6B.2 **Sea Surface Fluxes and Analysis: Datasets and Services at NCDC and WCRP**

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ABSTRACT

Both the modeling and observation communities agree that accurate sea and land surface processes are key to the improvement of numerical weather prediction (NWP) and climate model forecast skills. In response, various World Climate Research Programme (WCRP) working groups initiated and promoted the Surface Flux Analysis (SURFA) and the Global Energy and Water Cycle Experiment (GEWEX) SEAFLUX projects. The SURFA objective is to establish a facility for the evaluation of surface fluxes and related parameters from NWP and climate models. This facility is equally useful for the evaluation of satellite-based fluxes and related parameters - the focus of the SEAFLUX.

The National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) participates in both projects and serves as the central archive for the SURFA datasets (http://www.ncdc.noaa.gov/oa/rsad/air-sea.html). The SURFA archive currently includes the *in situ* data from the OceanSITES (http://oceansites.org/) and the NWP model output from the European Centre for Medium-Range Weather Forecasts (ECMWF) and German Deutscher Wetterdienst Research and Development (DWD). Additionally, the NOAA National Centers for Environmental Prediction (NCEP) NWP and climate model simulations are archived at NCDC by the NOAA National Operational Model Archive and Distribution System (NOMADS; http://nomads.ncdc.noaa.gov). Satellite-based turbulent air-sea fluxes and related parameters are also being developed at NCDC. These include the global 0.25º seawinds and sea surface temperatures blended from multiple satellites and *in situ* observations, and retrievals of sea surface air temperature and humidity using a neural-network from the AMSU measurements onboard the NOAA polar orbiting satellites. The datasets are available through interactive web services (linked at http://www.ncdc.noaa.gov/oa/rsad/air-sea.html).

1. THE WCRP SURFACE FLUX ANALYSIS (SURFA) INITIATIVE AND IMPLEMENTATION

Project SURFA is an initiative of the WCRP Working Group on Numerical Experimentation (WGNE) and the Working Group on Surface Fluxes (WGSF). The ultimate objective of SURFA is to facilitate the evaluation of near real-time NWP model fluxes and related fields, over both land and ocean, against high quality reference data. The SURFA ideas and infrastructure will also be utilized to evaluate climate models and satellite observations using the most accurate direct in-situ observations available. SURFA is complementary to and has synergies with international atmospheric and oceanic reanalysis efforts and other WCRP programs such as the GEWEX SEAFLUX and LANDFLUX. It has been promoted by other WCRP working groups such as WCRP Observation and Assimilation Panel (WOAP) and Ocean Observations Panel for Climate (OOPC). SURFA is intended to benefit scientists seeking both historic and near-real time quantitative assessments of flux models, data and products. Presently, the SURFA NWP archive contains high-resolution (0.25°x0.25°) NWP fluxes, with much higher resolution than usually available from re-analysis data (e.g. for ERA-40 only about 160 km x 160 km).

The SURFA initiative began with the recognition by the modeling and observation communities that accurate descriptions of the sea and land surface processes are key to the improvement in the forecast skills of both NWP and climate models. The importance for accurate air-sea fluxes has been documented in numerous international reports (e.g., WCRP 112) and journal publications. Significant progress has been made through collaborative international efforts, including the improvement of empirical formulae used to estimate the fluxes (e.g., the bulk formulae for latent and sensible fluxes; Fairall et al., 2003; Brunke et al., 2003; and the radiative transfer model (RTM) for radiative fluxes through clouds, WCRP 112).

Nevertheless, present coupled ocean-atmosphere model simulations are subject to a variety of biases. Additionally, uncertainties in the most commonly used fluxes (Figure 1 as an example) are still mostly unknown and these flux estimates are not necessarily consistent with the processes in the ocean. Figure 1a shows the significant systematic differences among some popular flux products. Figure 1b shows the implied turbulent diffusivity when the sea bulk parameterization is used with data from World Ocean Atlas climatology (Toole et al 2004). Heat input into the ocean is underestimated, resulting in up-gradient turbulent heat flux at the pool bottoms, over the Atlantic warm pool regions for the following products: ECMWF fluxes (Gibson et al. 1997) over 12 months, NCEP-1 fluxes (Kalnay et al. 1996) over the later half of the year, and globally balanced COADS94 (da Silva et al. 1994) fluxes over the last two months of the year (Figure 1b). The results for the unadjusted COADS94 and SOC98 (Josey et al. 1998)

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fluxes were just the opposite. Although the fluxes were consistent with the ocean physical principles, they resulted in diathermal turbulent mixing rates that are larger than directly observed in the thermocline (e.g., Polzin et al., 1995; Gregg, 1998; Ledwell et al., 1998). This implies that the unadjusted COADS94 and SOC98 heat fluxes were likely overestimated. This is consistent with the global ocean heat flux surpluses, averaged to 30-40 W/m^2 globally, in the two products.

The SURFA project hypothesis is that scientists will better understand, predict, and mitigate the uncertainties and inconsistencies if they have access to ongoing comparisons of indirect flux estimates and related variables with direct in-situ observations. An example of this concept for solar flux cloud forcing is shown in Figure 2, where two reanalysis products are compared with three independent observations in the tropical Eastern Pacific (Cronin et al., 2006; Fairall et al. 2008).

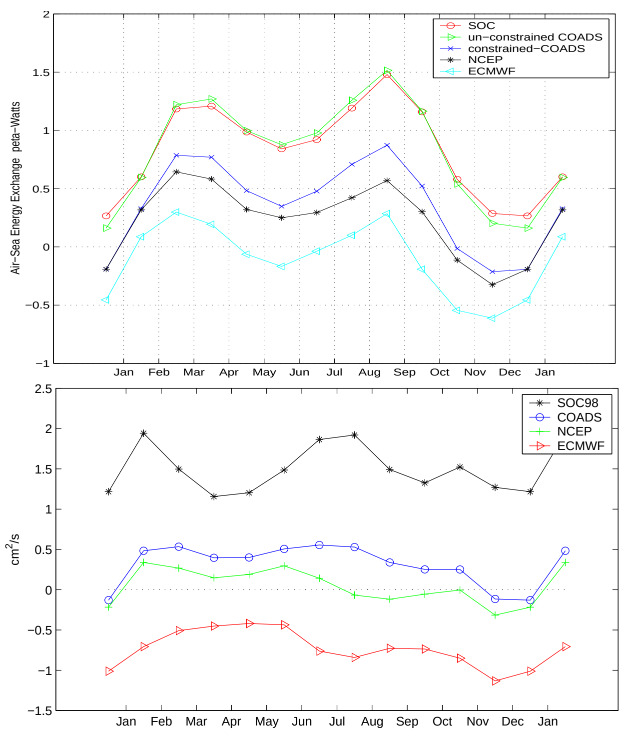

Figure 1: (a) – Upper Panel: Mean annual cycle of net heat input from the atmosphere to the Atlantic 27ºC warm water pool from several air-sea flux products (see inserted legend for details). Note the similarity in the annual cycle and offsets in values of the different products (Toole et al. 2004). (b) – Lower Panel: Mean annual cycle of the inferred average diathermal diffusivity at the Atlantic 27ºC warm water pool bottom from several air-sea flux products (see inserted legend for details) and WOA98 (NODC 1998) ocean data. Negative values indicate up-gradient turbulent fluxes (Zhang et al., 2002).

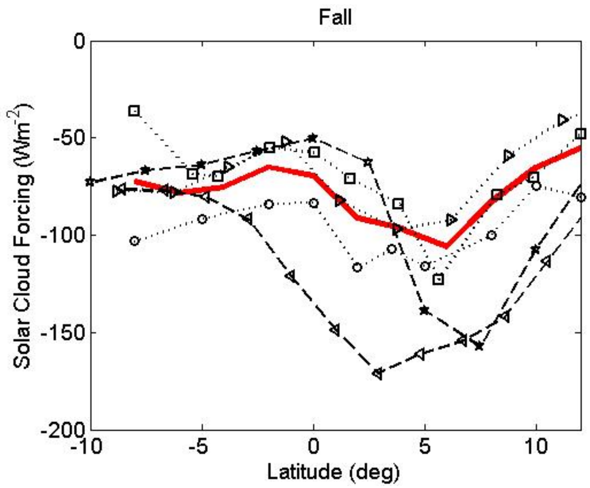

Figure 2: Cloud forcing as a function of latitude along 110/95 W averaged for October 1999-2003. The symbols for measurements are: TAO buoys – circle, NOAA ship data – square, ISCCP – right pointing open triangle, mean of these three - solid red line. The symbols for the reanalysis products are: NCEP2 – left pointing triangle, and ERA40 – star (Cronin et al., 2006; Fairall et al. 2008).

In the 22nd session of WGNE (October 2006), a joint WGSF and WGNE meeting was held to streamline the SURFA efforts, in particular to coordinate the two components of SURFA: NWP simulations and in-situ observations. Following this meeting, the WGSF and WGNE SURFA coordinators defined the SURFA variable list, data archive grid (in both time and space), and data format.

For NWP simulations, model fields are provided on a regular latitude-longitude grid with a spacing of 0.25° x 0.25°. The scanning mode is from 0°E, 90°N [index (1,1)] to 359.75°E/0.25°W, 90°S [index (1440, 721)], with the first index running from West to East, the second from North to South. Each field comprises 1440x721 grid points. The data are written in WMO GRIB-1 format. All forecasts start at 12 UTC. For accumulated values, where the accumulation starts at the 0-h forecast, and for instantaneous values which are valid at the given forecast range, the following forecast ranges are provided: +12h, +15h, +18h, +21h, +24h, +27h, +30h, +33h, +36h. Each forecast range is in a separate file.

The SURFA variables include two (2) time-invariant (constant) fields, sixteen (16) instantaneous fields, thirteen (13) accumulated variables, and three (3) optional variables; details can be found at the SURFA website (http://www.ncdc.noaa.gov/oa/rsad/air-sea.html).

The SURFA project both supports and benefits from NCDC's activities in the themes of scientific data stewardship and the global water and energy cycles over both land and ocean, as well as reanalysis efforts. Presently, NCDC supports daily ingest of NWP simulated SURFA fields from ECMWF and German DWD, as well as the ocean reference station observations from the OceanSITES.

Over the land surface, a parallel data comparison capability is underway through the Satellite Product Evaluation Center (SPEC), currently in development at NCDC in partnership with NASA's Oak Ridge National Laboratory (ORNL) Data Active Archive Center (DAAC). The SPEC project goals are to provide integrated operational monitoring of data products; to support quantitative calibration, validation and algorithm improvement; and to support broader NOAA initiatives [e.g., the National Polar-orbiting Operational Environmental Satellite System (NPOESS), the Global Earth Observation System of Systems (GEOSS), GEWEX, Committee on Earth Observation Satellites (CEOS), etc]. SPEC also supports NOAA's new Climate Data Record (CDR) Project.

SURFA and SPEC use web-based approach to allow for transparent access to collocated (time and space) data distributed among centers at different physical locations. It also facilitates easy downloading of the different datasets in user-preferred formats (using format neutral data serving). They will provide additional analytical tool modules to analyze and visualize the data and perform routine evaluation of different model and satellite data against high quality in situ data

2. BLENDED AIR-SEA FLUX RELATED PRODUCTS AT NCDC

This section describes the globally gridded high resolution air-sea flux related parameters that are blended from observations of multiple platforms (ships, buoys, satellites, etc). The integrated use of multiple-platform observations reduces both systematic bias errors and analysis errors of the blended products. A sampling study was first carried out for the feasibilities of producing various high resolution gridded products for sea surface wind speed using up to six satellite observations. Consequently, global 0.25° gridded sea surface wind speeds are produced for temporal resolutions of 6-hourly and daily. For many oceanography applications that use vector winds, wind directions are added from NCEP Reanalysis 2. The hybrid vector winds are available from July 1987 onward. The widely used NOAA/Reynolds Optimum Interpolation (OI) SST analysis has improved from 1° and weekly to 0.25° and daily and uses both microwave and AVHRR satellite observations. The Version 2 OI Daily SST products are available from Nov 1981 onward. A neural network approach is used to develop the retrievals of sea surface air temperature (Ta) and humidity (Qa) from the AMSU sounder onboard the NOAA series of satellites. Blended 6-hourly and 0.5° (Qa) or 1° (Ta) gridded products are being produced and will be available from 1998 onward.

2.1 *Sea surface Wind (SSW)*

Sea surface wind speed has been observed from long-term multiple satellites, ranging from one in the mid 1987 to six or more since mid 2002 (Figure 1). Detailed sampling studies showed that on a global 0.25° grid, blended products with temporal resolutions of 6-hours, 12-hours and daily have become feasible since mid 2002, mid 1995 and January 1991, respectively (Zhang et al. 2006a). Thus four times per day global 0.25° snapshots have been produced since mid 1987 using spatial and time windows of 125 km and 12-hours. A 3-D near Gaussian interpolation was used to minimize aliases for the 6 times per day instantaneous fields. Figure 3 shows the time-line of satellite observations (left panel) and the spatial observation pattern (right panel). Figure 4 shows an example of the blended sea winds; vector plots are subsampled for viewing clarity.

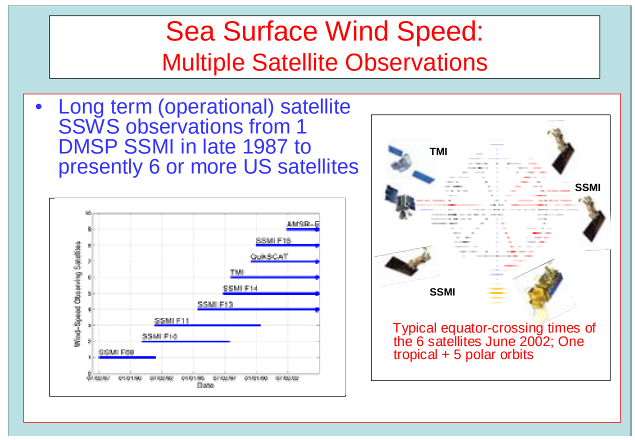

Figure 3: Timelines and tracks (schematic) of satellites that observe sea surface wind speeds.

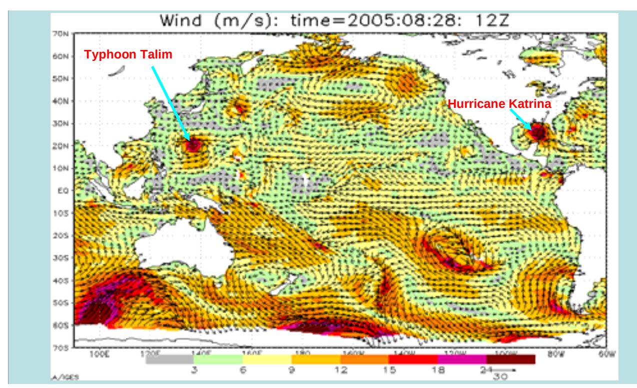

Figure 4*:* An example of the blended sea winds at 6-hour intervals. Note the simultaneous Typhoon Talim and Hurricane Katrina at this particular time.

2.2 *Sea surface temperature (SST)*

The widely used weekly and 1° grid NOAA/Reynolds OI SST analysis (e.g. Reynolds et al. 2002) has been improved with higher resolutions (daily and 0.25°) and using multiple satellites (both infrared and microwave) and in-situ data. An advantage of the microwave observations (e.g., from AMSR-E) is that it can see through clouds, thus provide much more data coverage over clouded areas and time periods. The new versions (Reynolds et al. 2007 and subsequent upgrade to Version 2) have the great improvements in term of resolving ocean features such as the meandering of the Gulf Stream, the Agulhas Current, the equatorial jets, etc (Figure 5). These are important because these regions have strongest air-sea interactions and modifications.

In all the OI SST analyses, satellite biases are corrected with regard to the in-situ observations. The satellite bias corrections are important for climate studies and monitoring. An efficient and sufficient in-situ network has been designed (Zhang et al. 2006b) and has become operational as part the Global Ocean Observing System (GOOS; Zhang et al 2009).

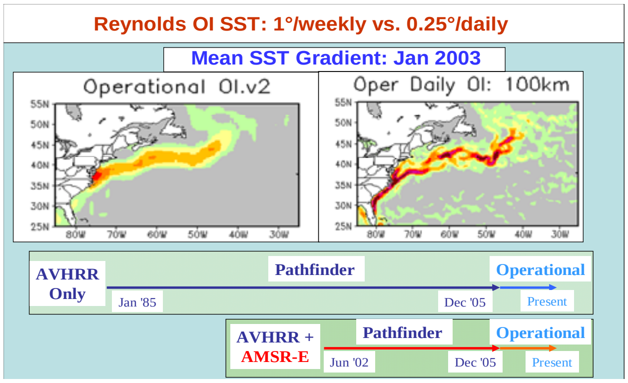

Figure 5: A comparison of the old and new Reynolds OI SST analyses. Shown are the spatial SST gradients for Jan 2003. The left is for the old weekly 1° OI SST (Reynolds et al. 2002); the right is for the new daily 0.25° OI SST. The bottom panels show the timelines of the available new OI SST analyses.

2.3 *Sea surface Air temperature (Ta) and humidity (Qa)*

The Ta and Qa retrievals are based on measurements from the AMSU sounder onboard the NOAA series of satellites (Shi and Zhang 2009). The Ta retrieval uses AMSU-A data, while the Qa retrieval uses both AMSU-A and AMSU-B observations. The Ta and Qa retrieval algorithms are developed using the neural network approach. The training datasets are constructed using co-located AMSU and buoy/ship data. The computation shows that the global RMSE for Ta is 2.11°C and 1.22 g/kg for Qa (Fig. 6). Retrievals are being computed for NOAA-15, -16 and -18. Blended and gridded products are developed.

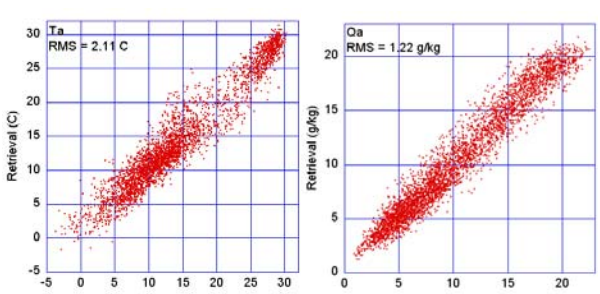

Figure 6: Scatter plots of retrieved Ta and Qa against independent in situ observations.

2.4 *Turbulent Air-Sea Fluxes*

With the blended and gridded products of sea surface winds, sea surface temperature, and sea surface air temperature and humidity, turbulent air-sea fluxes can be computed from the Bulk formulae. Currently we are using the TOGA COARE 3.0 for the turbulent flux computation. COARE 3.0 has an embedded subroutine to calculate cool skin and warm layer effects, thus diurnal cycle effects could be partially accounted for. The needed radiation fluxes are from NASA ISCCP-FD RadFlux (Zhang et al 2004).

3. DATA ACCESS

More detailed data descriptions and accesses can be found through the links at the NCDC Website: http://www.ncdc.noaa.gov/oa/satellite.html, then click on your desired products. Most of the datasets are accessible by multiple methods, including ftp, OPeNDAP/TDS, and interactive graphic interface such as LAS, from which one can do subsetting and downloading in one's desired formats (e.g., ascii/text, images, netCDF, IEEE binary, arcGIS, etc).

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