ERA report series

6 Evaluation of ERA-INTERIM forcing fluxes from an ocean perspective

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1 Introduction

Surface fluxes (of heat, momentum and fresh water) from the atmospheric reanalysis are of special relevance for the ocean community. Here we evaluate the differences between the surface fluxes from ERA-INTERIM (EI) and ERA-40 (E4), as well as their impact on the simulation of the global ocean. Two ocean models (HOPE and NEMO) have been integrated using daily fluxes from EI and E4 for the period 1989-2001. The differences in fluxes from EI and those from the operational NWP system (OPS in what follows) from 2002 onwards are also evaluated. Both ocean models have global coverage, at resolution of approximately one degree with equatorial refinement, but they have different horizontal grid, vertical discretization, numerics and physics. In spite of being quite different, the models may still have common errors, likely arising from a coarse horizontal resolution, and therefore the results should be interpreted carefully. Still, the exercise will be able to quantify the “dispersion” in the ocean estimation given the dispersion in the surface fluxes, and will established whether or not there is consensus on which set of fluxes produces better ocean simulations. In the model integrations, the sea surface temperature (SST) is strongly relaxed to the OI-v2 SST analysis (Reynolds et al 2002). The nudging term (or flux correction) is proportional to the SST error, and will be used as a diagnostic. Correlation of model sea level with the altimeter-derived sea level anomalies is also used to judge the interannual variability of the surface fluxes. Unless stated otherwise, the statistics presented here are for the period common period between EI and E4 (1989-2001), although comparison between EI and OPS, for the period 2002-2006, will also be discussed in the context of time evolution.

2 Results

2.1 Solar heat flux and SST error

The solar heat flux reaching the ocean is very different in EI compared to E4, and dominates the difference in total heat flux between the two products. Figure 1 shows the 1989-2001 mean difference, which exhibits large scale spatial structure: compared to E4, EI has larger values of the solar radiation mainly over the convective areas, and less solar radiation over the stratocumulus coastal regions. In the warm pool area, the increase in solar heat flux in EI amounts to doubling the net heat flux into the ocean, from 15 W/m2 in E4 to 30 W/m2 in EI. The time evolution of the solar heat flux (not shown), indicates that EI has consistently larger values than E4, and after 2002 the values of EI tend to converge to those of OPS. The solar radiation in EI has weaker interannual variability than in E4.

Figure 2 shows the differences in the flux correction from the NEMO model in selected regions (shown in the left upper panel). The differences have been partitioned into mean value (top right), seasonal cycle (bottom left) and interannual variability (bottom right). The flux correction needed when using E4/EI is shown as grey/red bars respectively. The figure shows that the increase in solar radiation in EI is beneficial in the Western Pacific, where the absolute value of the flux correction is reduced by more than half. Reduced values of the flux correction are also observed in the Eastern Indian Ocean (not shown). However, in the rest of the ocean, the total flux correction term is negative when using EI, and its absolute value is often larger than when using E4, as if the additional solar heat flux in EI were excessive. The overestimation of the solar heat flux in EI may be responsible for the excess of net heat flux into the global ocean, which in EI amounts to an imbalance of 8 W/m2. The lower panels in figure 2 shows that the seasonal and interannual components of the flux correction

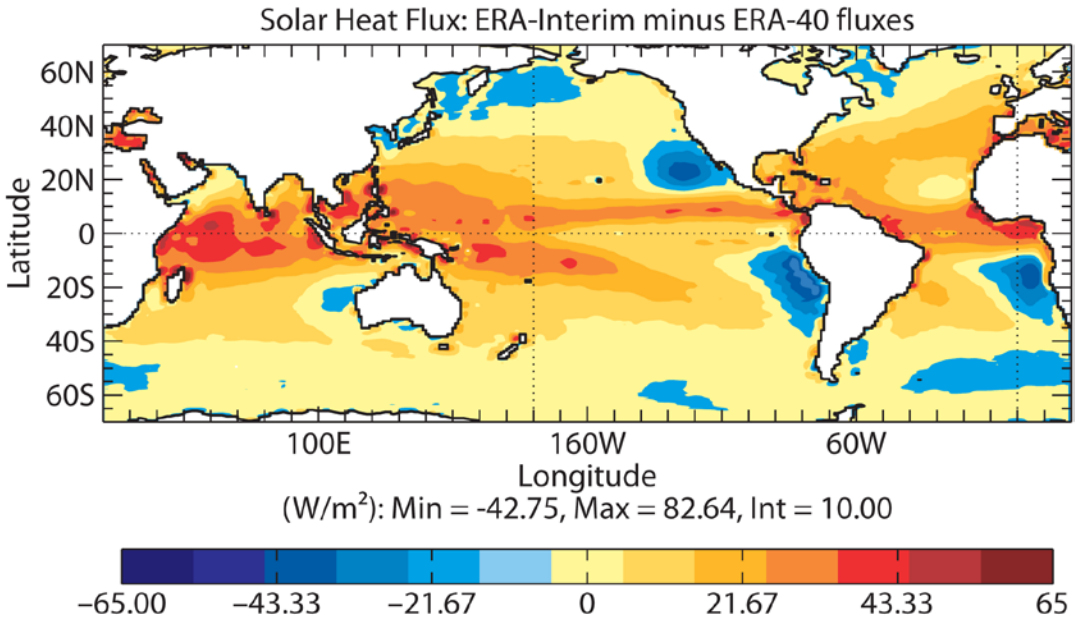

Figure 1: Mean difference in the solar radiation from ERA-Interim versus ERA-40. Largest differences occur over the convective areas, where more solar radiation reaches the surface in ERA-Interim, and over the stratocumulus regions, where the surface solar radiation is less in ERA-Interim. Units are W m^{-2}.

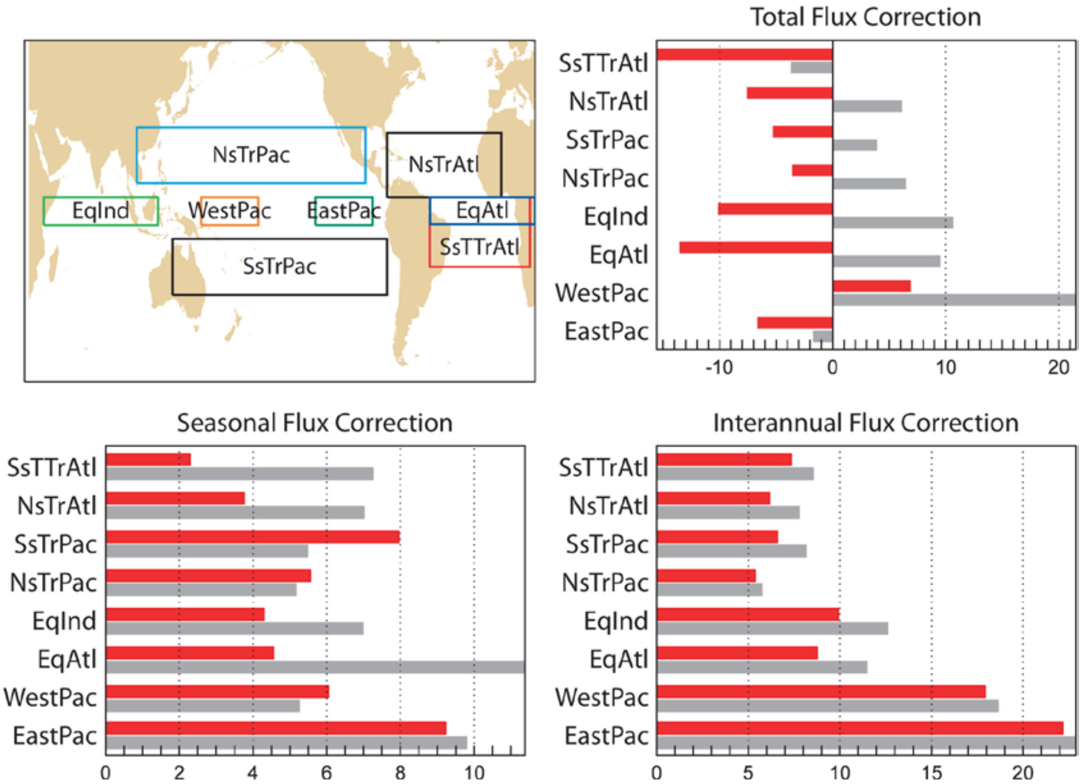

Figure 2: Flux correction (proportional to SST error) from the integrations of the NEMO ocean model forced by E4 (grey) and EI (red).

term is substantially reduced when using EI, indicating that both the seasonal and interannual variability of the atmospheric fluxes are better represented in EI than in E4. Results from the HOPE model (not shown) lead to similar conclusions.

2.2 Wind stress, sea level and ocean currents

Differences in the mean surface winds stress are shown in figure 3. In the tropics, the largest differences are in the meridional component, where they often exceed the 10% value. EI shows increased divergence in the Western Pacific and Indian Ocean and reduced cross equatorial southerly winds in the Eastern Pacific and Equatorial Atlantic. Differences in the zonal component are smaller than 5% in most of the tropics, except for the Equatorial Indian Ocean, where the differences exceed the 30% value. At high latitudes, EI shows consistently stronger westerlies (about 5% stronger) than E4, probably related with the higher horizontal resolution in EI. The impact of resolution on the mean wind stress is further suggested by the differences between EI and OPS (not shown): as the resolution of the operational model increases the differences between EI and OPS decreases. In the later years (2004 onwards), the OPS wind stress are even stronger than EI, and the pattern of differences in figure 3 almost reverse (albeit with weaker amplitude). Wind stress differences in the seasonal cycle have a typical value of 20% both in the zonal and meridional components. Differences are larger at the seasonal and interannual time scales (between 30%-40%).

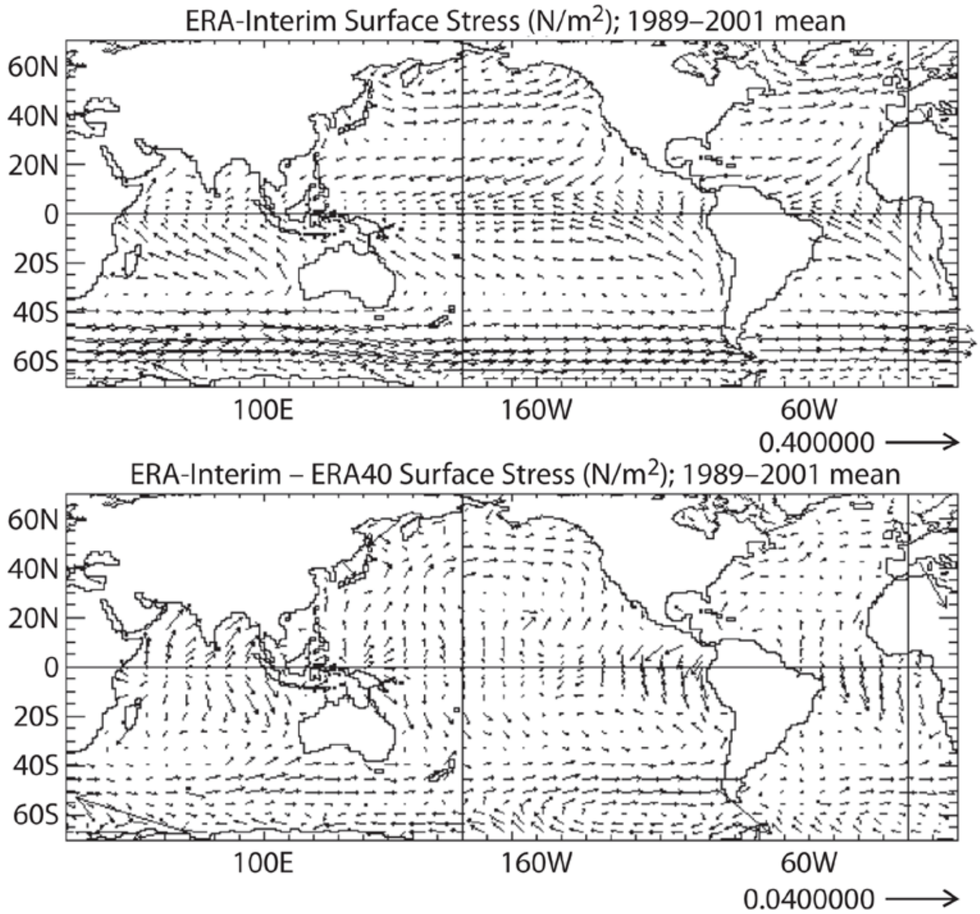

Figure 3: Mean wind stress in EI (top), and differences in wind stress between EI and E4 for the period 1989-2001. Note the stronger westerlies in EI at high latitudes, likely related to the increased horizontal resolution. In the Equator, the main differences are in the meridional component of the wind stress.

As an example, figure 4 shows the time evolution (12-month running mean) of the meridional wind stress in several regions for E4/OPS (black line) and EI (red line): note the convergence between the curves in the latest period, and the large differences in the low frequency component of the wind, especially that associated with ENSO in the South and Equatorial Pacific. In some areas (South and Equatorial Atlantic, North Subtropical Pacific) there is a clear offset from the beginning between EI and E4, but not between EI and OPS. Hence, the step-like variability associated to the transition between E4 and OPS is likely to be spurious, and it is absent in EI.

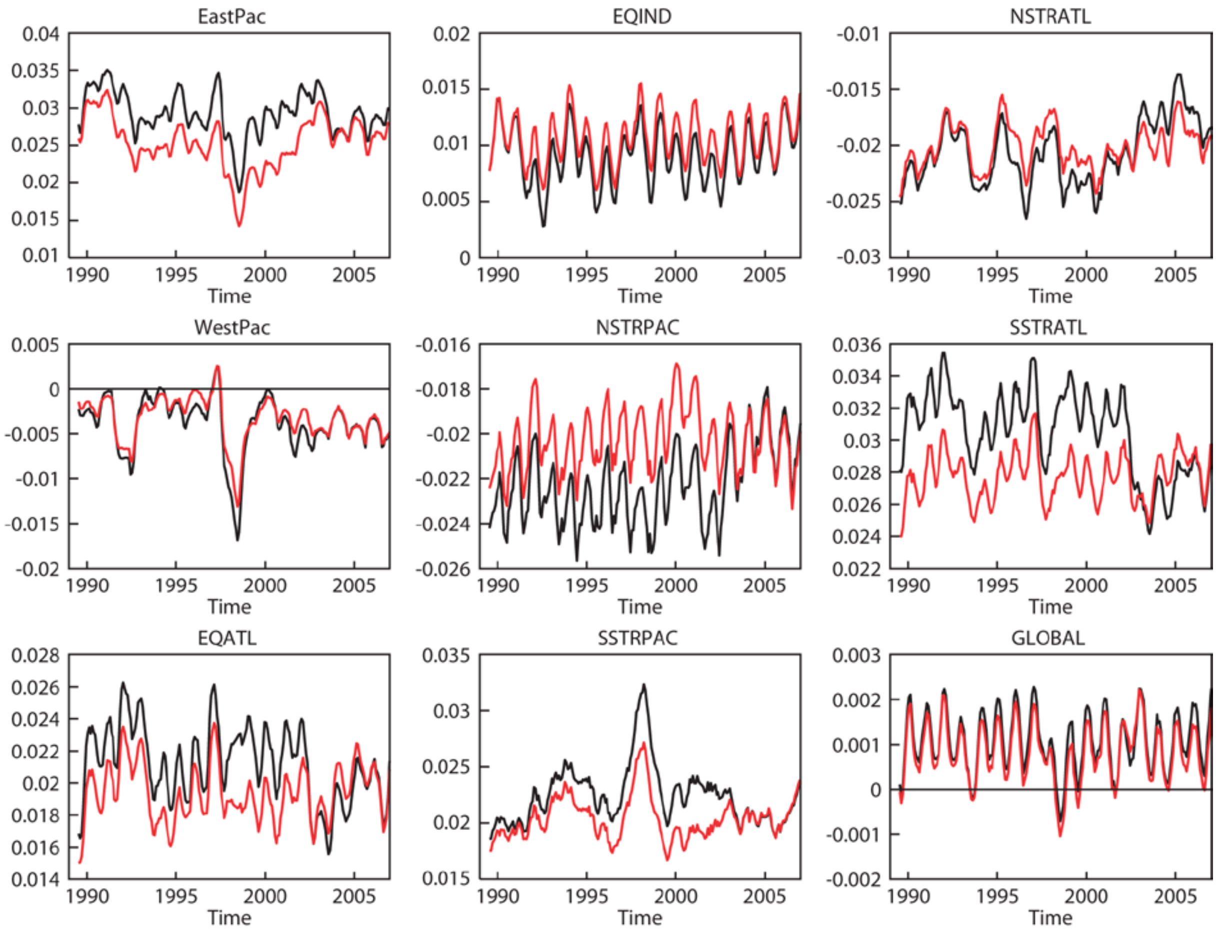

Figure 4: Time evolution (12-month running mean) of the meridional wind stress from E4/OPS (black) and EI (red). Note the large differences in the low frequency component. Also note the convergence between EI and E4/OPS at the end of the record.

The impact of the differences in surface fluxes in the ocean circulation can be summarized by the impact on the model sea level (SL). Figure 5 shows the SL from the NEMO model forced by EI fluxes (NEMO-EI, top) and the differences respect the integration of NEMO forced by E4 (NEMO-E4, bottom). The meridional gradients in the NEMO-EI are stronger, with lower sea level in the North Atlantic, North Pacific and around the Antartic Circumpolar current, and higher sea level in the tropics, particularly on the western sides of the subtropical gyres, consistent with the increased zonal component of the EI-wind stress at mid latitudes. The zonal gradient in the Equatorial Pacific and

Indian Ocean are slightly larger, and so are the sea level differences between the tropical Pacific and Atlantic. Most noticeable is the increased sea level in the Eastern half of the Pacific around 15N, which reflects the weakening of the local meridional pressure gradient and related weakening of the North Equatorial Counter Current (NECC, not shown) in the NEMO-EI integration. At the Equator, the weaker EI cross-equatorial winds in the Eastern Pacific and Atlantic reduce the upwelling, weakening the meridional circulation cells. Overall, the equatorial currents are increased in the western Pacific and decreased in the Eastern part. Comparison with the TAO currents indicate that the former is a positive change while the later is not. Results from the HOPE model lead to similar conclusions.

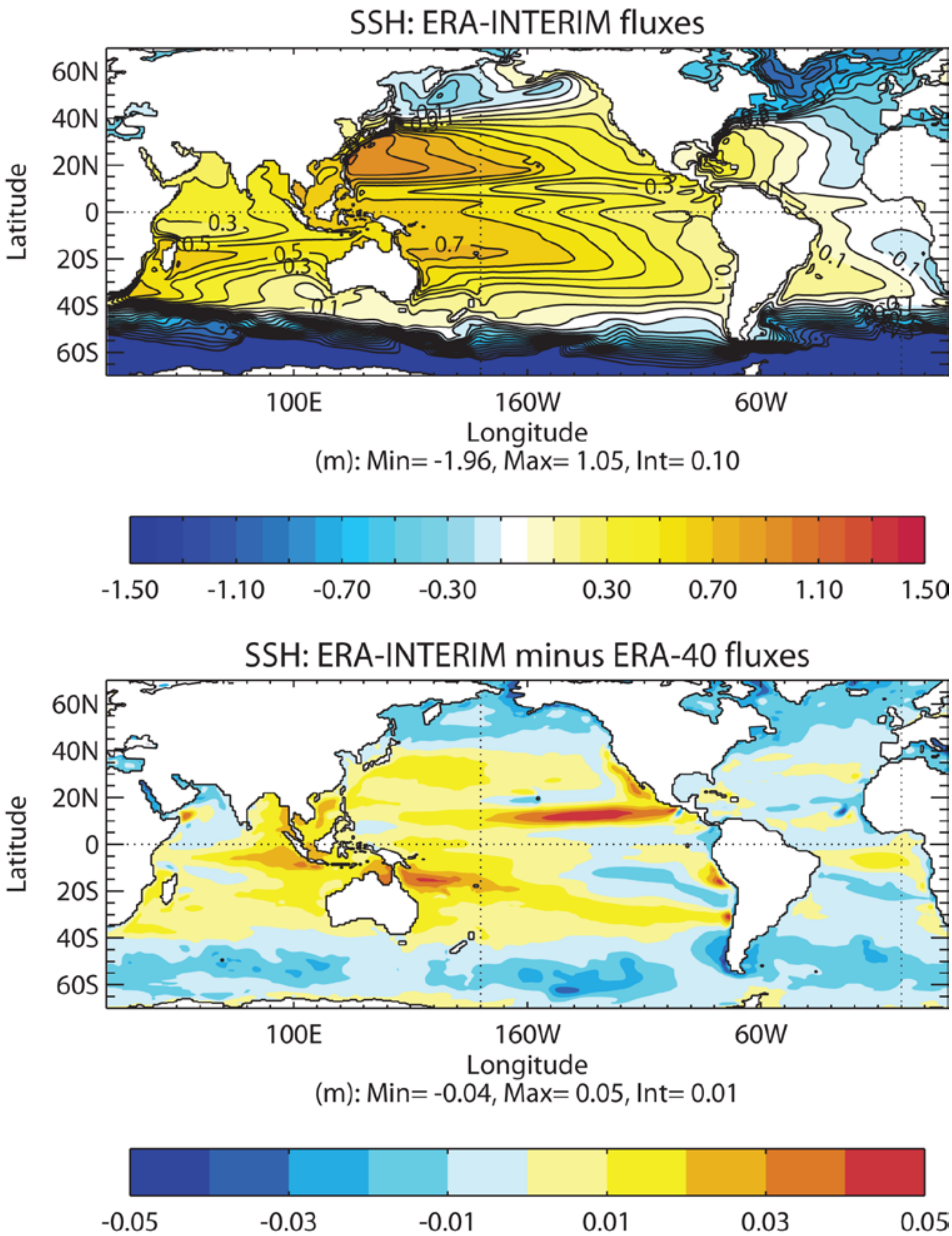

Figure 5: Mean sea level. Top: NEMO forced by EI. Bottom: differences between NEMO-EI and NEMO-E4. Units are m.

Changes in the mean of the upper ocean caused by the differences between EI and E4, although robust and with a clear spatial structure, are relatively small compared to the differences arising from ocean models. However, change in the interannual variability of the upper ocean is largely determined by the change in the forcing fluxes, namely the wind stress. The differences between EI and E4 fluxes produce changes in interannual variability of the upper ocean (heat content, thermocline depth or sea level) exceeding 30% in most of the areas. In the Equatorial and South Tropical Atlantic the changes are as large as 60%. Altimeter-derived sea level anomalies have been used to evaluate the interannual variability of the different model integrations for the period 1993-2006. The correlation of the detrended interannual anomalies of the SL from NEMO and altimeter are show in figure 6. The interannual variability is better represented with the EI fluxes than with the E4/OPS: in all the areas, the correlation is higher when the model forced by EI fluxes (red bars) than when is forced by E4/OPS fluxes. The improvement is more noticeable in regions where the correlation was poor with E4/OPS, namely the Atlantic and subtropics. Similar results are obtained when using the HOPE model. Correlation of the model surface currents with the OSCAR currents confirms the improvement of the interannual variability.

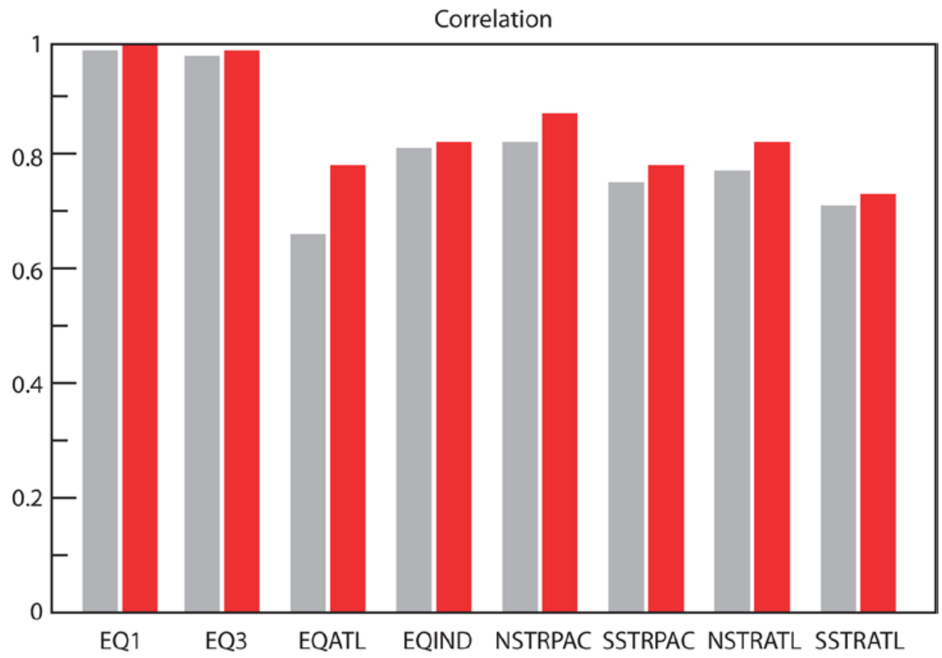

Figure 6: Correlation between sea level interannual anomalies from NEMO and altimeter. Red (grey) bars are for NEMO-EI (NEMO-E4/OPS). The global mean trend has been removed. The statistics have been computed for the period 1993-2006.

2.3 Fresh water flux and ocean salinity

One of the largest differences between EI and E4 resides in the fresh water flux (precipitation minus evaporation or PME). The PME from E4 had large errors, and a corrected version was used to force ocean models (Troccoli and Kallberg 2004). By construction, the corrected E4-PME annual mean over the global oceans was constrained to be -1.1 Sv, so it would balance the river discharge estimates (Dai and Trenberth 2002). However, the balance was disrupted when the operational PME from OPS was used after 2002, where the amount of fresh water into the ocean increased dramatically (see figure 7).

In contrast, the PME from EI is quite stable, and shows little interannual variability, although there seem to be a jump around 1992. Its annual average integrated over the global oceans is -0.9 Sv, which, if estimates of the river discharge are correct, would result in too much fresh water flux into the ocean.

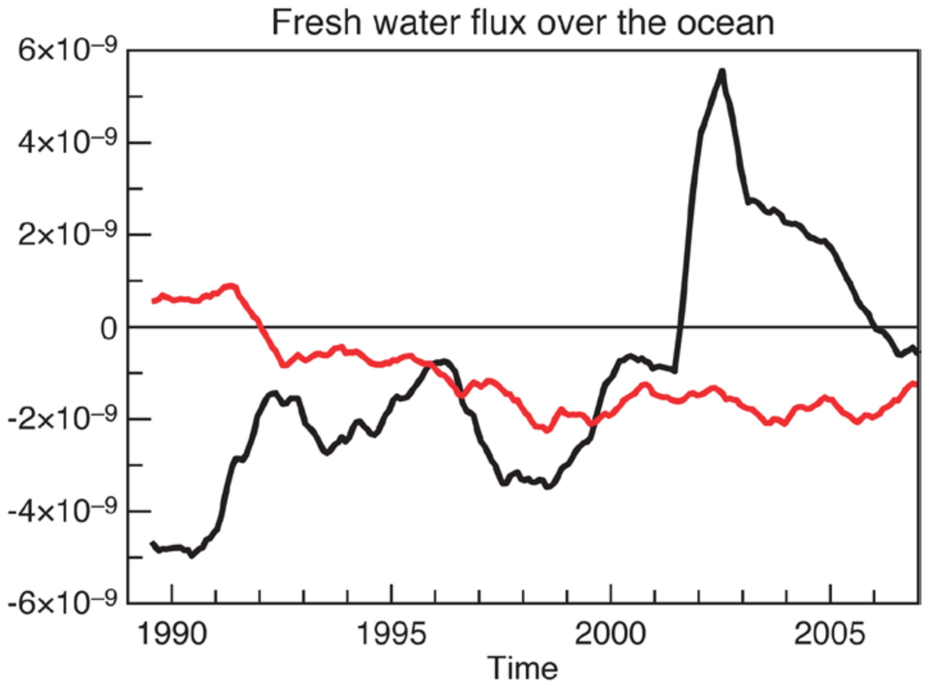

Figure 7: Time evolution of the globally averaged fresh Water flux. Red for EI and black for E4/OPS. Note the transition to operations after 2002 in E4/OPS, and the comparatively small jump in EI 1992.

3 Impact on seasonal forecasts of SST

The version of the coupled model used in the S3 seasonal forecasting system (Anderson et al 2006, Molteni et al 2007) has been used to evaluate the impact of EI surface fluxes in ocean initial conditions used to produce the seasonal forecasts. Four sets of coupled experiments comprising 71 initial dates (3 months apart) for the period Apr 1989 to Oct 2006. For each initial date a 5-member ensemble, 6-month coupled hindcast was produced. In two experimental sets, the ocean initial conditions were produced by forcing the HOPE ocean model with ERA-40/OPS and EI fluxes. We refer to these experiments as CNTL-E4 and CNTL-EI respectively. In other two sets (ASSM-E4 and ASSM-EI) the ocean initial conditions were produced as before, but this time assimilating ocean data using the same system as in the operational re-analysis (Balmaseda et al 2008). The assimilation of ocean data generally reduces the uncertainty in the ocean state arising from forcing fluxes.

The impact of EI forcing fluxes is most noticeable in the Equatorial and South Tropical Atlantic regions, where the forecast skill of the SST is largely improved when using EI fluxes in the production of ocean initial conditions. Figure 8 shows the anomaly correlation as a function of lead time for forecasts of SST over the Equatorial Atlantic area. The positive impact of EI fluxes is evident in experiments with and without data assimilation. These are areas where the performance of the current seasonal forecasting system is particularly poor, and assimilating ocean data does not usually improve the skill. Poor forcing fluxes and model error were considered a major obstacle for skilful seasonal forecasts in these areas. The improvement in forecast skill when using EI in these areas, consistent with the improved estimation of the ocean state discussed in previous sections, opens the possibility of improved operational seasonal forecast in the years to come.

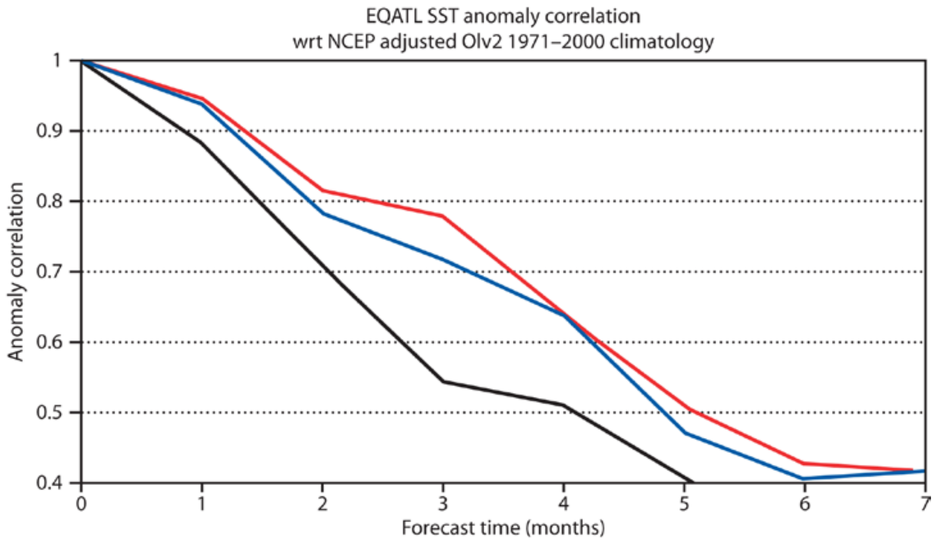

Figure 8: Anomaly correlation skill for seasonal forecasts of SST in the Equatorial Atlantic. The forecasts were initialized using E4/OPS (blue) and EI (red) in the production of the ocean initial conditions. For comparison the skill of persistence is also shown as a dashed black line. Statistics are computed from 71 initial dates during the period April 1989 to October 2006 (3 month apart).

4 Conclusions

Two ocean models (HOPE and NEMO) have been used to assess the impact of EI fluxes in ocean model simulations. Both ocean models indicate the EI surface fluxes are an improvement respect E4, especially in the representation of the seasonal and interannual variability. This is particularly noticeable over the Atlantic, where EI fluxes improves the correlation of the model sea level with the altimeter data, consistenly in both NEMO and HOPE.

The estimation of the incoming solar radiation is quite different in EI and E4, with EI having larger values over the convective tropical areas and lower values on the coastal stratocumulus regions. The spatial structure of these changes is benefitial for the representation of the ocean state, but the global integral of the net heat flux into the ocean solar is overestimated in EI by about 8W/m2.

The version of the coupled model used in S3 seasonal forecasting system has been used to evaluate the impact of EI surface fluxes in the ocean initial conditions. Results show that the SST forecasts produced with EI are in general more skilful, this being particularly true in the Equatorial and South Atlantic. Given that the skill of seasonal forecasts in these areas has always been particularly poor, the improvement arising from the EI forcing fluxes offers for first time promising perspectives for the future operational seasonal forecasts over the Atlantic regions.

5 Further reading:

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