Ocean Reference Stations

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1. Project Summary – Ocean Reference Stations

Rationale: The Woods Hole Oceanographic Institution (WHOI) Ocean Reference Station project is carried out to provide critical, sustained observations of a key region of the ocean – the trade wind region. As the earth sits in space, sunlight heats the earth in a broad, equatorial region. The ocean and atmosphere both are driven by the thermal gradients between the equator and the poles; the oceans, with their ability to store, transport, and release heat and moisture to the atmosphere, play an important role in weather and climate. Air that is heated rises at the equator and descends in the subtropics, resulting in broad regions of winds flowing from the east to the equator. Around the globe these easterly trade wind regions cover roughly 50% of the ocean surface, in a wide belt spanning the equator. These regions are where the equatorial concentration of solar heating leads to net ocean heating and where in turn large evaporation and accompanying latent heat flux provides energy and moisture to drive the atmosphere over a range of scales, from the general Hadley circulation that is the source of the trade winds down to intense hurricanes intensified by that heat and moisture. They are also where the ocean provides CO_2 to the atmosphere in contrast to the higher latitudes where the ocean gains CO_2 from the atmosphere. Integrated across the expanse of the trade wind regions, errors and uncertainties in the exchange of heat, freshwater, momentum, and compounds such as CO_2, can challenge our ability to understand the way in which the atmosphere and ocean interact and how that interaction should be represented in models used to predict weather and climate variability.

To provide sustained, climate-quality observing of the trade wind region, we have developed surface moorings with the capability of making sustained, accurate observations at the sea surface and in the water column and have chosen and occupied three key trade wind sites. These surface moorings are known as Ocean Reference Stations (ORS). The three sites, shown in Figure 1, are the Stratus ORS, the NTAS (Northwest Tropical Atlantic Station) ORS, and the WHOTS (WHOI Hawaii Ocean Timeseries Site) ORS. Together, the three sites

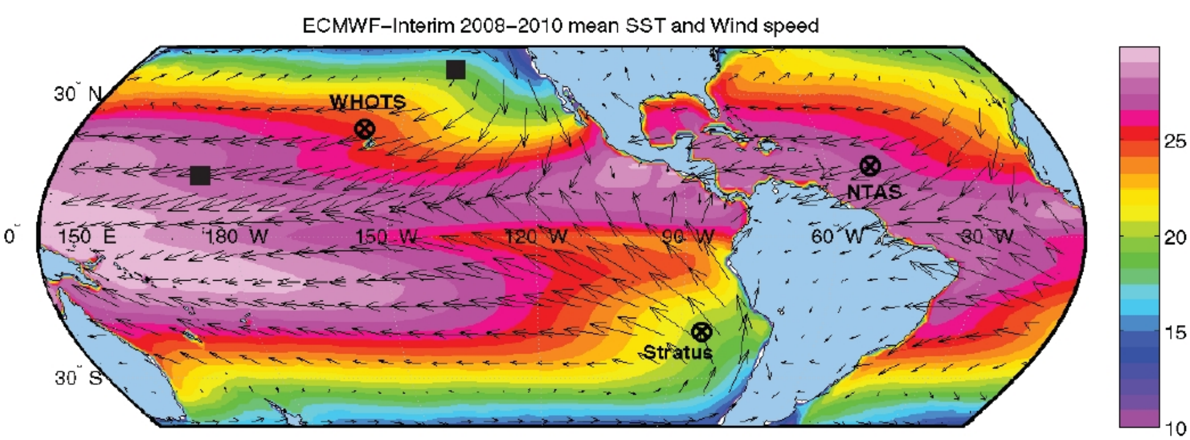

Figure 1. SST (colors) and surface wind vectors from the ECMWF-Interim reanalysis for the period 2008-2010. The positions of the Stratus, NTAS and WHOTS ocean reference station buoys are indicated. The corresponding virtual positions of the Stratus and NTAS buoys, relative to the North Pacific Hadley circulation and SST, are indicated by black squares. From Dr. Roger Lukas, Univ. of Hawaii, partner at WHOTS.

form a comprehensive array in two ways. First, they sample distinct branches of the trade wind regime. The black squares in Figure 1 are the positions of NTAS and Stratus relative to WHOTS based on their position within the trade wind system; note that Stratus, at the furthest distance from the region of convergence between the Northeast and Southeast Trades, samples the region of descending atmospheric flow in the Hadley circulation and the origin of the trade winds, while NTAS, samples they trade winds close to the convergence zone which is the ascending branch of the Hadley circulation, and WHOTS samples the fully developed trade winds in between. Second, the three sites have regional attributes. Stratus is under the persistent marine stratus clouds that characterize the region offshore of northern Chile, in a cool eastern boundary current regime and, due to the proximity of the Andes, away from the tracks of energetic synoptic weather systems; atmospheric, oceanic, and coupled models continue to fail to correctly represent the physics at work there and typically yield sea surface temperatures that are too cool. NTAS lies in the North Atlantic trade wind regions through which the hurricanes that reach eastern North America track, and accurate representation of how the ocean's heat and moisture in this region fuel the growth of those hurricanes is needed. WHOTS, close to the Hawaiian Islands where the Keeling time series documents the increase of atmospheric CO_2, provides not only a critical benchmark time series of oceanic CO_2 but also an emerging record of links between changes in the regional hydrological cycle (rainfall, evaporation) and the variability and dynamics of the upper ocean there due to changes in ocean salinity.

The reasons for our approach, the use of surface moorings for sustained observations, are: 1) the need to obtain high temporal resolution, sampling down to minutes to record high amplitude, short-lived events in the surface meteorology, air-sea fluxes, and upper ocean structure, 2) the need to sample with high vertical resolution in the stratified upper ocean that is in close contact to the atmosphere and links the upper ocean to the interior of the ocean, 3) the need to sample a changing environment in a sustained way, and 4) the need to provide continuous time series at a point for validation, verification, and calibration of models and remote sensing methods. Designing and building a surface mooring, developing and using accurate instruments with low-power consumption that can run unattended, instrumenting the surface buoy with these meteorological and pCO2 sensors and the mooring line with temperature, salinity, velocity, and other ocean sensors, and carrying out on-site verification of the moored instrumentation when the ship services the mooring each year are the best technical approach and the one we use at the three ORS. The resulting meteorological and oceanographic observations provide a set of high quality air-sea fluxes of heat, freshwater and momentum as well as upper ocean heat and salt content. The scientific rationale for the collection of these flux products is manifold: 1) to describe the upper ocean variability and the local response to atmospheric forcing; 2) to motivate and guide improvement to atmospheric, oceanic, and coupled models; 3) to calibrate and guide improvement to remote sensing products and capabilities; and 4) to provide anchor points for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to create more accurate global fields.

Scope: The work done under this project accomplishes seeks to do the following: 1) maintain long-term surface moorings, known as Ocean Reference Stations, in three key trade wind locations, one in the North Atlantic, one in the North Pacific, and one in the South Pacific, 2) use the data from these moorings to accurately quantify the local climatologies and variability of the air-sea fluxes, sea surface temperature, surface currents, upper ocean heat content and transport, and, with NOAA partners, the air-sea flux of carbon dioxide, and 3) use the data collaboratively to improve understanding of the processes and dynamics at these sites and thus the numerical models of the atmosphere, the ocean, and the coupled atmosphere-ocean applicable to these regions.

Three Ocean Reference Stations are being maintained: A site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Time-series (HOT) site at 22.75°N, 158°W known as the WHOI Hawaii Ocean Time-series Station or WHOTS. Moorings at the Stratus and NTAS sites were first deployed in 2000 and 2001, respectively, and became long-term Ocean Reference Stations. WHOTS was established in 2004, in collaboration with investigators that have made shipboard and moored observations in that region in recent years. Each of these sites is visited once per year. Before the cruise the new instruments are calibrated and prepared and the surface buoy and mooring are built. During the year, real time data flow and quality is monitored. After the cruise, instruments are calibrated and refurbished, data are recovered and processed, and the cruise is documented.

Anticipated data, products, outcomes: In FY2011, the WHOI Ocean Reference Station project carried out cruises to each of the three sites to recover moorings in service for a year and deploy new moorings NTAS was serviced by the NOAA Ship Ron Brown in November 2011. Stratus was serviced by RV Moana Wave on a cruise from Arica, Chile to Arica, Chile, March 31, 2011 to April 16, 2011. WHOTS was recovered and redeployed in July, 2011 on the NOAA Ship Hi'ialakai. Each cruise resulted in the collection of the internally recorded data on the instrumentation on the buoy and the mooring line and supporting data sets from the ships, such as meteorological data for comparison with the buoy meteorological data. From the deployment of a new buoy, onward, the surface meteorological data is available in near-real time, with hourly averages typically telemetered via Service Argos. The WHOI Ocean Reference Station data are not placed on GTS; instead they are used as independent data for validation of models by users such as ECMWF (European Centre for Medium Range Weather Forecasts) and NCEP (National Centers for Environmental Prediction).

The web sites associated with the three WHOI Ocean Reference Stations are the primary means for documenting work each year, sharing real time data, and providing archived data. The key Web Sites are: NTAS – http://uop.whoi.edu/projects/NTAS/ntas.html; Stratus – http://uop.whoi.edu/projects/Stratus/stratus.html; and WHOTS - http://www.soest.hawaii.edu/whots/ and http://uop.whoi.edu/WHOTS/projects/whots.html. For each site the WHOI web page provides an overview, detailed description (with links to mooring diagrams and technical reports), access to real time data, and access to archived data. Real time data is quality controlled on an ongoing basis, and sensors that degrade are flagged, with data removed from real time access. After the moorings are recovered, quality control and processing is directed first to develop high quality time series of surface meteorology and air-sea fluxes; these time series are typically available within twelve months of recovery, allowing post-deployment sensor calibrations to be completed first. The present new year of surface meteorology and air-sea fluxes is then merged with previous time series to make continuous time series; this is the products that are most requested by various users. Processing and preparation of data files for the ocean sensors then follows, with temperature and salinity done first. Work on the velocity data provides the most challenge due to the impacts of biofouling and fishing gear on current meters and the greater complexities of quality controlling current meter data.

Intended Users: The users of Ocean Reference Station data are: 1) Numerical Weather Prediction (NWP) centers, including the National Centers for Environmental Prediction (NCEP) in the United States, the European Centre for Medium-Range Weather Forecasts (ECMWF) in Europe, the Centre for Australian Weather and Climate Research (CAWCR); 2) climate modeling groups and groups analyzing the realism of climate models, NCAR (National Center for Atmospheric Research) in the U.S. and the international SURFA (Surface Flux Analysis) project where ORS data is used as validation truth for examining the performance of many different climate models from different countries; 3) those analyzing and assessing the realism of satellite retrievals at the sea surface (sea surface temperature) and of surface meteorology (e.g., winds) and surface waves, including investigators at NASA (National Aeronautics and Space Administration) and ESA (European Space Agency); 4) those working to developed gridded fields of air-sea fluxes of heat, moisture, and momentum to accurately determine and monitor these fields on a global basis, including Dr. Lisan Yu at WHOI, whose OAFlux project uses the ORS data to validate the OAFlux fields; 5) investigators and researchers studying air-sea interaction, cloud physics, and upper ocean dynamics at key locations, such as under the marine stratus clouds off Chile (Stratus) and in trade wind locations such as NTAS and WHOTS; 6) investigators working under VOCALS (VAMOS Ocean Cloud Land Atmosphere Study, where VAMOS is the Variability of the American Monsoon Systems of the international CLIVAR (Climate Variability research program)), which has focused on improved understanding and prediction of the marine stratus and its impacts on climate over the Americas; and 7) ocean model developers and users at US research and operational model centers, who use the time series of ocean variability at the ORS to examine the realism of ocean models and the time series of surface fluxes to evaluate the forcing fields they use to drive their ocean models.

Users of the ORS platforms in addition to our effort include: 1) the National Data Buoy Center (NDBC), an NDBC surface wave package is installed on the Stratus ORS to provide surface wave data in the extremely data sparse eastern South Pacific, 2) NOAA PMEL (Pacific Marine Environmental Laboratory), which has installed instrumentation to measure carbon dioxide in the surface waters at the Stratus and WHOTS ORS, and 3) investigators from WHOI, LDEO (Lamont-Doherty Earth Observatory of Columbia University), the Institut fur Meereskunde an der Universitat Kiel (IFMK), and Dr. Sam Laney (WHOI, funded by NASA to study ocean color) who have installed or will be installing instrumentation to study ocean mixing, oceanic oxygen minimum layers, and ocean color.

2. Scientific and Observing System Accomplishments

Overview: In FY2011 we carried out a cruise to each of the three ORS as described above. NTAS recovered a mooring and deployed a new mooring using the NOAA Ship Ron Brown in November 2011. Stratus was serviced by RV Moana Wave on a cruise from Arica, Chile to Arica, Chile, March 31, 2011 to April 16, 2011. The Stratus 10 mooring had parted and the surface buoy recovered in July 2010. The lower part of Stratus 10 was recovered and the new

Stratus 11 mooring set in April 2011. WHOTS was recovered and a new mooring deployed in July, 2011 on the NOAA Ship Hi'ialakai.

Deliverables: In our recent Work Plan we identified as the basic deliverable the data from the ORS. The deliverables from the ORS are indeed the data, supported by the documentation of the cruises and methods used to collect the data. The directly observed data fall into three main categories: 1) Surface meteorology and air-sea fluxes. The surface wind speed and direction, air temperature, relative humidity, barometric pressure, incoming shortwave radiation, incoming longwave radiation, and rain rate are measured at a once per minute rate. Logged at the same time are buoy bridle temperature and salinity; 2) Surface oceanographic data. The ORS buoys are typically equipped with multiple floating or fixed point temperature sensors to obtain ocean temperature at or close to the sea surface. In addition, an effort is made to place a shallow fixed point current meter or to use an upward looking high-resolution Doppler profiler to obtain a value to be used as surface current; 3) Ocean observations of temperature, salinity, and velocity along the mooring line in the upper thermocline and surface layer; Stratus has recently added dissolved oxygen measurements. The surface meteorology, surface temperature, and surface current are used with the bulk formulae to compute a fourth product: 4) Air-sea fluxes of heat, freshwater, and momentum. The most recent ORS mooring designs (e.g. NTAS-11 now deployed and Stratus and WHOTS to be deployed in 2012) include additional sensors to obtain deep ocean temperature and salinity (within 40 m of the seafloor). Ancillary observations by cooperating investigators add: 5) surface wave data by NDBC at Stratus and NTAS; 6) pCO_2 by NOAA PMEL at Stratus and WHOTS; 7) dissolved oxygen observations at Stratus by Lothar Strama from Kiel, Germany; and 8) in the water radiance observations at WHOTS by Sam Laney of WHOI. Surface meteorology is available in real time and the remaining data follow as described above.

The data return from WHOI-deployed meteorological and upper ocean instrumentation on ORS has been sustained at high level over 27 buoy-years of deployments. We have compiled statistics for "usable data" – data of sufficient quality to be carried to post processing and used in analysis, although in some cases requiring post calibration or adjustment. For meteorological variables we find usable data return of 93.5% at Stratus (over 10 years), 96.5% at NTAS (over 10 years) and 97.7% at WHOTS (over 7 years). It is important to note that because we deploy redundant meteorological sensors on each buoy, a single instrument failure does not compromise the deliverables. Considering the deliverable for surface meteorology a single record of surface meteorological variables created from the best performing sensor of each pair, the usable data return increases further from the values quoted above. For subsurface variables we find usable data return of 90.1% at Stratus (over 10 years) and 92.5% at NTAS (over 9 years). The high usable data return allows continuous multi-year time series of air-sea fluxes and upper ocean response to be constructed which serve a variety of purposes.

The ORS in particular address the following ocean observing system program deliverables:

• **Sea surface temperature and surface currents**. The ORS surface buoys have been instrumented to give improved sea surface temperature observations. Floating sea surface temperature sensors and temperature sensors embedded at shallow depth directly into the foam buoy hulls have added unique capability. Because they sample surface and near-surface ocean temperature and because they have collocated, high quality air-sea fluxes, ORS data sets are sought by investigators working on diurnal warm layer dynamics and remote sensing of SST. ORS Stratus data are being used by Prytherch et al (in preparation) in a new study of the dynamics and predictability if the diurnal warm layer. ORS data have been supplied to other investigators studying diurnal warming and remote sensing of SST (e.g. Bill Emery, Dudley Chelton). All three ORS have shallow current observations, which are used in computing of the air-sea fluxes, where the surface wind relative to the surface current is needed (Stratus and WHOTS –10 m depth; NTAS – 6 m depth). An effort has been made at ORS Stratus to improve sampling near the surface by adding upward looking, high resolution acoustic Doppler current profilers to the mooring at 15 m depth.

• **Ocean heat content and transport.** The ORS buoys are equipped with temperature, salinity, and velocity sensors from the upper thermocline to the surface (at Stratus, these go deeper, to 1,800 m). As a result, the temporal evolution of the mixed layer and its heat storage can be tracked as well as the heat content of the upper ocean. At the same time, the velocity observations and surface forcing data allow net upper ocean transports to be computed and for that transport to be decomposed into wind-driven and geostrophic transport components.

• **Air-Sea Exchanges of Heat Momentum and Freshwater.** The ORS are equipped to make state of the art, sustained air-sea flux observations, providing the air-sea exchanges of heat, freshwater and momentum. At the three ORS we can define a local climatology and quantify anomalous departures in wind forcing, local heat balance, and local hydrologic cycles.

• **Ocean Carbon Uptake and Content**. Collaboration with Chris Sabine at NOAA PMEL has added pCO_2 observations to Stratus and WHOTS.

FY2011 Achievements: In FY2011 we carried out a cruise to each of the three ORS, quality controlled and processed data, and served data to users.

Scientific Advancements: Work began on documenting the three sites as three representative trade wind sites. In support of this, Weller reviewed sensor performance, found a problem with the incoming shortwave radiation sensors aging and showing calibration drift. Weller and Chris Fairall visited Frank Bradley at CSIRO, Canberra, Australia and began to develop procedures to correct this error; at the same time they verified the accuracy of the new incoming longwave radiation sensor used at the ORS. With the radiation sensor calibration being addressed, we are building a unified, continuous record of surface meteorology and air-sea fluxes at each of the three ORS. Weller has begun a paper to document these records, which will be a uniquely valuable resource for climate researchers.

The science impact of the Stratus site continues as a benchmark for climate research in the Stratus region and for the VOCALS ReX (VAMOS (Variability of the American Monsoon System) Ocean Cloud atmosphere Land Study Regional Experiment) in particular. The Stratus mooring points to the role of ocean processes in freshening and cooling the ocean mixed layer.

WHOTS serves to build upon previous record with an important improvement. WHOTS, like the other ORS, records local air-sea forcing (exchanges of heat, freshwater and momentum) as well as local ocean variability. WHOTS points to the role of several processes acting to control the local ocean state, including changes in the balance between surface rainfall and evaporation and transports by eddies of masses of water from distant locations. At the same time comparisons between WHOTS and global models, such as ECMWF, show the regional representativeness of the ORS observations.

The NTAS ORS is in a region where the mechanisms controlling SST and upper ocean heat content are of interest. The seasonal cycle dominates the net heat flux, with the seasonal migration of the ITCZ modulating heat flux and rainfall. Interannual variability is evident in the minimum and maximum seasonal values as well as the timing of seasonal transitions. This is a region where interaction between wind, evaporation and SST are important, and there is interest in the role of advective cooling during periods of wind relaxation when evaporative cooling is reduced and thus there is a tendency for local SST increase (without advection).

Significance of these scientific advancements: The ORS results are particularly significant in two areas: 1) Benchmarking three trade wind sites – the three ORS now provide accurate local climatologies of surface forcing and upper ocean variability. As such they form the basis for us to go forward and examine model errors and biases and identify those that are characteristic of how these models represent the trade wind region. They also form the basis for tracking anomalies in surface forcing and upper ocean heat content and identifying the spatial representativeness of such anomalies by looking at decorrelation scales in the atmosphere (in model and OA Flux fields) and in the ocean (in Argo float data). 2) Quantifying the processes at work to maintain the state of the upper ocean – the combination of accurate local forcing and good time/space resolution in the upper ocean allows us to identify the major contributors to local heat, freshwater, and momentum balances. Stratus, for example, at first obtained accurate fluxes that showed, in contrast to models, that the upper ocean there was heated by the atmosphere and needed ocean processes for cooling and freshening. Subsequently, Stratus data has motivated modelers and other researchers to examine the roles of ocean eddies and vertical mixing. In the immediate future, the Stratus ORS will serve as a focal point for collaborative study of the low oxygen layer found below the upper thermocline.

Impacts of lack of funding: Two funding pressures are evident.

First, the reduced funds available for use of NOAA and charter vessels has greatly increased the certainty of the timing the cruises to recover and redeploy the ORS. For example, the NOAA Ship Ron Brown did not go into the Pacific in F2011, and Stratus was done with a charter vessel without full equipment. Setting a surface mooring requires either a ship with a multibeam depth sounder or a ship with a single point depth sounder and ~5 days of additional time to steam a pattern to do the mapping. The ship should also have an Acoustic Doppler Current Profiler (ADCP) to observe the currents during mooring deployments and a well-calibrated, climate quality set of meteorological sensors to validate the moored meteorological sensors. Lack of bottom mapping capability greatly increases the risk of mooring failure. Lack of an ADCP increases the risk during mooring deployment of an unsuccessful deployment. Lack of shipboard meteorological sensors requires us to deploy at additional cost such a set of sensors.

Second, flat budgets have resulted in steady erosion of resources. We no longer purchase over-the-side insurance, and we would need to request funds from the program to replace any significant loss of moored equipment and instrumentation. Funds for shipping are constrained, and the loss of the NOAA Ship Ron Brown in the Pacific has required additional shipping expenditures to ship to meet charter vessels in port as opposed to loading/unloading from the Brown in Charleston.

Websites:
The key Web Sites are: NTAS – http://uop.whoi.edu/projects/NTAS/ntas.html;
Stratus – http://uop.whoi.edu/projects/Stratus/stratus.html;
and WHOTS - http://www.soest.hawaii.edu/whots/ and
http://uop.whoi.edu/WHOTS/projects/whots.html.

Data Collection Specifics:
a. Ocean Reference Station data is used as withheld data to validate models. To ensure it is not assimilated, data are not placed on GTS.

b. Telemetered, real time data are available at:
1. WHOI http://uop.whoi.edu
2. OceanSITES ftp://data.ndbc.noaa.gov/data/oceansites/DATA/ (in project subdirectories) and ftp://ftp.ifremer.fr/ifremer/oceansites/DATA/ (e.g. /NTAS /STRATUS /WHOTS
3. OceanSITES via THREDDS: http://dods.ndbc.noaa.gov/thredds/dodsC/data/oceansites/DATA/catalog.html
4. As NDBC "partner platforms":
   http://www.ndbc.noaa.gov/station_page.php?station=41nt0 (NTAS)
   http://www.ndbc.noaa.gov/station_page.php?station=32st0 (Stratus)
   http://www.ndbc.noaa.gov/station_page.php?station=station=51wh0 (WHOTS)

c. Delayed mode data to be found at WHOI (http://uop.whoi.edu) and at the OceanSITES ftp servers and THREDDS server listed above

d. Data are archive at uop.whoi.edu and at the OceanSITES servers at NDBC and IFREMER.

e. http://uop.whoi.edu, also from OceanSITES.org, via the "data" page (via NDBC/IFREMER GDACs)

f. Yes, we have picked up the data from the NDBC OceanSITES GDAC.

2.1. Outreach and Education

Teacher at Sea: The ORS effort each year makes space available on its cruises to the NOAA Teacher at Sea program. Stratus has hosted six Teachers at Sea, one cruise being subject of one of the children's books on Teacher at Sea published by NOAA. In Arica, Chile past participation by a Chilean Teacher at Sea has been kept alive by hosting visits from her present classes in the port of Arica. WHOTS has hosted four Teachers at Sea; WHOTS also hosted a NOAA Hollings Scholar on a cruise.

Video: ORS Stratus hosted volunteer Diane Suhm on the Stratus cruise on the NOAA Ship Ron Brown in 2010 and funded her to produce a video documenting that cruise. This video was recently provided to the Climate Observation Division. A shorter version has run on cable TV in Massachusetts and will be used at public lectures in Woods Hole. A variety of (non-professional) video footage is also available from NTAS and Stratus cruises.

Student Participation and Training: The Stratus cruises, whenever possible, offer space to undergraduate and graduate students to provide hands on experience at sea. A graduate student from the University of Chile, Santiago made radiosonde observations in the wind jet off the coast of Chile on one cruise. Students from the University of Concepcion, Concepcion, Chile have participated on several Stratus cruises. Graduate students and postdocs from Bigelow Marine Laboratory, George Mason University, Colorado State University, WHOI, the University of Washington, the University of California, Santa Barbara, the University of Hawaii, CICESES (Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California), Southampton Oceanography Centre, UK (now National Oceanography Centre), University of Miami, the University of Buenos Aires, and Texas A&M University have also participated. An excellent example of impact is Dr. Carlos Moffat. He sailed on a Stratus cruise as an undergraduate at Univ. of Concepcion, liked the work, came to WHOI for graduate school, and returned to Univ. of Concepcion as faculty in oceanography. WHOTS and NTAS provide space and research opportunities as available for undergraduate and graduate students from the University of Hawaii (WHOTS) and the Scripps Institution of Oceanography (NTAS).

Regional Outreach: Stratus has used opportunities derived from sailing from different Central and South American ports for regional outreach. Staff from INOCAR (Institute of Naval Oceanography) in Ecuador, the Hydrographic Division of the Peruvian Navy (DHN), the Institute of Marine Sciences of Peru (IMARPE), and the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA) have joined Stratus cruises.

3. Publications and Reports

3.1. Publications by Principal Investigators

Publications by Weller or Plueddemann using Stratus, NTAS or WHOTS:

Yu, L., R. A. Weller, and B. Sun, 2004: Mean and variability of the WHOI daily latent and sensible heat fluxes at in situ flux measurement sites in the Atlantic Ocean. *Journal of Climate*, **17(11),** 2096-2118.

Yu, L., R. A. Weller, and B. Sun, 2004. Improving latent and sensible heat flux estimates for the Atlantic Ocean (1988-1999) by a synthesis approach. *Journal of Climate*, **17**, 373-393.

Yu, L., X. Jin, and R. A. Weller, 2006. Role of net surface heat flux in seasonal variations of sea surface temperature in the tropical Atlantic Ocean. *Journal of Climate*, **19**(23)**,** 6153-6169.

Cronin, M. F., N. A. Bond, C. Fairall, and R. A. Weller, 2006. Surface cloud forcing in the east Pacific stratus deck/cold tongue/ITCZ complex. *Journal of Climate*, **19**(23)**,** 392-409.

Colbo, K. and R.A. Weller, 2007. The variability and heat budget of the upper ocean under the Chile-Peru stratus. *Journal of Marine Research,* **65**, 607-637

Weller, R. A., Bradley, E. F., Edson, J., Fairall, C., Brooks, I., Yelland, M. J., and Pascal, R. W., 2008. Sensors for physical fluxes at the sea surface: energy, heat, water, salt. *Ocean Sci. Discuss*., **5**, 327-373.

Yu, L., R. A. Weller, 2008. Objectively Analyzed air-sea heat Fluxes (OAFlux) for the global ice-free oceans. *Bulletin of the American Meteorological Society*, **88**(4), 527-533.

Colbo, K. and R. A. Weller 2009. The accuracy of the IMET sensor package in the subtropics. *Journal of Atmospheric and Oceanic Technology*, **26**(9), 1867-1890.

Ghate, V. P., B. A. Albrecht, C. W. Fairall, R. A. Weller, 2009: Climatology of surface meteorology, surface fluxes, cloud fraction and radiative forcing over south-east Pacific from buoy observations. *Journal of Climate,* **22,** 5527-5540.

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Cowles, T., J. Delaney, J. Orcutt, R.Weller, 2010. The Ocean Observatories Initiative: Sustained Ocean Observations Across a Range of Spatial Scales. *Mar. Tech. Soc. Jrnl.*, 44(6), pp.54-64.

Cronin, M. F., R.A. Weller, and R.S. Lampitt, 2012: Ocean Reference Stations. IN: Earth Observation, INTERCH, in press.

Duennebier, F. K., R. Lukas, E.-M. Nosal, J. Aucan, and R. A. Weller, 2012: Wind, waves, and acoustic background levels at Station ALOHA. *J. Geophys. Res.*, doi:10.1029/2011JC007267, in press.

In preparation:

Holte, J., F. Straneo, R. A. Weller, J. T. Farrar, and C. Moffat, 2012: Eddy observations in the southeast Pacific Ocean. To be submitted to *J Geophys. Res.*

Prytherch, J. J. Thomas Farrar, and Robert A. Weller, 2012: Observations and models of the diurnal warm layer. To be submitted to *J. Geophys. Res.*

Proceedings:

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3.2. Other Relevant Publications (this year)

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