OS42B HC: Hall III Thursday 1330h

Air-Sea Exchange II

Presiding: **W K Melville,** Scripps Institution of Oceanography**; W Asher,** Applied Physics Laboratory

OS42B-100 1330h POSTER

Estimating air-sea Fluxes of Momentum and Heat Using the Dissipation Method

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Estimating the exchange of momentum and heat using the dissipation method continues to be an active research topic in ocean-atmosphere interactions since this method is less sensitive to instrument platform motion and sensor alignment. In this study, the traditional dissipation method and the new approaches suggested by Albertson et al. (1996) and Hsieh et al. (1996) to estimate momentum and heat fluxes were compared using velocity and temperature measurements in the atmospheric surface layer. These measurements were carried out over a wide range of atmospheric stability and turbulent intensity conditions. Taylor's hypothesis, flux divergence terms, and stability correction functions which play important roles in the dissipation methods were also evaluated. Our measurements showed that discarding the flux divergence term resulted in systematic under-predictions of the sensible heat flux by the dissipation methods. The proposed dissipation method by Hsieh et al. (1996) for estimating sensible heat flux was also extended to momentum flux and its implications for stability correction functions were discussed.

OS42B-101 1330h POSTER

Estimating Overwater Momentum Flux Directly From Routine NDBC Buoy Measurements

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Recent advances in air-sea interaction studies have made it possible for the overwater momentum flux to be estimated directly from routine buoy measurements provided by the National Data Buoy Center (NDBC). First, the relative effect of wave age versus wave height on the wind stress is demonstrated. It is found that there is virtually no difference between the two methods. However, since the wave steepness approach requires only the input of significant wave height and dominant wave period, it is adopted for this study. Second, a relationship between the gust factor and the turbulence intensity is determined. Third, by substituting the values of stability parameter and wave steepness computed above, the drag coefficient is obtained. Fourth, applying these stability parameter and drag coefficient values, the exponent of the power-law wind profile is determined so that the wind speed at 5 m height (for most NDBC buoys) can be extrapolated to the standard 10 m. Finally, the momentum flux is estimated.

OS42B-102 1330h POSTER

Measurements of sea surface emissivity and air-sea heat flux during Gasex 2001

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One of the factors on which accurate remote sensing of sea surface temperature (SST) measurement depends is knowledge of the optical properties of seawater. Retrieved temperatures are very sensitive to sea surface emissivity (SSE), which is required to convert measured infrared radiances to temperatures. A change of 1% in SSE results in a change in SST retrieval of 0.24K at 3.6μm and 0.73K at 12μm, so in order to achieve the accuracy required for climate studies (0.3K), SSE must be known to better than 0.5% in the 8-12μm window and 1% in the 3-4.5μm region. SSE can be calculated from the complex refractive index of water. This is, however, not well known and that of seawater is even less so. Now, infrared interferometry allows measurement of the spectral emissivity of the sea surface in the field.

When wind blows over a water surface, a capillary wave field is produced almost instantaneously. The surface wave field changes with wind speed, fetch and wave age, however and an instantaneous surface of a patch of ocean is the result of the instantaneous wind, the long waves produced by the wind field at a distance and the underlying swell. Added to the wind, wind history and wind-wave interaction is the motion of the platform from which the meaurements are taken. Theoretical models of SSE have been produced which model the geometry of a wind-roughened sea in terms of facets and slope distributions and parameterise it as a function of wind speed. Comparison of these models with field data from Gasex 2001 are presented.

An evaluation of a new technique for remote sensing air-sea heat flux in the field using eddy correlation fluxes measured during Gasex 2001 will also be presented.

OS42B-103 1330h POSTER

Measurements of Sea-to-Air Fluxes of DMS with the Gradient Flux Technique

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In the past year, we have measured sea-to-air fluxes of dimethylsulfide (DMS) on the FAIRS and GasEX-2001 cruises, and from the stationary MPN platform in the North Sea. We measure DMS gradients above the ocean, and calculate fluxes using the Gradient Flux approach. With simultaneous measurements of aqueous DMS concentrations measured in surface water we determine kgas, the gas transfer velocity. I will discuss the details of our measurements, present flux and gas transfer results from the MPN and FAIRS experiments, and compare them with simultaneous measurements of DMS air-sea exchange using the Relaxed Eddy Accumulation and Eddy Correlation techniques.

OS42B-104 1330h POSTER

The Use of Direct Observations Over the Aerosol Particle Size Distribution From the Shoreline Environmental Aerosol Study (SEAS) When Inverting Lidar Data (Initial Results).

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The principal difficulty of inverting lidar data into the aerosol particle size distribution (APSD) lies in a limited amount of optical information yielded by lidar observations. We mean the impossibility for a lidar to provide data over a reasonably wide continuous spectral range. We have developed the inversion method of mean ordinates that targets just this problem. The method proved its efficiency in our numerical experiments. The efficiency of the method depends on the measurement accuracy and on the number of lidars employed. When one or two lidars are used, as it takes place in SEAS, the method allows retrieving only the general slope of the APSD curve. Any particulars cannot be distinguished.

In order to better the inversion efficiency, we invoked an additional constraint in a form of APSD observations on a limited particle size interval. Our numerical experiments show that the inversion accuracy improves significantly when using direct APSD data.

We applied the inversion method of mean ordinates to inverting SEAS lidar data. Here we describe initial inversion results with an APSD constraint and without it. We also give a provisional comparative analysis of the inversion results and observations.

OS42B-105 1330h POSTER

Preliminary Lidar Studies of the Trade Wind Mixed Layer Near Hawaii: Island Blocking and Air Mass Effects

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Scanning lidar measurements have been made on the SE side of Oahu (Bellows Beach) for over 3 years. The data clearly show that sea salt is well mixed throughout the mixed layer and decreases in the cloud layer becoming negligible above the trade wind inversion (free troposphere). Based on lidar inferred aerosol mass concentrations, we have found the depth and strength of the mixed layer changes even though the winds appear to be typical trades (winds from the NE). At times the observed mixed layer extends throughout the boundary layer while at other times it extends only up to 400-600 m height which is approximately cloud base. On other occasions the mixed layer increases in height, as one gets closer to the Oahu windward coastline. On one occasion we were able to release a radiosonde at Bellows Beach, which clearly showed the lidar observed mixed layer, was in good agreement with the mixed layer one would predict from potential temperatures.

We are currently beginning a study of the meteorological conditions, which affect the trade wind near Hawaii. Lihue radiosondes, large-scale model data and lidar data sets are being collected for a 2-year sample period. We will carry out 3-day back trajectories for the air arriving at Hawaii and will calculate the change in sea surface temperature along the path to quantify the surface-heating rate. The upper level divergence will also be calculated for the different cases. Preliminary examples of the different trade wind conditions and their effects on the mixed layer soundings and lidar derived aerosol properties will be given. The effects of island blocking will also be illustrated for the different trade wind conditions.

URL: http://www.soest.hawaii.edu/lidar

OS42B-106 1330h POSTER

Interfacial Control of the Air-Water Exchange of Helium and Sulfur Hexafluoride at High Turbulence Levels

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It is often assumed that the transfer of a sparingly soluble gas across a air-water interface is rate-limited by transport from the interface into the bulk aqueous phase. This transfer rate is commonly parameterized in terms of the liquid-phase transfer velocity, k_L, and increasing levels of near-surface turbulence have been shown to increase k_L. It has also been shown that when the system is rate-limited in the aqueous phase and the interface is free from surface active material, k_L is a function of the square root of the molecular diffusivity, D, of the gas in the water. This $D^{1/2}$ scaling is important in oceanographic applications, where direct measurement of k_L is not possible for most gases. Therefore, k_L must be determined using a more easily measured species and the value for the reference species is scaled to the gas of interest assuming a $D^{1/2}$ dependence.

At extremely high turbulence levels, the $D^{1/2}$ scaling could be invalid because the transfer process can become rate limited by transfer of gas molecules across the air/water interface. In this case, the system is said to be under interfacial control and the value of k_L as measured from the change in concentration of a tracer gas will be independent of the system turbulence and no longer scale as $D^{1/2}$. Based on anomalous results observed during gas transfer measurements made as part of the LUMINY project, it has been suggested recently that at high wind speeds, the air-water transfer of helium and sulfur hexafluoride exhibit interfacial control. If true, this finding would greatly complicate current parameterizations for air-sea exchange, which all assume that k_L scales as $D^{1/2}$ regardless of wind speed.

In order to test the hypothesis that air-water transfer velocities of helium and sulfur hexafluoride are governed by interfacial rate controlled at high wind speeds, we have measured k_L for both helium and sulfur hexafluoride in a small stirred tank at varying levels of aqueous-phase turbulence. Even at the highest turbulence levels, we find no evidence that the transfer kinetics deviate from that expected assuming liquid-phase rate control. Relating the measured k_L value to those predicted from commonly used oceanic parameterizations of k_L show that our highest turbulence levels are equivalent to a wind speed of approximately 35 m s^{-1}. Therefore, we conclude that there is little concern that interfacial rate control is an important factor in parameterizing air-sea gas exchange.

OS42B-107 1330h POSTER

Influence of rain on air-water gas exchange in the Biosphere 2 ocean

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Rain has been shown to significantly enhance the rate of air-water gas exchange in fresh water, and the mechanism behind this enhancement has been studied in laboratory experiments. In saltwater environments such as the ocean, however, the effects of rain are further complicated by the potential of causing a density stratification of the surface water. Since it is difficult to conduct experiments in the ocean examining rain-induced gas exchange, we conducted SF_6 evasion experiments at Columbia Universitys Biosphere 2. The facility is ideally suited for such an experiment because the physics that govern rain-induced air-water gas exchange in the Biosphere 2 ocean should translate directly to the real ocean. The Biosphere 2 ocean contains 2,650 m^3 of saltwater (salinity = 35.5) and has a surface area of 711 m^2. There is a vacuum wave generator capable of creating sufficiently energetic waves to circulate water in the ocean and enough turbulence to enhance air-water gas exchange. Sprinklers installed 13 meters above the ocean allow generation of realistic (terminal velocity) rain, although the rain generator currently installed at Biosphere 2 generates raindrops that are biased towards lower dropsizes relative to rain in nature (i.e., rain drop size distribution dominated by drops smaller than Marshall-Palmer distribution). Rain rate during the experiments was 35 mm h^{-1}, and average kinetic energy flux was 0.9 J m^{-2} s^{-1}, as calculated from raindrop size distribution. Results of measurements show a rapid depletion of SF_6 from the surface layer (< 50 cm) due to rain enhancement of air-water gas exchange. However, because vertical mixing is retarded by stratification, only gas exchange of SF_6 in the top layer is enhanced and the overall exchange rate after several hours is similar to conditions without rain. These findings suggest that short intense rain events may accelerate gas exchange in oceanic environments. Further experiments are planned at Biosphere 2 using a more realistic rain generator as well as additional instruments to measure the physical properties of the water

OS42B-108 1330h POSTER

Modeling the Evolution of a Fresh Surface Anomaly Produced by Tropical Rainfall

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The evolution of a rain-produced fresh surface anomaly observed in the western equatorial Pacific warm pool was modeled by use of the Blumberg-Mellor primitive equation model with level 2.5 Mellor-Yamada (MY) turbulent closure. The model domain consisted of a periodic channel, 120x120 km in the horizontal and 300 m in the vertical with 100 sigma levels in the vertical. The initial density was horizontally homogeneous and the vertical stratification was similar to the observations. The model was spun-up for 1.5 days with an along-channel wind stress of 0.12 N m^{-2}, and an upward heat flux of 225 W m^{-2}. Following spin-up, rainfall was applied as a surface boundary condition over a small portion of the domain. The size, duration, and average and maximum amount of the rainfall were, respectively, 20x20 km, one hour, 23 mm, and 57 mm. The model captures basic features of the observations. Immediately after the rainfall, the fresh lens trapped buoyancy and momentum in shallow layer, while inhibiting turbulent mixing below the layer. Six hours after formation, the density anomaly was mixed down to 40 m depth, and there was a positive anomaly in velocity of 0.2 m s^{-1} in the direction of the wind. Simulations showed upwelling at the upwind edge of the lens and downwelling at the downwind edge. The maximum vertical velocity at the base of the mixed layer was about 20 m d^{-1}. K-Profile Parameterization (KPP) and the Kantha-Clayson version of MY were used to examine the sensitivity of the lens evolution to different turbulent closure schemes. The KPP mixing deepens the density anomaly at approximately twice the rate of the MY level 2.5 schemes.

OS42B-109 1330h POSTER

Shipboard Underway Measurements of Near Surface Temperature with Through-the-Hull Sensors

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Near-surface diurnal warming due to intense solar heating and low wind speed can elevate the temperature within a few meters of the surface by several degrees above that of the mixed layer below. Previous investigators have used temporary installations on the bow of a moving ship to measure the near-surface temperature profile by utilizing the vertical motion of the ship. In order to evaluate the feasibility of using permanent, through-the-hull sensors, we recently installed a combined temperature and pressure sensor in the unused 2-m intake port on the NOAA ship R/V Ronald H. Brown. Here we compare this 2-m contact temperature with a wide variety of other temperature measurements made during the EPIC cruise in late 2001. Continuous measurements made from the Brown include radiometric skin temperature, temperature measured with a towed surface-floating sensor, hull temperature measured at 2-m, and temperature of water from the 5-m intake port. The temperatures are also compared to sensors on buoys periodically deployed near the ship. Notable features in the data include the signature of diurnal warming and the effect of rain. Based on the success of this initial installation, we propose to install a series of through-the-hull access ports in the bow with which to make continuous underway measurements of temperature and salinity.

OS42B-110 1330h POSTER

Physical Processes at the Air-Sea Interface During an Impulsively Initiated Wind Event

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Physical processes in near-surface waters play an important role in determining gas exchange rates. Waves and near-surface turbulence act to renew the thin surface diffusive sublayer from the bulk ocean, while breaking waves can disrupt the sublayer and inject bubbles into the upper water column. Here we present results from a field experiment in a harbour that aimed to relate the surface and subsurface processes. Waves and wave-breaking were measured with a microwave radar and wave gauges. Near-surface turbulence was measured with both acoustic instruments and a temperature microstructure profiler. Differences between the acoustic timeseries and microstructure profile estimates of dissipation rate were observed in certain situations. The rate of turbulent energy dissipation near the surface was observed to exceeded the Law of the Wall model, but was also found to be strongly affected by near-surface stratification.

OS42B-111 1330h POSTER

Field Observations of Microbreaking and its Modulation by Swell Waves

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The modulation transfer function between infrared (IR) radiometer measurements of ocean surface skin temperature, T_{skin}, and surface displacement have shown that T_{skin} is modulated by swell waves. A likely mechanism for this phenomenon is modulation of microscale wave breaking by swell waves. When a cool skin layer is present, preferential microbreaking along the phase of a swell wave will cause a momentary increase in T_{skin} as warmer water from below is mixed up to the surface. In order to demonstrate the relationship between skin temperature modulation and microbreaking modulation, we made simultaneous, co-located measurements with an IR radiometer, and IR imager, and a wave gauge. The measurements were made during the FAIRS (Fluxes, Air-sea Interaction, and Remote Sensing) experiment which took place on the research platform FLIP off Monterey, CA in the fall of 2000. When a cool skin layer was present, modulation of T_{skin} measured by the radiometer was compared to the passive IR signature of microbreaking in the imagery. Under conditions when the passive signature was not measurable, an active IR imaging technique was used in which a small patch of the ocean surface was heated briefly by a CO_2 laser pulsed at 1 Hz. Time series of the rate at which the heated patch decayed back to ambient temperature were derived from the imagery. If preferential microbreaking occurs along the phase of a swell wave, then we expect a faster decay of the patch. Results of the modulation transfer function between the patch decay rate and surface displacement are presented.

OS42B-112 1330h POSTER

Dissipating Short Gravity Surface Waves by Parasitic Capillaries

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Viscous dissipation is negligible for ocean surface waves longer than a fewer centimeters. However, parasitic capillaries are always appeared on the forward phase of short gravity waves, and they are quite steady. These capillaries are steep and are strongly dissipated by viscosity. This dissipation is compensated by the energy extracted from the underlying short gravity waves. The short gravity wave dissipation due to parasitic capillaries is measured in a laboratory tank.

The newly constructed tank is about 1 m wide, 4.5 m long, and .5 m deep made with all plaxglass walls. Waves from 5 cm to 20 cm are generated mechanically at one end of the tank and dissipated on a beach at the other end. Waves are measured at distances away from the wave paddle to calculate dissipation rate. The measured dissipation rate is about 50 times larger than the viscous dissipation depending on the slope and wavelength of short gravity waves. The tank is carefully cleaned and kept in a clean lab to avoid surface contamination which can influence surface tension.

An adequate assessment of parasitic dissipation bears importance in a number of applications that affect small-scale air-sea interchanges. In measuring short wave growth rate, the proper rate of dissipation rate has to be deducted from measured wave growth when the slope of the short gravity waves is over 0.1. In modeling the ocean short wave spectrum, the dissipation due to parasitic capillaries are also need to well be determined.

OS42B-113 1330h POSTER

Evaporation and Turbulent Transport at the Sea Surface

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When water evaporates at the sea surface, a thin layer of surface water is cooled and made more salty. As a consequence the surface becomes gravitationally unstable and overturns on a small scale. Observations of the surface expression of this process have been carried out by use of an infra-red imaging camera capable of detecting temperature fluctuations of a few hundredths of a degree. The camera was mounted on a boom extending forwards on a launch, 1.5 meters above the water surface. Data from this device can resolve spatial scales down to a few millimeters at a video rate of 30 frames per second. Unwanted reflections of skylight have been reduced by shading the field of view by an overhead aluminum shield that reflects skylight from its upper surface but absorbs radiation from below.

Typical turbulent cells appear with horizontal spatial scales of several centimeters. The patterns of thermal structure change rapidly with time. Sometimes there are miniature "Langmuir" like cells with a pronounced directional character and at other times a more or less isotropic pattern is expressed.

Since diffusion of the excess salinity at the sea surface is much slower than temperature, the unstable density structure in the top few millimeters of water is expected to exhibit two scales: a sharp density gradient just below the surface from salt concentration and a more gentle gradient from the temperature decrease. The contributions to density increase at the very surface are predicted to be greater for salt than for temperature, but the density anomally integrated over depth is mainly controlled by temperature.

Calculations of the initial motions caused by this density instability under the influence of viscosity show that the horizontal scale of overturns is controlled by the thickness of the unstable density gradient in the absence of velocity shear. In the ocean, where wind stress encourages water current shears, this result may be greatly altered.

OS42B-114 1330h POSTER

Small Scale Waves and Ocean Surface Roughness

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Small scale ocean surface waves are the roughness element of the air-water interface. The directional distribution of ocean surface roughness is an important parameter in air-sea interaction and ocean remote sensing studies. The preferred representation of the ocean surface roughness properties is the directional wavenumber spectrum. Such data have become available recently thanks to advances in computer and optical measurement technologies. We present some recent measurements of directional wave properties using spatial measurement techniques. The data are acquired by a new scanning slope sensing and wave gauge array buoy developed at the Naval Research Laboratory. The system is designed to measure the directional characteristics of short surface waves in 0.004 to 1 m wavelength range. The free-drifting buoy also serves as a floating instrument platform and carries a suite of environmental sensors (above surface: 2 sonic anemometers, 1 thermometer, 1 humidity sensor; subsurface: 1 acoustic current meter, 1 thermometer, 3 pressure sensors, 1 3D accelerometer, 1 2D tilt sensor) and two video recorders (one above water and one subsurface). The major instrument is the scanning slope sensor. The lateral resolution of the system is 2 mm by 2 mm covering an area 10 cm by 10 cm. The square area is sampled at 50 frames per second. Detailed spatial and temporal evolution of small scale surface waves can be derived from such dataset.

OS42B-115 1330h POSTER

Group Structure And Spatial Variations For Small Scale Ocean Waves

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It is very important to understand the structure of small scale ocean surface waves because they contribute primarily to the ocean surface roughness, which plays a critical role in the air-sea interaction processes. The recently designed NRL/SSC scanning slope sensor and wave gauge array buoy system is capable of measuring small scale ocean surface waves both temporarily (40 min) and spatially (40 wave gauges) to resolve wave lengths from as small as 4.0 mm to 1.0 m. In the October of 2001, ninety-nine data sets were collected with this system in the Gulf of Mexico. From visual inspection of the wave records, the group structure of small waves can be clearly seen. Therefore, the wave group factor and the mean length of run can be examined with the wave envelope and group induced long wave theory for each of the surface elevation records. Spatial variations of group characteristics will be studied with the wave gauge arrays. The instrument system was also equipped with several environmental sensors that simultaneously recorded wind speeds (at two different levels), air-water temperatures, humidity, surface current, white-capping and long period swells. The effects of wind forcing, stability, wave breaking, swell and current on the spatial variation of the group structure will also be presented.

OS42B-116 1330h POSTER

On the Disperisve Relationship of Small Scale Wind Waves

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The dispersive relationship of small scale wind waves is an important properity of ocean wave dynamics. To study the dispesive relation of small scale wind waves, it is desirable to have simutaneou measurment in both spatial and temporal domains. We present some recent measurements of wave dispersion properties under various marine envriomental constions in the Gulf of Mexico with wind speeds ranging from 2 to 12 m/s. These measurements were carried out by a wave gauge array (40 gages) mounted on a free-drifting buoy developed at the Naval Research Laboratory. The buoy system is designed to measure the short surface waves in 0.004 to 1 m wavelength range. The buoy also serves as a floating instrument platform and carries a suite of sensors to acquire simultaneous measurements of marine environmental parameters. The presence of swells shows a significant affect on the dispesion relation of short wind waves. Discussions of environmental factors affecting the dirspersion relation are also presented.

OS42B-117 1330h POSTER

Dissipation of Turbulent Kinetic Energy in the Near-surface Layer of the Ocean and Air-Sea Gas Exchange

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The gas transfer velocity can be related to the dissipation rate of turbulent kinetic energy in the near-surface layer of the ocean (Kitaigorodskii and Donelan, 1984). Turbulence in the upper layer of the ocean is generated by convection, shear, and surface waves. The upper ocean turbulence may be affected by stratification (diurnal cycle, rainfalls, etc.) and by organized motions (Langmuir cells, billows, ramp-like structures etc.) This work is aimed at the analysis of the near-surface turbulence measurements done during TOGA COARE (Soloviev and Lukas, 2001) and GasEx-98 (Soloviev et al., 2001). The measurements are done with the bow-mounted sensors (when the ship is en route) and with a free-rising profiler (during stations). Under strong winds (observations are done up to 20-m/s wind speeds), the enhancement of dissipation rate due to surface wave breaking is up to a factor of 20 compared to the wall layer prediction. The dissipation data appears to be consistent with the Craig and Banner (1994) model, when the surface roughness from the waterside is parameterized as a linear function of significant wave height. Under low wind speed conditions, stratification effects are found to be of importance when the gradient Richardson number approaches (or exceeds) its critical value (0.25). The statistics of the individual experimental points with respect to the model prediction is consistent with the intermittency of turbulence typical for the upper ocean mixed layer. Application of the upper ocean turbulence results to parameterizing the air-sea gas exchange is discussed.

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OS42B-118 1330h POSTER

Vorticity and Turbulence Measurements in Langmuir Circulations

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We conducted an oceanic observational experiment to study the dynamics of Langmuir circulation and its effect on the vertical mixing in the upper oceanic boundary layer. The primary instrument is the Electro-Magnetic Vorticity Meter (EMVM). The EMVM measures three components of turbulence velocity and the downwind and vertical components of vorticity. A comprehensive set of ancillary instruments was mounted on the EMVM to measure the dissipation rate of turbulence kinetic energy (ε), temperature, salinity, and optical scattering. Directional surface waves, wind speed and direction, video images of sea surface (for identifying surface convergence zones), and surface skin temperatures were measured simultaneously. Observations were taken underway on a course parallel with the wave crests. Measurements of EMVM were obtained at several fixed depths with occasional vertical profiling of vertical stratification.

In August and September of 2001, measurements were taken in two fetch-limited sites in Puget Sound, WA, under various wind stress conditions with the wind speed varying between nearly zero to 18 knots. The mean significant surface wave height was 0.1 m, and the mean wave period was 3-4 s. The typical surface Stokes drift U_S was 0.05 m s^{-1} and the mean surface friction velocity u_* was 0.006 m s^{-1}. The turbulent Langmuir number La $(=u_*^{1/2}U_s^{-1/2})$ was 0.35 suggesting that the Stokes drift was dynamically important during our experiment. Popcorn was deployed off the downwind side of the RV. Downwind streaks were established within minutes. These convergence streaks were observed even when the wind speed was as low as 8 knots and were aligned parallel to the wind with the typical spacing between 2 and 6 m. The surface mixed layer was about 2–6-m deep and was rapidly modified by the tidal advection of horizontally inhomogeneous water.

Preliminary analysis shows that the vertical and downwind components of vorticity have similar magnitudes at depths below 2 m. At 2-m depth, the typical vorticity magnitude is about 0.6 s^{-1}. The variance of vorticity (enstrophy) increases toward the sea surface. The vertical profile of enstrophy scales well with inverse depth. Similarly, ε increases toward the sea surface with a typical value about 10^{-6} m^2 s^{-3} at

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2-m depth and is greater than the surface wind scaling ($u_*^3/\kappa z$) by at least a factor of 3.

OS42B-119 1330h POSTER

LES of the Ocean Mixed Layer: the Effects of Wave Breaking and Langmuir Circulation

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Large eddy simulation (LES) of the ocean mixed layer is carried out in which the effects of wave breaking and Langmuir circulation are included. Wave breaking is represented by random forcing that is consistent with the observational data of the upper ocean microstructure, and Langmuir circulation is realized by the Craig-Leibovich vortex force. High-resolution numerical simulations (240 x 240 x 64) are carried out with or without each contribution, utilizing a parallel computing code. It is found that Langmuir circulations, which are represented by the coherent linear structure of the vertical velocity field extending downward to the depth of the mixed layer, dominate the vertical mixing process. However, if the turbulence production by wave breaking becomes stronger while the wind stress becomes weaker, Langmuir circulation weakens and breaks down ultimately, resulting in the drastic change in the mixing process. Interaction between wave breaking and Langmuir circulation is investigated further. Profiles of the mean velocity and turbulent dissipation rate are analyzed and compared with the recent observations of the upper ocean. The implication of the present LES results is discussed in view of the one-dimensional ocean mixed layer model.

OS42B-120 1330h POSTER

Revised Estimate of the Mass of DOC Annually Scavenged From the Surface Waters of the World Ocean by the Bubbles Formed in Breaking Waves

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Monahan and Dam [2001] recently estimated that the bubbles rising to the sea surface beneath Stage-A whitecaps collected some 1.9 Gt C/yr. As a starting point in their calculation they adopted a corrected version of the bubble spectrum of Deane [1997] as the spectrum of bubbles in the Alpha-plume beneath each Stage-A whitecap. Deane and Stokes [1999] recently published the results of further measurements of Alpha-plume bubble spectra, which show, when compared to Deane's earlier results, a significant enhancement in the concentration of bubbles in the 700 - 1500 micrometer bubble radius range. Introducing the new Deane and Stokes Alpha-plume bubble spectrum in the equations of Monahan and Dam [2001], yields in the first instance the finding that the surface area of all the bubbles that burst per second per unit area of Stage-A whitecap is 28.3/sec. [This represents an increase by a factor of 2.3 over the earlier estimate of Monahan and Dam.] More pertinently, this means that the cross-sectional area of all the bubbles that burst per second per unit area of Stage-A whitecap is 7.07/sec. Multiplying this number by the fraction of the sea surface covered by Stage-A whitecaps when the wind is 7 m/sec, 0.00016 [Monahan, 1989], and by the aggregate area of the world oceans, 3.61×10^14 m^2 [Sverdrup et al, 1942], results in an estimate of 4.08×10^11 m^2/sec as the total cross-sectional area of all the bubbles that burst each second on the surface of all the oceans. Now introducing, as per Monahan and Dam [2001], the scale depth of an Alpha-plume when the winds are 7 m/sec inferred from Thorpe [1982], 1.4m, yields, as the total volume of surface waters swept out by all the bubbles that burst each second, 5.72×10^11 m^3/sec. In order to obtain an estimate of the total dissolved organic carbon scavenged per second, it is now necessary to multiply this result by the a factor, E, representing the efficiency with which bubbles scavenge organic matter from seawater, and by C, an estimate of the characteristic concentration of dissolved organic carbon in the oceanic mixed layer. Adopting again, for the reasons discussed in Monahan and Dam [2001], a value of 3.5×10^{-4} for E, and a C of 7×10^{-4}kg m^{-3}, yields the conclusion that 1.40×10^5 kg C are scavenged per second by the bubbles rising beneath all the Stage-A whitecaps existing momentarily on the surface of all the earth's oceans. This number is equivalent to 4.4 Gt C/year. Neither of the Alpha-plume bubble measurements of Deane and colleagues indicated the presence of bubbles larger than 3mm radius, and this was used as the upper limit for the integrations of the present authors. Recently Bowyer [2001] published results for bubbles just below the sea surface near breaking waves off the coast of Ireland that indicated the presence of bubbles with radii as great as 6mm. Using Bowyer's results to extend the modified Deane Alpha-plume bubble spectrum to bubble radii of 6mm, and repeating the computations reported above, only resulted in a further increase in the estimate of carbon scavenged of 1%. As per the discussion in Monahan and Dam [2001], it is to be expected that some fraction of the dissolved organic carbon scavenged by bubbles will not, upon the bursting or dissolution of the carrier-bubbles, remain as organically rich clumps, but much of it will remain in such aggregations. Thus, any consideration of the global carbon budget of the oceanic surface layer needs to consider the implications for carbon export implicit in this mechanism.

OS42B-121 1330h POSTER

Spatial and Temporal Characteristics of Satellite-Measured Whitecap Coverage and Sea-Salt Aerosols

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Oceanic whitecaps are the major source of sea-salt aerosols. Sea-salt aerosols are the dominant natural aerosols in remote marine air. They control the radiative properties of the clean background atmosphere by scattering incoming sunlight, changing cloud properties and lifetime, and providing media for chemical reactions. The inclusion of sea-salt radiative forcing in climate models improves predictions. The generation of sea-salt aerosols is the first, and one of many processes that must be simulated.

The generation function for sea-salt aerosols currently used in climate models is based on the relation between whitecap coverage and wind speed. Effects of other variables, beside wind, yield a more realistic evaluation of sea-salt aerosol loadings. A new method has been developed for estimating whitecap coverage on a global scale using the satellite-measured brightness temperature of the ocean surface. Whitecap coverage evaluated with this method incorporates the effects of sea-surface temperature, salinity, wind fetch, wind duration, and amount of surface-active material.

An extensive database of whitecap coverage has been compiled with the new method and used to derive spatial and temporal characteristics of oceanic whitecaps and sea-salt fluxes. We will present global daily and monthly maps of whitecap coverage. The spatial distribution of oceanic whitecaps will be discussed and compared with that calculated from wind speeds. The effect of sea-surface temperature will be demonstrated. Seasonal variations in whitecapping will be tracked. Implications of the new estimates of whitecap coverage will be illustrated by evaluating global sea-salt aerosol flux, CO_2 exchange, and ocean albedo in the presence of whitecaps.

OS42B-122 1330h POSTER

The Influence of Bubbles from Breaking Waves on Marine Light Fields

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Bubbles entrained by waves breaking at the ocean surface can significantly change the optical scattering properties of the water depending on their concentrations and size distributions. While the effects of the bubbles on the bulk optical scatter and backscatter (b and bb) can be determined using size dependent scattering efficiencies based on Mie scattering calculations, significant uncertainty remains in our understanding of the bubble densities entrained and the oceanographic processes which govern their lifetimes in the upper ocean. Due to the unsteadiness of the surface wave breaking field at a given sea state, the entrained bubbles are highly variable both temporally and spatially, resulting in significant variability of optical scatter in the surface wave layer. Depending on background optical constituents of the ocean, the amount of scatter from the bubbles is significant compared to those typically attributed to chlorophyll and its derivatives. As a result, bubbles may lead to potentially significant errors in retrieval of remotely-sensed hyperspectral data in regions of high sea states. Results from a number of recent laboratory and field experiments conducted under the ONR HYCODE will be presented. The results and their implications to the next generation of optical remote sensing satellites will be discussed including the potential for using ocean color measurements for remotely sensing air-sea interaction processes.

OS42B-123 1330h POSTER

Dissipation Measurements in a Bubble Plume

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Bubble plumes are planned to provide mixing and aeration in a large reservoir to hold combined sewage from flood events in the Chicago area. Because gas transfer depends on the dissipation of turbulent kinetic energy, we estimated dissipation due to a bubble plume from thermal microstructure measured with a Self Contained Autonomous MicroProfiler. The bubble plume was created by pumping air through a diffuser at the bottom of a 7-meter deep tank. Effects of airflow rate on the magnitude of the dissipation and the shape of the profile will be presented. The results will be discussed in terms of the scaling of Bombardelli et al. (2001), who derived an intrinsic length scale of the bubble plume that accounts for the effect of airflow rate and water depth. Implications of the experimental results for gas transfer in the prototype reservoir will also be discussed.

URL: http://www.staff.uiuc.edu/~rehmann

OS42B-124 1330h POSTER

Estimation of Horizontal Geostrophic Heat Advection and its Error over the Kuroshio Extension from Satellite Altimetry

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Horizontal geostrophic heat advection within an oceanic mixed layer is estimated and its errors are rigorously assessed over the Kuroshio Extension region, to assist the heat balance study and the surface heat flux estimate regularly in time and extensively in space. For collocation and simultaneity with in situ reference data, orthogonal velocities are computed by automatically estimating the cross-angle between ocean current and altimeter track rather than employing the commonly-used objective mapping method. The orthogonal components of the heat advection have similar magnitude, as a result of strong zonal velocity and large meridional temperature gradient. The errors in the mixed layer depth are estimated to 24% and 46% of the signal for the systematic and random errors respectively. Those for the geostrophic velocities are respectively 29% of the signal and an absolute value of 12 cm s-1. Correlated errors in the altimeter records are formulated and calculated. According to our conservative estimate, the errors in the basinwide mean monthly surface heat flux values are 46 W m-2 and 61 W m-2, or 150% and 300% of the signal for the zonal and meridional heat advection respectively. If the geostrophic velocity error is assumed to 10% of the signal as in other studies, the total error in the geostrophic heat advection reduces to 9.2 W m-2 which is within the target error for climate studies. The error formulation can apply flexibly to various temporal and spatial scales.

OS42B-125 1330h POSTER

Response of Deep-Water Convection and Formation to High-Resolution Atmospheric Forcing in the Northwestern Mediterranean Sea

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The northwestern Mediterranean Sea (Gulf of Lion) is one of the regions in the world where deep-water convection and formation are likely to occur during the winter season. The convection is strongly related to intense winter storms, which bring cold and dry air (the Mistral) over preexisting weakly stratified water in the northwestern Mediterranean Sea. In this study, the atmospheric component of the US Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) is used to construct high-resolution reanalyses of surface fluxes over the Mediterranean Sea using all available observations. The period of the reanalyses is from October 1998 to September 2000. The reanalyzed fields include 10-m surface wind, wind stress, sensible and latent heat fluxes, sea surface temperature, solar and long-wave radiation, and accumulated precipitation. The temporal resolution of the fields is 1 hr and the horizontal resolution is 27 km. The high-resolution reanalyses are used to force the oceanic component of COAMPS, the Navy Coastal Ocean Model (NCOM). NCOM is executed on a 6 km horizontal grid with 40 levels in the vertical. We will present simulation results of the deep-water convection and formation responses to several Mistral events during the 1989/1999 and 1999/2000 winter seasons.

OS42B-126 1330h POSTER

Simulated air-sea CO_2 flux: Comparison between virtual flux and free surface formulations.

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To deal with the dilution and concentration of tracers due to evaporation (E) and precipitation (P), most ocean models that conserve volume, introduce a fictitious flux proportional to the average surface salinity and to local (P-E). For example, this is the specified protocol for the second phase of OCMIP (Ocean Carbon Model Intercomparison). This has been a cause of concern for two reasons. First, the magnitude of the computed virtual flux turns out to be comparable to the actual air-sea flux exchange. Second, it should be applied to all tracers, but instead is applied only to tracers whose local surface concentration is large enough so that the addition of this extra flux does not produce negative values. To test the validity of the virtual flux approximation, we have used the POP model (Parallel Ocean Program developed at Los Alamos National Laboratory), which has recently, been enhanced to account, for the changes in concentration due to a time varying top layer thickness. Thus, we compare steady-state bio-geochemical simulations with and without the new enhancements. Preliminary results suggest that except for minor local differences, mainly concentrated in the Southern Ocean, the virtual flux appropriately accounts for the changes in tracers due to variations in the volume of the top layer. However, the virtual flux approximation was based on the assumption of zero net average (P-E). Therefore, the virtual flux may not be appropriate under scenarios of future climate change which could involve changes in net freshwater transport to the ocean.

OS42B-127 1330h POSTER

Stable Isotopic Compositions and Fractionations of Carbon Monoxide in Seawater

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Carbon monoxide (CO) reacts with most of the hydroxyl radicals in the troposphere, so that the changes in the mixing ratio of atmospheric CO influences the chemical balance of the troposphere and the mixing ratio of the reduced species. It is well known that the oceans act as a source of atmospheric CO, since the concentration of CO dissolved in oceanic surface waters is supersaturated with respect to the equilibrium value in the troposphere. Since estimations of the total source strength of CO flux from the oceans show wide variation, ranging from 10 to 245 Tg/yr, more investigations of the oceanic CO flux and of the mechanisms of production and consumption of CO within seawater are required. Stable isotope compositions have been used to develop constrains for the magnitudes of various sources and sinks of trace gases in the atmosphere, including for CO. We present the results of the first isotopic studies on seawater-dissolved CO. Open ocean seawater sampling was carried out in the western North Pacific (32.4^{o}N, 133.3^{o}E) on 21 June 2000. Coastal seawater sampling was carried out at Ishikari Bay (Hokkaido, Japan). The concentration of CO and the stable carbon and oxygen isotopic compositions were measured by using continuous-flow isotope mass spectrometry. Large variations in both carbon and oxygen isotopic compositions were observed in seawater-dissolved CO. The variations are in proportion to marked diurnal variations in its concentration, due to the combination of isotopically light CO production in seawater and enrichment of heavy isotopes during consumption of CO by microbial action. Compared with the isotopic compositions of dissolved organic matter (DOM), from which most of the oceanic CO is derived, isotopic compositions of the CO produced from it agree well for δ^{18}O, but are depleted in ^{13}C by more than $20^o/_{oo}$. We also observed a large degree of carbon isotope fractionation ($15\sim30^o/_{oo}$) in laboratory photochemical CO formation from formic acid and acetic acid, indicating large fractionation processes for the carbon isotopes during the photochemical production of CO from DOM. Isotopic fractionation factors during bacterial oxidation of CO in seawater were estimated to be 1.005±0.002 and 1.006±0.002 for carbon (α_c) and oxygen (α_o), and the mean δ^{13}C and δ^{18}O for CO emitted from the oceans were estimated to be $-40^o/_{oo}$ and $+15^o/_{oo}$, respectively. Oceanic CO can be an important source of isotopically light CO relative to fossil fuel combustion and biomass burning, which is valuable when calculating the global CO budget using isotopic tracers.

OS42B-128 1330h POSTER

Nitrous Oxide Fluxes and Production in the Eastern Caribbean Basin

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The ocean is a net source of nitrous oxide (N_2O) to the atmosphere but many oceanic global budgets do not consider heterogeneity and gradients present in many regional seas. We present evidence for a significant latitudinal gradient in surface production and fluxes of N_2O in the Eastern Caribbean basin. The Orinoco Plume Expedition (ORIPEX VI) aboard the University of Puerto Rico R/V Chapman followed a cruise track through the southeastern Caribbean Sea from the southwest coast of Puerto Rico to the northern coast of Venezuela and back covering an area of approximately 64,000 km ^{2} with a diverse biogeochemical gradient from coastal upwelling systems to oligotrophic zones representatives of tropical seas. Near-surface waters exhibited N_2O supersaturation at all stations with the highest values observed in the coastal upwelling zone (up to 532 %). Sea-air N_2O flux computations resulted in a latitudinal gradient ranging from 1.9 $\mu mol.m^{-2}.d^{-1}$ for oligotrophic oceanic stations to 106.2 $\mu mol.m^{-2}.d^{-1}$ at coastal upwelling stations.

Ammonium oxidation rates were estimated using chlorate as a specific metabolic inhibitor of nitrite reduction where the rate of nitrite accumulation over time equals the rate of ammonium oxidation. Mixed layer ammonium oxidation rates for the oceanic and coastal upwelling stations ranged from 10 $\mu mol.m^{-3}.d^{-1}$ (SD = 7, n = 36) to 36 $\mu mol.m^{-3}.d^{-1}$ (SD = 19, n = 36), respectively. Assuming a yield of N_2O production relative to ammonium oxidation of 0.3% for stratified oceanic stations and integrating the N_2O production rate to the mixed layer depth (average = 75 m), we estimate oceanic production rates of approximately 2.5 $\mu mol.m^{-2}.d^{-1}$ (SD = 1.6, N = 36). These production rates are not signicantly different for the estimated sea-air exchange rates. We thus conclude that oceanic mixed layer N_2O production by nitrification can sustain the estimated sea-air N_2O fluxes. However, N_2O production by nitrification in the shallow (25 m) coastal upwelling area (overall mean = 2.9 $\mu mol.m^{-2}.d^{-1}$, SD = 1.3) is insufficient to supply the estimated N_2O emission to the atmosphere. Thus, a substantial fraction of the N_2O fluxes at this site must result from denitrification or vertical transport of dissolved N_2O from deeper waters. A N_2O mass balance budget in the core of the upwelling zone considering inputs through vertical transport (41.6 $\mu mol.m^{-2}.d^{-1}$) and in situ production and losses through lateral advection (98.9 $\mu mol.m^{-2}.d^{-1}$) and airsea exchange yields a production deficit of approximately 139.3$\mu mol.m^{-2}.d^{-1}$ or about 49% the estimated sea-air flux. We attribute the deficit to denitrification in the low oxygen upwelling system.

OS42B-129 1330h POSTER

Inorganic Carbon and CFC Distributions in the Canadian Arctic

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Some consider that early signs of global climate change may be detected by observations made in the Arctic regions. Variation of ice cover properties influences air-sea interaction as well as the circulation and biological productivity and results in the change of oceanic uptake of atmospheric CO2 and anthropogenic gasses such as CFCs. The Canadian Arctic spans from the Baffin Bay to the Beaufort Sea. At the surface, Pacific water enters the western part of the Canadian Basin through Bering Strait and flows out to the North Atlantic through Davis Strait. During periods of ice formation, brine drainage produces dense water on the shelf, which then spreads offshore and during periods of ice melt, melt water increases the water column stability. High biological production in the same region during the summer, together with the river run-off contributes to transport of carbon.

We present distributions of inorganic carbon and CFCs in the Canadian Arctic to identify water masses and their transport and to study controlling processes of carbon cycles. Data were collected at Davis Strait, Nare Strait, Hudson Strait, Jones Sound, Parry Channel and Beaufort Sea from August to October 1997 on board CCGS Louis S. St. Laurent.

Preliminary results show high concentration of CFC-12 (3.0 pmol/kg) throughout the surface layer extending from 30m to over 150m in the Jones Sound. The oldest water was found at the bottom of the Beaufort Sea where CFC-12 concentrations were less than 0.2 pmol/kg at depths below 2000 m. This old water flows into the western part of the Canadian Archipelago, but does not reach Baffin Bay. At Davis Strait, concentrations of CFC-12 in the surface layer are higher at the eastern part of the transect than at the western part, while a homogeneous water mass with low CFC-12 concentrations extends from 800 m to the bottom. The distribution of total inorganic carbon, in general, inversely correlates with that of CFC-12. However, inorganic carbon distribution is further complicated by the local biological activity and river run-off.

OS42B-130 1330h POSTER

Response of Sea Surface Directional Wave Spectra in a Hurricane to the storm translation speed

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The effects of the hurricane translation speed on the variation of wave characteristics are investigated from a series of numerical experiments using a third generation wave model, WAVEWATCH-III. The experiments are designed for four idealized hurricanes: stationary, slow-moving (2.5 m/s), typical-speed (5.0 m/s), and fast-moving (10 m/s). The directional wave spectra obtained at various points in four difference directions from the hurricane eye are examined. The simulated directional wave spectra are compared with the Hurricane Bonnie (1998) directional wave spectra obtained from NASA Scanning Radar Altimeter (SRA) on 24 and 26 August 1998.

For the slow-moving and typical-speed hurricane cases, the wind-generated surface waves propagate ahead of the storm as decaying swells. However, for the fast-moving hurricane, the maximum group velocity (9.9 m/s) of the waves becomes close to the hurricane speed (10 m/s). As a result, the waves to the right of the hurricane track become trapped within the hurricane and thus are exposed by prolong forcing from the wind. The significant wave heights and mean wavelengths generated with this trapped-fetch reach almost twice the values observed in the stationary hurricane case. The wave spectra to the right of the hurricane appear to be as a unimodal swell propagating in the direction of the hurricane translation, while the spectra in the rear and left to the hurricane eye display more complex structure.

OS42B-131 1330h POSTER

Air-Sea Interactions during the Passage of a Winter Storm over the Gulf Stream: A 3D Coupled Atmosphere-Ocean Model Study

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A three-dimensional, regional, coupled atmosphere-ocean model with full physics is developed. The model performs well in simulating an atmospheric cyclone that intensified off the Carolina coast and traveled over the northwestern Atlantic Ocean on 19-20 January 1998. Model diagnosis is used to examine the air-sea heat and momentum exchanges and the responses in the upper ocean. Maximum ocean-to-atmosphere heat flux appears over the Gulf Stream in the South Atlantic Bight (SAB), which results in rapid deepening of the cyclone off the Carolina coast. After the cyclone leaves the SAB, the heat flux maximum moves to over the Gulf Stream off Cape Hatteras and later northeast of Hatteras, which in turn enhances the wind locally. Oceanic response is closely related to the wind direction. Southerly and southwesterly winds tend to strengthen the Gulf Stream at the surface, whereas the northeasterly winds reduce the Gulf Stream and also generate the southwestward flows on the shelf. Running the atmospheric model alone with unchanged SST overestimates the oceanic effect on the cyclone, with the surface wind being about 5 to 10 percent stronger. Large differences in the surface heat flux appear near the Gulf Stream mender troughs due to wind-driven lateral shifts of the stream, which in turn enhance the local northeasterly winds.

OS42B-132 1330h POSTER

Interannual Variability in Air-Sea Fluxes of O_2 and CO_2

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We use an ocean general circulation model driven with daily meteorological forcing to study the mechanisms of air-sea O_2 and CO_2 flux variability, and to estimate the significance of this variability for the estimation of global CO_2 sinks. The model's mean air-sea fluxes of CO_2 are found to be consistent with the data based estimates of Takahashi et al. (Proc. CO_2 in the Oceans, 1999) in all regions. Regional air-sea O_2 fluxes are consistent with the results of Ganachaud (PhD MIT, 1999) in all regions except the Southern Ocean. Interannual variability of the modeled global air-sea CO_2 flux is $\pm$ 0.5 PgC/y and interannual variability in the air-sea O_2 flux is $\pm$ 60 Tmol/y.

The amplitude of interannual variability in the air-sea CO_2 flux exceeds that of previous model estimates, due to stronger physical variability in this model, and approaches estimates from atmospheric inversions. However, comparison of model surface variability with TOPEX/Poseidon satellite altimetry indicates that our model still underestimates the variability of the real ocean. Thus our estimates of air-sea gas flux variability probably represent lower bounds.

We find that global, interannual variability of the air-sea flux of CO_2 is dominated by the Tropical Pacific region and ENSO. Interannual variability of the global O_2 flux, however, feels contributions of comparable magnitude from the Tropical Pacific and the polar oceans, in particular the North Atlantic. The sensitivity of the O_2 flux to North Atlantic variability reflects the strong variability in deep convective mixing in that region and the relatively short gas exchange timescale for O_2. CO_2 is fairly insensitive to the Atlantic variability due to buffering and the consequent long gas exchange timescale. Combining the model (lower bound) estimates of global air-sea gas flux variability, with the observed atmospheric trends we will infer the variability (upper bound) of the terrestrial sink of CO_2.

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The Impact of Waves on Surface Currents

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Ocean models usually estimate surface currents without explicit modelling of the ocean waves. To consider the impact of waves on surface currents, we use a wave model in a modified Ekman layer model, which is imbedded in a diagnostic ocean model. Thus, we explicitly consider wave effects, for example Stokes drift and wave-breaking dissipation, in conjunction with the Ekman current, mean currents and wind-driven pressure gradient currents. This is an explicit implementation of the equations for wave-induced currents, as derived by Jenkins (1986, 1987, JPO). WAM-type model terms are used to estimate energy input to waves by wind and removed by wave-breaking dissipation. The ocean model follows that described by Tang and DeTracy (1999, JGR, vol. 104, 23411-23425). Previously these equations by Jenkins were used to estimate wave-induced forcing on ice floes (Perrie and Hu, 1997, JPO). This coupled wave-ocean model is compared to measurements from the Labrador Sea Deep Convection Experiment of 1997. We show that the wave effect is largest in rapidly developing intense storms, when wave-modified currents can briefly exceed the usual Ekman currents by as much as 40%. A large part of the increase in velocity can be attributed to the Stokes drift. Reductions in momentum transfer to the ocean due to wind input to waves, and enhancements due to wave breaking dissipation are each of the order 20-30%.

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The Effect of Wind Wave Breaking and Vertical Resolution on Simulation of Surface Currents in 3D Hydrodynamical Models

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Simulated trajectories of oil spills and objects drifting near the sea surface are often based on surface circulation produced by 3D hydrodynamic models. Understanding the sources of uncertainty in these fields is thus essential in order to make useful decisions based on these models. The 3D models typically have relatively coarse vertical resolution and frequently employ two equation turbulence closure sub-models (e.g. k-e or Mellor-Yamada 2.5) that are tuned to treat the sea-surface as a solid boundary, yielding law-of-the-wall behavior near the sea-surface during strong wind forcing. Observations made over the last decade, however, have demonstrated that during breaking wave conditions, such behavior greatly overestimates the vertical shear in the horizontal velocity and underestimates the amount of near-surface mixing. The developing conceptual model is that there are three dynamical regions near the sea surface: (1) an inner wave-mixed layer of thickness about one wave height in which intense mixing and TKE dissipation occurs, (2) an intermediate wave-influenced layer of thickness several wave heights in which the downward diffusion of TKE from breaking waves is important and (3) an outer shear-driven log layer region. Recently, the behavior of two equation models has successfully been modified to account for these wave-breaking effects.

What influence do these factors have on the surface currents simulated with the hydrodynamic models? Here we investigate the variability in modeled surface currents that is obtained by varying the assumptions about vertical mixing processes and vertical resolution. When the models are run in the traditional way (wave-breaking not included), they produce a logarithmic increase in velocity as the sea surface is approached from below. This is not only at odds with observations of velocity shear, but for vertical resolutions in common use, the current in the surface layer can be dependent on the layer thickness, clearly an undesirable and potentially dangerous effect. When wave-effects are included, the near-surface shears are significantly reduced, matching observations, surface currents are reduced, and the simulated currents are less sensitive to the near-surface grid resolution.

Simulations incorporating wave-enhanced mixing provide a better match to the observed near-surface shear and dissipation rates. However, we demonstrate that they predict surface currents that are significantly weaker than those expected from historical observations of surface Lagrangian transport. We discuss the constraints this discrepancy places on such models and evaluate whether models and observations can be reconciled.

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Scalar Flux-Profile Relationships for Water Vapor Over the Open Ocean

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Over the ocean, direct measurement of the turbulent fluxes is very difficult due to platform motion, flow distortion, and the effects of sea-spray. Instead, marine meteorologists and oceanographers have long relied on flux-profile relationships that relate the turbulence fluxes of momentum, heat and moisture (or mass) to their respective profiles of velocity, temperature, and water vapor (or other gases). These flux-profile relationships are required in indirect methods such as the bulk aerodynamic, profile, and inertial dissipation methods that estimate the fluxes from mean, profile, and high frequency spectral measurements, respectively. The flux-profile or flux-gradient relationships are also used extensively in numerical models to provide lower boundary conditions and to "close" the model by approximating higher order terms from low order variables.

The most commonly used flux-profile relationships are based on Monin-Obukhov (MO) similarity theory. These semi-empirical relationships attempt to account for the relative roles of mechanical versus thermal forcing on turbulent exchange. For example, the relationships attempt to parameterize the observation that equal values of the momentum flux are associated with larger velocity gradients in stable versus unstable conditions, i.e., more shear is required in stable conditions to overcome the stratification. MO similarity has been validated by a number of overland experiments including the landmark Kansas, Minnesota, and ITCE experiments in the 1970s. These and other experiments have generated a number of similar semi-empirical functions that are used in the indirect methods over the ocean. However, the use of overland measurements to infer surface fluxes over the ocean is questionable, particularly close to the ocean surface where wave-induced forcing can affect the flow. Therefore, the universality of these relationships to all surface layers is a current topic of intense debate.

Direct measurement of the atmospheric fluxes along with profiles of water vapor and temperature were made during the 2001 GASEX experiment in the equatorial Pacific. These measurements are being analyzed to address the applicability of parameterizations derived from overland measurements to the marine surface layer. The measurements were made from the R/V Brown at the end of a boom that placed the sensors 10-m upwind of the bow. Turbulent fluxes of momentum, heat, and water vapor were made by sonic anemometers/thermometers and infrared hygrometers. A mast at the end of the 10-m boom supported a profiling system that moved a suite of sensors between 3 and 12 meters above the mean sea level. The moving sensors were referenced against a fixed suite of sensors to remove naturally occurring variability during the profiling periods. Preliminary results show good agreement with commonly used parameterizations based on overland measurements. This indicates that the MO similarity functions are applicable over the ocean in conditions where the theory is applicable, i.e., in surface layers where the structure of the turbulence is dominated by the relative importance of mechanical (i.e., wind shear) versus thermal forcing. The role of wave-induced forcing on the lowest levels of the profile will be discussed.