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WORKING GROUP ON SURFACE FLUXES

END-OF-TERM REPORT

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DELIVERED ADDED VALUE OF ACTIVITY / PROJECT

WGSF made major strides toward the goals formulated by the JSC in the ToRs by initiating air-sea flux validation activities, building new parameterizations and methodologies for producing air-sea flux fields, developing guidance materials for climate-quality flux observations, and assessing 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 strong, and helped to bridge WCRP with IGBP adding value to both programmes. Progress has been achieved in our understanding of the mechanisms contributing to 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. The WGSF has served as a strong catalyst for all these activities, many of which were directly initiated and supervised by the group.

MAJOR ACTIVITIES AND ACHIEVEMENTS

In 2003-2007 WGSF, through different means and in various modes of work contributed to 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 comprehensive compendium to observational practices and estimation of air-sea fluxes at sea. New observational programmes contributed to a better parameterisation of radiative fluxes (e.g. Fairall et al. 2008) 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. The SAMOS (<http://samos.coaps.fsu.edu/html/>) project performs a similar function by archiving high-quality, high-resolution observations from research vessels. Together, these efforts form a foundation for validation of all types of flux products, including 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) is the main basis for such products. Global satellite-derived air-sea flux products have now achieved space-time resolution matching that of operational NWP flux products spanning more than two decades. This led to the development of the global blended products based on synthesis of in situ measurements, merchant ship observations, satellite data, and re-analyses (Yu and Weller 2007), covering now the period of about 3 to 4 decades.

Validation of NWP-generated air-sea flux products against high-quality in situ measurements is being developed under the revitalized SURFA project of WGSF and WGNE. An FTP site for daily ingest of SURFA data is now operational at the U.S. NCDC (see <ftp://eclipse.ncdc.noaa.gov/raid1b/surfa>). This opens a new avenue in understanding of the role of air-sea exchanges in improving weather and climate prediction. The development of air-sea flux products for forcing of ocean GCMs considerably improved the quality of the simulation of ocean general circulation at various 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 modelling activities in air-sea interaction at high latitudes in the presence of sea ice have improved our understanding of air-sea interaction in the Arctic and Antarctic, including impacts of air-sea fluxes variability on sea ice thickness. The progress in the WGSF-SOLAS cooperation 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 modelling activities (described in WGSF's *Flux News* 2, 3, and 4), which established more accurate quantitative estimation of surface biogeochemical fluxes including deposition.

CHALLENGES

The aim to better observe and predict climate at a variety of time and space scales poses new challenges for the air-sea flux community.

Global residual estimates of Trenberth and Fasullo (2007), Fasullo and Trenberth (2007) and Liu and Xie (2008, *Flux News* 5) show a possibility of obtaining sufficiently accurate estimates of air-sea energy balances on global and regional scales, including estimates of meridional transports of mass and energy. Closure of the global estimates is dependent on the uncertainties in the global surface flux fields. Most available flux products are becoming more consistent with the in situ air-sea flux data and demonstrate good performance when used as forcing functions for modeling. However, validation efforts identify significant regional biases in the products. The reasons for their existence are still to be explained and documented for the benefit of end users.

There are now global multi-decadal homogeneous radiative flux products at weather-scale resolution (e.g. Zhang et al. 2006) but similar estimates of surface turbulent flux variability on time scales from several years to several decades are still insufficiently accurate. Progress in this area, if achieved, will allow extensive analyses of surface exchanges in coupled model experiments including the future climate simulations. This will help to better understand the role of air-sea fluxes in climate change, which is expected to be very significant. 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, 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. 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. LandFlux is developed in co-operation with the Integrated Land Ecosystem-Atmosphere Process Study (iLEAPS), targeting (among other issues) mechanisms of gas fluxes over land controlled by vegetation. Similarly to WGSF and SOLAS and SEAFLUX in the area of air-sea fluxes, LandFlux and iLEAPS address physical and biogeochemical surface exchanges over land. The uncertainties in estimates of surface fluxes over land are also large and need to be systematically quantified and documented.

PUBLICATIONS AND OTHER PRODUCTS, OUTREACH AND CAPACITY BUILDING

Publications are multiple. A range of flux products (NWP-, satellite- based and blended) are available from <http://www.coaps.fsu.edu/RVSMDC/FSUFluxes/nav.php?s=5>. References for this report are at ftp://ftp.etl.noaa.gov/user/cfairall/wcrp_wgsf/meetings/jsc_france_08.

WGSF produces *Flux News*, a newsletter, which is published twice a year at no cost to WCRP. It is gaining more and more recognition and interest among the flux science community. CLIVAR IPO helps to distribute the publication. WGSF thanks CLIVAR for this help.

The Guide to Making Climate Quality Meteorological and Flux Measurements at Sea by Bradley and Fairall (2006) is a significant contribution to capacity building. The WGSF

website also provides access to relevant computer programs and data sets.

GOALS AND PLANS FOR ACTIVITIES IN 2008 AND INTO 2009, NEEDED INTERACTIONS

Given the complexity of the issues related to surface fluxes over the oceans and land and the need for improved global flux products with estimated uncertainty, the research on physical and biogeochemical exchanges requires support, review and coordination. It is recommended therefore that WGSF is transformed into a group with expertise in all these scientific areas, covering space-time scales from micro-scale to global and from seconds to decades, and various ways of surface flux estimation (in situ, satellites, NWP). 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.

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 inclusion of land fluxes into surface flux work fits perfectly the goals of CLIVAR linking, in particular, ocean signals to climate variability on the continents. Furthermore, the CLIVAR achievements in the evaluation of air-sea flux datasets against in situ observations (Josey and Smith 2006) should complement flux validation activities currently conducted within WGSF. As a bridge between land and ocean fluxes, the new WGSF will be more than relevant to GEWEX, which 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 change in the annual latent heat flux by 1 W/m^2 is equivalent to an 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 currently unachievable. Variations of surface net heat flux during several weeks of the Indian *monsoon* break cycle may be as large as $100\text{-}200 \text{ W/m}^2$; 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 parameterisation of ocean signals represented by surface fluxes.

Many *extreme weather and climate events* are associated with tropical and extra-tropical cyclones. Surface turbulent fluxes in major cyclones may amount locally to 2000 W/m^2 , which is an order of magnitude larger than mean monthly and seasonal values. Accurate quantitative estimation of such fluxes requires extension of the existing and development of new parameterisations. Due to the objective limitations of in situ flux measurements in severe weather environment, this work requires input from laboratory modelling, surface layer theory, remote sensing and analysis of surface flux statistics. Furthermore, extreme events over the continents are often strongly localised 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 redistribution 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 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.

WGSF and SOLAS provide an important pillar of the bridge between WCRP and IGBP. The

collaboration between LandFlux and iLEAPS on physical and biogeochemical exchanges over land can become another such pillar. With regard to the prediction of climate change at regional scale, the WGSF shall prioritise the methodologies of the adaptation of global surface flux products to regional scale by refining spatial and temporal resolutions. This will be a challenging task for both air-sea and land-atmosphere surface flux communities.

PROPOSAL to JSC

A recommendation to JSC on WGSF is to agree that WCRP (probably jointly with IGBP) requires a renewed Working Group on Surface Fluxes that would benefit various types of climate prediction and analysis of climate variability and change by

- reviewing the requirements of the different WCRP project in surface flux products and planning the activities to meet these requirements;
- ensuring effective communication and co-ordination between research activities of WCRP and IGBP on surface fluxes;
- encouraging research and operational activities aimed at the development of new surface flux products and improvement of the knowledge on surface fluxes;
- keeping the scientific community and the JSC informed of progress achieved; and
- evaluating and assessing existing flux products and facilitating access to them.

Proposed specific objective for the nearest perspective:

- prepare a white paper on the optimal approach to the issue of surface fluxes: what is required from the “flux science” for climate research and prediction, what is feasible and what should be the WCRP approach to this problem.

Other possible tasks for the renewed WGSF could be:

- ongoing compilation, evaluation, and intercomparison of existing and development of new surface flux data sets, including those of biogeochemical fluxes;
- further improvement of parameterisations of physical and biogeochemical fluxes, quantification of uncertainties in surface flux products, and development of metadata for these products;
- assessment of model sensitivity to and limits on predictability from errors associated with surface fluxes and development of objective analysis schemes and data assimilation techniques in support of the coupled system (re-) analysis;
- development of strategy for merging and combining surface flux data sets to meet the requirements of WCRP and IGBP;
- development of the requirements for flux and flux-related observations in co-operation with IGBP, GCOS, GOOS and other relevant activities;
- interaction with and support to SOLAS and iLEAPS.

IPO, PROGRAM ADMINISTRATION AND MANAGEMENT

Continuation of the active support by JPS for WCRP will be required for successful work of a new WGSF.

ADDITIONAL COMMENTS FOR THE JSC

Work on surface fluxes has been one the most economical (cost-efficient) activities of WCRP. The WGASF and WGSF achievements over the last 11 years, significant momentum of and interest to current activities, established links with all WCRP core projects, panels and working groups, the restarting SURFA project, existing communication and capacity building means such as Flux News and various internet-based resources, guarantee the efficiency of work and will help the extended WGSF to be a success.

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