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Title:	A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin
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Permission to post abstract on ORION Web site: ☑ Yes ☐ No

Abstract: (*400 words or less)*

The coastal margin of the Northeast Pacific (NEP) ocean is unique in that it is strongly influenced by local wind and buoyancy driving, interannual variability originating in the tropical Pacific, and variations in large-scale North Pacific circulation. The physical setting within the Pacific Northwest region offers contrasts for comparative studies, for example narrow versus wide continental shelves, smooth versus highly-variable coastline and bottom bathymetry, and various degrees of freshwater forcing. There exists sufficient data to help site observatory assets and, in a few places, there are historical records of ecosystem response to long-period climate variability, a legacy upon which to base multidecadal ORION observations. We identify specific science objectives on: large-scale transport of water and biogeochemical properties; large-scale along-coast gradients in productivity and community structure; mesoscale ecosystem response in two contrasting coastal regions (central Oregon with its strong, flow-topography interaction and central Washington with its strong river-influenced dynamics); hypoxia; harmful algal blooms; carbon dynamics and cross-margin flux; and tidally generated internal solitary waves.

We propose a multi-scale ocean observatory constructed upon the various elements of the ORION infrastructure to include a cabled, cross-margin Endurance Line along the historic Newport, Oregon, hydrographic line (44.65N) and a second Endurance Line off central Washington (46.5N) within the region of influence of two major freshwater sources (Columbia River; outflow from the Strait of Juan de Fuca). To allow detailed examination of fluxes and rates of physical, biological and chemical processes, we propose two Pioneer Arrays, one over the central Oregon shelf to address coastal ecosystem response to wind-driven upwelling and downwelling modulated by flow-topography interaction, and one off central Washington to detail the dynamics of river-influenced shelf ecosystem response. The Endurance and Pioneer Arrays will include vertical profiling systems capable of making multi-parameter measurements over the entire water column. An acoustic tomography array off the NEP continental margin, including the bifurcation region, is proposed to constrain the large-scale velocity and temperature fields. We propose to use autonomous underwater vehicle gliders on a set of lines encompassing the NEP continental margin to obtain long-term, repeated measurements of upper-ocean volume transport and water property flux. Land-based, high-frequency radar backscatter will be used to provide continuous mapping of surface circulation.

We also propose an advanced sensor development activity (CO2 sensors; automated plankton detection; genome-based sensors) and modeling to optimally design the observing array and to deliver accurate four-dimensional physical and biogeochemical ocean fields using data-assimilation techniques.

Please describe below key non-standard measurement technology needed to achieve the proposed scientific objectives: (*250 words or less*)

Upper- and deep-ocean vertical profiling moorings.
Integration of bio-acoustics and plankton imaging systems into profiling moorings.
Low-cost, submersible CO2 sensors.

Proposed Sites:

Site Name	Position	Water Depth (m)	Proposed Duration: Start Date	Proposed Duration: Deploy (months)	Proposed Duration: Revisits during deployment	Site-specific Comments
Newport Oregon	44.65N, coast-126W	25-3000m	1 Oct '06	120 +	2x per yr	start ASAP
Central Washington	47.0N, coast -125W		1 Oct '07	120 +	2x per yr	phase in after Newport line
Pioneer Oregon	44N, 124.5W	"	1 Mar '07	36	4x per yr	start in first year
Pioneer Washington	46.5, 124.5W	"	1 Mar '10	36	4x per yr	start after Pioneer OR

List of Project Participants

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A Multi-Scale Ocean Observatory for the Northeast Pacific Continental Margin

Project Summary

The coastal margin of the Northeast Pacific (NEP) ocean is unique in that it is strongly influenced by local wind- and buoyancy-driving, by interannual variability originating in the tropical Pacific and communicated via both the oceanic coastal wave guide and by atmospheric teleconnections, and by variations in the large-scale North Pacific circulation. The physical setting within the Pacific Northwest (PNW) region offers important contrasts for comparative studies, for example narrow versus wide continental shelves, smooth versus highly-variable coastline and bottom bathymetry, and various degrees of freshwater forcing. There exists sufficient exploratory data to help site observatory assets and formulate scientific objectives. In a few places, there are historical records that aid the analysis of the response of the ocean ecosystem to long-period climate variability, a legacy upon which to base the multidecadal ORION observations. We identify specific science objectives on: large-scale transport of water and biogeochemical properties; large-scale along-coast gradients in productivity and community structure; mesoscale ecosystem response in two contrasting coastal regions (central Oregon with its strong, flow-topography interaction versus central Washington with its strong river-influenced dynamics); hypoxia; harmful algal blooms; carbon dynamics and cross-margin flux; and tidally generated internal bores and nonlinear internal wave packets.

We propose a multi-scale ocean observatory constructed upon the various elements of the ORION infrastructure. This telescoping approach is designed to obtain the data over the wide range of spatial scales needed to address our science objectives. We propose a cabled, cross-margin Endurance Line along the historic Newport, Oregon, hydrographic line (44.65N) extending from the inner shelf, across the continental slope into the adjacent deep ocean. A second proposed non-cabled, cross-margin Endurance Line off central Washington (46.5N) is within the region of influence of two major freshwater sources (Columbia River; outflow from the Strait of Juan de Fuca – hereafter, JdF). To allow detailed examination of fluxes and rates of physical, biological and chemical processes, we propose to deploy two Pioneer Arrays, one over the central Oregon shelf to address coastal ecosystem response to wind-driven upwelling and downwelling modulated by flow-topography interaction, and one off central Washington to detail the dynamics of river-influenced shelf ecosystem response. The Endurance and Pioneer Arrays will include vertical profiling systems capable of making detailed multi-parameter measurements over the entire water column. An acoustic tomography array in the waters adjacent to the NEP continental margin, including the bifurcation region, is proposed to constrain the large scale velocity and temperature fields. We propose to use autonomous underwater vehicle gliders on a set of lines forming a control volume encompassing the northeast Pacific continental margin to obtain long-term, repeated measurements of upper-ocean volume transport and water property flux. Land-based, high-frequency radar backscatter will be used to provide continuous time-series mapping of the varying surface circulation over a range of spatial scales, in near-real time. The proposed water-column observatory infrastructure can be collocated with observatory elements necessary to study gas hydrate dynamics and sub-seafloor seismic activity associated with the PNW subduction zone.

We also propose an advanced sensor development activity (CO_2 sensors; automated phyto- and zooplankton detection; genome-based sensors) and modeling to optimally design the observing array and to deliver accurate four-dimensional physical and biogeochemical ocean fields using data-assimilation techniques.

1. Program Rationale

The region off Oregon, Washington and British Columbia is the northern portion of the California Current System (CCS), the eastern boundary current of the North Pacific subtropical gyre. This region is one of the most productive in the world, from standing stocks of plankton, up the food chain to fish and mammals. The ocean ecosystem off the Pacific Northwest (PNW) responds to physical forcing events with a wide range of spatial and temporal scales. Water and the material it contains are transported eastward by the North Pacific Current (West Wind Drift) which splits to contribute to both the CCS to the south and to the subpolar gyre to the north (**Fig. 1**). These large-scale currents are modulated by climate variability, in particular on decadal (10-40 years) time scales, with profound consequences for the ocean ecosystem in this region and beyond (**Figs. 5 & 6**). The continental margin – the region from the coast out over the continental shelf and slope and beyond into the adjacent deep ocean as far as coastal water properties extend – off the PNW is also strongly influenced by dynamic interannual variability (1-3 years) (**Fig. 7**) originating in the equatorial Pacific both through the coastal ocean wave guide and through atmospheric teleconnections, again with dramatic consequences for the local ocean ecosystem.

The coastal oceans off the Pacific Northwest are prototypical wind-driven upwelling and downwelling ecosystems with strong seasonal variations in flow direction and primary productivity. Local production during the spring and summer is fueled by the upwelling of deep, nutrient-rich water during wind events lasting 2-20 days (the "weather band") (**Fig. 2**). The degree of upwelling-driven primary production is strongly modulated by changes in source water characteristics as influenced by the aforementioned interannual and interdecadal variability. The intensity of local production (**Fig. 4**) is also dependent on both flow-topography interaction (**Fig. 8**) and the influence of buoyancy input from the two major freshwater inputs to PNW waters, the Columbia River (**Figs. 3 & 9**) and flow through the Strait of JdF (primarily the Fraser River).

The coastal ecosystem response to physical forcing ranges from "balanced" primary production fueling a healthy marine food web to intensified production of toxin-producing harmful algal blooms (HABs) to respiration of excess organic material creating hypoxic "dead zones" (**Fig. 11**). In recent years, HABs events have been increasing in frequency along the PNW coast (Trainer et al., 2002) (**Fig. 12**). Regions of hypoxia have been recurring on the central Oregon coast (Grantham et al., 2004). Salmon runs have increased dramatically early in the 2000s and then decreased again. The Columbia River provides a major time variable sediment source to the continental margin of the PNW.

Wind-driven coastal upwelling and downwelling fronts, together with the edges of large-scale river plumes, are locations of intense ecosystem response to property variations on the scale of a few kilometers or less. Recently, the role of tidally generated internal bores and nonlinear internal waves, on material transport, mixing and the subsequent ecosystem response has become apparent (**Figs. 13 & 14**). The combination of these relatively high-frequency motions with wind- and buoyancy-created ocean fronts in modulating ecosystem response presents new sampling challenges that cannot be met with traditional approaches.

The coastal ocean off the PNW is inextricably tied to the adjacent deep ocean both through changes in source waters for upwelling, but also by export of water properties offshore and downstream. Pacific Northwest waters form the northern, upstream region of the California Current System. Hence cross-margin transport of nutrients, plankton and larvae influence this productive eastern boundary current far downstream. Recent studies suggest that coastal upwelling in this region is particularly efficient at fixing atmospheric CO2 and that the region may serve as a sink of CO2 from surface waters on par with much of the North Pacific. The details of the transformation of that organic matter near the seafloor and its export from the shelf are still unknown, but are surely influenced by the event- to decadal-scale ecosystem variability.

In a broader context, the local production of organic material and its delivery to the seafloor along the continental margin off the Pacific Northwest is likely tied to the occurrence of gas hydrates in the sediments of the subduction complex on the continental slope. The subduction zone setting, in turn, results in focused fluid pathways that lead to methane seeps and massive gas hydrate deposits on the seafloor and in earthquakes that may be one of the factors controlling episodicity of venting and gas hydrate formation. This cycle is completed as the local circulation transports methane within and across the water column (**Fig. 15**), thus controlling its path to the atmosphere and subsequent influence on climate variability. The observatory elements needed for the study of water column processes can be collocated with elements needed for an observatory to study gas hydrate dynamics and for observation of sub-seafloor seismic activity associated with the Pacific Northwest subduction zone.

In spite of the high productivity of the important PNW ecosystem, surprisingly little is known about fundamental processes that determine the variability in its individual components. For example, there have been no comprehensive papers addressing the seasonal evolution of community structure; no papers on evolution of grazing pressures, etc. Why are these data not available? They are lacking because of the fundamental difficulty of examining thousands of plankton samples by hand (see **Fig. 16** for an alternative) and because the existing infrastructure does not allow scientists to propose studies with sufficient sensors to "close the box" for flux and rate studies. Although existing data have been sufficient to detail one recent large scale transport event (the 2002 "Subarctic Invasion") and its ecological consequences, in general, consistent long time series of physical transport resolving variability over years to decades have not been obtained, primarily due to cost. Time series of nutrients and plankton have not been available due to lack of appropriate sensors and the energy to power them. Long term data series are particularly lacking over the continental slope, which is the source water region for almost all of the nutrients in this region.

On the other hand, we note that long term time series from earlier decades are sufficient to provide baselines for future variability (Smith et al., 2001; Landry et al, 1989; Hickey, 1989). Moreover, process-oriented studies in this region are sufficient for scientists to identify the most beneficial sites for an observing system and the appropriate sensors to deploy. Thus, the PNW is fully ready to exploit the benefits of an ocean observatory. We are poised and ready to make long-term, multi-parameter measurements of a dynamic ocean ecosystem being forced at time scales ranging from hours to multi-decadal climatic periods.

We are a multi-institutional, interdisciplinary group of oceanographers ready address these long-term themes:

- Large time and space scale transport of water, nutrients and plankton
- Regional ecosystem variability
- Cross margin fluxes.

2. Scientific Objectives

This section is organized into scientific themes spanning the spatial and temporal scales of interdisciplinary ocean science. The emphasis is on experiments and objectives targeted at water-column processes over the continental margin forced by air-sea interactions, freshwater buoyancy inputs and through interaction with North Pacific circulation. In the following section on experimental design and observing requirements, we propose a set of observatory elements to address the scientific objectives that arise from the three thematic topics listed above.

2.1 Large-scale Transport of Water and Biogeochemical Properties

The regional oceanography of the PNW continental margin is influenced by the bifurcation of the North Pacific Current, and by the seasonally varying, strong north-south boundary currents: the California Current, the California Undercurrent and the Davidson Current (**Fig. 1**). The California Current is a surface-intensified, equatorward current that can reach speeds of 0.5–1.0 m s^{-1} and extends into the water column down to 500–1000 m. The California Undercurrent is a subsurface poleward current with a core at 200 m and an average speed of 0.15 m s^{-1}. The Davidson Current is a strong (up to 1 m s^{-1}) poleward, surface-intensified flow found over the continental shelf and slope in winter. These currents transport heat, salt, nutrients, dissolved oxygen, plankton, and invertebrate larvae north and south and are crucial to the ecosystem response in this region. The eastern boundary currents exhibit variability on a variety of time scales from the 2–5-day event time scale, through the seasonal time scale to interannual (El Niño/La Niña) and interdecadal [Pacific Decadal Oscillation (PDO)] variability.

The California Undercurrent extends along the upper continental slope of the entire US west coast and is relatively difficult to observe given its subsurface nature. This large-scale feature transports nutrient, salt, heat and plankton and larvae hundreds to thousands of kilometers along the coast. The undercurrent transport responds to interannual variability (Huyer et al., 2002) and provides a portion of the high-nutrient source water that is upwelled seasonally onto the continental shelves. In contrast to the US east coast, very few nutrients (iron being an exception) are provided to the PNW coastal ocean by river plumes. The undercurrent has been invoked as a possible mechanism for transporting phytoplankton seed stock as well as fish larvae throughout the region. On the other hand, because the flow in the undercurrent is oppositely directed from surface flows, it has been suggested that vertically migrating zooplankton may use the undercurrent to maintain a regional location (Swartzman et al, 2005). In spite of these important attributes, long term (> a few months) measurements in the undercurrent are almost nonexistent.

Besides being influenced by advective fluxes, PNW waters are affected by interannual changes originating in the tropical Pacific and communicated northward by coastally trapped waves. One example is deepening of the pycnocline and hence nutricline during El Nino years. We propose to combine observations from the PNW region (see section 3) with those from farther south (Pacific Coast RFA response) to examine this process.

A multi-faceted approach will be used to obtain the necessary in-situ measurements of the control volume encompassing the northeast Pacific continental margin. Within the control volume in deep water, acoustic tomography will be used to measure the low-wavenumber synoptic flow and temperature fields. A set of east-west and north-south lines forming a control volume encompassing the northeast Pacific continental margin will be sampled with autonomous underwater vehicle gliders to obtain long-term, repeated measurements of upper-ocean volume transport and water property flux. Two heavily instrumented, multi-parameter east-west Endurance Lines of moorings will provide unprecedented, year-round, long-term time series. The combination of these three methodologies will allow us to address scientific questions related to large-scale eastern boundary current transport.

Important questions include:

- What is the spatial and temporal variability of the meridional transport of physical and biogeochemical properties (from the 2–20-day weather band to interannual and interdecadal)?
- What is the relationship between meridional transport and large-scale forcing by the wind and/or alongshore pressure gradients?
- How do the depth of the nutricline and its concentration of macronutrients affect coastal primary productivity?
- Is the California Undercurrent important for maintenance and/or spread of biological populations?
- What influences the time variability of the bifurcation of the North Pacific Current and how does its variability affect ecosystem response in PNW waters?

2.2 Large-Scale Along-Coast Gradients in Productivity and Community Structure

The general patterns of productivity and community succession in upwelling systems are well-known. Upwelling characteristics include an onshore to offshore progression from phytoplankton-poor newly upwelled water, to a highly productive diatom bloom, followed by nutrient exhaustion and smaller phytoplankton better suited to stratified conditions (Margalef, 1978). Sustained relaxation and downwelling conditions are typified by lower productivity and dominance by non-diatom phytoplankton. Superimposed on this simplified pattern, however are complex hydrographic and event scale changes which affect plankton community structure, trophic pathways, and carbon export in ways that are poorly known for most upwelling systems. For instance, under El Nino conditions, upwelled water off the Oregon coast is dominated by small pico (<2 um) and nanophytoplankton (Hood et al. 1992; Corwith and Wheeler, 2002), rather than large diatoms. Species and size-structure of the phytoplankton largely determine trophic pathways and carbon export (e.g. Michaels and Silver, 1988), which can change on times scales of days to weeks. At present, our knowledge of how the ecosystem responds to changes (seasonal, event, decadal) in the PNW system is limited by the sparseness of species-level observations with adequate temporal and spatial resolution.

Although both are upwelling systems, the productivity regimes on the Washington and Oregon coasts have many apparent, but not well understood, differences. For instance, chlorophyll is generally higher toward the north, as shown by seasonal time series of vertically integrated chlorophyll (Landry et al., 1989), satellite-derived ocean color (Strub et al., 1990; Thomas and Strub, 2001) and a dozen recent surveys of this region (Peterson, pers. comm.). The limited data available suggest that primary productivity follows the same spatial pattern, and is particularly surprising because the alongshore wind stress responsible for macronutrient supply (Huyer, 1983) increases in the opposite direction to the productivity. Nevertheless, the seasonal variation in macronutrient supply to the mid-shelf does not differ substantially between the two regions (Landry et al., 1989), a possible consequence of enhanced upwelling from submarine canyons that indent the Washington shelf edge (Hickey, 1997). Model studies (Allen et al.,

1995) show that a wider, gently sloping shelf results in slower circulation (i.e., possibly greater retention) and that the upwelling flow tends to be more concentrated in the bottom boundary layer than in steeper regions (hence more inflow from the richest layers and more bottom contact for micro-nutrient supply). Thus, the fact that the width of the shallow nearshore (<100 m deep) widens by more than a factor of two north of the Columbia mouth might contribute to the apparently similar levels of macronutrients across the region. However, it would not readily explain the higher primary productivity to the north.

Greater secondary productivity (e.g., in euphausiids and copepods; Landry and Lorenzen, 1989) is also observed off the northern WA coast and near the Columbia plume. Recent studies show that the abundance of euphausiid eggs is always higher (~700%) on the Washington shelf compared to the Oregon shelf (Peterson, pers. comm.) although zooplankton communities are similar on the two shelves (Peterson et al., 1979; Landry and Lorenzen, 1989). Juvenile salmon are more abundant on the northern coast and in the plume (Pearcy, 1992). Information on microzooplankton in the region is not yet sufficient to discern along-coast gradients, but substantial biomass of ciliates and heterotrophic dinoflagellates have been recorded on both the Washington coast (Chester, 1978; Landry and Hassett, 1982; Landry and Lorenzen, 1989; Lessard, unpubl.) and in upwelling waters off Oregon (Neuer and Cowles, 1994; Sherr and Sherr, 2002). As microzooplankton are the dominant herbivores in most coastal planktonic food webs (e.g., Neuer and Cowles, 1994; Strom et al., 2001), their biomass and grazing activities are key components to understanding trophic consequences of variations in phytoplankton structure and productivity.

Important questions include:

- Is phytoplankton community structure and productivity similar over the entire PNW?
- How does phytoplankton community structure change with event, season, year, and decades? Why does it change?
- How do bacteria, micro- and macrozooplankton biomass and community structure change over time/space? How are changes related to phytoplankton community structure?
- Are water property changes caused by local variation in forcing, changes from along the coast, or imposed from offshore by basin-scale effects?

2.3 Mesoscale Ecosystem Response in Two Contrasting Coastal Regions

The PNW coastline is relatively straight—thus jets, eddies and meanders that commonly occur off California are relatively less common (Hickey, 1998). Nevertheless two mesoscale features in the region have been shown to be of critical importance to the regional ecosystem. Both of these features – Heceta Bank off central Oregon and the JdF Eddy off northern Washington and southern Vancouver Island – modify circulation and local nutrient supply and enhance local productivity in their vicinity. The JdF eddy, located off the mouth of the Strait of JdF, is a seasonal feature caused by the interaction of flow exiting the Strait, the shelf edge coastal jet and the underlying topography (Tully, 1942; MacFadyen et al., 2005). Water transiting this eddy is ejected into the large-scale southward coastal jet system under upwelling conditions, subsequently moving southward.

2.3.1 Flow-Topography Interaction and Ecosystem Response over Heceta Bank, Oregon.

Recent studies off Oregon have revealed the importance of flow-topography interaction between the wind-driven coastal upwelling jet and a large submarine bank, Heceta Bank (Oke et al., 2002b; Castelao and Barth, 2005a; Barth et al., 2005a,b). Hydrographic and velocity observations and numerical modeling results show that the wind-driven coastal upwelling jet increases its separation from the continental shelf downstream of Heceta Bank as the spring-summer upwelling season progresses (**Fig. 8**). This occurs because the cumulative seasonal input of wind energy has made the upwelling jet more inertial and less able to follow alongshore changes in bottom topography. Separation also occurs more readily when the intrinsic length scale of the flow (the Rossby radius of deformation) is close to the bank width as it is for flow over Heceta Bank (Castelao and Barth, 2005b). As the equatorward upwelling jet follows the mid-shelf isobaths around Heceta Bank, it leaves a "lee" or shadow region on the inshore side where currents are weaker and retention times are greater (Barth et al., 2005a,b; Castelao and Barth, 2005a; Kosro, 2005). This allows local primary production to outpace advective loss so that intense phytoplankton blooms are found in this region (**Figs. 8 & 11**). Respiration of organic matter exported to depth is a likely contributor to hypoxia in bottom water over Heceta Bank (see section 2.4). The increased residence times may also allow blooms to persist, possibly depleting certain micronutrients or leading to physiological stress that may cause domoic acid production in some diatoms (see section 2.5).

The separated jet downstream of the Bank creates considerable cross-shelf transport of heat, salt and chlorophyll (carbon) and contributes significantly to the properties of the California Current System (CCS) (Barth et al., 2000; 2002; Strub and James, 2002). In contrast to the spring/summer upwelling condition, wintertime shelf flow is to the north in the Davidson Current and little is known about its interaction with bottom topographic features. It is, therefore, critical to understand the time-dependent flow-topography interaction that leads to cross-margin transport and the connection between the continental shelf and the adjacent deep ocean.

Important questions include:

- How does the flow field over a mesoscale bank depend on wind-forcing, flow strength, seasonality (i.e., flow direction) and ocean climate variability?
- What are the consequences of this variability in forcing for the coastal ecosystem (e.g., productivity, community structure, development of hypoxia)?
- What are the along- and cross-shelf fluxes of heat, salt and carbon created by flow interaction with a mesoscale bank region throughout the year?
- How are cross-shelf property fluxes partitioned between the bottom boundary layer and the geostrophic interior?
- How predictable are coastal circulation and ecosystem response on a mesoscale bank? What does this imply about observing system requirements for coastal forecasting?

2.3.2 River-Influenced Coastal Ocean Dynamics and Ecosystem Response

The PNW shelf has two primary sources of freshwater—the Strait of JdF to the north, and the Columbia River, in the center. Neither the Fraser nor the Columbia are significant sources of macro nutrients to the coastal ecosystem. Nevertheless both features are responsible for delivery of large amounts of nutrients to the coast—in both cases via mixing and entrainment of upwelled coastal waters. The nutrients fuel high plankton growth in the region offshore of the strait (MacFadyen et al., 2005) as well as off the mouth of the Columbia (**Fig. 4**). Much of the water exported from the Strait of JdF is entrained in the southward flowing coastal jet influencing the Washington shelf. The plume from the Columbia River is a dominant feature in the hydrography of the U.S. West Coast, transporting dissolved and particulate matter, phyto- and zooplankton, larvae, and contaminants hundreds of kilometers along and across the continental margin (Barnes et al., 1972; Grimes and Kingsford, 1996) (**Fig. 3**). The Columbia plume flows northward over the shelf in fall and winter, and southward offshore of the shelf in spring and summer. However, the plume also changes direction, thickness and width with every change in local wind stress magnitude or direction (Hickey et al., 1998, Garcia-Berdeal et al., 2002). Recent studies have shown that the Washington shelf is rarely without some remnant freshwater even in summer—the plume is frequently bi-directional (Hickey et al., 2005) (**Fig. 9**). At such times, upwelling is inhibited on the Washington coast (**Fig. 10**). Thus, the Washington shelf is influenced by two freshwater sources in summer; in contrast, the central Oregon shelf is influenced solely by the Columbia River although local river input of freshwater and macro- and micro-nutrients is likely important off Oregon in winter.

The Columbia River plume is turbid, providing better refuge from grazing for higher trophic levels. Deep mixing is inhibited by high stratification at the base of the plume, thus tending to keep plankton within the euphotic zone. Plumes alter regional near-surface current patterns, providing along-plume jets for rapid transport, and convergences and trapping at frontal boundaries on the edges. For juvenile salmonids, the strength of the river flow and plume size appear critical as they move from freshwater to saltwater (Pearcy, 1992).

The exchange and eventual fate of terrestrial freshwater input has an important influence on the coastal ocean and the adjacent ocean basin. The cross-margin exchange of fresh water injects a wide range of scalar properties to the shelf system, and adds buoyant water dynamics. Freshwater input also impacts global climate by changing upper-ocean stratification, which in turn affects heat and momentum fluxes between atmosphere and ocean. Our lack of understanding of these processes is reflected in the very crude methods used in GCMs to study climate and ocean-atmosphere interaction in response to the introduction of terrestrial freshwater to the open ocean (Lee et al., 2005).

Important questions include:

- How does a large point source of freshwater affect the dynamics of shelf circulation?
- What is the role of time varying freshwater input in structuring the ecosystem?
- How does the presence of a river plume affect cross-shelf transfer of plankton, local upwelling, grazing, HABs occurrence and nutrient supply?
- What is the fate of freshwater delivered to the PNW shelf on event to decadal time scales? To what extent does it impact the stratification and freshwater content of the greater ocean basins?

2.4 Hypoxia in the Pacific Northwest

A previously unappreciated form of interannual variability occurred off the US west coast during 2002 when an anomalous water mass of Subarctic origin “invaded” the region from the north (**Fig. 7**, right panel; **Fig. 11**, upper panels) (Freeland et al., 2003). These large-scale, interannual signals have profound influence on the upwelling source waters (from 50-150 m depth) for the central Oregon shelf. Changes in shelf water properties and circulation, from event scale to interannual, have significant impact on coastal ocean ecosystems. The upwelling of nutrient-rich water into the euphotic zone over the shelf results in high phytoplankton productivity (Small and Menzies, 1981) and flow-topography interaction can result in regions with intense, concentrated productivity (Barth et al., 2005a,b). The combination of anomalous low-oxygen, nutrient-rich source waters in 2002 led to enhanced phytoplankton production over Heceta Bank (**Fig. 11**, lower left) (Wheeler et al., 2004; Thomas et al., 2004). The anomalously strong Subarctic water signal entering the northern California Current was traced to anomalous atmospheric forcing in the Gulf of Alaska using Argo float and ship CTD data (Crawford et al., 2005).

The combination of low-oxygen source water and microbial respiration of sinking phytoplankton material led to hypoxic conditions in the lower water column off central Oregon (**Fig. 11**, lower right panel) (Grantham et al., 2004). The hypoxia event lasted at least 60 days and there was significant die-off of Dungeness crabs and rockfish (Grantham et al., 2004). Time series on the Washington shelf indicate that near-bottom waters also were likely hypoxic during this event. Similar hypoxic conditions were observed off the central Oregon coast during summer 2004 with significant crab die-offs but relatively little impact on fish (F. Chan, H. Weeks, pers. comm.). In 2004, source water characteristics were statistically indistinguishable from average conditions, hinting at the increased importance of local respiration and retention versus anomalous source waters in creating low-oxygen shelf water. Having year-round, nearly continuous, long-term measurements of subsurface water properties, including chlorophyll fluorescence and dissolved oxygen, will allow us to more definitively assess the role of physical, chemical and biological processes in these important ecosystem changes.

Important questions include:

- What is the alongshore and temporal variability of coastal hypoxia in the PNW?
- What drives the invasion of anomalous Subarctic Water into the northern CCS?
- What are the relative contributions of low-oxygen, nutrient-rich source water versus local respiration in driving shelf waters hypoxic in the northern CCS?
- What wind conditions are optimal for retention of productive waters over Heceta Bank and subsequent intense phytoplankton blooms and hypoxia?

2.5 Harmful Algal Blooms

During the past decade the economic consequences of harmful algal blooms on fisheries and ecosystem health have been severe along the U.S. west coast. For example, the closure of Washington State beaches in 1991 to recreational and commercial shellfish harvesting due to high domoic acid concentrations in shellfish resulted in a $15-20 million revenue loss to local fishing communities (Horner and Postel, 1993). Domoic acid (DA), which is produced by several species of the diatom *Pseudo-nitzschia,* causes amnesic shellfish poisoning in mammals, including humans, resulting in severe neurological effects and even death. The commercial Dungeness crab industry on which the Quileute Indian tribe depends for employment lost 50% of their income in 1998 due to harvest closures. The entire razor clam harvest of the Quinault tribe, on which they depend for both subsistence and commercial revenue, was again lost in the fall of 1998 (Trainer and Wekell, 2000). A survey of domoic acid along the entire U.S. west coast continental shelf in summer 1998 suggests a strong relationship between DA concentration and mesoscale topographic features (**Fig. 12**). Off northern California where large coastal promontories and hence rapid offshore transport occur, DA levels are low. Offshore of the Strait of JdF, over Heceta/Stonewall bank in Oregon, offshore of Monterey Bay (inshore of the Farallone Islands) and near the Santa Barbara Channel, DA levels are higher. One common characteristic of high DA regions is their capacity to have longer retention times than other coastal regions. The seasonal JdF eddy has been shown to be an initiation site for toxic blooms of *Pseudo-nitzschia* (Trainer et al., 2002). These toxic blooms are advected south of the eddy in the coastal jet and are transported onto the coast during periods of downwelling (MacFadyen et al., 2005). Incidents of paralytic shellfish poisoning, caused by the dinoflagellate *Alexandrium*, also leads to frequent shellfish closures in the PNW. Outbreaks of HABs have been increasing in frequency worldwide as well as in the PNW (Anderson, 1995), reinforcing the public health needs for sustained observations of these phenomena and the conditions that initiate them.

Important questions include:

- Are HABs increasing in time over the open shelf, or is it simply that transport to shore (where we see its impacts) is increasing?
- Are HABs tied to specific geographic sites and if so, why?
- What aspects of ecosystem variability lead to onset of HABs?

2.6 Carbon Dynamics and Cross-Margin Flux

It has long been recognized that the upwelling margins of the North East Pacific (NEP) are highly productive regions. What had not been recognized until recently, however, is how important these regions might be to air-sea CO_2 exchange and deep ocean carbon sequestration. In fact, the carbon dynamics of the margins of the North American continent are poorly understood and are under sampled to the point that it is uncertain whether or not the margins are a net source or sink of atmospheric CO_2. Some studies have suggested that the "continental shelf pump" could be responsible for as much as 1 Pg C yr^{-1} sink globally. A recent analysis using satellite data suggests that the margins may be responsible for more than 40% of carbon sequestration in the ocean [*Muller-Karger et al.*, 2005]

On much of the west coast, summer-time upwelling brings high-pCO_2 water as well as abundant pre-formed nutrients to the surface. As a result, photosynthetic uptake often depletes upwelled nutrients and drives surface–water pCO_2 to very low levels. This can make such regions large local net sinks for atmospheric CO_2, as observed by Hales et al. (2005a). In other cases (Friederich et al., 2002) biological demand is insufficient to take up the excess CO_2 in upwelled waters and such areas are net sources of CO_2 to the atmosphere. The relative importance of upwelling of high-pCO_2 waters versus rapid biological consumption of excess nutrients, and the resulting effect on air-sea CO_2 exchange has been shown to affect the chemistry of marine airmasses impinging on the North American continent (Lueker et al., 2003). The degree to which these same upwelled waters carry and exchange methane from benthic sources on the shelf and upper slope is also unknown but this process might constitute a significant source of methane to the atmosphere (Heeschen et al. 2005; Collier and Lilley, 2005).

More recently, using budgets of oxygen and particulate organic carbon (POC) in the same region, Hales et al (2005b) showed that essentially all of this newly-produced carbon appears to be exported from the shelf, probably to the deep ocean where it is sequestered for centuries or longer. Hales et al. (2005b) suggested a mechanism whereby modulation of the frequency and intensity of upwelling-favorable conditions on timescales of several days could lead to frequent events where POC suspended in the bottom-boundary-layer was transported to the shelfbreak and subsequently sunk into the deep ocean. In summary, carbon is just one of many water properties (others include nutrients, fresh water, dissolved oxygen, plankton) for which we require a more quantitative understanding of its cross-margin flux.

Important questions include:

- Is the coastal margin of the NEP ocean a net sink or source of atmospheric CO_2?
- Within the PNW, how does carbon export vary with shelf width, river influences, nutrient supply and shelf break topography?
- How does carbon export to the sediments change over time?
- What are the carbon export mechanisms from the shelf to the deep sea and how do they change over time?

2.7 Tidally Generated Internal Bores and Nonlinear Internal Wave Packets

Tidal forcing provides a continuous source of energy to the coastal ocean. With improved modeling capability and increased bathymetric resolution the prediction of barotropic tidal elevation and currents off Oregon are becoming increasingly more accurate. However, the internal tide is more complicated and will require in situ observations in order to make advances in a predictive capability. Internal tides are internal waves generated in a stratified ocean by the interaction of tidal driven flow with topography. The continental slope serves as an effective generator of internal tide propagating cross-shelf. As it propagates and shoals, the internal tide becomes nonlinear, and often develops into an internal bore accompanied by an energetic packet of high-frequency oscillations (sometimes called solitons, solitary waves or solibores) (e.g., Liu 1988; Sandstrom and Oakey 1995; Henyey and Hoering 1997) (**Fig. 13**). As the bore and nonlinear wave packet continue to shoal, energy is dissipated and vertical mixing occurs. This mixing may play an important role in the circulation of the coastal ocean and is currently not included in regional modeling efforts. The nonlinear wave packets may also serve as an important mechanism for cross-shelf transport – onshore advection of particles in the upper water column and the simultaneous offshore advection at depth (e.g., Lamb 1997). This process may be important in both larval recruitment and sediment transport (e.g., Bogucki and Redekopp 1999, Shanks 1988). The internal tide is not as predictable as the barotropic tide as it is sensitive to the vertical and horizontal stratification which varies at low frequencies. The presence of jets and eddies will also affect the propagation and evolution of the internal tide. In winter when shelf waters are more mixed than in summer and the foot of the downwelling front is on the outer shelf, nonlinear internal wave of elevation can propagate along the near-bottom density interface (**Fig. 14**). Observations of summertime nonlinear internal waves of depression have been limited to short-term ship (several days) and moored (tens to 100 days) measurements, while wintertime bottom wave packets have rarely been documented (Klymak and Moum 2003).

Important questions include:

- What are the background and tidal conditions that lead to the generation of internal bores and nonlinear internal wave packets?
- How do these features evolve as they propagate across the shelf?
- What is their contribution to cross-shelf transport, sediment resuspension and mixing?

2.8 Flow Interaction with Hydrate Ridge Methane Source

The Newport Hydrographic Line (44.6N), occupied since the early 1960s, is located just to the south of Hydrate Ridge, an offshore topographic feature with well-characterized seafloor gas hydrates and methane seeps (eg.Suess et al., 2001, Torres et al. 2004, Trehu et al., 2004). When methane enters the water column at 600-800 m, it is subject to transport by the local circulation (Heeschen et al., 2005) (**Fig. 15**). This opens the possibility for some very synergistic experiments, namely the use of methane to trace water circulation and the predictions of the methane's fate based on knowledge of local circulation processes. For example, Rehder et al. (2002) show how out-gassed methane is brought to the surface by wind-driven coastal circulation. This accelerates the transport of methane from the seafloor to the atmosphere where methane plays a strong role as a greenhouse gas. It has also been recognized that shallower, active methane sources on the Heceta Bank complex provide methane fluxes that may be greater or equivalent to those from the deeper hydrate system (Collier and Lilley, 2005). While Rehder et al. (2002) demonstrated the existence of this process, long-term, year-round measurements are needed to quantitatively assess the importance of this link between a sub-seafloor process and ocean-atmosphere dynamics.

We propose to link our Endurance Array off Newport, Oregon, to biogeochemical studies proposed for Hydrate Ridge (see RFA response by Trehu et al.). By using the same observatory elements, specifically a cable providing power and communications, we can fully observe both sub-seafloor and water column processes. Although gas hydrates are found in many places on the world's continental slopes and some locations have been well-studied from a geological and chemical point-of-view, Hydrate Ridge is unique in being collocated on a long-time hydrographic line anchoring a region with high ecological interest.

3. Experimental Design and Observing Requirements

We propose a multi-scale ocean observatory constructed upon the various elements of the ORION infrastructure. The observatory will combine east-west, cross-margin Endurance Lines, focused Pioneer Arrays, surface velocity mapping from land-based HF radar arrays, an acoustic tomography array, far-field information from deep-sea buoys spanning the subtropical-subpolar boundary, and water property and flux information from autonomous underwater vehicle gliders (**Fig. 17**). We also propose an advanced sensor development activity and a modeling effort, the latter to optimally design the observing array and to deliver accurate four-dimensional ocean fields using data-assimilation techniques.

3.1 Endurance Lines

Two cross-margin Endurance Lines are proposed: one off central Oregon along the historic Newport hydrographic line (44.65N); the other in the central Washington historic data region (46.5 N) (**Fig. 17**). These arrays will extend from the inner shelf, across the continental slope into the adjacent deep ocean. We propose that the Oregon Endurance Line be cabled either as part of the regional cabled observatory (RCO) or as an extension up onto the continental margin from the RCO backbone. As described above, this cabled observatory will be used not only for our water-column oriented scientific objectives but also for seismic and gas hydrate research due to its crossing of the NEP subduction zone and its proximity to Hydrate Ridge (**Fig. 18**). The

Endurance line will consist of multi-parameter vertical profiling systems, bottom-mounted ADCPs and full water column moorings with surface buoys to facilitate meteorological measurements, the study of internal solitons and the telemetry of subsurface data to shore. While exact depths are subject to revision, we suggest that profilers and nearby water-column moorings be located at the 25, 50, 80, 150, 500, 1500 and 3000-m isobaths. This line together with lines across the continental margin both north (proposed here for along 46.5N and as occupied by NEPTUNE Canada along ~48.5N) and south (proposed for Crescent City 41.9N and Monterey Bay 36N in a RFA response for US West Coast research) will allow the study of alongshore transport and wave propagation along the entire US west coast.
To take full advantage of the comparative approach along the PNW continental margin and to ensure that variability is adequately sampled to resolve dominant processes, we propose to deploy a second Endurance Line off central Washington along 46.5N (**Fig. 17**). This central WA line could be cabled if a convenient connection to the regional cabled observatory exists, but would most likely consist of autonomous moorings telemetering data to shore. The along-coast separation between the two proposed Endurance Lines is sufficient to resolve along-shelf gradients in physical and chemical properties and the ecosystem response (chlorophyll standing stock and primary productivity). This line is deliberately sited within the region of influence of two freshwater plumes, one from the Columbia River, the other from the Strait of JdF. The Newport line is south of the Columbia River, hence only influenced by it during summer. During wintertime the Washington line is ideally suited for study of sediment input to and deposition in the coastal ocean by the Columbia River. Combined with the Newport line, the two will bracket the Columbia River over all seasons with high resolution measurements.

Additional measurements will be made offshore along these two Endurance Lines by using gliders (see below and **Fig. 17**). The velocity fields measured by the Endurance Lines will be connected through the use of long-range land-based coastal HF radar arrays extending along the entire PNW coast (see below).

3.2 Pioneer Arrays

Possibly the most successful coastal ocean field program was the 1981-1983 Coastal Ocean Dynamics Experiment (CODE) (Beardsley and Lentz, 1987). The heart of this program was a coherent (in the along-shelf) moored array maintained during upwelling conditions in 1981 and 1982. This array provided data to test seminal ideas about upwelling, coastally trapped waves, bottom boundary layer mixing and the marine atmospheric boundary layer. Data from this program continue to be used today for the testing of physical oceanographic numerical models. The proposed Northeast Pacific ocean observatory will not only allow similar measurements year-round but we now have the capability to make time-series measurements of bio-optical, chemical and bio-acoustic properties on similar time and space scales as we do for physical properties. This newly developed capability, and emerging CO_2 detection and DNA probe technologies, will provide researchers with the chance to make analogous advances in understanding ecosystem dynamics in a prototypical wind-driven coastal region.

To allow detailed examination of fluxes and rates of physical, biological and chemical processes, we propose to deploy two Pioneer Arrays. One will be located over the central Oregon shelf anchored by the Newport Endurance Line and intended to address scientific objectives related to coastal ecosystem response to wind-driven upwelling and downwelling and flow-topography interaction (localized high production, off-margin flux, preferential regions for hypoxia and HAB formation). The **Oregon Pioneer Array** will encompass Heceta Bank, adding three cross-margin mooring lines to the Newport Endurance Line to extend the along-shelf coverage to over 125 km (**Fig. 18**). Each Pioneer Array mooring line (43.5, 43.825, 44.25N) will consist of 6 vertical profiling moorings, a subset of which – two on the shelf and one off -- will have nearby full-water column moorings with surface buoys. Moorings will be placed at the same isobaths as on the Newport Endurance Line to allow property flux measurements to be made. The array extends well seaward of the continental shelf break (200 m) in order to estimate the cross-shelf flux of water properties (heat, salt, carbon, nutrients). For mooring locations in water depths greater than 200 m, we propose a hybrid profiling system consisting of a fixed mooring line with traveling profiler from the sea floor up to within 200 m together with a winched profiling system from 200 m up to the sea surface (see description of **deep-ocean** and **upper-ocean profilers** below). The line at 44.25N is chosen to occupy the high-chlorophyll and potentially hypoxic region on Heceta Bank (**Figs. 8 & 11**), and will coordinate with the measurements taken at 15 m and on the rocky intertidal by the PISCO program (see section 4). The lines at 43.5 and 43.825N will allow cross-margin flux estimates during the southward flow regime of spring-fall, as the line at 44.65N will allow during northward flow during winter. The full water-column measurements just south of Heceta Bank (43.825N) will enable the study of rapid sinking and injection of POC off the continental margin (Barth et al., 2002; Hales et al., 2005b). Scientific objectives requiring high spatial-resolution of surface currents will be aided by the use of a standard-range land-based HF radar array (see section 3.6).

We also propose a second Pioneer Array (**Fig. 19**) in a region of smooth shelf topography along the southern Washington coast anchored by the Endurance Line at 46.5N. The **Washington Pioneer Array** focuses on small scales, and is designed to link physical and chemical forcing to the distribution and community structure of phytoplankton and microzooplankton, in a region of high productivity that is strongly influenced by freshwater (from the Columbia River). The array is defined by 9 mooring locations. At each of these a full suite of hydrographic, chemical, and optical properties will be measured using the upper-ocean profilers as described in section 3.3. This will allow observation of the distribution of ecosystem properties in the volume, as a function of time, as well as the flux of these properties through the volume boundaries. On the three central moorings (the "Pioneer Process Moorings," **Fig. 19**) we include additional instrumentation. To identify and track changes in the community structure of the >5 um phytoplankton and microzooplankton, imaging cytometers (FlowCAMs, see Advanced Sensor Development, section 3.7.2) will be added to the profilers. In addition we will take high resolution video images in order to optically characterize the patchiness of resources (mostly phytoplankton) and consumers (mostly microzooplankton), and in particular how aggregated the consumers are to resource patches. Each of the three Pioneer Process Moorings will have a nearby secondary mooring, consisting of a surface buoy and a fixed line, as described in section 3.3. The three fixed lines will be instrumented with SEACATS and ADV's at 1, 3, 5, 10, and 20 m depths in order to resolve detailed time series of stratification and turbulence in the plume-affected surface waters.

3.3 Observing Requirements for Profiling Moorings

We propose to use profiling moorings as part of both the Endurance Lines and Pioneer Arrays. Profiling moorings have the advantage of producing high vertical-resolution measurements using just one sensor suite package as opposed to multiple copies in the vertical of expensive instruments. Profilers can also “hide” on the ocean floor to help minimize bio-fouling which is greatest in the upper-ocean euphotic zone and to help avoid damage from fishing and other maritime activity. Much of our coastal ecosystem research is concentrated in water depths of 200 m or less (**Figs. 17-19**), and thus requires an **upper-ocean profiler**. There are also scientific objectives only addressable with the ability to profile over greater depths over the continental slope and adjacent deep ocean. For this purpose, we require a **deep-ocean profiler** operating on a fixed mooring line and capable of profiling from (local) full-ocean depth (~3000 m) to within 200 m of the surface at which depth a stable platform will be provided for mounting other sensor packages, including an upper-ocean profiler (**Fig. 20**).

The **upper-ocean profiler** will consist of: a completely self-contained, modularly-integrated sensor, instrument controller, winch, power and telemetry system; a biofouling-resistant and hydrodynamic profiling platform; sensors to sample the physical (pressure, temperature, salinity, velocity), biological (chlorophyll fluorescence; multifrequency acoustics, e.g., Tracor Acoustic Profiling System - TAPS), chemical (dissolved oxygen; nitrate concentrations, e.g. Satlantic ISUS), and optical (spectral downwelling irradiance, beam attenuation, backscattering) properties over the entire water column. To maximize our chances for success, we propose to first equip the profiling systems with existing optical and acoustical bulk property sensors and then use these to guide the use of sensors that can identify organisms, e.g. optical plankton imaging systems (see section 3.7.2). The design specifications of this system include: 6-month duration when operated autonomously; operational in water depths up to 200 m; a minimum of 8 profiles per day; and a vertical resolution of less than 0.25 m. In addition, the built-in telemetry will allow for near real-time transmission (via radio, cell phone or Iridium phone) of the data to shoreside computers and remote programming/control of system operations. When connected to a seafloor cable, data transmission and power will be supplied from the seafloor junction box.

It is important that measurements be made near the ocean bottom for much of the research proposed here, i.e. within a few meters and without the observations being disturbed by the measurement platform. Near-bottom instrumentation should include an upward-looking acoustic Doppler current profiler (ADCP) to obtain high-resolution velocity profiles and sensors to measure near-bottom pressure, temperature, conductivity, chlorophyll, dissolved oxygen and suspended particle load. Bottom-boundary layer (BBL) measurements should be made on a stable platform connected to a seafloor cable or powered autonomously with data communicated to the upper-ocean profiler (acoustically and/or inductively) for telemetry to shore.

To insure high vertical-resolution measurements near the sea surface, to allow for meteorological instrumentation, and to help facilitate buoy-to-shore communications for non-cabled upper-ocean profilers, a mooring with a large surface buoy will be required at several cross-shelf locations. The mooring line will contain T and C sensors sampling at 1-min intervals at various depths, especially concentrated in the upper ocean, to aid in resolving upper boundary layer processes as well as the propagation of nonlinear internal wave packets. The buoy will also contain a downward looking 1200-kHz ADCP to capture the detailed current structure in the upper ocean. The meteorological package will measure wind velocity, atmospheric pressure, air temperature, humidity, and solar and infrared radiation. The mooring provides a stable platform for collecting (via acoustic and/or radio) data from nearby vertical profilers and for telemetering all data to shore.

An estimated power budget for the upper-ocean profiling system assumes a 180-day deployment, profiling 8 times/day in a 200-m water column at 0.5-1 m/s, with the profiler traveling about 800 km. When connected to a cable, the required power for the sensor suite is

~40W at 12VDC and for the winch is ~70W at 48VDC. So a total power requirement with some room and to allow for voltage step down would be about 150W. For the proposed duty cycle (8 profiles/day) on an autonomous profiler, the 12V sensor power system requires 380 Amp-hours for a 180-d deployment, while the 48V winch power system requires 255 Amp-hours.
We propose a **deep-ocean profiler** to be attached to a cabled observatory node, thereby removing power as the major constraining factor (**Fig. 20**). A profiler docking station with an inductive coupler will transfer power from the cabled node to a McLane moored profiler (MMP). This will permit near-continuous profiling (>95 % duty cycle), at 0.25 m s^{-1}. Further, inductive communications will be used to offload profiler data at modest rates in real-time; this will enable true adaptive sampling capability. With sensors on the profiler and dual sensors at fixed points top and bottom on the mooring, cross-calibration and overall robustness will be improved. The subsurface float has a secondary junction box on it and provision for ROV servicing of arbitrary instrument packages; for instance, on the subsurface float, acoustic instrumentation (e.g., an ADCP) can remotely sense the ocean to the surface, as well as a winched profiling system (the **upper-ocean profiler** described above) to carry in-situ point sensors through the mixed layer to the surface. A secondary junction box is also at the base of the mooring for additional sensors, again serviced with an ROV. These secondary junction boxes will provide nominally several hundred watts and 100 Mb/s Ethernet. For use in the cabled portion of the regional observatory, modifications will be developed over the next ~5 years, e.g. high-rate inductive communications at every docking, increased speed to ≥ 0.4 m s^{-1} and increased payload capacity.

3.4 Acoustic Tomographic Array

We propose to implement an acoustic tomography in-situ remote sensing array in the waters beyond the shelf several hundred kilometers, including the bifurcation region, to constrain the large scale velocity and temperature fields (**Fig. 17**). Tomography transceivers will be placed on moorings connected to RCO nodes in deep water, the sites are those recommended in the RECONN report. The moorings will support full water column profiling capability (see below; as proposed in the RFA response by Daly et al.).

Individual fixed paths between transceivers give temperature and absolute velocity averaged along the path. One-way/average travel time measured along a path gives sound speed (temperature) while reciprocal travel times (in each direction) give velocity (sound travels faster with a current than against). For arrays, many paths at many horizontal angles are used to reconstruct the fields of interest using geophysical inverse methods. The measurement is fundamentally synoptic at the speed of sound (1500 m/s). These methods are the only way to obtain direct, large-scale, low-noise vorticity measurements. As the number of instruments N increases, the number of paths (data) to the other instruments grows as N^2, a result achievable now with the multi-node RCO infrastructure. In **Fig. 17** with 10 transceivers, there are ~30 paths drawn. Given a nominal area of 500km x 1000 km, the resolution is about 130 km. In this region, the amount of depth dependent information will range between two and four independent measurements per path, and will depend on the details of the acoustic propagation (e.g., the bathymetry and the seasonal sound speed structure). It is often useful to think of a tomography array as an antenna sensitive to a range of wavenumbers (related to path length and orientation). In many respects such an array is ideal for measuring wave and eddy propagation. The recent interest in long range propagating internal tides arose partly as a result of data from a 1987 tomography experiment in the central North Pacific (Dushaw et al., 1995). More recently, tomography arrays have been used to measure the far-field radiated tides in the HOME experiment (Pinkel et al., 2000). The robustness of the sensors is a general characteristic of acoustic devices (e.g., 60 year life of Navy hydrophones, 8 years and increasing for an ATOC source). This is especially important for operations and maintenance considerations. The RCO directly enables this observing capability by providing adequate power (~100 W during a transmission), communications (Mb/s), and accurate and precise timing (1 μs).

3.5 Autonomous Underwater Vehicles

We propose to occupy a set of east-west and north-south lines forming a control volume encompassing the northeast Pacific continental margin with autonomous underwater vehicle gliders to obtain long-term, repeated measurements of upper-ocean volume transport and water property flux. Glider lines will extend offshore along our two proposed Endurance Lines at 44.6 and 46.5N to at least 130W, the edge of the proposed regional cabled observatory on the JdF plate (**Fig. 17**). We also propose to operate a glider from the coast out to 130W along Line P, the historic hydrographic line occupied by Canadian scientists between southern Vancouver Island and Station Papa (50N, 145W), and along 41.9N, a historic hydrographic line off Crescent City, CA.. These four E-W glider lines are each 400-500 km long and can be transited in 16-30 days at glider speeds of 15-25 km/d. A N-S line along 130W will close the control volume and measure the east-west transport of water and the material it contains in the North Pacific Current. The 41.9N line will not only allow estimates of the flux of coastal water and the material it contains into the CCS, but also serves to set the upstream boundary conditions for the PNW during winter when the Davidson Current adjacent to the coast is flowing northward. By using multiple gliders, we can obtain at least monthly measurements along these lines, sufficient to address our scientific objectives regarding the seasonal and interannual variations in ecosystem response to physical forcing. Gliders must be capable of operating for at least 3 months (but 6 months would be desirable), sampling to at least 1000 m and capable of carrying the following sensors: temperature, conductivity, pressure, chlorophyll fluorescence, dissolved organic matter fluorescence, light backscatter, dissolved oxygen and a hydrophone.

3.6 Coastal HF Radar

Surface current mapping with HF backscatter (CODAR SeaSonde, WERA, etc.) will provide continuous time-series mapping of the varying surface circulation over a range of spatial scales, in near-real time, from land-based systems. Surface current maps will be produced hourly with velocity accurate to 0.1 m s^{-1}. Long-range systems, operating at 4-5 MHz, will be spaced alongshore at about 100 km separation, and measure currents from the shelf to O(160km) offshore, with horizontal resolution of O(5-10km) [Kosro and Paduan, 2002; Paduan et al., 2004]. Such an array, initiated in 2001, now including six coastal sites and spanning more than 500 km alongshore and offshore to the end of the Newport Hydrographic Line, is presently mapping the entire coast of Oregon, and portions of northern California and southern Washington (**http://bragg.coas.oregonstate.edu/ORCoast**). Long-range systems will be used to resolve the larger scale components of the mesoscale circulation, including the seasonal progression and alongshore variations in the intensity, width, and orientation of the coastal jet, as affected by winds and by topography. Continuous coverage alongshore allows current features to be tracked over large distances and local process studies to be placed in context of the larger-scale circulation. Models have shown significant skill improvement when assimilating standard-range HF data (Kohut et al., 1999; Oke et al., 2002a; Kurapov et al., 2003; Paduan and Shulman, 2004), and programs to assimilate long-range data into offshore models have been proposed.

Augmenting the long-range array, an embedded sub-array of standard-range HFs (2-km resolution, 40-km range) will be used to provide higher spatial resolution of shelf processes in the proposed Pioneer Array regions overlying Heceta Bank off central Oregon and the central Washington shelf north of the Columbia River. An existing, long-term array (presently three elements) observes the northern part of the flow/topography interaction over Heceta Bank [Kosro, 2005]. Adding a fourth system south of the present array will extend coverage to the southern flank of Heceta Bank, where onshore flow is anticipated. A new moveable array of three new standard-range HFs will be required for the central Washington shelf study site and then could be used sequentially along the coast, to prolong high-resolution mapping of the Columbia River outflow or to map the flow regime of the Strait of JdF.

3.7 Advanced Sensor Development and Platform Integration

3.7.1 CO_2 Sensing Technology

CO_2 sensing in the coastal oceans presents several unique challenges. Dynamic ranges are large, and the scales of temporal and spatial variability are short. Some of the most active regions are in shallow water where large research vessels cannot routinely operate and large moorings cannot be deployed. Existing technology for moored CO_2 measurement is physically large, requiring large moorings for deployment; complicated, with many gas and liquid flow pathways; expensive, at roughly $20K per unit; and ultimately designed to monitor the small changes experienced by the open ocean over long timescales. While their immediate deployment in the coastal oceans will be invaluable, we must be working towards developing small, inexpensive, rugged sensors that can respond to the rapidly changing conditions of the coastal ocean.

Of the existing moored CO_2 systems, we propose to integrate the colorimetric system marketed by Sunburst Sensors LLC on our proposed Endurance Line moorings. This system works by measuring changes in the color of an indicating solution enclosed within a gas-permeable membrane, which is sensitive to changes in pH driven by CO_2 diffusion through the membrane. The system measures with 1 ppm resolution in pCO_2, can operate up to 1500 m and has the ability to make 8-12 measurements per day for deployments of slightly greater than 1 year. We plan to deploy surface and near-bottom sensors at three locations—the near-shore, the mid-shelf, and the shelf-break—on each of the two Endurance Lines.

We intend to develop new CO_2 sensors, based on our extensive experience with gas-liquid separations using microporous hydrophobic membrane material. About the size of a human index finger, these sensor modules will enclose small sensor elements for temperature, humidity, pressure, and CO_2 within a cylinder of supported membrane material. Data and power will be transmitted via a cable to a beachball-sized float that will house batteries, data acquisition and storage hardware, and real-time telemetry capabilities. As such, we expect these systems to ultimately be deployable from small coastal research vessels and moored in shallow water. We estimate that the cost per system will ultimately be about $5K. Central to the success of this technology is the development of very small-scale CO_2 sensing technology. Two categories are under consideration: infra-red and gas-chromatographic based systems. Currently, Telaire markets a small IR-based system with sufficient resolution and stability for a few hundred dollars. Using nano-technology, Ion-Optics is developing finely-tuned emitter-detector chips that can be manufactured for maximum sensitivity in the CO_2 absorption band. Finally a new highly proprietary nano-technology-based gas-chromatographic system is under development at Honeywell. If this technology is successful, many other dissolved gases could be measured simultaneously with CO_2. We are currently in discussions to provide calibration and field testing for these developmental technologies in exchange for some of the prototype sensing elements.

3.7.2 Automated Phyto- and Microzooplankton Species Detection and Enumeration

The FlowCAM (Fluid Imaging Technologies, Edgecomb, ME) is an imaging-in-flow cytometer that combines the capabilities of flow cytometry and microscopy. The instrument automatically images and enumerates individual cells and records size and fluorescence characteristics as seawater is pumped past a laser and microscope objective. The images are suitable for species identifications in many instances (e.g. **Fig. 16**), as well as general size and taxa assignments. While capable of detecting cells down to 1 μm, the FlowCAM is most suitable for >5 μm cells, and can detect large chains and microzooplankton up to 1 mm in size. The images and data can be transmitted back to shore via cell phone or cable for analysis as well as real-time monitoring for harmful algal species. We propose to integrate a submersible version of the FlowCAM into the upper-ocean profiling mooring sensor package and use them at three cross-shelf locations in our proposed Oregon and Washington Endurance Lines.

3.7.3 Genome-based Biological Sensors

The increasing availability of genome sequences for key microbial components of ocean ecosystems is transforming our understanding of this "hidden majority" of organisms. A new generation of biological sensors based on this accumulating DNA information is now being considered. These sensors are envisioned as being based either directly (e.g., DNA information to determine organism identity) or indirectly (e.g., protein information to determine organism function) on genome information. A National Oceanographic Partnership Program (NOPP)-sponsored workshop (chaired by G. Armbrust, UW) entitled "Monitoring and measurement of the ocean genome" was recently held in Washington, DC to identify both near-term and future research areas and strategies to advance the use of "genome-enabled" environmental biosensors in the ocean. Collection of long-term biological data sets through use of these biological sensors, in combination with sensors that measure physical and chemical parameters, will provide new perspectives on the nature and effects of global climate change, pollution, and other environmental perturbations on the world's oceans.

Genome-based biological sensors will initially allow us to ask "who's there and when." As these sensors become more advanced, we will be possible to ask "what are different organisms doing." For example, are the potentially toxic species that are detected actually producing the toxin? And finally, one of the most exciting aspects of the potential for these sensors is that they will permit targeted experiments to be conducted "on the fly." For example, if potentially toxic species of phytoplankton are detected during routine monitoring, the instrumentation could be tuned to focus on these species in more detail (Babin et al., 2005). We propose to pursue the integration of these genome-based sensors in our observatory infrastructure at the earliest possible date.

3.8 Modeling

The integration of observations with physical circulation and ecosystem models will be critical to the success of ocean observatory science. In order to ensure this success, observing system science programs must include dedicated modeling components. The observatory system proposed here has been developed in part on the foundation of extensive modeling studies of dynamical processes on all relevant scales. These include physical circulation models of the North Pacific (Curchitser et al. 2005), the CCS (Marchesiello et al., 2003, Shulman et al. 2004), the Oregon and North California shelf (Pullen and Allen, 2000, 2001, Gan and Allen 2002a, 2002b, Oke et al., 2002b, 2002c, Kuebel Cervantes and Allen 2005) and estuaries (Baptista et al., 2005), as well as coupled physical-biological models of the Oregon coastal zone (Spitz et al., 2003, 2005) and Individually Based Models (IBMs) for zooplankton dynamics (Batchelder et al., 2002b). Effective methods for the assimilation of data in coastal ocean models have been developed and implemented to study barotropic tides (Egbert et al., 1994, Erofeeva et al., 2003), internal tides on the Oregon shelf (Kurapov et al., 2003), and wind-driven shelf circulation (Oke et al., 2002a, Kurapov et al., 2005a, 2005b, 2005c). Altimeter observations of the eastern North Pacific have been assimilated in larger scale models (Rhodes et al., 2001).

As when implementing any complicated observing system, observing system simulation experiments (OSSEs) will be required to design this observing array. The simulations will take into account the attributes of the different sensing modalities, the time/space sampling, and the expected signal and noise levels for the phenomena of interest. For example, the optimization of the proposed tomography array will include acoustic simulations that will help guide the specific site locations. It should be emphasized that OSSEs have not been used to optimize the observational infrastructure outlined here, but they should be an important, early effort in ORION activities.

A dedicated and comprehensive multi-scale eastern North Pacific modeling program that extends these existing modeling efforts and enables their successful integration with observatory system measurements is an essential element of the proposed observing system science program. This program will include a range of forward and data-assimilating nested oceanic models forced with meteorological observations and data-assimilating atmospheric model products. On the basin and regional scales, satellite SSH and SST will be assimilated. Shelf circulation models will additionally assimilate HF radar, mooring and hydrographic survey data. The shelf circulation models will provide boundary conditions to the estuarine models. To obtain optimal and dynamically balanced solutions and their error estimates, advanced data assimilation methods will be used (e.g., Chua and Bennett, 2001). Forward model integrations and data comparisons will be used to formulate and explore hypotheses regarding circulation dynamics and ecosystem coupling. Optimal combinations of physical and biological fields from observing system measurements and the data-assimilating models will provide continuous, multi-year, dynamically balanced ocean analyses with quantitative error estimates for hypothesis testing, statistical and dynamical analysis, and observing system design refinement. Important processes to be examined include the mechanisms of interannual variability, large-scale alongshore transport in the coastal zone, cross-shelf and cross-slope transport, physical-biological interactions, ocean-atmosphere interactions, surface and bottom boundary layer variability, the role of turbulence and mixing, and ocean-estuarine exchange. The successful combination of both modeling approaches with the proposed observing system measurements is central to the achievement of the proposed science objectives.

4. Project Management Considerations

Achieving the interdisciplinary science objectives focused on ocean dynamics and ecosystem response as outlined in section 2 will require the skills and coordination of a broad range of ocean scientists from multiple institutions, for example those listed on this RFA response and others. NSF, through its CoOP program, has fostered interdisciplinary coastal research and the community has thrived in this framework. OOI-based interdisciplinary science is a natural next step. What is more revolutionary is the chance for scientists concentrating on water-column processes to collaborate with geologists, geophysicists and chemists studying seafloor processes, for example detailing the outflow of methane and its subsequent transport as proposed here.

Within the water column community itself, there is recognition that a group larger than just a single discipline or a single institution must collaborate to accomplish the objectives of modern interdisciplinary ocean science. Much as the physical oceanographers and atmospheric scientists from multiple institutions worked together to accomplish the science breakthroughs of the Coastal Ocean Dynamics Experiment in the early 1980s, it is now time for oceanographers interested in processes along the continental margin to accomplish the science objectives outlined here. Toward that end, we propose to establish an ocean observatory, an interactive laboratory, in which all are welcome and encouraged to participate. We suggest that the PNW is an ideal place to site such an observatory because the region exhibits a wealth of geophysical signals over a broad range of time and space scales.

To help phase in the proposed OOI infrastructure, we suggest that the Newport, Oregon, Endurance Line be established as soon as funding becomes available for two reasons. First, this will continue and dramatically improve the long-term measurements of ecosystem response along this historic hydroline and, second, will allow OOI infrastructure to be combined with studies of Hydrate Ridge and the Cascadia subduction zone. The central Oregon Pioneer Array could be started 6 months later, but still in the first year in order to jump-start early science results from the OOI project. The central Washington Endurance Line should be installed in the second year of the OOI in order to maximize temporal overlap with the Newport Endurance Line, the two of which will bracket the Columbia River in all seasons and allow contrasts between the two shelves to be studied. Lastly, the central Washington Pioneer array should be installed after the end of the 3-yr Oregon Pioneer array experiment. It should be remembered that efforts to maintain critical assets in the Pioneer arrays, as judged by their importance in combining with data-assimilating numerical models to provide accurate 4-dimensional circulation and ecosystem fields, should be made to maximize the longevity of high spatial-resolution ocean observatory science in this region.

We note that there are several existing programs in the PNW, coordination with which would greatly benefit the proposed ORION science. The observations and modeling of the Columbia River Estuary (CORIE) program will benefit the study of freshwater and property fluxes into the coastal ocean. Measurements of ocean physics, biology and chemistry conducted in shallow water in concert with study of the intertidal and subtidal ecosystems off central Oregon and the Washington coast conducted by the Partnership for Interdisciplinary Study of Coastal Oceans (PISCO) and the NOAA Olympic Coast National Marine Sanctuary program, respectively, will benefit ORION science proposed for farther offshore. Excellent remote-sensing groups exist at PNW institutions (e.g., the Cooperative Institute for Oceanographic Satellite Studies at OSU; the remote sensing groups at UW) and their participation in this proposed observatory science will be crucial. The 2005 closures of southern Washington beaches and the subsequent coast-wide closure of Oregon beaches due to elevated levels of domoic acid in razor clams illustrates the importance of communication between ocean scientists working on HABs and state managers. Quantitative understanding of the processes leading to these closures – hypothesized late-spring storm events transporting *Pseudo-nitzschia* blooms from Heceta Bank, Oregon shoreward and as far north as southern Washington – is a key goal of our proposed ORION observatory science..

Interactions with the PNW fishing community regarding the placement of OOI infrastructure needs to begin now. One mechanism could be through the "Scientists and Fishermen's Exchange" (SAFE) program (**http://www.fishresearchwest.org/current_opportunities/aboutSAFE.asp**). The SAFE program – organized by Oregon Sea Grant Extension – is an informal group of fishermen and scientists working together to build trust and a mutual understanding of the industry and ocean sciences. SAFE strives to provide an open environment for discussing research activities, needs for scientific information and potential collaborations that are relevant to marine issues. We suggest that Education and Public Awareness efforts within the ORION Project Office and its advisory committees would be helpful in working with Oregon and Washington Sea Grant to make progress on this issue. Finally, we point out that Education and Public outreach opportunities are possible at long-established and popular ocean science centers and public aquaria in the PNW (Hatfield Marine Science Center, Oregon Coast Aquarium, USFS Cape Perpetua Visitor Center – see **Fig. 18 –** Seaside Aquarium, Seattle Aquarium).

Coordination and synergies with other OOI elements

Coordination of our proposed activities with the science and infrastructure plans of other groups submitting OOI RFA responses provides opportunities to gain more than any one team might accomplish alone. Besides the specific geophysical and chemical research proposed for Hydrate Ridge off Oregon described above (section 2.8) and the use of our proposed cross-margin Endurance Lines as part of the **Pacific Coast array** for detection of propagating climate signals (section 3.1), there are several other group efforts that would compliment ours. The RFA response of Daly et al. proposes full water column profiling moorings at the offshore sites recommended in the RECONN (2004) report; these will clearly be of use in constraining the large scale flow. We propose to use data collected from two **deep-sea buoys** located in the subpolar gyre (Papa 50N, 145W) and directly to the south in the subtropical gyre (Uncle 40N, 145W). Meteorological observations (see RFA response by Weller et al.) will be helpful for improving atmospheric circulation models, the output from which is important as the driving force for regional ocean circulation and ecosystem models of the northeast Pacific. Observations in the upper 1000 m of the water column of temperature, salinity, velocity, chlorophyll fluorescence, light backscatter, nutrients (nitrate) and dissolved oxygen will provide the far-field values necessary for tracking the low-frequency changes in source water characteristics for the eastern North Pacific. Our proposed Endurance Lines could serve as platforms for bottom seismometers used to study **subduction zone processes** (RFA response by Trehu et al.) and, together with the proposed measurement of ecosystem response, would add value to **acoustic studies of marine mammals and fish**.

Our proposed tomographic array transmitters can provide precise underwater **navigation signals** for gliders, AUVs and floats. Ultimately, these mobile platforms could be used as tomography receivers increasing the availability of acoustic ray paths for determination of water velocity and temperature. In fact, any observatory receiver listening to the proposed sources can be used to obtain more paths, improving density within the region as well as extending coverage into the basin. Many additional receivers are being proposed for fish and marine mammals (Horne et al. and Miller et al.), ambient sound (including wind and rain, Nystuen et al. and Alvero et al.), seismic T-phases (Stephen et al., and Toomey et al.), and basin-scale heat content and dynamics (Worcerster et al.).

Lastly, we are aware of and propose interaction with **NEPTUNE Canada** projects focused on water-column processes and infrastructure: “Biophysical Linkages Underlying Variability in Coastal Ocean Processes off the West Coast of Vancouver Island” (Contact: John Dower); “Ecological and Biophysical Determinants of Primary and Secondary Production in a Coastal Marine Ecotone and Implications for Fish and Baleen Whales” (Contact: Dennis Jelinski); “Towards Real-Time Observations and Modeling of Tsunamis and other Infragravity Waves off the West Coast of North America (Contact: Josef Cherniawsky).

5. Data Management Considerations

Although we are in general a group from the PNW, the infrastructure we advocate is intended for use by all ocean scientists and educators. It is a community experiment, an ocean laboratory sited in a region with compelling scientific questions. Toward that end, data will be openly available through the ORION Data Management and Archiving System (DMAS). Our responsibility will be to provide expertise for insuring the highest quality data. We must provide (and thoroughly test) the quality control algorithms we give to the ORION DMAS to run operationally. This will require funding for marine technicians and ocean scientists as part of operations and maintenance of the proposed infrastructure. Other post-acquisition use of ORION data will be exploration and analysis (data “mining”) of the myriad interdisciplinary data sets, again requiring funded technical and scientific positions.

As a specific example, land-based HF surface velocity data will be processed and made available in both near real-time, for immediate use, and delayed-mode, for more complete and quality-controlled results. A regional HF data center now performs quality control, archival of the cross-spectral, radial and total vector data, and will produce analysis products tailored to observatory needs. In addition, it will work with the national data centers presently under development (e.g. Roadnet), and will support emerging national Ocean.US DMAC standards.

During data acquisition, we require real-time interactive access to our proposed vertical profiling systems so that we may respond by adapting our observational strategies (changes in profiling frequency, vertical range of profiling and/or sample intervals; notification to ship-based scientific investigations; targeting of autonomous vehicle assets; etc.).

We will interact with the range of regional ocean observing activities, specifically to make sure our data are available and our standards consistent. These include the PNW IOOS regional association Northwest Association of Networked Ocean Observing Systems (NANOOS) and the Pacific Coast Ocean Observing System (PaCOOS) which has strong interest in the PNW. We will of course be in close contact with Canadian colleagues regarding compatibility with the NEPTUNE Canada and VENUS DMAS. Regarding satellite remotely sensed data, we will continue our productive relationship with the NOAA Pacific Fisheries Environmental Laboratory (PFEL) and with NOAA NESDIS through the Cooperative Institute for Oceanographic Satellite Studies (CIOSS) at OSU.

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Figures

Figure 1: (left) Regional circulation in the northeast Pacific. (right) Eastern boundary current system of equatorward and poleward flows off the Pacific Northwest coast.

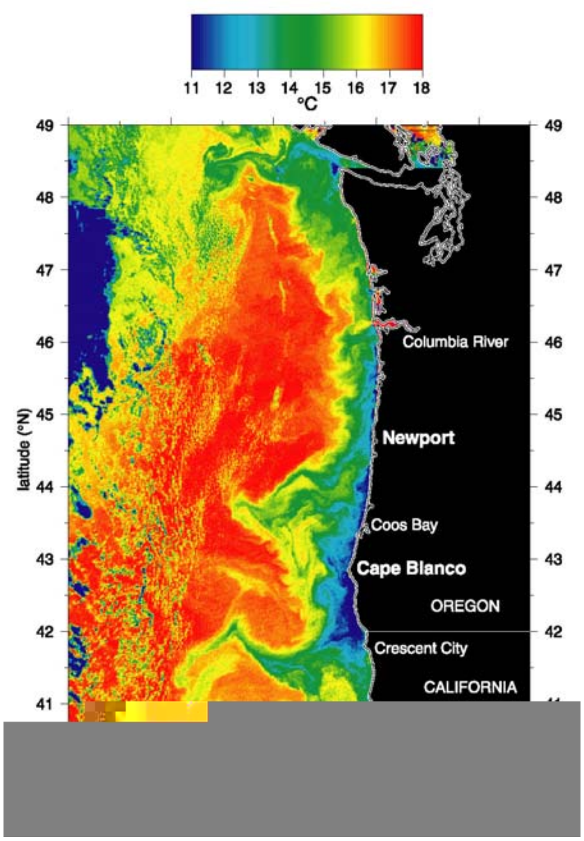

Figure 2: (left) Sea-surface temperature during summer showing cold upwelled water near the coast along the PNW coast. (right) Bottom bathymetry off the PNW.

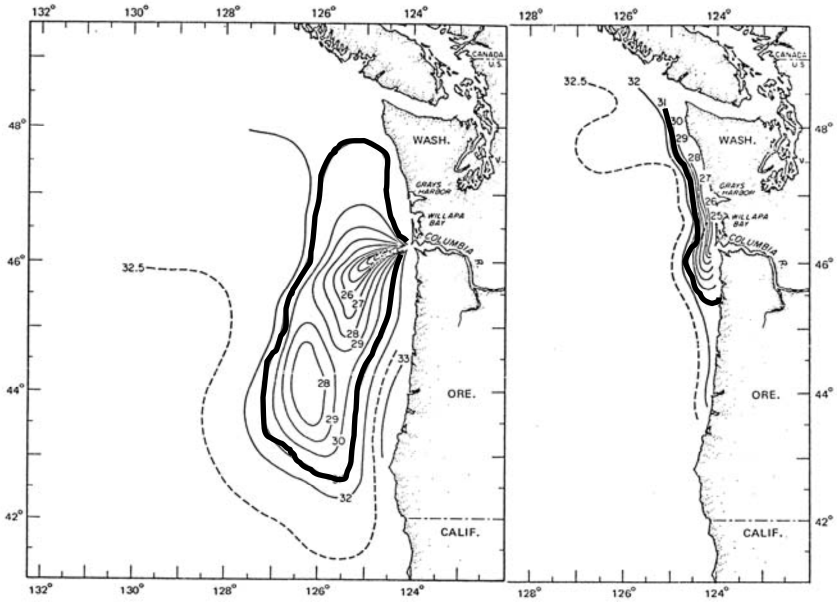

Figure 3: Sea-surface salinity during (left) summer and (right) winter showing the influence of the Columbia River outflow. The 31 isohaline is bold. (After Barnes et al., 1972)

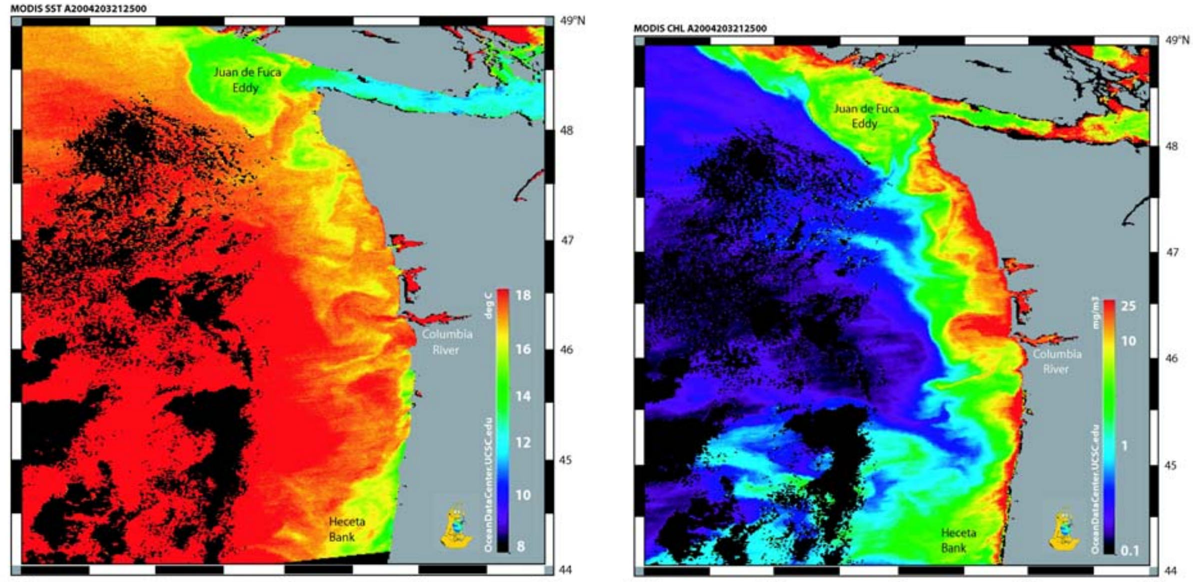

Figure 4: July 2004: Satellite SST from July 2004 showing upwelling in the south along the Oregon coast, the Juan de Fuca eddy off the Strait of Juan de Fuca and the Columbia River plume influences on the Washington shelf. (right) Satellite-based chlorophyll estimates showing large-scale gradients along the PNW coast and the Columbia River plume influence. (Courtesy of R. Kuedela.)

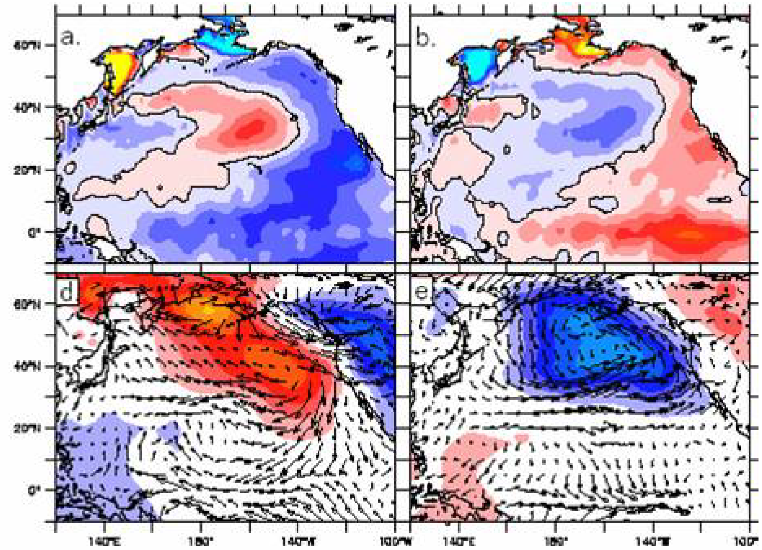

Figure 5: (top) Sea-surface temperature anomalies averaged over Nov-Feb from (left) cool (1970-1976) and (right) warm (1977-1983) phases of the Pacific Decadal Oscillation. (bottom) Anomalies of sea level pressure (color) and winds for the same time periods. (After Peterson and Schwing, 2003.)

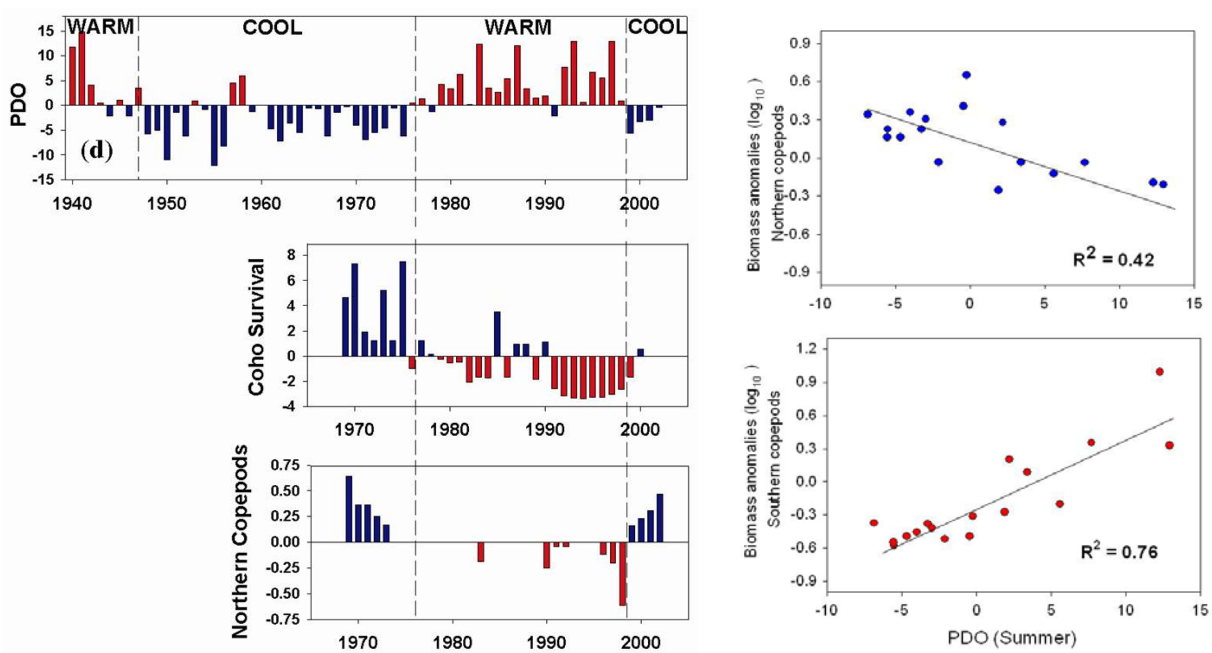

Figure 6: (left) Time series of (top) the PDO index summed annually over May-Sep, (middle) coho salmon survival and (bottom) biomass anomalies of cold-water copepod species. (right) Biomass anomalies of (top) northern and (bottom) southern copepod species versus the summer PDO index. (From Peterson and Schwing, 2003 and Peterson, unpublished data.)

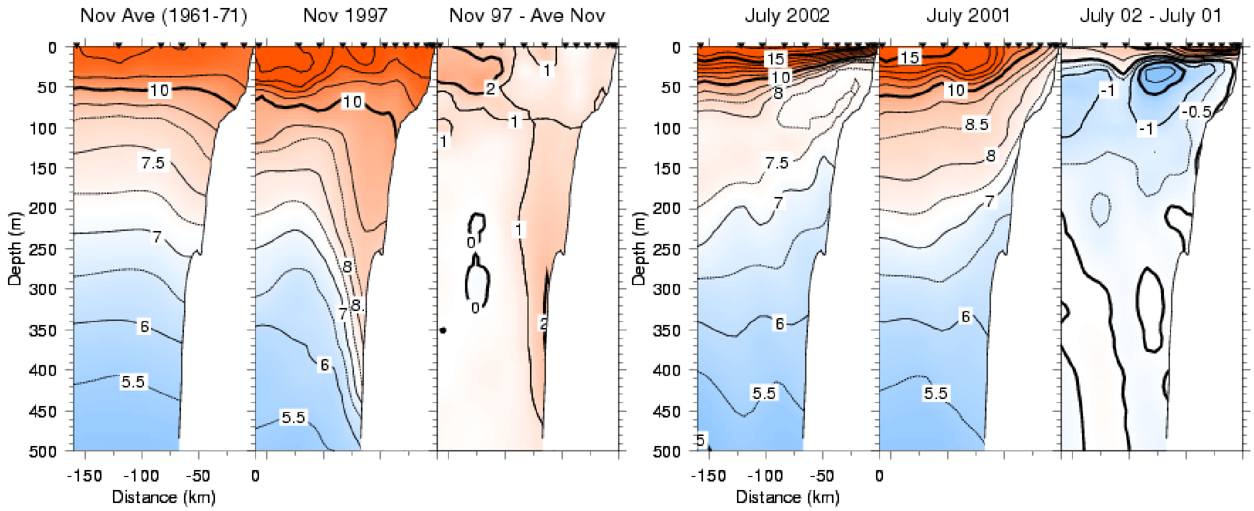

Figure 7: Vertical sections of temperature off Newport, Oregon during the (left) 1997 El Nino and the (right) 2002 Subarctic Invasion. (From Huyer et al., 2002 and Freeland et al., 2003.)

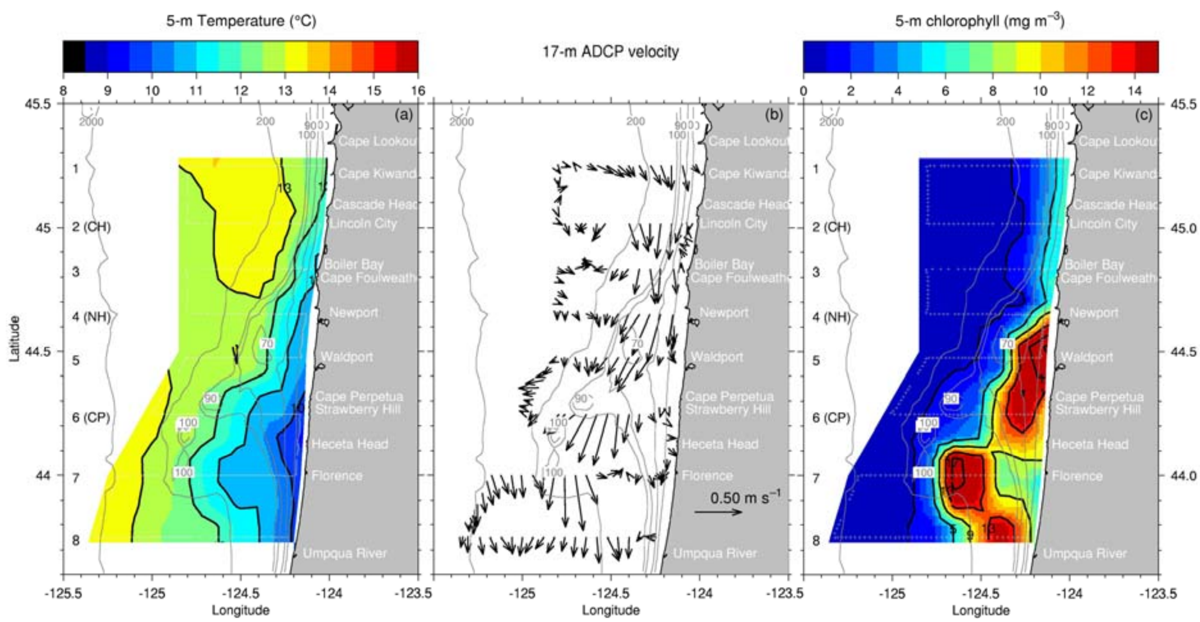

Figure 8: Maps of near-surface temperature, velocity and chlorophyll over Heceta Bank off central Oregon during spring 2001. (From Barth et al., 2005.)

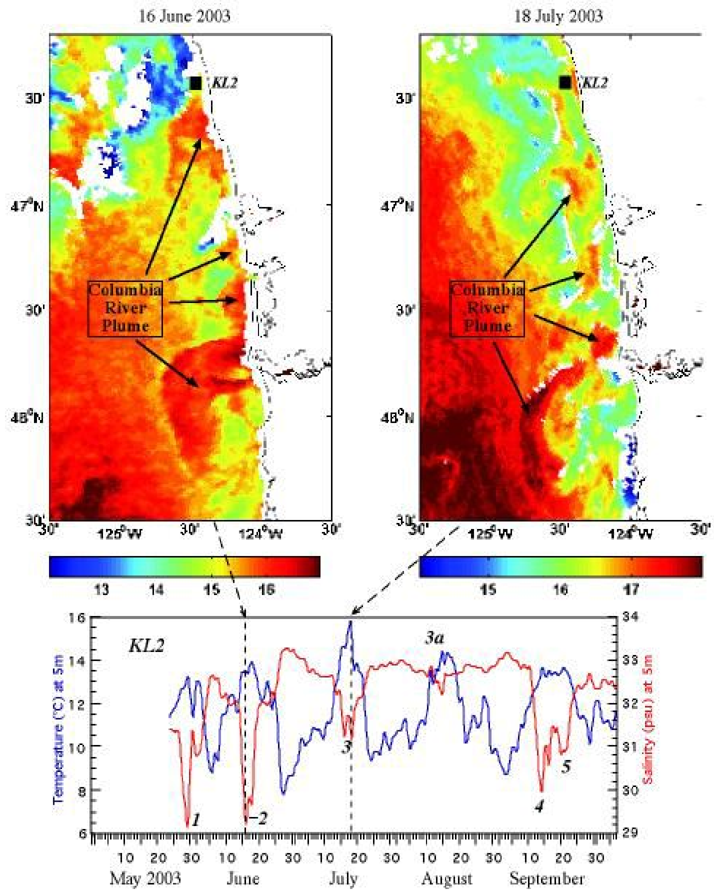

Figure 9: Example of summertime bi-directional Columbia plume as seen in satellite-derived sea surface temperature. This phenomenon occurs frequently in summer months, with new plumes developing off WA each time a storm passes through the region. The setting with respect to temperature and salinity at 5 m on the inner shelf at KL2 is shown in the lower panel. Mooring location is shown on the satellite images. (From Hickey et al., 2005.)

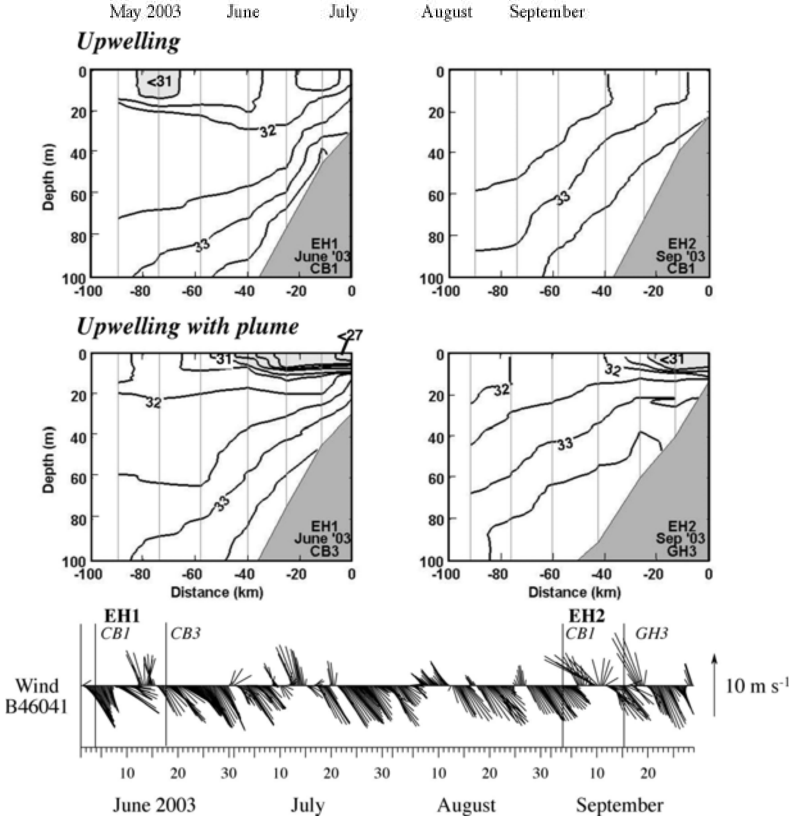

Figure 10: Contoured salinity sections across the central Washington shelf illustrating inhibition of upwelling by the Columbia plume. Data are shown at the end of several days of upwelling-favourable winds(upper panels) and during upwelling-favorable winds following a recent storm (lower panels) when a new plume has developed on the WA shelf. To provide the environmental setting, vector wind time series (N-S-E-W frame) are also shown. (From Hickey et al., 2005.)

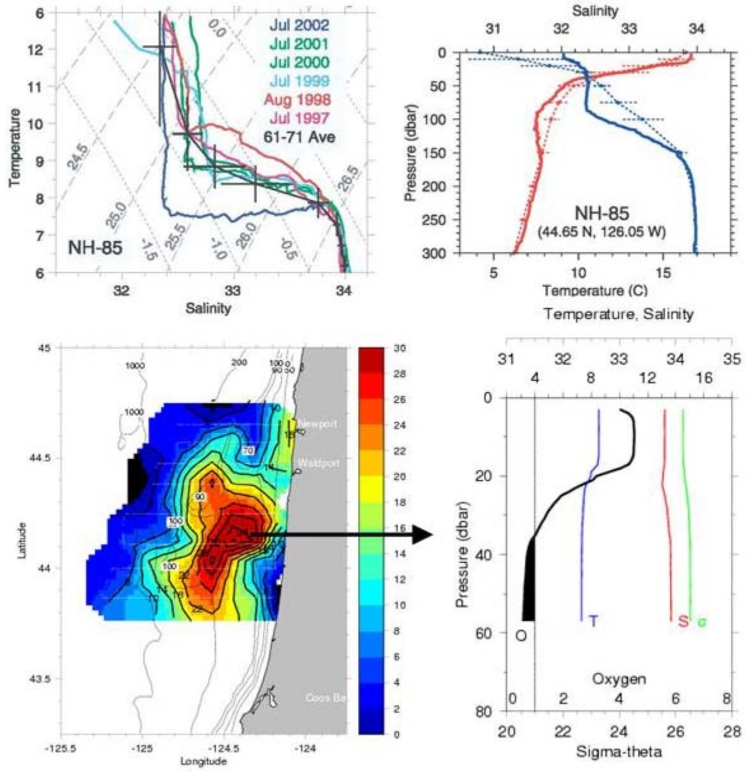

Figure 11: Subarctic water invasion and hypoxia over Heceta Bank in 2002: (upper left) T-S diagram on the Newport Hydrograhic (NH) line showing the anomalous, cold, fresh mid-depth water mass during summer 2002; (upper right) vertical profiles of temperature and salinity on the NH line showing anomalies between 25 and 150 m; (lower left) 5-m chlorophyll (mg m^{-3}) with maximum values in excess of 20 mg m^{-3} over Heceta Bank; and (lower right) vertical profiles at a station within the high chlorophyll feature over Heceta Bank showing hypoxic water within 20 m of the bottom (from Freeland et al., 2003 and Grantham et al., 2004).

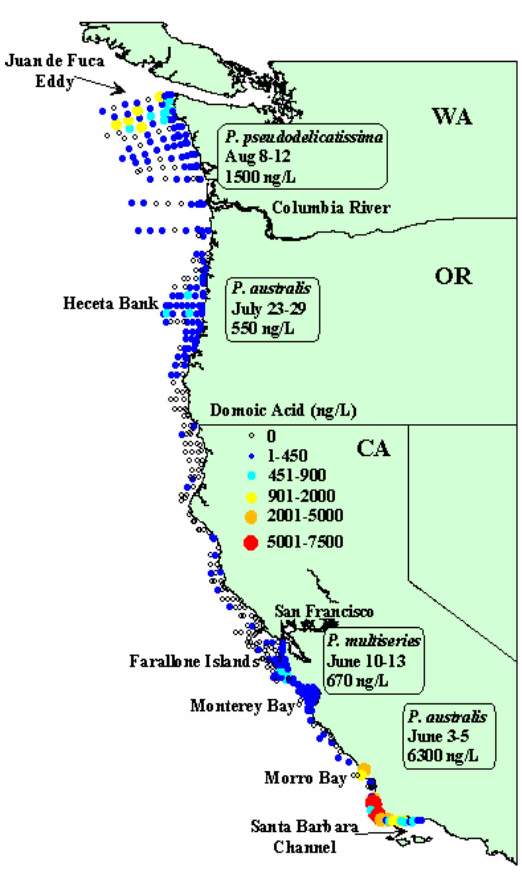

Figure 12. Particulate DA in *Pseudo-nitzschia* species on the U.S. West Coast in 1998. Maximum concentrations of DA and toxic species are indicated to the right of each area of high toxin. Each of these areas is associated with relatively retentive circulation patterns. (Hickey and Banas, 2003; data from Trainer et al., 2000, 2002).

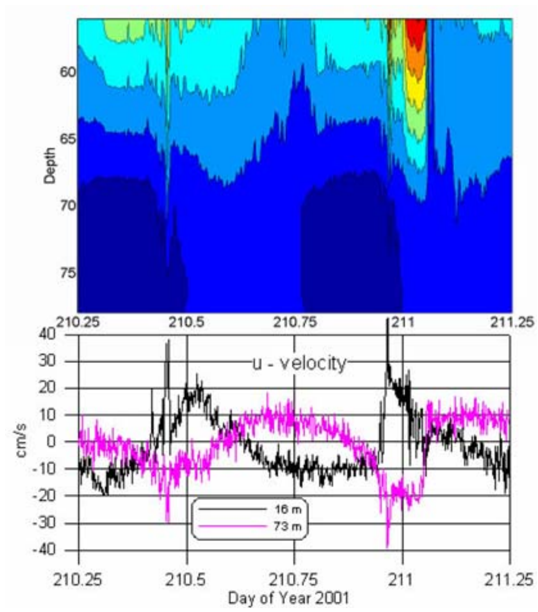

Figure 13: A one-day time series from an 80-m site on the Oregon shelf (45ºN). The cross-shelf component of velocity (u) shows a strong semidiurnal internal tide that is out of phase between 16 and 76 m (lower panel). The corresponding near-bottom temperature is also shown with 0.1ºC contour levels (upper panel). Sharp jumps in u and T indicate highly nonlinear internal waves (From Levine, unpublished data.)

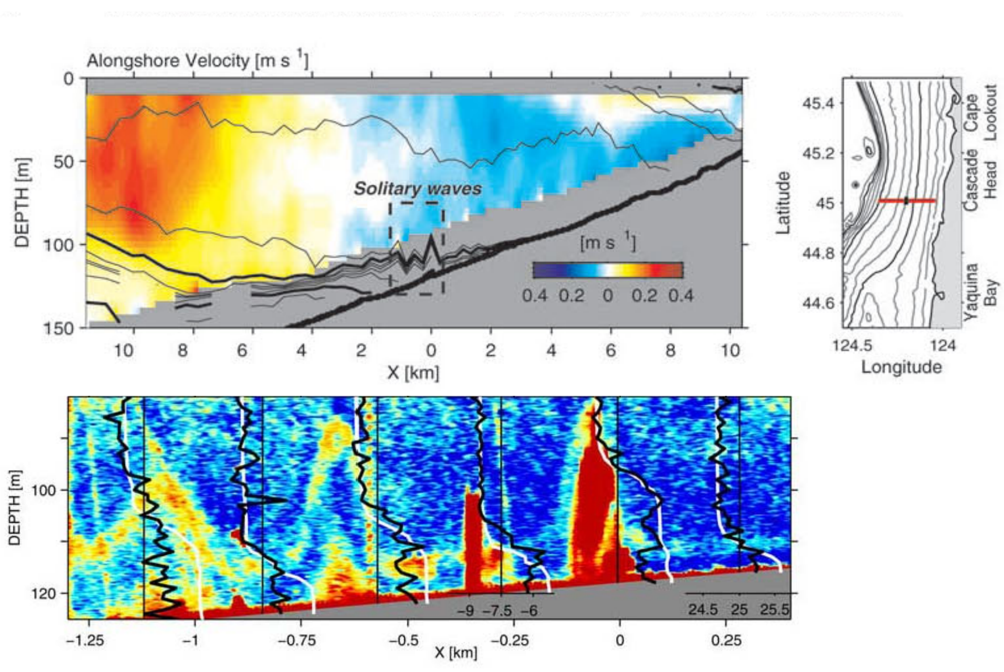

Figure 14: Near-bottom solitary waves observed during January 2003 off central Oregon. (top) Potential density and along-shelf velocity (color). (bottom) 120-kHz echosounder image (red is high intensity) with profiles of turbulent dissipation (black) and density. (From Klymak and Moum, 2003.)

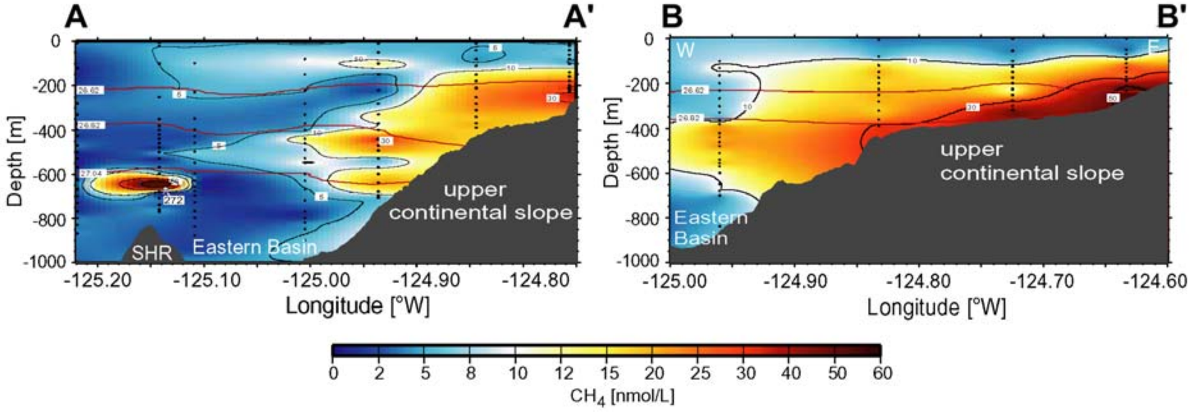

Figure 15: Methane concentrations along two hydrographic transects of the margin near the Newport Line (44.65N). Section A-A' spans from the upper continental slope out to Southern Hydrate Ridge (SHR) where intense deep plume associated with the hydrates can be seen. Section B-B' focuses on the upper slope and emphasizes the shallower sources, possibly associated with Heceta Bank and related slope seeps. (From Heeschen et al., 2005).

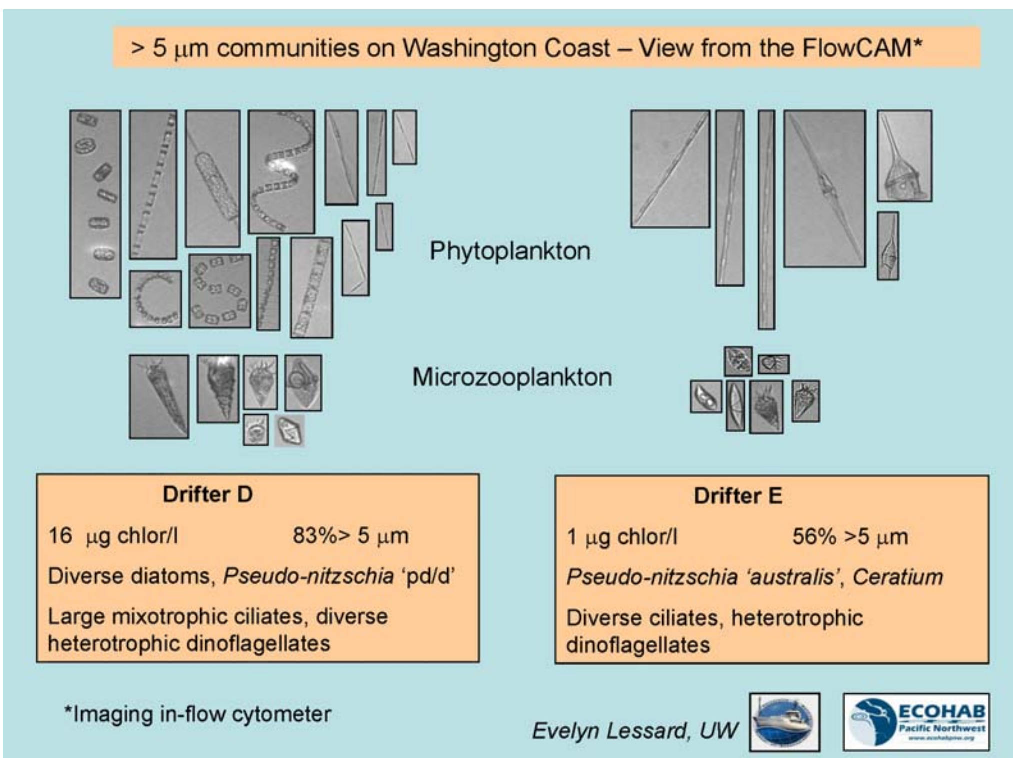

Figure 16: FlowCAM images showing representative phytoplankton and microzooplankton from two sites on the Washington coast, sampled one week apart in September, 2003. (Courtesy of E. Lessard, UW.)

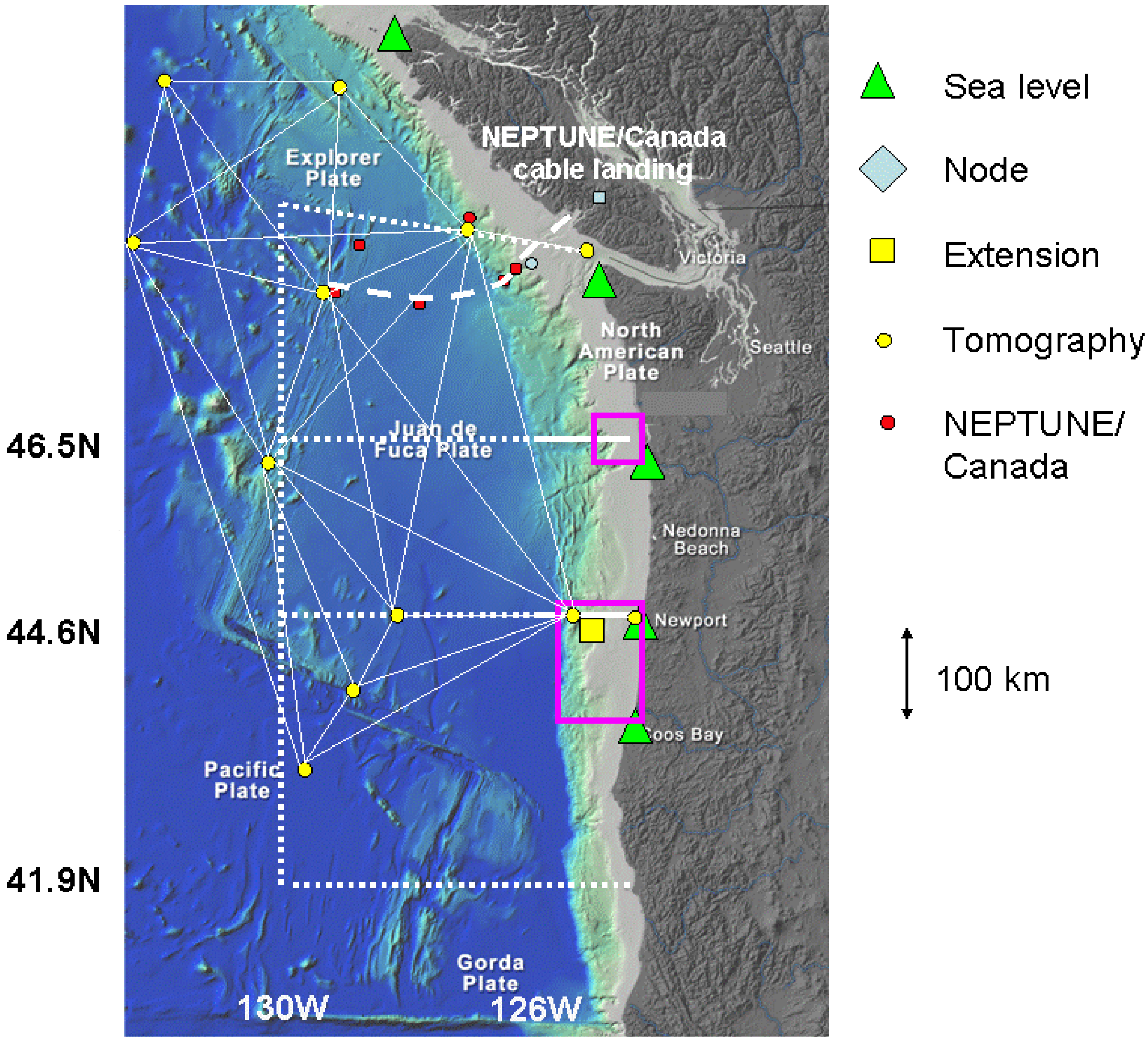

Figure 17: Proposed Pacific Northwest ocean observatory elements: Endurance Lines (solid white E-W lines near coast at 44.6 and 46.5N); Pioneer Arrays (magenta rectangles); glider lines (dotted white); acoustic ray paths from transceivers (light white lines and yellow bullets). A dashed white line connects elements of NEPTUNE Canada forming a northern "E-W" line.

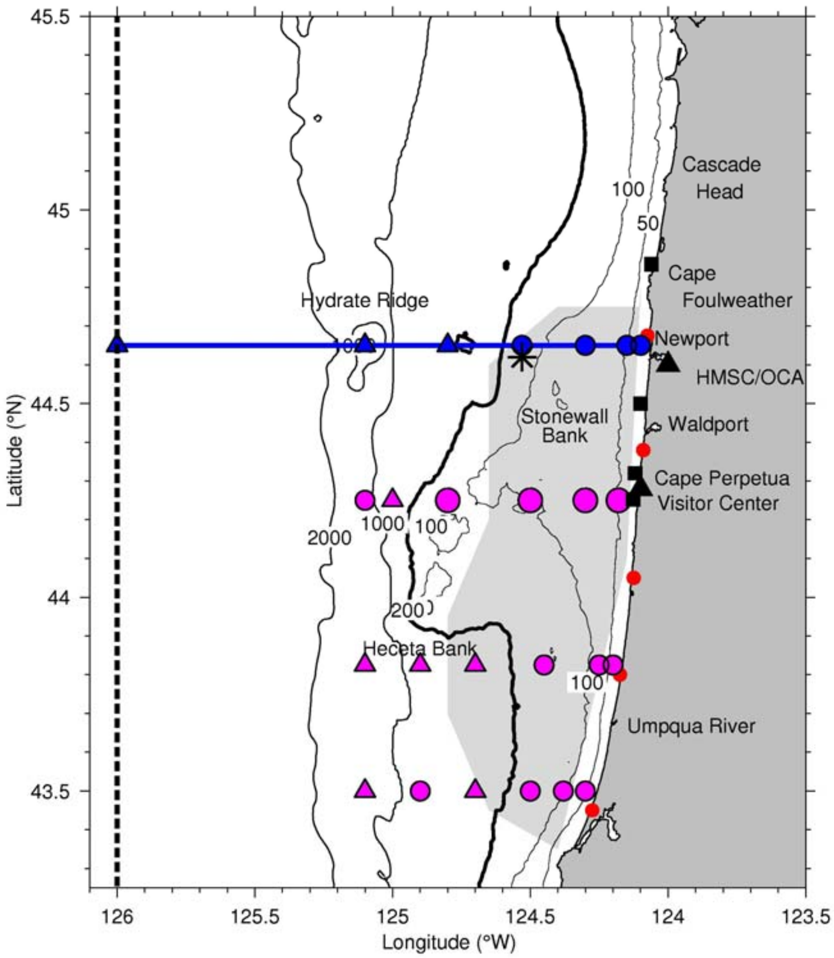

Figure 18: The Newport Endurance Line with mooring locations (blue) and Pioneer Array moorings over Heceta Bank (magenta). Filled circles indicate upper-ocean vertical profilers and filled triangles indicate hybrid upper- and deep-ocean profilers. All shelf locations (depth < 200 m) are also occupied with bottom boundary layer packages and water-column moorings with surface buoys. Existing PISCO nearshore moorings (squares) and NDBC buoy (asterisk). Gray-shaded area is coverage of standard-range, land-based HF radar (sites indicated by red bullets) and thick, dashed line along 126W indicates coverage for long-range HF radar. Outreach/education activities to take place at the Hatfield Marine Science Center (HMSC) and Oregon Coast Aquarium (OCA) in Newport and at the USFS Cape Perpetua Visitor Center.

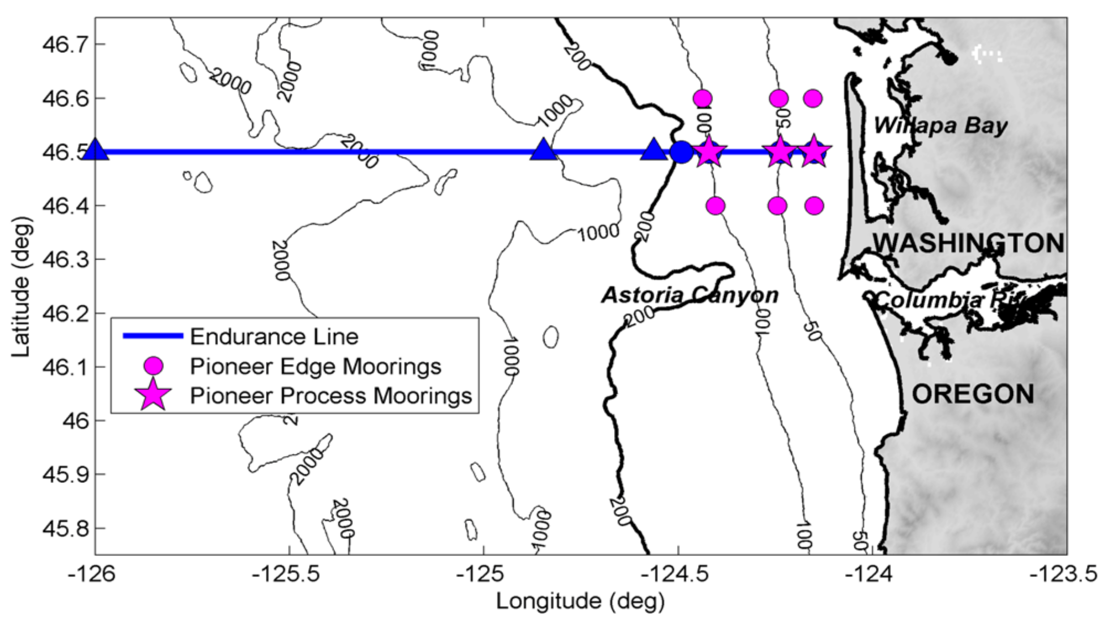

Figure 19: Locations of the Washington coastal Endurance Line and Pioneer Array with symbols as for the Oregon map. The Pioneer Array is approximately 20 km on a side, leaving 10 km between moorings.

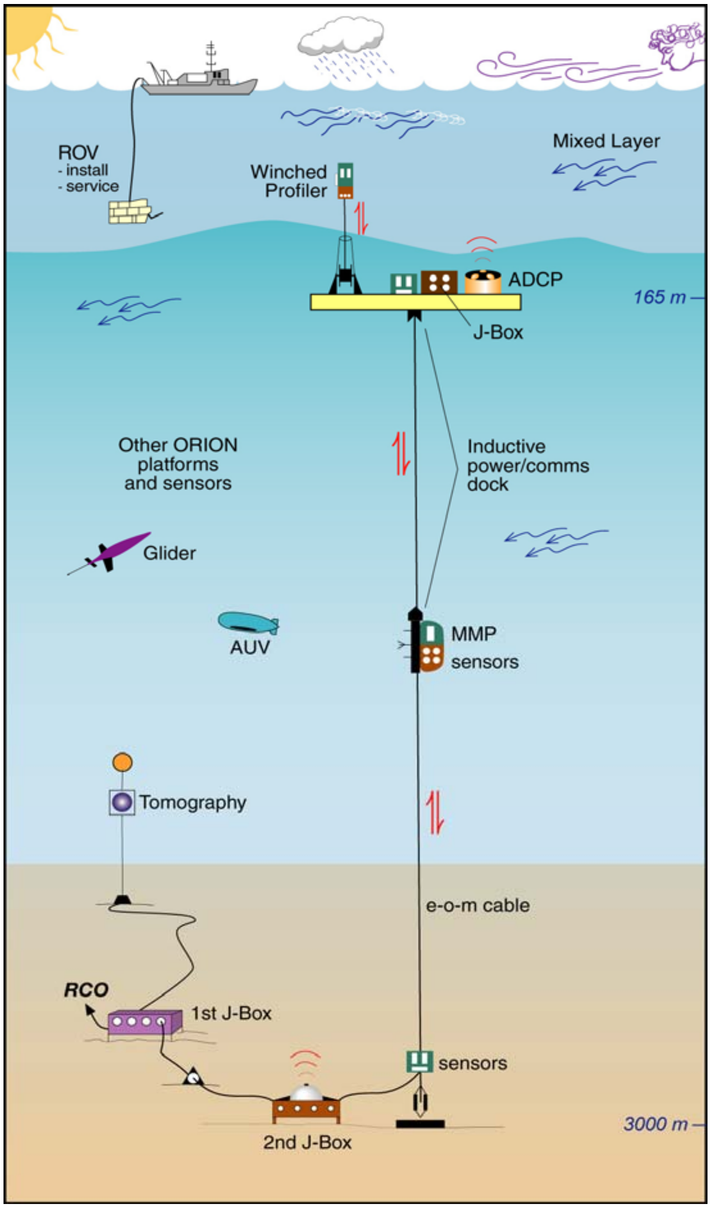

Figure 20: A deep-ocean profiling mooring based on the McLane Moored Profiler (MMP) operating on an electromagnetic cable beneath a stable platform at 200 m. The deep-ocean profiling mooring is connected to a seafloor cable via a junction box. On top of the stable 200-m deep platform is mounted an upward-looking ADCP and a winched profiling system carrying a multi-parameter sensing package capable of telemetering data to shore.

BIOGRAPHICAL SKETCH

John (Jack) A. Barth

A. PROFESSIONAL PREPARATION

University of Colorado, Physics (Cum Laude), B.A., 1982

Massachusetts Institute of Technology Woods Hole Oceanographic Institution Joint Program, Oceanography, Ph.D., 1988

B. APPOINTMENTS

Professor, COAS, OSU (2001-present)
Associate Professor, COAS, OSU (1996-2001)
Associate Professor (Senior Research), COAS, OSU (1995-1996)
Assistant Professor (Senior Research), COAS, OSU (1989-1995)
Research Associate (Postdoctoral), College of Oceanography, Oregon State University (1987-1989)

C. PUBLICATIONS

Most Closely Related to Proposed Project

Barth, J. A. (1994) Short-wavelength instabilities on coastal jets and fronts, Journal of Geophysical Research, 99:16095-16115.

Shearman, R. K., J. A. Barth and P. M. Kosro (1999) Diagnosis of the three-dimensional circulation associated with mesoscale motion in the California Current, Journal of Physical Oceanography, 29:651-670.

Barth, J. A., S. D. Pierce and R. L. Smith (2000) A separating coastal upwelling jet at Cape Blanco, Oregon and its connection to the California Current System, Deep-Sea Research II, 47:783-810.

Oke, P. R., J. S. Allen, R. N. Miller, G. D. Egbert, J. A. Austin, J. A. Barth, T. J. Boyd, P. M. Kosro and M. D. Levine (2002) A modeling study of the three-dimensional continental shelf circulation off Oregon. Part I: Model-data comparisons, Journal of Physical Oceanography, 32:1360-1382.

Barth, J. A., S. D. Pierce and T. J. Cowles (2005) Mesoscale structure and its seasonal evolution in the northern California Current System, Deep-Sea Research II, 52:5-28.

Other Significant Publications

Barth, J. A., T. J. Cowles, P. M. Kosro, R. K. Shearman, A. Huyer and R. L. Smith (2002) Injection of carbon from the shelf to offshore beneath the euphotic zone in the California Current, Journal of Geophysical Research, 107(C6), 3057, doi:10.1029/2001JC000956.

Barth, J. A., S. D. Pierce and R. M. Castelao (2005) Time-dependent, wind-driven flow over a shallow mid-shelf submarine bank. Journal of Geophysical Research, in press.

Austin, J. A. and J. A. Barth (2002) Variation in the position of the upwelling front on the Oregon shelf, Journal of Geophysical Research, 107(C11), 3180, doi:10.1029/2001JC000858.

Grantham, B. A., F. Chan, K. J. Nielsen, D. S. Fox, J. A. Barth, A. Huyer, J. Lubchenco and B. A. Menge (2004) Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific, Nature, 429:749-754.

Samelson, R., Barbour, P., Barth, J., Bielli, S., Boyd, T., Chelton, D., Kosro, P., Levine, M., Skyllingstad, E.and J. Wilczak (2002) Wind stress forcing of the Oregon coastal ocean during the 1999 upwelling season. Journal of Geophysical Research, 107(C5), 3034, doi:10.1029/2001JC000900.

D. SYNERGISTIC ACTIVITIES

- Participant in science planning activities: Global Ocean Ecosystems Dynamics Eastern Boundary Current Program Implementation Team, 1993-1994; NSF Coastal Ocean Processes (CoOP) Wind-Driven Transport Experiment Planning, 1993; NSF Advances and Primary Research Opportunities in Physical Oceanography Studies Workshop Steering Committee, 1997-1998; Coastal Ocean Processes and Observations: Advancing Coastal Research, CoOP Observatory Science Workshop Organizing Committee, 2002; Coastal Observatory Research Arrays Meeting Organizing Committee, 2003; ORION Science Planning Workshop, 2004.
- Public science lectures: Active participant in Operation Pathfinder Teacher Education Program, OSU Hatfield Marine Science Center, Newport, OR; Presentations at local elementary schools and mentoring of Boy Scouts on Oceanography Merit Badge; Led public tours of R/V Wecoma, R/V Thomas G. Thompson and R/V Roger Revelle as part of COAST and GLOBEC NEP (2001-2002).
- Input to ocean policy: Oregon Ocean Policy Advisory Council Dialogue With Experts, Newport, OR, February 2002; Coastal Processes and Ballast Water Workshop, Pacific States Marine Fisheries Commission, Gladstone, OR, March 2002; Review Panel Member for Huntington State Beach, CA, Shoreline Contamination Study, 2002-2003.
- Leadership of national programs: Global Ocean Ecosystems Dynamics Northeast Pacific Program Exec. Comm., 2000-present; NSF Coastal Ocean Processes (CoOP) Steering Comm., 2000-2004; Northwest Association of Networked Ocean Observing Systems (NANOOS) Steering Committee, 2004-present; Pacific Coast Ocean Observing System (PaCOOS) Board of Governors, 2003-present; NSF ORION Executive Steering Committee, 2004-present.
- Service to scientific community: National Center for Atmospheric Research Scientific Computing Division Advisory Panel, 1992-1994; Eastern Pacific Oceanic Conference (EPOC), Secretary, 1992-1996, President, 1998-2001; NSF Physical Oceanography Panel, Nov. 1995.

E. COLLABORATORS & OTHER AFFILIATIONS

i) Collaborators

J. Austin-ODU
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C. Mengelt-UCSB
P. Oke-UNSW Australia
S. Pegau-OSU/UAF
W. Peterson-NOAA/NMFS
T. Takahashi-LDEO
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D. Ullman-URI
A. van Geen-LDEO
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J. Wilczak-NOAA/ETL
C. Wilson-NOAA/NMFS

ii) Advisors

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Doctoral: K. H. Brink, WHOI

(iii) Thesis Advisor (7) and Postgraduate-Scholar (4) Sponsor

Masters: Bassirou Diaw (1997), Senegal Hydrographic Office; Glenn May (1997), OSU; Maria Jose Juan Jorda, OSU; Jennifer Simeon (2000), GFDL
Doctoral: R. Kipp Shearman (1999), OSU, Renato Castelao, Anthony Kirincich, OSU
Postgraduate-Scholars: Jay Austin (1998–2000), ODU; Darek Bogucki (1997–99), UMiami/RSMAS; Andrew C. Dale (1997–99), OSU; Michael W. Ott (2001–04), ODU; Stephen D. Pierce (1995–98), OSU

VITA

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a. Professional Preparation

B.S., 1967, University of Toronto, Toronto, Ontario, Canada (Mathematics and Physics)
M.S., 1969, Scripps Institution of Oceanography, La Jolla, UCSD, Calif. (Physical Oceanography)
Ph.D., 1975, Scripps Institution of Oceanography, La Jolla (Physical Oceanography)

b. Appointments

1985 - present Professor, School of Oceanography, U. of Washington
1980 - 1985 Research Associate Professor, School of Oceanography, U. of Washington
1974 - 1980 Research Assistant Professor, School of Oceanography, U. of Washington

Professional Memberships

Fellow, American Meteorological Society; Member, American Geophysical Union

c. Publications

Five most closely related publications

Hickey, B.M. (1998) Coastal Oceanography of Western North America from the tip of Baja California to Vancouver Is. In: K.H. Brink and A.R. Robinson (eds), The Sea, Volume 11, Chapter 12, pp. 345-393, Wiley and Sons, Inc.

Garcia-Berdeal, I., B.M. Hickey and M. Kawase (2002) Influence of Wind Stress and Ambient Flow on a High Discharge River Plume. J. Geophys. Res., 107(C9): 3130.

Hickey, B.M. and N. Banas (2003) Oceanography of the Pacific Northwest Coastal Ocean and Estuaries with Application to Coastal Ecosystems. Estuaries, 26(48): 1010-1031.

MacFadyen, B.M. Hickey and M.G.G. Foreman (2005) Transport of surface waters from the Juan de Fuca eddy region to the Washington coast: implications for HABs. Submitted to Cont. Shelf Res.

Hickey, B.M., S. Geier, N. Kachel and A. MacFadyen (2005) A bi-directional river plume: the Columbia in summer. Cont. Shelf Res. In Press.

ii. Five other significant publications

Trainer, V.L., B.M. Hickey and R. Horner (2002) Biological and physical dynamics of domoic acid production off the Washington USA coast. Limn. Oceanogr., 47(5): 1438-1446.

Hickey, B.M., E. Dobbins and S.E. Allen (2003) Local and remote forcing of currents and temperature in the Central Southern California Bight. J. Geophys. Res., 108(C3): 3081, doi: 10.1029/2000JC000313, 2003.

Swartzman, G. and B. Hickey (2003) Evidence for a regime shift after the 1997-1998 El Niño, based on 1995, 1998 and 2001 acoustic surveys in the Pacific Eastern Boundary Current. Estuaries, 26 (4B): 1032-1043.

Banas, N.S., B.M. Hickey and P. MacCready (2004) Dynamics of Willapa Bay, Washington: a highly unsteady, partially mixed estuary. J. Phys. Oceanogr., 2413-2427.

Swartzman, G., B. Hickey, M. Kosro and C. Wilson (2004) Core undercurrent and equatorward surface currents in the Pacific Eastern boundary current in summer 1995 and 1998 and their relationship to the distribution of Euphausiids. Deep Sea Res. In Press.

d. Synergistic Activities

Invited Speaker, Fall Meeting of American Geophysical Union, Dec. 2004.
Invited "Fireside Chat" Speaker, EPOC Conference, September 2003, Wrigley Center, Catalina Is., CA.
Invited Speaker, GEOHAB meeting, Lisbon, Portugal, November 2003.
Invited Speaker, Harmful Algal Bloom Symposium, WHOI, December 2003.
Invited Speaker, Ocean Sciences Meeting, January 2003.
Invited Participant, HABs in Upwelling Systems Workshop, Lisbon, Portugal, Nov. 2003.
Invited Speaker, Burrowing Shrimp Workshop, Nahcotta, Washington, April 2002.
Member, COOP (Coastal Ocean Processes) National Steering Committee, 1997-2001.

e. Collaborators & Other Affiliations

i. Collaborators

Dr. Susan Allen, Univ. of British Columbia,
Dr. David Armstrong, Univ. of Wash.,
Dr. Ken Bruland, UC Santa Cruz,
Dr. Laurie Connell, U. Maine,
Dr. Allan Devol, Univ. of Wash.,
Dr. Michael Foreman, Inst. of Ocean Sci.,
Dr. David Jay, Oregon Health & Sci,
Dr. John Klinck, Old Dominion University,
Dr. Mike Kosro, OSU,
Dr. Miles Logsdon, Univ. of Wash.,
Dr. Cliff Mass, Univ. of Wash.,
Dr. Andreas Munchow, Univ. of Delaware,
Dr. Jan Newton, Univ. of Wash.,
Dr. Bill Peterson, OSU/NMFS,
Dr. Charles Simenstad, Univ. of Wash.,
Dr. Richard Thomson, Inst. of Ocean Sci.,
Dr. Vera Trainer, NWFSC, Seattle, WA,
Dr. Mark Wells, U. of Maine
Dr. Ginger Armbrust, Univ. of Wash.,
Dr. Antonio Baptista, Oregon H. & Sci. U.,
Dr. William Cochlan, SFSU,
Dr. Ed Dever, Scripps Inst.,
Dr. Elaine Faustman, Univ. of Wash.
Dr. Rita Horner, Univ. of Wash.,
Dr. Mitsuhiro Kawase, Univ. of Wash.,
Dr. Raphael Kudela, UC Santa Cruz,
Dr. Evelyn Lessard, Univ. of Wash.,
Dr. Parker MacCready, Univ. of Wash.,
Dr. Jim Moum, OSU,
Dr. Jonathan Nash, OSU,
Dr. Angelica Peña, Inst. of Ocean Sci.,
Dr. Curtis Roegner, NMFS, Hammond, OR,
Dr. Gordon Swartzman, Univ. of Wash.,
Dr. LuAnne Thompson, Univ. of Wash.,
Dr. Charlie Trick, Univ. of W. Ontario,
Dr. Alexander Yankovsky, Nova SE

ii. Graduate & Postdoctoral advisors

Dr. Russ Davis, Scripps Institution of Oceanography   Dr. Bruce Taft, retired

iii. Thesis advisers for the following students [Ph.D. (4) M.S. (14)]

Francisco Werner Ph.D., UNC, Gary Torgrimson M.S., UW, Nancy Pola M.S., Marco Venturi M.S., Albert Hermann Ph.D., NOAA/PMEL, Hyungmoh Yih Ph.D., Elizabeth Dobbins M.S., NOAA/PMEL, Elizabeth Elliot M.S., Xuemei Zhang M.S., Christopher Moore M.S., NOAA/PMEL, Alok Gupta M.S., Irene Berdeal-Garcia M.S. UW, Amy MacFadyen M.S., UW, Ryan McCabe UW, Neil Banas Ph.D, UW.

CUMULATIVE PROPOSAL BUDGET

FOR ORION USE ONLY

ORGANIZATION Oregon State University	PROPOSAL NO.	DURATION (MONTHS)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR John (Jack) A. Barth	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted (If Different)
1. ______	__	__	__	$______	$______
2. ______	__	__	__	______	______
3. ______	__	__	__	______	______
4. ______	__	__	__	______	______
5. ______	__	__	__	______	______
6. (___) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	__	__	__	______	______
7. (___) TOTAL SENIOR PERSONNEL (1-6)	__	__	__	______	______
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (___) POSTDOCTORAL ASSOCIATES	__	__	__	______	______
2. (___) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	__	__	__	______	______
3. (___) GRADUATE STUDENTS				______	______
4. (___) UNDERGRADUATE STUDENTS				______	______
5. (___) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				______	______
6. (___) OTHER				______	______
TOTAL SALARIES AND WAGES (A + B)				______	______
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				______	______
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				______	______
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Endurance Lines $8,300,000; Pioneer Arrays $8,000,000 Acoustic Tomography Array $3,000,000; Autonomous Underwater Vehicle Gliders $1,000,000 Coastal HF Radar $860,000					
TOTAL EQUIPMENT				$21,160,000	______
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				______	______
2. FOREIGN				______	______
F. PARTICIPANT SUPPORT 1. STIPENDS $ ______ 2. TRAVEL ______ 3. SUBSISTENCE ______ 4. OTHER ______					
TOTAL NUMBER OF PARTICIPANTS (______) TOTAL PARTICIPANT COSTS				______	______
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				______	______
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				______	______
3. CONSULTANT SERVICES				______	______
4. COMPUTER SERVICES				______	______
5. SUBAWARDS				______	______
6. OTHER ______				______	______
TOTAL OTHER DIRECT COSTS				______	______
H. TOTAL DIRECT COSTS (A THROUGH G)				______	______
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) ______ ______					
TOTAL INDIRECT COSTS (F&A)				______	______
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				______	______
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				______	______
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$21,160,000	$_____

M. COST SHARING: PROPOSED LEVEL $______	AGREED LEVEL IF DIFFERENT: $______			
PI/PD TYPED NAME AND SIGNATURE*	DATE	**FOR ORION USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* ______	DATE ______	Date Checked	Date of Rate Sheet	Initials-ORG

OOI Form 1030 (10/99) ***Supersedes All Previous Editions***

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Budget Justification: Total $21,160,000; Duration: 10 years (includes two 3-yr back-to-back Pioneer Array deployments)

Profiling Moorings

Each **upper-ocean profiler** is estimated to cost $250K with a basic physical and bio-optical sensor suite: pressure, temperature, salinity, velocity, chlorophyll fluorescence, dissolved oxygen, nitrate, spectral downwelling irradiance, beam attenuation and light backscattering. The three FlowCAM plankton imaging systems ($50K each) and multifrequency bioacoustics sensors (e.g., Tracor Acoustic Profiling System, $100K) to be placed on the upper-ocean profilers at three cross-shelf locations on both Endurance Lines add $0.9M. The cost for CO_2 sensors ($20K each) at the surface and near-bottom at the same three cross-shelf locations on each Endurance line is 0.24M.

Since the costs of the basic mooring and secondary junction boxes for the **deep-ocean profiler** is covered in the OOI, the incremental cost of the deep profiler itself with sensors is $302K in equipment and an estimated $80K in labor. The McLane Moored Profiler (MMP) costs $103K and the sensors include: Seabird 52MP/43F $CTDO_2$ (2 each on subsurface float and base of mooring, 1 on MMP); Wet Labs BBF2 optical backscattering at 470 nm and 700 nm, and chlorophyll fluorescence within the same volume (1 each location); Falmouth Scientific 2-axis acoustic current meter (1 on MMP); RD Instruments Workhorse Sentinel 150-kHz ADCP on subsurface float; color camera (with video server to make it a web cam), on subsurface float looking at MMP dock. Expect two 2-day visits per year with ROV for instrument calibration/change-out (assuming ROV replaceable profiler); basic mooring should last 10 years. It will take approximately 10% of the capital cost per year to maintain.

Fixed Instruments

The bottom boundary layer (BBL) package (upward-looking ADCP, T, S, pressure, chlorophyll fluorescence, dissolved oxygen, light backscatter, data handler, acoustic telemetry, acoustic release) is estimated to cost $75K. The profilers and BBL packages will be serviced twice per year using 0.5 days per mooring.

One-time capital cost for the fixed, water-column moorings are based on the need for two sets of sensors per mooring for turnaround capability (Total=$0.66M): surface buoy ($30k) x 5 moorings=150K; T sensors ($1k) x 4, 5, 7, 7, 7 (For moorings at 25, 50, 80, 100, 150m respectively)=30Kx2=60K; T/C sensors ($3.5k) x 2, 3, 4, 4, 4=60Kx2=120K; data acquisition controllers ($3k) x 5 moorings=15Kx2=30K; ADCPS ($25k) x 5 moorings=125Kx2=250K; meteorological sensors ($5k) x 5 moorings=25Kx2=50K. Maintenance costs (based on 2 cruises/yr) (Total=$30K): hardware ($7K); calibration twice per year ($22K). Yearly labor costs (Total=$150K): data handling and archiving (8 mos); management (6 mos).

Endurance Lines ($8.3M)

Using the estimates for the moorings above and the requirements for the Newport Endurance line of 8 upper-ocean profilers ($2.57M), three of which are equipped with plankton imaging, bioacoustics and CO_2 sensors, and 3 deep-ocean vertical profiling systems ($1.15M), 5 BBL packages ($0.375M) and 5 water-column moorings ($0.66M), one-time capital costs are approximately $4.75M. This does not include the cost of the cable proposed for the Newport Line. For the central WA Endurance line, there are 4 upper-ocean profilers ($1.57M), three of which are equipped with plankton imaging, bioacoustics and CO_2 sensors, and 3 deep-ocean vertical profiling systems ($1.15M), 4 BBL packages ($0.3M) and 4 water-column moorings (0.53M), one-time capital costs are approximately $3.55M.

Heceta Bank Pioneer Array (and subsequently used on central WA shelf)($8M)

Using the estimates for the moorings above and the requirement for 10 upper-ocean profilers ($4.4M), all of which are equipped with plankton imaging, bioacoustics and CO_2 sensors and 6 deep-ocean ($2.3M) vertical profiling systems, 10 BBL packages ($0.75M) and 2 deep water-column moorings ($0.5M), one-time capital costs are approximately $8M.

Acoustic Tomography ($3M)

To provide synoptic large-scale offshore temperature and flow fields that provide outer boundary conditions to the continental margin region, acoustic topography instrumentation will be placed on 10 of the 12 moorings proposed in the Daly et al. RFA response (**Fig. 17)**. We note that one of these locations, offshore on the Newport Line, is also proposed here for a full water column vertical profiling system. The transceivers will be commercial Webb Research Corporation 250-Hz “sweeper” sources with STAR receiver/control electronics, at $250K each.

Autonomous Underwater Vehicle Gliders ($1M)(recurring yearly costs of $0.38M)

To occupy the four E-W and two N-S glider lines will require simultaneous operation of six gliders. An additional two gliders will be used to rotate into the glider array in order to maintain continuous operations. Each glider is estimated to cost about $125K for a total initial cost of $1M. To operate the array will take two full-time technicians at an annual cost of $200K including benefits and overhead. Supplies, mainly batteries, communications costs, mainly Iridium satellite phone, sensor calibration and computer-related fees are expected to be $30K/year per glider for a total yearly cost of $180K.

Coastal HF Radar ($0.86M)(recurring yearly costs of $0.5M)

To expand the long-range HF array off the PNW will require the installation of two new sites in Washington. The existing Heceta Bank short-range array can be made functional for the proposed science goals by adding two new elements. A new, 3-element short-range array to be used at the central WA site is proposed. Thus onetime costs total $860K: extend LR array including GPS for frequency sharing and transponders ($300K); 5 standard-range elements with installation costs ($520K); frequency-sharing upgrade to standard-element array ($40K).

Operational costs include 4 technicians to operate the 15-element HF array ($400K) and a science/technical manager at 0.5 FTE ($85K). Yearly operational costs (communication, travel, computing, data reporting) are approximately $60K.

Advanced Sensor Development (recurring yearly costs of $0.25M)

New CO_2 sensor development will require mostly personnel support for design, construction, testing, and initial deployment, with some cost for hardware, in sum estimated at $125 K/yr. A similar amount is needed for development and integration of new genome-based sensors.

Modeling (recurring yearly costs of $1M)

The modeling effort to help address the scientific objectives and to help optimize the observational infrastructure for this proposed northeast Pacific ORION project is substantial. It will require doing circulation and ecosystem modeling on a variety of scales from the entire North Pacific, down through the scale of the eastern North Pacific including the split of the North Pacific Current, to the scales covered by the proposed Pioneer Arrays. At each scale, many full-time positions will be required, as will money for substantial computer hardware for running models and archiving and organizing the output. Based on similar existing or proposed efforts, each of which individually are currently limited to a substantially smaller range of scales, we estimate these costs at $1M per year.

Final Comments

In this proposal we include only the tasks directly related to the field work. In the large context, the field work is just one component of the complete science project that includes: project management (science and engineering), field/instrumentation/operations and maintenance, data quality control and handling (assuming ORION handles "DMAS"), data analysis, modeling, data assimilation, and integration and synthesis. Education and outreach is spread throughout. Each of these tasks is multi-million dollar in its own right. Given the diversity of instrumentation (and our experience with real-time data), quality control is a significant task, upon which all the rest depend. There needs to be dedicated scientists, technicians and students performing data-oriented analysis, refining and tuning of existing models and developing new ones (especially the chemistry and biology), rigorously combining the data and models to constantly find weak points in the latter, and to finally integrate, synthesize and disseminate the knowledge gained from this endeavor.