MCCIP Marine Climate Change Impacts Partnership

Topic

Air-sea exchange of heat and freshwater

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Executive summary

Air-sea exchanges of heat and freshwater plays an important role in driving the circulations of both the atmosphere and ocean. These fluxes are parameterised to force numerical models of the ocean and atmosphere and measurements are essential for validation of coupled ocean-atmosphere models. Despite their importance these fluxes are poorly known and the quality of their representation in models not well quantified. The turbulent fluxes of sensible and latent (evaporative) heat are difficult to measure directly and quantitative measurements of precipitation over the ocean from both rain gauges and remote sensing are notoriously unreliable.

From the limited information available there is little evidence for major changes in air-sea fluxes of heat and water in regions around the UK, despite important changes in variables such as sea temperature on which the fluxes depend. Natural variability is high, and the confidence in the measurements low, making the signal to noise ratio unfavourable. The global water cycle is likely to intensify but the effect of this change within the UK is uncertain.

Current research which may in time improve our knowledge of the air-sea fluxes of heat and water includes: planned long time series of direct flux measurements; improved parameterisations of the fluxes; bias adjustments of marine meteorological observations used as input to the parameterisations; and crucially improved representation of the fluxes in numerical weather prediction and climate models.

Full review

Headline Text

Expected impacts of climate change on the air-sea heat and freshwater fluxes in the UK marine environment are very uncertain but likely to be small; existing flux datasets have not been evaluated for climate change signals in this region.

Background

The surface exchange of heat and freshwater plays an important role in driving the circulations of both the atmosphere and ocean. Despite their importance the fluxes are poorly known and the quality of their representation in models not well quantified. It is known that the fluxes increase with increasing wind speed, but the exact relationship is not yet known, particularly for strong wind conditions. The turbulent fluxes of **sensible and latent (evaporative) heat** are difficult to measure directly, and such measurements are usually restricted to short-duration air-sea interaction cruises on research ships. However, since 2006 measurements of the fluxes have been made routinely in the Norwegian Sea at Ocean Weather Station M as part of the "Surface Ocean Lower Atmosphere Study". These continuous measurements in a region that experiences frequent storms will allow the behaviour of the fluxes to be better determined over the next few years (http://www.noc.soton.ac.uk/ooc/CRUISES/HiWASE/index.php).

Based on such research, quality parameterisations have been developed to estimate the fluxes from the more common measurements of standard meteorological parameters. To estimate the sensible and latent heat fluxes it is necessary to know the air-sea temperature difference, the air-sea humidity difference and the wind speed with high accuracy. It is possible to use routine measurements of these parameters from **Voluntary Observing Ships (VOS)** to calculate flux fields in UK waters (e.g. Josey *et al.* 1999), but the resulting fields are very sensitive to biases in the input data (e.g. Kent *et al.* 1993, Josey *et al.* 1999, Berry *et al.* 2004, Kent & Kaplan 2006, Thomas *et al.* 2007). Flux datasets developed from ships have not yet been evaluated for potential signals related to climate change although such an analysis is planned under the NERC **Oceans 2025** research programme which will run from 2007-2012. Work is currently under way at the National Oceanography Centre, Southampton (NOCS) to improve VOS based estimates of surface fluxes using improved bias adjustments along with better methods of combining data and calculating fluxes and the new dataset will form part of the planned study.

Output from atmospheric reanalyses (numerical weather prediction models which assimilate a range of surface and atmospheric observations and have a fixed model scheme) provide another potentially useful source for investigating climate change impacts on the air-sea heat and moisture fluxes. However, as for the ship based datasets, they have not yet been evaluated for potential surface flux signals related to climate change. Evaluations of fluxes from currently available atmospheric reanalyses (Uppala *et al.* 2005, Kalnay *et al.* 1996) have revealed that they contain significant biases (e.g. Smith et al. 2001; Josey, 2001). In addition, their low spatial resolution means that use in coastal locations is limited. Current operational numerical weather prediction models have increased resolution and improved flux algorithms than the existing atmospheric reanalyses. However, archives of their output cannot be used to produce consistent time series, and hence diagnose climate change, due to the very changes in model formulation that have resulted in improved flux estimates. The next generation of reanalyses will have higher resolution and improved representation of fluxes but these are still in the planning stage and will not be available for several years. Furthermore it is not clear whether they will reach the accuracy required to detect climate impacts on surface fluxes given the likely small magnitude of the expected changes (discussed below).

Currently, it is not possible to make direct estimates of the surface fluxes of heat and moisture from satellites. Indirect estimates of the fluxes from remote sensing are poor due to the lack of accurate air temperature and humidity measurements from space (WGASF, 2000). Additionally, time series from satellites are relatively short.

A further major problem is uncertainty over the expected impact of anthropogenic climate change on the air-sea heat and moisture fluxes which is only now beginning to be determined using coupled climate models. The few model evaluations carried out to date indicate that the impacts on the individual heat flux components are likely to be small, of the order of a few Wm^{-2} (Pierce *et al.,* 2006). At the global scale, analysis of ocean warming over the last 50 years indicates that the mean net heat flux associated with climate change is very small about 0.3 Wm^{-2} (Levitus *et al.,* 2000). Disentangling such small signals from interannual variability which may be many tens of Wm^{-2} is going to be a major challenge which is likely to require the synthesis of all available information including *in situ* and remotely sensed measurements, numerical modelling and **heat and water budget** studies.

In addition to small changes in the overall balance of heat exchange associated with climate change there may be larger regional signals as a result of shifts in the spatial location and intensity of major atmospheric modes of variability (the most significant one for the UK being the **North Atlantic Oscillation**, NAO) and the frequency of extreme weather events. The NAO has a major impact on air-sea heat exchange in the North Atlantic and a shift in its position may result in the largest signal in the air-sea heat and moisture fluxes in UK waters that can be attributed to anthropogenic climate change, and the one most readily detectable with observation based datasets.

Sensible and Latent Heat Fluxes

One of the better estimates of surface turbulent flux fields currently available is probably the Woods Hole Oceanographic Institution "OAFlux" product (Yu *et al.* 2004a). Derived from a combination of satellite and reanalysis fields the resulting product exploits the best features of both data sources and performs well when compared with high quality flux estimates (Yu et al. 2004b). However, given the problems with data from each source the confidence in estimates of change from this dataset is still low. The OAFlux dataset presently covers the period 1981-2002.

Figure 1 shows the sensible and latent heat fluxes in UK waters for the full period 1981 to 2002 from the OAFlux dataset. Both components of the flux are typically negative, indicating heat loss from the ocean to the atmosphere. Figure 1a shows the sensible heat flux averaged over the whole period. The sensible heat flux is small, around 20Wm^{-2}, with the largest fluxes found to the northwest of Scotland. Latent heat fluxes are larger, typically around 50Wm^{-2} (Figure 1b). Both components are smallest in the North Sea and largest to the northwest of the UK. Changes in the fluxes averaged over the region 7˚W:3˚E and 50˚N:60˚N are small. Changes in the sensible heat flux are negligible and there is a possibility of a small increase in the magnitude of the latent heat flux. Increasing latent heat flux could be driven by increasing wind speed, although this is made less likely by the absence of a similar increase in the sensible heat flux. More likely is a slight increase in the air -sea specific humidity difference related to increasing air temperatures, but further research is required to support this tentative conclusion. The mean annual cycle in each component is around 30Wm^{-2} (Figure 1d).

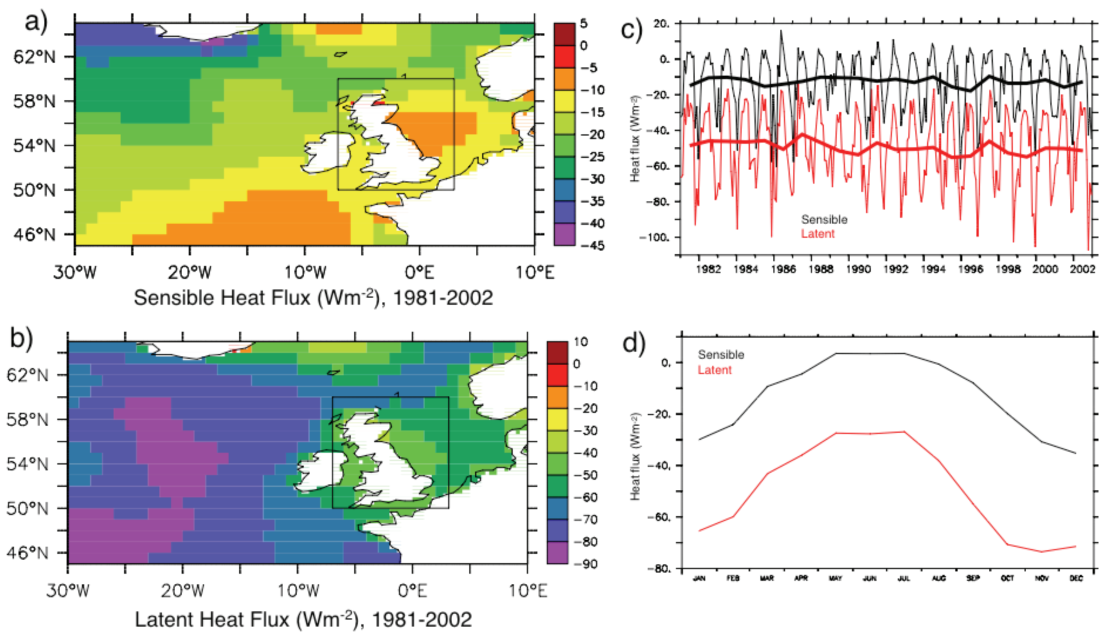

Figure 1: Sensible and latent heat fluxes from the OAFlux dataset (Yu et al. 2004a). a) sensible heat flux (Wm^{-2}) averaged over the full period of the dataset (1981 to 2002). b) as a) but for the latent heat flux (Wm^{-2}). c) monthly mean and annual average sensible and latent heat fluxes averaged over the region 7˚W to 3˚E and 50˚N to 60˚N indicated by the box in a,b). d) average seasonal cycle in sensible and latent heat flux for the period 1981 to 2002 for the same region as c).

Freshwater Fluxes

The freshwater exchange at the ocean surface is a balance between precipitation and evaporation (latent heat flux). Precipitation over the ocean can be measured from space or by marine radar but is poorly quantified, partly due to the difficulty of obtaining reliable ground truth. The Global Precipitation Climatology Project (Huffman *et al.* 2001) combines information from several satellites with *in situ* data to produce global datasets covering the period January 1979 to the present. As this dataset is constructed from data from many different satellites and sensors it is unlikely to give reliable estimates of trends over small regions. In addition the quality of the data is uncertain close to coasts. Another source of precipitation information in coastal waters may be the Met Office rain radar network, established in the 1980s. The likely consistency of this record for estimates of change is unclear. Rain gauge records at coastal stations have been maintained by the Met Office and are shown in Figure 2 for selected locations. Month-to-month variability is high and there is little obvious trend in any of the available time series. It is noted that no allowances have been made for small site changes and developments in instrumentation so the confidence in the results is probably moderate. All the measurements are made from land so confidence in these data to give representative trends for wider UK waters is likely to be low.

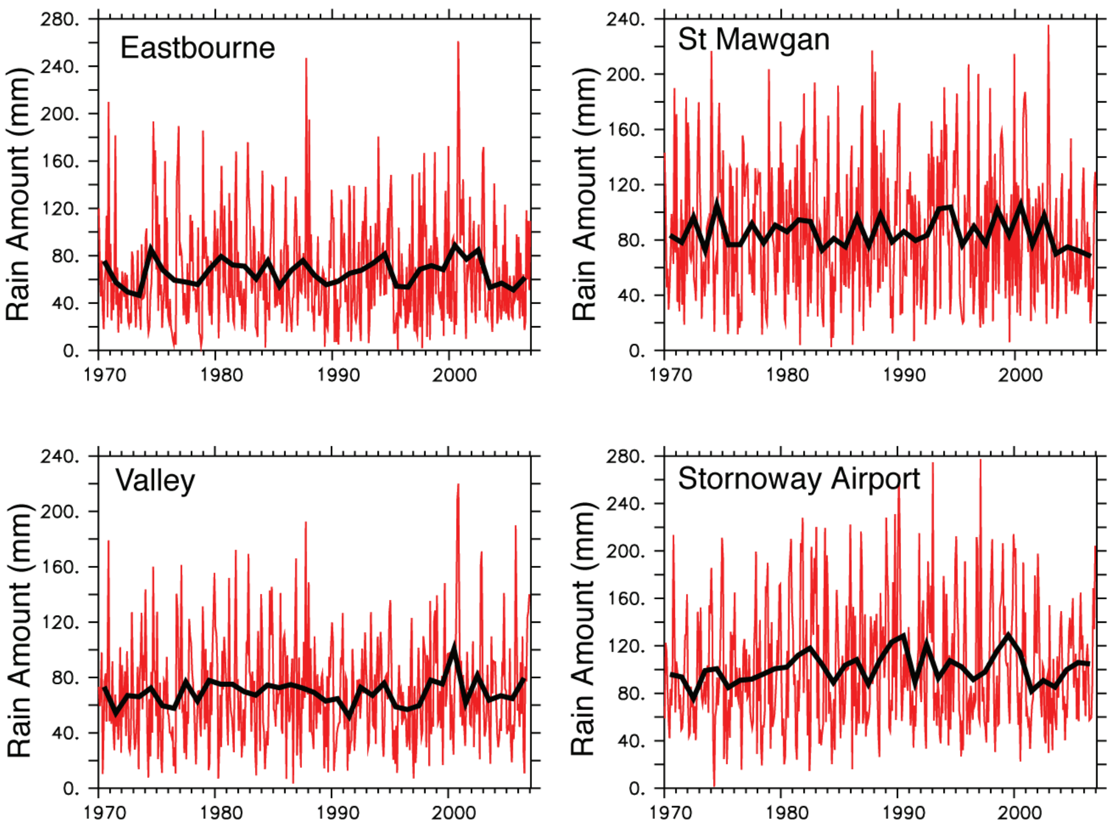

Figure 2: Monthly total rain amounts from selected coastal stations in the Met Office rain gauge network (data available from http://www.metoffice.gov.uk/climate/uk/stationdata/index.html). Monthly total rain amounts (mm) are shown in red and the annual mean of the monthly rain

amounts in black.

Predicted changes

The Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4, IPCC 2007) states that as global surface temperatures increase, the current generation of climate prediction models show an intensification of the global hydrological cycle. Globally averaged mean atmospheric water vapour, evaporation and precipitation are all projected to increase. Precipitation is predicted to decrease in the subtropics and increase at high latitudes. Intensity of precipitation events is projected to increase and precipitation extremes increase more than mean precipitation in most tropical and mid- and high-latitude areas.

Recent comparisons of satellite and climate model estimates of the total amount of water in the atmosphere and the precipitation (Wentz *et al.* 2007) show inconsistencies that cannot be reliably attributed to either the models or the satellite estimates. Although the qualitative predictions of changes to the hydrological cycle are thought to be robust globally, there can be little confidence in predictions of quantitative and regional changes.

Confidence assessments

‘What is happening now’ – Low

‘What could happen in the future’ - Low

Confidence in regional estimates of both present and future changes is low.

Knowledge gaps

See review

Commercial impacts

Not stated

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WGASF Report: http://www.soc.soton.ac.uk/OOC/WGASF/

IPCC 4th Assessment Report: http://ipcc-wg1.ucar.edu/