Spring 2007.

T3-2745 Poster

Neocalanus spp. and food web structure in the HNLC Gulf of Alaska

Michael **Dagg**[1], Hongbin Liu[1] and Suzanne Strom[2]

[1] Louisiana Universities Marine Consortium, 8124 Highway 56, Chauvin, LA, 70344 U.S.A.
E-mail: mdagg@lumcon.edu
[2] Shannon Point Marine Center, Western Washington University, 1900 Shannon Point Road, Anacortes, WA 98221-4042, U.S.A.

The open Gulf of Alaska is a High Nutrient Low Chlorophyll (HNLC) system, characterized by low concentrations of phytoplankton, a community dominated by small cells, and iron limitation of, especially, the larger phytoplankton, the diatoms. Recent data indicate the contribution made by *Neocalanus* spp. to establishing and maintaining the community structure of the subarctic HNLC ecosystem should be re-evaluated. Shipboard experiments indicate *Neocalanus* spp. have very high clearance rates, often several liters copepod^{-1} d^{-1}, on large phytoplankton and microzooplankton but are unable to consume small particles < 5 μm. This selective removal contributes to establishment and maintenance of the observed structure the foodweb in the Gulf of Alaska. *Neocalanus* spp. (a) directly prevent the accumulation of large phytoplankton cells (which are growing slowly due to iron limitation but nevertheless are growing), and (b) indirectly stimulate the accumulation of the smaller phytoplankton by consumption of their major predators, the microzooplankton. Key components of this revision are: low growth rates of large cells due to iron limitation; low concentrations of large cells that result in high (maximum) clearance rates by copepods; copepod consumption of microzooplankton that otherwise would consume smaller phytoplankton; and large populations of *Neocalanus* spp. concentrated in the photic zone.

T3-2736 Poster

Interactive effects of irradiance and temperature on the photosynthetic physiology of the pennate diatom *Pseudo-nitzschia granii* (Bacillariophyceae) isolated from Ocean Station P

Rana W. **El-Sabaawi**[1] and Paul J. Harrison[2]

[1] Department of Botany, University of British Columbia, 6270 University Blvd., Vancouver, BC, V6T 1Z4, Canada
Current address: Department of Biology, University of Victoria, P.O. Box 3020, Station CSC, Victoria, BC, V8W 3N5, Canada. Email: rana@uvic.ca

[2] Departments of Botany, and Earth and Ocean Sciences, University of British Columbia, 6270 University Blvd., Vancouver, BC, V6T 1Z4, Canada
Current address: AMCE Program, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong

Ocean Station P diatoms have been shown to be co-limited by light and iron in the winter season. Winter is also the time of the lowest surface temperature in the region. A few studies have shown that the effects of light and temperature are interlinked in algae, but the extent of this has not been investigated in oceanic diatoms. This study examines how light and temperature interact to influence growth rates, chlorophyll *a* and photosynthetic efficiency in the oceanic pennate diatom *Pseudo-nitzschia granii*, isolated from Ocean Station P. This species does not grow beyond 20°C, and the relationship between growth and temperature in this diatom is similar to Arctic as apposed to temperate diatoms. Growth rates are modulated by both light and temperature but are always greatest at ~14°C. Chlorophyll *a* per cell is affected primarily by temperature, except at the maximum chlorophyll *a* per cell (at 10°C) where the effects of light are noticeable. At both ends of the temperature gradient, cells display evidence of chlorosis even at low light intensities. Chlorophyll fluorescence data suggest that cells at 8°C are significantly more efficient in their photosynthetic processes than cells at 20°C despite having comparable amounts of chlorophyll. Cells at low temperature show photosynthetic characteristics similar to high-irradiance adapted cells. These data indicate that low temperature may actually improve the cell's ability to live at low light levels. The decline of growth rates beyond the optimum growth temperature coincides with the cell's inability to accumulate chlorophyll in response to increasing temperature. The decline in photosynthetic ability at 20°C is likely due to a combination of high-temperature stress on cellular membranes and a decline in chlorophyll. Our results highlight the importance of the interactions between light and temperature and the need to incorporate them in the development of phytoplankton models for the subarctic Pacific.

T3-2752 Poster

Iron distributions, enhancement, and transport in the Gulf of Alaska

Wm. Keith **Johnson**[1], C.S. Wong[1], N. Sutherland[1], J. Nishioka[2] and S. Takeda[3]

[1] Climate Chemistry Laboratory, Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada. E-mail: johnsonk@pac.dfo-mpo.gc.ca
[2] Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819, Japan
[3] Department of Aquatic Bioscience, Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan

Low iron values have been shown to be a major cause for limiting phytoplankton growth in large high-nitrate low-chlorophyll (HNLC) areas of the world oceans which includes the Gulf of Alaska. Iron values at Ocean Station Papa (OSP or P26) measured over the last decade have proven that OSP is one of the most iron depleted areas in the oceans. Surface mixed layer values have frequently been as low as 0.02 nM. Episodic events such as dust storms, eddies and anomalous gyre circulation elevate the surface iron concentrations in the Gulf of Alaska resulting in increased productivity. In 2002 a mesoscale iron enrichment experiment was conducted near OSP to observe the biological and biogeochemical responses to the added iron. Iron concentrations were elevated 2 orders of magnitude above ambient levels. We analyzed 5 fractions or phases of iron: soluble (<0.03 μm), dissolved (<0.22 μm), total dissolved (acidified dissolved, <0.22 μm), labile (unfiltered), and total (acidified, unfiltered). From these, we also calculate non-labile iron, colloidal iron (0.03–0.22μm), and both labile and non-labile particulate iron (>0.22 μm). Here, we describe iron distributions and the evolution of iron phases in the upper ocean during the enhancement experiment and compare with natural elevated iron events.

T3-2759 Poster

West African weather systems in the development of tropical cyclones

T. **Salami**[1], O.S. Idowu[2] and E.E Balogun[3]

[1] Forecast Office, Nigerian Meteorological Agency, Murtala Mohamed International Airport Ikeja Lagos, P.M.B. 1215, Oshodi Lagos, Nigeria
[2] Central Forecast Office, Nigerian Meteorological Agency, P.M.B. 1215, Oshodi, Lagos, Nigeria E-mail: oluseun_idowu@yahoo.com
[3] Department of Physics, Obafemi Awolowo University Ile Ife Osun State, Nigeria

Tropical cyclones have their origins from areas of low atmospheric pressure over warm waters in the tropics or subtropics. We have carefully studied the interconnection between the West African Weather Systems (WAWS) and their subsequent development into Tropical Cyclones.

Between 2004 and 2005, we studied the interconnection and the teleconnection between the WAWS and the various occurrences of Tropical Cyclones and their eventual development into Hurricanes. We noted that critical synoptic characteristic and the environmental properties of the Systems; the thermodynamic conditions of the storms trajectory and the conditions of the ocean are all closely linked. It is therefore believed that proper understanding and monitoring of these systems will play a very vital role in early detection of potential WAWS that may develop into Tropical Cyclones and even Hurricanes. More practical issues will be presented.

It was recorded that over the period 1992–2001, weather and climate-related disasters especially those of Tropical Cyclones origin killed about 622 000 people, affected more than two billion, left millions more homeless, devastated arable land and spread diseases.

T3-2731 Poster

Simulating Canadian SOLAS experiments at OSP with a 1-D coupled atmosphere-ocean-biogeochemical model

Nadja **Steiner**[1], Ken Denman[2,3], Svein Vagle[2], Norm McFarlane[3] and Larry Solheim[3]

[1] School of Earth and Ocean Sciences, University of Victoria, CCCma, 3964 Gordon Head Rd., Victoria, BC, V8N 3X3, Canada. E-mail: nadja.steiner@ec.gc.ca
[2] Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada
[3] MSC, Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada

The Canadian SOLAS program has been running for the past 5 years with a strong component focusing around Ocean Station Papa (OSP). As part of Canadian SOLAS we have developed a 1-D atmosphere-ocean-biogeochemical model to investigate the coupling between atmosphere–ocean exchanges and the planktonic ecosystem at OSP. The atmospheric Single Column Model (SCM) is based on the CCCma Atmospheric General Circulation Model. The ocean component employs the General Ocean Turbulence Model (GOTM). A 7-component ecosystem model is embedded in GOTM, which includes nitrogen, carbon, silica, oxygen and DMS (currently tested) cycling. The model is applied to the following C-SOLAS experiments: First, we used observations from the Subarctic Ecosystem Response to Iron Enrichment Study (SERIES) in 2002 combined with atmospheric reanalysis data (NCEP, ECMWF) to initiate and force the coupled physical model. We studied the models sensitivity to forcing, vertical resolution and timing of fertilization. Results show that during SERIES, shallow boundary layer heights occurring when DMS production was highest suppressed dispersion into the atmosphere; and that strength and length of the response to iron enrichment at OSP depend strongly on short term atmospheric conditions. Second, we simulated time periods of the North East Pacific SOLAS mooring, which has been maintained since September 2002. In addition to CTD recorders the mooring is equipped with Gas tension devices at four depths, oxygen sensors and fluorometers for chlorophyll estimates. Here, we focused on the intercomparison of simulated and observed nitrogen and oxygen variability. A strong chlorophyll signal observed in summer 2003 and a weaker signal in May 2004 can be explained by natural iron input either laterally or from below the mixed layer.

T3-2726 Poster

Effects of warm eddies on temperature inversions in the Gulf of Alaska

Hiroji Onishi[1], Hiromichi **Ueno**[2] and William R. Crawford[3]

[1] Division of Marine Bioresource and Environmental Science, Graduate School of Fisheries Science, Hokkaido University, 3-1-1 Minato-cho, Hakodate, 041-8611, Japan. E-mail: onishi@fish.hokudai.ac.jp
[2] Institute of Observational Research for Global Change, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima-cho Yokosuka, 237-0061 Japan
[3] Ocean Sciences Division, Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, 9860 West Saanich Rd., Sidney, B.C., Canada

Warm anticyclonic eddies in the Gulf of Alaska have an important role in bringing micro-nutrients from coastal areas to off-shore HNLC (High Nutrients and Low Chlorophylls) regions. They also bring heat in sub-surface waters, forming temperature inversions (T-invs) in mesothermal layers. In the subarctic North Pacific, the seasonal cycle of surface heating and cooling also forms temperature inversions having mesothermal and/or dicothermal structures. In this study, hydrographic data from Argo profiling floats obtained during 2001–2005 were analysed to compare the distribution of T-invs and their intensity with the distribution of warm eddies distinguished by dynamic height (100/1000 m) in Argo profiles. Using anomalies from the standard dynamic heights of the World Ocean Atlas 2001 annual data in each small area (Lat. 2.5° × Long. 5.0°) set in the Gulf of Alaska, some threshold levels of anomalies were established. Distribution of large-scale warm eddies (over 0.05 dyn.m) in this study is similar to the previous results of track charts of Sitka and Haida Eddies. Large T-invs and large scale eddies were not observed for all years in the central region of the Alaskan Gyre where water structure under a strong shallow halocline is very stable. On the other hand, many large T-invs were observed in the Alaska Current east of 145°W and the Alaskan Stream, and about 30% of them were located in eddies (over 0.01 dyn.m). Significantly, about half of large T-invs were observed in warm eddies in 2004 and 2005 when winter cooling was small and thus large T-invs were rarely observed. On the other hand, after a severe autumn and winter cooling in 2001-2002, the locations of most of the large T-invs were independent of the distribution of warm eddies.

T3-2725 Poster

Seasonal and interannual variability of temperature inversions in the NE Pacific

Hiromichi **Ueno**[1], Eitarou Oka[1], Toshio Suga[1,2], Hiroji Onishi[3] and Dean Roemmich[4]

[1] Institute of Observational Research for Global Change, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima-cho Yokosuka, 237-0061, Japan. E-mail: uenohiro@jamstec.go.jp
[2] Department of Geophysics, Graduate School of Science, Tohoku University, Aoba-ku, Sendai, 980-8587, Japan
[3] Division of Marine Bioresource and Environmental Science, Graduate School of Fisheries Science, Hokkaido University, 3-1-1 Minato-cho, Hakodate, 041-8611, Japan
[4] Scripps Institution of Oceanography, UCSD, 9500 Gilman Drive, La Jolla, CA 92014, U.S.A.

Hydrographic data from Argo profiling floats obtained during 2001–2005 and from expendable bathythermograph observation during 1993–2005 (HR XBT Program, Line PX38) were analyzed to study seasonal and interannual variability of temperature inversions in the NE pacific. In the northern part of the NE pacific (130º–160ºW, 52º–60ºN), the temperature minimum at the top of temperature inversions outcropped and was renewed every winter except in winter 2003, causing a seasonal cycle in the magnitude of temperature inversions (ΔT), with the maximum at the end of winter. In winter 2003, the temperature minimum scarcely outcropped, and consequently ΔT showed remarkable interannual variation: its monotonic decrease through winter 2003 overwhelmed the seasonal cycle. On the other hand, in the southern part (140º–160ºW, 42º–48ºN), ΔT did not show a seasonal cycle. The ΔT was around 0.3ºC during 1993–1998, rapidly increased during 1998–1999, decreased a little in the latter half of 1999, kept around 0.7ºC during 2000–2003, and decreased in 2004. In winters 1998 and 1999 when ΔT rapidly increased, SST was much colder than that in the previous winter and temperature minimum outcropped, which increased ΔT in both years. This indicates that in the area of 140º–160ºW, 42º–48ºN, where temperature inversions were thought to be formed by advection, temperature inversions were formed in the in situ winter mixed layer at least in 1999 and 2000. In the meanwhile, temperature inversions were formed by advection during 1993–1997 and 2000–2005, and ΔT during 2000–2003 were larger than that during 1993–1997. This could be because of the intensification of eastward North Pacific Current around 1997.

T3-2738 Poster

Biogeochemical characteristics of coastal phytoplankton blooms

Patricia A. Wheeler and Jennifer Jarrell **Wetz**

College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331, U.S.A.
E-mail: pwheeler@coas.oregonstate.edu

As part of the U.S. GLOBEC Northeast Pacific Program we made repeated seasonal hydrographic surveys in the northern California Current system between September 1997 and September 2003. Here we compare summer upwelling (July–August) observations for four hydrographic sections during 2000 through 2003. During these summer cruises we observed 24 phytoplankton blooms (defined as stations with three or more depths with total organic carbon (TOC) > 80 μM). For each "bloom" station we analyzed inorganic nutrients, oxygen, chlorophyll (Chl) standing stocks, particulate organic carbon and nitrogen (POC and PON), TOC, dissolved organic carbon (DOC), and dissolved organic nitrogen (DON).

We examined property-property plots of inshore, midshelf and offshore blooms. Nitrate *vs*. salinity and TOC *vs*. salinity plots showed three distinct patterns. In general, TOC concentrations increased as nitrate concentrations decreased. The slope of TOC *vs*. nitrate averaged –4.68 (μmol TOC/μM NO_3^-) for inshore stations, –1.82 (μmol TOC/μM NO_3^-), and –1.34 (μmol TOC/μM NO_3^-) for offshore stations. The observed patterns suggest biogeochemical differences in the blooms depending on distance from shore.

Little difference was seen in means for TOC, percent POC, C:N or oxygen saturation between locations. However, C:Chl ratios averaged 47 g/g for inshore blooms and were approximately 185 g/g for the midshelf and offshore blooms. Plots of integrated POC *vs*. integrated Chl followed a hyperbolic relationship except when nitrate was depleted. N-depleted blooms showed elevated POC levels relative to the Chl concentrations. The results will be discussed in terms of the relative importance of light and nutrients in controlling the magnitude and biogeochemistry of the coastal blooms.

T3-2732 Poster

Riverine input of macronutrients, iron, and organic matter to the coastal ocean off Oregon, U.S.A., during the winter

Michael S. **Wetz**[1], Burke Hales[1], Zanna Chase[1], Patricia A. Wheeler[1] and Michael M. Whitney[1, 2]

[1] College of Oceanic and Atmospheric Sciences, Oregon State University, 104 COAS Admin. Bldg., Corvallis, OR 97331, U.S.A. Email: mwetz@coas.oregonstate.edu

[2] Department of Marine Sciences, University of Connecticut at Avery Point, 1080 Shennecossett Rd., Groton, CT 06340, U.S.A.

Three cross-shelf transects were sampled off northern Oregon in February, 2003, coincident with flooding of Coast Range rivers, in order to assess the riverine impact on coastal ocean biogeochemistry. During downwelling conditions, low salinity (~25) river-influenced water was located in a narrow band near the coast and contained elevated macronutrient, iron, and organic carbon concentrations. Wind relaxation allowed the river-influenced water to spread out at the surface across the shelf. This particular flood event increased the shelf surface-water pools of nitrate by 20–50% and silicate by 80-190% over non-flood nutrient levels. Given that the predominant downwelling conditions during winter tend to minimize cross-shelf transport, riverine iron that flocculates (*i.e.*, colloidal Fe) or sinks to the bottom (*i.e.*, particulate Fe) will likely remain on the shelf to support summer upwelling production. Of the major eastern boundary current systems, the northern California Current (including Oregon) and Portugal Current (*i.e.*, Iberian Peninsula) were found to have the highest coastline length-normalized riverine discharge rates. In contrast, riverine inputs for the central California, Canary (*i.e.*, northwest Africa), Benguela, and Peruvian Current systems averaged only 3–35% of that in Oregon. The patchy riverine input (and narrower shelves) might explain why iron limitation is more widespread off California and Peru than Oregon. These results show that small coastal rivers, which are characteristic of the U.S. Pacific Northwest, can significantly alter coastal biogeochemical cycles and influence ecosystem structure.

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