WGSF

Newsletter of the WCRP Working Group on Surface Fluxes

WCRP

FLUX NEWS

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ICSU International Council for Science

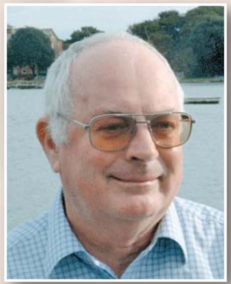
UNESCO

WGSF welcomes the new WCRP Director and the JSC Chair!

Professor **Ann Henderson-Sellers** commenced her duties as the Director of WCRP on 1 January 2006. Ann is one of the world's top experts on the influence of land-cover and land-use change on climate. Previously she was the Head of the Institute for Nuclear Geophysiology of the Australian NSTO. She is a Fellow of AGU, AMS and the Australian Academy of Technological Sciences and Engineering. Ann is one of the ISI's 'most highly cited' authors. She was a founder and also led the WCRP/GEWEX Project for the Intercomparison of Land-Surface Parameterisation Schemes (PILPS). She has been a member of the Scientific Committee of IGBP, a Coordinating Lead Author of the Second IPCC Assessment Report, and the President of IAMAS International Commission for Climate. Welcome Ann!

Dr. **John A. Church** of CSIRO Marine Research and Antarctic CRC, Australia, has been appointed the new Chair of the JSC for WCRP. Dr. Church is an eminent physical oceanographer. He devoted many years to studying regional and global ocean general circulation. John co-edited (with G. Siedler and J. Gould) a comprehensive monograph 'Ocean Circulation and Climate', which summarised the decade of the World Ocean Circulation Experiment. John's current area of expertise is sea level and its changes. In this area he has provided new levels of understanding of the mechanisms driving sea level variability. He is a Coordinating Lead Author of the chapter on sea level in the IPCC Third Assessment Report. Before becoming the Chair of JSC for WCRP John served as its officer and Vice-Chair (from 2004). Welcome John!

The 2006 Sverdrup Gold Medal to air-sea flux science



Dr. Peter Taylor of the National Oceanography Centre, Southampton, UK, has won the prestigious American Meteorological Society Award *'for major contributions to our understanding of ocean-atmosphere interactions and for determination and leadership in improving the climatology of air-sea fluxes based on measurements from ships.'*

Congratulations from WGSF!

Peter Taylor answers the editors' questions and shares his views about the past, the present and the future of air-sea interactions on pages 4—5.

WGSF solas

WGSF and SOLAS cooperation

This Issue of FLUX News is compiled to give a view of the WGSF-SOLAS cooperation. This cooperation as demonstrated over the last four years has become one of the most successful examples of collaboration between WCRP and IGBP within the Earth System Science Partnership. What has been achieved? Where are we now in understanding air-sea biogeochemical exchanges? How does the physical flux science improve our understanding and quantification of air-sea gas transfer? Finally, where should we go next? Find the answers to these questions on pages 6—14.

Air-Sea Fluxes and WCRP Science

Position paper of the Joint Planning Staff for WCRP

Vladimir Ryabinin

Joint Planning Staff for WCRP
Geneva, Switzerland

The role of the ocean in climate change has always been at the centre of WCRP interest. For example, through its TOGA project, WCRP studied in detail a most significant mode of ocean–atmosphere interaction, the El Nino — Southern Oscillation; laid out the foundations of the tropical Pacific and Indian Ocean observation system; and developed the ability to predict El Nino with several months lead time. Such an approach when fundamental research and efficient observation are unified to create predictive potential is followed in the new WCRP Strategy for the years 2005-2015 entitled 'Coordinated Observation and Prediction of the Earth System'. A new and very essential postulate of the Strategy is that the current tasks of extended and more accurate prediction make it necessary for WCRP to step out from the its traditional 'physical' domain and start to work more actively with all Earth System Science Partners in the areas of chemistry, biology, ecosystem studies, and the socio-economic sector.

At its recent meeting in March 2006 in Pune, India, the WCRP Joint Scientific Committee reviewed the current foci of WCRP research and identified several cross-cutting topics of great importance. They are:

- Monsoons
- Extreme events in future climate
- Seasonal and interannual forecasting
- Chemistry and climate interactions
- Anthropogenic climate change
- Sea-level rise
- International Polar Year 2007/2008

The continuing research by the four core projects of WCRP (CliC, CLIVAR, GEWEX, and SPARC) and the IGBP-SCOR-WCRP-CACGP 'Surface Ocean — Lower Atmosphere Study' (SOLAS) will be synthesised in these cross-cutting topics. It is clear that each of them has a bearing on the ocean-atmosphere fluxes.

The seasonal (up to interannual) forecasting, which is coordinated by the CLIVAR Working Group on Seasonal and Interannual Prediction (WGSIP) and the WCRP Task Force on Seasonal Prediction (TFSP), strives to identify and exploit predictability that various domains of the Earth System are capable of producing. Feedbacks, in which the oceans, land surface, and stratosphere are involved, will be examined through a series of sensitivity experiments with modern coupled models. Probably, WGSIP and TFSP should also consider predictability associated with information on atmospheric chemistry, e.g. through events, such as dust storms, affecting formation of aerosols with feedbacks involving clouds and radiation. Seasonal forecasting is now seen to be an initial value problem, not only for the atmosphere but also for other parts of the Earth System, and above all, for the upper layer of the ocean. In this respect, it is the air-sea fluxes that uncover the predictability potential of the ocean on the seasonal to interannual time-scales. Such WCRP cross-cutting activities as monsoon prediction will apparently rely very strongly on potential predictability of the ocean upper layer.

The complex problem of the anthropogenic climate change requires significant extension of studies on the ocean's role in climate. Continuing advances in physical research must be complemented by intensive development of research on chemistry, biology, and climate. The initial emphasis of WCRP is on interactions of chemistry and climate. It will be led by WCRP/SPARC and IGBP/IGAC with contributions from several other projects. These should address not only the physics of the ocean carbon cycle but also other deficiencies in our knowledge, as well as future changes in this cycle in a warmer climate.

SOLAS, which is the main focus of this issue of *Flux News*, is very successful in generating momentum for studies of biogeochemical fluxes and related processes in the ocean and atmosphere boundary layers. The research on ocean-atmosphere fluxes is active. Yet, at present the researchers still work primarily with bulk formulas and try to find universal relations of gas and particle transfer coefficients with the averaged wind speed. The roles of wind wave breaking and the stage of development (wave age) are only starting to receive the required attention. There have been as yet no spectral or large eddy simulation models for biogeochemical interactions between the ocean and atmosphere.

The domain of physical fluxes is more developed, in principle. The forecasting system of ECMWF comprises a joint model of wind waves and the atmosphere. Several centres have started to use coupled models for seasonal prediction. Nevertheless, the agreement of flux climatologies produced by various NWP centres is still far from perfect. It still proves very difficult to organise exchange of flux products by forecasting centres and their systematic comparison with estimates based on *in situ* observations. This all means that significant errors should be anticipated in forecasts because of inaccuracies in the air-sea flux parameterisations and input data.

The WGSF was established in 2004. Based on the legacy of WGASF, which provided comprehensive intercomparison of different air-sea flux products, the working group has achieved very good results in preparing guidance materials for computation of surface fluxes. More progress is required now in organising new-level flux intercomparison activities with a particular focus on contribution to longer-term forecasting.

The current WGSF composition is oriented towards activities centred on the ocean surface fluxes. By the end of 2007, the terms of all WGSF members will have expired. Therefore, it is of vital importance now to use the remaining time to actively launch such activities as SURFA and to ensure stronger cooperation between various groups working on ocean surface fluxes. Involvement of the leading modelling and NWP centres in this work is crucial to ensure that the improved flux climatologies result at the same time in more advanced and better-tuned parameterisations in predictive models. In addition, WGSF should start thinking about how to prepare the planned extension of the WGSF mandate towards the global scale, which will include land surface fluxes. In this direction, the WGSF will have to keep the momentum of the ocean flux work and start to cooperate more actively with WCRP's GEWEX and IGBP's iLEAPS. The views and proposals of WGSF members and other interested scientists on the way forward would be very much appreciated. Please send your comments either to Chris Fairall or to me.

Thank You Peter!

At the end of the XXVIII Session of JSC for WCRP in Pune, India, 6—11 March 2006, Prof. Dr. Peter Lemke stepped down from the position of JSC Chair after 6 years of extremely successful work for WCRP. The JSC thanked P. Lemke for all that his outstanding efforts in increasing the WCRP's role in understanding climate predictability and the quantification of human effects on climate.

It was under Peter's leadership that WCRP started its strategic move towards a closer cooperation with other ESSP programmes, most importantly with IGBP. Peter initiated and led the development of the new WCRP Strategic Framework for 2005—2015 entitled «Coordinated Observation and Prediction of the Earth System».

With regard to our field, Peter enthusiastically promoted air-sea flux science in WCRP projects. He strongly supported the creation of WGSF in 2003 following the success of WGASF in 1996—2001. It was his idea that WGSF should establish a close cooperation with SOLAS thus providing a testing ground for a wider WCRP-IGBP cooperation.

We have all benefited from Peter's global vision of climate problems and we admired his exceptional friendliness and civility with which he moderated some very tough discussions.

Being a distinguished sea-ice modeller Peter continues to successfully lead the Climate Sciences Research Division of The Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany. He is a Coordinating Lead Author of the Fourth IPCC Assessment Report.

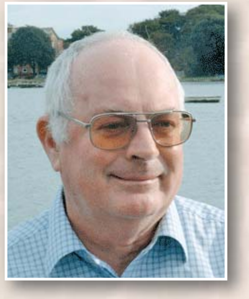
The next issue of *Flux News* (January 2007) will focus on air-sea fluxes for the forcing of ocean general circulation models in different resolutions. We welcome contributions from both sea-air interaction and ocean modelling communities.

The closing date for submisions is 1 November 2007

The 2006 Sverdrup Gold Medal to air-sea flux science

Dr. Peter Taylor, the Head of the James Rennell Division of the National Oceanography Centre, Southampton, UK, has won the prestigious American Meteorological Society Award *'for major contributions to our understanding of ocean-atmosphere interactions and for determination and leadership in improving the climatology of air-sea fluxes based on measurements from ships.'*

WGSF congratulate Peter Taylor with this award and are proud that he co-chaired WGASF, the predecessor of WGSF, in 1996-2002. Peter Taylor has kindly agreed to share his views on the development of surface flux science for WCRP and to answer questions about the past, the present and the future of air-sea interactions.



Interview with Peter Taylor

National Oceanography Centre, Southampton, UK

by Nadia Kovaleva

NK: Dr. Taylor, congratulations on being the recipient of the Sverdrup Gold Medal. Could you please share with us the experience of receiving this prestigious award. What was the most exciting thing about achieving this recognition?

PT: Obviously it's a great honour. Sometime last October, the phone rang just as I was leaving the office and I decided I'd had enough for the day and didn't answer. So later when I listened to my voicemail and heard the message from Keith Seitter, the AMS Executive Director, I could hardly believe it; in fact I had to email him to make sure! But now I'm very pleased because I see the award as recognising the work of the all Met Team here at the National Oceanography Centre, Southampton. Indeed, I think my most valuable accomplishment in air-sea interaction research is that I've built a team of scientists who now are more knowledgeable than I am and who are continuing to carry the work forward.

NK: What changes have taken place over the last 10 years, since 1996 when you became co-Chair of the SCOR/WCRP Working Group on Air-Sea Fluxes (the predecessor of WGSF)? Which activities around the world have led to major achievements?

PT: Personally, I'd choose the activities, which have facilitated many other studies. To take a home grown example, the new surface flux climatologies such as those developed at the Southampton Oceanography Centre (now the National Oceanography Centre, Southampton), and at Goddard Space Flight Center have found wide use. They exploit our improved certainty with regard to the transfer coefficients, and our better understanding of the error sources. But the activity which forms the basis for these *in situ* climatologies, and for many other climate studies, is the 'International Comprehensive Ocean-Atmosphere Data Set' (ICOADS); that really is the vital project. Another activity which has and, I believe, increasingly will provide important knowledge is the establishment of 'flux' reference sites. The Woods Hole group has made a major contribution with their buoy deployments, as has PMEL in establishing the TAO buoy array in the Pacific.

A vital application of the reference buoy data, and also research ship measurements, has been establishing the magnitude of biases in the reanalysis fields. The various reanalysis projects certainly qualify as an activity which has had a major impact over the last 10 years. Going back to 1996, the first NOAA/NCEP reanalysis had just been completed between 1985 and 1993 and was busily working backwards in time through the 1980's and 1970's. The ECMWF 15 year reanalysis (ERA-15) was completed in September 1996. Both suffered from various problems and errors and since then we have had further reanalyses such as ERA-40, NCEP AMIP-2, and the new Japanese 25—year Reanalysis Project (JRA-25). While certainly not perfect, the flux fields from the climatologies have proved very attractive to modellers because of the good temporal and spatial resolution and the global coverage.

These are just examples which spring to mind, I'm sure there are many more; development and validation of the COARE algorithms for example.

NK: What are the major problems in quantitative estimation of air-sea energy and mass exchanges? Which of them still remain as unresolved as they were 10 years ago, and which are new, i.e. have been identified over the last 10 years?

PT: What's old? I'm frustrated that we still don't have global fields of the air-sea heat fluxes, calculated from observations, which both balance the global heat budget (to the accuracy to which it must balance) and also agree with measurements from a range of reference sites. What's new? There is much more concern about the effect of various aerosols on the radiation budget; it would be nice if that would help us balance the budget but it's probably wishful thinking. There is also concern over changes in ocean salinity; research on that is hindered by an old problem — determining reliable fields of precipitation over the ocean.

NK: What is your projection for the next ten years? What directions should flux science choose in order to achieve the most realistic description of sea-air energy exchanges for climate?

PT: I can remember an oceanographic look-ahead in, I guess, the 1970's which said we'd have aircraft carriers as research vessels by now; lesson learnt. However I do have a major concern for the observing system. I was involved with the Ocean Observing System Development Panel report of 1995, and since then the OceanObs'99 conference and the Ocean Observation Panel for Climate. Development of the observing system is now being actively carried forward by GOOS and GCOS, but despite all these efforts and recommendations, we still do not have an adequate, guaranteed future observation system which will give the data we need for climate. The Voluntary Observing Ship programme, which has been such a very important resource over the last several decades, is now decaying before our very eyes. Since SeaSat in 1978, satellites have proved invaluable for mapping sea surface temperature, surface wind vectors, surface height, sea state, ocean colour, and other essential climate variables (radiation fields for example). However, as recently emphasised by Dudley Chelton and Mike Freilich, continuity of the satellite data sets into the future is not assured. It is vital that we continue to fight for the observing systems, which we need.

NK: Given the particular focus of the coming issue — cooperation with SOLAS — and the present WGSF mandate to account for biogeochemical fluxes, what are, in your view, the major challenges for cooperation between physical and chemical flux researchers?

PT: During the last decade, improved (and cheaper) sonic anemometers and the application of techniques such as Computational Fluid Dynamics, have confirmed that, in the open ocean, the drag coefficient typically increases with increasing wind speed. Furthermore, the rate of increase has been shown to be more or less that suggested by researchers some 25 years or more ago. This increase implies an increasing aerodynamic roughness length, which has to be caused by the changing geometry of the sea surface, that is the wave field. However, even now we don't have a parameterisation in terms of the wave field that works under all circumstances. Partly this is because only some data sets have adequate wave data. Nevertheless, I also believe that a major reason is that, in the open ocean, the wave field is rarely if ever a 'pure wind sea' and the swell component interacts with the local wind waves causing breaking and altering the roughness. The good news is that the sensible and latent heat flux coefficients have been found to be less affected by the sea state then the drag. For example, it is only recently that the Boulder NOAA group, using improved sensors and measurement techniques, have demonstrated the corresponding, smaller increase in the transfer coefficient for water vapour. In contrast, the bad news is that there is good reason to believe that the biogeochemical air-sea fluxes will be strongly dependent on sea state. This implies that a very large data set will be needed to develop and test flux parameterisations. It will make great sense for physical and chemical flux researchers to collaborate in obtaining the required data.

NK: Thank you very much, Dr. Taylor. We wish you good luck with your further research and successful leadership of James Rennell division.

Photo: J. Kalisch

The Sverdrup Gold Medal, named for Harald Ulrik Sverdrup, a pioneer in the field of oceanography, is one of the highest honours of the American Meteorological Society, the US's leading professional society for scientists in the atmospheric and related sciences. The award is given to researchers who make outstanding contributions to the scientific knowledge of interactions between the oceans and the atmosphere.

Collaboration and Synergy between SOLAS Implementation-2 Working Group and the WCRP Working Group on Surface Fluxes

Wade R McGillis

Chair, International SOLAS IMP2
Columbia University, New York,
New York, USA

Daniela Turk

Executive Program Officer
International SOLAS IMP2
Dalhousie University
Halifax, Canada

Peter Liss

Chair, International SOLAS
University of East Anglia
Norwich, UK

Jeff Hare

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University of East Anglia
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The SOLAS Implementation-2 (IMP-2) Working Group represents the 2nd of the 3 SOLAS scientific FOCI. IMP-2, led by Wade McGillis and Daniela Turk, is responsible for providing planning, logistics, and integration of SOLAS Focus 2 (www.int-solas.org). The SOLAS Focus 2 scientific aim is 'to develop a quantitative understanding of processes responsible for air-sea exchange of climate and weather relevant compounds (CWRCs), momentum and energy to permit accurate calculation and predictions of regional and global fluxes.' This focus is critical to understanding the processes and links between the oceans, atmosphere, climate, and weather (Figure 1). It is an obvious complement to the WCRP Working Group for Surface Fluxes (WGSF). The WGSF was established to review the requirements of the different WCRP programmes for surface sea fluxes including biogeochemical fluxes, develop communication and coordination between various related research initiatives, encourage research and operational activities on surface fluxes, and keep the scientific community and the WCRP JSC informed of the progress. Furthermore, the WGSF is charged with generating flux data sets, improving measurement technologies, parameterisations and flux field production algorithms, and assessments of sensitivity of climate models and limits of predictability associated with uncertainties in surface fluxes. Therefore, SOLAS/IMP-2 and WCRP/WGSF work together to establish the dependence of interfacial transfer processes on physical, biological, and chemical factors: at the interface; and throughout the atmospheric and oceanic boundary layers; and the contribution of horizontal and vertical transport and transformation of CWRCs.

A more detailed description of SOLAS Focus 2 is given in the SOLAS Science Plan and Implementation Strategy. The implementation of SOLAS Focus 2 is distributed into three activities including: exchange across the air-sea interface; processes in the oceanic boundary layer; and processes in the atmospheric boundary layer.

The need for this cross-cutting SOLAS focus is illustrated in that most coupled atmosphere-ocean climate and weather models employ surface flux corrections and closure-schemes, indicating that the current physical processes controlling the air-sea fluxes are not properly parameterised. SOLAS Focus 2 research will develop an improved fundamental understanding of these processes and improved parameterisations for use in coupled climate and weather predictions. Another major challenge for SOLAS Focus 2 is to bridge phenomenon that transcends from the micro-scale to regional and global scales. Air-sea exchange processes are often studied at small spatial scales (mm to 10's of m) and then this process information is applied to global scales.

IMP-2 has international representation spanning a broad range of oceanic and atmospheric researchers (Table 1). The implementation group has developed a plan that will co-ordinate research within SOLAS Focus 2 while allowing periodic and timely updates and revisions. IMP-2 is naturally integrated with SOLAS IMP-1 and IMP-3, the SOLAS Data Management Task Team (DMTT), and IMP-2

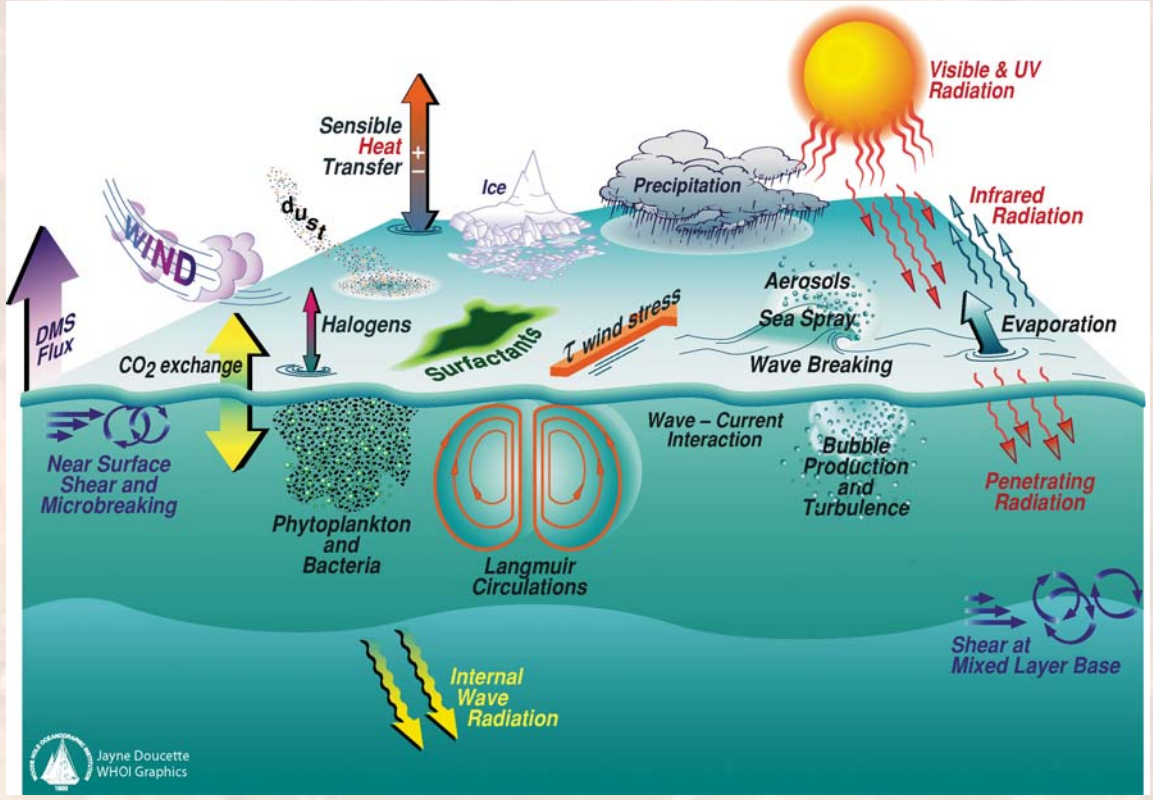

Figure 1: Diagram to illustrate SOLAS, its interdisciplinary domains, and the major operative processes (courtesy of Jayne Doucette, WHOI; and Wade McGillis, Columbia University).

Table 1: 20 members of the international SOLAS IMP-2 group on air-sea exchange

Activity	Participant	Inst	Nation	E-mail
Chair	**Wade McGillis**	CU	USA	wrm2102@columbia.edu
Project Officer	**Daniela Turk**	Dal	Canada	daniela.turk@dal.ca
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Satellites/waves	**Jacqueline Boutin**	LODYC	France	jb@lodyc.jussieu.fr
Meteorology	**Frank Bradley**	CSIRO	Australia	frank.bradley@csiro.au
Satellites/biology	**Mary-Elena Carr**	JPL	USA	mary-elena.carr@jpl.nasa.gov
Air-Sea Fluxes	**Chris Fairall**	NOAA	USA	chris.fairall@noaa.gov
Biophys Modelling	**Veronique Garcon**	CNES	France	veronique.garcon@notos.cst.cnes.fr
Microlayer Bio	**Keith Hunter**	Otago	New Zealand	khunter@alkali.otago.ac.nz
Surface Processes	**Satoru Komori**	Kyoto	Japan	komori@mech.kyoto-u.ac.jp
Spray/Aerosols	**Gerrit de Leeuw**	TNO	NL	deleeuw@fel.tno.nl
Ice/Snow	**Lisa Miller**	IOS	Canada	millerli@pac.dfo-mpo.gc.ca
Deliberate Tracers	**Phil Nightingale**	PML	UK	pdn@pml.ac.uk
Aerosol Models	**Douglas Nilsson**	Stockholm	Sweden	douglas.nilsson@itm.su.se
Surface Ocean	**Al Plueddeman**	WHOI	USA	aplueddemann@whoi.edu
Atmosph. Chem.	**Geert-Jan Roelofs**	Utrecht	NL	roelofs@phys.uu.nl
Satellite Physics	**Detlef Stammer**	Hamburg	Germany	stammer@ifm.uni-hamburg.de
Microlayer Phys	**Wu-Ting Tsai**	Taiwan U.	Taiwan	wttsai@cc.ncu.edu.tw
Surface Ocean	**Svein Vagle**	IOS	Canada	vagles@dfo-mpo.gc.ca
CO_2 fluxes	**Rik Wanninkhof**	NOAA	USA	rik.wanninkhof@noaa.gov

planning efforts are regularly reviewed by the International SOLAS Science Steering Committee (SSC) and WCRP administration. Additional charges of the IMP-2 efforts are to provide contributions to the SOLAS Open Science Meetings and Summer Schools, work closely with World Climate Research Programme's (WCRP) Working Group on Surface Fluxes (WGSF), develop strong interactions with other International Geosphere-Biosphere Programme (IGBP), Scientific Committee on Oceanic Research (SCOR) and WCRP sponsored international programs such as IMBER, LOICZ, CLIVAR and the Global Carbon Project (GCP). The SOLAS IMP-2 group has identified target global study sites that are essential to quantify the air-sea exchange processes and elucidate the factors controlling the transfer (Figure 2). These studies will be conducted in areas where there is a significant flux of climate relevant gases and where the oceanic and atmospheric environmental forcing is distinct and separable from simple wind forcing. These provinces have also been adopted by IMP-1 and IMP-3.

laboration and data management. Generating an ongoing database for past/present/future observational, modelling, and theoretical activities;

- Providing information and collaborating on IMP-2 projects with SOLAS IMP-1 and participating in joint workshops and data synthesis meetings;
- Promoting joint SOLAS/IMP-2 and WCRP/WGSF collaborations: international experiment planning and logistics;
- Contributing to WGSF and SOLAS Newsletters;
- Facilitating the organization, lectures, field experiments, and funding for entraining students and young scientists;
- Providing SOLAS data strategy and facilitating and advocating open data exchange. Maintaining strong data management linkages, infrastructure and resource sharing between national programs;
- Establishing and maintaining an IMP-2 web site for disseminating information.

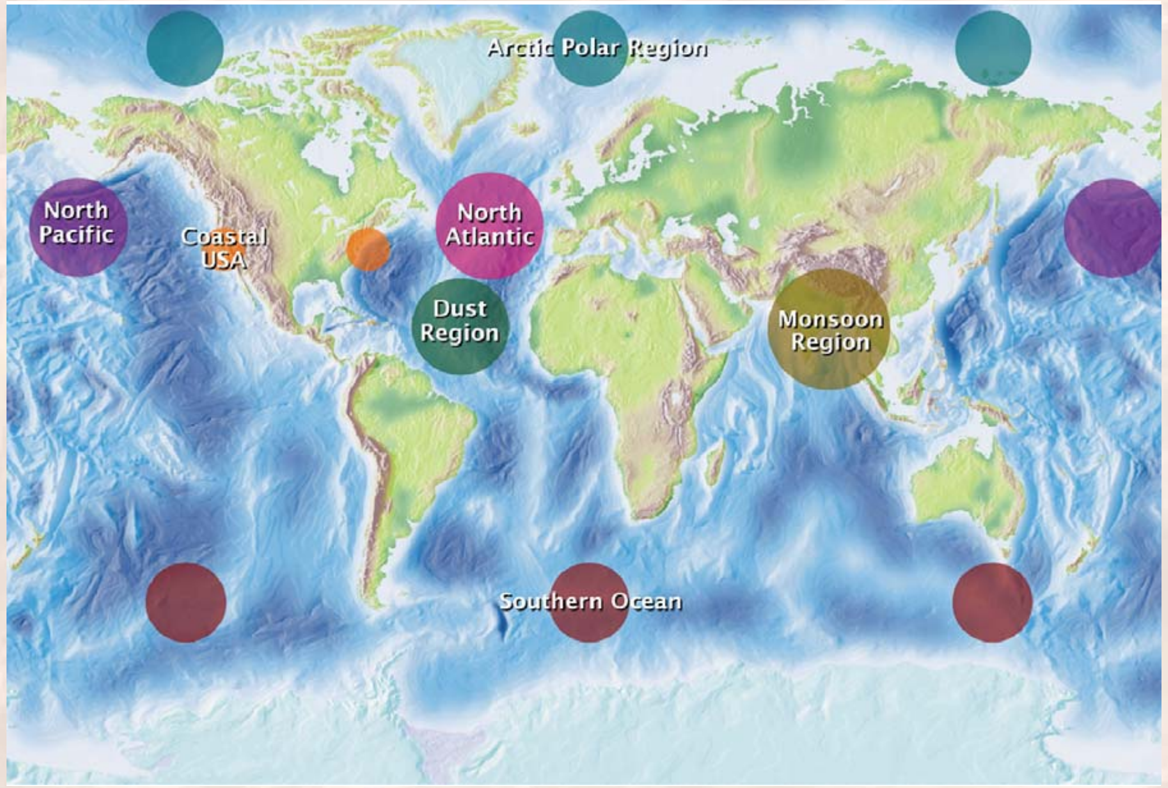

Figure 2: Air-sea gas exchange regions recommended for study.

The SOLAS Implementation Plan for Focus 2 has now been completed and is available on the International SOLAS website. The current mission of IMP-2, in collaboration with the WGSF include:

- Encouraging, inspiring, soliciting, collecting, and compiling IMP-2 International SOLAS projects under the IMP-2 developed protocol for international col-

SOLAS IMP-2 and the WCRP WGSF first jointly met in Montreal in May 2004. Subsequent meetings have occurred in Halifax (October 2004), Montreal (March 2005), and in Tokyo (May 2005). A joint Working Group meeting was held in Honolulu (February 2006) during the 2006 AGU/ASLO/TOS Ocean Sciences Meeting. Future IMP-2 and WGSF activities include the development of review manuscripts on both air-sea gas and aerosol fluxes, the production of a handbook for ship-based flux observations (authors Bradley and Fairall), and joint meetings in Heidelberg, Germany (September 2006), Xiamen, China (March 2007), Ottawa (2008), New York City (2009), and at the Air-Water Gas Transfer Conference in Kyoto, Japan (2010).

We are excited about the synergistic relationship between SOLAS and WCRP as manifested with the IMP-2 / WGSF collaboration, and we look forward to the continued strong scientific effort they represent.

The generous support for IMP-2 planning activities by the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) Dalhousie University, CA, the International SOLAS Project Office, UK, National Science Foundation and Columbia University, USA is gratefully acknowledged.

Recent Developments in Parameterisation of Air-Sea Gas Exchange

David K Woolf

Centre for observation of Air-Sea Interactions and fluxes
National Oceanography Centre, Southampton, UK

The air-sea flux of gases is commonly expressed in terms of a simple formula resembling the bulk formulae used for other air-sea fluxes:

$$\text{Flux} = -k\,\Delta C$$

where 'ΔC' is the effective concentration difference driving the flux and 'k' is the air-sea transfer velocity of the gas. It is a key aim of WGSF and SOLAS to improve estimates of the transfer velocity for all geophysically significant gases and for the full range of environmental conditions. Here, we review some recent developments in this direction.

Key to recent progress has been the development of new methods for the measurement of air-sea gas fluxes (Fairall *et al*., 2000). Finally we have adequate data to test existing parameterisations of air-sea gas transfer, and this is driving a new effort to model air-sea gas exchange. Most of the parameterisations of air-sea transfer velocity in current use are simple empirical formulations in terms of wind speed, but there is now a trend towards more physically-based models. Key drivers other than direct wind forcing are buoyancy forcing and the role of surface waves in atmosphere-ocean energy transfer. Transfer across both atmospheric and marine boundary layers must be considered in modelling the turbulent air-sea transfer of gases, though for most important gases, including carbon dioxide, the top millimetre of the ocean has a dominant effect on transfer rates. Theoretical profiles and fluxes of gases can be calculated by an extension to the turbulent transfer theory used for temperature profiles (Fairall *et al*., 2000 and 2003). Measured temperature profiles can provide validation of this theory and in particular, measurements of the cool skin of the oceans provide a test for the part of the model that is most critical for gas transfer.

From above, we have a reasonable working theory for the direct turbulent transfer of gases in steady state conditions that includes wind and buoyancy forcing. However, comparisons of model predictions with actual carbon dioxide (CO_2) transfer velocities reveal significant difficulties (Hare *et al*., 2004). Firstly, fitting the model to different data sets requires modification of a coefficient for different data sets; this may be related to the role of surface films in modulating gas transfer rates. Secondly, explanation of measured transfer velocities at high wind speeds requires an additional mechanism that enhances transfer in these conditions. Bubble-mediated transfer of gases (Woolf, 1997) provides such a mechanism, since bubbles provide a path across the oceanic boundary layers in parallel to direct transfer. Hare *et al*. (2004) were able to fit the combined 'NOAA/COARE' model to measured transfer velocities albeit with some modification of coefficients to fit individual datasets and this has established the NOAA/COARE model as a prototype 'physical' model of gas transfer velocities.

While as summarised above NOAA/COARE is consistent with measured CO_2 transfer velocities, it is not unique in that respect. For instance, it is possible to reduce or dismiss bubble-mediated transfer and instead hypothesise a non-linear increase in direct transfer at high wind speeds. However, there is an important difference in predictions between direct transfer models and bubble-mediated transfer models for the relative transfer velocities of different gases. According to direct transfer models, the relative transfer is simply related to the relative molecular diffusion coefficients of the gases, but bubble-mediated models predict a strong sensitivity to solubility with smaller transfer velocities for more soluble gases (Woolf, 1993). Thus, we can look to the measured transfer velocities of different gases for indirect but powerful evidence to discriminate between models. Recent measurements of the flux of dimethyl sulphide (DMS; a more soluble gas than carbon dioxide, but also primarily limited by transfer across the liquid boundary) indicate a relatively linear response of transfer to wind speed with no evidence of a strong enhancement at high wind speeds (Blomquist *et al*., 2006). Direct transfer models cannot explain this result and therefore we have persuasive, if indirect, evidence that bubbles play an important role in the transfer of CO_2 in high winds. Moreover, the NOAA/COARE model is consistent so far with measured transfer velocities of both carbon dioxide and DMS.

Some difficulties with the above interpretation remain. One objection is that the coefficient of bubble-mediated transfer has been altered for different datasets. Another objection is that laboratory 'wind wave tank' experiments generally indicate only a minor contribution by bubbles (de Leeuw *et al*., 2002) while wave-breaking frequency will be greater in the laboratory than in the field. Both of these objections may be overcome by the same insight: that wave breaking (or 'whitecapping') is not simply dependent on wind speed and that the energy dissipated in wave breaking (and the volume of entrained as bubble plumes) will be greater in a more developed sea. This is consistent with considerations of the energetics of wind waves (Woolf, 2005) and is not contradictory to the total frequency of breaking reducing with increasing wave development, since dissipated energy and air entrainment increases rapidly with wavelength. Further, there is strong empirical evidence that whitecapping is generally greater in a more developed wind sea (Zhao and Toba, 2001). Thus, a model of gas transfer velocities incorporating sea-state-dependent wave breaking (Woolf, 2005) is flexible enough to explain the available data.

We can be optimistic that we are making real progress, but much remains to be done. 'Consistent' and 'correct' are very different and we await more comprehensive datasets to confront the models. Certainly simultaneous data on transfer velocities of more than one gas and measurements of bubble plume characteristics should provide a much sterner test of the models. We hope to gather such datasets from planned experiments of UK SOLAS ('DOGEE SOLAS' and 'SEASAW' supported by Natural Environment Research Council). Also, we know already that the models of bubble-mediated transfer require some development (Woolf *et al*., 2006) and more data should drive further improvements. On the other hand, we believe that we can catch a glimpse the future, and these new models are being exploited to produce new climatologies of air-sea gas flux (Fangohr and Woolf, 2006).

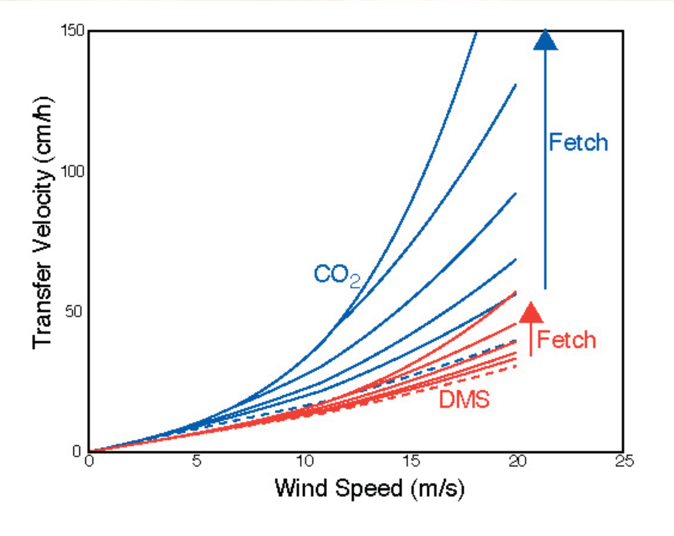

Figure. The transfer velocity of carbon dioxide and dimethyl sulphide versus wind speed, based on the models of Woolf (1997, 2005). Direct transfer is shown by the dashed lines; CO_2 and DMS direct transfer are in a ratio of 1.3:1. Total (direct + bubble-mediated) transfer is shown by the full lines; CO_2 and DMS bubble-mediated transfer are in a ratio of 6:1. The set of curves represent the range of values that results from different wave development; each curve corresponds to a particular fetch.

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Sea Spray Source Function: Micrometeorological Measurements at the FRF field research facility in Duck, North Carolina, USA

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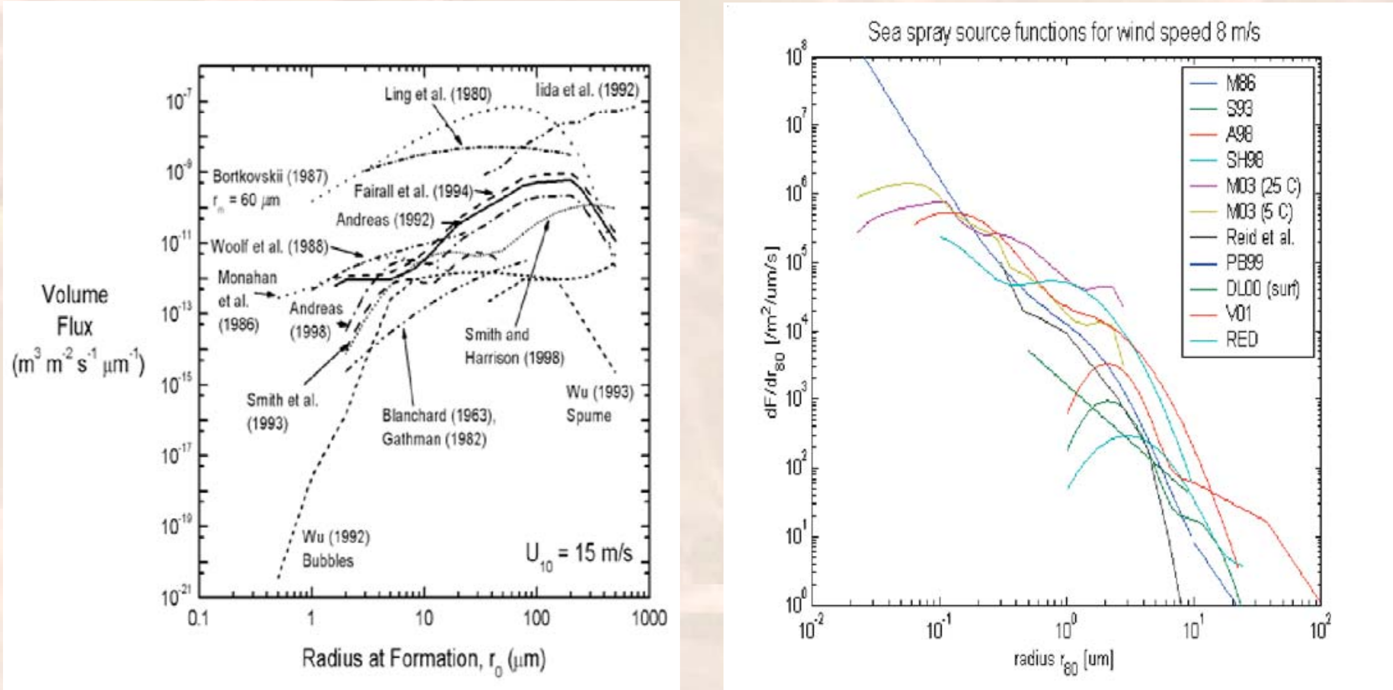
Sea spray source functions (S3F) vary by as much as 6 orders of magnitude (Andreas, 1998, 2002). However, recent efforts using different methods (Schulz et al., 2003), usually lead to results that, for the sub-micron particles, converge to within about a factor of 10 or better, see Figure 1.



(a)

(b)

Figure 1: Overview of sea spray source functions:
(a) published until 1998 (Andreas, 2002)
(b) comparison of recently published sea spray source functions with the more 'traditional' source functions M86, S93 and A98.

Most of these methods are indirect, i.e. they rely on inverse modelling (e.g., Vignati *et al*., 2001; De Leeuw *et al*., 2003) or on assumptions of steady state leading to balance between production and removal of sea spray particles (e.g., Fairall *et al*., 1994; Smith *et al*., 1993; Smith and Harrison, 1998). The latter method has been questioned by Hoppel *et al*. (2002) because of the uncertainty in atmospheric residence time of aerosols and thus in their deposition velocity (except for particles large enough that their deposition is governed by gravitation (roughly > 5—10 µm). Other indirect methods rely on measurements of whitecap cover as function of environmental conditions (usually wind speed u_{10} or friction velocity u*) combined with laboratory measurements of the amount of aerosol produced per surface area of whitecap (e.g., Monahan *et al*., 1986; Mårtensson et al., 2003). Reid *et al*. (2001) deduced the surface flux of sea spray from aircraft measurements on the filling of the boundary layer with sea spray with fetch in off shore wind. A limitation of this method is that it can only be applied in coastal conditions. Similar considerations apply to source functions derived from measurements of aerosol gradients in the surf zone (De Leeuw *et al*., 2000).

Micro meteorological measurements of the S3F

Direct measurements of the production of sea spray are provided by mi crometeorological techniques, which were first applied by Nilsson *et al*. (2001) using a flux system consisting of a sonic anemometer and a condensation particle counter (CPC), providing the total aerosol concentration for particles larger than 10 nm. This flux package was complemented with an optical particle counter equipped with an inlet heated to 300°C, to volatize all aerosol components except sea salt. This method provides a direct measurement of the sea salt spectral flux. This was first tested on FLIP during an experiment near Hawaii (Anderson *et al*., 2004) with moderate results (De Leeuw *et al*., 2003; Nilsson *et al*., 2003).

UNISOURCE and WASFAB experiments

After improvements, this flux package was deployed from the 560 m long pier at the US Army Corps of Engineers Field Research Facility in Duck (NC, USA; http://www.frf.usace.army.mil/), see Figure 2. This site was selected because of the long pier and supporting meteorological and oceanographic measurements. The experiments took place in November 2004 (UNISOURCE: De Leeuw *et al*., 2005) and in October 2005 (WASFAB: De Leeuw *et al*., 2006; Zappa *et al*., 2006), with the goal to further test the methods and to obtain a comprehensive set of measurements to further constrain the sea salt source function. In particular, the analysis is intended to test which parameters, other than wind speed and friction velocity, influence the S3F, such as wave height, age and steepness, sea surface temperature, salinity, and atmospheric parameters such as wind speed, fetch, micrometeorological fluxes, thermal stability (Smith and De Leeuw, 2004).

Figure 2. The FRF pier extends 560 m into the North Atlantic Ocean. The sea bottom gently slopes to a depth of about 10 m at the end of the pier. Supporting meteorological and oceanographic data are routinely available from the FRF.

The flux package was mounted on a meteorological mast at the far end of the pier at a height of 16.2 m above mean sea level. A second aerosol flux package was added, where the aerosol size spectra were measured with a frequency of 10 Hz using a CLASP (Compact Lightweight Aerosol Spectrometer Probe) being developed by the University of Leeds (Norris *et al*., 2006). CLASP is based on fast response MetOne particle counters (0,2—7 µm diameter). This suite of aerosol flux instruments was further complemented by a Licor LI-7500 open path sampler for water vapor and CO_2 fluxes. Supporting instruments included a sea spray package consisting of PMS OAP and FSSP, a TSI APS, a PMS OPC based volatility system that continuously cycled between 50°C and 700°C to determine the contributions of volatile components and sea spray to the total particle size distribution, an aethalometer to determine the absorbing aerosol fraction and a met station. During WASFAB a boom extending ≥ 8 m from the pier end was added with another set of instruments, including a Riegl altimeter to measure wave heights, Licor LI-7500 open path sampler, and a sonic anemometer (Zappa *et al*., 2006). The height up and distance out from the pier were selected to minimize air-flow perturbation due to obstruction by the pier and buildings at the end of the pier. Other wave measurements are available from buoys and meteorological and oceanographic parameters are available from the standard suite of instrumentation maintained at FRF.

Preliminary results

Initial results from micrometeorological measurements during the UNISOURCE experiments in November 2004 and the WASFAB experiments on October 2005 show that in onshore winds the conditions are representative for open ocean conditions. For instance, drag coefficients compare favorably with the TOGA-COARE 2.6 parameterisation for drag coefficient over the open ocean for the range of wind speeds encountered (up to 16 ms^{-1}) (Zappa *et al*. 2006). The relevant spectra of micrometeorological parameters and aerosol concentrations show the expected behaviour.

Figure 3 shows two weeks of data from the UNISOURCE experiments in November 2004. Heat and water vapor covariances trace friction velocity quite well, and also the CO_2 covariances are generally well behaved, with a tendency to have both positive and negative values. All these fluxes have a different wind speed dependence between the first and the second storm (De Leeuw *et al*., 2005; 2006). The aerosol fluxes, shown for integrated concentrations in the diameter range 0.11—0.375 µm are much more scattered. However, they seem to generally trace the wind speed and u*. The interpretation of these data is in progress.

After WASFAB in October 2005, the measurements of drag coefficients were continued at the FRF facility, to start a long-term program on the influence of drag coefficients and wave development, in cooperation between FRF, LDEO and TNO.

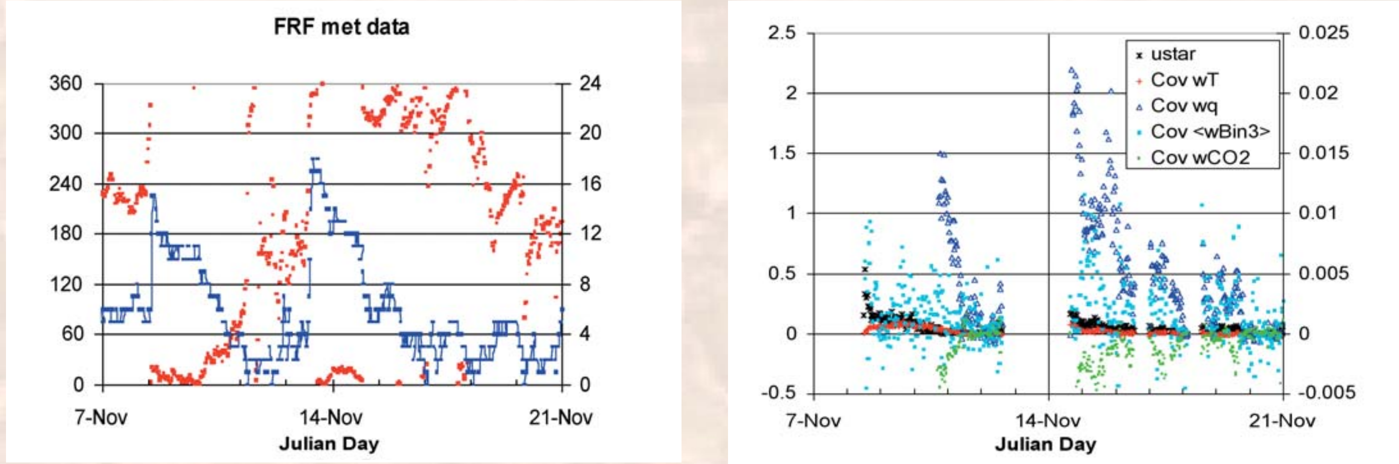


Figure 3. Two weeks of data from the UNISOURCE experiment in November 2004. The left panel shows the wind direction and wind speed from the FRF standard meteorological data. Note that the pier is aligned almost E-W, i.e. easterly winds (0°—170°) are on-shore and westerly winds are off-shore. Storms with winds of over 16 m/s were experienced starting on 8 November and on 13 November. The right panel shows preliminary results from micrometeorological measurements in the tower, at 16 m above the sea surface. There is a data gap from 13 to 15 November when the instruments were removed from the mast because of forecasted lightning. The LICOR LI-7500 was installed on 11 November, hence there is no data from before that date.

Acknowledgements

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Research in Small Scale Transport Processes: The Heidelberg Aeolotron

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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 processes in the air-water interface, which poses the main transport resistance between the oceans and the atmosphere. Modelling and predictions of our global climate can only be improved by gaining a more complete understanding of the mechanisms involved in transporting energy and mass between the atmosphere and the sea. Representing the body of water closest to us, one might be tempted to believe that it is also the most accessible. However, this is clearly not the case as a comparison of the involved dimensions indicates. Undulations of the sea-surface can range from a few millimeters to several meters in windy conditions. In contrast, the sea-surface microlayer extends roughly 1 to 1000 μm below the surface. It consists of the viscous and thermal sublayers which are the topmost 1000 and 300 μm of the water surface, while the diffusion sublayer refers to the top 50 μm. Accurately resolving the properties of these minute boundary layers on top of waves bigger by a few orders of magnitudes still represents an experimental challenge. The importance of increasing our knowledge in this field has been recognised by a number of national funding agencies through the SOLAS initiative. Particularly the SOLAS Implementation Group 2 is concerned with exchange processes at the air-sea interface. Recently, improvements have been made in modelling the small scale processes involved as well as measuring them in laboratory settings as well as in the field, both temporally and spatially highly resolved. In the Institute of Environmental Physics at the University of Heidelberg, Germany, a world wide unique experimental facility has been build, the Heidelberg Aeolotron (named after Aeolus, the Greek god of the winds). This annular wind/wave facility with 10 m in diameter was purpose built for the investigation of small-scale air-sea interaction processes. It goes without saying that its airspace is gas tight and its walls are well insulated for heat. The Aeolotron is well equipped with novel imaging optical techniques that make various parameters of these processes visible. These imaging techniques go hand in hand with digital image processing for an automated quantitative analysis of the image sequences obtained. The Heidelberg Aeolotron is open to scientists from around the world to conduct their measurements for experimental research in air-sea interaction.

The circular Heidelberg Aeolotron and a view of the wave field during an experiment.

A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea

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1. Background

The need for accurate fluxes of heat and momentum in the coupled ocean-atmosphere system has been acknowledged for at least two decades. The sensitivity of coupled air-sea models to small changes in values of air-sea fluxes, induced the WOCE observing program and process studies such as TOGA-COARE to set an accuracy target for the measurement of net heat exchange across the ocean-atmosphere interface of ±10Wm^{-2} over short to medium timescales (WCRP 1985). However, comparison of observations from several research ships during TOGA-COARE revealed that raw measurements fell short of this goal. The reasons for these disagreements were examined and identified, and in many cases corrections could be made. It became apparent that if the requirements of climate research were to be met, more care must be taken to ensure the accuracy of measurement of basic meteorological variables used for the calculation of turbulent and radiative air-sea fluxes (Weller *et al*. 2004). Such careful observations may be referred to as of «climate-quality».

Following the publication of its report on the status of air-sea flux datasets and observational methods (WCRP 2000), the WCRP/SCOR Air-Sea Fluxes Working Group (co-chairs Dr Peter Taylor and Dr Sergey Gulev) convened an international workshop at Potomac MD, to discuss its findings, and to consider the applications of future air-sea flux measurement for climate research generally, for validation of satellite observations and the requirements of climate models. The Workshop noted that ‘the techniques to obtain high quality data for flux estimation at sea are very demanding’ and recommended ‘the assembly of a Technical Manual on air-sea flux measurement methods’ (WCRP 2001).

In March 2003, Florida State University hosted the 1st High-Resolution Marine Meteorology (HRMM) workshop, under the auspices of the NOAA/OGP Ocean Observing Initiative, where the quality of basic measurements needed for accurate air-sea fluxes was again discussed. The meeting also examined the notion that valuable data could be obtained from research ships operating in rarely visited regions. Often these ships have the necessary sensors on board, and technicians to maintain them, but no mechanism exists to collect such flux-relevant data of opportunity. If instituted those involved would need training in the techniques of collecting high-quality meteorological data at sea. The meeting report (COAPS 2003) recommended to ‘Produce a reference manual of best procedures and practices for the observation and documentation of meteorological parameters, including radiative and turbulent fluxes, in the marine environment’.

The formation of the Working Group on Air-Sea fluxes by WCRP at about that time (see article by Chris Fairall in Issue 1 of Flux News) gave the impetus for these two almost identical proposals for a ‘Handbook of best practice’ to proceed. At the second workshop of the HRMM in April 2004, and at the inaugural meeting of the WGSF in October, a detailed synopsis of the proposed handbook was presented for comment, and generally accepted. On this basis, writing proceeded with a concentrated effort when both authors were on board the R/V Ron Brown for the month of October 2005. The first draft was available for review by members of the WGSF by the end of that year. Extensive comments were provided by Liz Kent, Bob Weller, Peter Taylor, Ed Andreas, Shawn Smith, Mike Reynolds, Eric Schulz, and Will Drennan, the majority of which have been incorporated into a second draft.

2. Scope

The Handbook is intended for a wide readership. Primarily it is for the guidance of scientists and technicians responsible for the installation and/or maintenance of meteorological equipment on board ships, whether research vessels specifically engaged in air-sea studies, ships collecting relevant data of opportunity, or commercial vessels recruited to the Voluntary Observing Ship network. It can provide background for PI’s on oceanographic cruises, who need air-sea fluxes as supplementary data for their study. It may also benefit those who assimilate field data into models, to be aware of possible limitations and to ask questions regarding quality and accuracy. Importantly, the Handbook will provide material for students new to the field of ship-based meteorological and air-sea flux measurements.

The second workshop of the HRMM in April 2004 (COAPS 2004) resolved that equipment existing or subsequently installed on ships and maintained according to the principles embodied in the Handbook be identified as part of the Shipboard Automated Meteorological and Oceanographic System (SAMOS), which will collect climate-quality data to be archived and distributed via an assigned Data Acquisition Centre. The Handbook will be a guide to SAMOS and similar projects.

At this stage, we focus solely on the observations required for the calculation of *bulk* fluxes. Eddy-correlation ('direct') flux measurement and associated instruments are not considered in the Handbook, these methods not yet being regarded as operational at sea. Likewise, methods for determining air-sea transfer of trace gases are not considered, although developments in this area are rapid and the WGSF commitments to SOLAS will bring these methods into our ambit. The Handbook will be maintained online through the SAMOS initiative, and will be updated and expanded as new methodology and instrumentation become readily available.

3. Content

The broad readership presented the problem of how to cater in the one manual for users between the extremes of a simple 'how to' guide, and enough detail to design an experiment. We have attempted to do this with a Quick Reference of the most critical information and procedures, a «stand-alone» practical source, with comprehensive details in the main body of the Handbook. We list the chapter headings to indicate the subject matter covered:

Contents
Background
Quick Reference
Flux Measurements From Ships and Buoys
1. The air-sea fluxes
2. Basic variables input to bulk algorithms
3. Bulk-flux meteorological sensors
4. Measurement systems
5. Particular problems on ships and buoys
6. Location of instruments
7. Instrument calibration
8. Intercomparisons
9. Documentation (metadata)
10. Securing the data
11. Bulk flux algorithms
Appendices

The characteristics of the environmental variables are described, why it is so much more difficult to measure them at sea than over land, and ways of dealing with this. We also refer to procedures such as calibration, and comparison with other instruments, which help ensure the quality of the data. Stress is also laid on the critical importance of documentation, particularly of the location and state of the measuring instruments, and notes of any occurrence, e.g. roosting birds, which may impair data quality.

There are several specialised Appendices; physical formulae, constants and conversion factors used in the analysis of atmospheric data and the calculation of air-sea fluxes (which you can never find when you need them); a description of the TOGA-COARE bulk flux algorithm; an analysis of thermal radiative flux errors; examples of shipboard observations; links to relevant web sites; and the SAMOS specifications for standardization of data formats, and metadata requirements.

The Handbook is liberally furnished with photographs from actual cruises, and graphs of real data.

4. Outlook

The second draft has been made available to the WGSF membership and to the participants in the 1st Joint Workshop of GOSUD and SAMOS to be held in Boulder, May 2—4 2006. It is scheduled for discussion of topics which have arisen during the review process, and which can be best resolved in open forum. Immediately following the workshop, the authors plan to revise and prepare the first edition for publication as hard copy. It will also be available on the WGSF website http://www.etl.noaa.gov/et6/wgsf/

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Global 0.25° Gridded 6-Hourly and Daily Sea Surface Winds from Multiple Satellites



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1. Introduction

Advances in understanding the coupled air-sea system and numerical modelling of the ocean and atmosphere demand increasingly higher resolution data over the global ocean surface, as documented in several WMO programs (e.g., WMO/TD-No. 1036, 2000; Curry *et al*. 2004). Some applications require that fluxes be computed at temporal and spatial resolutions of up to 3 hours and 50 km, respectively. Observationally, these requirements can only be met by utilizing multiple satellite observations of sea surface wind (SSW), sea surface temperature (SST), and sea surface air temperature and humidity (Ta and Qa). The above four variables are the necessary components to compute the turbulent (latent and sensible) air-sea heat fluxes through empirical bulk formulae. Efforts are being made at the U.S. National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center to produce globally gridded high resolution datasets for the above four parameters from multiple-satellite and in-situ observations on an operational basis. Here, we describe the feasibility and production of high resolution global sea surface wind speed. The SSW, Ta and Qa have higher frequency variability than SST in general.

2. Data Coverage

Sea surface wind has been observed from both in-situ platforms and multiple satellites. In the satellite era, in-situ observations play a critical role in calibrating and validating satellite observations. However, with the dense satellite sampling, in-situ observations play a minor role in reducing random and sampling errors in blended analyses using both in-situ and satellite observations (e.g., Zhang *et al*. 2006).

The time line of the long-term US sea surface wind speed observing satellites is shown in Figure 1. The coverage is sparse in early years, and the number of satellites gradually increased to about three in mid 1990s and to six since mid 2002.

The individual satellite data used in this study were obtained from the Remote Sensing Systems, Inc. (e.g., Wentz 1997) for their uniformity of the retrieval algorithms for the multiple satellites over the whole time period, and for their wide use in producing various air-sea turbulent fluxes (e.g., Chou *et al*. 2003 and citations therein). Using these datasets, we explore the possibility of producing blended global products on a 0.25° grid for various temporal resolutions. The 0.25° grid approximates the high resolution of the above satellite observations. This 0.25° grid resolution also marginally resolves oceanic boundary currents such as the Gulf Stream where large turbulent fluxes and large flux gradients frequently occur.

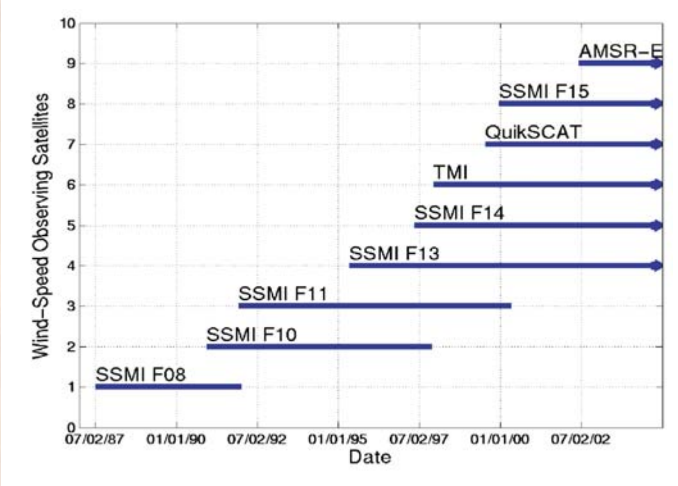

Figure 1. Timeline of the long-term US sea surface wind speed satellites used in this study.

Over the years, the ocean has become sampled in more detail as indicated in Figure 1 and quantified in Figure 2. The averaged sampling time interval decreased rapidly from late 1987 to mid 1990s, from more than 14 hours to less than 8 hours. Further decreases from mid 1990s were more moderate and eventually converged from tropics to high latitudes in early 2000. This is a simplified view on average; detailed global sampling distribution patterns are available from the authors.

3. Globally Gridded Products

On global average, 6-hourly products on the global 0.25° grid have become feasible since 2000. A simple objective analysis method (Zeng and Levy 1995) was used to generate our gridded and blended products on the 0.25° grid and 4 times per day at 00, 06, 12 & 18Z (UTC or GMT). Additionally, daily fields were generated by averaging the 4 snapshots of the day, and monthly fields were computed by averaging the daily fields. Climatological monthly means were then computed from the monthly data for certain chosen base time periods (e.g., 1995—2005); earlier data were not used in this climatology because there were limited early satellites. The blended data for all the above resolutions (6-hourly, daily and monthly) are processed from 9 July 1987 to present. However, caution must be exercised when using the 6-hourly data for the early time period, for which time aliases may be large due to the data under-sampling (c.f. Figs. 1 and 2). All of

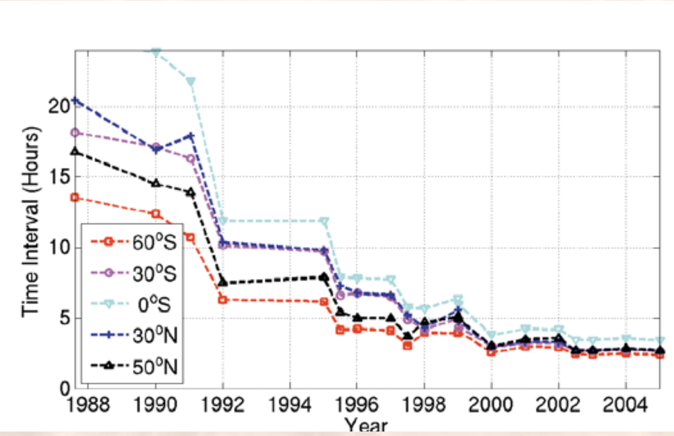

Figure 2: Averaged sampling time intervals in the 0.25° bins and as functions of time and latitude, using the satellites shown in Figure 1. Values are zonal averages along five latitude circles and averaged over 1-week periods at the beginning of selected months, for which there were new satellite additions or reductions.

these data and supporting MATLAB, FORTRAN and GrADS routines are freely available to the research community through the links at the website http://www.ncdc.noaa.gov/oa/rsad/blendedseawinds.html. Wind directions corresponding to the above resolutions will be added soon. Future products on SST, Ta and Qa will also be linked to this site.

An example of the analyzed global winds at 12Z, 28 August 2005 is shown in Figure 3, on which simultaneous Hurricane Katrina and Typhoon Talim are clearly shown. Remember that the satellite-retrieved winds may still underestimate the maximum winds in regions with heavy precipitation.

Acknowledgements:

The individual satellite data were downloaded from the website of the Remote Sensing System (RSS), Inc. (http://www.remss.com/). We thank Debra Smith at RSS for answering our detailed questions. Mention of a commercial firm does not constituent endorsement by the U.S. government.

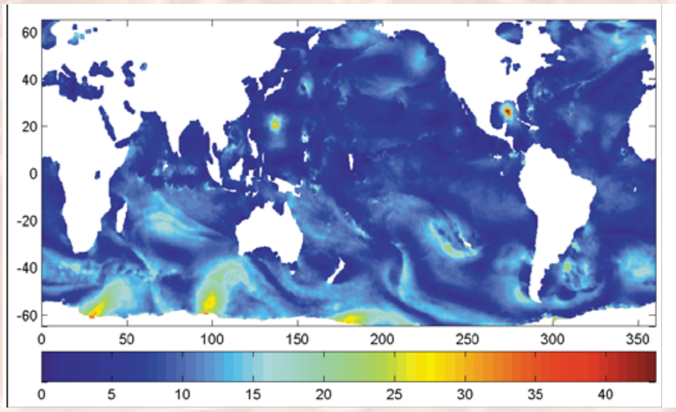

Figure 3: An analysis of the global sea surface winds at 12Z, 28 August 2005, reconstructed from observations of the six satellites shown in Figure 1.

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XXVII Session of the Joint Scientific Committee for WCRP, Pune, India, 6—11 March 2006

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The XXVII annual session of the Joint Scientific Committee for WCRP was held on 6—11 March 2006 in Pune at the Indian Institute of Tropical Meteorology. JSC welcomed the new WCRP Director Professor Ann Henderson-Sellers who started her duties on 1 January 2006 at WMO Headquarters in Geneva (see the front page).

Significantly, this year's session took place in parallel with the annual meeting of the Scientific Steering Committee of IGBP. At these sessions (6—7 March) JSC/WCRP and SSC/IGBP jointly discussed the following projects, which represent the mutual interest and are co-sponsored by the two committees: SOLAS, GCP, GWSP, GECAFS, GEC & HH, START, MAIRS, NEESPI and AMMA.

The SOLAS presentation which was of particular importance for WGSF was given by SOLAS SSG Chair, Peter Liss of the University of East Anglia, UK. P. Liss stressed the importance of a close cooperation between SOLAS and WGSF in understanding the mechanisms of air-sea transfer of biogeochemical properties and in assessing the impact of these processes on the coupled climate system. Although this cooperation is currently concentrated on Focus 2 of the SOLAS Implementation Plan (Exchange Processes at the Air-Sea Interface and the Role of Transport and Transformation in Atmospheric and Oceanic Boundary Layers), both WGSF and SOLAS are looking forward to extending this cooperation (for more details see the article by W. McGillis *et al.* in this issue). During the discussion, both WCRP and JSC communities expressed the view that cooperation between WGSF and SOLAS represents one of the most successful test beds for the general partnership between IGBP and WCRP. Also, it was pointed out that the achievements of SOLAS in understanding the air-sea gas and biogeochemical exchanges can boost the work of WGSF, and vice versa, that the SOLAS community could benefit from the WGSF expertise in air-sea interaction physics and global flux field analysis.

Further, the reports from two joint WCRP/IGBP task forces were heard. A.R. Ravishankara and P. Rasch presented the developments in Atmospheric Chemistry and Climate (AC&C) and J. Shukla, J. Mitchell and M. Martin delivered the WCRP/IGBP Modelling Strategy focusing on Earth System models. Finally, the joint session considered the GEWEX-iLEAPS and CLIVAR-PAGES collaboration. For WGSF the prospects of cooperation with iLEAPS are particularly important due to the potential for WGSF to cover not only surface fluxes over the ocean, but also surface fluxes over land.

At subsequent sessions of JSC/WCRP (8—11 March, 2006), we heard the reports from the WCRP Panel on Observations and Assimilation (WOAP), the WCRP Modelling Panel (WMP) and the WCRP Task Force on Seasonal Prediction (TFSP). These were followed by the cross-cutting topics, such as Monsoons, Atmospheric chemistry and climate, Sea-Level Rise and Extreme events. Then the progress of the WCRP core projects and Working Groups was covered.

For our Working Group (WGSF) the CLIVAR report presented by Tim Palmer and Tony Bussalachi was of particular importance due to the developments in ocean reanalyses after the Boulder Ocean Reanalyses Workshop (2004). The report of WGNE by Martin Miller addressed the further necessity of a close cooperation between WGSF and WGNE on SURFA and the evaluation of surface fluxes in NWP models (see M. Miller's article in Issue 1).

The report of WGSF was presented by its Chair Chris Fairall. He spoke of the major achievements of WGSF over the last year highlighting, in particular, the completion of the Flux Measurements Handbook (see the article by F. Bradley and C. Fairall in this issue) and the launch of *Flux News*. Also, C. Fairall announced that WGSF is planning a summer school on air-sea interaction for young scientists, for which a close cooperation with START and SOLAS will be essential. SOLAS in particular has already gained an excellent experience in organizing summer schools.

Report of OOPC was presented by Ed Harrison of PMEL (Seattle). He covered the recent activities of the oceanographic communities in implementation of the in situ component of the initial global ocean observing system (GOOS) as a part of GCOS. Of a special importance for WGSF is the potential use of the drifting buoys for massive measurements of the most complete set of surface parameters. Currently most of these buoys are measuring only SST with some occasional buoys measuring winds and SLP.

The JSC stated in its decisions that it supports the forthcoming joint meeting of WGSF and WGNE on SURFA and NWP fluxes in Boulder in November 2006 as well as the joint meeting of WGSF representatives with SOLAS in Heidelberg in September 2006. Another important decision includes the JSC approval for WGSF to negotiate with IGBP (through iLEAPS) and some WCRP bodies the possibility of WGSF covering surface fluxes over both sea and land. The WGSF chair in cooperation with JSC and JPS has already started work on the implementation of these decisions. We hope for progress to be achieved by the next JSC session scheduled to take place on 26—30 March 2007 in Zanzibar, Tanzania.

Several crucial organizational changes were made at the final executive session. The JSC Chair Peter Lemke stepped down after his 6 years of extremely successful work for WCRP. The JSC thanked P.Lemke for all that his outstanding efforts have contributed to increasing WCRP's role in understanding climate predictability and the quantification of human effects on climate. JSC appointed John Church of CSIRO Marine Research and Antarctic CRC (Australia) as a new Chair of JSC for WCRP. V. Ramaswamy of GFDL (Princeton) was appointed as new JSC Vice Chair and Guoxiong Wu of the Chinese Academy of Sciences as a new JSC Officer.

SEAFLUX Third Workshop

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The Third SEAFLUX Workshop was held at Wakulla Springs, FL on March 2 and 3, 2006 with 28 participants from America, Europe, and Asia. The SEAFLUX project is dedicated to producing climatological data sets of air-sea fluxes of heat, moisture, and momentum, under the auspices of the GEWEX Radiation Panel. Funding for the workshop was supplied by the NOAA Office of Climate Observation.

The workshop consisted of one and a half days of overview presentations combined with time for discussions. The overall goals of the presentations were to discuss issues associated with the SEAFLUX Intercomparison Project, the issues associated with the retrievals of various parameters necessary for the production of air-sea fluxes, new directions in bulk flux algorithms, and issues associated with gridding, blending, and assimilation of data. Further scientific presentations covered recent analyses of variability of satellite flux data sets, relationships between satellite-derived fluxes and models, and in situ data needs for validation and assimilation into the satellite flux fields. A final workshop report is being produced and can be obtained from the SEAFLUX website (http://www.gfdi.fsu.edu/SEAFLUX). Several flux products are being produced by the members of SEAFLUX, including both operational and historical products.

The highlights of the scientific results presented include:

- There is some benefit to the use of numerical weather prediction or reanalysis products for estimations of near-surface specific humidity, but especially in the tropics it creates a very homogeneous field. Other very promising satellite-only methods include the use of multi-sensors including sounders to determine near surface air temperature and specific humidity. Regional and seasonal biases still exist in the products, and more data is needed at high and low extremes of temperature and humidity.
- The use of satellite-derived surface flux fields leads to improvements in modelling of the equatorial Pacific and other regions as compared to model simulations using ECMWF fluxes. The IPCC models show too little variability in tropics, and have bimodal latent heat flux populations (Figure 1).
- Sea surface temperature fields from satellite products can vary by over 1°C on average, with seasonal and regional (especially over western boundary currents) biases. The use of skin temperature is important, and diurnal warming is a factor in flux determination.
- Several different satellite products show evidence of increased evaporation over the last 15 years, which seems to be dependent on wind speed and is consistent with a strengthened Hadley circulation. Precipitation does not display a significant trend.
- In general, bulk flux formulae work well mainly for medium wind speed ranges (5 ms^{-1} – 12 ms^{-1}). More investigation is needed for low wind speeds (less than 3 ms^{-1}) and high wind speed (higher than 20 ms^{-1}). For the latter, consideration of wave information may be helpful especially with respect to the spatial and temporal resolutions of the final flux products.
- There are alternative methods (e.g., Xie and Liu 2005: http://airsea-www.jpl.nasa.gov/publication/paper/Xie-Liu-2005.pdf) to the bulk parameterisations for latent heat flux retrievals on longer time scales that can be used for comparisons of the budgets.
- The use of multiple sensors and multiple times requires careful work with gridding and blending of the products, but can significantly reduce errors.
- More in situ data is needed at high wind speeds. More data is available from ships of opportunity, and there is some high-quality data available that can be used for comparison and algorithm development.

Several recommendations from the SEAFLUX workshop are directly related to the objectives of the WGSF. These include

- Creating several test beds of data for developers of satellite-derived surface fluxes. Test beds include: wave data for use in developing parameterisations for wind speeds on the order of 20—30 ms^{-1}, sea surface temperature diurnal warming data sets to investigate effects on fluxes and for inclusion in SST products, monthly evaporation budgets based on hydrologic balance, and longer time series of near surface air temperature and specific humidity from sounder data.
- Encouraging further in situ measurements of fluxes, including wave data, especially in regions of high winds and ocean fronts such as western boundary currents. Measurements should include high-quality basic surface and meteorological variables (i.e., wind speed, specific humidity, air and sea temperature) as well as related uncertainties. Continue to make such data widely available to the SEAFLUX community (via web page).
- Continuing to explore intercomparisons and encouraging continued understanding of differing flux data sets by using ocean models to study oceanic energy transport and sea surface temperatures.
- Encouraging continued research into methods of blending, gridding, and error characterization of fields based on multiple satellites at multiple time and spatial resolutions.
- Identifying the cause of differences between data sets and models in both long term and zonally averaged latent heat fluxes.
- Ensure that the community is aware that such data and products as ocean vector winds, microwave imagers and sounders, and sea surface temperatures continue with a fairly high spatial and temporal sampling to insure our ability to determine correct variability in the surface fluxes.

There was some discussion at the workshop concerning the interaction of the WGSF and SEAFLUX. The overall impression was that SEAFLUX should focus on the development and evaluation of flux products. Clearly this needs to be a funded effort and several members of the SEAFLUX community are actively pursuing product development. The WGSF should facilitate coordinated efforts across the in-situ, satellite, and modelling communities.

One area where the WGSF could foster collaboration is between SEAFLUX and the agencies responsible for satellite observations. Several presentations illustrated the problem of using a long time series of surface winds derived from different satellite instruments. The reprocessing of such series is highly recommended to fix the biases at regional or global scales. In addition, the WGSF should work with SEAFLUX to propose methods or develop tools that facilitate comparisons between satellite- and ship-derived flux estimates.

The SEAFLUX community did recommend that the WGSF create a list of and provide links between *in-situ* data collection, flux analysis, and modelling projects that focus on air-sea fluxes. Through a wide range of international programs (CLIVAR, GOOS, etc.) the development and assessment of air-sea flux products is being conducted, but in many cases these efforts are not well integrated. A goal of the WGSF is to promote and interconnect flux activities. SEAFLUX would benefit from any WGSF efforts to coordinate access to in-situ flux (both bulk and direct) measurements and the expanding array of model, in-situ, satellite, and blended flux products. Based on the results in Figure 1, a clear need exists to coordinate the efforts of the climate modelling community and the flux product developers to understand the differences and uncertainties in the model and 'data'-based fluxes.

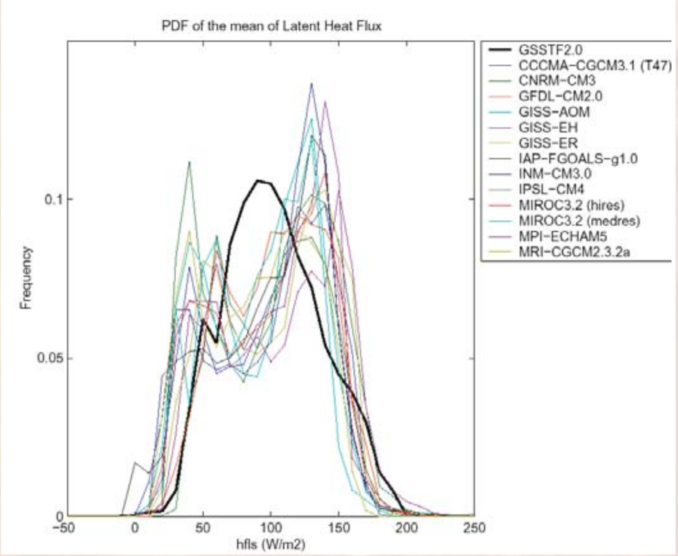

Figure 1. PDF of the mean field of latent heat flux from 1988—2000, from the Goddard satellite flux data set (GSSTF2.0) and the IPCC models (from A. Romanou, W. B. Rossow, and R. Roehrig).

Recent Articles on Air-Sea Fluxes

Steven E. Lohrenz and Wei-Jun Cai, 2006:
Satellite ocean color assessment of air-sea fluxes of CO_2 in a river-dominated coastal margin.
***Geophysical Research Letters*, 33, L01601, doi:10.1029/2005GL023942**

Quantification of the contributions of river-influenced margins to regional CO_2 fluxes is difficult due to the high degree of spatial and temporal variability in these regions. We describe an algorithm for assessment of surface water partial pressure of CO_2 (pCO_2) from MODIS imagery in the northern Gulf of Mexico. Principal component analysis and multiple regression were used to relate surface pCO_2 to environmental variables (T, S, chlorophyll). Subsequent retrieval of corresponding products from MODIS-Aqua L1B data permitted the assessment of regional distributions of pCO_2. An area of low pCO_2 was evident in the vicinity of the Mississippi River delta, consistent with field observations. Regional surface air to sea fluxes of CO_2 were estimated as 2.0–4.2 mmol C m^{-2} d^{-1}.

Frank Röske, 2006:
A global heat and freshwater forcing dataset for ocean models.
***Ocean Modelling* 11, 235—297**

A global dataset based on the ECMWF Re-Analyses (ERA) is presented that can be used as surface boundary conditions for ocean models with sea-ice components. The definition of these conditions is based on bulk formulae. To study the mean ocean circulation, a mean annual cycle on a daily basis was constructed from ERA for all relevant parameters including wind stress. Continental runoff is considered by using information about the catchment areas of the rivers and about the main drainage basins. The bulk formulae were extended by using sea ice concentration.

To estimate meridional heat transports (MHT) and to avoid any drift in ocean model simulations, the heat and fresh water budgets have been closed by applying an inverse procedure to fine-tune the fluxes towards observed transports. To improve the MHTs on the Southern Hemisphere the winds and the short wave radiation at southern higher latitudes should be corrected. Furthermore, tests were performed concerning short wave radiation which was increased in the tropics and decreased in the subsidence zones.

The heat and fresh water fluxes are assessed by using a scheme of Macdonald and Wunsch based on hydrographic sections. The net heat fluxes of ERA and of the forcing dataset are consistent with the heat flux divergences and convergences estimated by this scheme except for parts of the South Atlantic and the Indian Ocean sector of the Southern Ocean where none of these datasets is consistent with these estimates. In the subtropical South Indian Ocean the forcing dataset is consistent with these estimates while ERA are not. The flux components of ERA and the forcing dataset were compared to several observational datasets (SRB, SOC, HOAPS, GPCP, and CMAP). For each component, at least one of these datasets (especially HOAPS) supports the effects of the inverse procedure and the bulk formulae almost globally with some regional exceptions: short wave radiation in the tropical oceans and the subtropical North Atlantic, latent heat flux at higher latitudes, and precipitation in the northern North Atlantic.

Comparisons to the NCAR/NCEP Re-Analyses (NRA) (versions 1 and 2) and the ECHAM model in place of ERA lead to similar results. In the North Atlantic the net heat fluxes of the model based datasets approach the hydrographic estimate with increasing resolution. Applied to any ocean/sea-ice model and compared to ERA, the forcing dataset would induce only a relative small net sea-surface buoyancy loss.

A comparison of the forcing dataset to measurements made using one buoy deployed in the western Pacific warm pool and five buoys deployed in the subduction region of the Northeast Atlantic shows that at the site of the first buoy the net heat fluxes of the forcing dataset are in poorer agreement than those of ERA. At the sites of two subduction buoys both datasets show the same level of agreement within the error bars specified. At the sites of the three remaining subduction buoys the forcing dataset shows a marginal improvement on ERA.

Karine Béranger, Bernard Barnier, Sergey Gulev, and Michel Crépon, 2006:
Comparing 20 years of precipitation estimates from different sources over the world ocean.
***Ocean Dynamics*, doi 10.1007/s10236-006-0065-2**

The paper compares ten different global precipitation data sets over the oceans and discusses their respective strengths and weaknesses in ocean regions where they are potentially important to the salinity and buoyancy budgets of surface waters. Data sets (acronyms of which are given in Section 2) are categorised according to their source of data, which are (1) in situ for Center for Climatic Research (Legates and Willmott, 1990; Archive of Precipitation Version 3.01, http://climate.geog.udel.edu/~climate), Southampton Oceanography Centre (SOC) (Josey et al., J Clim 12:2856–2880, 1999) and University of Wisconsin-Milwaukee (UWM) (Da Silva et al. 1994); (2) satellite for Microwave Sounding Unit (MSU) (Spencer, J Clim 6:1301–1326, 1993), TOPEX (Quartly et al., J Geophys Res 104:31489–31516, 1999), and Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite (HOAPS) (Bauer and Schluessel, J Geophys Res 98:20737–20759, 1993); (3) atmospheric forecast model re-analyses for European Centre for Medium-range Weather Forecast (ECMWF) (Gibson et al. 1997) and National Center for Environmental Prediction (NCEP) (Kalnay et al., Bull Am Meteorol Soc 77:437—471, 1996); and (4) composite for Global Precipitation Climatology Project (GPCP) (satellites and rain gauges, Huffman et al., Bull Am Meteorol Soc 78 (1):5—20, 1997) and Climate Prediction Center Merged Analysis of Precipitation (CMAP) (satellites, rain gauges and atmospheric forecast model, Xie and Arkin, Bull Am Meteorol Soc 78(11):2539–2558, 1997). Although there is no absolute field of reference, composite data sets are often considered as the best estimates. First, a qualitative comparison is carried out, which provides for each data set, a description of the geographical distribution of the climatological mean precipitation field. A more careful comparison between data sets is undertaken over periods they have in common. First, six among the ten data sets (SOC, UWM, ECMWF, NCEP, MSU and CMAP) are compared over their common period of 14 years, from 1980 to 1993. Then CMAP is compared to GPCP over the 1988—1995 period and to HOAPS over the 1992—1998 period. Usual diagnostics, like comparison of the precipitation patterns exhibited in the annual climatological means of zonal averages and global budget, are used to investigate differences between the various precipitation fields. In addition, precipitation rates are spatially integrated over 16 regional boxes, which are representative of the major ocean gyres or large-scale ocean circulation patterns. Seasonal and inter-annual variations are studied over these boxes in terms of time series anomalies or correlation coefficients. The analysis attempts to characterise differences and biases according to the original source of data (i.e. in situ or satellite, etc.). Qualitative agreement can be observed in all climatologies, which reproduce the major characteristics of the precipitation patterns over the oceans. However, great disagreements occur in terms of quantitative values and regional patterns, especially in regions of high precipitation. However, a better agreement is generally found in the northern hemisphere. The most significant differences, observed between data sets in the mean seasonal cycles and interannual variations, are discussed. A major result of the paper, which was not expected a priori, is that differences between data sets are much more dependent upon the ocean region that is considered than upon the origin of the data sets (in situ vs satellite vs model, etc.). Our analysis did not provide enough objective elements, which would allow us to clearly recommend a given data set as reference or best estimate. However, composite data sets (GPCP, and especially CMAP), because they never appeared to be really «off» when compared to other data sets, may represent the best recent data set available. CMAP would certainly be our first choice to drive an ocean GCM.

CALENDAR

28 Aug—1 Sept 2006, Summer school on Air-sea-interaction, Finnish Institute of Marine Research, Helsinki, Finland, http://www.fimr.fi/en/itamerikanta/scasi.html

31 Aug—1 Sept 2006, CLIVAR/GODAE Meeting on a Pilot Evaluation Effort of Global Ocean Syntheses, ECMWF, Reading, UK

6—8 Sept 2006, International Workshop on Transport at the Air Sea Interface, Heidelberg, Germany, http://klimt.iwr.uni-heidelberg.de/ws-transport/index.php3

18—22 Sept 2006, Joint Workshop of the GCSS Boundary Layer Clouds (BLC) and Pacific Cross-Section Intercomparison (GPCI) Working Groups, Goddard Institute for Space Science, New York, USA. http://www.gewex.org/gcss.html#meeting

24—29 Sept 2006, 9th International Workshop on Wave Hindcasting and Forecasting, Victoria B.C., Canada, http://www.oceanweather.com/waveworkshop/

4—8 December 2006, Second THORPEX International Science Symposium (STISS), Landshut, Bavaria, Germany, http://www.wmo.int/thorpex/2nd_Symposium.html

14—18 January 2007, 11th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS-AOLS), San Antonio, Texas, http://www.ametsoc.org/meet/annual/

6—9 March 2007, SOLAS Science 2007: A SOLAS open science conference, Xiamen, China, http://www.uea.ac.uk/env/solas/ss04.html

CONTENTS

Call for contributions:

The next issue of *Flux News* (January 2007) will focus on air-sea fluxes for the forcing of ocean general circulation models in different resolutions. We welcome contributions from both sea-air interaction and ocean modelling communities.

The closing date for submissions is 1 November 2007

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Sergey Gulev, Editor
Christopher Fairall, WGSF Chair
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