### OS32G-225 1330h POSTER

## Eddies in the South of the Subtropical Gyre of the South Pacific Ocean

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The objective of this study is to investigate the occurrence of eddies in the Southern part of the South Pacific Subtropical Gyre in French Polynesia using satellite altimetric and Acoustic Doppler Current Profiler (ADCP)data for the purpose of fisheries. The altimetric data show eddies with diameter of 100-400 km with a lifetime of at least 2 to 3 months in the latitude interval 15-35S, that is, centred several degrees north of the subtropical convergence. These eddies, located around the Austral islands and seamount chain, seem stationary. The stationary state is perturbed during an El Nino year. ADCP data obtained from two cruises in the South of French Polynesia are consistent with TOPEX/Poseidon altimetric data. The better spatial resolution of the ADCP shows that eddies in the South of French Polynesia smaller than 100 km could also exist. The origins of the eddies will be discussed.

### OS32G-226 1330h POSTER

## A Statistical Model for Time-Varying Wind-Driven Currents Based on Altimeter and Pacific Drifter data.

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Ralph and Niiler (JPO 1999) analyzed long-term mean ageostrophic circulation measured by WOCE drifters at 15m depth in the tropical Pacific. Their best statistical model had both the amplitude of the current and its vertical scale proportional to wind speed and inversely proportional to the square root of the Coriolis parameter. The 15m ageostrophic current vectors were optimally described by an angle to the wind and a magnitude proportional to the wind speed. We have repeated this analysis with 2-day averaged (i.e. time dependent) drifter data.

This allows us to explore the latitude variability of the angle between the wind and the 15m velocity, the proportionality of wind-driven current to wind speed, and optimal horizontal smoothing scale for computing geostrophic currents from the altimeter-derived SSH fields. Altimetry products (both along-track SSH and 2-D mapped fields) were used to estimate and remove the geostrophic velocity, reducing the variance of the observations by up to 70%. Wind model parameters were optimized on the residuals, reducing their variance by up to 30%. Winds from both NCEP and Atlas (Atlas, et al., JGR 1999) products were compared for efficacy in terms of variance explained.

### OS32G-227 1330h POSTER

## Regime shifts found in the Northern Hemisphere SST field

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A 'regime shift' is characterized by an abrupt transition from one quasi-steady climatic state to another, and its transition period is much shorter than the lengths of the individual epochs of each climatic state. In the present study, we investigate when regime shifts occurred and what was the difference in climatic states before and after the shifts, using the wintertime sea surface temperature (SST) field in the Northern Hemisphere. The relationship between changes in the SST field and those in the atmospheric circulation is also investigated.

In order to detect organized patterns of the SST variations, we adopt an empirical orthogonal function (EOF) analysis. As the results, the first mode is identical to El Nino/Southern Oscillation (ENSO) and so-called Pacific Decadal Oscillation (PDO), and corresponds to the Pacific/North American (PNA) pattern. The second mode, which relates to the Arctic Oscillation (AO), has a zonally elongated signal in both the North Atlantic and the North Pacific. EOF analyses to each oceanic basin are made separately and the robustness of these modes is confirmed.

In the present study, we define the regime shifts as the 'significant' and 'systematic' changes between the two quasi-steady states continuing more than 5-year. Then, in order to identify the years when regime shifts occurred in the SST field, we carefully inspect the time series of original gridded SST data and those of the EOF modes. As a result, six regime shifts are detected in the study period from the 1910s to the 1990s: 1925/26, 1945/46, 1957/58, 1970/71, 1976/77 and 1988/89. It is ascertained that the shifts at almost all grids are completed within one year. All regime shifts having similar SST and atmospheric circulation pattern including the changes in an intensity of the Aleutian Low (AL) and the corresponding SST changes in the central North Pacific. All regime shifts can be described well by the combination of the first and the second EOF modes. Duration between each regime shift is about 10 years, which are identical to the PDO. The simultaneous shifts in the first and the second EOF modes imply that the change in the AL activity associated with the PNA pattern might have some connection with that of the AO.

### OS32G-228 1330h POSTER

## Interaction between Island and Ventilated Thermocline: Implication for the Hawaiian Lee Countercurrent

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The interaction between an island and the wind driven subtropical circulation is investigated using a $2^1/_2$-layer ventilated thermocline model. The island is located in mid gyre and equatorward of the gyre center in order to simulate the Hawaiian Islands. The presence of the island creates three new dynamic regimes west and southwest of the island: one where the 2nd layer is at rest (the island shadow zone), one where the 2nd layer potential vorticity (pv) is determined by the western boundary current (wbc) outflow conditions at the northern tip of the island, and one where the pv is determined by the wbc outflow conditions at the southern tip. Each of the above regimes affects the baroclinic structure of the zonal jet extending westward from the southern tip of the island. We investigate the impact of the model on the Hawaiian Lee Countercurrent (HLCC), an eastward current crossing the western Pacific at the latitude of the southern tip of Hawaii (18°–20°N). We show that the HLCC is determined not only by the anomalous Ekman pumping generated by the presence of the islands, but also by the effect of the islands on the broader-scale Sverdup flow east of the island. In particular, the model predicts a zonally varying baroclinic structure in the HLCC which is consistent with observations.

### OS32G-229 1330h POSTER

## Interannual to Interdecadal Upper Ocean Variability in the Northeast Pacific

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Low frequency variability over the northeast Pacific is examined in terms of the one-dimensional response to local Ekman pumping according to the Hasselmann (1976) stochastic climate model. The model is forced with monthly wind stress curl anomalies derived from the NCEP reanalysis for the period 1948-2000. An empirical orthogonal function (eof) analysis shows that the leading mode of the response bears the signature of the Pacific Decadal Oscillation, and that the associated principal component captures the 'regime shift' of 1976/77. Comparisons between hindcast anomalies and in situ observations of pycnocline depth anomalies at Station P (215E, 50N) yield a correlation coefficient of 0.77 over the 43 year period 1957-1999. A further comparison with sea surface height anomalies derived from over 8 years of T/P altimetry data is presented. This shows good agreement in the spatial and temporal structure of the leading eofs between the model and observations. Overall, the results indicate that variability in upper layer thickness on interannual to interdecadal time scales over the northeast Pacific occurs largely as an integrated response to local Ekman pumping.

### OS32G-230 1330h POSTER

## Coastal Promontories and Associated Processes in the Coastal Ocean

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Coastal promontories or headlands are found along the coast of the world. Their shapes and sizes vary and so the hydrodynamic conditions around the promontories. In tide-dominated environment strong tidal mixing tends to lower the surface water temperature near the promontory, and the tidal front may develop between stratified offshore water and well-mixed coastal water. Strong current velocity is also found around the tip of the promontory and it is associated with the sea level depression. The maximum sea level depression is found at the minimum radius of curvature. Eddies may also develop due to the velocity shear caused by vorticity generation. Park and Wang (2000) suggested that the topographic vorticty tendency is responsible for the strong vorticity generation. Acceleration and deceleration of currents together with velocity shear result in net sediment movement around the coastal promontory. It has been shown that the promontory normal to the tidal stream is unstable and it tends to rotate cyclonically from the axis normal to the tidal stream. This study shows some examples of processes associated with coastal promontories and discusses the mechanisms responsible for those.

Park, M.-J. and D.-P. Wang 2000 Tidal vorticity around a coastal promontory, Journal of Oceanography, 56:261-273.

# OS32H HC: 318 A Wednesday 1330h

WED

## Air-Sea Exchange I

*Presiding:* **R Feely,** NOAA Pacific Marine Environmental Laboratory**; W McGillis,** Woods Hole Oceanographic Institution

### OS32H-01 1330h

## Equatorial Pacific Direct Air-Sea Carbon Dioxide Fluxes

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$CO_2$ exchange across the air-sea interface is an important mechanism in modulating global climate and the absorption of anthropogenically produced $CO_2$. Depending on the time of year, different regions of the ocean can be sources or sinks for atmospheric $CO_2$. Currently, it is estimated that the ocean as a whole acts as a sink for $CO_2$, taking up about 2 gigatons per year of the approximately 5.5 gigatons of carbon dioxide produced by industrial and agricultural activity. However, there is significant uncertainty in this estimate, largely because the kinetics of ocean-air $CO_2$ transfer are not well understood.

In February, 2001, the GasEx-2001 study took place aboard the NOAA Research Vessel Ronald H. Brown in the Eastern Equatorial Pacific near 3°S 125°W. The

primary objective was to use direct gas flux measurements to study the kinetics of air-sea gas exchange. A second focus was to determine the physical, chemical, and biological factors controlling $pCO_2$ in the surface water. The eastern Equatorial Pacific region is the largest oceanic $CO_2$ source to the atmosphere with large interannual variability caused by the ENSO cycle.

During GasEx-2001, an instrumentation suite was deployed on the Research Vessel Ronald H. Brown using a boom-mast system that included meteorological and $CO_2$ sensing systems for measuring air-sea fluxes. The bow system consisted of a suite of fixed sensors at the end of the bow boom and a second set of profiling sensors located on a vertical mast at the end of the boom. The LI-7500 Open-Path, LI-7000 and LI-6262 Closed-Path gas analyzers were used to make direct covariance $CO_2$ measurements and an additional LI-6262 performed atmospheric $CO_2$ and $H_2O$ vapor profile measurements. The end of the boom was 10 m from the ship bow rail to reduce flow distortion from the ship, and the vertical profiling mast was 8 m in height. The system consisted of high sample rate measurements of the 3-D wind vector, RH, air temperature, water vapor, DMS and $CO_2$.

The autonomous Air-Sea Interactions Spar (ASIS) buoy collected data on surface process variability including wind speed, wind stress, atmospheric stability, incident radiation, upper-ocean mixing, and surface wave state concurrently with data on air-sea $CO_2$ fluxes. ASIS supported two meteorological flux systems, each including an open-path $CO_2$ sensor during the experiment. Measurements from ASIS will be used to determine the role surface waves and turbulence play in limiting air-sea $CO_2$ exchange, essential to advancing the capability for remote-sensing of air-sea $CO_2$ fluxes.

Carbon dioxide micrometeorological techniques will be described and results discussed. The data produced from this multi-disciplinary effort include the air-sea flux and gas transfer velocity. The findings on the forcing of $CO_2$ fluxes under low wind speed conditions and strong diurnal heating can be incorporated into algorithms to improve our estimates of fossil fuel derived $CO_2$ uptake by the oceans.

### OS32H-02 1345h

## Carbon Chemistry of the Water Column During GasEx-2001

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Current large uncertainties in the air-sea flux of $CO_2$ prevent us from verifying the partitioning of fossil fuel $CO_2$ between the ocean and the terrestrial biosphere. This limits our ability to realistically model future atmospheric $CO_2$ levels. Techniques are now in hand to improve our estimates of air-sea $CO_2$ fluxes. The GasEx-2001 study was conducted from January–March 2001 in the eastern Equatorial Pacific at approximately 3°S, 125°W. The goal of the study was to use direct gas flux measurements to improve our understanding of the forcing functions of the kinetics of air-sea gas exchange. A second goal was to determine the physical, chemical, and biological factors controlling the $CO_2$ fugacity ($fCO_2$) in the surface water. The Equatorial Pacific has been a focal point for chemical and physical studies since it has a major influence on carbon source/sink variability through the El Niño/Southern Oscillation (ENSO) cycle. Strong vertical dissolved inorganic carbon (DIC) gradients were observed in the spatial and temporal surveys. The daily casts showed a clear decrease in DIC in the upper 40 m over the course of the experiment. Mixed layer DIC values dropped by $\sim 6$ $\mu$mol kg$^{-1}$ over the 13-day time-series. The intensive studies also indicated diurnal variations of 1–2 $\mu$mol kg$^{-1}$ in near-surface carbon distributions. The available hydrographic and geochemical data will be used to illustrate the observed variability and attempts to derive a carbon budget for the upper water column over the course of the experiment. The preliminary data suggest that the diurnal DIC changes result primarily from biology. The magnitude of the DIC change is consistent with the change in nitrate based on Redfield stoichiometry. Furthermore, the changes appear to occur throughout the mixed layer and not just in the upper few meters as does the diurnal thermal signature. The 6 $\mu$mol kg$^{-1}$ DIC drop observed during the drifter experiment, however, cannot be completely accounted for with changes in nitrate. Preliminary calculations suggest that horizontal and vertical mixing processes are relatively small. An appreciable portion of this DIC decrease, therefore, may be attributed to air-sea gas exchange.

URL: http://www.pmel.noaa.gov/co2/gasex2/

### OS32H-03 1400h

## Spatial and temporal variability of primary productivity during GasExII

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During GasExII (equatorial Pacific, February 2001), MBARI primarily measured phytoplakton biomass (using chlorophyll as a proxy) and phytoplankton productivity via carbon, nitrate and ammonium incorporation. The rates of carbon assimilation provide us with an estimate of total phytoplankton productivity, while the nitrate and ammonium measurements estimate the amount of 'new' versus 'recycled' production. In this presentation we will describe the temporal and spatial variability of phytoplankton biomass and productivity, in the context of the physical environment. The productivity data will be compared with both profile and underway data from the Fast Repetition Rate (FRR) Fluorometer, an instrument which attempts to measure photosynthetic rates optically, rather than experimentally. We will also describe some of the other data collected by MBARI during the cruise, including SeaWiFS ocean color images and daily optical profiles of the upper 100-200m. In the larger context of the process study, our goal is to incorporate the biological carbon uptake measurements with the physical and chemical data to resolve the carbon budget of the region.

### OS32H-04 1415h

## The air-sea fluxes of momentum, heat and CO2, measured from a drogued ASIS buoy

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During the GasEx-2001 field experiment in the eastern Equatorial Pacific Ocean, an Air-Sea Interaction Spar (ASIS) buoy was deployed from the RV Ronald H. Brown. The buoy was drogued, and drifted slowly for about 3 weeks. During this time, the buoy measured: direct (eddy correlation) turbulent fluxes of momentum, heat, and CO2; mean meteorology; surface waves; vertical profiles of currents, SST, pCO2 and salinity; and turbulence in upper ocean.

Here, ASIS fluxes are reported and compared with fluxes measured simultaneously from several systems on the RV Ronald H. Brown. We discuss the flux measurements in terms of some of the related physical processes: surface waves, oceanic turbulence, atmospheric stability and diurnal surface heating.

### OS32H-05 1430h

## Sea-to-air Exchange of Dimethylsulfide

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Abstract.-Uncertainty in the air-sea transfer velocity is the largest source of discrepancy in ocean-atmosphere budgets for trace gases. In situ micrometeorological methods measure air-sea fluxes on small spatiotemporal scales and can provide a better understanding of gas exchange rates. Much attention has been paid to the derivation of the transfer velocity from Eddy Correlation flux measurements of CO2 (Jacobs et al., 1999; McGillis et al., 1999; Wanninkhof and McGillis 1999). The application of the Gradient Flux technique for DMS and CO2 exchange has recently received attention (Baart et al., 1994; Putaud and Nguyen, 1996; McGillis et al., 2001). Improved measurement techniques and increased sampling have reduced the uncertainty. Results from experiments on the equatorial Pacific Ocean measuring DMS and CO2 flux by the Gradient Flux technique will be presented. These experiments are among the first in which sea-air CO2 and DMS fluxes are simultaneously measured by micrometeorological techniques.

### OS32H-06 1445h

## Comparison Between GasEx-2001 Direct Gas and Heat Flux Measurements and the Coare 2.6 Bulk Flux Model Including a Gas Transfer Parameterization

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Due to increased concern about the magnitude of global ocean sequestration of anthropogenically-generated carbon dioxide, the GasEx series of cruises (1998 and 2001) were designed to make direct measurements of the air-sea flux of CO2 over the open ocean, along with the relevant environmental forcing variables (wind, waves, boundary layer structure, surface characteristics, etc) which modulate the gas flux. One of the goals of this campaign is to make improvements to the gas transfer parameterizations which are used in larger-scale climate models.

During Gasex-2001, which occurred in the Equatorial Pacific in February and March, direct covariance measurements of the turbulent fluxes of carbon dioxide, heat, moisture, and momentum were obtained from 3 independent measurement packages: the NOAA Environmenatl Technology Lab (ETL), the Woods Hole Oceanographic Institution (WHOI), and the University of Miami Rosenstiel School for Marine and Atmospheric Sciences (RSMAS). These turbulence measurements were made from 2 platforms: the NOAA Ship Ronald H. Brown and the RSMAS Air-Sea Interaction Spar (ASIS) buoy. The direct covariance measurements of air-sea flux of carbon dioxide were obtained on these systems with both open-path and closed-path instrumentation.

We will present the direct flux results from this latest expedition from the various systems and compare the heat and momentum results to the latest version of the COARE Bulk Flux Algorithm. In addition, we will incorporate the Fairall et al Air-Sea Gas Transfer Parameterization into the bulk model and discuss the comparison between the direct gas flux measurements and the model output.

### OS32H-07 1530h INVITED

## The Use of Heat as a Proxy Tracer for Air-Water Gas Transfer

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Direct *in situ* measurement of air-sea gas fluxes is possible only for a limited suite of gases (e.g., $CO_2$, $O_2$, DMS, He/$SF_6$). Furthermore, the measurement techniques required for directly measuring gas fluxes often restrict the range of environmental conditions and spatio-temporal scales over which the fluxes can be measured. In order to develop a method for determining gas transfer velocities that can be used over a wide range of environmental conditions and length/time scales, heat has been proposed as a suitable proxy tracer for gas exchange. These heat-based approaches promise to provide a method for rapid and non-invasive measurement of the air-water transfer velocity, $k_L$. However, our recent laboratory and field measurements conducted using heat as a proxy tracer suggest that there may not be a direct correspondence between $k_L$ values derived using infrared imagery and those measured using conventional tracer techniques. The efficacy of using heat as a proxy tracer for air-water gas transfer will be examined in the context of these infrared imaging methods from a theoretical and practical standpoint.

## OS32H-08 1545h

### Observational Studies of Parameters Influencing Air-Sea Gas Exchange During the GasEx II in the Equatorial Pacific

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A physically based modeling of the air sea gas transfer that can be used to predict the gas transfer rates with sufficient accuracy as a function of micrometeorological parameters is still lacking. State of the art are still simple gas transfer rate/wind speed relationships. Previous measurements from Coastal Ocean Experiment in the Atlantic revealed positive correlations between mean square slope, near surface turbulent dissipation, and wind stress. It also demonstrated a strong negative correlation between mean square slope and the fluorescence of surface-enriched colored dissolved organic matter.

During the Equatorial Pacific Air Sea CO2 Exchange Experiment the Research catamaran LADAS allowed for the first time high resolution spatial and temporal synchronized measurements of the local wave statistics, surface enrichment, and heat exchange rate. Using heat as a proxy tracer for gases the net heat flux at the water surface and the temperature difference across the interface was measured. Thus, the controlled flux technique visualizes the exchange processes at the air water interface and reveals the details of micro turbulence at the water surface. Laboratory studies were carried out in the new Heidelberg wind-wave facility AELOTRON. Direct measurements of the Schmidt number exponent were done in conjunction with classical mass balance methods to estimate the transfer velocity. The laboratory results allowed to validate the basic assumptions of the so called controlled flux technique by applying different tracer for the gas exchange in a large Schmidt number regime.

Thus a modeling of the Schmidt number exponent is able to fill the gap between laboratory and field measurements field. Both, the results from the laboratory and the field measurements should be able to give a further understanding of the mechanisms controlling the transport processes across the aqueous boundary layer and to relate the forcing functions to parameters measured by remote sensing.

## OS32H-09 1600h

### A Laboratory Comparison Between Bulk gas Transfer Velocities and Heat Transfer Velocities Derived From Infrared Techniques

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The availability of sensitive, high-resolution infrared imagers has led to the development of active and passive infrared (IR) techniques to infer heat and gas transfer velocities at an air-water interface. In order to evaluate these techniques, a series of interfacial heat and gas transfer experiments have been carried out in the wind-wave tank at the Harris Hydraulics Laboratory (University of Washington, Seattle) for wind speeds ranging between 4 m/s and 9 m/s. Here we compare the results of the IR techniques with simultaneous bulk gas transfer velocities made using two gas tracers (He and $SF_6$). In the active IR technique, a $CO_2$ laser is used to heat a small patch on the water surface. The surface patch is tracked and its rate of decay is computed using image processing techniques. The decay rate can be used to compute a time scale based on a surface renewal model. In our analysis, we evaluate different techniques for computing the decay time and examine the effect of patch size and laser power. The passive IR technique uses the spatio-temporal variations in the IR images to extract the skin-bulk temperature difference. A comparison with direct measurements of this quantity is made. The heat transfer velocities derived from the active IR technique are compared with the bulk gas transfer velocities measured simultaneously. Results from previous experiments, showing that this technique overestimates the heat transfer velocity, are confirmed.

## OS32H-10 1615h

### Spatial and Temporal Highly Resolved Heat Flux Measurements in the Equatorial Pacific

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The net sea surface heat flux is a crucial parameter for quantitative measurements of air-sea gas exchange rates, as well as for climate models and simulations. However, current experimental data are scarce and imprecise. State-of-the art techniques depend on indirect measurements of meteorological parameters. They rely on a combination of data from different sensors using a number of heuristic assumptions. The spatial separation of these sensors and the need for temporal averaging over long time scales further reduce the practicability of these techniques. In this contribution spatially resolved measurements of less than 9 $mm^2$ to times scales of fractions of a second are presented. They are obtained with a thermographic technique that directly measures the net heat flux across the air-water interface.

Our technique uses a single infrared camera in order to quantitatively estimate the parameters of a surface renewal model of heat transfer. The use of only one standard infrared camera provides a very simple experimental setup for in situ measurements of the heat flux in the field. The underlying algorithm assumes that fluid parcels at the sea surface are statistically replaced with bulk water by surface renewal events. The surface water is exposed to surface heat fluxes and the temperature thus changing due to thermal conduction. The rate of temperature change directly scales with the net heat flux density across the interface. A digital image processing technique allows extracting the material derivative of the temperature with respect to time from a sequence of infrared images. From this derivative the net sea-surface heat flux as well as parameters of the surface renewal model can be extracted. A statistical analysis of the thermal images allows extracting the temperature depression across the cool skin, which is used in the heat flux estimates. Measurements conducted on the GasExII experiment in the Equatorial Pacific are presented.

URL: http://klimt.iwr.uni-heidelberg.de

## OS32H-11 1630h

### The Effects of Langmuir Circulations and Turbulence on the Sea-surface Temperature and Heat Fluxes.

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The initial generation of surface waves and turbulence at the surface of the ocean has a long been a problem of great interest. With the globally averaged wind speed in the range 6-7 $ms^{-1}$ and 40% of the time below 6 $ms^{-1}$, much of the air-sea interface is in a low wind speed regime. We present the results of laboratory and field experiments and numerical models on the stability of a wind-driven water surface to the initial generation of surface waves and small scale Langmuir circulations. Using modern quantitative flow visualization techniques, we show that the developing surface shear layer exhibits a variety of phenomena including the generation of a two dimensional wave field, the generation of Langmuir circulations, the turbulent transition of the surface shear layer, and the transition to random surface wave field. At these low wind speeds, when gravity capillary waves are first generated, we find a transition in the surface heat flux and surface cool skin coincident with the generation of small scale Langmuir circulations and turbulence. Observations in the field also suggest that the cool skin is first disrupted by the turbulent transition rather than microscale breaking waves. The data show that a 70% increase in the heat and gas transfer velocity across the surface induced by the Langmuir circulations. Results will be discussed in the context of near surface turbulence and its influence on the air-sea fluxes of heat and gas.



## OS32H-12 1645h

### Toward Parameterization of Air-Sea Gas Transfer Velocity Using Mean Square Slope of Short Wind-Waves

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Air-sea gas transfer is commonly parameterized as a function of wind speed or wind friction velocity, since wind is easily measured from ships and satellites and drives formation of wind-waves that promote gas transfer. However, variations in the surface wave field at a given wind speed lead to considerable scatter in relationships relating gas transfer velocity to wind speed. The parameterization is somewhat improved using wind friction velocity, which accounts for variations in form drag due to short wind waves. However, results of laboratory studies involving simultaneous measurements of gas flux, wind stress, and small-scale wave slope spectra suggest that gas transfer velocity is most accurately predicted by the mean square slope of waves of wavenumber greater than 25 radians/meter, even in the presence of surfactant films, which are known to modulate the wave field. Given the limited degree to which natural sea states can be simulated in laboratory wind-wave tanks, extrapolation of these findings to oceanic conditions has awaited confirmation by similar measurements in situ. Here we report such field measurements, which confirm a strong statistical correlation between mean square slope and transfer velocity. During the 1997 CoOP Coastal Gas Exchange Experiment off New England, gas transfer velocities and surface wave spectra were measured on short time scales commensurate with changes in atmospheric forcing. Using passive thermography, the sea surface temperature distribution was measured and the temperature difference

across the heat boundary layer was estimated from a surface renewal model. Estimates of the net heat flux were determined from direct measurement of latent and sensible heat fluxes and longwave emission. Heat transfer velocities were computed and scaled to gas transfer velocities using appropriate Schmidt numbers for heat and gas. Frequency-wavenumber slope spectra of small-scale waves (25-800 rad/m) were measured with a scanning laser slope gauge. Surface films were measured using a surface microlayer skimmer and fluorometry package. The field data show a strong correlation between gas transfer velocity and mean square slope, including observations made in areas with significant surface films. Comparison of transfer velocities with wavenumber-binned slope data indicate that the correlation becomes increasingly linear and statistically significant for wavenumbers above 100 rad/m; a poor correlation is observed for wavenumbers below 50 rad/m. Notable exceptions were observations made during rain events, when mean square slope at higher wavenumbers increased significantly without a concomitant increase in transfer velocity as measured using thermal imaging. Wave slope was generally negatively correlated with surface film enrichment, as measured by microlayer-subsurface differences in CDOM fluorescence. At low winds, wave slope was reduced 1-2 orders of magnitude by the presence of surfactant films and gas transfer velocity was poorly correlated with wind speed. The potential applicability of a robust transfer velocity-mean square slope relationship to remote sensing of transfer velocity fields will be discussed.

## OS32I HC: 319 A Wednesday 1330h

### Synthesis of Pacific Ocean Carbon Cycle Research II

***Presiding:*** **R Feely,** NOAA/Pacific Marine Environmental Laboratory**; F Chai,** University of Maine

#### OS32I-01 1330h

### Distribution of Anthropogenic $CO_2$ in the Pacific Ocean

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This work presents an estimate of anthropogenic $CO_2$ in the Pacific Ocean based on measurements from the WOCE/JGOFS/OACES global $CO_2$ survey. These estimates used a modified version of the $\Delta C^*$ technique originally proposed by Gruber et al. [1996]. Modifications include a revised preformed alkalinity term based on Pacific surface data, a correction for denitrification based on N* estimates, and an evaluation of the disequilibrium terms using an optimum multiparameter (OMP) analysis. The total anthropogenic $CO_2$ inventory over an area from 120°E to 70°W and 70°S to 65°N (excluding the South China Sea, the Yellow Sea, the Japan/East Sea, and the Sea of Okhotsk) was 44.5±5 Pg C in 1994. Approximately 28 Pg C was located in the Southern Hemisphere and 16.5 Pg C was located north of the Equator. The deepest penetration of anthropogenic $CO_2$ is found at about 50°S associated with the Subtropical Convergence. The shallowest penetration is found just north of the equator. Very shallow anthropogenic $CO_2$ penetration is also generally observed in the high latitude Southern Ocean. One exception to this is found in the far southwestern Pacific where there is evidence of anthropogenic $CO_2$ in the northward moving bottom waters. In the North Pacific, deep ventilation within the Kuroshio Extension and the subsequent circulation in the subtropical gyre generates a strong zonal gradient in the anthropogenic $CO_2$ penetration depth with the deepest penetration in the western Pacific. Relative to the Atlantic and Indian Oceans, the Pacific has the largest total inventory in all of the southern latitudes despite the fact that it generally has the lowest average inventory when normalized to a unit area. The lack of deep and bottom water formation in the North Pacific means that the North Pacific inventories are smaller than the North Atlantic despite the larger area in the Pacific.

URL: http://cdiac.esd.ornl.gov/oceans/glodap/index.html

#### OS32I-02 1345h

### Ocean Transport and Storage of Carbon in the South Pacific

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The WOCE/JGOFS hydrographic survey in the South Pacific Ocean is used as the basis for estimating the advective transport and storage of both natural and anthropogenic carbon. The mass transport fields are determined from a box-inverse model which adjusts an a priori estimate of the flow field in order to satisfy imposed constraints for selected geographic regions. The a priori estimate of the geostrophic velocity is based on the observed density distribution and carefully selected initial reference levels. A priori estimates of the surface Ekman transports are determined from annual climatological wind fields. A solution is found which is consistent with both the expected error in the initial transport fields and the uncertainty of the imposed constraints.

The observed carbon distribution is partitioned into natural and anthropogenic components based on analysis incorporating oxygen, nutrient and transient tracer observations. Rates of local oceanic anthropogenic carbon accumulation are estimated from a simple model assuming exponential growth of the perturbation. The South Pacific Basin is found to be a moderate sink of anthropogenic carbon, storing approximately 0.4 PG C/yr. Both air/sea flux and advective convergence are important components of the overall balance. A significant portion of the convergence is due to southward Ekman transport of tropical waters rich in anthropogenic carbon.

#### OS32I-03 1400h

### The Distribution and Inventory of Bomb Produced Radiocarbon in the Pacific Ocean

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The World Ocean Circulation Experiment provided the first three-dimensional description of the Pacific Ocean radiocarbon distribution. Measurement of the U.S. samples has been completed. Estimates of the bomb produced component were made using a new algorithm based on the strong linear correlation between natural radiocarbon and potential alkalinity. Unlike previous methods, the new algorithm works at all latitudes and can be used to approximate pre-bomb surface values.

The meridional distribution of bomb radiocarbon is similar that found for both chlorofluorocarbon and anthropogenic $CO_2$, however, notable differences exist, particularly at high southern latitudes. The differences are indicative of the fact that radiocarbon has a much longer air-sea equilibration time than either $CO_2$ or CFC. Measurable levels are generally restricted to the upper kilometer of the water column with deepest penetration found near 40 North and South and the highest concentrations somewhat equator-ward of that latitude. Unlike GEOSECS, the highest concentrations were frequently found in the upper thermocline rather than at the ocean surface. For the first time, evidence was found of slight bomb contamination in newly formed bottom waters adjacent to Antarctica.

The bomb produced radiocarbon inventory is minimal at high latitudes and has a relative minimum near the Equator. Maximum inventory values occur around 30 North and South latitudes with the north showing somewhat higher values at individual stations. On depth or density surfaces the bomb distribution is consistent with generally accepted flow patterns and is strongly influenced by convection and/or convection of mode and intermediate waters.

#### OS32I-04 1415h

### Bomb Radiocarbon and Anthropogenic CO2 in Ocean Biogeochemical Models

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The testing of thermonuclear bombs in the late 1950's and in the following decade has produced vast amounts of radiocarbon (14C), which was released to the atmosphere. Subsequently, this "bomb 14C" has entered the natural reservoirs of carbon, including the ocean. Measurements of 14C in the ocean show clear evidence of elevated 14C content that can be attributed to bomb testing, and this tracer offers a unique opportunity to study how carbon is taken up by the ocean. However, the distributions of bomb 14C and anthropogenic CO2 are not related in any simple way, because their atmospheric time-histories and gas exchange equilibration times are very different.

Here we investigate how bomb 14C and anthropogenic CO2 in the ocean are related to each other with the use of a suite of 3-dimensional ocean circulation models (GCMs) participating in the Ocean Carbon Model Intercomparison Project (OCMIP), which mandates the use of a standardized marine biogeochemistry model. A topic of interest is how the simulated distributions of bomb 14C and anthropogenic CO2 are affected by the relative strengths of parameterized vertical and horizontal mixing. The contrast in the distributions of the two tracers can be accentuated by the different model circulations. Preliminary analysis indicates that mixing in the Southern Ocean in particular plays an important role in their distributions. Another topic of interest is whether the penetration depth of bomb 14C is a good indicator of anthropogenic CO2 invasion for this decade. This expectation is borne out from the rough equivalence between the time since the injection of bomb 14C into the ocean until the recent large scale field surveys (Joint Global Ocean Flux Study and World Ocean Circulation Experiment) and the characteristic time constant of the atmospheric CO2 growth rate. As a result, the penetration depth of bomb 14C may intersect the more or less constant penetration depth of anthropogenic CO2 in this decade. If the ratio of the two penetration depths is demonstrated to be relatively robust amongst the different OCMIP models, the penetration depth of anthropogenic CO2 and thus its inventory can be estimated from the penetration depth of bomb 14C determined from observation.

The investigation of both of these topics illustrates significant model differences. We expect these differences to provide useful insights into the strengths and weaknesses of the GCMs, which will aid our ongoing efforts to improve these models and their predictive capabilities with regard to anthropogenic CO2 uptake by the ocean.

#### OS32I-05 1430h

### Inferring the Concentration of Anthropogenic Carbon in the Ocean from Tracers

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