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on Surface Fluxes

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New challenges for WGSF

During the second half of 2007 and the beginning of 2008 the WCRP WGSF will face an important transition. According to the terms of references of WGSF as formulated by the JSC in Reading in 2003 (JSC-24), WGSF will complete its first stage. However, different WGSF projects and activities during the last couple of years posed new requirements for quantitative estimation, parameterization, and understanding of the variability of global air-sea fluxes. Of a special importance is the analysis of biogeochemical air-sea exchanges, quantifying in particular the role of the ocean in the global carbon dioxide balance. Furthermore, WCRP equally needs to carefully consider the air-sea energy and mass exchanges over land; this is a new challenging task for WGSF.

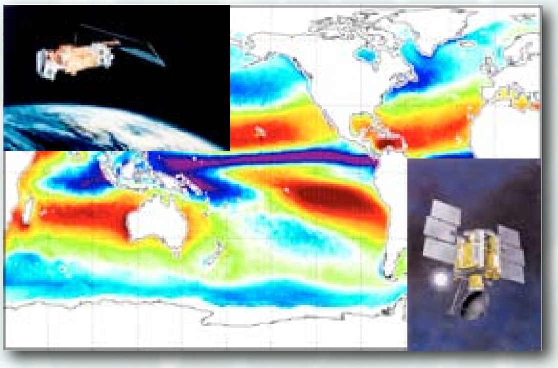
During the last years the WCRP core projects (CLIVAR, GEWEX, CLiC, SPARC) developed many activities in which air-surface fluxes play an important role. We can mention here: ocean reanalyses, SEAFLUX, OAFLUX, and numerous air-sea flux activities in high latitudes carried out under the IPY. These, along with a re-invigorated SURFA and enthusiastically supported WCRP JCOMM projects, such as VOSClim and wave operational activities, were in center of WGSF vision of the global air-sea interaction.

Over the last years, a new WCRP framework also organized its science through activities cutting across the core projects, such as Seasonal and Decadal Prediction, Sea Level Rise, Climate and Weather Extremes, Anthropogenic Climate Change, Monsoons, and others. All of these require extensive quantitative analysis of all types of air-sea exchanges at practically all space-time scales. In this view, WGSF needs to develop an effective strategy to properly address the urgent requirements of these 'hot' climate themes. Finally, WGSF continues to successfully serve as one of the few joint activities of WCRP and IGBP being partly formed by SOLAS experts and providing synergy of the two programmes under the Earth System Science Partnership (ESSP).

Approaching this transition time, WGSF needs to critically review important achievements of the last 10 years (starting from 1997 when WGASF, the predecessor of WGSF was launched) and to develop an effective strategy for air-sea flux activities within WCRP science for the next 10-years. We need to provide an outline for a balanced and cost-effective WCRP activity to succeed the WGSF in the future. Beginning with this FLUX NEWS issue, we invite the broader surface flux community to contribute to the design of the future 'instrument' of air-sea interaction coordination under WCRP.

Sergey Gulev, WCRP Liaison with WGSF
Chris Fairall, WGSF Chair

In this issue:



CLIVAR's Ocean Synthesls and Synthesis Evaluation Efforts

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CLIVAR's Global Synthesis and Observations panel was developed to promote and seek to implement strategies for a synthesis of global ocean, atmosphere and coupled climate information through synthesis efforts. The spectrum of applications of ocean synthesis for climate variability and prediction purposes span over seasonal-to-interannual, decadal-to-centennial time scales. Although currently the emphasis is on global ocean synthesis efforts, GSOP is also charged with a responsibility to promote the use of surface flux fields estimated in ocean syntheses and to develop surface flux data sets required by CLIVAR studies. This is supported WGNE, WGSF and the global atmospheric reanalysis efforts.

By combining ocean observations with state-of-the-art models, one can obtain an analysis of the time-varying ocean that, when taking into account errors in data and models in a mathematically rigorous way (and only then), must necessarily be more complete and better than the information from either of them alone. This is the heart of the ocean state estimation (often referred to as "data assimilation") which has as its goal to obtain the best possible description of the changing ocean by forcing the numerical model solutions to be consistent with the observed ocean conditions. This by itself is a very effective way to obtain a most complete description of the changing ocean from a limited set of observations. But at the same time it also identifies model components that need improvement, including initial conditions, surface forcing fields or internal model parameters. Therefore, the initial potential temperature (T) and salinity (S) fields are modified, as well as the surface forcing fields are adjusted in the state of the art assimilation efforts to bring the model into consistency with the observations. Changes in those fields (often referred to as "control" terms) are determined as a best-fit (in a least-squares sense) of the model state to the observations and their uncertainties over the full data period. As a result, the ocean state estimation, e.g. as provided by the ECCO consortium, does give an alternative to estimates of meteorological center provided surface flux fields, which are now determined so that the model optimally satisfies the available ocean observations. Ideally estimated surface flux fields should be consistent with reanalysis products or ship-based estimates. Any discrepancy can provide new information that may shed light on the quality of the atmospheric model, the ocean model or the *in situ* approach, or all together.

There are several ocean data assimilation efforts estimating the ocean circulation for the last 10 to 50 years. These applications serve various purposes such as forecasts, nowcasts or most accurate hindcasts. Consequently, they cover a range of accuracy and robustness requirements. Among those efforts that attempt to preserve model dynamics are the results from the ECCO consortium, using an adjoint of the ECCO/MIT model that is being adjusted over a decadal period to available ocean data. First global ocean state estimation procedures of the ECCO consortium go back to Stammer et al. (1997), followed by Stammer et al. (2002) and Köhl et al. (2007). The ECCO-GODAE effort is now continuing those early syntheses efforts more or less up–to-date on a 1° global grid (Wunsch and Heimbach, 2006). In parallel, results obtained from the German partner (GECCO) of the ECCO effort, cover also the last 50 years (Köhl and stammer, 2007a,b), going back to 1952 in parallel to the NCEP/NCAR or ERA40 atmospheric reanalyses. Data employed in those optimizations include essentially all available global data sets, e.g., the absolute and time-varying sea level, monthly mean sea-surface temperature data as well as scatterometry. Subsurface, the entire suit of hydrographic data are being used. At the surface, time-varying NCEP reanalysis fluxes of momentum, heat, freshwater, and NSCAT estimates of wind stress errors are used as constraints. Monthly means of the model state are required to remain within assigned bounds of the monthly mean Levitus et al. (1994) climatology.

An example of the ongoing 50-year long GECCO results (Köhl and Stammer, 2007a, b) are summarized in the Figure in terms of surface heat and freshwater fluxes estimated during the 50-year long optimization period. Shown, for comparison purposes, are similar fields from SOC and HOAPS. In both cases the large-scale structures agree; however, on regional and local scale, substantial differences can be encountered. Previously, Stammer et al. (2004) discussed the quality of surface flux fields estimated by the SIO ECCO effort over a 11-year period (Köhl et al., 2007) and showed that buoyancy flux adjustments are found to be within the crude prior error bars on these fields outside the boundary current regions. See Romanova et al. (2007) for details of a more recent analysis of GECCO surface fluxes with specific emphasis on surface freshwater fluxes.

As has already been mentioned, several groups have attempted ocean synthesis over the last 15+ years. Results from ECCO represent one high-quality example, and GECCO is another attempt of ocean reanalysis over the last 50 years. To understand the quality of each of those efforts, CLIVAR, in association with GODAE, is performing a global evaluation effort intended to determine, in a quantitative way, the skill, usefulness and limitations of all those existing synthesis approaches for climate research. For that purpose a comprehensive set of metrics, namely climate-indices and diagnostic quantities, has been proposed by a wide community, including CLIVAR basin panels. The first results of the evaluation effort can be found on the GSOP web page (http://www.

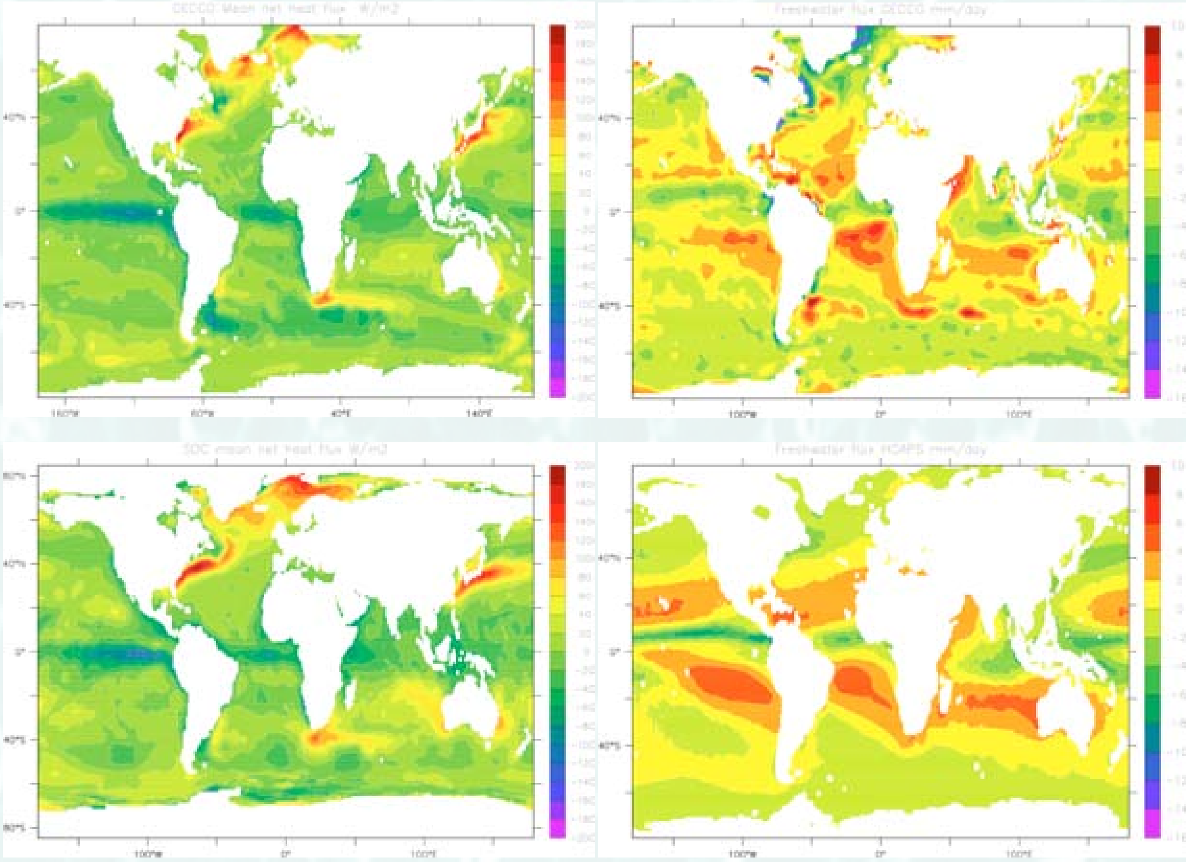

Figure. Upper panel: the mean net surface heat field as it results from the optimization. Lower panel: respective fields from SOC and HOAPS.

clivar.org/organization/gsop/synthesis/synthesis.php). As can be seen there, the evaluation effort includes a comprehensive discussion of the quality of surface flux fields, estimated by the more rigorous efforts.

As there are several surface flux products now, it was recommended by the GSOP panel that every new flux product should be compared against a reference flux data set to define regional or global differences. To guide the evaluation of new flux products from ocean syntheses, a white paper on flux evaluation was written by Josey and Shawn (2006), which is available from the GSOP web page (http://www.clivar.org/organization/gsop/synthesis/organization/gsop/docs/gsopfg.pdf). It is also intended to have a flux reference data set available on the GSOP web page in the near future.

To improve synthesis based surface flux estimates, error information about center-provided flux fields should be available. The need for such error covariances calls for every new reanalysis effort to be supplied with the information on its accuracy.

Before this becomes reality the community needs to think how to use the information provided by ocean reanalyses. Understanding the estimated changes relative to the NCEP/NCAR reanalysis or ERA40 in terms of errors in the ocean model will also help to identify errors in atmospheric models. At the same time we need to learn to use the results from ocean reanalyses to initialize coupled climate models, e.g., to improve their skill in the next climate assessment studies. Relevant efforts are now underway and we can expect much progress in this aspect over the next years, which might also include coupled assimilation efforts.

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Sea-ice flux in the Weddell Sea: New insights from an International Program for Antarctic Buoys drift experiment (IPAB) during Ice Station Polarstern in 2004

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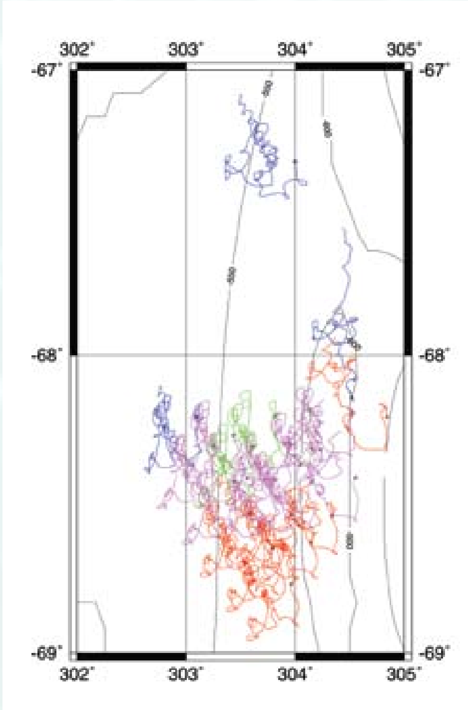

Figure 1. Drift tracks of 23 buoys deployed during the international ISPOL expedition of RV *Polarstern* in the western Weddell Sea (Heil et al., 2005). The Australian (red), US (pink), Finish (blue) and German (green) buoys were operated from Nov 28 to late December 2004.

Sea-ice drift is a significant component of the freshwater flux in the Southern Ocean. However, only little is known about major drift regimes and the underlying atmosphere-ice-ocean processes. Most information so far has been derived from drifting buoys deployed by the WCRP/SCAR International Program for Antarctic Buoys (IPAB). The IPAB aim is to maintain an observational network of drifting buoys in the Southern

Ocean south of 55°S, in particular within the sea-ice zone, to provide meteorological and oceanographic observations for real-time operational requirements and research purposes.

A proper representation of sea-ice fluxes in numerical models depends on correct parameterizations of ice dynamics, and of changes of the sea-ice thickness distribution as a function of ice deformation. The impact of these parameterizations varies regionally and largely depends on the prevailing ice regime. The western Weddell Sea is of particular importance for sea-ice advection and the associated freshwater transport, as it is one of the few regions in the Southern Ocean perennially covered by sea ice, and also holds some of the thickest Antarctic sea ice.

ISPOL

The IPAB drift experiment was performed during the German-led, international Ice Station Polarstern (ISPOL) campaign of the German research icebreaker RV *Polarstern* (Hellmer et al., 2006). The main goal of ISPOL was to study atmosphere-ice-ocean physical interactions, biological processes, and how they influence each other during late spring and during the onset of summer warming. For a period of five weeks, the ship was moored to an ice floe in the Western Weddell Sea to drift with the pack, and served as platform and laboratory for extensive physical and biological sea ice, meteorological, and oceanographic investigations.

During ISPOL in December 2004, IPAB participants from Australia, the US, Finland and Germany performed a dedicated drift experiment in the Western Weddell Sea to study small- and meso-scale ice motion and deformation, and to obtain unique information from this poorly studied region (Heil et al., 2005). Using the *Polarstern*'s helicopters they deployed an array of 22 buoys over a triangular region with a side length of 75 km (Figure 1). The array was deployed in a region previously identified by satellite radar imagery as a mix of first-year and second-year ice regimes. The array operated for a period of approximately five weeks, between November 28 and late December 2004. In addition one buoy was deployed to the north of the ISPOL array to provide information of the large-scale drift.

Meso scale ice deformation

Results of the ISPOL buoy array have recently been published by Heil et al. (2007). There was strong shear across the deformation array (Figure 1), likely as a result of bathymetry and proximity to the coast of the Antarctic Peninsula. While overall the northeastern buoys strongly drifted to the northwest, net differential motion over the western region was relatively small. During ISPOL net translation in the western part was westward, and even slightly south westward in the South. The net divergence of the ISPOL array was in excess of 30%. The whole array underwent an anti-clockwise rotation. Analysis of the sea-ice velocities revealed coherent sea-ice drift at separations of less

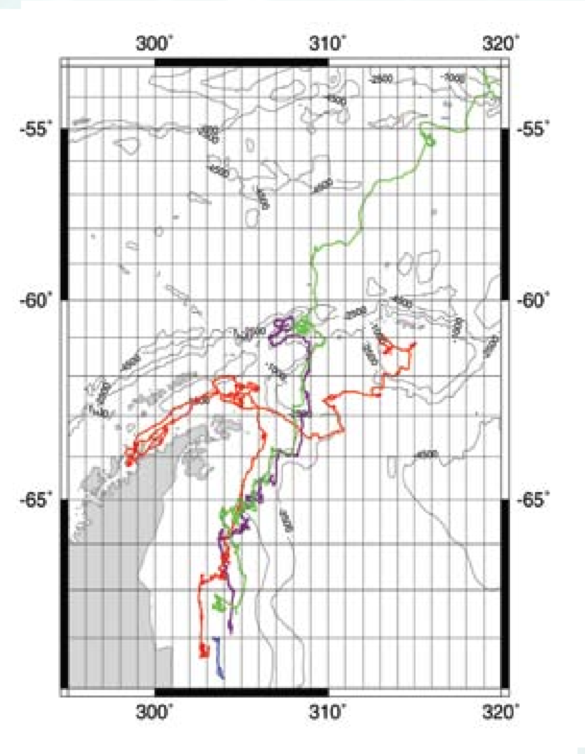

Figure 2: Drift of four remaining buoys in the Western Weddell Sea from late December 2004 through to mid June 2005. [Red: FIMR 1154; green: FIMR 5892; blue: AAD19020 (II); mauve: AAD19035 (II).] Bathymetric contours [at 600, 700, 800, 900, 1000, 2000, 3000, 4000 and 5000 m] are also shown.

than 70 km; and a correlation length scale of 60 km. Only about 40% of variability in the sea-ice velocity is explained by changes in wind velocity, which is significantly less than other studies have found for the region during winter (see Heil et al., 2007). The temporal variability for all deformation parameters was dominated by high-frequency (sub-daily) processes, due to tidal forcing and inertial response.

Large-scale drift after ISPOL study period

After completion of the meso-scale deformation study, one buoy remained on the ice and three buoys were re-deployed at the corner positions of the ISPOL array to contribute to the overall, long-term IPAB data set of large-scale ice motion, and to also provide measurements of surface air temperature and sea level pressure (Heil et al., 2005). The sea-ice drift is also representative for the drift of large numbers of icebergs in this region.

Figure 2 shows the drift of those remaining four buoys from January to June 2005. Buoy AAD19020 (Fig.2: blue) ceased operation in mid January 2005 and buoy AAD19035 in early June 2005. The remaining two show an interesting contrasting behaviour. While the easternmost buoy (Fig.2: green) closely followed the continental shelf break and left the Weddell Sea to the north, the westernmost buoy (Fig.2: red) remained on the shelf and turned westward into Bransfield Strait during austral winter 2005 before resuming north eastward drift in austral spring 2005. This difference in drift behaviour is indicative of extensive divergence at the outflowing branch of the western Weddell Gyre, with consequences for the freshwater flux in the region.

Acknowledgments

Our co-investigators and their institutions are thanked for access to their data, especially M. Johansson for post-ISPOL data of two FINNARP buoys. (Data are available via IPAB). The ISPOL buoy project was co-funded through IARC (IARC/JAMSTEC grant), AAD (Australian Antarctic Science grants 742, 2559 and 2678), the Finnish Antarctic Research Program (FINNARP), and AWI, and was supported by the Australian Government's Cooperative Research Centres Programme through the Antarctic Climate and Ecosystems Cooperative Research Centre. Our figures were compiled with GMT public domain software [Wessel and Smith, 1995].
IPAB website: http://www.ipab.aq
ISPOL website: http://www.ispol.de

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SOPHOCLES – Southern Ocean Physical Oceanography and Cryospheric Linkages

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This is a new project that will focus on model processes in Southern ocean–ice models ranging from those used on the time scales of climate change research through to those used for short term sea ice forecasting. The aim is broader than a model intercomparison, so the project will encompass how well the current models represent key Southern ocean processes, identify what processes are missing, and to develop and test new parameterizations of these processes that can be used in future generation models. We wish to engage with the observational community to use their data to constrain our models, in particular to take advantage of new satellite data, the fieldwork programmes that will occur during IPY and SOOS.

The aim is to consider all the components of the cryosphere that are in contact with the ocean, sea ice ice-shelves, circulation in ice shelf cavities, icebergs and freshwater fluxes from continental ice and glacier tongues. This approach will hopefully include a broader number of people from our community with its range of interests with the focus on producing the best outcome in more realistic representation of cryosphere and the Southern Ocean in future models.

The inaugural meeting of SOPHOCLES was held in Bergen on the 25th-26th August 2007, the weekend before the Polar Dynamics meeting. The first day of the meeting was attended by approximately 40 people, it was held jointly with WGOMD and followed a numerical methods meeting and had presentations from a number of modelling and observational perspectives. On the subsequent day a dozen people were involved in discussions which should lead to a draft planning document. It will be circulated widely in the Southern Ocean modelling community for comment.

There was some discussion on fluxes over the Southern Ocean, the sparsity of data leads to strong differences in the zonal means of observational and reanalysis flux products. The WGOMD CORE runs have used the Large and Yeager (2004) fluxes which substitute satellite products for NCEP derived fluxes, in particular using precipitation from GPCP, over the Southern ocean. There has been discussion with a number of researchers prior to the meeting who measure fluxes from ships, buoys and small aircraft during individual field programmes in the 90's and the present decade. It is proposed we compare these data with the Large and Yeager data set, taking into account that some of this data may have already been included in the reanalysis product. This analysis will also need to consider that some difference between point measurements from buoys, ships will not always compare well with satellite and model products which represent fluxes over a broader scale.

WGSF-SOLAS COOPERATION

The Sea Spray Gas Flux and Whitecaps Study (SEASAW)

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The Sea Spray Gas Flux *and* *W*hitecaps study (SEASAW) is one of several related UK SOLAS projects studying physical exchanges at the air-sea interface – along with the Deep Ocean Gas Exchange Experiment (DOGEE) and the High Wind Air-Sea Exchanges (HiWASE) study (Yelland et al. 2007). The principal aims of SEASAW are to study the exchange of CO_2 across the sea surface, and the generation of sea salt aerosol particles under high wind conditions. Two research cruises were undertaken in the north east Atlantic on the RRS Discovery (Figure 1) between November 7 and December 2, 2006 (cruise D313), and March 21 to April 12, 2007 (D317); cruise tracks are shown in figure 2. D313 encountered one of the worst runs of storms off the west coast of Scotland for a decade, with winds reaching force 12. Although measurements were obtained in conditions up to 15-minute average, 10-m winds of 23 m s^{-1}, and significant wave heights of up to 8.9 m, a combination of the extreme weather and technical problems severely constrained the measurement program during this cruise. D317 obtained a much more extensive data set in winds up to 18 m s^{-1}.

Figure 1. The RRS Discovery

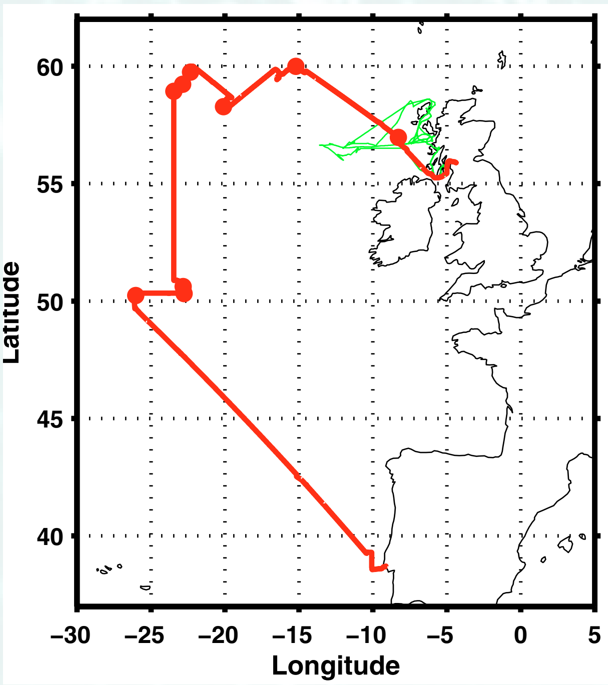

Figure 2. The cruise tracks for the SEASAW cruises, D313 (green) and D317 (red). The buoy deployments during D317 are marked by circles on the track.

The uncertainty in parameterizations of the air-sea exchange of CO_2 is a limiting factor for climate predictions. The wind-speed dependence of the flux has been assessed as being between u^2 and u^3 (Wanninkhof 1992; Wanninkhof and McGillis 1999), so that the impact of high wind speed events on the temporally averaged flux is disproportionate to their frequency of occurrence; however, to date there have been few direct measurements of CO_2 fluxes for winds above 10 m s^{-1}, and none above 15 m s^{-1}.

Sea-salt aerosols are the single most important factor influencing the radiation budget over the open oceans under clear sky conditions (Haywood et al. 1999) and, with the exception of dust, form the largest source of aerosol mass injected into the atmosphere (Hoppel et al. 2001). Existing sea spray source functions vary by 5 or 6 orders of magnitude (Andreas 2002); the most recent studies have reduced this scatter to around one order of magnitude for particles in the sub-micron range (Schulz et al. 2004). Most of the parameterizations are derived from indirect methods; only recently have direct estimates of particle fluxes been made via the eddy covariance technique, utilizing one or more condensation particle counters to provided pseudo size-segregated flux estimates (Nilsson et al. 2001; Geever et al. 2005; de Leeuw et al. 2003, 2006). de Leeuw et al. (2007) have recently made eddy covariance flux measurements with a PCASP utilizing a heated inlet to burn off all but the sea-salt fraction. A new high frequency aerosol instrument developed at the University of Leeds – the Compact Lightweight Aerosol Spectrometer Probe (CLASP) (Hill et al. submitted) – has enabled fully size-segregated eddy covariance flux estimates to be made with an instrument collocated with a sonic anemometer for the first time, dispensing with the need for long inlet tubes to lab based instruments, and consequent particle losses (Norris et al. 2006, 2007a, de Leeuw et al. 2007). A new version of CLASP was deployed for the first time during SEASAW (Norris et al. 2007b).

Measurements and Preliminary Results

Two independent flux systems were installed on the foremast of the Discovery for the SEASAW cruises (Figure 3). The AutoFlux system (Pascal and Yelland, 2004) consisted of two Gill R3A sonic anemometers and LiCOR-7500 open path gas analyzers mounted at either side of the foremast platform, approximately 18 m above the surface. A second system mounted on the top of the foremast, at 21 m, consisted of a sonic anemometer, LiCOR-7500, and 3 CLASP units with inlets situated ~0.5 m aft of the anemometer. CLASP provides a 16 channel aerosol size spectrum in the range 0.05 < R < 5 μm at 10 Hz, eddy covariance flux estimates can be made for each channel. Both flux systems incorporated motion packs to allow correction of the turbulent wind measurements for ship motion. Distortion of the mean flow over the ship can lead to significant biases in measured fluxes; for estimates made by the inertial dissipation technique this bias can be corrected using the results of numerical models of the flow around the ship (Yelland et al. 1998). Eddy covariance flux estimates cannot be directly corrected for the effects of flow distortion; however, since the effect should be common for all scalar fluxes e can utilize the corrected inertial dissipation estimates of a well characterized scalar flux, such as that of water vapour, to estimate the bias in the eddy correlation estimate, and then apply this correction to the scalar fluxes of CO_2 and aerosol (Yelland et al. 2007). While corrections for the effects of flow distortion have yet to be implemented, the preliminary results for the eddy correlation fluxes of sea spray aerosol are encouraging; figure 4 shows some results for a relatively low wind case, along with measurements from a fixed installation on the pier at the Field Research Facility at Duck, North Carolina (Norris et al. 2007a), and some recent sea-spray source functions from the literature. These are the first such measurements to be made over the open ocean.

Figure 3. The flux instrumentation on the foremast of the *Discovery*: the NOC sonic anemometers are mounted at either side of the mast platform with LiCORs situated just below and forward. The Leeds sonic is mounted on the leading edge of the plate at the top of the mast with a LiCOR just aft. The CLASP units are mounted flat on the plate with inlets collocated with the licor.

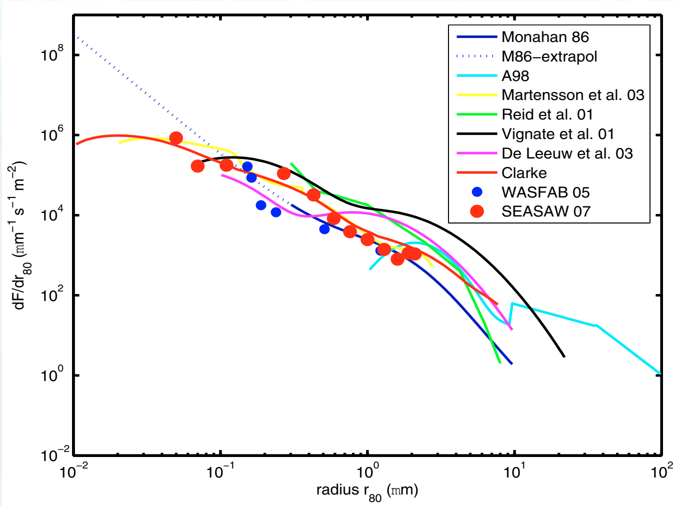

Figure 4. Eddy Correlation estimates of the sea-spray aerosol flux at U = 5 m s^{-1} compared with some recent parameterizations from the literature, and previous measurements with CLASP made during the WASFAB campaign in Duck, North Carolina, from Norris et al. (2007).

Most existing parameterizations for both sea spray and CO_2 fluxes are formulated solely in terms of the mean wind speed, although it is clear that many additional factors also influence the exchange processes; some of these are addressed by the SEASAW data set. Bubble bursting within whitecaps is central to the generation of sea salt aerosol (Blanchard and Woodcock 1957) and a strong influence on gas transfer (Woolf 1997). A pair of digital cameras mounted on the bridge recorded images of the sea surface every 30 s throughout daylight hours;

Figure 5. The tethered buoy. Main image: The buoy rides freely up and down a central, weighted, cable supported here by the aft crane, which keeps it in position. Inset: the buoy being lifted over the side of the ship – the CLASP inlets are visible above the flotation ring; the bubble imaging system is suspended beneath.

image processing techniques are applied to estimate the whitecap fraction. For limited periods a small tethered buoy (figure 5) was deployed with CLASP units sampling aerosol at between 0.4 and 1 m above the surface, and a bubble imaging camera (Leifer et al. 2003) 0.4 m below the surface; a motion pack allows the buoy's position on the waves to be determined. The combination of instruments will allow the aerosol and CO2 fluxes to be related to the bubble population and whitecap fraction. Wave state is recorded continuously by a ship-borne wave recorder; this data will be used to help investigate second-order effects on the surface fluxes resulting from non-equilibrium conditions between the wind and waves.

Acknowledgements

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SOLAS: the Surface Ocean-Lower Atmosphere Study

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WGSF SOLAS cooperation

The Surface Ocean - Lower Atmosphere Study (SOLAS) is a large international research programme that is strongly linked with the WCRP Working group on surface fluxes. Specifically, the aim of this research programme is to quantify the exchange of gases and particles between the ocean and the atmosphere and to understand the role that these exchanges play in ocean biogeochemistry, atmospheric chemistry and climate.

Briefly, the gases of interest to SOLAS can be divided into the longer-lived greenhouse gases (methane, nitrous oxide and, of course, carbon dioxide) and the shorter-lived trace gases (e.g. DMS, carbonyl sulphide, carbon disulphide, the halocarbons, ammonia, alkyl nitrates, isoprene, methanol). Many of the shorter-lived trace gases have been shown to play important roles in the production of aerosol particles via gaseous nucleation processes (e.g. DMS, ammonia), as well as directly impacting ozone chemistry and hence the oxidising capacity of the atmosphere (e.g. halocarbons).

Deposition of dust-laden aerosol particles in certain areas impacts ocean biogeochemistry, stimulating biological activity and potentially influencing the rate of carbon sequestration from the atmosphere, with knock-on implications for climate. In addition, the chemistry of all aerosol particles changes their optical properties and their propensity to attract water and develop into cloud condensation nuclei (CCN); both aerosol particles and CCN regulate climate by reflecting and refracting the incoming solar radiation.

All of the above gases and particles have sources and sinks in the upper ocean and/or the lower atmosphere. Of particular importance is their rate of exchange between these two reservoirs and, at a local or a global scale, an understanding of the net annual flux between them. My role as SOLAS Project Integrator is to help bring together as many SOLAS-relevant atmospheric and oceanic concentration measurements as possible to create definitive global datasets. From this, quantitative estimates of air-sea fluxes can be made by use of the latent air-sea transfer parameterisations being developed in SOLAS. Such flux estimates are of use to both the scientific community (modellers and experimentalists) and to policy makers.

Particularly for the less extensively studied compounds and particles, the aims of SOLAS Project Integration can only be achieved in conjunction with a willing and engaged community that is fully involved in all aspects of the process. To this end, a policy has been drawn up, which states that all contributors will be fully acknowledged for their contribution to global flux products, i.e. co-authorship for each relevant data set and publication(s) arising.

So far, work has focussed upon identifying what data exists and where it is archived – this is also known as the metadata. A SOLAS metadata inventory is under construction using the Global Change Master Directory (http://gcmd.nasa.gov/) that will eventually allow anyone within the scientific community to search for and identify datasets of interest. In the near future, efforts will shift toward the compilation of all relevant historical measurements at a global scale. For example, a project is already underway to collate a global surface ocean N_2O database (see the Project Integration webpage for details). Watch this space for further developments (http://www.bodc.ac.uk/solas_integration/whats_new/).

It should also be noted that successful projects are already well established for certain SOLAS-relevant compounds – there is already a relatively comprehensive DMS dataset available (http://saga.pmel.noaa.gov/dms/), and great effort has been expended toward an improved global CO_2 dataset (http://cdiac.ornl.gov/oceans/global_pco2.html).

Please do not hesitate to contact me (Thomas.Bell@uea.ac.uk) if you would like to contribute to any of the datasets that are being compiled as part of this project, or if you wish to find out more about this vital part of the SOLAS programme.

The HOAPS Climatology

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Introduction

Proper knowledge of global water cycle parameters and turbulent heat fluxes is an indispensable prerequisite for a successful modeling and understanding of the global climate system. High resolution global data sets of such information are required for various applications such as constraining the heat and freshwater transports in the global ocean, diagnosing regional and time variations, evaluating the surface fluxes in coupled atmosphere-ocean models, and providing surface forcing for ocean models. Schlosser and Houser (2006) pointed at the need for global climatological freshwater flux data sets. The compilation of the relevant quantities is, however, a challenging task, especially over the global ocean with the generally insufficient spatial and temporal coverage by ships or buoys.

Satellite based measurements became in recent years a reliable source of such data, providing good accuracy and equally dense spatial distribution over sea as over land. Especially since the availability of passive microwave detectors in space with their all weather observing capability, the derivation of some essential water cycle and energy flux components over the global ocean became possible.

The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) climatology uses the Special Sensor Microwave Imager (SSM/I) to derive such fields over the ice-free global oceans. It contains turbulent heat fluxes, evaporation, precipitation, freshwater flux and all basic state variables needed to derive these fluxes. One intention during the development of HOAPS was to derive the global ocean freshwater flux consistently from one satellite based data set. Consequently, great care was put into the inter-sensor calibration for homogeneous and reliable spatial and temporal coverage. Except for the SST, all HOAPS variables are therefore derived from brightness temperatures of the SSM/I radiometers on the polar orbiting DMSP (Defense Meteorological Satellites Program) satellites. Additionally, an efficient sea ice detection procedure based on the NASA Team algorithm is implemented.

The initial version of HOAPS was developed in 1995 mainly based on the algorithms of Bauer and Schlüssel (1993). An improved second version of HOAPS was available since the middle of 2004, featuring the concurrent use of all available SSM/I instruments up to December 2002, radiometer intercalibration and improved algorithms to derive sea surface flux parameters (Klepp et al., 2005b).

The most recent version, HOAPS-3, includes a new neural network based precipitation algorithm which substantially improves the precipitation and therefore the freshwater balance of the HOAPS climatology for the time span between July 1987 and December 2005. In addition, this version utilizes the newest NODC/RSMAS pathfinder version 5 SST data and a new algorithm to synthesize the defective 85GHz channel on the F08 instrument. The sea surface flux algorithms were not changed from the previous version.

Besides our own quality checks, first global evaluations of the performance of global ocean water cycle parameters revealed the high quality of the HOAPS evaporation product (Bourras, 2007).

Data Products

HOAPS-3 is divided into three main data subsets that originate from one common data source. The scan based HOAPS-S supplies global ocean fields of all parameters in SSM/I pixel level resolution for every individual satellite and the entire time period for case study applications and validation purposes. The gridded HOAPS-G data product contains pentads, monthly and climatological means of all 15 parameters for climate variability studies with a spatial resolution of 0.5 degrees. The HOAPS-C product links both data sets described above as it contains twice daily multi-satellite composites in 1 degrees resolution.

The HOAPS data sets are publicly available from *www.hoaps.org*. This address provides also a detailed overview of all 15 parameters and their specifications, as well as a general list of references on the product and a convenient data browsing interface.

Sea Surface Flux retrieval schemes and parameterizations

Latent and sensible heat fluxes are estimated with the bulk aerodynamic approach after Fairall (1996 and 2003) by an iterative loop to account for stability dependence of the transfer coefficients which is based on the COARE 2.6a bulk algorithm. This method depends on the variables wind speed, SST and atmospheric near surface specific humidity. All of these parameters are derived directly from the available satellite measurements. The air temperature for the derivation of the sensible heat flux is estimated as the average of two simple bulk approaches: From the near surface specific humidity assuming a constant relative humidity of 80 % at any time and from the SST assuming a constant temperature difference of 1 K.

Together with the new neural network based precipitation retrieval, this yields the freshwater flux E-P in units of mm/d.

The longwave net flux at the sea surface is computed after Schlüssel et al. (1995) from the atmospheric back radiation and the SST utilizing a spectrally integrated surface emissivity of 0.89 (Gardashov et al., 1988). The atmospheric back radiation is estimated directly from SSM/I measurements under clear or cloudy conditions using 22, 37 and 85 GHz channels.

Figures 1 to 4 show climatological means and zonal mean annual cycles of latent and sensible heat fluxes, longwave net flux, and net freshwater flux at the sea surface.

Conclusion

HOAPS-3 contains various state of the art data products of turbulent heat fluxes, evaporation, precipitation, freshwater flux and atmospheric state variables needed to derive these fluxes. Freely available monthly and pentad means, twice daily composites and scan based data make HOAPS-3 a versatile tool for studying ocean-atmosphere interaction on different time and spatial scales.

The comprehensive sampling due to the use of all available and carefully intercalibrated SSM/I instruments results in homogeneous and reliable spatial and temporal coverage and hence detailed information of the underlying weather situations. Major evaluation and validation efforts led to the use of new and improved algorithms for precipitation and wind speed along with an algorithm for the near surface specific humidity, resulting in appropriate products of surface fluxes and atmospheric parameters.

Further information on HOAPS-3 is available on the project webpage *www.hoaps.org*. A publication

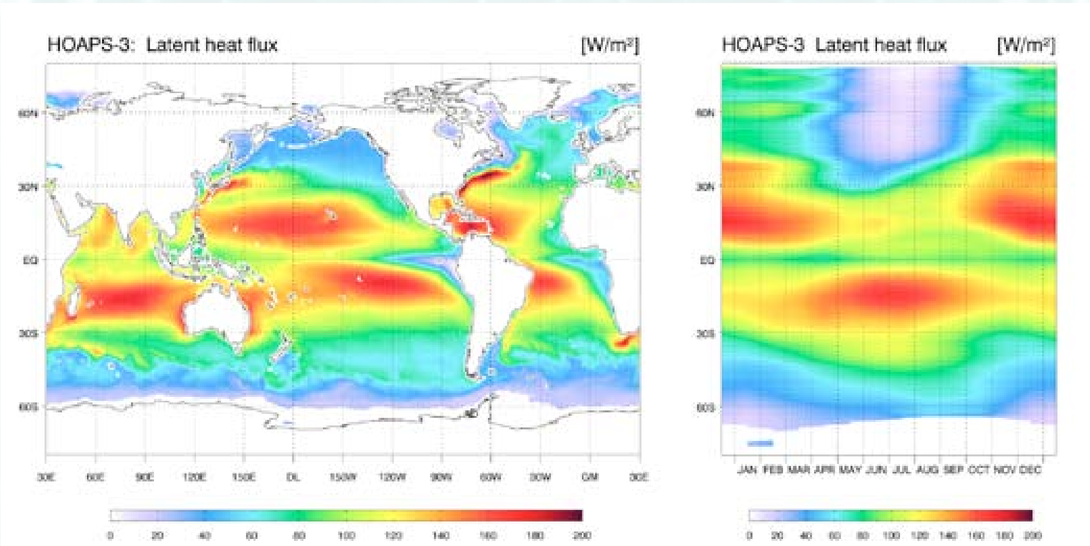

Figure 1. HOAPS-3 latent heat flux climatological mean 1988-2005 and climatological zonal mean annual cycle.

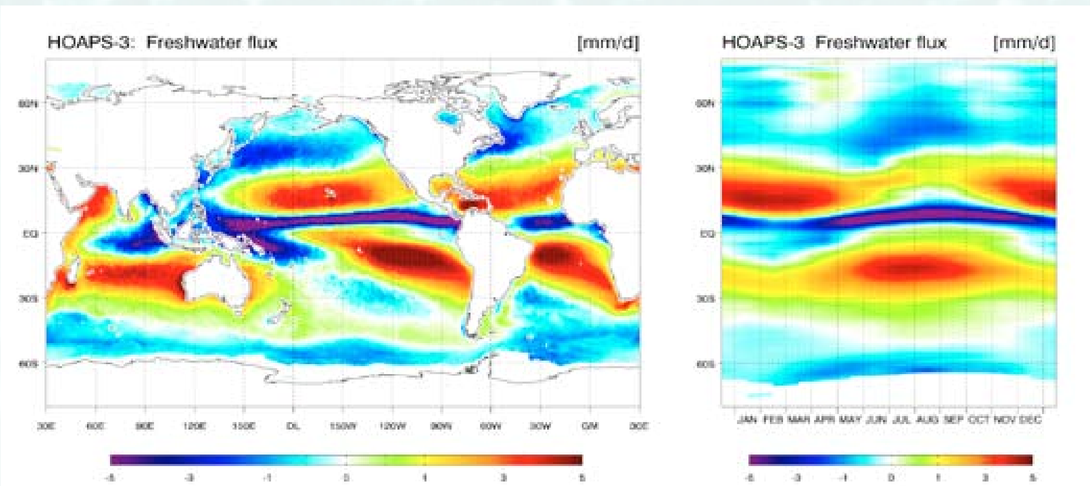

Figure 2. HOAPS-3 freshwater flux (evaporation-precipitation) climatological mean 1988-2005 and climatological zonal mean annual cycle.

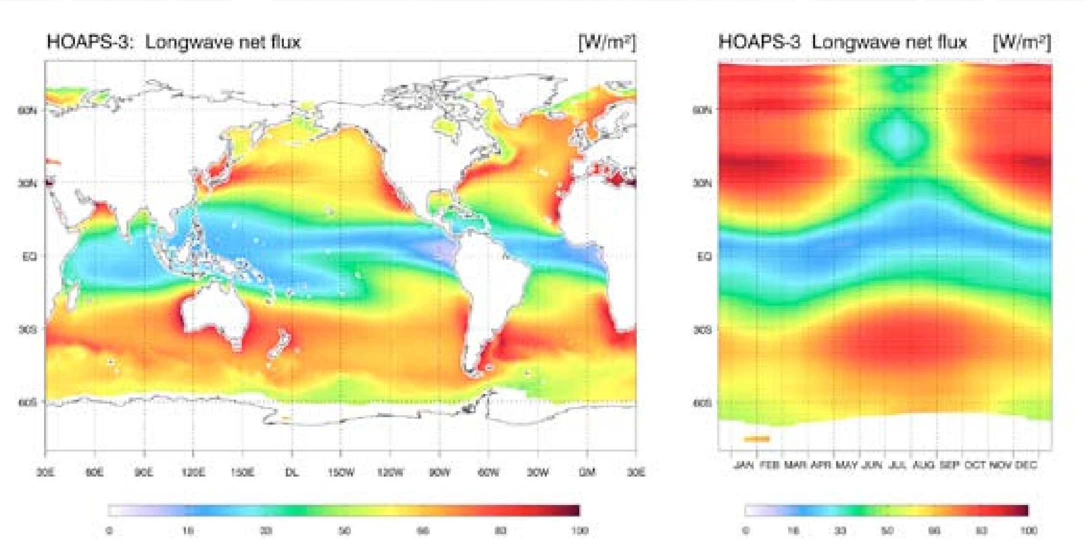

Figure 3. HOAPS-3 longwave net flux climatological mean 1988-2005 and climatological zonal mean annual cycle.

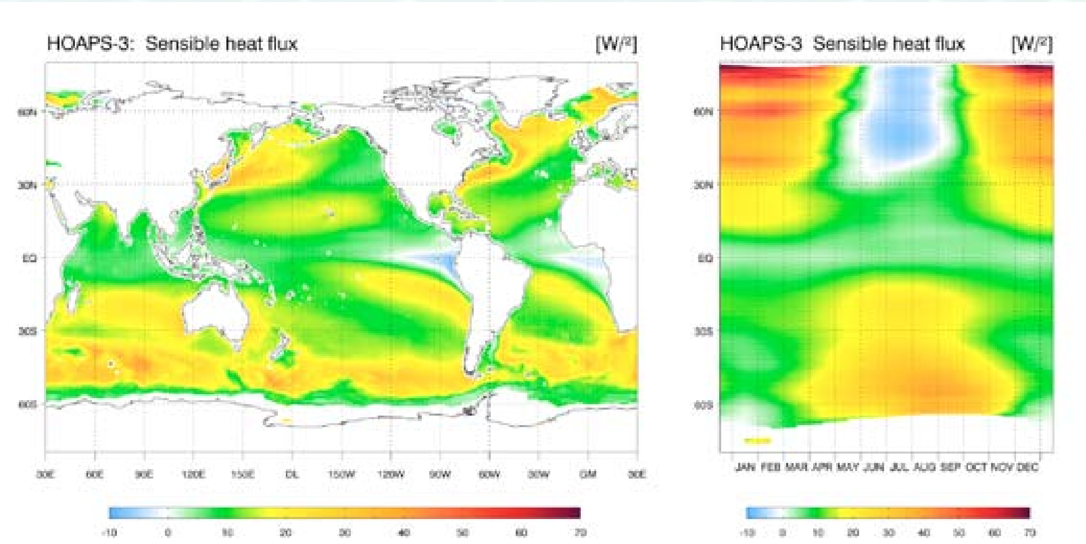

Figure 4. HOAPS-3 sensible heat flux climatological mean 1988-2005 and climatological zonal mean annual cycle

containing a detailed description of the HOAPS climatology is in preparation.

Acknowledgements

The essential inputs of all the unnamed present and former HOAPS team colleagues to the final product are explicitly acknowledged here. The project has been funded during the years by the German Science Foundation (DFG), the Max-Planck Society (MPG), and the Helmholtz society (HGF).

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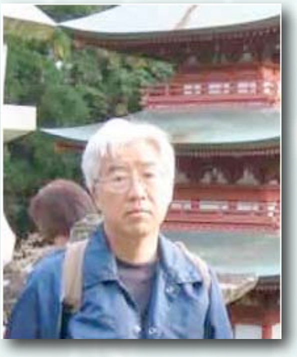
The Present State of the J-OFURO Air-Sea Interaction Data Product



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The ocean actively exchanges heat, water and momentum with the atmosphere at the ocean surface. The exchanged heat, water and momentum are transported by general ocean and atmospheric circulations on a global scale. Since the exchange and transport processes play important roles in the global climate, the estimation of the fluxes between the atmosphere and the ocean and those transports by the ocean and atmospheric circulations are very important for understanding the mechanism of the global climate. However, it is difficult to globally estimate the fluxes and transports by using in situ observation data such as ship observation data because they are extremely sparse in time and space. However, we can obtain considerably homogeneous data with high resolution using analysis and satellite data. Therefore, it is considered that analysis and satellite data are suitable for obtaining globally covered fluxes between the ocean and the atmosphere.

We have constructed ocean surface flux data sets mainly using satellite data. The data set named as Japanese Ocean Flux data sets with Use of Remote sensing Observations (J-OFURO) has been provided to scientists (Kubota et al., 2002) and has been used in many research studies. Recently new surface heat flux data have been constructed in J-OFURO, thereby upgrading it to version 2 (J-OFURO2). Version 2 has many improvements over version 1 for estimation of turbulent heat fluxes. There are three major differences between the latent heat flux (LHF) of J-OFURO1 and 2. First, multi-satellites data are used in J-OFURO2, while data from only one DMSP Special Sensor Microwave Imager has been used for the estimation of turbulent heat fluxes in the J-OFURO1. This is based on the results provided by Tomita and Kubota (2007) who demonstrated a remarkable reduction in the sampling error by using multi-satellite data, particularly, in regions with large daily variability in the wind speed and specific humidity. For example, we have used all available SSMIs (F08-F15), European Remote-sensing Satellite (ERS) 1/2, QuikSCAT, the Advanced Microwave Scanning Radiometer–EOS (AMSR-E), and the TRMM Microwave Imager (TMI) for the estimation of daily wind speeds. In J-OFURO2, we could recognize that the usage of multi-satellite data is quite effective, even if bias adjustments are not applied to each sensor. Figure 1 shows the time variation of wind speeds observed by the Kuroshio Extension Observatory (KEO) buoy and satellites. If only one satellite is used, the time series show many gaps, resulting in lower accuracy. However, with multi-satellite data, there are no gaps in the time series,

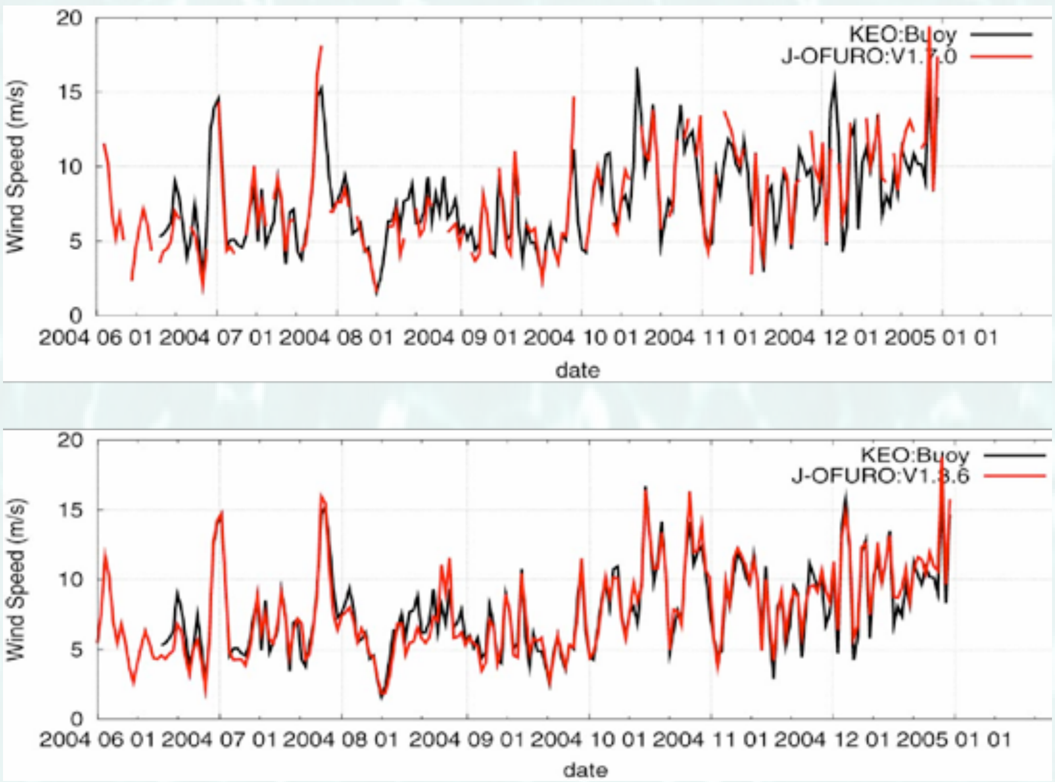

Figure 1. Time variation of wind speed data observed by KEO buoy and derived from (a). single satellite (DMSP/SSMI, F10) and (b). multi-satellite (DMSP/SSMI F13,14 and 15, Aqua/AMSR-E and QSCAT) data.

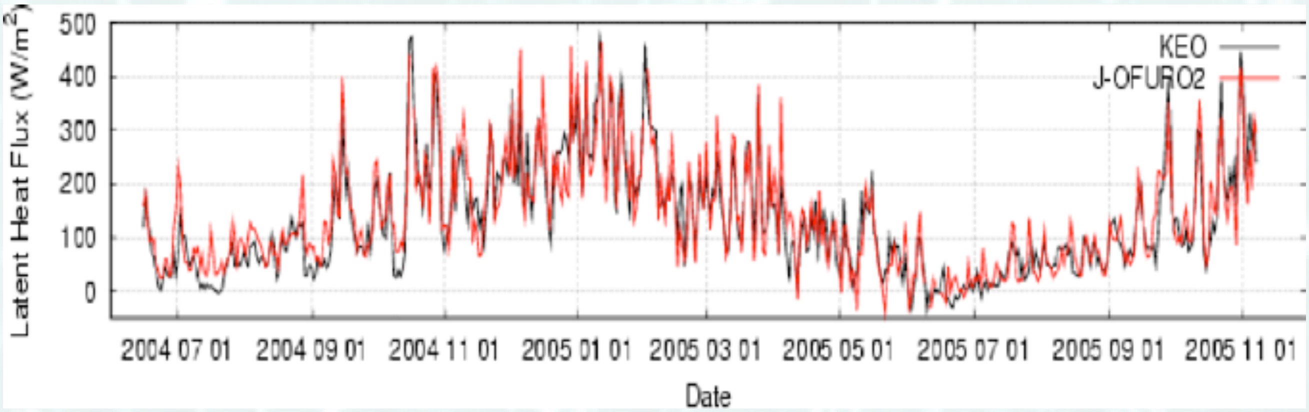

Figure 2. Time variation of LHF of J-OFURO2 and observed by KEO buoy.

and the accuracy is considerably higher, as shown in Figure 1b. On the other hand only the available SSMIs (F08-F15) are currently used for the estimation of air specific humidity at present because it is difficult to accurately estimate accurate air specific humidity using AMSR-E and TMI data still now. This is a future issue for the construction of J-OFURO3. Various data are merged by an optimum interpolation method (Kako and Kubota, 2006) into daily -mean data with a spatial resolution of 1°. Also, we changed gridded sea surface temperature (SST) data from Reynolds OI SST data (Reynolds and Smith, 1994) to Merged satellite and in-situ data Global Daily (MGD) SST data provided by Japanese Meteorological Agency (JMA). This change is based on the results of Iwasaki et al. (2007) in wherein five kinds of global SST products are compared and evaluated. The MGD SST has been constructed by using infrared SSTs (NOAA/Advanced Very High Resolution Radiometer), Microwave SSTs (Aqua/AMSR-E) and in-situ data (Kurihara et al., 2006). Subsequently, the bulk formula proposed by Kondo (1975) was also changed to Coupled Ocean-Atmosphere Response Experiment (COARE) bulk algorithm (Version 3.0). However, warm layer and cool skin effects are not included in J-OFURO2. The estimation method for the sensible heat flux (SHF) has been drastically changed. In J-OFURO1 we used a method proposed by Kubota and Mitsumori (1997) for calculating the SHF by multiplying the LHF by the climatological Bowen ratio derived from the European Centre for Medium Range Weather Forecasting (ECMWF) data. However, in J-OFURO2 the sensible heat flux is estimated from COARE 3.0 using our merged wind speed, MGD SST data and the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research Reanalysis (NRA1) air temperature data. Finally the temporal resolution is improved from a 3-day mean to a daily mean. Moreover, the data period is extended from 1992-2000 to 1988-2005. The radiation data in J-OFURO1 covers the region of the eastern Indian Ocean and the western and central Pacific Ocean between 60°N and 60°S, 80°E and 160°W, because we use only the Japanese geostationary satellite for the estimation of radiation flux. However, in many cases scientists require global flux data. Therefore, we provide the global net heat flux data, which is estimated by our turbulent heat flux data and the International Satellite Cloud Climatology Project (ISCCP) radiation data in J-OFURO2. However, we have estimated the upward longwave radiation by using the MGD SST data.

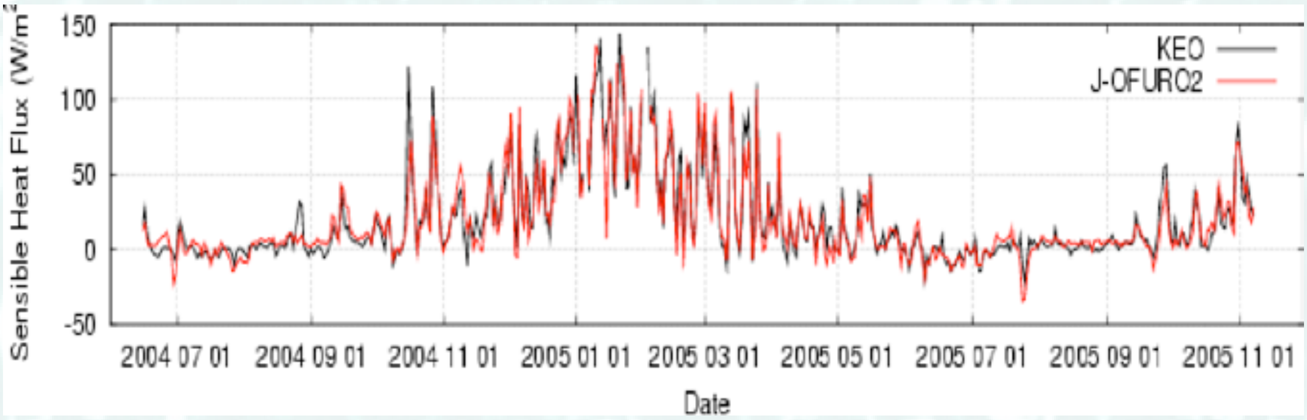

Figure 3. Time variation of SHF of J-OFURO2 and observed by KEO buoy.

The general feature of the global distribution of the J-OFURO2 LHF is similar to that of not only J-OFURO1 but also other products such as GSSTF2, NRA1, ERA40 and the Objectively Analyzed Air-sea Flux (OAflux). However, the amplitude in J-OFURO2 is relatively less than that in J-OFURO1, particularly in ocean deserts at the mid-latitudes. We have compared the J-OFURO2 LHF with the in situ LHF data observed by the KEO buoy. In June 2004, the KEO buoy was deployed in the Kuroshio Extension recirculation gyre at 144.6°E, 32.4°N by NOAA/

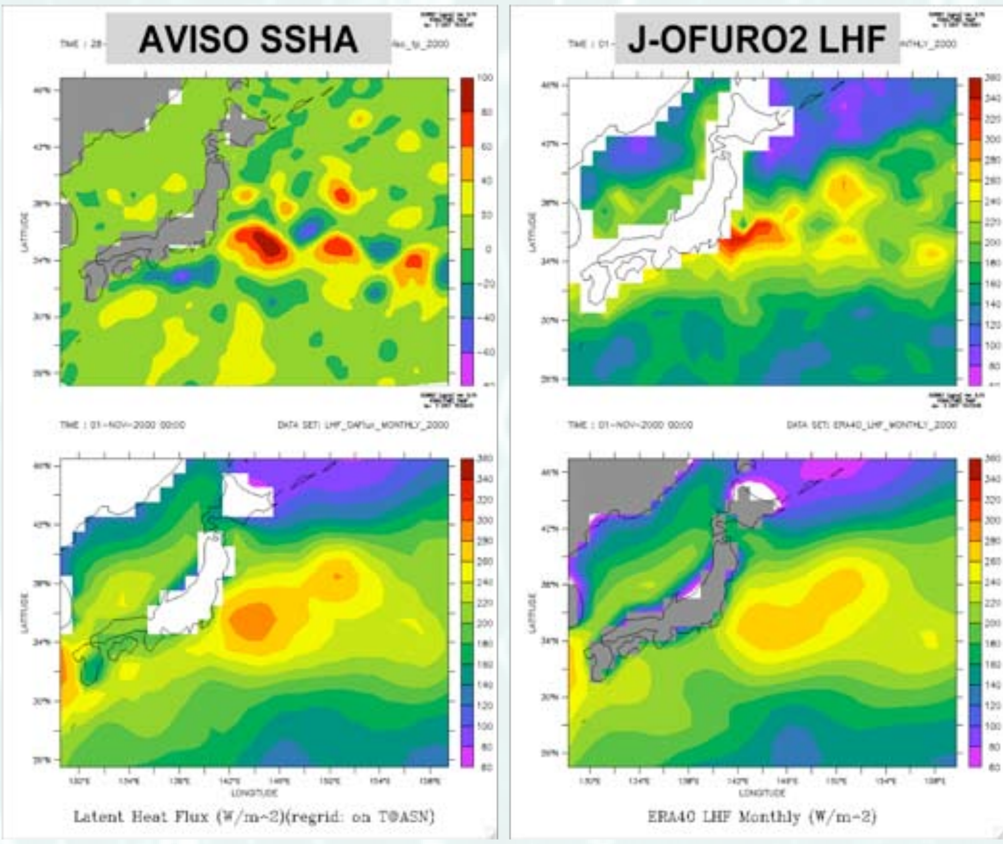

Figure 4. Monthly-mean values of sea surface height anomaly obtained using altimeter data and LHF by J-OFURO2, OAflux and ERA40 in the Kuroshio and Kuroshio Extension regions on November 2000.

Pacific Marine Environmental Laboratory (PMEL) to monitor air-sea heat, moisture, momentum and carbon dioxide fluxes, and temperature and salinity of the upper ocean. Figure 2 shows time variation of the J-OFURO2 LHF is in good agreement with the KEO LHF. The bias and the root-mean-square (RMS) error for a daily-mean value of the J-OFURO2 LHF are 7 W m–2 and 42 W m^{-2}, respectively. Kubota et al. (2007) showed that the bias and RMS error values for the NRA1 LHF are 38 and 48 W m^{-2}, respectively. Therefore, the J-OFURO2 LHF may give be more accurate than the NRA1 LHF. On the other hand, the bias and RMS values of the J-OFURO2 SHF are 0.2 and 10.8 W m^{-2}, respectively. Since those values for NRA1 are 9 and 20 W m^{-2}, respectively. The J-OFURO2 SHF is considerably more accurate than the NRA1 data, as shown in Figure 3.

It is well known that many warm eddies exist in the Kuroshio and Kuroshio Extension regions. Interestingly, we can find fine-scaled distribution of LHF associated with that of the sea surface anomaly observed by the TOPES/Poseidon altimeter (Figure 4). Such characteristics cannot be found in other LHF fields such as J-OFURO1, OAFLUX and ECMWF Reanalysis (ERA)40. This feature suggests that the ocean plays an active role for atmosphere over the warm eddies. As mentioned earlier, the use of multi-satellite data improves the accuracy of turbulent heat fluxes. Moreover, the use of multi-satellite data contributes to the representation of the fine structure of heat fluxes over the Kuroshio/Kuroshio Extension Regions.

J-OFURO2 data for scientific use can be freely obtained from the website http://dtsv.scc.u-tokai.ac.jp/J-OFURO2.

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Net Heat Flux and the Monsoon Active–Break Cycle


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A number of recent studies have emphasized the role of ocean in the Active-Break cycle (hereafter the AB cycle) of the Asian summer monsoon which has a period of around 40 days. Krishnamurti et al (1988) found that the fluctuations in surface wind speed and Sea Surface Temperature (SST) control the heat and moisture fluxes in the AB cycle. Using data from moored buoys in the north of the Bay of Bengal, Sengupta and Ravichandran (2001) have shown large amplitude oscillation of SST and net heat flux in north Bay of Bengal in the AB cycles of the monsoon season of 1998. Sengupta et al (2001) and the field experiments in the Bay of Bengal such as BOBMEX (Bhat et al. 2001) and JASMINE (Webster et al. 2002) have also shown large amplitude AB cycle changes in the net heat flux over the Bay of Bengal.

The Low Level Jetstream (LLJ) found by Joseph and Raman (1966) and Findlater (1969) with its core near 850 hPa level is closely associated with the AB cycle of the monsoon according to Joseph and Sijikumar (2004). During active monsoon spells, the core of the LLJ passes through the Indian peninsular between latitudes 12.5°N and 17.5°N and is associated with a large area of strong cumulonimbus convection in the Bay of Bengal. When the convection weakens there the LLJ turns clockwise over the Arabian Sea as shown by the modeling study of Rodwell and Hoskins (1995) and during the break monsoon that follows, the LLJ bypasses India and flows with its core between latitudes 2.5°N and 7.5°N. Joseph and Sijikumar (2004) also found that the strength of the daily convective heat source as represented by the OLR over the Bay of Bengal and the strength of the daily zonal wind at 850 hPa through the Indian peninsular (LLJ), both between latitudes 10°N and 20°N have the highest and significant linear correlation at a lag of 2 to 3 days, OLR leading.

Joseph and Sabin (2007) have suggested an empirical model for the AB cycle coupling the atmosphere and the ocean below in which SST, convection, LLJ and the net heat flux at the ocean surface have important roles. A typical Active-Break cycle of the Asian summer monsoon of period 40 days (pentads -2 to 5 through 0) is taken as beginning with maximum SST at pentad 0 over the north Bay of Bengal when the oceans to its west and east from longitude 40°E to 160°E, and between latitudes 10°N and 25°N (area A) also has high SST. During this pentad the recently found "Cold Pool" of the Bay of Bengal (between latitudes 3°N and 10°N) has its minimum SST (Joseph et al 2005). An area of convection takes genesis over the Bay of Bengal in the following pentad 1 in the zone of large SST gradient north of the cold pool and it pulls the LLJ through the Indian peninsular. Convection and the LLJ westerlies then spread to the western Pacific ocean during pentads 2 to 4. The four pentads 1 to 4 is taken as the active phase of the monsoon during which convection and LLJ have grown in a positive feed back process over area A. By the end of pentad 4 the SST over the area A has cooled and the convection weakens there, when the LLJ turns clockwise over the Arabian Sea and flows

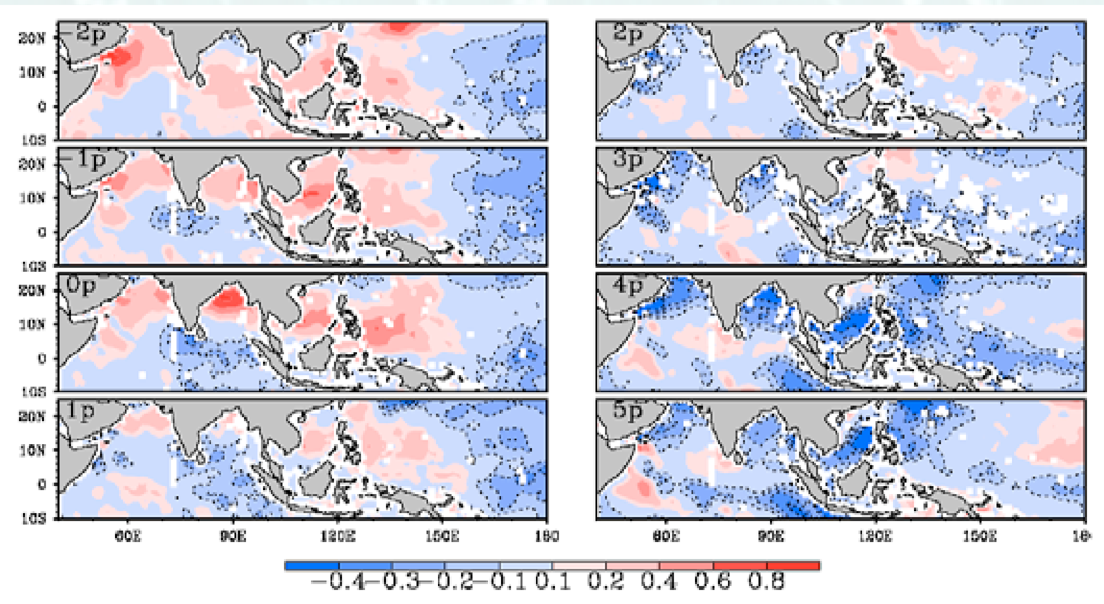

Figure 1. SST anomalies in °C of the 11 case composite of pentads –2 to +5 of the AB cycle, obtained by subtracting the 7 year July and August mean SST. For negative anomalies contours of –0.1 °C and less at intervals of 0.1 °C are marked by broken lines in addition to the shading (from Joseph and Sabin, 2007).

close to the equator in the Indian ocean. A band of convection develops at pentad 5 between the equator and latitude 10°S over the Indian ocean and it is nourished by the cyclonic vorticity of the LLJ now near the equator and the moisture supply through it. This is taken as the break monsoon phase lasting for about 4 pentads beginning from pentad 5 (pentads 5, -2, -1 and 0). With reduced wind and convection over the area A during the break phase, solar radiation and light winds make the SST there warm rapidly and a new active-break cycle begins. Net heat flux over the area A is assumed to control the SST there as already suggested by Sengupta et al (2001).

In Joseph and Sabin (2007) using TMI SST data of 7 years 1998 to 2005 (excluding 2002) 11 cases of AB cycle of July and August were identified (0 pentad with maximum SST in the Bay of Bengal box 15°N-19°N, 83°E-95°E) and their composites in the AB cycle studied in SST anomaly, 850 hPa wind (NCEP reanalysis) and convection (GPI rain). In this paper we study the net heat flux as a composite of the same 11 cases. Figure 1 gives the SST anomaly of the 11 case composite taken from Joseph and Sabin (2007). At pentad 0 the SST anomaly is very large (close to +1°C) over the area A. By pentad 4 this area has maximum negative SST anomaly (close to -1°C). It is hypothesized that this reversal of SST over a very large area (area A) combined with the presence or absence of LLJ in area A is the main driver of the AB cycle through the changes in the net heat flux produced there. Figure 2 gives the SST changes in the composite AB cycle in two boxes one over the Bay of Bengal and the other over the west Pacific ocean (both within area A). In the Bay of Bengal box SST has reached maximum at Pentad 0 (as defined) whereas in the west Pacific box SST has reached a higher maximum at pentad 2.

Net heat flux at the ocean surface Q_{net} is the sum of the fluxes of sensible heat Q_{sen}, latent heat Q_e, net insolation Q_s and net longwave radiation Q_l. Q_{sen} and Q_e are estimated using bulk formulae (Godfrey et al., 1998) based on daily TMI SST and TMI wind speed. Our estimate of net surface insolation Q_s is based on the empirical relation from Shinoda et al (1998) that Q_s is approximately equal to 0.93 times daily mean OLR in Wm-2. This method is well validated for

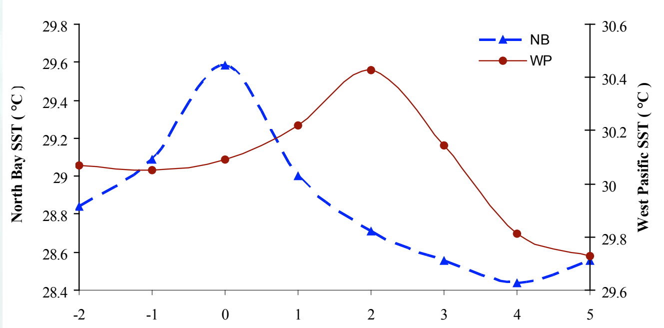

Figure 2. SST variation in °C form pentad -2 to pentad 5 of the composite AB cycle (mean of 11 cases) of the North Bay box averaged over 83-95°E, 15-19°N (NB) and the West Pacific box averaged over 125-135°E, 15-19°N (WP)

Indian ocean region using buoy data by Senguptha and Ravichandran (2001). Our estimate of Q_l is based on an empirical relation that uses OLR as a proxy for cloudiness (Shinoda et al., 1998). The empirical estimate of specific humidity and air temperature are based on Waliser and Graham (1993). Q_l is expressed through an empirical bulk formula (Budyko, 1974), evaluated by Josey et al. (1999). Fig 3 gives the two main componets of the heat flux (Q_e and Q_s) and the net heat flux (Q_{net}) for pentads 0 and 4 of the 11 case composite of Joseph and Sabin (2007). It is found that the most important contributor to the net heat flux is the latent heat flux as already shown by Krishnamurti et al (1988). The contribution by net insolation is also important. The other two fluxes Q_{sen} and Q_l are very small in comparison and so not shown in the figure.

From Figure 2 it is seen that in the north Bay of Bengal box, SST rises rapidly at pentad -1 and falls rapidly at pentad 1 whereas in the west Pacific box these changes are two pentads later. Fig 4 gives the net heat flux as composite of the 11 cases for the 8 pentads -2 to 5 through 0. The net heat flux is seen qualitatively to agree with figures 1 and 2 in the area covered by the SST anomalies (area A) and in the time rate of change of SST in the two boxes. Assuming a mixed layer thickness of about 40 metres and the heating of this layer by the whole of this flux, a net heat flux of 100 Wm^{-2} can change SST through 1°C only in about 20 days. In the studies by Joseph and

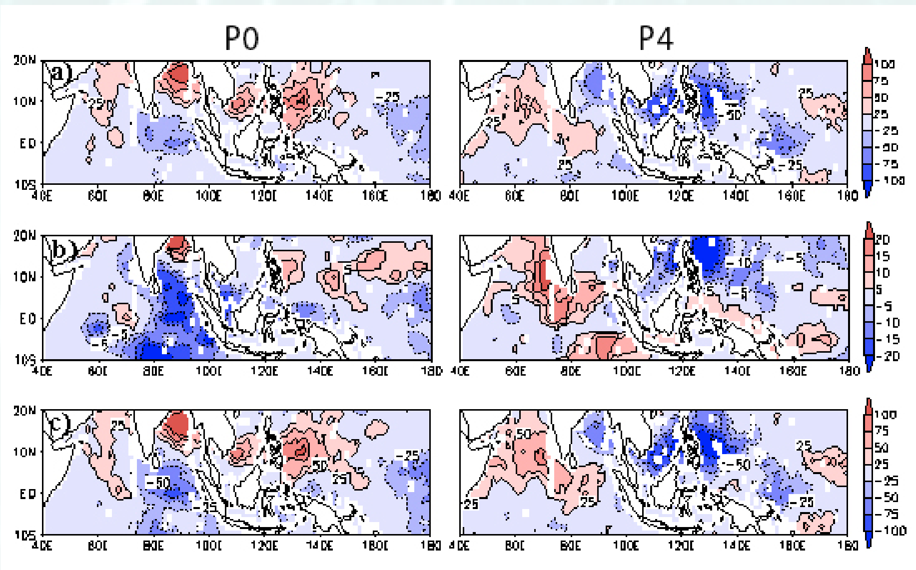

Figure 3. Composite of the 11 cases of AB cycle for pentads 0 and 4. a) Latent heat flux Q_e b) Short wave radiation flux Q_s and c) Net heat flux Q_{net} in Wm^{-2}. The two components of the net heat flux namely long wave radiation Q_l and sensible heat flux Q_{sen} are found to be very small in comparison to the others and not given in the figure.

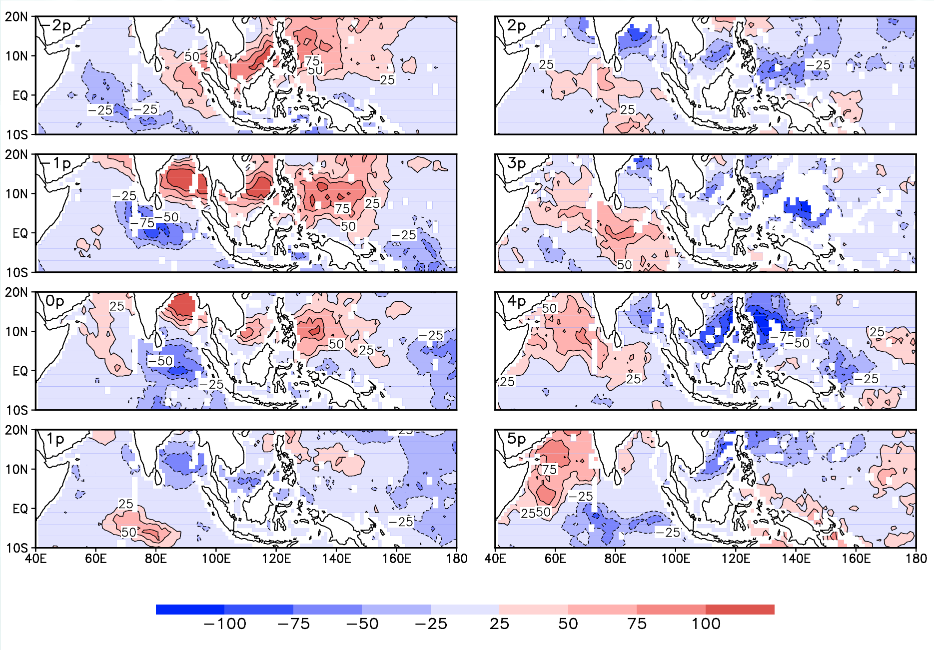

Figure 4. Net heat flux in Wm^{-2} of the composite AB cycle (mean of 11 cases) for pentads -2 to 5.

Sabin (2007) and Sengupta et al (2001) the time rate of change of SST is higher. Area A gets lot of fresh rain water and the mixed layer thickness can be much less than the assumed 40 metres during July and August. The Northern Bay of Bengal gets fresh water from river discharge also. We suggest modeling studies of the AB cycle as a coupled ocean – atmosphere phenomenon over the Indian and west Pacific oceans using a simple slab ocean in area A whose SST variations are controlled by the net heat flux.

Acknowledgements

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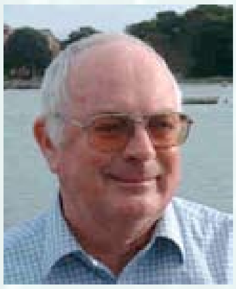
Improved Fluxes from Operational Observations: The VOSClim Project



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Quantifying the exchange of heat, freshwater and momentum between the atmosphere and the ocean remains a challenge. Direct flux measurements are typically made on air-sea interaction research cruises by dedicated teams of scientists and technical experts and are too sparse to give a global picture. Only recently have continuous measurements of the turbulent fluxes been attempted: the UK Surface Ocean Lower Atmosphere (SOLAS) project has funded a 3-year flux measurement program in collaboration with the Norwegian Meteorological Institute (DNMI) operating Ocean Weather Station "Mike" in the Norwegian Sea. Other sources of flux information include the OceanSITES moorings giving bulk formula estimates of the turbulent heat fluxes (sensible and latent heat) and radiative flux measurements at selected oceanic locations. Satellites can also measure the radiative flux components with good accuracy but the turbulent heat fluxes are hard to derive from remotely sensed parameters and this is likely to remain an area of active research for years to come.

The JCOMM Ship Observations Team (SOT) co-ordinates the operational collection of marine meteorological data for weather forecasting and climate applications. Meteorological observations received from ships recruited to the Voluntary Observing Ships (VOS) Scheme are exchanged via the Global Telecommunications System (GTS) so that they can be used for real time assimilation into numerical weather prediction models. They are subsequently archived in the International Comprehensive Ocean-Atmosphere Dataset (ICOADS, Woodruff et al. 1998, Worley et al. 2005) which provides the source data for many flux datasets (e.g. Isemer and Hasse 1987, Oberhuber 1988, da Silva et al. 1994, Josey et al. 1999). Reports from the VOS can be of variable quality and their suitability for the construction of climate datasets has been questioned (e.g. Wright 1986, Peterson and Hasse 1987). In recognition of these issues the World Meteorological Organisation (WMO) launched the VOS Special Observing Project - North Atlantic (VSOP-NA, Kent et al. 1993) which collected data between 1988 and 1990 from a subset of VOS reporting in the North Atlantic. The observations from the VSOP-NA ships were assessed for quality by comparison with a UK Met Office local-area weather forecast model using detailed information about the participating ships to aid interpretation of differences between the ship reports and the model output.

The VOS Climate Project (VOSClim, JCOMM 2002) is the natural successor to the more limited VSOP-NA. The primary objective of VOSClim is to provide a high-quality subset of marine meteorological data, with extensive associated metadata, to be available in both real-time and delayed mode. Specifically, the project gives priority to the following parameters: wind direction and speed, sea level pressure, sea surface temperature, air temperature and humidity. A larger, global, subset of ships has been recruited and more than 200 ships have participated in the project since it became operational in 2001. At the last meeting of SOT in April 2007 (JCOMM 2007) it was recognised

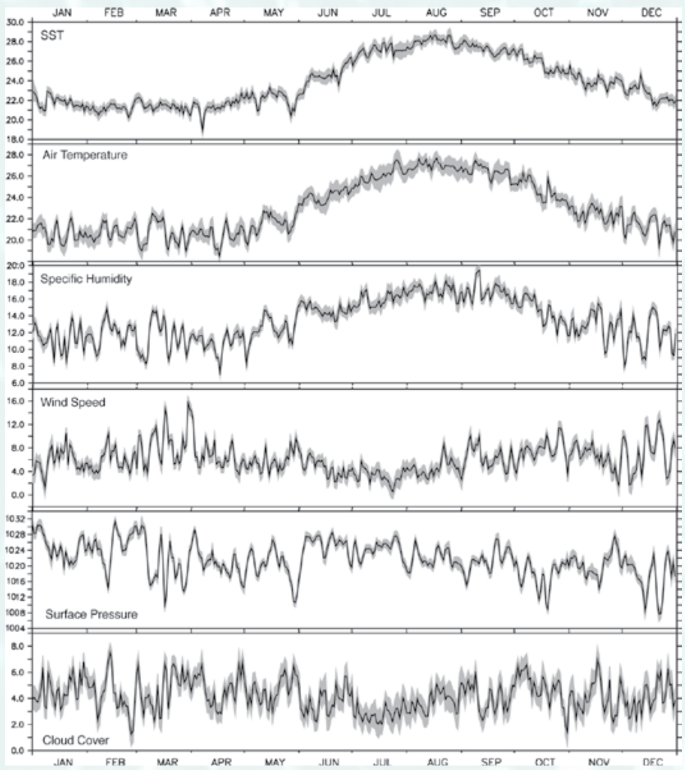

Figure 1. Daily meteorological conditions at 30°N 45°W during 1991: Sea surface temperature (°C), air temperature (°C), specific humidity (gkg^{-1}), wind speed (ms^{-1}), surface pressure (hPa), cloud cover (octas). The values have been calculated using an optimal interpolation scheme and data from ships only. The grey area indicates the estimated uncertainty (± one standard deviation).

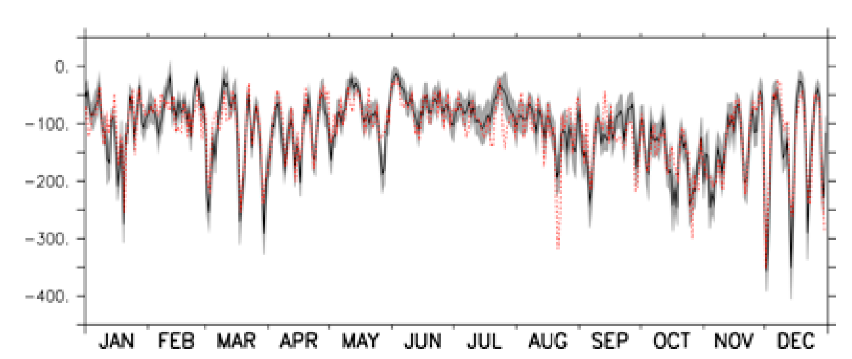

Figure 2. Daily latent heat flux (Wm^{-2}) at 30°N 45°W during 1991. The black line shows values calculated from VOS data with the uncertainty estimate (grey shading). The red dotted line is the OAFlux value

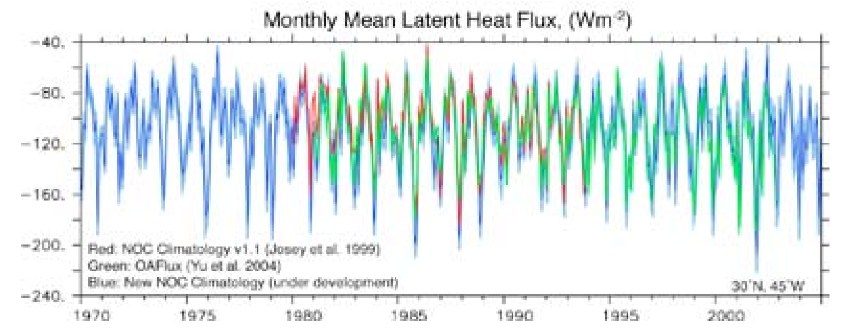

Figure 3. Comparison of monthly mean latent heat flux (Wm^{-2}) for 30°N 45°W for new VOS dataset (blue with 1-sd uncertainty in light blue shading), the NOC v1.1 dataset (red) and OAFlux (green).

that the good practices developed for VOSClim ships should be adopted more widely across the VOS fleet.

The results of the analysis of VOSClim are already being used to identify and adjust for biases in VOS observations (Berry and Kent 2005). The dataset was key to an assessment of the adequacy of the marine meteorological observing system commissioned by the Met Office. It is expected that the data might also be used to validate coupled atmosphere-ocean climate models; to provide ground truth for calibrating satellite observations; and to provide a high-quality reference data set for bias adjustment of observations from the VOS fleet.

Fluxes calculated from VOS reports are essential to improve our knowledge of air-sea interaction at basin scales. The data and information from VOSClim enable us to produce the best flux datasets from the VOS data. As an example, Figure 1 shows daily meteorological fields from VOS for 1991 for 45°W, 30°N, including uncertainty estimates. These are used to calculate flux estimates, Figure 2 shows the latent heat flux together with the OAFlux synthesis product (Yu et al. 2004) which combines model and satellite data to estimate the fluxes. The two flux products compare well, and the uncertainty estimates which accompany the in situ VOS fluxes show where the differences are due to lack of data, and where the differences need further investigation. Currently the VOS dataset covers the period 1970 to 2006 (Figure 3), but there are plans to extend the data back in time to give a 50-year dataset.

The WCRP Working Group on Surface Fluxes and Working Group on Numerical Experimentation are currently setting up the SURFA Flux Intercomparison (see article by Chris Fairall in FluxNews 1). The datasets from VOS form an important component of SURFA, alongside flux data from weather prediction models, OceanSITES, research vessels and satellites.

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More of MORE: the first MORE cruise onboard RV Polarstern

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Figure 1. Scientific crew of research cruise ANT-XXIII-10 of RV *Polarstern*. From left: Samuel Morin, Andreas Wassmann, Andreas Macke, John Kalisch, Gerhard Haerendel, and Alexei Sinitsyn.

Introduction

Clouds remain one of the biggest obstacles in our understanding of the coupled ocean-atmosphere climate system (IPCC, 2007). Even under realistic forcing from observed wind, humidity and pressure fields climate models have difficulties to reproduce the correct spatial and temporal climatology of cloud cover (Bedacht et al. 2007). Due to the strong inhomogeneity of cloud patterns on those scales that are relevant to radiative transfer processes it is clear that subgrid-scale processes must be accounted for in-radiative transfer parameterizations (Cahalan et al. 2005). Combined observations of physical and radiative properties of clouds are a key to adjusting and/or validating such parameterizations.

In 2003 the Meridional Ocean Radiation Experiment (MORE) was initiated by S. Gulev and A. Macke as a joint initiative of thve P. Shirshov Institute of Oceanology and the Leibniz-Institute for Marine Sciences IFM-GEOMAR. The research goal is to conduct long-term measurements of surface energy fluxes above the ocean at mid-latitude, subtropical and tropical conditions with an emphasis on the role of the cloudy atmosphere in forming the short wave (SW) and long wave (LW) radiation fluxes. Starting in 2004 regular Atlantic transects of the two Russian RVs *Academician Vavilov* and *Academician Ioffe* have been used to perform surface energy radiative flux and standard atmospheric measurements. As a result, improved parameterizations of the SW and LW fluxes at the sea surface (based on standard meteorological variables for different cloudy sky conditions) have been developed. See Sinitsyn et al. (2006) for a description of the first MORE cruises.

MORE 2007

In April 2007 the German research vessel *Polarstern* was utilized for the 6th MORE cruise on the leg from Cape Town to Bremerhaven (cruise ANT-XXIII-10). *Polarstern* is well equipped for meteorological research as well as routine meteorological services. The meteorological observatory is permanently manned with a weather technician/observer from the German Weather Service (DWD) who performs routine 3-hourly synoptic observations and the daily upper air soundings. The meteo-observations also include pyranometer and pyrgeometer measurements of the downwelling solar and thermal broadband irradiances. In addition, a Kipp&Zonen Net Radiometer CNR-1 with up-and down-looking pyranometer and pyrgeometer operated by IORAS were used on this cruise. Sky images were obtained from a total sky imager manufactured at IFM-GEOMAR with a temporal resolution of 15 seconds. This device was first used on the 5th MORE cruise onboard *Academician Ioffe* in autumn 2006. It enables a detailed analysis of the role of cloud cover and cloud type on the radiation budget at the sea surface and on the ship based atmospheric profiling.

Also, on this cruise a multi-channel microwave radiometer (HATPRO, Radiometer Physics) was first used in the open ocean for continuous observations of atmospheric temperature and humidity profiles as well as liquid and precipitable water paths (see Figure 2).

Figure 2. Filling the HATPRO microwave radiometer with liquid nitrogen for calibration

Atmospheric water vapour profile information between 300 and 1000 hPa is derived from HATPRO frequency channels operating between 22 and 28 GHz. Under calm sea conditions boundary layer scans can be performed to substantially increase the vertical resolution within the lower 1000 m of the atmosphere. Together with ceilometer measurements of cloud base heights and sun photometer measurements of aerosol optical thickness, the data from the microwave radiometer provide a unique set of parameters to analyse the downwelling solar and thermal radiation at the sea surface in terms of the atmospheric conditions. As an example, Figure 3 shows a time series of liquid water paths together with temperature and humidity profiles. Due to retrieval errors the microwave radiometer shows positive LWP of about 50 gm^{-2} even for clear sky conditions. These errors were expected as the current retrieval was designed for mid-latitude atmospheres over land. With the help of auxiliary data (cloud camera, ceilometer) it will be possible to correct for such biases in the ongoing analysis.

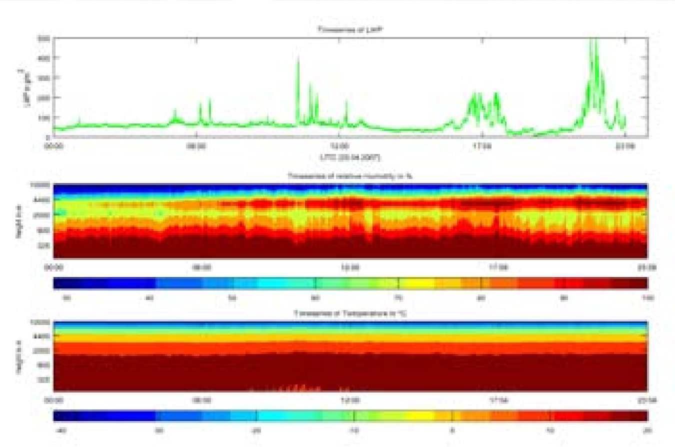

Figure 3. Time series of relative humidity (middle plot) and temperature profiles (lower plot) together with vertically integrated cloud liquid water (upper plot).

Outlook

The 7th MORE cruise will take place during the *Polarstern* cruise ANT-XXIV-1 in autumn 2007 with onboard instrumentation identical to the previous cruise.

In addition to the study of cloud-humidity-radiation feedbacks the collected data will also be used to provide validations of satellite based retrievals of 1) surface radiation budget from Meteosat Second Generation (MSG), and 2) temperature and humidity profiles from the recently launched European operational polar orbiting weather satellite METOP-A. From January 2008 MORE will be joined by the Wilhelm-Gottfried Leibniz PAKT Initiative OCEANET. Between 2008 and 2010 they will perform six Atlantic transects onboard RV *Polarstern.* The potential of the planned cruises of *Academician Ioffe* and *Academician Vavilov* will also be utilized.

From its start in 2004 MORE has been gaining more advanced instrumentation and has increased the number of scientific partners. The scientific goals are getting more interdisciplinary with contributions from marine chemistry, marine biology and physical oceanography. We would like to encourage all interested researchers to collaborate with the MORE community on instrumentation and data analysis in order to improve our understanding of the role of clouds and radiation on physical, biological and chemical processes in the ocean-atmosphere system.

Acknowledgements

The MORE experiment is currently supported by the Russian Federal Agency of Science and Innovation, the Leibniz-Institute for Marine Sciences, and the German Weather Service. The experiments on the Polarstern cruise ANT-XXIV-1 received additional support from EUMETSAT. We are also grateful to the Alfred Wegener Institute for valuable support in the organization of the reserach cruises with RV *Polarstern*. We owe special thanks to Radiometer Physics for quick error handling during the cruise and to Alexander Smirnov from NASA Goddard Space Flight Center for the provision, calibration and analysis of the sun-photometer.

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RECENT PUBLICATIONS

Christoph S. Garbe, Robert A. Handler, Bernd Jähne (Eds.)

Transport at the Air-Sea Interface. Measurements, Models and Parametrizations

2007, XXIV, 320 p. 127 illus. With CD-ROM., Hardcover, ISBN: 978-3-540-36904-2

Predictions of our future climate vary greatly, with detailed forecasts still subject to debate. One key uncertainty is caused by the lack of our present knowledge of transport processes at the air-water interface, which poses the main transfer resistance between the oceans and atmosphere. Modeling and predictions of our global climate can only be improved by gaining a more complete understanding of the mechanisms involved in transporting energy, mass and momentum across the air-sea interface.

This monograph contains selected, peer-reviewed post-conference contributions of the International Workshop on Transport at the Air-Sea Interface, which took place at Heidelberg University from September 6-8, 2006. The focus of the monograph is on small-scale processes directly at the interface. It includes the topics:

-Small-scale transport processes at the air-sea interface: surface divergence, microscale and largescale wave breaking, intermittency and rain-induced gas exchange;

-Novel measurement techniques including eddy correlation measurements, active and passive thermography, visualization of concentration fields by fluorescent dyes, profile measurements and visualization of flow fields by particle imaging velocimetry (PIV);

-Modeling of the transport across the air-water interface and simulation of flow fields as well as concentration fields in the boundary layer, and

-Parameterizations of the transfer process for global modeling.

Included in this book is a CD-ROM containing image sequences demonstrating results of numerical simulations of transport processes as well as imaging measurements and products thereof. These sequences give insights into the processes involved and the state of the art of visualization of air sea interactions. The complete hyperlinked text of the book is also available on the accompanying CD-ROM.

FLUX MEETINGS

XXVIII Session of the JSC for WCRP, Zanzibar, Tanzania, 26-30 March 2007

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The 28th session of the Joint Scientific Committee for WCRP took place in Zanzibar, Tanzania on 26-30 March 2007. The WGSF report put together by Chris Fairall was presented by Sergey Gulev who also read the SOLAS report formulated at the SOLAS SSG in March 2007, Xiamen, China). The JSC noted that WGSF, jointly with WGNE, had achieved success in reinvigorating SURFA, and the first flux NWP data had started to be acquired by NCEP. The Handbook on Flux Observation was published (see Bradley and Fairall in Flux News, Issue 2, July 2006). The JSC welcomed the on-going publication of Flux News. At the time of the Zanzibar meeting three issues had been produced. Furthermore, the two major reviews on gas and particle exchange which were being finalised by WGSF, received positive remarks. The future of WGSF was discussed at the Session with the view of merging it with SOLAS. The merge was not recommended because their scopes, although partly overlap, do not match sufficiently well. The JSC, therefore, suggested to continue accommodating the flux work in the WCRP programme and to start tackling global land fluxes.

The JSC recommended that the WGSF Chair (Chris Fairall) and the WCRP Liaison with WGSF (Sergey Gulev) in cooperation with the JPS for WCRP (Vladimir Ryabinin) propose measures to preserve the current momentum in the WCRP surface flux work, especially the continuance of SURFA and the development of issues related to global fluxes (i.e. fluxes over land). This is now the number one priority for WGSF (see the editorial note to this issue on the front page). During the last day discussions a number of surface flux related projects were considered as potentially worthy of endorsement and support by WCRP after 2007. Beside SURFA these are VOSClim (see Kent et al. in this issue), SEAFLUX, ocean reanalyses and others. These should be considered as pillars for a dynamic pan???-WCRP activity in the area of surface fluxes. This will be coordinated by WGSF in close cooperation with the WCRP core projects (CLIVAR and GEWEX) and WGNE. As regards the collaboration with SOLAS, it should undoubtedly continue to be carried out in order to provide synergy of our understanding of physical and biogeochemical fluxes. Moreover it will serve as an important link between WCRP and IGBP.

In addition to holding traditional discussions on core projects and working groups reports, the 28th session of JSC spent much time discussing the future of WCRP, particularly its funding and the need to strengthen the WCRP role in the ESSP. The detailed coverage of these issues can be obtained from the Annual Review of WCRP and the Report of the 28th Session of the JSC (available at http://www.wmo.ch/pages/wcrp/PG_Reports_JSC.html). A special event at the 28th JSC Session was the Africa Climate day during which climate scientists from African countries presented the results of their regional and global climate research. Dave Griggs and Carolina Vera, the JSC members, were elected the new JSC Officers. Herve Le Treut kindly offered to host the 29th session of JSC next year in Bordeaux, France. It is critical for WGSF to do its best to develop a well justified and motivated strategy to present at that Session.

FLUX Calendar

11-16 November 2007,10th International Workshop on Wave Hindcasting and Forecasting, Turtle Bay Resort, North Shore, Oahu, Hawaii, USA, http://www.waveworkshop.org

28 January - 1 February 2008, 3d WCRP International Conference on Reanalysis, Institute of Industrial Science, University of Tokyo, Komaba Campus, Tokyo, Japan, http://jra.kishou.go.jp/3rac_en.html

4-8 February 2008, The 3rd International TRMM Science Conference, Bally's Hotel, Las Vegas, USA, http://trmm.gsfc.nasa.gov/

2–7 March 2008, Ocean-Atmosphere Exchanges and Meridional Transports in Global Water and Energy Cycles, Topical Session at the 2008 Ocean Sciences Meeting, Orlando, Florida, USA, http://www.agu.org/

C O N T E N T S

Call for contributions:

The next issue of Flux News
(No 5, January 2008) will focus on
the WGSF cooperation with SEAFLUX
and particularly on the papers from the recent 4th SEAFLUX workshop (Amsterdam, The Netherlands, 27 Sept 2007).
The closing date for submissions is
15 November 2007

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