Synthesis of Basin Scale Air-Sea Flux Fields

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Introduction

New basin-scale air-sea flux fields are being developed based on the following strategy:

- Obtain time-series data from surface flux reference sites in key meteorological regimes around the world. The reference sites are occupied by surface moorings with accurate, well-calibrated sensors. Observations are extended over multiple years by "re-seeding" the site with a new mooring.
- Obtain spatial information by equipping research vessels and volunteer observing ships (VOS) with the same high quality sensors as on the moorings. The VOS that run high-resolution XBT lines and/or pass near flux reference sties are the highest priority for installation.
- Ensure accuracy by rigorous calibration procedures. Sensors go through laboratory calibration procedures both before and after deployment, supplemented by field comparisons.
- Use these in-situ fluxes as part of an assimilation effort that brings in satellite remote sensing data and surface meteorology from global numerical weather prediction (NWP) models.

Further details of this strategy and an example of new surface flux fields for the Atlantic are described below.

The ASIMET System

The Air-Sea Interaction Meteorology (ASIMET) system is a suite of meteorological and sea surface sensors that are deployed with different housings and packaging depending on the application: Buoys (Fig. 1), ships (Fig. 2), or special purpose installations. ASIMET modules (one or more sensors plus front-end electronics) may be self-powered and self-logging, connected to a central power supply and logger, or both. Together, these modules measure Air temperature (AT), specific humidity (SH), sea surface temperature and conductivity (SST, SSC), wind speed and direction (WSPD, WDIR), barometric pressure (BP), shortwave radiation (SWR), longwave radiation (LWR), and precipitation (PRC). Data are recorded at one minute intervals. Observed meteorological variables are used to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

The companion poster by Weller et al. describes the ASIMET system, sensor calibration techniques, and field performance in more detail.

Figure 1 : A surface flux buoy in the Atlantic with ASIMET modules.

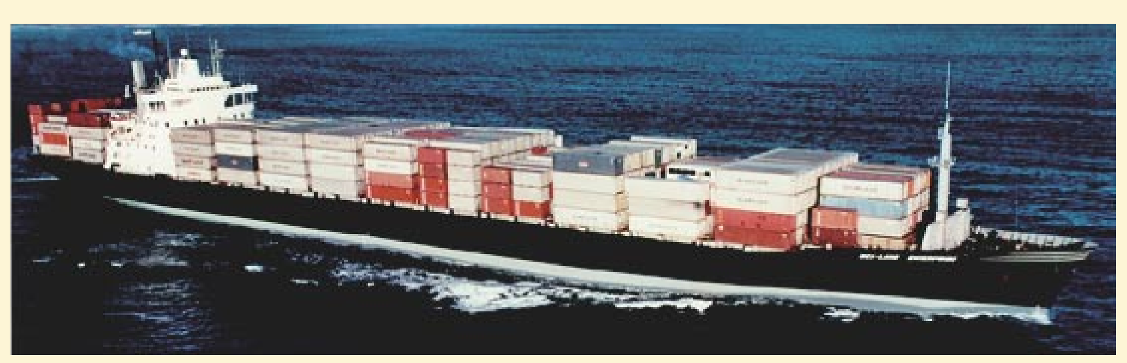

Figure 2 : A surface flux buoy in the Atlantic with ASIMET modules.

Comparison with NWP Models

As an example of ASIMET meteorology and fluxes vs. NWP models, we show results from the 2001 Northwest Tropical Atlantic Station (NTAS) flux reference site compared to model products from ECMWF and NCEP. The NTAS site is at approximately 15° N, 51° W, maintained through successive, annual turnarounds of a surface mooring. The ASIMET data were from the best performing sensors on the buoy. The ECMWF data were the output of the diagnostics module (DDH) for the grid point nearest the buoy. The NCEP data were extracted from the nearest grid point in the NCEP/NCAR Reanalysis data set. The ASIMET (1 min) and ECMWF (1 hour) data were averaged over six hours to match the NCEP time base.

			ECMWF		NCEP	
Label	Variable	Units	Mean	StdDev	Mean	StdDev
AT	air temperature	°C	0.1	0.6	-0.2	0.6
SH	specific humidity	g/kg	-0.4	0.6	0.7	0.9
BP	barometric press	mb	0.2	0.6	-5.2	2.0
SST	sea temperature	°C	-0.2	0.4	-0.3	0.3
PRC	precipitation	mm/hr	0.1	0.3	0.1	0.3
LWR	longwave rad	W/m^2	3	11	-1	16
SWR	shortwave rad	W/m^2	-24	77	1	85
WSPD	wind speed	m/s	-0.7	1.2	0.0	1.4
WDIR	wind direction	deg	6	14	-1	14
Qs	sensible heat	W/m^2	0	6	-2	9
Ql	latent heat	W/m^2	-15	31	-12	46
SWn	net shortwave	W/m^2	-21	72	-20	81
LWn	net longwave	W/m^2	2	11	-3	16
Qnet	net heat flux	W/m^2	-33	77	-37	90

Table 1: MWP models–ASIMET

The results are shown in Table 1. For many of the meteorological variables the mean differences are within the expected accuracy of the buoy sensors. The most notable discrepancies are NCEP BP and ECMWF SWR. The small difference standard deviations for ECMWF BP and LWR indicate that variability on short time scales is being captured successfully by the model. In contrast, SWR, WSPD, and WDIR have difference standard deviations much greater than the sensor accuracy, indicating significant discrepancies in the model fields on short time scales. The difference statistics for heat flux components indicate that the models to relatively well in estimating Qs and LWnet, but have significant errors in Ql and SWnet. The mean errors in Qnet are 2-3 times larger than the expected error of 10-15 W/m2 from the buoy. The large difference standard deviations for Qnet indicate that both models have shortfalls in capturing variability on short time scales.

Net Heat Flux Comparisons

Monthly average net heat flux estimated from selected surface mooring data sets in a variety of meteorological regimes are used for comparison of in-situ and modeled heat flux over periods of 1-2 years (Fig. 3). Five different in-situ time series are presented from surface mooring data in the Atlantic, Pacific, and Indian Oceans. NWP models are represented by the ECMWF operational forecast model and the NCEP Version 1 and 2 reanalysis-forecast models. Flux climatology from the Southampton Oceanography Center (SOC), which is based on VOS reports from 1980-1993, is also included. All buoy fluxes were computed using the TOGA COARE bulk flux algorithm (2.6b), whereas the NWP models and the SOC climatology use their own flux algorithms.

Distinct seasonal cycles are evident in the two year records from the Subduction mooring in the subtropical north Atlantic and the STRATUS mooring in the southeast tropical Pacific. Seasonal variability is less dramatic at the PACS site in the tropical Pacific and the NTAS site in the northwest tropical Atlantic. The Arabian Sea site shows the strongest short-term variability. The NWP and SOC fluxes tend to capture the seasonal cycles, but short-term discrepancies of tens of W/m2 and persistent biases of up to 50 W/m2 indicate the regional shortcomings of these global data sets. Certain sites and seasons (e.g. PACS-winter, NTAS-spring) show particularly large discrepancies. In several cases the 13 year SOC climatology shows better agreement with the buoy flux than the NWP model run for that year.

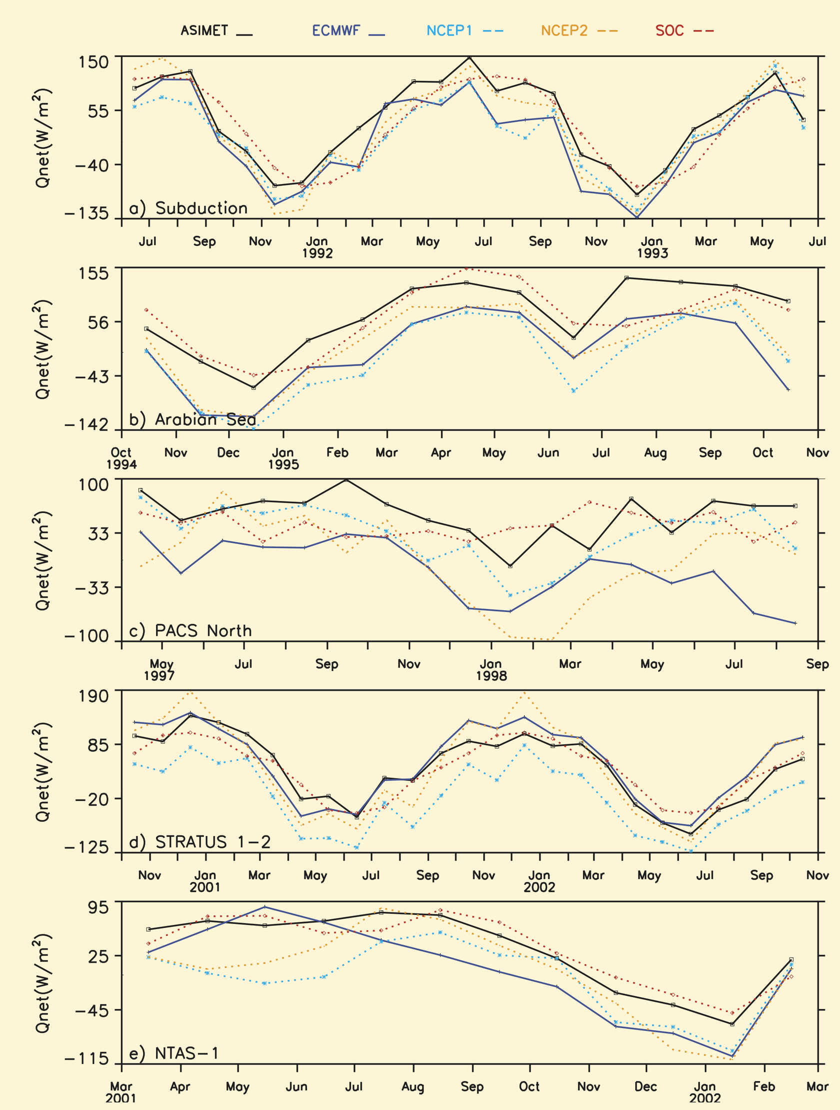

Figure 3. Time series of monthly averaged net surface heat flux (Qnet) at 5 different surface mooring sites. In-situ fluxes computed from ASIMET surface meteorology using the COARE 2.6b algorithm are compared with fluxes from ECMWF and the NCEP version 1 and 2 reanalysis. The SOC flux climatology is also shown.

Synthesized Flux Fields for the Atlantic

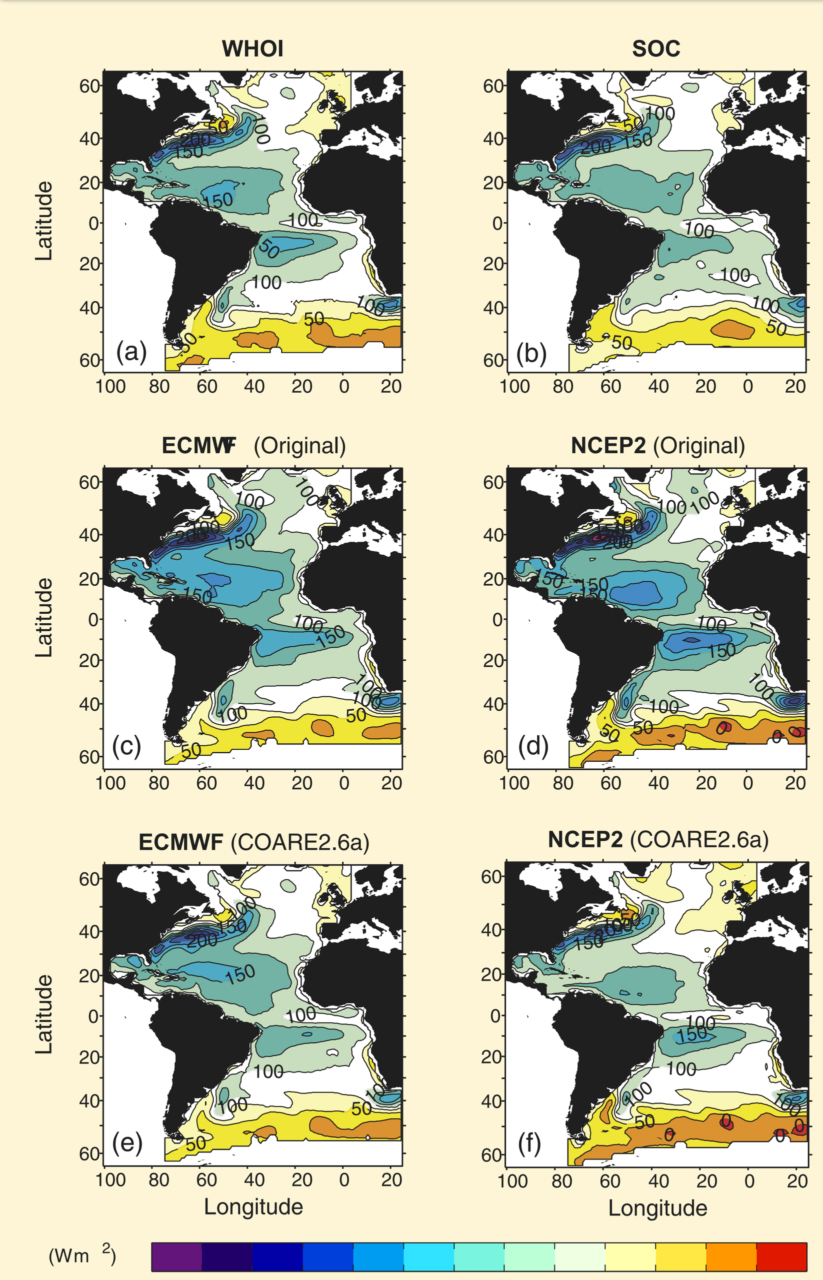

Figure 4. The sum of latent and sensible heat flux, averaged over the period 1988-1997 from (a) the WHOI objective analysis, (c) the ECMWF operational analysis, and (d) the NCEP2 reanalysis. Also shown is (b) the SOC climatology. The (e) ECMWF and (f) NCEP2 fluxes were recomputed from surface meteorology using the COARE algorithm

A daily analysis of latent and sensible heat fluxes for the Atlantic Ocean (65° S to 65° N, 1x1° resolution) for the period from 1988 to 1999 was created from a synthesis of several data sources and a weighted objective analysis. Surface variables included wind speed and specific humidity from the SSMI, SST from the AVHRR, and surface analyses from the ECMWF operational forecast model and the NCEP Version 2 Reanalysis-forecast model. Sensible and latent heat fluxes were computed using the TOGA COARE bulk flux algorithm. Since the solution from the objective analysis has the minimum error variance and the COARE algorithm represents the state-of-the-art for bulk flux estimation, improvement is expected over the flux fields generated by ECMWF and NCEP. In order to separate out differences due to improved surface variables from those due to the bulk flux algorithm, the ECMWF and NCEP fluxes were also re-computed using the COARE algorithm.

The resulting long-term mean heat flux (sensible plus latent) fields are shown in Fig. 4. All six flux products have a similar depiction of major sensible and latent heat exchange centers, but vary in magnitude. The overall magnitude of the WHOI fluxes is closest to the SOC analysis for the region north of 20° S, whereas the two NWP products overestimate latent and sensible heat losses over the entire basin. Re-computing the NWP fluxes using the COARE bulk flux algorithm changes the ECMWF flux moderately (10-15 W/m2) and the NCEP flux substantially (25 W/m2), but does not improve the comparison with SOC climatology. This indicates that the relatively good performance of the WHOI objective analysis results from both improvements in the surface meteorology and improvements in the bulk flux algorithm.

Validation Using In-Situ Observations

Basin-scale verification of the flux products is difficult because high-quality, independent data are relatively rare. Here we use in-situ observations from ships and buoys (Fig. 5) for validation. The in-situ observations are grouped into four regions: SUBDUCTION, which contains the five Subduction experiment buoys, COAST, which contains buoys from five field projects in the western north Atlantic, PIRATA, which contains twelve buoys in the tropical Atlantic, and KNORR, which includes two winter cruises from the Labrador Sea to Woods Hole. Comparison of daily time series from the WHOI objective analysis with the in-situ data showed that overall variability in sensible and latent heat fluxes was best represented in the SUBDUCTION and PIRATA regions. The fluxes were the least representative in the KNORR region.

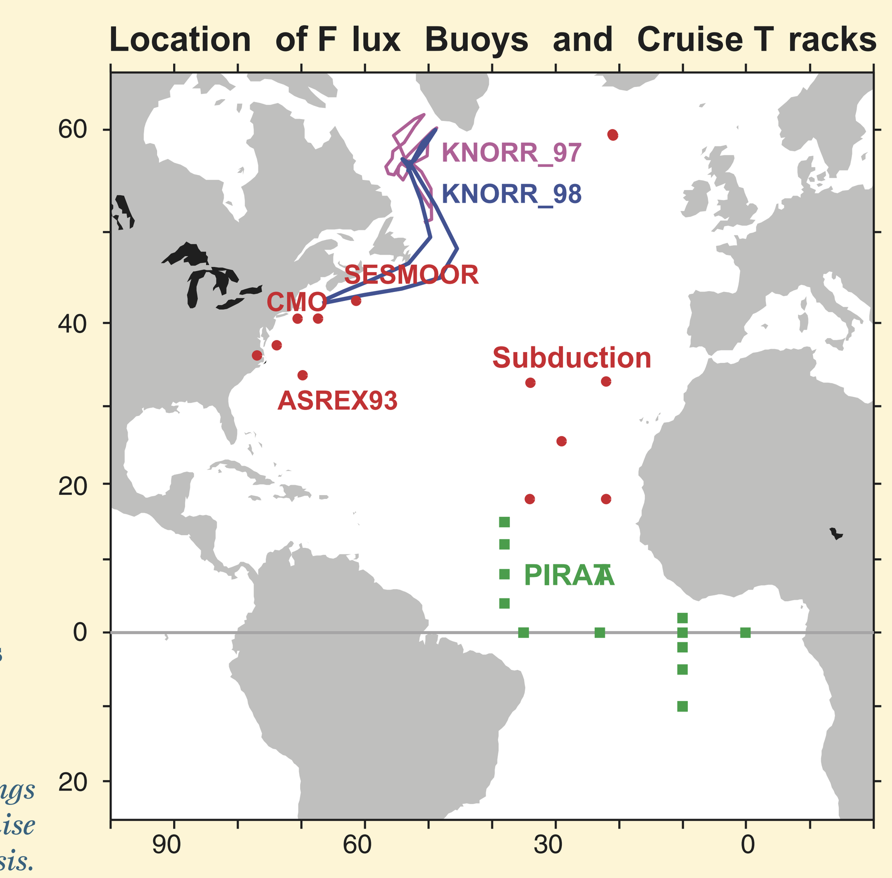

Figure 5. Locations of WHOI surface moorings (red), PIRATA array moorings (green) and cruise tracks (blue) used in the validation analysis.

Two statistical plots (Figs. 6 and 7) summarize the time-mean comparison of fluxes from the WHOI objective analysis, ECMWF, and NCEP2 with the in-situ observations for all four regions. The WHOI fluxes not only had a time-mean closest to the in-situ data in all regions, but also had the smallest standard deviation. The degree of improvement in surface meteorological variables was different for different regions. For example, wind speed from the WHOI analysis was closer to the in-situ values in the SUBDUCTION, COAST, and PRIATA regions, but not in the KNORR region. The most consistent results were for specific humidity, where the WHOI analysis was closest to the in-situ mean and had the lowest standard deviation at all four sites. The WHOI SST estimates were found to be the most sensitive to the quality of the input variables. For example, cloudy conditions during the comparison periods in the COAST and KNORR regions resulted in inconsistent AVHRR retrievals and an increase in the difference from in-situ SST. It is notable that ECMWF and NCEP2 overestimated latent and sensible heat losses at all locations by 10-35%. Still, the trend and year to year variations of the NCEP2 fluxes were consistent with the WHOI analysis and the SOC climatology. In contrast, the ECMWF fluxes showed discrepancies that may be related in part to the updating and revision of the operational model.

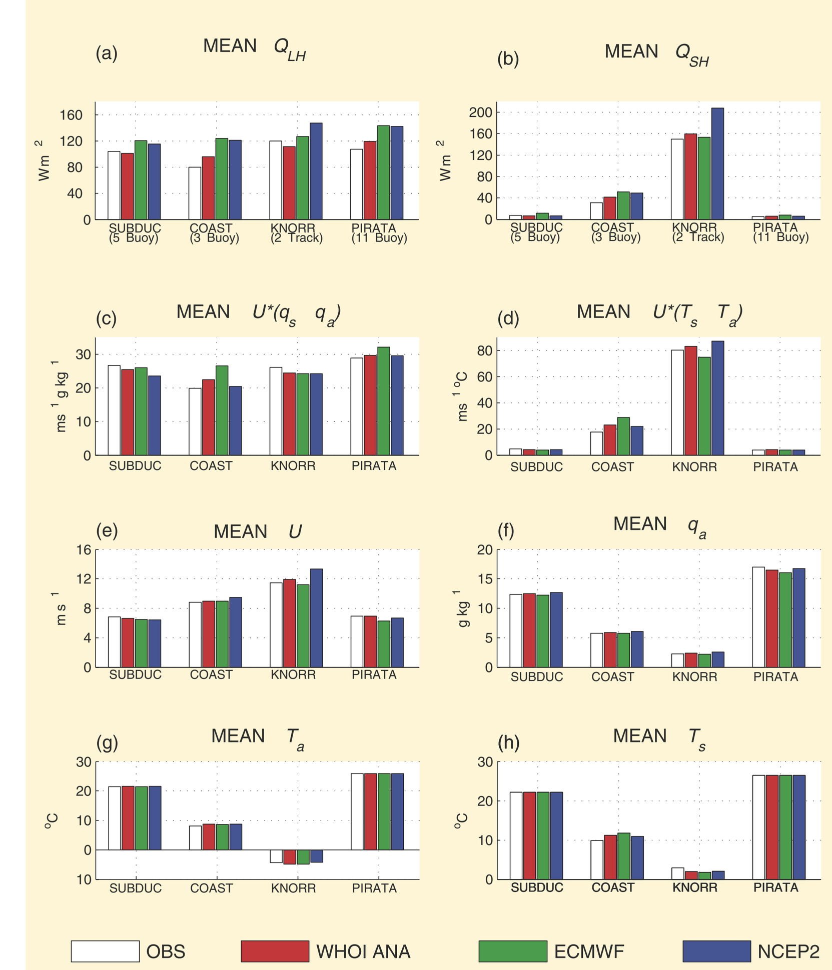

Figure 6. Comparison of mean latent and sensible fluxes, and flux-related meteorological variables, averaged over the buoy/ship measurement periods.

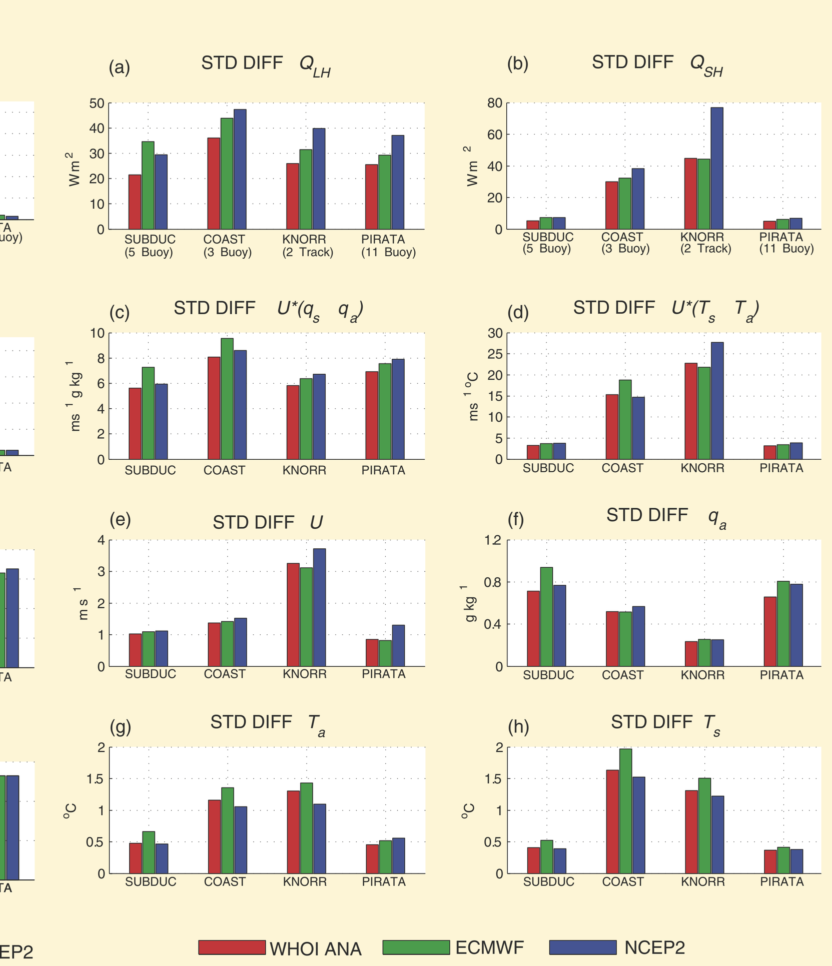

Figure 7 Comparison of standard deviations of daily differences between buoy/ship measurements and various products.

For Further Information

The Upper Ocean Processes Group: **http://uop.whoi.edu**
Archived surface mooring data: **http://uop.whoi.edu/uopdata**
The ASIMET system: **http://frodo.whoi.edu**
VOS Climate Project: **http://uop.whoi.edu/vos**
CSIRO Online: **http://www.csiro.au**
SOC Meteorology Team: **http://www.soc.soton.ac.uk/JRD/MET/met index.php3**