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To cite this version:

Bernard Barnier, Laurent Brodeau, Thierry Penduff. News: Ocean surface forcing and surface fields. Mercator Ocean Quarterly Newsletter, 2006, 22. hal-00248168

HAL Id: hal-00248168

https://hal.science/hal-00248168v1

Submitted on 27 Mar 2020

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News: Ocean surface forcing and surface fields

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Exchanges of energy and water occurring at the air-sea interface establish links and feedbacks between the atmosphere and the ocean, and are key processes in the climate and weather systems. There are great needs in climate and oceanographic research for high quality estimates of large scale fluxes of heat, freshwater and momentum. There has been substantial progress in our knowledge of the ocean surface fluxes in recent years. Nevertheless, new challenges have emerged, stimulated by the use of eddy-resolving ocean general circulation models (OGCMs) to investigate the ocean decadal variability and by the rapid development of operational oceanography. The state of our knowledge in the field of air-sea exchanges of energy and water is comprehensively covered in the report on air-sea fluxes from the WCRP working group (1). For in-depth considerations on the need of surface fluxes in operational ocean analysis and forecasting systems, we recommend the book chapter by W. Large (2).

Surface flux estimates

Attempts to produce climatologies and long-term (decadal) time series of the air-sea flux fields differ in many aspects. For example, Figure 1 compares over a 17-years period, the downward radiations provided by the CORE data set (3) (basically a satellite observation based product), with the one from the ERA40 data set (4) (the recent atmospheric re-analysis performed at ECMWF). Both data sets are considered as state of the art products in terms of flux estimates. In the long term mean, the ERA40 product compared to the CORE one shows a deficit of radiation on the equatorial band and an excess at higher latitudes (Figure 1a). Globally, the ocean receives more radiation (between 2 to 5 Wm-2) with ERA40 (Figure 1b). But the most striking difference between the two data sets is found in their representation of the inter-annual variability (Figure 1cd): ERA40 is showing a quite unrealistic decreasing trend in the inter-tropical band. Similar differences are found between climatologies and time series of the other heat and freshwater fluxes (5).

Reasons for that are many, and the lack of observational data is one. But there is one major difficulty for heat flux estimation which is intrinsic to the nature of the fluxes: while the magnitude of individual heat flux components is of the order of a few 100 Wm-2, the net heat flux and the inter-annual variability of the fluxes are of the order of a few 10 Wm-2, and the long-term changes in heat content (or heat transport) of the world ocean is consistent with changes in surface heat flux of a few Wm-2. Thus, the difference of a few W/m2 pointed out in radiative fluxes of CORE and ERA40 (Figure 1b) is significant. This places stringent requirements on the accuracy of flux calculations, since a 10% error on a flux component may introduce a first order bias in the net heat balance. This l kely explains why biases can be observed between flux estimates using different sources and retrieval methods.

The accuracy of flux calculations is therefore a critical issue. If uncertainties on air-sea fluxes are difficult to quantify because of a lack of direct measurements, they decrease as time and space averaging is performed. The best known constraint is that the long-term mean heat and freshwater fluxes should balance near zero at global scale. However, the use of high resolution ocean models in research and operational systems demands fluxes and surface variables with global coverage at spatial-scales of the order of 10 km and time-scale of a few hours. To meet this demand on every flux or variable entering the forcing function of an OGCM is presently out of range. The accuracy of flux calculation at these scales is thus a new challenge, which is presently taken up with satellite measurements and numerical weather prediction models. Two papers in this newsletter focus on this issue, and present on-going efforts to estimate a consistent set of wind fields at a 6 hour sampling from satellite measurements (paper by A. Bentamy and D. Croize-Fillon), and to produce highly sampled SST (paper by H. Roquet).

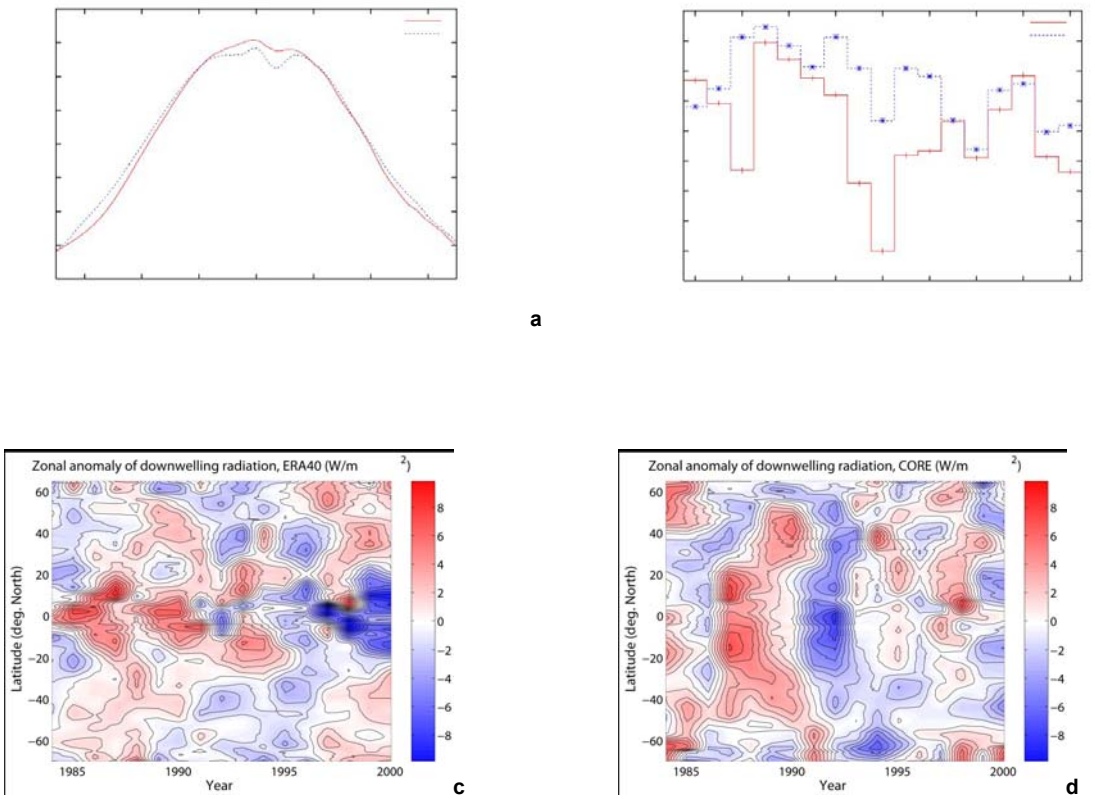

Figure 1
Comparison over the period 1984-2000 of the zonal average of the total down-welling radiation (solar plus infrared) provided by CORE (red line) and ERA40 (blue line) data sets. Are shown: a) the distribution with latitude of the long term (17 years) mean, b) the global averaged annual mean for individual years, and the year to year variations in ERA40 (c) and CORE (d).

Ocean surface forcing

At first thought, the ocean/atmosphere coupling in the surface exchanges is so strong that driving an ocean-only model (i.e. not coupled with an atmospheric model) with observed surface fluxes (i.e. fluxes obtained from observation of surface variables) could be considered as a silly exercise. Nevertheless, oceanographers have been very successful in running ocean-only models in those conditions, provided that some kinds of parameterisation of the ocean feedbacks were used. Therefore, in the process of constructing a forcing function for OGCMs, it would be an error to separate the problem of the estimation and accuracy of surface fluxes and other surface variables, from that of the formulation of the surface boundary condition used by the model. In the NEMO community, two different methods are commonly used to account for the ocean feedbacks on the forcing fluxes, which put different requirements on the surface fields.

The flux correction method [6] simply utilizes the global observed flux fields (radiative fluxes (solar and infrared), turbulent fluxes (wind stress, sensible and latent heat, evaporation), precipitation and river runoff). The ocean feedback is parameterised by a relaxation to an observed sea surface temperature (SST) (with a time scale which varies with space and time expressing the sensitivity of the surface fluxes to small changes in SST. The operational MERCATOR analysis system presently uses a simplified version where the relaxation time scale is kept constant.).

There are several criticisms levelled at this method. One is that the model SST is not fully prognostic (but it allows a prognostic meridional heat transport). This criticism can be ignored when performing ocean analysis or re-analysis (i.e. with data assimilation) for which a prognostic SST is not an issue. In that case the feedback term may be seen as a "physically consistent nudging" of the model solution to the observed SST and it contr butes to constrain the model to remain close to observations (albeit not in an optimal way). Another serious criticism is that the physical consistency between the various components of the forcing (like between evaporation and latent heat) could be lost or seriously degraded when the flux correction become large, which happens frequently in model simulations. In forecast model calculation (i.e. with no data assimilation) this may deteriorate the model solution.

NDLR:

Per definition, Latent Heat flux (Q_E) and Evaporation (E) are proportional [W. Large, 2] (eq. 1).

Eq. (1) $Q_E=-\Lambda E$ where $\Lambda=2.5 \times 10^6$ j/kg

In numerical simulation using the flux correction method, Q_E and E are initially proportional. However, as the simulation is being performed, Q_E and E end up not to be proportional anymore. Indeed, the largest part of the flux correction is attributed to a correction of Q_E, without any proportional correction applied to the E field. The initial E stays out the same during the whole simulation, whereas Q_E is being modified because of the flux correction. Hence, the physical consistency between Q_E and E is being lost or degraded throughout the simulation when the flux correction becomes large.

The bulk method (7) utilizes bulk aerodynamic formulae and the model SST to calculate the turbulent fluxes (which are locally most sensitive to changes in SST). Observed flux fields are used for the downward solar and infrared radiation, precipitation and river runoff just as in the flux correction method. The representation of the ocean feedbacks is not explicit but lies in the bulk formulae. Air-sea physics are better accounted for in this formulation than in the flux correction method, which introduces additional degrees of freedom. However, as we already mentioned, uncertainties on the exchange coefficients are quite large at the eddy permitting/resolving resolution, and the coefficients used in bu k formulae may need to be adjusted. An interesting approach to that issue is presented in this newsletter by S. Skachko et al., who investigate the possibility to estimate the turbulent exchange coefficients using sequential data assimilation of ARGO heat and salinity profiles in a realistic coarse resolution global model.

The demand of air-sea fluxes expressed by the ocean modelling community is increasing rapidly: the need to resolve the diurnal cycle at global scale with a few km scales is already strong. But increasing the accuracy of flux estimation at global scale is a particularly difficult problem. Meeting the demands expressed by our community will certainly require important additional observational means and long term efforts. It is thus likely that uncertainties in the forcing function of ocean models will remain large for some time. It is therefore important that we increase our understanding of the sensitivity of our models to uncertainties in the forcing function. This issue is addressed in this Newsletter from two different angles. A paper by N. Ayoub et al. explores on monthly time scales the errors induced in the surface layers of a ¼ North Atlantic model by uncertainties in the atmospheric forcing fields. Interestingly, this study is among the first using ensemble simulations with an eddy-permitting model. Another paper by A.L. Dhomps et al. investigates the sensitivity of a South East Pacific regional Mercator configuration to presently available high resolution surface wind fields (obtained from blending Quickscat satellite winds and ECMWF analysis).

Concluding remarks

Our experience in the Clipper and Drakkar projects is that every time we undertook a new series of simulations with a given model configuration, we had to do an empirical correction and adaptation of the available forcing data. Unfortunately, there is no simple methodology to define the forcing function of a simulation. A common approach to decide which forcing data to select is to carry out flux calculations using bu k aerodynamics formulae and observed SST. Fluxes obtained are then extensively compared to other flux data sets, and empirical corrections are performed on various fields, usually in order to correct obvious biases, and to have mean heat and freshwater fluxes balanced to nearly zero at global scale and providing acceptable meridional heat transports. However, this does not assure that these properties of the corrected fluxes will be conserved during model integration (due to the parameterisation of ocean feebacks). We have many examples of models going in a way opposite to that expected using the above procedure (8). Our present impression is that an accurate definition of the forcing requires dedicated sensitivity experiments using the model configuration. It is not clear that significantly coarser resolution models can be used for such sensitivity experiments. Examples with NEMO are that the 2° global configuration ORCA2 shows, in long term calculations, a sensitivity to the forcing fields different than that shown by the 1/2° configuration ORCA05, whereas ORCA05 and ORCA025 (1/4° configuration) tends to show a similar sensitivity. And we may have different sensitivity with eddy permitting model (as the 1/12° resolution future Mercator configuration).

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