Program

Monday, November 28 (Evening):

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| 7 pm | Public Lecture | Kenneth L. Denman<br>*The North Pacific - Our Ocean Is Changing and Why We Should Care* | Shaw Centre for the Salish Sea |

Tuesday, November 29, ***Celebrating accomplishments***:

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| 9:00-9:30 | Introduction | Settle-in<br>Welcome from organisers<br>Welcome from Regional Director, Science (DFO Pacific) | IOS Auditorium |
| 9:30-10:00 | Plenary Lecture | Bill Large<br>*From Station P to the Southern Ocean: a journey of contrasts* | IOS Auditorium |
| 10:00-10:30 | Plenary Lecture | Angelica Peña<br>*Phytoplankton and upper ocean biogeochemistry along Line P: What have we learned about the NE Pacific?* | IOS Auditorium |
| 10:30-11:00 | Coffee | Coffee | IOS Atrium |
| 10:30-12:30 | Posters w/coffee | *Celebrating accomplishments Posters* | IOS Atrium |
| 12:30-1:30 | Lunch | Bring or buy lunch in the cafeteria | IOS Cafeteria |
| 1:30-2:00 | Plenary Lecture | Bill Crawford/Frank Whitney<br>*Climate driven variability along Line P* | IOS Auditorium |
| 2:00-2:30 | Plenary Lecture | Charles Miller<br>*Contributions of Station P to the Understanding of Basic Oceanic Ecodynamics* | IOS Auditorium |
| 2:30-3:00 | Coffee | Coffee | IOS Atrium |
| 2:30-4:30 | Posters w/coffee | *Celebrating accomplishments Posters* | IOS Atrium |
| 4:30-4:50 | Talk (*Looking Forward* teaser) | Steven Hallam<br>*From fjords to open seas: Microbial Systems Ecology of Expanding Oxygen Minimum Zones in the Northeast subarctic Pacific Ocean* | IOS Auditorium |
| 4:50-5:30 | Discussion | Kick-off of discussion of scientific contribution to mark the 60$^{th}$ anniversary; special issue? Review article(s)? | IOS Auditorium |

Tuesday, November 29 (Evening):

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| 6:30 pm | Reception | Dinner reception at aquarium | Shaw Centre for the Salish Sea |

Program

Wednesday, November 30, ***Looking forward***:

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| 8:30-9:00 | Plenary Lecture | Sayaka Yasunaka<br>*Surface nutrients in the North Pacific from ship-of-opportunity observations* | IOS Auditorium |
| 9:00-9:20 | Talk | Andrew Ross<br>*The Line-P Iron Program: exploring the biogeochemistry of trace elements in the NE Pacific* | IOS Auditorium |
| 9:20-9:40 | Talk | Maurice Levasseur<br>*Testing the responses of the NE Pacific plankton to atmospheric iron depositions: pros and cons of onboard microcosms experiments* | IOS Auditorium |
| 9:40-12:00 | Posters w/ coffee | *Looking forward Posters* | IOS Atrium |
| 10:00-10:30 | Coffee | Coffee | IOS Atrium |
| 12:00-1:00 | Lunch | Catered lunch in Cafeteria | IOS Cafeteria |
| 1:00-1:30 | Plenary Lecture | Heather Benway<br>*Working across time-series to broaden our view of a changing ocean* | IOS Auditorium |
| 1:30-1:50 | Talk | Meghan Cronin<br>*The Station P mooring array -- resolving physical and biogeochemical processes across seasons, years, and into the future* | IOS Auditorium |
| 1:50-2:10 | Talk | Jody Klymak<br>*Canadian – Pacific Robotic Ocean Observing Facility* | IOS Auditorium |
| 2:10-2:30 | Coffee | Coffee | IOS Atrium |
| 2:30-2:50 | Talk | Tetjana Ross<br>*Evolving DFO fieldwork: new technology, new ideas* | IOS Auditorium |
| 2:50-3:10 | Talk | Philippe Tortell<br>*Coupling the F and O in*<br>*DFO: New generation tools for enhanced ocean monitoring and fisheries analysis in the Subarctic Pacific* | IOS Auditorium |
| 3:10-4:00 | Discussion | Open discussion of what is missing from Line P?<br>How can the Line P program improve? | IOS Auditorium |

***Public Lecture*** **Monday, November 28, 7 pm**

**The North Pacific - Our Ocean Is Changing and Why We Should Care**

*Kenneth L. Denman, University of Victoria*

The North Pacific Ocean controls our weather and climate in British Columbia. Moreover, it is home to the marine ecosystems that support our fisheries – especially the iconic salmon. Humans, both directly by activities including overfishing and various forms of polluting, and indirectly by changing the climate through producing more greenhouse gases, are causing changes in the North Pacific and its ecosystems beyond those expected from natural variability. In this talk, Dr. Denman will describe key features of the North Pacific and the coastal waters of British Columbia, and will show recent observations of how these waters are changing. He will conclude with forecasts on how the ocean is expected to change in future decades, and how marine ecosystems are likely to respond to these changes.

***Celebrating accomplishments*** **Tuesday, November 29, plenary lectures**

**From Station P to the Southern Ocean: a journey of contrasts**

*William G. Large, National Center for Atmospheric Research, Boulder Colorado*

The premise is examined that the upper ocean of the north-east Pacific was better understood by the 1980s than large regions of the southern Hemisphere are today. The major reason for the disparity is because of the observations, both routine from Line P/ Station P and experiments in the vicinity (Ken Denman's thesis, STREX, MILE). These data led to closure of the annual heat and freshwater budgets and to understanding the annual cycle above the strong permanent halocline at about 120m depth. These achievements are fundamental to more recent studies of climate variability and change in the region. In contrast, there is a dearth of observations in many southern regions, but there is sufficient to show very different upper ocean behavior from the north-east Pacific. As this situation has improved over the years, in particular with the advent of Argo and remote sensing, it has becomes evident that much of this difference is due to a very different salinity structure. In the Southern Ocean understanding of the upper ocean remains elusive, because the salinity structure is particularly complicated and the unusually strong surface forcing is poorly known.

**Phytoplankton and upper ocean biogeochemistry along Line P: What have we learned about the NE Pacific?**

*Angelica Peña, Institute of Ocean Sciences, Fisheries and Oceans Canada*

**Climate-driven variability along Line P**

*Bill Crawford and Frank Whitney, Emeriti, Institute of Ocean Sciences, Fisheries and Oceans Canada*

Freshening of the mixed layer in the subarctic Pacific, strongly evident at Station P, is increasing the stratification of the upper subarctic Pacific Ocean, weakening ventilation, and changing the concentrations of nutrients and oxygen. This long-term trend of enhanced stratification is not leading to declines in mixed-layer nutrients, which are kept at elevated levels in the Alaska Gyre by the persistent upwelling winds of the Aleutian low pressure system. However, events such as the warm anomaly of 2013-15 can reduce winter supply and seasonal utilization of mixed-layer nutrients. In contrast, Oxygen levels ($O_2$) are declining in pycnocline waters (~100-400 m) at Station P and also at Station P20, with the strongest decrease from about 1995 to 2003. This 60-year decline is not present at Line P stations within the influence of the continental margin (Stations P12, P8 and P4), where a decline in $O_2$ is evident only since 1980, preceded by increasing $O_2$ from earliest observations in the 1950s to 1980.

**Contributions of Station P to the Understanding of Basic Oceanic Ecodynamics**

*Charles B. Miller, Prof. Emeritus, Oregon State University*

Canadian weatherships occupying Station P (50°N, 145°W) in the Gulf of Alaska provided their "POGO" science techs a platform for gathering time-series of oceanographic data. Those became the basis for a new understanding of pelagic ecosystem dynamics in the subarctic Pacific. In particular, a critical puzzle was revealed by four time-series repeated around the year for many years: frequent hydrographic profiles (T, S, O2), mixed layer chlorophyll, concentrations of nitrate, phosphate and silicate and upper water-column zooplankton abundance. The puzzle was the absence of seasonal phytoplankton blooms, despite the persistence of non-limiting, major nutrient levels year-around. The major nutrients do cycle, lower but never growth-limiting in the summer, higher in winter, but chlorophyll oscillates much faster between quite narrow limits, about 0.2 to 0.6 mg $m^{-3}$. Partly this could be explained by the permanent halocline at 80 to 120 m (moving with internal wave activity), which inhibited complete downward flushing of algal stocks in winter. But, that did not explain the absence of blooms in the bright (well, brighter) summer sunshine, when a shallower thermocline should have kept phytoplankton up in that light. Possibly the reason was the zooplankton, most of the early spring to late summer stock being large copepods. The seasonal cycling of the ecosystem was "shifted" up the food chain a step, as shown by summaries of zooplankton abundance estimates by Robin LeBrasseur and John Fulton.

In the late 1970s, Bruce Frost (with Karl Banse) and I became independently fascinated by this puzzle, and getting together we proposed to check out the grazer hypothesis. That led us, along with Canadian colleagues, through many steps and misadventures, to eventually traipsing after John Martin, toward what we termed the SUPER synthesis, usually now called the "ecumenical iron hypothesis" (a phrase offered by John Cullen). Much of that explanation, iron-limitation of large phytoplankton growth, but with complications of protozoan grazing and a role for ammonia cycling, seems confirmed. Of course, questions have arisen, answers have been offered and more issues remain to be studied. The talk will review this history briefly and consider the present status of our understanding.

***Looking Forward*** **Wednesday, November 30, plenary lectures**

**Surface nutrients in the North Pacific from ship-of-opportunity observations**

*Sayaka Yasunaka, Japan Agency for Marine-Earth Science and Technology*

National Institute for Environmental Studies (NIES, Japan) and Institute of Ocean Sciences (IOS, Canada) has carried out ship of opportunity measurements of nutrients (phosphate, nitrate, and silicate) and partial pressure of CO2 since late 1980s [Wong et al. 2002; Whitney et al. 2011; Yasunaka et al. 2014]. Using the ship of opportunity data and others, seasonal to decadal variability of sea surface nutrients and dissolved inorganic carbon (DIC) in the North Pacific were clarified. Nutrient and DIC concentrations were high in the subarctic in winter and low in the subtropics. In the summer, substantial amount of nutrients remained unutilized in subarctic and the northern part of the subarctic-subtropical boundary region. In the subtropics, nutrients were almost entirely depleted throughout the year, while DIC concentrations showed a north-south gradient and significant seasonal change. Nutrients and DIC showed a large seasonal drawdown in the western subarctic region, while the drawdown in the eastern subarctic region was weaker, especially for silicate. The subarctic-subtropical boundary region also showed a large seasonal drawdown, which was most prominent for DIC and less obvious for nitrate and silicate. In the interannual time scale, the Pacific Decadal Oscillation was related to a nutrients and DIC seesaw pattern between the subarctic-subtropical boundary region and the Alaskan Gyre through the changes in horizontal advection, vertical mixing and biological production. When the North Pacific Gyre

Oscillation was in the positive phase, nutrient concentrations in the subarctic were higher than the mean states. Trends of phosphate and silicate averaged over the North Pacific were negative, while nitrate trend was insignificant.

**Working across time-series to broaden our view of a changing ocean**
*Heather Benway, Woods Hole Oceanographic Institution*
This presentation will introduce the Ocean Carbon & Biogeochemistry (OCB) Program and its Ocean Time-series Committee. Ocean time-series such as Line P play a critical role in addressing science questions related to the function of marine ecosystems and how they are responding to environmental change. In recent years, OCB has collaborated with partner programs on numerous synthesis and coordination efforts to build a global network of biogeochemical ocean time-series that can support science at and across time-series. This presentation will highlight those activities and their outcomes, including forward-looking community recommendations from a 2016 Town Hall Meeting (Ocean Sciences) on mechanisms to support such a network.

***Looking Forward Talks***
**Tuesday, November 29,**
**From fjords to open seas: Microbial Systems Ecology of Expanding Oxygen Minimum Zones in the Northeast subarctic Pacific Ocean**
*Steven Hallam, University of British Columbia*

**Wednesday, November 30,**
**The Line-P Iron Program: exploring the biogeochemistry of trace elements in the North-East Pacific**
*Andrew R.S. Ross, Institute of Ocean Sciences, Fisheries and Oceans Canada*
Oceanographic data have been collected along Line-P since 1956 and are among the few time series of sufficient quality and duration to be useful in examining the long-term variability of the oceans. Total and dissolved iron have been measured intermittently along Line-P since 1997, providing a unique series of such measurements between the iron-rich coastal waters of British Columbia and Station P in the HNLC waters of the Alaska gyre. In 2012 Fisheries and Oceans Canada scientists together with collaborators at the universities of Victoria, Laval and British Columbia established the Line-P Iron Program to ensure the continuity of iron measurements along Line-P and provide a framework for process-oriented studies of iron, copper and other trace elements in the NE Pacific. This presentation will review the historical Line-P Fe dataset and describe how different approaches are being used to study the distribution, biological utilization, and speciation of trace elements and isotopes (TEIs) along Line-P. It will also describe how these data are being made available to support international efforts (including GEOTRACES) to better understand the roles of TEIs in marine ecosystems and climate change.

**Testing the responses of the NE Pacific plankton to atmospheric iron depositions: pros and cons of onboard microcosms experiments**
*Maurice Levasseur, Université Laval*
Life in the North-East Pacific is sporadically stimulated by atmospheric depositions of desert dust and volcanic ash. These depositions provide iron to the system, an essential micronutrient for autotrophic phytoplankters usually found in limiting concentrations in this part of the Global Ocean. Studying the impact of these depositions is problematic owing to their episodic nature and the rapid cycling of iron in surface waters. The Line P monitoring program offered the opportunity to alleviate this problem through the wielding of onboard incubation experiments during which NE Pacific waters were amended with various amounts of dust, ash or chemical forms of iron. Here we will review what has been learned about Asian dust and volcanic ash deposition from these onboard bioassays conducted throughout

several Line P cruises, discuss the pros and cons of these manipulation experiments, and propose research avenues for the next 10 years.

**The Station P mooring array -- resolving physical and biogeochemical processes across seasons, years, and into the future**
*Meghan Cronin, NOAA Pacific Marine Environmental Laboratory*

**Canadian – Pacific Robotic Ocean Observing Facility**
*Jody Klymak, University of Victoria*
C-PROOF is a proposed ocean observing facility using a substantial fleet of gliders, floats, and moorings to resolve the temporal and spatial scales that the coastal and open ocean evolve on. Building on the success of the Argo float array, C-PROOF aims to help develop and deploy the next generation of Bio-Argo floats. We will also deploy a glider array, necessary to capture the sharp gradients between the Eastern boundary currents and the open Gulf of Alaska, and on into the coastal and estuarine domains. By using physical and biogeochemical sensors, we will better understand and quantify upper ocean processes, and to feed this understanding through to improved model forecasting, both by improving parameterizations in the models and by supplying data for assimilation and validation.

**Evolving DFO fieldwork: new technology, new ideas**
*Tetjana Ross, Institute of Ocean Sciences, Fisheries and Oceans Canada*
This presentation will highlight the recent and forthcoming research by Line P scientists at DFO. While maintaining a core set of measurements over decades is critical to the success of Line P, it is through constant innovation, both by adding new, complimentary measurements and new ways of looking at the data, that we gain knowledge.

**Coupling the F and O in DFO: New generation tools for enhanced ocean monitoring and fisheries analysis in the Subarctic Pacific**
*Philippe Tortell, University of British Columbia*
With its focus on physical and chemical oceanography and lower trophic level (i.e. plankton) processes, the Line P program has not explicitly examined patterns in the spatial and temporal distribution of fish stocks. Historically, fisheries-related research has been led by scientists at the Pacific Biological Station. In an attempt to bring oceanographic and fisheries research more closely together, we have initiated the new Subarctic Pacific Ecosystem Analysis Research (SPEAR) program, funded as an NSERC Strategic Project. Our goal is to bring together oceanographers (from various domains), statisticians, fisheries scientists, and DFO managers and Applied Science staff to develop new understanding of coupled variability in ocean conditions and fisheries stocks. We seek to provide observational and modelling tools to help inform stock assessments and future prediction of fish biomass under changing ocean conditions. In this presentation, I will review current progress towards our research objectives, and discuss on-going and future activity.

***Celebrating accomplishments*** **Tuesday, November 29, posters**

**Nutrient limitation zones of the Gulf of Alaska and Line P as revealed by satellite measurements of chlorophyll and sea surface height**

*Bill Crawford, Emeritus, Fisheries and Oceans Canada, Institute of Ocean Sciences.*

Ocean surface waters of the central Gulf of Alaska are relatively rich in macro-nutrients, due to relatively low concentration of iron relative to macro-nutrients in subsurface waters that upwell in the Alaska Gyre. In contrast, coastal waters are rich in iron as well as macro-nutrients, due to remineralization processes on the continental shelf, tidal mixing, upwelling, relaxation of winter downwelling, and input from rivers. Satellite imagery reveals several processes whereby mesoscale eddies transport these iron-rich waters from the continental margin to mid-gyre. However, along Line P, nitrate-depleted waters penetrate close to shore, due to lack of mesoscale eddies forming along Line P, and the advection of nutrient-depleted waters from the south. These features of the Gulf of Alaska and Line P are revealed by images that combine sea surface height contours and monthly composites of surface chlorophyll concentration.

**Temporal variability of dissolved iron species in the mesopelagic zone at Ocean Station PAPA**

*Jay Cullen, University of Victoria*

Deposition of atmospheric aerosols to the surface ocean is considered an important mechanism for the supply of iron (Fe) to remote ocean regions, but direct observations of the oceanic response to aerosol deposition are sparse. We observed a dissolved Fe and Fe(II) anomaly at depth that is best explained as the result of aerosol deposition from Siberian forest fires in May 2012. Interestingly, there was no evidence of enhanced dFe concentrations in surface waters, nor was there a detectable phytoplankton bloom in response to the suspected aerosol deposition. Dissolved Fe (dFe) and Fe(II) showed the strongest enhancement in the subsurface oxygen deficient zone (ODZ). In the upper 200 m, dFe concentrations were at or below historical averages, consistent with a short residence time of aerosol particles in surface waters and possible scavenging loss of dFe. Aerosol toxicity and/or dominance of particle scavenging over dissolution of Fe in the upper water column may have contributed to the lack of a detectable phytoplankton response.

**Interannual variability in sperm whale acoustic occurrence at Ocean Station PAPA from 2007-2012 related to oceanography**

*Niki Diogou, Oregon State University*

Understanding cetacean habitat preference in far offshore pelagic locations, such as near Ocean Station PAPA (OSP, 50°N, 145°W) is particularly difficult, largely due to harsh weather that inhibits visual survey efforts. However, acoustics can facilitate surveys targeting highly vocal species. An autonomous Passive Acoustic Listener (PAL) was deployed at OSP for 6 years to investigate the occurrence of sperm whales (Physeter macrocephalus). Acoustic detections were present throughout the year but presented a consistent seasonal pattern, with increased summer and reduced winter detections. To investigate the drivers of interannual variability in sperm whale occurrence we used a selection of in-situ and satellite-derived oceanographic measurements as proxies for ocean productivity and prey availability. An explicit time-series analysis framework, using a multimodel inference technique, accounting for temporal lags, multicollinearity, and serial temporal autocorrelation, indicated the following as best descriptors for the sperm whale acoustic occurrence at OSP: (1) ocean heat content, (2) meridional current component at 35 m 20 days earlier, (3) eddy kinetic energy, (4) strength of the deep pycnocline 5 days earlier, (5) sea surface temperature (SST), and (6) standard deviation of SST (presence of thermal fronts). This is, to our knowledge, the first attempt using OSP oceanographic measurements to evaluate cetacean habitat preferences. The value of long term acoustic recordings is related both to the efficiency of this method to collect otherwise inaccessible data in a cost-effective way, and to the significance of detecting

interannual ecological responses which can be used to predict ecosystemic impacts of climate variability and anthropogenic change.

**The Blob - or, how odd can the ocean really get?**

*Howard Freeland, IOS, Scientist Emeritus*

In early 2014 a large Gulf of Alaska SST anomaly was observed in the so-called Reynolds data set (ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oimonth_v2) and this feature became known popularly as "The Blob". The peak anomalies in The Blob showed deviations from normal of up to 4.6 standard deviations, which makes it an extreme anomaly. To put that in perspective, for time series of monthly means the return period for an anomaly >4.5sigma is 2800 years. On the principle that an extraordinary observation requires extraordinary proof, we apepal to other observations for corroboration. As a spoiler, the answer is, yes the ocean really was that unusual.

**Using dissolved noble gases to quantify air-sea exchange processes**

*Roberta C. Hamme, University of Victoria and Steven R. Emerson, University of Washington*

The rate of air-sea gas exchange affects research areas from ocean uptake of anthropogenic carbon to the apparent long-term decline in dissolved oxygen in the intermediate ocean. We are developing techniques to use high precision noble gas measurements to quantify gas exchange rates and other physical processes affecting gases at the ocean surface. Because each noble gas has differing physical properties (solubility, temperature dependence, diffusivity), they react differently to processes like diffusive gas exchange, bubble dissolution, temperature change, and variation in atmospheric pressure. We present measurements of neon, argon, krypton, and xenon from seven locations spanning the globe, with Station P in the subarctic North Pacific being one of our most consistently sampled locations with measurements starting in 2010. Using these measurements, we demonstrate a technique to quantify physical processes affecting gas saturations and to predict the physically driven saturations of other gases. The deepest water at Station P is one of the most challenging to interpret, because it represents a mixture of multiple deep water masses with different histories. Samples nearer the surface offer the potential to target processes in intermediate water mass formation regions. We use our global dataset to illustrate both the power of the technique and the challenges. These measurements should eventually provide a useful metric for comparison to numerical climate models to evaluate the parameterization of gases, including carbon dioxide, during water mass formation.

**Marinimicrobia SAGs reveal Co-metabolic interactions of uncultivated along ecothermodynamic gradients**

*Alyse Hawley, University of British Columbia*

Marinimicrobia are an abundant and ubiquitous bacterial candidate phyla abundant in oxygen minimum zones (OMZs), the deep ocean and reduced environments. While Marinimicrobia are in the Fibrobacteres-Chlorobi-Bacteroidetes (FCB) superphylum the metabolic capacity remains largely undefined. Here we analyze 26 MRINIMICROBIA single-cell amplified genomes from seven different environments along ecothermodynamic gradients including open ocean waters, oxygen minimum zones and anoxic, hydrocarbon enriched environments. Recruitment of metagenomic contigs from OMZ waters and bioreactor samples combine with tetra-nucleotide frequency analysis produced nine Marinimicrobia clades originating from four distinct ecothermodynamic niches. Analysis of Marinimicrobia clade population genomes revealed stream-lined genomes, genes for a gram negative cell wall, sugar metabolism and carbon fixation among the different groups. Analysis of energy metabolism genes and respiratory pathways revealed various roles in the nitrogen and sulfur cycles and an increasing propensity for co-metabolism in more reduced environments. Open Ocean Marinimicrobia were highly stream-lined and contained proteorhodopsin. Marinimicrobia from OMZ oxycline contained

genes for partial denitrification, feeding into anammox and nitrification, and polysulfide reductase with a potential role in the cryptic sulfur cycle. Marinimicrobia from below the oxycline contained NiFe hydrogenase and nitrous oxide reductase, potentially complementing SUP05 group, which lacks this final step for denitrification. MRINIMICROBIA from highly reduced methanogenic environments contained genes commonly found in bacteria involved in cascading syntrophic interactions with fatty acid degraders and methanogens. Overall the MRINIMICROBIA show diverse metabolic capacity and respiratory versatility as well as energy storage capacity and an increased reliance on co-metabolism in more reduced environments.

**Refined estimates of net community production along Line P and La Perouse derived from O2/Ar measurements and N2O-based corrections for vertical mixing**

*Robert Izett, University of British Columbia*

Net community production (NCP) defines the balance between gross primary production and total respiration, and sets the upper limit on carbon export from marine surface waters. Recent developments in autonomous, ship-based instrumentation have facilitated estimation of NCP at high spatial and temporal resolution, using underway measurement of the mixed layer oxygen-argon ratio (O2/Ar). Normalization of O2 by Ar removes the effects of temperature and salinity-dependent changes in O2 solubility, but does not account for physically-induced changes in O2 concentrations resulting from vertical transport of low O2 sub-surface waters into the mixed layer. Recent work suggests that surface water nitrous oxide (N2O) supersaturation can be used as a tracer of this flux, as N2O is primarily produced through nitrification below the euphotic zone. To date, this approach has not been applied to field data. We present N2O-corrected NCP estimates from the 2016 Line P and La Perouse cruises. We use discrete profiles of N2O and measurements of surface N2O supersaturation to estimate the vertical flux of O2 into the mixed layer. Our data provide high spatiotemporal coverage of NCP measurements in a region of strong coastal-oceanic productivity gradients. Our results show that mixing is a significant term in the O2 mass balance of dynamic coastal waters, particularly during periods of upwelling, with lower mixing contributions in the stratified open ocean waters.

**Integrating biogeochemistry with multi-omic sequence information in a model oxygen minimum zone**

*Stilianos Louca, University of British Columbia*

Over the past decade, high-throughput molecular techniques generating multi-omic sequence information (DNA, mRNA and protein) have transformed our perception of microbial ecology, conceptually linking microorganisms at the individual, population, and community levels to a wide range of ecosystem functions and services. Here we develop a biogeochemical model that describes metabolic coupling along the redox gradient in Saanich Inlet---a seasonally anoxic fjord with biogeochemistry analogous to oxygen minimum zones (OMZ). The model reproduces measured biogeochemical process rates as well as DNA, mRNA, and protein concentration profiles across the redox gradient. Simulations make predictions about the role of ubiquitous OMZ microorganisms in mediating carbon, nitrogen, and sulfur cycling. For example, nitrite "leakage" during incomplete sulfide-driven denitrification by SUP05 Gammaproteobacteria is predicted to support inorganic carbon fixation and intense nitrogen loss via anammox. This coupling creates a metabolic niche for nitrous oxide reduction that completes denitrification by currently unidentified community members. These results quantitatively improve previous conceptual models describing microbial metabolic networks in OMZs. Beyond OMZ-specific predictions, model results indicate that geochemical fluxes are robust indicators of microbial community structure and, reciprocally, that gene abundances and geochemical conditions largely determine gene expression patterns. The integration of real observational data, including geochemical profiles, process rate measurements, as well as metagenomic, metatranscriptomic and metaproteomic sequence data

into a biogeochemical model, as demonstrated here, enables holistic insight into the microbial metabolic network driving nutrient and energy flow at ecosystem scales.

**Optical Characterization of Dissolved Organic Carbon in the Gulf of Alaska**

*Fang Cao, City University of New York, and William L. Miller, U.S. National Science Foundation*

Characterizing refractory dissolved organic carbon (rDOC) in the deep ocean is a critical step along the path to quantifying the sources and sinks for this, the largest DOC reservoir in the ocean. Given the size and vast expanse of this pool, relatively few studies provide the vertical and spatial sampling for a detailed examination of rDOC in the deep ocean. Here we report high resolution vertical distributions (>30 stations; 0 to >5000m) of chromophoric dissolved organic matter (CDOM) and fluorescent DOM (FDOM) measured as excitation-emission matrix spectra (EEMs) coupled with parallel factor analysis (PARAFAC) along line P and throughout the Gulf of Alaska. Here we sampled the most refractory DOC in the ocean, identifying four “humic-like” and two “protein-like” fluorescent components and infer potential processes responsible for the observed distributions. “Humic-like” components were low in the surface, possible reflecting photobleaching, and increased to a constant level at depth. In contrast, “protein-like” components have higher surface levels, likely due to biological production and decrease with depth potentially from microbial consumption. Vertical profiles of CDOM and protein-like components in the dark ocean (>200 m) suggest distribution of these optical components is largely controlled by microbial remineralization with physical mixing in these slowly upwelled waters that cannot be neglected. We further examine potential relationships between AOU and bulk DOC measurements with “protein-like” components as potential proxies for examining DOC in the deep ocean.

**International Group for Marine Ecological Time Series (IGMETS): assessing global oceanic changes through joint time series analysis**

*Andrew Ross, Fisheries and Oceans Canada*

Sustained time series observations provide a wealth of data on ocean physics, biogeochemistry and ecology that can be used to examine, test and refine hypotheses about the functioning of the ocean. Such time series not only allow us to observe processes such as ocean warming, circulation, eutrophication and deoxygenation but also generate information about key ecological processes and how the marine environment is being affected by climate change at the local, regional and global levels. Maintaining these time series is critical to identifying and predicting such changes; however, existing observations are limited in use if they are not made accessible. The International Group for Marine Ecological Time Series (IGMETS) was formed under the auspices of the UNESCO Intergovernmental Oceanographic Commission (IOC) with the aim of integrating and broadening the utilization of existing time series data to help promote cost-efficiency for new and established sampling programs, increase awareness of these programs and their importance, create a platform for modeling studies, and provide a strong basis for future predictions to support sound policy decisions and advice. This poster shows how the Line-P Program and other North Pacific Time Series are contributing to the IGMETS initiative.

**Onshore versus offshore trends in carbon export and primary production by comparing methods along Line P**

*Amanda Timmerman and Roberta C. Hamme, University of Victoria*

The export of organic carbon to depth via the biological pump sequesters carbon from the surface ocean, lowering the atmospheric carbon dioxide concentrations by about 200 ppm. Understanding current export and primary production rates will provide insight into possible climate change scenarios, for example if carbon export rates are increasing it could sequester additional anthropogenic carbon dioxide. One approach to better constrain rates is to compare methods in order to quantify method

biases and identify consistent differences. We present two methods to estimate carbon export (O2/Ar dissolved gas ratio and 15NO3 uptake), two methods for gross primary production (triple oxygen isotope and 18O incubations) and one method for primary production (13C incubations). Measurements were conducted at the major stations along Line P in 2015 and 2016. A previous study sampled a subset of the methods in 2007-2009 & 2014 and will be compared to the data in this study. Preliminary results show carbon export rates are generally low offshore and consistent between methods, whereas onshore (P4), carbon export is variable and methods do not agree well. Primary production has a similar trend with higher rates onshore than offshore. Conversely, gross primary production methods agree best at P4 and are more variable offshore. We are working to identify controls on rates of carbon export and primary production, such as phytoplankton species, iron concentrations, and environmental parameters. This study will contribute to better understanding the biological pump in the subarctic northeast Pacific Ocean.

**North Pacific Kinetic Energy Decomposition**

*Manman Wang, University of Victoria*

The upper ocean is host to overlapping vortical and internal waves dynamics over the submesoscales (10-100km), both of which are poorly represented in eddy-resolving ocean models. We examine observations at these scales using horizontal-wavenumber kinetic energy spectra, collected in the North Pacific subpolar gyre from shipboard ADCP measurements and compare them to spectra from a 1/36th degree numerical simulation output. At scales between 10 and 100 km, the ADCP along-track $\hat{C}^u$ and across-track $\hat{C}^v$ kinetic energy spectra approximately follow power laws of $k^{-2}$ and have a ratio $R=\hat{C}^v/\hat{C}^u\approx1$. For purely non-divergent motions, the order of the power law and R should be the same, so divergent motions are important. A Helmholtz decomposition estimates the fraction of kinetic energy that is contributed by internal waves and balanced vortex components. Decomposed vortex components follow a power law of $k^{-2}$ with ratio $R\approx2$, consistent with predictions for a non-divergent flow, while internal waves are mostly consistent with the Garrett and Munk internal wave model. This falls between previous observations that were either dominated by vortical motions in strongly baroclinic regions like the Gulf Stream, or dominated by internal waves, like the subtropical Pacific. There were modest seasonal changes; vortical motions are slightly stronger in February than in June, whereas the amplitudes of the internal wave component increases in June. Depth variability of non-divergent vortical flows show that at low wave-number energy decreases. However, there was no evidence of high-wavenumbers becoming more red with depth, inconsistent with predictions of surface quasi-geostrophic theory. Conversely, in the simulations the depth variability of the decomposed vortex components is in agreement with predictions of surface quasi-geostrophic theory. The simulations had very weak internal wave fields.

**The Subarctic Pacific is Panting**

*Frank Whitney, Fisheries and Oceans Canada - Emeritus*

A steep oxycline in the NE Pacific restricts most animal life to the upper few hundred meters. Increasing ocean stratification is reducing oxygen supply, thus shrinking this habitat.

**Did the “blob” affect Net Community Production? Observations at Ocean Station Papa from 2013 to 2015**

*Bo Yang, University of Washington*

A time-series of chemical tracers (oxygen, nitrate, and dissolved inorganic carbon , DIC) measured with profiling floats and a mooring at Ocean Station Papa were used in a one dimensional upper ocean model to estimate net community production (NCP) from 2013 to 2015. The transition from 2013 to 2014 marked the beginning of strong positive temperature anomaly observed in the Northeast Pacific. Annual

net community production (ANCP) was determined to be 2.4, 1.0, and 3.2 mol C $m^{-2}$ $yr^{-1}$ for year 2013, 2014, and 2015, respectively, with uncertainties of ~ ± 0.6 mol C $m^{-2}$ $yr^{-1}$. Summer NCP rates in the mixed layer remained relatively consistent for these three years (12.5 – 14.8 mmol C $m^{-2}$ $d^{-1}$), so the decline of ANCP in 2014 is probably due to enhanced respiration or increased mixing with sub-pycnocline waters in the winter of this year. Mixed layer summer NCP rates from oxygen and DIC mass balance were consistent (11.7 – 15.0 mmol C $m^{-2}$ $d^{-1}$), while the estimates from nitrate mass balance were significantly lower (6.9 – 9.2 mmol C $m^{-2}$ $d^{-1}$). Underestimate of NCP from nitrate mass balance is probably due to the horizontal transportation of nitrate, which is not considered in the one dimensional model. Horizontal advection has greater influence on the nitrate mass balance than oxygen or DIC mass balance because of the strongly increasing surface water nitrate concentration to the southwest which is upstream of the mean horizontal surface flow.

**Using hyper-spectral optical measurements to examine phytoplankton assemblage composition in the Subarctic Pacific**

*Chen Zeng, University of British Columbia/Tongji University, and Philippe Tortell, University of British Columbia*

The NE Subarctic Pacific Ocean encompasses a variety of oceanographic conditions, from high productivity coastal waters to offshore, iron-limited regions. Significant attention has focused on understanding the spatial and temporal patterns of plankton biomass and taxonomic composition in across the Subarctic Pacific, as these factors exert a significant impact on the productivity of higher trophic levels, including commercially valuable fish. Recent work along Line P has begun to compile observations of phytoplankton pigments, which can be used, along with microscopic analyses, to examine assemblage composition. This approach is based on the use diagnostic pigment signatures, which yield characteristic spectral absorption properties that can be observed using ship-based optical sensors and remote sensing. We have recently begun deploying sea-going optical sensors to examine the absorption characteristics of surface waters across the Gulf of Alaska in the Subarctic Pacific. Our research objective is to evaluate the potential of these optical measurements to provide information on phytoplankton size-class distributions and functional group abundances. Our preliminary results suggest that this approach holds promise for identifying changes in phytoplankton group abundances across hydrographic features in the coastal and open ocean waters of the Subarctic Pacific. On-going work aims to couple our ship-based measurements with satellite-based observations of water-leaving irradiance at different wavelengths.

***Looking Forward*** **Wednesday, November 30, posters**

**Time-Series Coordination Efforts of the US Ocean Carbon and Biogeochemistry Program**

*Heather Benway, Woods Hole Oceanographic Institution, and Susanne Neuer, Arizona State University*

This poster presentation will provide an overview of the interests and activities of the Ocean Time-series Committee (OTC), a subcommittee of the US Ocean Carbon & Biogeochemistry (OCB) Program's (www.us-ocb.org) scientific steering committee. OCB is a scientific coordinating body that facilitates collaborative, interdisciplinary research opportunities and initiatives within the US and with international partners. The OTC's focus is to highlight the importance of shipboard time-series as unique observing assets to the oceanographic and climate research communities, and to encourage synergistic and collaborative technology and methods development, including development and validation of sensors and autonomous devices and their integration into existing time-series observations. Recently, OCB OTC has coordinated, supported, and participated in a number of activities to improve communication and collaboration across time-series in an effort to develop and strengthen a global time-series network and facilitate synthetic scientific products that provide a broader spatial perspective

of changing marine ecosystems. With this presentation, we hope to stimulate a discussion about Line P's unique contributions in the context of a global network and share new ideas about the goals and visions for the future of time-series observations. We also welcome new ideas from the community about how to enhance scientific and logistical coordination and collaboration in the international time-series community.

**Optical properties of Subarctic Pacific waters across contrasting hydrographic and productivity regimes**

*William Burt, University of British Columbia*

Satellite algorithms exploiting optical properties of surface waters to infer biogeochemical processes perform relatively well on global scales, but calibration against in-situ field data remains critical to improving accuracy on regional scales. To date, in-situ data relating optical properties to phytoplankton biomass and primary productivity have been focused mainly in open ocean systems, and more recently, in mesotrophic regions of the Atlantic Ocean. It thus remains unclear how these relationships may extrapolate to high-productivity near-shore regions (where a disproportionate amount of marine carbon cycling occurs), or offshore waters of the Pacific Ocean where iron limits primary productivity. Here, we present in-situ measurements of particle absorption (ap), attenuation (cp) and backscatter (bbp) collected across a spectrum of productivity regimes in the SubArctic Pacific, including iron-limited low productivity waters of the Gulf of Alaska, mesotrophic shelf waters along the central coast of British Columbia, and hyper-productive eutrophic waters of the Vancouver Island upwelling regime. We examine the coherence of these optical measurements with indices of phytoplankton biomass (e.g. Chl a) and productivity (O2/Ar – derived net community production) across the different regions, and across sharp hydrographic frontal boundaries. We also explore an apparent temporal component to the backscatter signature that may be related to diel zooplankton migration patterns. We use discrete and underway measurements of bulk particulate organic carbon (POC), phytoplankton-specific carbon (from flow cytometric sorting), and high precision liquid chromatography (HPLC) to validate optical measurements. We also compare the ship-board optical data with observations derived from satellite-based remote sensing.

**Ocean Observatories Initiative Measurements at Station Papa**

*Edward Dever, Oregon State University*

The OOI Station Papa moorings and gliders have been maintained since June 2013 and have been turned on a yearly basis in summer. The observations include one mooring with a profiler CTD, O2, chl-a fluorescence and optical backscatter, and point velocity from 310 to 4000 m. Two profiling gliders are assigned to sample the upper 1000 m near these profilers. Two nearby moorings have fixed subsurface sensors that include pH, temperature and conductivity at multiple depths, acoustic Doppler current profilers and three channel active bio-acoustics sensors. OOI data are now coming online. Interested users can register at the OOI website (oceanobservatories.org).

**Interannual variation in summer zooplankton stable isotope values from a Line P time series (2008-2016)**

*Brian Hunt, Institute for the Oceans and Fisheries, University of British Columbia; Hakai Institute*

Carbon and nitrogen naturally occur in two stable isotopic forms. These isotopes are taken up by primary producers in a food web in ratios that reflect the interacting effects of temperature, elemental availability (e.g. nutrient concentrations), and productivity levels, among other factors. Subsequently, the baseline primary producer isotope ratio is transferred through the food web and transformed with largely predictable increases between trophic levels. The Carbon (δ13C) and Nitrogen (δ15N) stable isotope ratios of an organism's tissues therefore provide a powerful source of information on the

environmental and food web conditions experienced by that organism. Here we present a nine year time series of size fractionated zooplankton stable isotope data collected during summer along Line P. We evaluate interannual variation in isotope ratios, and their variation along a coast to offshore gradient, and their response to temperature, nutrients and phytoplankton biomass. We specifically consider these data in the context of zooplankton food web structure, productivity, and energy transfer efficiency.

**Rivers Inlet: An analysis of historical CTD data in the context of new observations**

*Jennifer Jackson, Hakai Institute*

Rivers Inlet, on British Columbia's central coast, is an economically, ecologically, and culturally important region. Although Rivers Inlet once had the second largest sockeye salmon run in British Columbia, salmon numbers began to decline in the 1970s and have never recovered. Fisheries and Oceans Canada have been collecting oceanographic data in Rivers Inlet most years since 1951. From 2008 to 2010 and from 2013 to present, the Hakai Institute have collected high-resolution CTD and biochemical data in Rivers Inlet from spring through fall. Here we combine these CTD datasets to examine historical and current ocean conditions with an emphasis on seasonal and inter annual variation.

**Trace metal-macronutrient decoupling along Line P**

*David Janssen, University of Victoria*

Dissolved zinc (Zn) and cadmium (Cd) both show nutrient-type distributions with depth profiles driven by biological uptake in surface waters and remineralization of sinking biogenic particles. Both metals show strong coupling with macronutrients in the global ocean; Zn depth profiles and global distributions show strong correlation with silicic acid (Si) and Cd profiles and distributions correlate strongly with phosphate (PO43-). We present dissolved Zn data from August 2012 and dissolved Cd and Cd stable isotope (ε112/110Cd) data from August 2012, 2013 and 2014 along Line P highlighting the decoupling of trace metal and macronutrient pairs. Surface waters show low metal:macronutrient ratios, likely due to enhanced uptake of metals in the High-Nutrient, Low-Chlorophyll subarctic northeast Pacific. Samples from the nutricline show trace metals are elevated relative to macronutrients, suggesting remineralization of comparatively metal-rich particles. Samples from oxygen-depleted waters along the transect show deficits of trace metals relative to macronutrients. This is consistent with metal removal in low-O2 waters, which we propose is due to the formation of insoluble metal sulphides in anoxic microenvironments around sinking particles in low-O2 waters. Deep waters (>1500 m) show metal:macronutrient ratios in agreement with global deepwater averages. Our data demonstrate the unique environment of the Line P transect in the global ocean and highlight remaining questions in trace metal biogeochemical cycling as well as the potential role that future work along Line P can serve in answering these questions.

**Line P: Leading the InFORM network in monitoring for Fukushima contamination on the Canadian coast**

*Jonathan Kellogg, University of Victoria*

The Integrated Fukushima Ocean Radionuclide Monitoring (InFORM) network is a partnership between academic, government, private organizations, and citizen scientists to monitor the arrival of Fukushima-derived radiation, cesium-134 (t1/2 = ~2 years), cesium-137 (t1/2 = ~30 years) in Canadian waters. The network was founded in 2014 to coordinate Canadian monitoring and to provide timely, quality, information to the public. InFORM is based on DFO Line P monitoring, which began shortly after the accident in 2011, and revealed both the plume’s leading edge at Station Papa in 2012 and its arrival in Canadian territorial waters in 2013. Continued InFORM monitoring will capture the peak of contamination, predicted in 2016-2017 for BC waters, utilizing a network of oceanic, coastal, and biotic

sampling. Understanding oceanic conditions, through samples collected during Line P and other cruises, serves as both model validation and a way to forecast coastal conditions. Closer to population centers, seawater samples are collected monthly by dedicated citizen scientists in 16 coastal communities. Salmon from each of BCs major fisheries are sampled to assess human and ecosystem health risks due to bioaccumulation. Monitoring has shown radionuclide activity levels (~10 Bq $m^{-3}$ in the central NE Pacific) are well below Canadian safe drinking water standards (10,000 Bq $m^{-3}$). Similarly, levels in salmon from 2015 were very low (<0.6 Bq $kg^{-1}$ for both 134Cs and 137Cs) compared to food standards (1,000 Bq $kg^{-1}$). However, InFORM monitoring is also finding contamination elevated relative to numerical model simulations and these data will help refine model predictions.

**Quantifying secondary production using the biomass spectra theory**

*Lian Kwong, University of British Columbia*

Zooplankton play a pivotal role in the World's oceans, acting as the fundamental link between phytoplankton and commercially valuable fisheries. These highly diverse ubiquitous organisms provide an important source of nutrition for a myriad of marine organisms, while also playing a key role in biogeochemical cycling. There is currently little understanding of the functional processes at the zooplankton level, particularly those of secondary production in the marine plant-to-fish continuum. Methods for estimating secondary production have proven to be labor intensive and overall inadequate in the past. I will estimate secondary production using fundamental principles of ecosystem structure outlined by the biomass spectra theory. Marine pelagic food webs are largely size-structured, and because ecological rates (i.e., growth, mortality, energy transfer, etc.) scale with size, secondary production can be estimated using normalized biomass size spectra (NBSS). Using zooplankton net-samples and multi-frequency acoustic data collected in collaboration with Fisheries and Oceans Canada during several monitoring voyages (Line P and LaPerouse), secondary production will be estimated using NBSS. The results of this study will yield a biomass/production size-dependent model based on the biomass spectra theory, which will be linked to regional satellite algorithms estimating phytoplankton composition, as well as historical fisheries catch data. This project will advance science by developing more accurate and efficient methods of estimating secondary production and more importantly energy transfer efficiency. By understanding the missing link between phytoplankton and fisheries, we will be able to more accurately quantify fisheries productivity based on zooplankton standing stock and its size distribution.

**Continuous water column observations along Line P**

*Steve Mihaly, Ocean Networks Canada*

At station Papa and near station P4, near-continuous water column measurements of primary variables are being conducted using vertical profilers. These type measurements allow the assessment of finer-scale time variability of the primary variables measured on the coarse temporal scale Line P cruises.

**The Line-P Iron Program: exploring the biogeochemistry of trace elements in the North-East Pacific**

*Andrew Ross, Institute of Ocean Sciences, Fisheries and Oceans Canada*

Oceanographic data have been collected along Line-P since 1956 and are among the few time series of sufficient quality and duration to be useful in examining the long-term variability of the oceans. Total and dissolved iron have been measured intermittently along Line-P since 1997, providing a unique series of such measurements between the iron-rich coastal waters of British Columbia and Station P in the HNLC waters of the Alaska gyre. In 2012 Fisheries and Oceans Canada scientists together with collaborators at the universities of Victoria, Laval and British Columbia established the Line-P Iron Program to ensure the continuity of iron measurements along Line-P and provide a framework for process-oriented studies of iron, copper and other trace elements in the NE Pacific. This presentation

will review the historical Line-P Fe dataset and describe how different approaches are being used to study the distribution, biological utilization, and speciation of trace elements and isotopes (TEIs) along Line-P. It will also describe how these data are being made available to support international efforts (including GEOTRACES) to better understand the roles of TEIs in marine ecosystems and climate change.

**Estimating secondary production and trophic transfer efficiency along Line P**

*Theresa Venello, J.F. Dower and A.R. Sastri, University of Victoria*

Zooplankton monitoring along Line P has traditionally focused on estimating abundance and biomass at the seven "major" sampling stations. Recently, we have expanded this work to include in situ estimates of secondary production. Our measurements are based on assaying the decay of chitobiase, an enzyme involved in the recycling of chitin. During moulting, crustacean zooplankton liberate chitobiase into the surrounding water in an amount proportional to their body size. The result is a community-level estimate of secondary production akin to those derived from $^{14}C$ and $^{13}C$ for primary production. To date, we have secondary production estimates from Line P cruises in 2005 and 2016 with future sampling occurring until 2018. In 2016, net community production (NCP) was also estimated using an underway $O_2$/Ar system in addition to discrete $^{14}C$ primary productivity estimates. Historically, difficulties in estimating secondary production have meant that trophic transfer efficiencies (TTE) involving zooplankton have either been estimated using biomass, or modeled. However, using the techniques outlined above, we are now able to routinely estimate TTE and the transfer of energy at the base of marine food webs along Line P. By combining zooplankton community composition data with secondary production and TTE estimates we can also investigate how climate-related changes in zooplankton community structure may contribute to shifts in energy transfer in the NE Pacific.