OS32K HC: 315 Wednesday 1330h

Equatorial Oceanography II

Presiding: **M McPhaden,** NOAA/ PMEL**; J C Picaut,** Institut de Recherche pour le Developpement

OS32K-01 1330h INVITED

Mechanisms of the 1997 El Nino and its Rapid Turn Into La Nina

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The intensity of the 1997 El Nino and the 8 C sudden drop in SST around 0-130W during the turn into La Nina in 1998 were a surprise to the scientific community. This succession of warm and cold events was observed from start to finish with a comprehensive set of remotely-sensed and in situ observations. In this presentation we use these observations and some model results to infer the mechanisms of the preconditioning, onset, evolution and decay of the 1997 El Nino and its transition into the 1998 La Nina. An accumulation of warm water in the west and equatorial wave reflection on the western ocean boundary appeared favorable for the development of El Nino. However, the action of a series of westerly wind bursts from December 1996 to June 1997, notably in March 1997, was instrumental in setting up this huge El Nino. The westerly wind bursts excited equatorial downwelling Kelvin waves and advected the eastern edge of the warm pool eastward, which triggered a distinct warming over the central and eastern parts of the equatorial basin. Once these warmed regions joined, the coupling between the sea surface temperature and surface winds was fully effective, and El Nino reached its mature phase. By that time, much of the warm waters of the western equatorial Pacific was transferred toward the east by surface eastward currents. The demise of El Nino and its turn into La Nina in spring 1998, were due to the arrival in the east of various interrelated phenomena. Upwelling was brought from the west by favorable off-equatorial wind stress curl, and equatorial Kelvin waves generated by easterly winds and wave reflection on the western ocean boundary. Additional upwelling was brought from the east by equatorial Rossby waves generated by westerly winds. These various upwelling signals were added to the general uplifting of the thermocline, due to the slow discharge of the upper layer of the equatorial basin by diverging surface currents. A series of equatorial Kelvin and Rossby waves, characterized by upwelling and opposite surface currents, led to the break-up of the warm waters, the surfacing of the thermocline and the drastic drop in SST in May 1998 around 0-130W. Interestingly, a model study of particle trajectories suggest that most of the waters that outcropped at this location came from the subtropics through western boundary currents and the equatorial undercurrent. A few months latter, additional cold waters were brought from the east, easterly winds expanded from the west, and La Nina turned into a growing mode. This description of the 1997-1998 El Nino-La Nina is discussed in view of the current theories of El Nino: the delayed action, the advective feedback, the recharge-discharge and the western Pacific oscillators.

OS32K-02 1355h

The Observed Mechanisms of Interannual SST Evolution in the Tropical Pacific: 1981-2001

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Data of SST and near surface velocity derived from the ENSO observing system are used to construct the spatial averages of the local change and horizontal advection terms in the interannual SST, or T', equation in NINO-3 and NINO-4 regions. These terms are: $[\partial T/\partial t]' + [(V \cdot \nabla T)]'$, where [ ] is the spatial average over each region and $'$ denotes the interannual change based on deviation from 1988-2001 mean. It is found that the largest contribution to the advection comes from $[< V > \cdot \nabla T']$, where $<>$ is the time mean velocity (96% at NINO-3, 93% at NINO-4); in both regions the advection by the mean northward velocity dominates. It is found that

$$c\rho h[\partial T/\partial t]' + [(V \cdot \nabla T)]' = -\alpha[T]' - \beta[U_*]' + \varepsilon$$

is a model equation in which the left hand side accounts for 82% of the variance on the right hand side in NINO-3 and 76% of the variance in NINO-4.

The terms $-\alpha[T]' - \beta[U_*]'/h$ are a model for the perturbation of the vertical convergence of the turbulent latent heat flux due to changes of the ocean surface parameters, T' and wind friction velocity, U'_*, respectively, in the bulk formulas; h is the vertical mixing depth or scale over which this convergence occurs; ε is the remainder. The magnitude of the regression coefficients, α, β, imply that this vertical mixing scale, h, is 88m at NINO-3 and 110m at NINO-4, consistent with microstructure observations of the tropical, night-time convective penetration of turbulence. At NINO-3, β is not significantly different from zero. Since advection by the mean velocity is the largest contribution, these analyses are extended to 1981-2001 period, where it is found that the model equation accounts for 98

These analyses suggest that, for realism, the tropical Pacific El Nino prediction models must achieve an accurate near surface mean circulation and vertical mixing parameterization. Specifically, the northward component of advection that is primarily due to the wind-driven Ekman velocity and vertical mixing of night-time latent cooling has to be well modeled.

OS32K-03 1410h

Interannual Sea Level Changes and Associated Mass Transports in the Tropical Pacific (1964-1999)

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The main modes of interannual climate variability in the tropical Pacific are identified using satellite-derived wind (ERS) and sea level (Topex-Poseidon) data from 1993 to 1999, and output from a linear model forced by observed FSU wind from 1964 to 1999. During the 1993-1999 period, the dominant ENSO signal consists on a zonal seesaw pattern in sea level around the date-line, associated with an equatorial patch of zonal wind centered on the date-line. This oscillation is described in terms of equatorial waves. A second mode of variability, mainly linked to the strong 1997-1998 El Niño event, depicts a meridional seesaw pattern in sea level around 5°N, associated with opposite zonal wind anomalies in the north-western and south-eastern tropical Pacific. Both modes are well reproduced in the linear model forced by either the ERS (1993-1999) or the FSU (1964-1999) wind. The second mode, particularly active during the very strong 1982-1983 and 1997-1998 El Niño events, is reminiscent of the recharge oscillator theory. However, it shows no equatorial symmetry and its temporal function seems to include a decadal component. Sensitivity studies showed simple wind patterns are responsible for the sea level zonal and meridional seesaw patterns. The role of horizontal mass advection on the sea level variations is then quantified in the 15°S-5°S, 156°E-80°W southern box, the 5°S-5°N, 136°E-80°W equatorial box and the 5°N-15°N, 136°E-80°W northern box. For both modes of variability, there is little mass advection across 15°N and 15°S. At the ENSO time-scale, the equatorial box fills (El Niño) and empties (La Niña) mainly through zonal geostrophic transport across its western boundary, and counteracting meridional transport mitigates this mass budget. The second mode of variability contributes to the buildup and depletion of the equatorial band mainly through changes in the 5°N meridional geostrophic transport. Its modulation at decadal time scale could explain the shift from prevailing La Niña conditions before the 1982-1983 major El Niño event to prevailing El Niño conditions after. Complementary results based on 1948-1999 outputs from an OGCM are discussed.

OS32K-04 1425h

Interannual Volume Changes and Heat Transport Pathways in the Tropical Pacific

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Previous observational and numerical modeling studies have arrived at contradictory conclusions about mass and heat transport, particularly meridional transport, in the tropical Pacific during El Niño events. The present study uses TOPEX/Poseidon altimetric heights and a sigma-coordinate model to asses tropical Pacific volume changes during El Niño. We find that the volume of the tropical Pacific (20°S - 20°N) increases gradually prior to El Niño events, and then falls sharply during the events. The volume drop within a few degrees of the equator is largely countered by a volume increase between 8° and 20°N, but there is still a change over the tropical Pacific (20°S - 20°N) as a whole. The redistribution of volume within the tropics on interannual time scales involves large-scale transport both zonally and meridionally. The horizontal heat fluxes and the heat flux at the sea surface dominate these changes and redistributions of volume. In this study, we explore the three-dimensional pathways of heat transport in detail, as well as the dynamics behind them.

OS32K-05 1440h

Interannual Variability in Pacific Ocean Tropical/Extra-tropical Transport

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Interannual variability in Pacific Ocean circulation and transport has been observed throughout the 1990s using ongoing High Resolution XBT/XCTD (HRX) transects and TOPEX/Poseidon altimetric data. The Pacific-wide HRX network includes transects enclosing the tropics at about 22N and 31S plus the Indonesian Throughflow (ITF). The HRX network was created to observe variability of the upper ocean, including boundary currents, interior circulation, and choke point transports.

In the North Pacific, the similarity of geostrophic transport to the North Pacific SLP Index demonstrates a dominant role of large-scale atmospheric forcing and a rapid basin-wide oceanic response. Poleward Ekman transport and equatorward thermocline transport across 22N peaked simultaneously in early 1994 and again in early 1997. These maxima of the shallow overturning circulation resulted in maxima of northward heat transport - about 1 pW compared to a mean of 0.8 pW. The interannual time-series of meridional heat transport was similar to that of air-sea heat loss north of the 22N transect.

In the subtropical South Pacific (31S), net meridional transport (13.0 Sv northward mean) balances the Indonesian Throughflow (ITF, 11.9 Sv westward). As in the North Pacific, the South Pacific/ITF combination shows maxima in the shallow overturning cell in 1994 and 1997 (export of the warmest layers from the tropical Pacific, import of cooler waters). A 15-year time-series of zonal geostrophic transport in the southern tropics shows strong quasi-biennial and decadal signals.

Combining the North Pacific, South Pacific, and ITF transects, large exports of heat from the tropical Pacific - about 1.6 pW in early 1994 and 1997 - accompanied maxima in the shallow overturning circulation (exceeding minima by 10 Sv). This occurred during the development of El Nino episodes. The minimum heat export, about 0.8 pW, was in early 1998 during the developing La Nina. While heat storage and air-sea flux in the tropical Pacific are primary elements of the heat budget, ocean transport also plays a significant role in interannual variability.

HRX sampling continues, with enhancements to include improved meteorological sensors, research-quality 2000-m XBTs and salinity from the Argo float project.

URL: http://www.hrx.ucsd.edu

OS32K-06 1455h

The Role of Air-Sea Interaction and Non-Normality in Controlling the Structure and Growth of Optimal Perturbations of ENSO

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The optimal perturbations of the low-frequency coupled ocean-atmosphere eigenmodes are explored using a hierarchy of hybrid coupled models. The model hierarchy consists of an OGCM of the tropical Pacific ocean coupled to three different atmospheric models: a statistical model, a simple dynamical model, and a model of the atmospheric boundary layer. The structure and growth rate of the optimal perturbations is found to depend strongly on the atmospheric dynamics and air-sea interaction processes that are included in each model. It is shown that these processes influence the degree of linear dependence of the system eigenmodes which in turn directly controls the growth attainable by the optimal perturbations. The implications of these findings for ENSO predictability and ensemble prediction will be discussed.

OS32K-07 1530h

The Response of a Coupled Model of ENSO to Observed Estimates of Stochastic Forcing

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In this work, we examine the role that the observed intraseasonal variability can play in controlling the observed ENSO variability. To this end, we force an intermediate ENSO model with observed stochastic forcing which is defined as the part of the atmospheric variability that is uncoupled from the ocean. The stochastic forcing is estimated from the NCEP/NCAR reanalysis of heat-flux and surface winds and Reynolds Sea Surface Temperatures in the Tropical Pacific. Principal Component Analysis of the stochastic component shows no preferred mode of variability and decorrelation times of a few days. A 51-year stochastically-forced model integration shows some similarities with the observed equatorial SST. The model's free parameters are chosen so that the coupled system is asymptotically stable (with a decay time of about 3 years). Therefore, these results support the hypothesis that a significant fraction of ENSO variability may be due to stochastic forcing. Using the ideas of generalized linear stability theory, the dynamically important contributions of the stochastic forcing are isolated, and it is shown that most of the variability is produced by stochastically-induced Kelvin waves in the western and central Pacific.

OS32K-08 1545h

The Equatorial Thermocline Outcropping - A seasonal control on the Tropical Pacific Ocean-Atmosphere Instability strength

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One of the major factors determining the strength and extent of ENSO events, is the instability state of the equatorial Pacific coupled ocean-atmosphere system and its seasonal variations. This study analyses the coupled instability in a hybrid coupled model of the Indo-Pacific region, using the adjoint method for sensitivity studies.

We found that the seasonal changes in the ocean-atmosphere instability strength in this model are related to the outcropping of the thermocline in the east equatorial Pacific. From summer to early autumn when the thermocline outcrops over a wide area in the East Pacific, there is a strong surface-thermocline connection and anomalies that arrive as Kelvin waves from the west along the thermocline can reach the surface and affect the SST and thus the coupled system. Conversely, from late winter to early spring, when the thermocline outcropping is minimal, the surface de-couples from the thermocline and temperature anomalies in the thermocline depth range do not affect the surface and dissipate within the thermocline. It is found that the connection between the surface and the thermocline in the model is mainly through vertical mixing, rather than through upwelling as commonly parameterized in intermediate models.

It is therefore suggested that the seasonal ocean-atmosphere instability strength in the equatorial Pacific is strongly influenced by the thermocline outcropping and its seasonal modulation, a physical mechanism that can be represented properly only in models that employ the full dynamics of the mixed-layer.

OS32K-09 1600h

A Numerical study of the interannual variability of the equatorial Pacific Ocean circulation

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A numerical experiment has been performed to simulate realistic ocean circulation and to investigate the interannual ocean variability by using a high-resolution global ocean circulation model. After 20-year numerical integration by climatological surface wind, temperature and salinity data, the interannually varying surface wind and temperature data are used to force the model ocean from 1982 to 1998. The model simulates the El Niño events in 1982-83 and 1986-87, and the La Niña events in 1984 and 1988, though the model sea surface temperature in the eastern Pacific Ocean is lower than observations by about 1 to 2 degrees. The model shows interesting features of variations in the western boundary currents (e.g., the New Guinea Coastal Undercurrent Current: NGCUC, the Mindanao Current: MC) and eddies (i.e., the Halmahera and Mindanao Eddy: HE and ME) associated with the strong ENSO events. In the growing and mature period of El Nino, they show typical structures though they are affected by the unusually shallower thermocline in the western equatorial Pacific. On the other hand, they are entirely different from usual after mature state of El Niño. The HE and ME become weak and are sometimes unidentifiable. The NGCUC turns to the east on the equator without overshooting the equator. These unusual circulation patterns are identified in boreal summer in 1983 and 1998 in the model. The decreasing cross equatorial component of the NGCUC is consistent with the ADCP mooring observation. The anomalous wind stress curl over the central equatorial Pacific may be responsible for this event.

OS32K-10 1615h

Why do Indian Ocean SST anomalies due to rainfall matter for El Nino predictions?

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A four-active-thermodynamic-layer-model of the Indian Ocean coupled to a quasi-equilibrium tropical atmosphere model is run forced by FSU winds over 1980-2000, in 2 different configurations for the rainfall forcing. One corresponds to climatological rainfall. The second is the rainfall simulated by the atmospheric model when the latter is forced by observed SST over 1980-2000. The analysis is focused on the period 1992-2000 which has two major events in 1994 and 1997 when the rainfall over the Indian warm pool (usually 10 mm/day) almost drops to zero. In response to the anomalous equatorial easterlies blowing over the Indian Ocean during these events, the sea level off of Java drops by 30cm according to TOPEX or the model. The difference between the two experiences is as little as 1 cm in sea level, but as big as 1 psu in salinity, 1.5 Degree C in sea surface temperature (SST). The atmospheric model shows that the SST changes of the Indian ocean have an impact on the local Indian atmosphere, and on the remote winds of the Pacific as well. In particular, the model simulates each year westerly wind bursts (WWB) in the western Pacific which have different characteristics in time and strength, depending on the presence or not of the Indian SST changes. Consequences on the El Nino predictions initiated in late 1996 are illustrated by testing the two different configurations of WWB in a tropical Pacific ocean model coupled to a statistical atmosphere.

OS32K-11 1630h

A Unified Layered Theory of Wind-driven Equatorial and Mid-latitude Circulation

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A theory has been developed to take account of the finite depth of wind-driven frictional influence in a steady layered ocean model. It can be illustrated in its simplest form in a $2\frac{1}{2}$ layer model. The motivation for the theory was to develop an account of the interaction of friction and stratification in wind-driven equatorial circulation. An equation is derived that gives the baroclinic circulation by the wind; the equation is hyperbolic in a certain limit, and can be solved by the method of characteristics. Difficulties arise when characteristics intersect: speculations will be given on resolving these difficulties. In mid-latitudes, the theory reduces to the standard surface Ekman layer theory, with potential vorticity conservation in layers below it. A bonus is that it gives an account of the surfacing of a layer interface through the Ekman layer. The theory unifies mid-latitude planetary geostrophic theory with equatorial theory. Some results will be shown for circulation driven by idealized wind stress fields and averaged winds from the QuikSCAT scatterometer.

OS32K-12 1645h

Equatorial Upwelling Calculated from QuikSCAT Winds in the Eastern Pacific

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QuikSCAT winds have been used to calculate upwelling circulation in a number of meridional sections in the eastern equatorial Pacific. The calculation is based on a simple frictional theory that extends the midlatitude Ekman model to include the equatorial region. The singularity at the equator in the classical model is removed by considering the effects of stratification. Inputs to the model include, besides wind stress, a diagnostic specification of an interface representing the thermocline. The upwelling circulation

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transitions smoothly from being driven by wind stress curl off the equator to being driven (in part) by wind stress divergence at the equator. Unlike in midlatitudes, upwelling depends strongly on the vertical eddy coefficient of friction. The resulting circulation cells will be compared to features of the circulation, such as the equatorial cold tongue, as inferred from microwave measurements of SST by the TRMM Microwave Imager.

OS32L HC: 314 Wednesday 1330h

Coupling of Biogeochemical Processes Between the Upper and Mesopelagic Ocean II

Presiding: **R B Rivkin,** Memorial University of Newfoundland**; L Legendre,** Laboratoire d"Ocanographie de Villefranche

OS32L-01 1330h INVITED

Mysterious microbes of the mesopelagic

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Microbes and microbial processes in the mesopelagic zone are not especially well characterized. New approaches for characterizing and quantifying microbial community members, and some of their functional properties, are now being applied to microbes living in this vast habitat. As might be expected, the phylogenetic composition of microbes in the mesopelagic is different from that found in the upper water column. For instance, archaea are quantitatively significant members of mesopelagic microbial communities. Cell numbers of one archaeal group in particular, the planktonic crenarchaeota, can approach the sum of all other bacterial groups combined at mesopelagic depths. The unique properties of these archaea, including their potential CO2 fixing capabilities, likely influence carbon and energy cycling at subphotic zone depths of the Pacific Ocean. Other aspects of mesopelagic microbial communities also need to be understood in greater detail. For instance, in recent work we have found novel groups of ribulose-1,5-bisphosphate carboxylase/oxygenase (RubisCO) genes in DNA depth profiles and bacterial artificial chromosome (BAC) libraries. These RubisCO genes appear to be quite common at depths between 100m to 3000m off the California coast. The origin, function and significance of these mesopelagic RubisCO genes, and their involvement in deep-sea autotrophic processes, is one of many mysteries remaining to be solved in mesopelagic microbial communities.

OS32L-02 1350h

Distribution, Bacterial Utilization and Transport of Dissolved Organic Matter in the Far North Atlantic, May 2000.

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Dissolved organic matter (DOM) is an important and dynamic component of the ocean carbon cycle. It can be transported long distances horizontally and exported vertically. The extent of transport, however, is dependent on the lability of component compounds and the intensity of microbial oxidation/mineralization as well as circulation. We measured the concentrations of dissolved organic carbon, nitrogen and phosphorus (DOC, DON and DOP) in the upper 1000 m on a detailed mesoscale hydrographic survey of the Faroes - Iceland - Scotland region of the North Atlantic Ocean (57-65N, 2-25W; RRS DISCOVERY Cruise 253), to estimate their transports, and the stoichiometric ratios of transported DOM in the ambient circulation. The region is characterized by ridge- and -bank topography with bottom depths ranging from <100 to >2000 m. Bacterial stocks and production rates were also estimated.

Our survey occurred during or just following the spring phytoplankton bloom in the south part of the study area, and preceded the bloom in the north. Vertical profiles suggest some net production of DOM had occurred. DOC and DON concentrations in the upper 25 m were elevated by several micromolar relative to deeper water. Bacterial abundance ranged from 1 - 8 x 10^8 cells/L and production rates were generally low. Following large-volume incubations on ambient DOC, newly produced bacterial biomass had $\Delta^{14}C$ values of -230 to -150, i.e. radiocarbon ages of 1300-2000 years, indicating at least a small fraction of older DOC had been incorporated. Assuming 10% conversion efficiency, the bacterial turnover time of semilabile DOC in the upper 100 m was 50-100 d. The low bacterial turnover potentially enables long-range transport of DOM in the region. We will estimate net transports using a new diagnosis of the regional circulation made on the same cruise.

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OS32L-03 1405h

The Response of Surface and Deep Bacterioplankton to High Molecular Weight and Low Molecular Weight fractions of Dissolved Organic Carbon in the Sargasso Sea

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Deep convective mixing during winter can result in a portion of the seasonally accumulated DOC to be mixed to depths below the euphotic zone at the Bermuda Atlantic Time-series (BATS) site. Following stratification of the water column a portion of the exported DOC becomes trapped below the euphotic zone and is removed. Experiments demonstrate that when surface water DOC, resistant to rapid degradation by surface microbial assemblages, is inoculated with water from 250 m DOM is removed on time scales of weeks. In addition, previous studies have demonstrated rapid cycling of high molecular weight (HMW) DOC relative to low molecular weight (LMW) DOC (Amon and Benner, 1994). Here we will present data from an experiment conducted in August 2001 designed to investigate whether bacterioplankton collected at different depth horizons (10 and 250 m) would respond differently to surface water fractionated into HMW and LMW DOC. Water collected from 10 m at the BATS site was fractionated into HMW (greater than 1000 KD) and LMW (less than 1000 KD) DOC by tangential flow filtration. Each molecular weight fraction was then divided in two and inoculated with microbial assemblages collected from 10 m and 250 m. The seawater cultures were incubated at in situ temperatures in the dark for one week.

Bacterioplankton production (as measured by change in cell abundance) was greater in the molecular weight fractions inoculated with 250 m water compared to same media inoculated with 10 m water. For example, in treatments where HMW and LMW DOC were inoculated with 250 m water bacterial abundance increased 8 and 5 fold, respectively. This compared to just a 2 fold increase in bacterial abundance in treatments inoculated with 10 m water. The availability of DOC to deep water microbial communities has implications for C cycling through DOC at BATS. We will present data describing the variability of microbial community structure and DOC dynamics within these experiments.

Amon, R. and R. Benner, 1994. Nature 369: 549 552.

OS32L-04 1420h

Penetration of the Bomb ^{14}C Signal Into the Central North Pacific Ocean and Sargasso Sea Over the Last Decade

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Radiocarbon and $\delta^{13}C$ measurements are presented for dissolved and suspended particulate organic carbon (DOC, POC) and dissolved inorganic carbon (DIC) from the water column in the central North Pacific (31^oN, 159^oW) and the Sargasso Sea ($31^o50'N$, $63^o30'W$).

Results are available from 1987 and 1999 for the Pacific and from 1989 and 2000 for the Atlantic. Penetration of the bomb ^{14}C signal at the Pacific site was detected in DIC as deep as 3000 meters. In 1999, $\Delta^{14}C$ of suspended POC in the Pacific was approximately 50 $^o/_{oo}$ lower throughout the entire water column than values found 12 years earlier. In 2000, $\Delta^{14}C$ values of suspended POC at the Atlantic site were lower at 0-100 m depth than values obtained 11 years earlier; higher values were found in 2000 for depths greater than 600 m. Discussion of the penetration of the bomb ^{14}C signal into these two mid-gyre regions, and implications for the flux of carbon between the surface and the deep sea, will be presented.

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Dissolved Organic Carbon Export with North Pacific Intermediate Water Formation

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The biological pump primarily occurs by two mechanisms: sinking of biogenic particles and downward mixing of dissolved organic carbon (DOC) with the oceans overturning circulations. The locations, timing and rates of particle flux have been studied extensively for several decades. Advances in characterizing the traits of DOC export, in contrast, have been hampered by a dearth of data. Here an evaluation of DOC export with the formation of North Pacific Intermediate Water is presented. Data from sites representing the region's important water masses (North Pacific subtropical, subpolar, and subtropical transitional) are used to demonstrate and quantify the process. We suggest that subpolar, DOC-replete Oyashio water mixes with subtropical, DOC-deplete Kuroshio water in the Mixed Water Region east of Japan. The new intermediate water, formed at a rate of 2-5 Sv, supports net DOC export at $13 \pm 6 Tg C y^{-1}$, delivering water with elevated concentrations of relatively young DOC to the central North Pacific. Based on these findings, we present an alternative explanation for the ^{14}C-DOC age gradient recently reported for intermediate depths of the North Pacific.

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Mesopelagic Bacterial Processes in the Subarctic Pacific: Distribution, Production and Ectoenzyme Activities

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