Ship of Opportunity (VOS)

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1. PROJECT SUMMARY

Ships of Opportunity, also known as Volunteer Observing Ships or VOS, are merchant marine ships that make repeated ocean passages. In this project we focused on developing instrumentation for fast container ships that make regular crossings of broad areas of the ocean basins and, if possible, those that pass close to our Ocean Reference Stations (ORS), which are surface moorings at fixed locations (Figure 1). This provided broad spatial sampling of the regimes found across ocean basins that is an excellent complement to the high time resolution sampling at our fixed time series sites (ORS). When possible we also selected ships that were used by other groups for deployment of XBTs (expendable bathythermographs) and profiling floats, as sharing of logistic support facilitates the work. Our goal was to obtain from the selected VOS time series of surface meteorology and ships position that are complete and accurate and thus allow us to compute, using the bulk formulae, time series of air-sea heat (sensible, latent, shortwave, longwave, and net), freshwater, and momentum flux. These time series are used to quantify the spatial variability in the in-situ surface meteorology and air-sea fluxes, to identify spatial biases and other others in gridded meteorological and flux products (such as those from the National Centers for Environmental Prediction (NCEP) or those developed from remote sensing methods), to develop improved fields of air-sea fluxes over the oceans, and to support climate research.

The instrumentation used on the VOS is the Air-Sea Interaction Meteorology (ASIMET) system developed at WHOI and available commercially through Star Engineering. An ASIMET system collects one minute averaged values of wind speed and direction, air and sea surface temperature, relative humidity, barometric pressure, incoming shortwave radiation, incoming longwave radiation, and precipitation. Although the packaging is different, the sensors and electronics used for the VOS project are the same as those used on the surface buoys in the ORS project. Thus, there is significant synergy between VOS and ORS instrument development activities. The implementation of the ASIMET hardware on the VOS is the AutoIMET. AutoIMET is a distributed, wireless, system developed at WHOI for making systematic, climate quality measurements of surface meteorology from ships of opportunity. The AutoIMET system interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives the meteorological data and sends in hourly reports via Inmarsat.

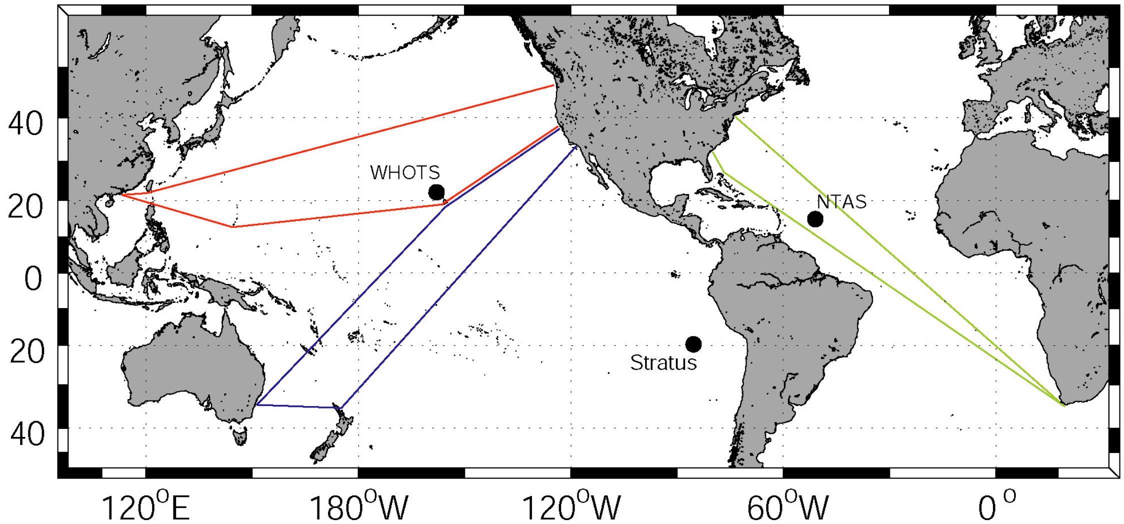

Figure 1. Schematic of routes occupied by the WHOI VOS program along with location of the WHOI ORS sites. Ships occupying the different routes were: Horzon Enterprise, northern Pacific route (red); Columbus Florida and Direct Tui, southern Pacific route (blue); SeaLand Express, trans-Atlantic route (green), Merkur, north Atlantic route (not shown).

The ASIMET sensors produce high-quality data, accurate enough to support calculation of monthly air-sea heat exchanges to better than 10 W m^{-2}. The data from the VOS are used to: 1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields, 2) motivate improvements to existing parameterizations and algorithms used in models and in preparing products from satellite data, 3) provide the data needed to correct existing climatologies, and 4) validate new model codes and remote sensing methods. The VOS data, due to the cross-basin, repeat sampling, are an important resource for work to improve the accuracy of global fields of the air-sea fluxes of heat, freshwater, and momentum and to document variability and change in the coupling of the atmosphere and the ocean.

The VOS provide a challenging operating environment in which to make high quality surface meteorological observations. Acceleration and vibration, radio frequency interference, freezing temperatures, and power surges are among the issues we have faced. Examination of performance and failure rates of ASIMET sensor modules revealed where the present set of modules introduce reliability problems and negatively impact data return rates. This led to a variety of analysis and development activities which provided improved sensors for both VOS and ORS programs. As newly developed ASIMET modules become commercially available, these benefits will be passed on to the oceanographic community. These activities are described in more detail below under Instrument Development.

A subcontract to colleagues at the National Oceanographic Centre (NOC, formerly Southampton Oceanography Centre) in the U.K. has addressed another aspect of the challenge of working from VOS – flow distortion by the structure of the ship and its cargo – in order to predict the likely biases in wind speed measurements. Given the range of shapes and sizes of ships in the merchant fleet, simple generic ship shapes were developed and used to represent different types or classes of ships. The generic results have some limitations for bow-on flows, but in general wind observations were shown to be most sensitive to the ratio of the height above the bridge z to the “step height” H (the bridge-to-deck distance for bow-on flows and bridge-to-waterline for beam-on flows). A normalized height z/H of 0.4 or greater is desirable to keep speed distortion to about 10%. The case of bow-on flows over container ships is complicated because the ship’s geometry changes with the number of containers loaded and their distribution. It was suggested that wind bias estimates could be made using the VOS data by comparing beam-on winds speeds (corrected for flow distortion) with un-corrected bow-on speeds.

2. PROGRAM STATUS

The Ships of Opportunity Program has been managed as three tasks: A) VOS Field Operations, B) Instrumentation Upgrades, and C) Data Processing. When submitting our work plans for 2008 last year, we presented a plan to refocus this effort that met with agreement. We took the position that we now had in hand a sufficient body of data from VOS, were facing continuing challenges in identifying suitable ships on desirable routes, and were finding increasing challenges in upgrading the instrumentation common to our VOS and Ocean Reference Station (ORS) moorings. As a result, we proposed ramping down for now VOS Field Operations, while maintaining support for the Instrumentation Upgrades and Data Processing components. This proposal was agreed upon and we reduced our request in this project from $680,699 to $489,735.

Moving forward, the VOS program will no longer be identified or reported on separate from the Ocean Reference Station (ORS) project. Instead, in preparing the work statement and budget for 2009 we have brought our entire effort under the ORS project. The VOS Instrumentation Upgrades effort is now included within a new element of the ORS project, Sustaining Engineering. The instrumentation development and upgrades that in the past supported both VOS and ORS efforts now targets just ORS. Continued work on VOS data processing will be supported at a modest level within the existing NTAS Analysis budget.

3. ACCOMPLISHMENTS

3.1. VOS Field Operations

This is the final year of field operations while we ramp down the data collection effort. We have typically supported ASIMET installations on two ships, and this was the case during the reporting period. A first-order challenge is the short lifetime of a given ship on a given route. Our longest running vessel has been the Horizon Enterprise, doing the Oakland -Hawaii-Guam-Taiwan-Tacoma run (Figure 1). The second VOS was an Atlantic ship (originally the SeaLand Express and then the Merkur during 2004-2005). In February 2006, the Atlantic ship was sold and our Atlantic VOS operations were discontinued. At present we are maintaining two Pacific installations, the Horizon Enterprise and the Horizon Hawk. This includes the preparation and calibration of the systems, and recovery of the raw data as well as the ancillary time series of ships’ position and velocity. The Enterprise stopped going all the way across the Pacific, and now runs between the West Coast and Hawaii (Figure 2a). Recognizing the value of the complete trans-pacific route, an AutoIMET system was installed on the Horizon Hawk, which runs from the west coast to Hawaii, Guam, Taiwan, Hong Kong, and back to the west coast (Figure 2b).

Horizon Enterprise   Horizon Hawk

Figure 2. Recent routes for the Horizon Enterprise (left) and Horizon Hawk (right).

Specific activities relating to supporting the VOS Horizon Enterprise and Horizon Hawk during the reporting period are listed below:

- September/October 07, Tacoma, WA and Oakland, CA: Meet the Hawk in Tacoma for a new AutoIMET installation, sail with the Hawk to Oakland to complete the installation. Return to Tacoma to meet the Enterprise for an AutoIMET calibration turn-around.

- November/December 07, Oakland CA: Meet the Enterprise and the Hawk to repair their AutoIMET humidity and wind sensors, respectively.

- January 08 Tacoma, WA and Oakland, CA: Meet the Hawk in Tacoma for AutoIMET repairs, sail with the ship to Oakland for evaluation.

- March 08, Honolulu, HI: Meet the R/V Kilo Moana to install an AutoIMET system for the WHOTS ORS mooring recovery cruise in June; prepare the AutoIMET installation on the Enterprise for her upcoming shipyard period (take down most sensors).

- April 08, Oakland CA: Meet the Hawk for a standard AutoIMET calibration turn-around.

- June 08, Oakland CA: Meet the Enterprise following her return from the shipyard to re-install AutoIMET wind component only. This represented the termination of full AutoIMET data acquisition and SEAS data distribution on the Enterprise.

- July/August 08, Tacoma, WA: Meet Horizon Enterprise and Horizon Hawk for wind sensor repairs. A decommissioning trip planned for early 2009 will represent the termination of AutoIMET data acquisition and SEAS data distribution on the Hawk.

3.2. Instrumentation Upgrades

The VOS are a challenging operating environment in which to make high quality surface meteorological observations. Performance evaluation and sensor failures have shown the need to upgrade some sensor modules to address problems. Prototype new sensor modules are built and tested at WHOI and in the field and are then phased into use on the VOS and ORS moorings. Two examples of note relate to wind and longwave radiation. Early wind deployments showed the need for a dedicated GPS system coupled to the wind measurement, and development work was done to provide GPS as part of the VOS installations. Experience over multiple deployments showed the vulnerability of the mechanical propeller and vane wind sensor on VOS installations, and led to the development of a new ASIMET wind module based on a Gill sonic anemometer (Figure 3) that is under test now as a replacement for the current mechanical sensor.

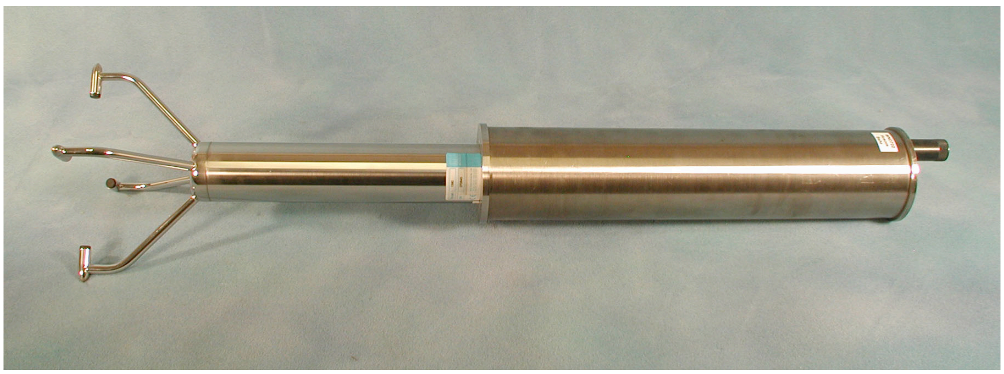

Figure 3. ASIMET sonic anemometer module based on a Gill OceanObserver II.

Examination of repeated pre- and post-deployment calibrations, and efforts to get close agreement (to roughly 2 W m^{-2}) in calibrated sensor modules identified the incoming longwave radiation module as introducing the largest uncertainty in our heat flux estimates. Effort was focused on modifying module electronics, improving calibration procedures, and evaluating alternate sensors. Specifically, a new “front end” circuit board (preamplifer for the thermopile voltage from the longwave sensor) has been developed and implemented in an upgraded longwave module using the Eppley sensor. In addition, a longwave module based on a Kipp and Zonen CP-4 sensor has been developed and tested. Intercomparison with longwave sensors from Chris Fairall’s group during cruises on the NOAA Ship *Ronald H. Brown* showed we were successful in improving ASIMET longwave performance.

Within the last few years we have found that some of the components in our ASIMET circuit boards are no longer available or soon to be obsolete, including the digital memory cards used to log the data and specific circuit board components. As a result, upgrades are being made to the ASIMET electronics. The PCMCIA-type flash memory (which is getting hard to obtain and is difficult to use) is being replaced by digital flash memory. Obsolete parts and cold sensitivities are being identified in conjunction with design of a new processor board.

At the same time, under this effort, we have gone forward with an effort to develop the capabilities within the ORS/ASIMET instrumentation to collect subsurface ocean data on ORS moorings, bring it up to the surface by inductive and acoustic telemetry methods, and integrate this averaged (and thus decimated to a reasonable volume) subsurface data into the telemetered data stream coming from ORS. In support of this we also worked at implementing Iridium-based data telemetry. Full implementation of this pathway for the ORS must, however, await NOAA arranging a tariff agreement that would reduce to cost to us of using Iridium.

3.3. Data Analysis

The basic deliverable of the VOS program is the data, supported by the appropriate metadata. Descriptions, technical information and raw data from the several VOS being serviced can be accessed through on our VOS website: http://uop.whoi.edu/projects/VOS/vos.html. Data (plots) are presented for all ship sets. Quality controlled data files are available for the VOS Enterprise for April 2002 through May 2006. Data from other cruises are available by request from Frank Bahr (fbahr@whoi.edu).

In addition to data processing to produce quality controlled files for each VOS, effort under this task includes the use of VOS data to develop information about the accuracy of flux fields on basin scales and the spatial variability and coherence of surface meteorological fields. Our initial focus was on results from VOS tracks passing near the NTAS buoy at 15 N, 51 W. Tracks from the VOS Merkur in 2004 resulted in six "encounters" where the ship passed within a 500 km radius of the buoy (Figure 4). The duration of a typical encounter was about one day. Auto- and cross-correlation analyses, showed that auto-correlation times for both buoy and ship meteorological variables are from 3-6 h, barometric pressure and shortwave radiation show correlation between buoy and ship (due to the atmospheric tide and diurnal solar cycle, respectively), and other variables have weak or no correlation. This work can be extended using time series records from nearby NDBC buoys (Figure 4) as well as shipboard meteorological data from the NTAS mooring service cruises.

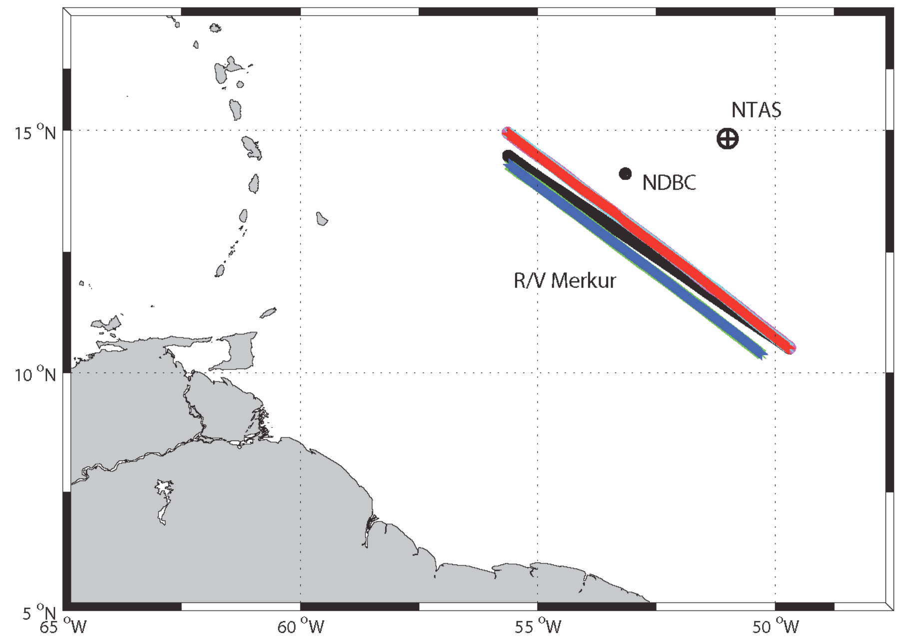

Figure 4. Ship tracks for 6 passes of the VOS Merkur within 500 km of the NTAS ORS.

Data from the Horizon Enterprise, which crosses the North Pacific on an approximately 5-week schedule, are the most complete and provide the most extensive spatial coverage. These data were used in two studies comparing in-situ meteorology with that from the ECMWF numerical weather prediction model. The first study focused on the ~2400 mile segment between Oakland, California, and Honolulu, Hawaii. Surface meteorology from the VOS was compared with that from the ECMWF model for 29 transects during 2003 – 2006 (Figure 5). Most variables showed good agreement in the mean, but large standard deviations indicated shortcomings in of the ECMWF model on short spatial scales. Some variables did have notable mean differences, for example ECMWF wind speed was ~2 m/s less than the VOS on average. The second study focused on downwelling longwave irradiance (LWR) observed from 10 round-trips along the full north Pacific route during calendar 2004. The VOS observations were compared to LWR from two global model products – the NCEP-2 reanalysis and the International Satellite Cloud Climatology Project (ISCCP) longwave product. Annual mean values along the VOS tracks and the seasonal cycle at several fixed locations were compared.

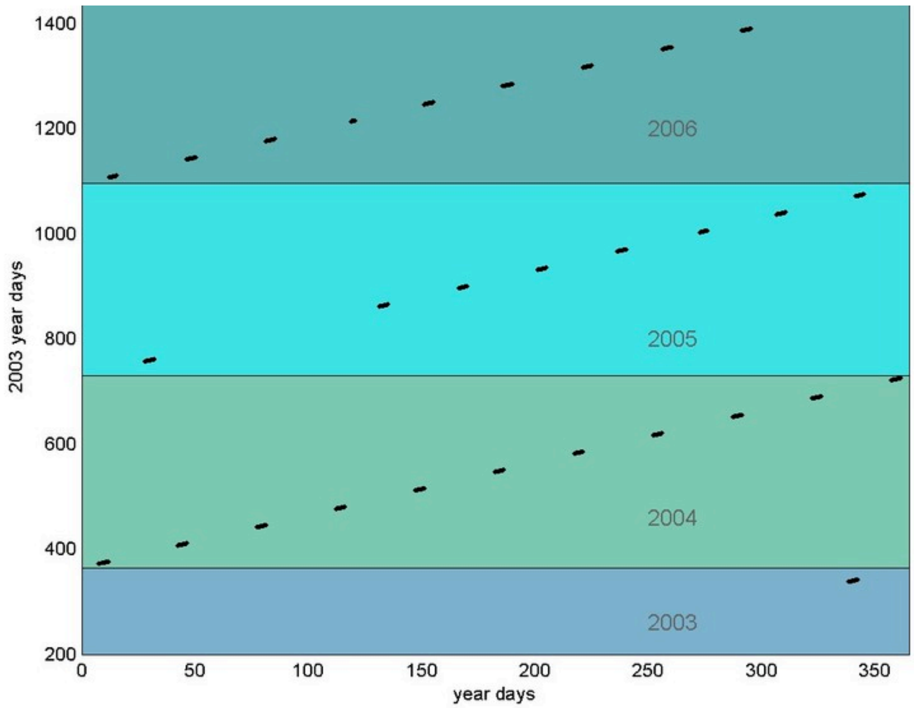

Figure 5. Season vs. year breakdown of twenty nine VOS Horizon Enterprise transects between Oakland CA and Honolulu for the period 2003 – 2006.

Comparisons of annual mean LWR along the northern VOS route showed ISCCP to be consistently more accurate than NCEP, whereas NCEP was more accurate along the southern route (Figure 6). This behavior is consistent with the annual mean difference (NCEP – ISCCP), which indicates a change in the relative amplitudes along 40 N. Applying meridional corrections of opposite slope, increasing NCEP by about 20 W/m to the N and ISCCP by 20 W/m to the S, would improve the comparison with VOS observations. Comparison of the seasonal cycle in selected regions showed relatively good agreement among VOS, NCEP and ISCCP where the cycle amplitude was strongest. The VOS data indicate that the 'tongue' of strong seasonal variability extends further to the east than shown by NCEP and that there is a weak seasonal cycle to the south that is not captured by NCEP or ISCCP. Further work will include extending the analysis period from one to three years, improving the space and time registration of the comparison (e.g. by using daily NCEP and ISCCP data along the individual VOS tracks rather than monthly data along the average track), and including ORS moorings at the WHOTS and KEO sites as tie-down points.

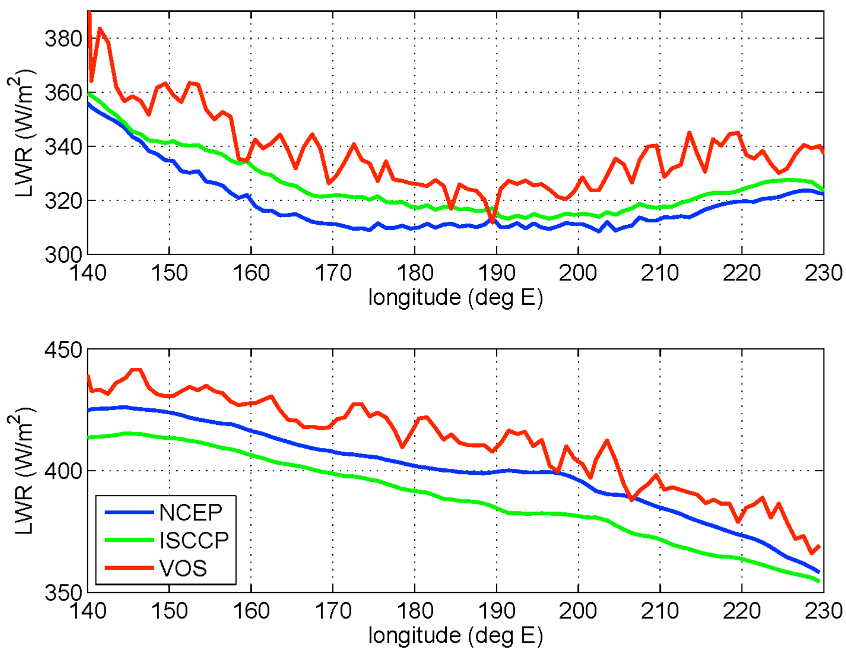

Figure 6. Comparison of longwave radiation (LWR) form the VOS Horizon Enterprise (red), the NCEP-2 reanalysis (blue) and the ISCCP flux product (green). The upper panel is along the northern leg of the north Pacific route (Figure 1) and the lower panel is along the southern leg.

4. PUBLICATIONS AND REPORTS

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