# Surface fluxes and WCRP science

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## 1. Looking back from 2008

Over the last 4 years the WCRP Working Group on Surface Fluxes (WGSF) has carried out a considerable amount of work. Good progress has been achieved in our understanding of the mechanisms forming air-sea flux variability on different temporal and spatial scales. New flux products of higher accuracy and finer resolution have been developed and can now be used for all types of climate research. WGSF by far exceeded the expectations formulated by the JSC in the ToRs by initiating systematic validation activities, building new methodologies of air-sea flux field production, developing guiding materials for climate-quality flux observations and assessing all sources of errors and uncertainties in the air-sea flux products. The mandate of WGSF also covered ocean-atmosphere biogeochemical fluxes. Cooperation of WGSF and SOLAS in this area has been very strong, and helped to bridge WCRP with IGBP. Now, when the term of WGSF is to expire, it is time to plan an extended surface flux enterprise for the WCRP.

The surface flux activities of WCRP have been going on for 11 years now. Between 1996 and 2001 there existed the Working Group on Air-Sea Fluxes (WGASF). WGSF took over from them in 2003 targeting the problem areas identified in the comprehensive review of flux science and practices (WGASF 2000). WGSF's progress in 2003-2007 has been associated with a number of specific accomplishments. A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea by Bradley and Fairall (2006) has provided a most comprehensive compendium to observational practices and estimation of air-sea fluxes at sea. New observational programmes contributed to a better parameterization of radiative fluxes (e.g. Fairall et al. 2007) as well as turbulent fluxes. The VOSClim project (Kent et al. 2007) together with the OceanSITES initiative (http://www.oceansites.org/index.html) have become the source of reference flux observations by Voluntary Observing Ships (VOS) and high quality flux data from buoys. They form firm ground for validation of all types of flux products, be they VOS-based, remotely sensed or NWP-derived. New metadata (Kent et al. 2007) along with new algorithms for the corrections of marine meteorological variables and estimation of sampling errors in VOS records and fluxes (Kent and Berry 2005, Gulev et al. 2007a,b) open a new era in the development of VOS flux products. Continuously updated ICOADS collection of marine observations (Woodruff et al. 2005) forms the basis for such products.

> BETTER CLIMATE OBSERVATION AND PREDICTION CAN ONLY BE ACHIEVED IF WE MINIMIZE THE UNCERTAINTIES OF THE GLOBAL ENERGY BALANCE AND INCREASE THE ACCURACY OF THE ESTIMATION OF VARIABILITY OF AIR-SEA FLUXES ON ALL TIME SCALES.

Global satellite-derived air-sea flux products (see this issue) have now achieved space-time resolution matching that of operational NWP flux products and cover the periods up to 2 decades. This led to the development of the global blended products based on synthesis of in situ measurements, merchant ship observations, satellite data and reanalyses (Yu and Weller 2007). As regards NWP-generated air-sea flux products, their validation against high quality in situ measurements is on the way under the revitalized SURFA project of WGSF and WGNE. The development of air-sea flux products for the forcing of ocean GCMs (see Flux News 3) considerably improved the quality of the simulation of ocean general circulation in different resolutions. Furthermore, the ocean state estimation by GCMs in data assimilation mode now provides new surface net heat and freshwater flux products consistent with oceanic observations (Stammer 2007).

New observational and modeling activities in air-sea interaction at high latitudes in the presence of sea ice (see Flux News 4 articles) have improved our understanding of air-sea interaction in the Arctic and Antarctic, including impacts of air-sea fluxes variability on sea ice thickness, which itself is the measure of the air-sea flux. The progress in the WGSF-SOLAS co-operation is manifested in two major reviews (nearly completed) on gas and particle transfer by W. McGillis and G. De Leeuw. Also, over the last 4 years there were other numerous observational and modeling activities (covered in Flux News 2, 3 and 4) which established more accurate quantitative estimation of surface biogeochemical fluxes including deposition.

## 2. Surface fluxes adding value to climate observation and prediction

The aim to better observe and predict climate poses new challenges for the air-sea flux community. Firstly, we need to minimize the uncertainties of the estimates of global surface fluxes and to improve our understanding of the global energy balance. Global residual estimates of Trenberth and Fasullo (2007), Fasullo and Trenberth (2007) and Liu and Xie (2008, this issue) show a possibility of obtaining accurate estimates of air-sea energy balances on global and regional scales, including estimates of meridional transports of mass and energy in the climate system. In order to evaluate such global balance estimates we now need to deliver surface flux products able to adequately represent them. Secondly, we have to achieve much better accuracy in the estimation of variability of air-sea fluxes on time scales from several years to several decades. This is especially important now when satellites have started to provide global multi-decadal homogeneous radiative flux products at weather-scale resolution (e.g. Zhang et al. 2006). Although, the crucial role that surface fluxes play in climate variability is obvious, a proper quantification of this role is still hampered by insufficient accuracy of surface flux estimates. Progress in this area, if achieved, will allow to extensively analyse surface fluxes in coupled model runs including the future climate simulations. This will help to understand the role of fluxes at the air-sea interface in climate change. In this context, the continuing co-operation with SOLAS will be very important for quantifying the ocean's role in the redistribution of the greenhouse gases, first of all carbon dioxide.

> SURFACE LAND FLUXES PLAY A CRUCIAL ROLE IN REGIONAL CLIMATE VARIABILITY. THE LANDFLUX AND iLEAPS PROVIDE A COMPREHENSIVE ANALYSIS OF BOTH PHYSICAL AND BIOGEOCHEMICAL SURFACE EXCHANGES OVER LAND.

Surface land fluxes, although smaller in magnitude compared to air-sea fluxes (Fasullo and Trenberth 2007), exhibit much stronger spatial differentiation and may play a crucial role in regional climate variability. Although the uncertainties in estimation and parameterization of surface fluxes over land are in many respects different from those of air-sea fluxes, they are also large. The LandFlux initiative launched recently by the GEWEX Radiation Panel in co-operation with the GEWEX Land Surface Study (GLASS) is expected to address this situation by producing a new generation global, multi-decadal surface turbulent flux data product. Importantly, LandFlux is developed in co-operation with the Integrated Land Ecosystem-Atmosphere Process Study (iLEAPS), targeting (among other issues) the mechanisms of gas fluxes over land controlled by vegetation. Similarly to WGSF and SOLAS in the area of air-sea fluxes, LandFlux and iLEAPS provide a comprehensive analysis of both physical and biogeochemical surface exchanges over land.

> SKILLS OF SEASONAL AND DECADAL PREDICTIONS CRUCIALLY DEPEND ON THE ACCURACY OF ESTIMATION AND PARAMETERIZATION OF OCEAN SIGNALS REPRESENTED BY SURFACE FLUXES.

## 3. Challenges for a 2008+ WCRP Surface Flux enterprise

Given the complexity of the issues related to surface fluxes over the oceans as well as over land, and the necessity to deal with both physical and biogeochemical exchanges at the same time, the WCRP now faces the need to provide more co-ordination in this area. The Working Group on Surface Fluxes can, therefore, be transformed into a group with expertise in all these scientific areas, covering different space-time scales from micro-scale to global and from seconds to decades, and different sources of surface flux estimates (in situ, satellites, NWP). In its new capacity WGSF shall work in a close co-operation with all WCRP core projects (GEWEX, CLIVAR, SPARC and CliC), panels (WOAP and WMP) and working groups (WGNE and WGCM). The aim of the future working group should be to continuously address the changing requirements of all WCRP research components in surface fluxes and to facilitate the generation of new flux products representing ocean-atmosphere (including sea ice) and land-atmosphere physical and biogeochemical interactions. The inclusion of land fluxes into surface flux work fits in perfectly with the goals of CLIVAR linking, in particular, ocean signals with continental climate variability. Furthermore, the CLIVAR achievements in the evaluation of air-sea flux datasets against in situ observations (Josey and Smith 2006) should enrich the existing surface flux validation activities and initiate new ones. This multitask working group will be more than relevant to GEWEX which currently leads both SeaFlux and LandFlux activities. Finally, such a group will be of benefit to CliC which deals with fluxes associated with both marine and terrestrial cryosphere.

The WGSF in its extended format will undoubtedly contribute to the existing cross-cutting activities of WCRP. Sea level rise is largely driven by evaporation and precipitation processes. The annual change in the latent heat flux by 1 W/m2 is equivalent to the oceanic water column of 12 mm. In terms of sea level change, this value is one order higher than the observed rate of change. At the same time, even for the state of the art long-term air-sea flux estimates this accuracy is hardly achievable. Variations of surface net heat flux during several weeks of the Indian monsoon break cycle may be as large as 100-200 W/m2, however an accurate estimation of this signal requires much better spatial and temporal resolution of the flux fields than that we have now. The skills of the seasonal and decadal prediction crucially depend on the accuracy of estimation and parameterization of ocean signals represented by surface fluxes. Many of extreme weather and climate events are associated with intensive tropical and extra-tropical cyclones. Surface turbulent fluxes in such cyclones may locally amount to 2000-3000 W/

m2 which is an order of magnitude larger than mean monthly and seasonal values. Accurate quantitative estimation of these extreme fluxes requires the extension of the existing and the development of new parameterizations. Given the objective limitations of in situ flux measurements in a severe weather environment this requires consolidated effort of laboratory modeling, surface layer theory, remote sensing and analysis of surface flux statistics. Furthermore, extreme events over the continents are often strongly localized in space and time and, therefore, their physical description and prediction requires accurate estimation of land-atmosphere fluxes with very high space-time resolution. Surface fluxes, being responsible for the re-distribution of energy and gases between the components of the Earth climate system, play a crucial role in the projection of the anthropogenic climate change. The Atmospheric Chemistry & Climate initiative of WCRP does not directly deal with the Earth surface processes. However, in the future, biogeochemical exchanges and, in particular, those tackled in co-operation with SOLAS and iLEAPS, will definitely contribute to this important sector of WCRP science.

IN ORDER TO MEET NUMEROUS CHALLENGES IN SEA-AIR AND LAND-ATMOSPHERE INTERACTIONS WE NOW NEED A PAN-WCRP ENDEAVOR IN THE AREA OF SURFACE FLUXES. THE END OF THE CURRENT TERM OF THE WGSF SHOULD SEE THE PROVISION FOR AN EXTENDED MANDATE.

Considering the growing role of climate science as a component of the ESSP, it is very important that the WGSF continues to maintain an effective link between the WCRP and IGBP. Today, WGSF and SOLAS provide an important pillar of the bridge between these two programmes. Potential collaboration with LandFlux and iLEAPS on land-atmosphere fluxes including biogeochemical exchanges can become another such pillar. As regards the WCRP involvement in regional climate change, the WGSF shall prioritize the methodologies of the adaptation of global surface flux products to regional scale by refining spatial and temporal resolutions. Again, this is a challenging goal for both air-sea and land-atmosphere surface flux activities.

In order to meet these numerous challenges we now need a pan-WCRP endeavor in the area of surface fluxes. The end of the current term of the WGSF should see the provision for an extended mandate. Also, bearing in mind the current financial difficulties of WCRP, the WGSF, which has proved to be the most cost-effective activity of WCRP, will fit in perfectly with the Programme's budget.

The WGASF/WGSF achievements over the last 11 years, the involvement of all the WCRP core projects, panels and working groups, as well as well the established practices of operation and such instruments as Flux News and the Internet resources, guarantee the usefulness and the future success of an extended WGSF.

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WE HOPE THAT THIS CONCEPT ARTICLE WILL PROVIDE THE GROUND FOR DISCUSSING THE FUTURE CO-ORDINATION OF SURFACE FLUX WORK WITHIN THE SURFACE FLUX COMMUNITY, ALL WCRP GROUPS AND JSC PRIOR TO THE 29TH ANNUAL SESSION OF JSC IN BORDEAUX, FRANCE, 31 MARCH - 4 APRIL 2008.