US CLIVAR Working Group on High Latitude Surface Fluxes

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1. Motivation

US CLIVAR has established a Working Group on High Latitude Surface Fluxes this year, with the particular goal of addressing some of the myriad challenges associated with air-sea and air-ice-ocean exchanges in Arctic, Antarctic, and Southern Ocean regions. The working group activities are motivated by several identified deficiencies in estimates of high latitude surface fluxes (e.g., sensible and latent heat, radiative fluxes, stress, and gas fluxes).

First, in situ observations of fluxes are difficult to obtain because high latitude regions are remote and require instrumentation able to withstand high winds, extremely rough seas, and cold temperatures. Such observations are vital for satellite calibration, which is one approach to filling the void of traditional observations.

Second, the unique conditions in high latitude regions mean that lessons learned in equatorial and subtropical regions do not necessarily translate into improvements in high latitude fluxes. For example, winds over the Southern Ocean are among the strongest in the world, both in magnitude and frequency of occurrence, and can exceed the speeds for which scatterometer wind retrieval algorithms have been tested and the range of validity for standard drag coefficients. Northern Hemisphere, high-latitude, extreme marine storms occur less often, but tend to strengthen much more rapidly. Ocean and atmospheric stratification in high latitude regions can be extremely weak, resulting in deep mixed layers, and it can be extremely strong, pushing the limits of existing stability parameterizations. High latitude regions are also characterized by ice and ice/water mixes, which add additional complexity to calculating and applying fluxes.

Third, since high latitude regions are under-going rapid climate change, marked by rapidly diminishing ice cover, we expect that the character of high latitude fluxes is also changing. That is, flux climatologies are evolving in regions where the characteristics of either the overlying atmosphere or the upper ocean are changing. Fluxes through an ice-free Arctic Ocean, for example, are distinctly different from fluxes through a high-albedo, ice-covered Arctic Ocean. A substantial reduction in the extent of an ice sheet will modify the fluxes in a wider area than that of the changing ice sheet, due to modification of the overlying air mass. These fluxes are expected to have a large influence on both atmospheric and oceanographic circulation and meridional energy transfer, which will impact global climate in fundamental ways: as examples, high latitude surface fluxes control meridional overturning circulation in the ocean, ocean uptake of CO_2, and meridional transport of heat in the atmosphere.

Flux products that include high latitudes can differ substantially, even in their climatological annual averages, and they do not resolve small-scale features that are present in sea surface temperature or wind fields. For example, monthly averaged sensible and latent heat fluxes were compared for nine research quality products, and found to differ by >40Wm^{-2} in both sensible (Fig. 1) and latent (Fig. 2) heat fluxes for the high latitude (ice free) southern and northern portions of the Atlantic basin. In particular, sensible heat fluxes in the Southern Ocean have a relatively large spread among products compared to the rest of the Atlantic basin (for at least the 5th through 75th percentiles of fluxes over what is considered to be year-around open water). Latent heat fluxes have a relatively small spread in the high southern latitudes due to the relatively small values of this flux; however, the spread in the high northern latitudes is rather wide for the stronger events. The wide range of values for these fluxes is a major issue for high latitude energy budgets. In contrast, monthly stress products are in relatively good agreement; however, synoptic scale (and finer) variability in reanalysis products is highly suspect in the Southern Ocean (Hilburn et al. 2003). This finding appears to be partially related to a very strong dependence on rawindsonde data in these products (Langland et al. 2008). The strengths and weaknesses of flux products differ from product to product, and are not sufficiently well described.

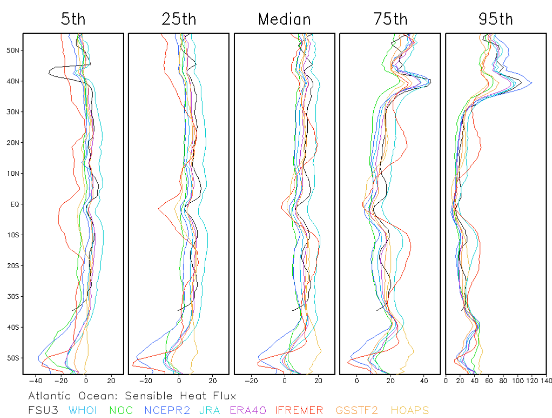

Fig. 1. Distributions (5th, 25th, 50th, 75th, and 95th percentiles) of contributions to zonally averaged Atlantic sensible heat fluxes. Reanalysis products include NCEPR2 (Kanamitsu et al. 2002), JRA25 (Onogi et al. 2007), and ERA40 (Uppalla et al. 2005). Satellite derived products include IFREMER and HOAPS2 (based on method of Grassl et al. 2000). The HOAPS2 variables examined herein are identical in the HOAPS3 product. Products based on ship and buoy observations include FSU3 (adapted from the method of Bourassa et al. 2005) and NOC1.1 (formerly SOC; Josey et al. 1998). Hybrid NWP model and satellite products include WHOI (Yu and Weller 2007) and GSSTF2 (Chou et al. 2003). These products were chosen because they are freely available, reasonably easy to obtain, and reasonably homogeneous throughout a common comparison period. The common period of March 1993 through December 2000 is examined.

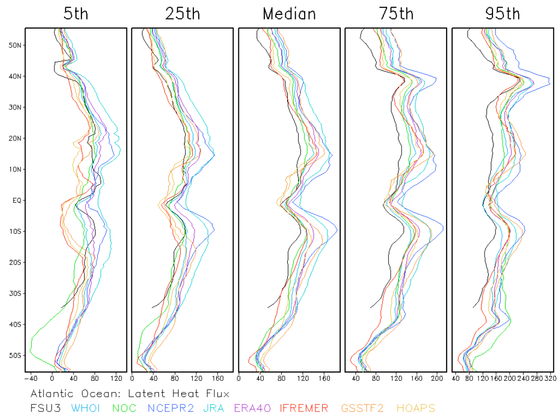

Fig. 2. As for Fig. 1, except for the latent heat flux.

At this point, it is not clear to the developers of flux products what accuracies and resolutions are required to study key processes in high latitudes. While concerns about fluxes are common, there has not always been extensive communication between the users of flux products, who hope for accurate gridded fields, and the observers of fluxes, who concern themselves with the details of turbulent boundary layer physics. The physics considered in flux parameterizations also changes the distribution of extreme forcing events (Fig. 3), which have a disproportionately large impact on some atmosphere and ocean processes.

Furthermore, there is often a disconnect with the producers of gridded flux fields and large segments of the user community. Similarly, Arctic and Antarctic specialists rely on somewhat different funding streams and have tended not to interact; analogous issues apply for meteorologists and oceanographers. However, there appears to be much common ground.

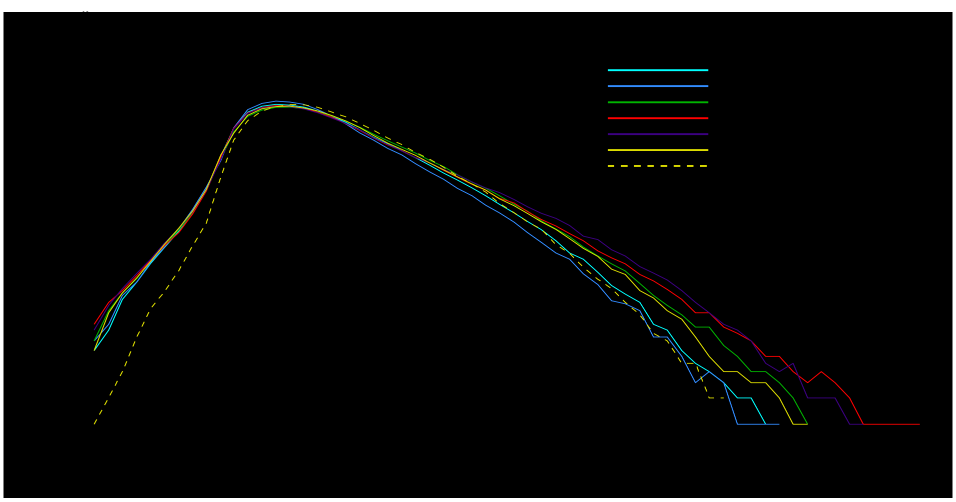

Fig. 3. Latent heat flux probability distributions for various models. Six of the models (Large and Pone 1981; Smith 1988, Large et al. 1994; HEXOS: Smith et al. 1992; Taylor and Yelland 2001; and Bourassa 2006) have been coded to differ only in their stress related parameterization (drag coefficient or roughness length). Two models are used as coded: COAREv3 (Fairall et al. 2003) and Kara et al. (2005).

The International Polar Year (IPY) intensive observing period (2007-09) is now underway, and several high latitude flux programs are just beginning. Spurred by IPY, planning is starting for Arctic and Southern Ocean observing systems. While IPY has drawn the attention of a large number of international committees, there has been comparatively little focused effort on high latitude fluxes. These fluxes are of interest for a wide range of oceanographic, atmospheric, and over-ice applications. This provides a particular impetus for the US CLIVAR working group.

2. Objectives

The High Latitude Surface Flux Working Group has a largely scientific focus, aimed at evaluating the current state of knowledge for high latitude fluxes, disseminating our evaluation to the broader scientific community, and laying groundwork for improved flux estimates. The working group will consider air-sea fluxes of momentum, heat, radiation, freshwater, and gas. It will also evaluate fluxes through open ocean, ice covered regimes as well as transition zones, and will consider both Arctic and Antarctic/Southern Ocean regions.

The group has two specific goals that it intends to address in its two year lifetime:

A. Assess status of flux products for momentum and heat in high-latitude regimes, providing an honest assessment of the state of flux products; evaluate commonalities between Arctic and Antarctic. These will be assessed on a variety of spatial/temporal scales that are important to the user community.

B. On the basis of the flux assessment, identify priorities for continued flux observations, parameterizations, and requirements for updated reanalyses and gridded flux products.

The working group is beginning to make plans for a workshop focused on high latitude surface fluxes. A key goal for this workshop is to engage a broader range of perspectives.

3. Participation

The co-chairs are Mark Bourassa (Florida State University, FSU) and Sarah Gille (Scripps Institution of Oceanography, SIO). The other members of the working group are Cecilia Bitz (University of Washington), Dave Carlson (IPY, British Antarctic Survey), Will Drennan (University of Miami), Chris Fairall (NOAA, Boulder), Ross Hoffman (Atmospheric and Environmental Research, Inc.), Gudrun Magnusdottir (University of California, Irvine), Mark Serreze (University of Colorado), Kevin Speer (FSU), Lynne Talley (SIO), Gary Wick (NOAA, Boulder). Additional participants are Ian Renfrew (University of East Anglia) and Rachel Pinker (University of Maryland).

The working group welcomes input from others and expects to coordinate with programmatic groups focused both on surface fluxes and on the Arctic and Antarctic regions, including IPY, the Study of Environmental Arctic Change (SEARCH), the Climate and Cryosphere Project (CliC), the CliC/International CLIVAR Arctic Climate Panel, the International CLIVAR Southern Ocean Panel, the Arctic Ocean Model Intercomparison Project (AOMIP), the Southern Ice-Ocean Model Intercomparison Project (SIOMIP), the Global Energy and Water Cycle Experiment (GEWEX), the Arctic Observing Network, the Southern Ocean Observing System, SEAFLUX, Shipboard Automated Meteorological and Oceanographic Systems (SAMOS), the World Climate Research Program Working Group on Surface Fluxes, the Surface Ocean—Lower Atmosphere Study (SOLAS), and the Southern Ocean Gas Exchange Experiment (GasEx).

Further information about the working group is available on the web: http://www.usclivar.org/Organization/hlatwg.html

4. Summary of Initial Findings

The working group has begun by carrying out a detailed assessment of the current status of high latitude fluxes. We have reviewed user requirements for fluxes and have considered the state of turbulent flux models used to evaluate observations and of numerical weather prediction of fluxes.

The required accuracy of fluxes depends greatly on the application, with the temporal and spatial scales of the application largely dictating the accuracy requirements. A very rough estimate of desired accuracy (bias) in the net heat flux is $10Wm^{-2}$ when averaged over perhaps a season or a year. On the other hand, to evaluate long-term trends in ocean heat content, an accuracy of $0.3Wm^{-2}$ might be required (Levitus 2005); however, such estimates are unlikely to be achievable with any available measurement systems. There are a wide range of spatial and temporal scales associated with high latitude applications. On the finer scales, the applications are consistent with resolving the inertial cycle. On larger scales, monthly fluxes on basin wide are useful. Fluxes are not measured on any of these scales: they are estimated through bulk formulas and estimates of pressure, sea surface temperature, water wave characteristics, near surface wind, temperatures, and humidity. These variables are also not well observed in high latitudes, except for satellite observations of wind and sea surface temperature, and even these do not meet the finest desired sampling. Variability on the largest mesoscale, and perhaps finer scales, makes substantial contributions to monthly average fluxes, particularly near shorelines and ocean fronts.

We have found that recent surface turbulent flux models have much more similar results than older models. One area of difference is the manner in which wave data are used to modify the fluxes: this subject is an active area of debate within the flux community and is an important matter for high latitude surface turbulent fluxes. These different parameterizations result in substantial differences in fluxes, particularly stress, for wind speeds greater than roughly 16 ms^{-1}. The model-to-model differences in turbulent heat fluxes are smaller in a percentage sense. The influence of atmospheric stability on surface turbulent fluxes is typically (but not always) small over the open ocean; however, stability is a very important consideration near oceanic fronts and near shorelines or ice edges, particularly in winter when relatively cold air is rapidly transported over much warmer water. The paucity of flux observations for such conditions is a key limiting factor in the improvements of models and budgets for these fluxes. Improved satellite sampling, and satellite observations of fluxes or flux related variables would be of great help in improving the accuracy of high latitude fluxes.

Numerical weather prediction (NWP) provides an alternative to satellite observations; however, NWP accuracy would clearly benefit from improved observations. One of the disadvantages of NWP-based surface fluxes is that the accuracy of these fluxes is a low priority for weather forecasting, since weather forecasts are relatively insensitive to surface fluxes. Recently, it has been found with several atmospheric models that increased vertical resolution near the surface (e.g., adding one layer) results in much stronger coupling of the surface to the free atmosphere. This finding bodes well for the improvement of surface fluxes in future NWP models; however, for the time being NWP-based fluxes (particularly reanalyses) have large biases. These biases can be reduced by using any of the modern flux algorithms on bias adjusted winds, temperatures, and humidities. The SURFA project is currently making operational NWP data available for examination.

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