RESEARCH DEPARTMENT
MEMORANDUM

To:	DR, HMD, Wave Section, Seasonal Forecasting Section, MERCATOR OCEAN
Copy:	Hans Hersbach, Dick Dee, Anton Beljaars, Peter Bauer, Roberto Buizza
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Date:	March 14, 2013 — File: R60.9/JB/10104
Subject:	**Use of MERCATOR surface currents in the ECMWF forecasting system**

Abstract

An impact study of using MERCATOR surface currents in the ECMWF forecasting system has been carried out. It confirms preliminary results that surface currents can have a beneficial impact on the quality of ocean wave analysis and forecasts.

1 Motivations.

Preliminary results on the impact of using high resolution surface current data in the ECMWF forecasting system were presented during the Workshop on Ocean-Atmosphere Interactions (ECMWF, 10-12 November 2008). It was shown that surface currents can impact the system in three ways. Firstly, by including surface currents in the prescription of the no-slip boundary condition at the surface of the oceans, it was found that both the surface stress but also the whole surface wind profile was affected, somehow counter balancing each others (Hersbach and Bidlot, 2008, hereafter HB08). As a consequence, the impact of the surface currents on the wind forcing applied to the ocean wave model is reduced with respect to the naive hand waving argument that the ocean waves (and other surface processes) see the relative winds. Secondly, ocean waves propagation characteristics are directly influenced by the presence of surface currents (both in physical space and spectral space). The same currents that are used in the atmospheric model can be passed to the wave model via the coupling interface together with the modified surface stress. As a result, the wave field is altered and the updated sea state information passed back to the atmospheric system. Thirdly, at analysis time, for observations that measure quantities near the sea surface, the observation operators that relates model variables to observed quantities have to be adapted to account for the presence of a moving sea surface. The change will alter how observations are used by the assimilation system.

As explained in HB08, all technical developments to ingest and use surface current data have been done. Back in 2008, we had at our disposal daily mean surface current fields from the MERCATOR global analysis products disseminated at 0.5° resolution. In a preliminary impact study, we were able to run slightly over a month of the T511 system (40km) with a wave model resolution of 0.5°. Technically, it all worked fine, but no substantial conclusions were made on the benefits of using surface currents in the forecasting system. Partly, the horizontal resolution of the current data was still a bit too coarse, but also, we had used analysis data from MERCATOR that would not be available in near real time for use in the operational running of our forecasting system.

Since then, ECMWF has signed a collaboration agreement with MERCATOR for the operational dissemination of their analysis and forecasts data at the highest available resolution. The operational resolution of the atmospheric model (IFS) has been upgraded to T1279 (16km) and the wave model (WAM) to 0.25° (28 km). Therefore, it was opportune to re-assess the impact of surface ocean currents in the latest version of operational system.

2 MERCATOR data.

Every Wednesday, Operations receives daily-mean data from the latest run of the operational MERCATOR system, global data on a $1/4^{\circ}$ grid (product PSY3V2) and also $1/12^{\circ}$ data for the North Atlantic (PSY2V3). The products are essentially a 2 week analysis followed by a 14 day forecast. Note that the MERCATOR system uses ECMWF atmospheric data as part of their forcing data. The 14 day analysis can actually be split between the first 7 days, which has seen all available ocean data (”best estimated”) and the remaining 7 days that has only seen limited amount of data. If we want to use these data into the operational system, obviously we should not use the analysis data as they have already passed their ”valid by” date. We could use the forecast data, however, we are intending to use these data to prescribe the slowly varying global ocean currents (a bit like we do with the SST), therefore, we do not want to keep the fast moving transient features that are present in the data. We also want to retain some of the characteristics of the analysis. It was found that averaging over a period of about 8 days yields the necessary slow varying characteristics. Hence for any given day in the week from the Thursday to the following Wednesday, a 8-day sliding window ending on the day in question is used to produce the necessary averages. These averaged daily data are then used to prescribe the surface currents for the analysis of that day and any forecasts that are initialised from that analysis. In the process, the data are converted from netcdf to grib in order to be consistent with the other input to the IFS.

HB08 described all the necessary technical changes that were needed to supply the current information to the atmospheric circulation component of the Integrated Forecasting System (IFS), which in turns provides it to the wave model (WAM) via the coupling interface. Essentially, the surface currents enter the system via the surface analysis, a path similar to the treatment of SST. Once available in the IFS, the currents are assumed to be fixed for the remaining of the model run. They will be used to prescribe the boundary condition over the ocean and modify the observation operators for surface observations in the 4D-Var assimilation system. Because of the coupling between IFS and WAM, the effect of the surface currents will be passed to the wave model firstly via the modified surface stress in response to wind profile adjustment due to the moving ocean surface. Secondly, via the direct impact non uniform surface currents have on wave propagation properties (HB08). When IFS and WAM are coupled, the surface currents that are used by IFS are passed to WAM via the coupling interface (along side the other forcing fields). WAM can also be run as a stand alone model. In that case, the currents are read in from an input file.

In this memo, I am reporting on the results from simulations based on data from the end of December 2009 to the end of February 2010. Figure 1 shows the mean surface currents as obtained by averaging the surface current data that were supplied to IFS over the period of interest. One can clearly see the areas of strong currents, such as the western boundary currents (Gulf Stream, Kuroshio, Agulhas), but also the strong currents and counter currents in the Tropics. Note also the strong persistent Antarctic Circumpolar current in the Southern Ocean.

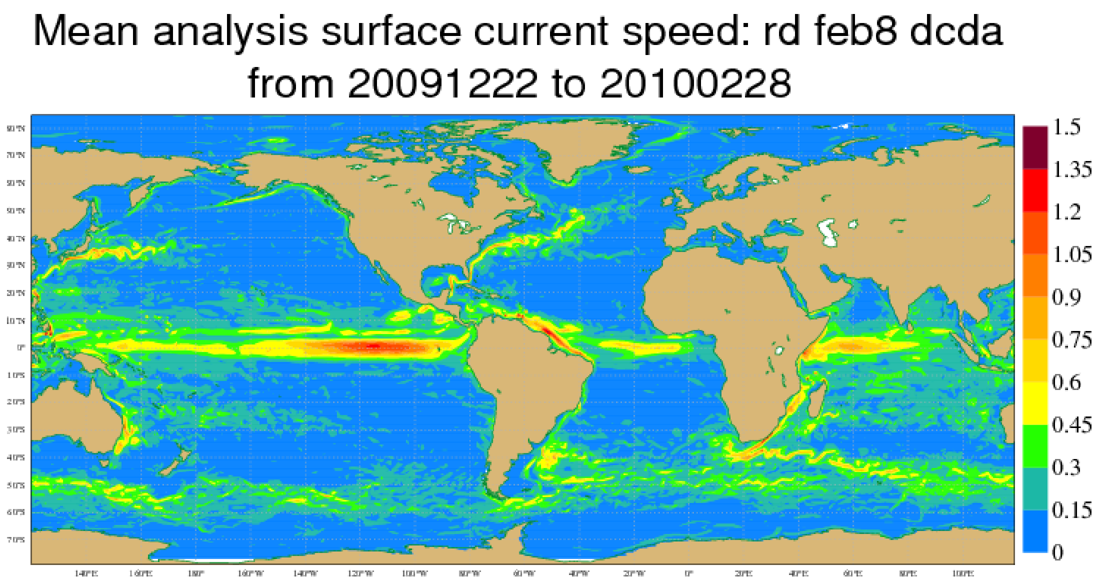


Figure 1: Mean surface current speed as obtained from MERCATOR (m/s).

3 Impact of surface currents on the analysis system.

In order to assess the impact of using surface currents, the CY36R3 research version of the operational forecasting system was used. This implies running the analysis system in the early delivery configuration in which 10 day high resolution deterministic forecasts are computed from the 00 UTC short-cutoff analysis (as in operations, only observations that have arrived at ECMWF within the cut-off time (4UTC) are used). The quality of this short-cutoff analysis is sustained by initialising it from delayed-cutoff analyses which are using all observations that have reached ECMWF within about 12 hours. The resolution of the atmospheric model was T1279 (16km) with 91 level in the vertical. The wave model resolution was 28km with 36 directions and 36 frequencies for the spectra. The delayed-cutoff analysis data are archived every 6 hours and can be used to assess the impact of surface currents. An experiment with currents (feb8) was run from December 21, 2009, 00 UTC to March 1, 2010,00 UTC and can be compared to a reference run (febp).

As discussed in HB08, the surface wind profile will adjust in response to the presence of surface currents. This is clearly seen when comparing the 10m absolute wind speed for both runs. The mean difference (Fig. 2, top panel) shows that the 10m winds are increased over areas of the oceans where the winds tend to run in the direction of the currents (equatorial currents, storm tracks in both hemispheres), whereas the winds are decreased in the areas where winds and currents are opposing (equatorial counter-currents). Surface processes, such as wave generation, are actually controlled not by the winds at 10m height but rather by the effect of the air flow over the surface in the form of surface stress. For this reason, the wave model is actually forced by the 10m neutral wind - a representation of the surface stress in unit of wind speeds - which is determined in the IFS from the surface stress using the logarithmic wind profile. As shown in the middle panel of Fig. 2, the presence of surface currents will reduce the surface stress in areas where both quantities are in the same direction and increase it where they are opposing.

Intuitively, one would assume that surface processes are affected by the relative flow - the one with respect to the moving ocean surface. However, by comparing the magnitude of the change in neutral wind speed (Fig. 2, middle panel) with the strength of the current (Fig. 1), one can see that only about half the impact of the currents is passed to the surface stress. As explained in HB08, in response to the change in surface stress, the whole surface wind profile is adjusting. Areas with increased/decreased surface stress will see a slowing

Table 1: Comparison of the model first guess with altimeter wave heights from ENVISAT, Jason 1 and 2 for the Northern Hemisphere (NH) (north of 20°N), the Tropics (20°S to 20°N) and the Southern Hemisphere (SH) (south of 20°S). The model data are from the delayed cut-off analysis and the period covered is December 22, 2009, 00 UTC to February 28, 2010, 00UTC. The standard deviation of the difference (stdev) and bias (model-altimeter) are shown and n is the number of collocations for each sub-areas.

Comparison with altimeter wave heights : stdev [bias] (m)			
	no currents	currents	n
NH	0.398 [-0.082]	0.395 [-0.083]	162,184
Tropics	0.192 [-0.055]	0.184 [-0.047]	200,893
SH	0.326 [-0.055]	0.323 [-0.054]	345,849

Table 2: Comparison of the model analysis with buoy data. Most buoys reporting wave data are in the Northern Hemisphere. The model data are from the delayed cut-off analysis and the period covered is December 22, 2009, 00 UTC to February 28, 2010, 18UTC. The standard deviation of the difference (stdev) and bias (model-buoy) are shown and n is the number of collocations for significant wave height (H_s), mean wave period (T_z) and peak period (T_p).

Comparison with buoy data: stdev [bias]			
	no currents	currents	n
H_s (m)	0.338 [-0.038]	0.336 [-0.041]	38,488
T_z (s)	0.795 [-0.178]	0.781 [-0.229]	27,952
T_p (s)	1.558 [-0.050]	1.548 [-0.091]	24,565

down/speeding up of the absolute winds at 10m.

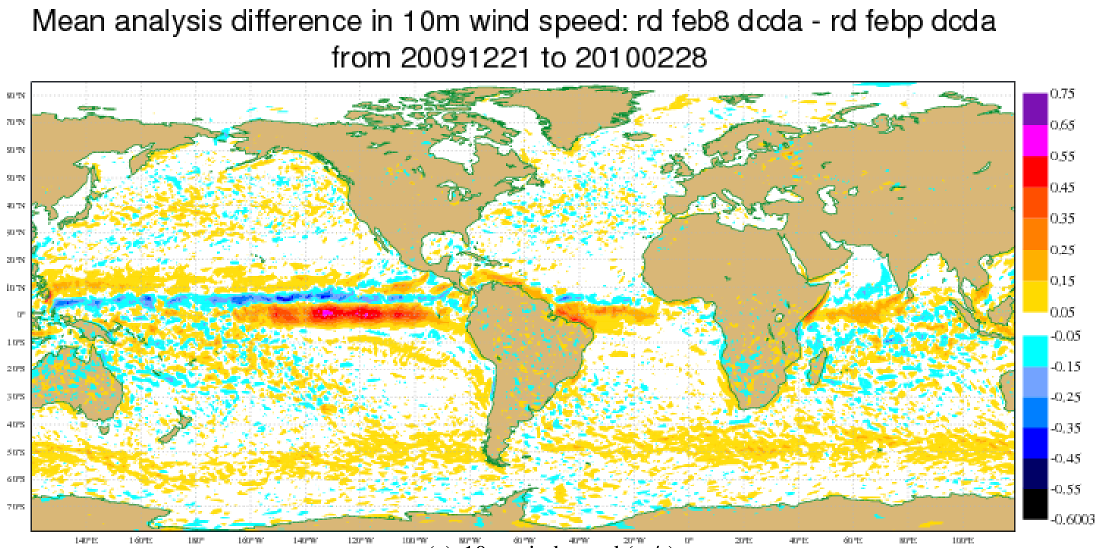
Finally, the net impact of the change in surface stress due to the surface currents and their effect on the wave propagation can be seen in Fig. 2 (bottom panel). The bias with respect to global altimeter wave heights for the reference run without currents is shown in Fig. 3 (top panel). There is a clear underestimation of the model in the counter-equatorial current in the Pacific Ocean. This feature is nicely reduced in the run with currents (Fig.3, bottom panel). A few other areas also appears to benefit from the presence of the currents, and for few other areas, it is the opposite.

The global impact of using currents on the wave model analysis is summarised in Table 1 for a comparison against global altimeter wave heights and in Table 2 for a comparison against buoy data. Using surface currents is rather beneficial on the wave model results, especially in the Tropics. The impact at buoy locations is rather small on wave heights, but still beneficial on other aspect of the wave fields, such as periods. Note that generally moored buoys are not deployed in areas where currents might be strong, hence the limited impact at buoy locations.

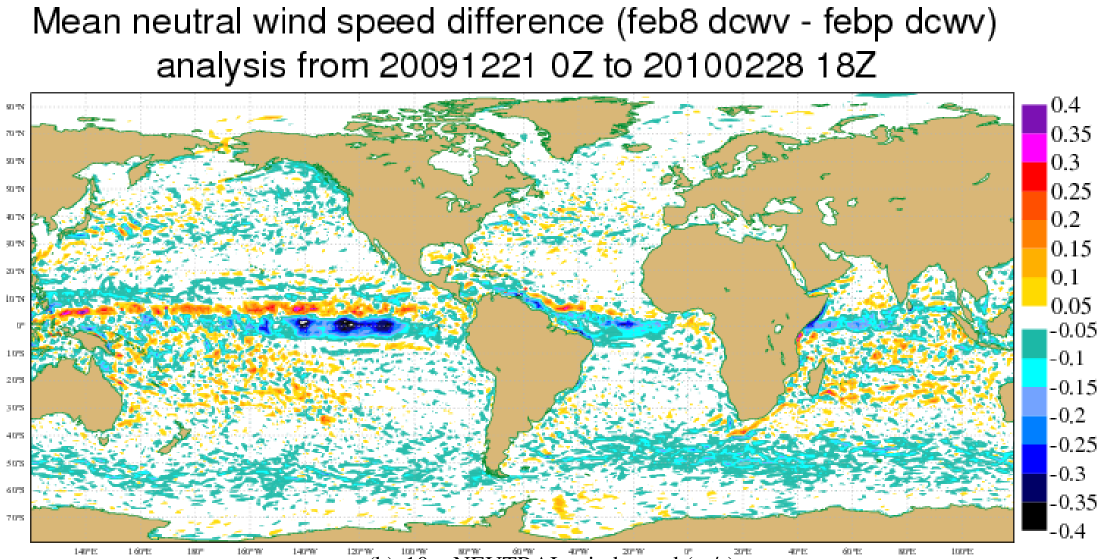
The impact on the 10m winds is given in Table 3 for a comparison against wind observations at moored buoys and in Table 4 for a comparison against ASCAT winds. The model fit to the wind data is not improved when currents are present, in particular in the Tropics but it is still within the uncertainty limits of the reference run.

4 Wave hindcasts.

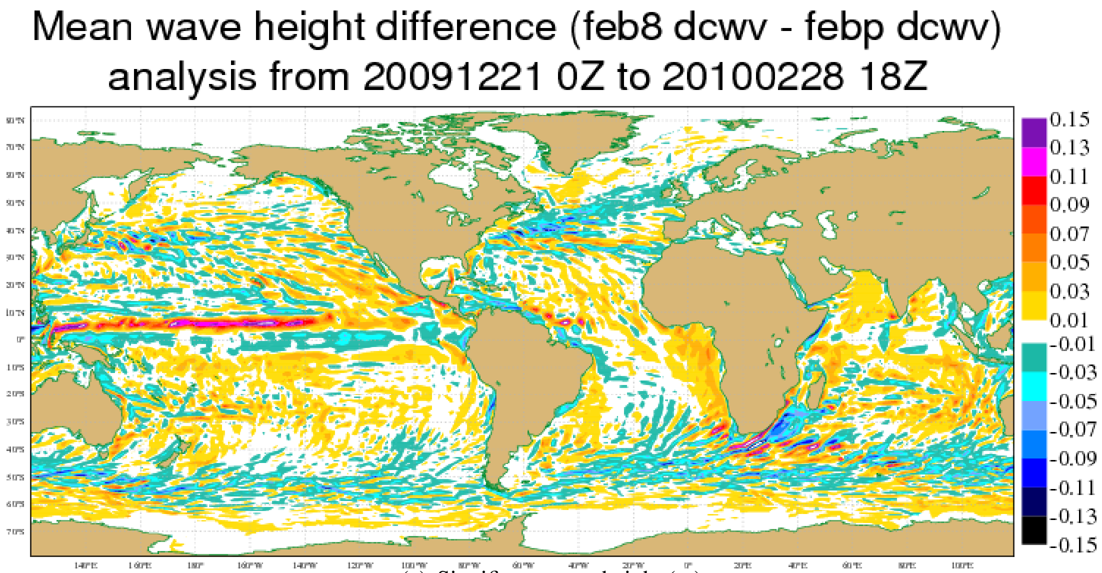
Fig. 2 (bottom panel) shows the net impact of using currents on the wave model analysis. It was discussed that two effects are altering the waves, namely the modified stress and the direct impact of surface currents on



(a) 10m wind speed (m/s)

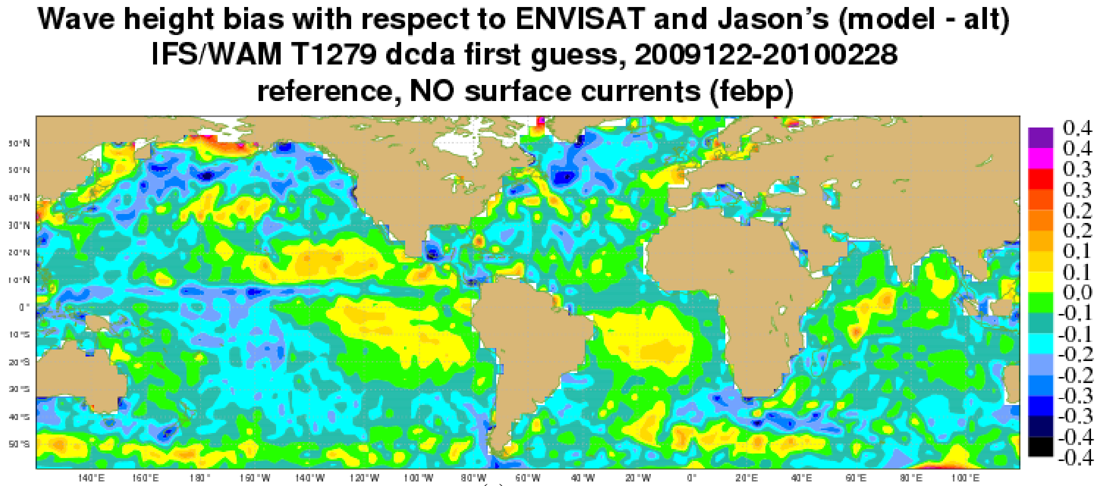


(b) 10m NEUTRAL wind speed (m/s)

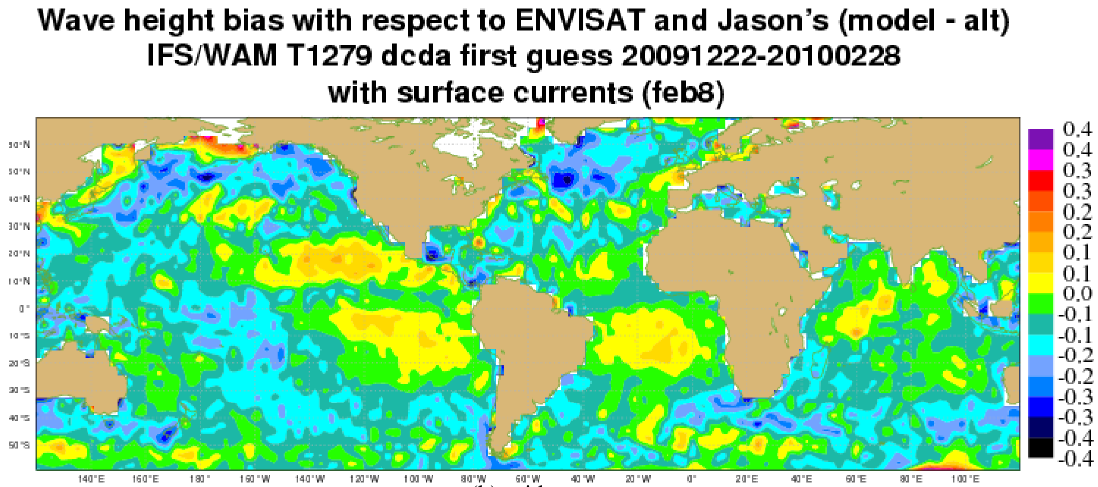


(c) Significant wave height (m)

Figure 2: Mean analysis difference between a run with surface current (feb8) and a reference without any current (febp)



(a) no currents



(b) with currents

Figure 3: Bias (model-altimeter) with respect to altimeter wave height data from Envisat, Jason 1 and 2. Model first guess data were used and altimeter data are the gridded super-observations used in experiment. No corrections were applied to the altimeter data. Statistics were computed with all model-altimeter collocations within $3°x3°$ grid boxes.

Table 3: Comparison of the model analysis with moored buoy absolute wind speed for the Northern Hemisphere (NH) (north of 20°N), the Tropics (20°S to 20°N) and the Southern Hemisphere (SH) (south of 20°S). The model data are from the delayed cut-off analysis and the period covered is December 22, 2009, 00 UTC to February 28, 2010, 18UTC. Buoy winds are adjusted to 10m height. The standard deviation of the difference (stdev) and bias (model-buoy) are shown and n is the number of collocations for each sub-areas.

Comparison with buoy winds : stdev [bias] (m/s)			
	no currents	currents	n
NH	1.320 [-0.161]	1.320 [-0.179]	29,977
Tropics	1.090 [-0.316]	1.097 [-0.296]	18,257

Table 4: Comparison of the model background with ASCAT winds (scatterometer on the MetOp-A satellite) for the Northern Hemisphere (NH) (north of 20°N), the Tropics (20°S to 20°N) and the Southern Hemisphere (SH) (south of 20°S). The model data are from the delayed cut-off analysis and the period covered is December 21, 2009, 00 UTC to March 1, 2010, 00UTC. The standard deviation of the difference (stdev) and bias (model-ASCAT) are shown and n is the number of collocations for each sub-areas. The ASCAT data are those that were used by the assimilation system, therefore in the experiment with currents, the winds are the relative winds (HB08).

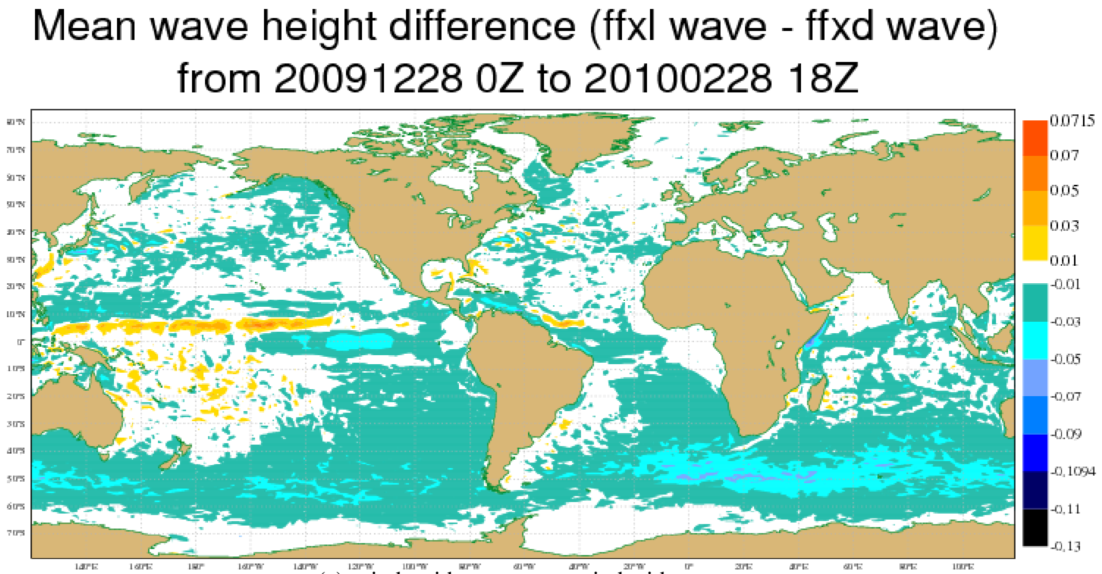
Comparison with ASCAT winds: stdev [bias] (m/s)			
	no currents	currents	n
NH	1.39 [0.227]	1.39 [0.216]	594,096
Tropics	1.27 [-0.057]	1.28 [-0.088]	792,064
SH	1.13 [0.023]	1.13 [-0.015]	1135,960

wave propagation. In order to show the relative impact of both effects, wave model hindcasts were performed. These are essentially wave model runs without the active coupling to the IFS. The necessary forcing fields (winds, currents) are provided from archived data. These runs are much cheaper to run than the fully coupled system. To simplify the problem even further, no wave data assimilation is performed. The same wave model configuration as before was used.

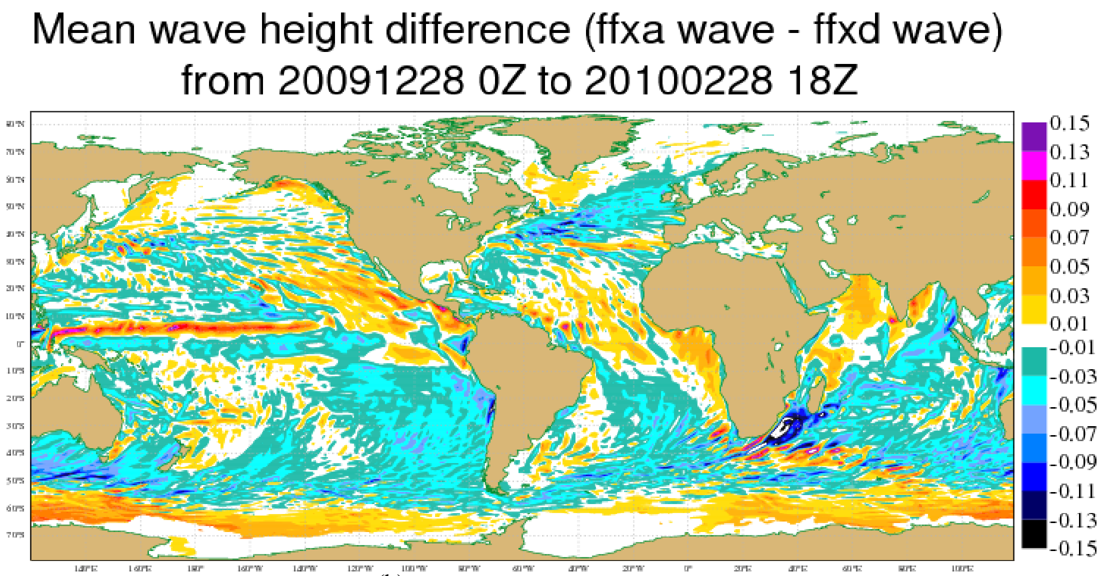
Fig. 4 (top panel) shows the impact of forcing the wave model with surface stresses from the previous experiment in which surface currents were provided to the IFS (feb8) when compared to a reference obtained with winds with no current effects (febp). In first approximation, one can assume that the difference in surface stress is the result of the presence of surface currents. As could be expected, the impact is similar to the change in surface stress, albeit slightly smoother due to the averaging nature of waves (a wave field at any given point over the ocean is a combination of locally generated waves and waves that have propagated from neighbouring areas).

The middle panel of Fig. 4 illustrates the type of direct impact non uniform surface ocean currents have on waves. Because of current induced refraction, wave heights tend to increase when waves are travelling against a non uniform current and decrease otherwise. Such impact is nicely visible when swell from the Southern Ocean propagates against the Agulhas current off the south-eastern coast of South Africa or in the counter equatorial current at around 5°N in the Tropical Pacific Ocean. Of course, this pattern of increase/decrease is present everywhere, in particular in areas with strong meandering currents and eddies, such as the Gulf Stream, the Kuroshio, the North Brazilian current. The resulting wave field is a modulation of increase and decrease which are advected further downstream.

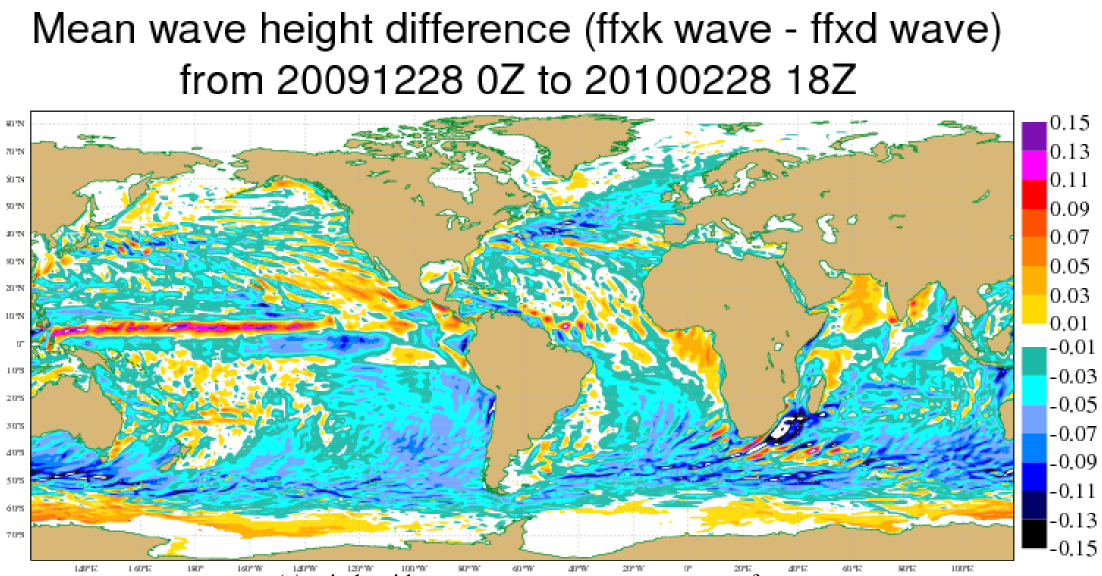
Combining the two effects of modified surface stress and currents in WAM resulted in the bottom panel of Fig. 4. Comparing the three figures, it can be seen that the direct effect of the currents on the waves accounts for about 2/3 of the total impact, whereas the impact of the modified stress for about 1/3. Note that the differences between the hindcast runs appear the be larger than in the case of the coupled runs. This can be partly attributed to the assimilation of wave data in the coupled runs (recall that the hindcasts were performed without any data assimilation) as well as to the differences forcing (every 6 hours with no feedback to the atmospheric model in the hindcasts but every 12 minutes with feedback to the IFS).



(a) winds with currents vs wind without currents



(b) currents on waves vs no currents



(c) winds with currents + currents on waves vs reference

Figure 4: Mean wave height difference between hindcast runs (m).

5 Forecast scores.

As mentioned earlier, 10 day forecasts were also computed. When averaged over the different areas, standard atmospheric scores were mostly neutral. Fig. 5 shows an example for the geopotential height root mean square error of the forecasts for both Northern and Southern Hemispheres.

As seen in Fig. 2, the wave height analysis is quite modified by the presence of surface currents. For this reason, the wave height scores were computed against their own analysis (as it would be if the system were to become operational). Generally, the forecast scores are improved, in particular in the Tropics and in terms of mean error elsewhere.

6 Conclusions.

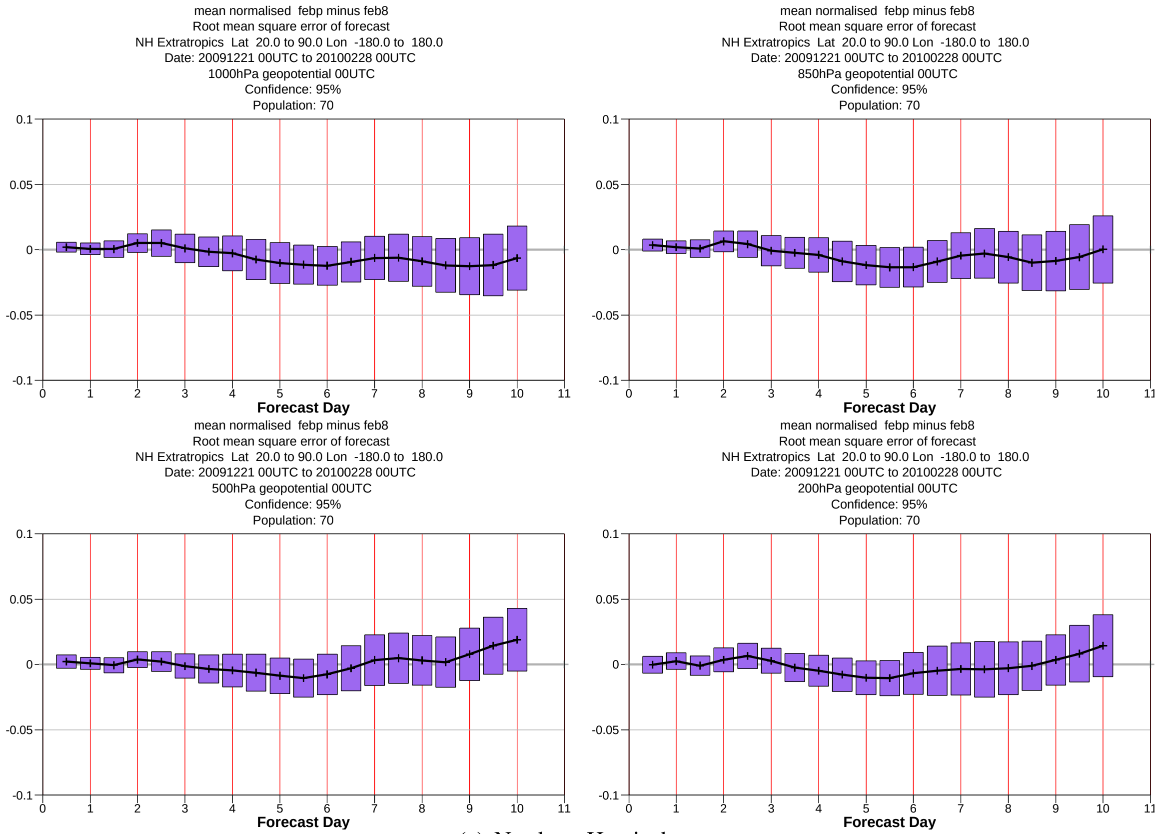
An impact study was performed with the ECMWF forecasting system in which surface currents from MERCATOR OCEAN were incorporated into the analysis as well as the forecast system. The data from MERCATOR were processed in such a way that only the slow varying features were retained. By prescribing surface current as part of the ocean surface boundary condition, it was demonstrated that both the surface stress and the surface wind profile above will adjust such that the effect on surface stress is only about half of what would have been intuitively obtained by subtracting the ocean current from the surface wind in which no account was taken of surface current. Surface currents also affect the propagation properties of ocean waves. This direct effect on the waves, combined with the change in surface stress result in locally marked changes in the wave field that were generally found to be beneficial. Impact on the atmosphere is less clear, even though forecast scores were generally neutral. More experimentations should take place to further validate these findings. Surface observations, such as scatterometer data, are sensitive to the properties of the ocean surface. The observation operators that relate model variables to observed quantities were modified to account for surface currents. More work is needed though to fully access the impact of currents on the proper retrieval of information from those observations.

7 Acknowledgments.

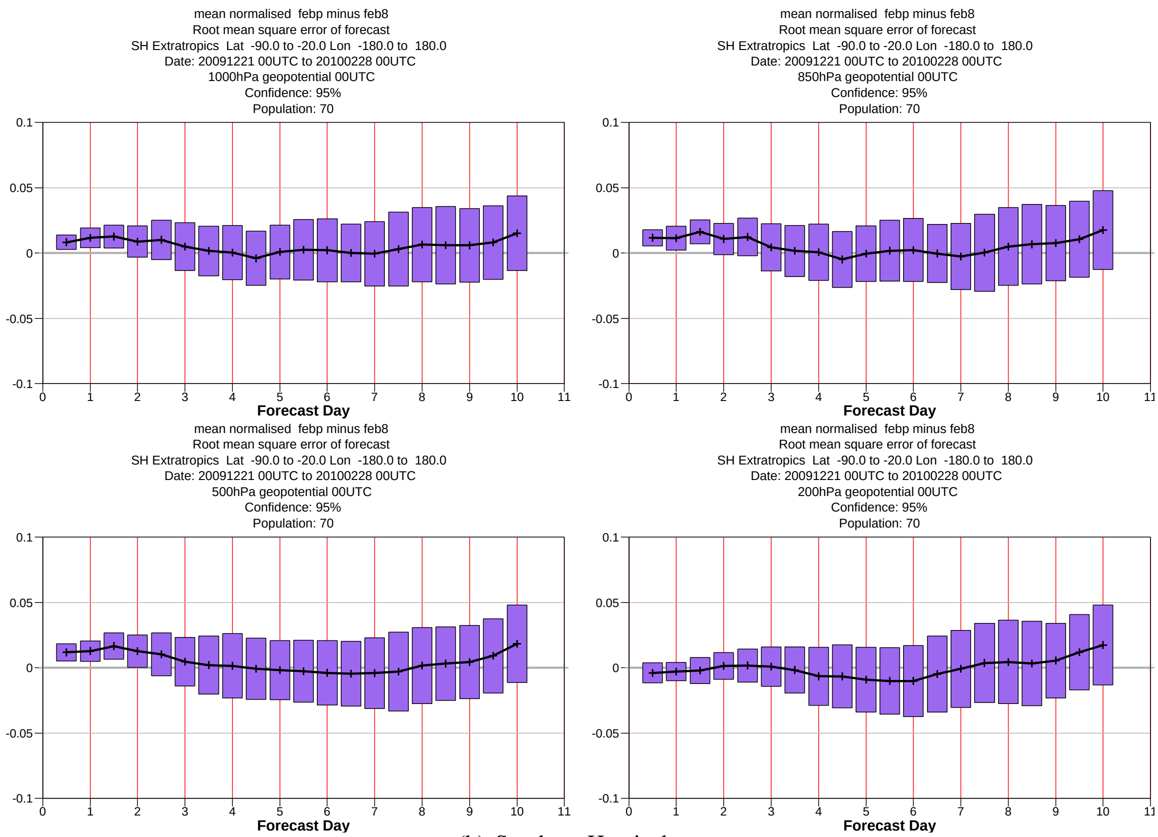
ECMWF would like to acknowledge MERCATOR OCEAN for the provision of their ocean surface data under contract 2009/SG/CCTR/21.

Reference.

Hersbach H. and J.-R. Bidlot, 2008: The relevance of ocean surface current in the ECMWF analysis and forecast system. *Proceeding from the ECMWF Workshop on Atmosphere-Ocean Interaction*, 10-12 November 2008. Available online at: http://www.ecmwf.int/publications/library/do/references/list/28022009



(a) Northern Hemisphere



(b) Southern Hemisphere

Figure 5: Normalised difference in geopotential height root mean square error of the forecasts when compared to the operational analysis. The difference is defined as reference (febp) minus the experiment with currents (feb8), such that positive values indicate a reduction in errors of the run with currents.

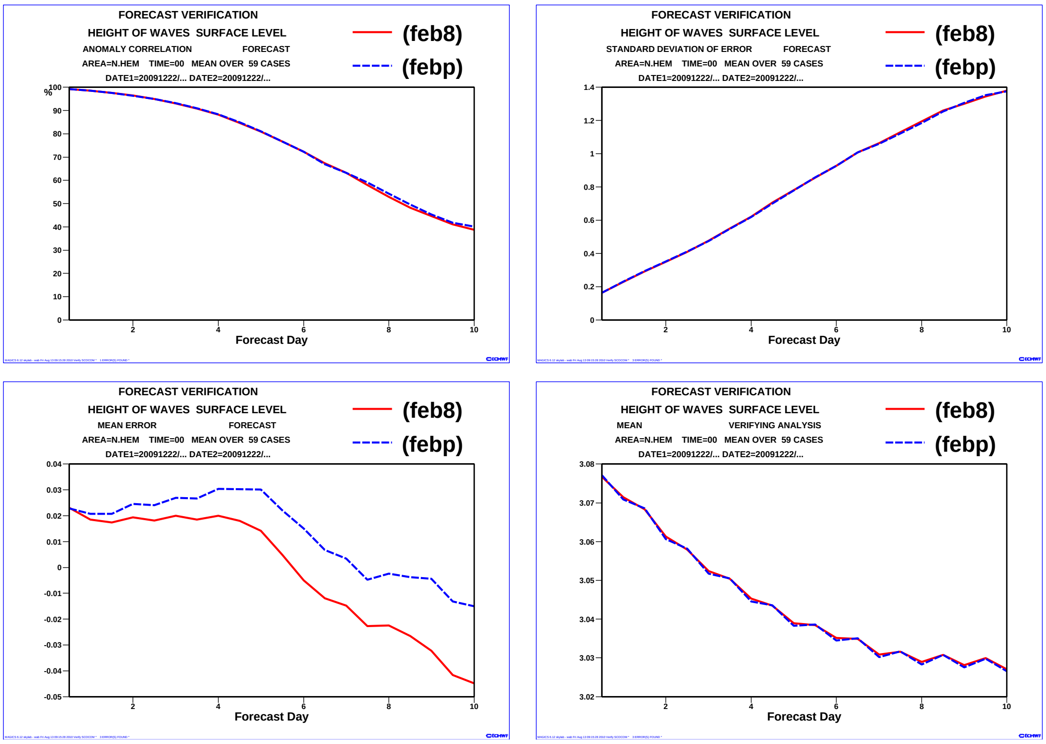


Figure 6: Wave height scores for the Northern Hemisphere against own analysis. The experiment with currents (feb8) is the solid red line and the reference (febp) is the dash blue line.

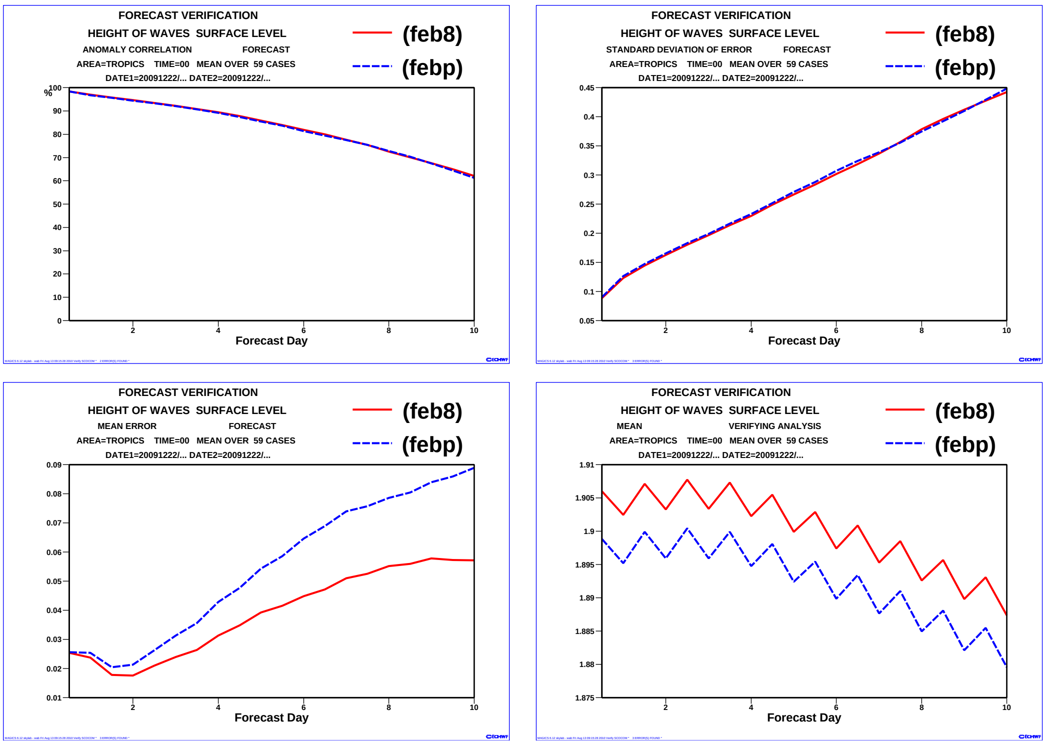


Figure 7: Wave height scores for the Tropics against own analysis. The experiment with currents (feb8) is the solid red line and the reference (febp) is the dash blue line.

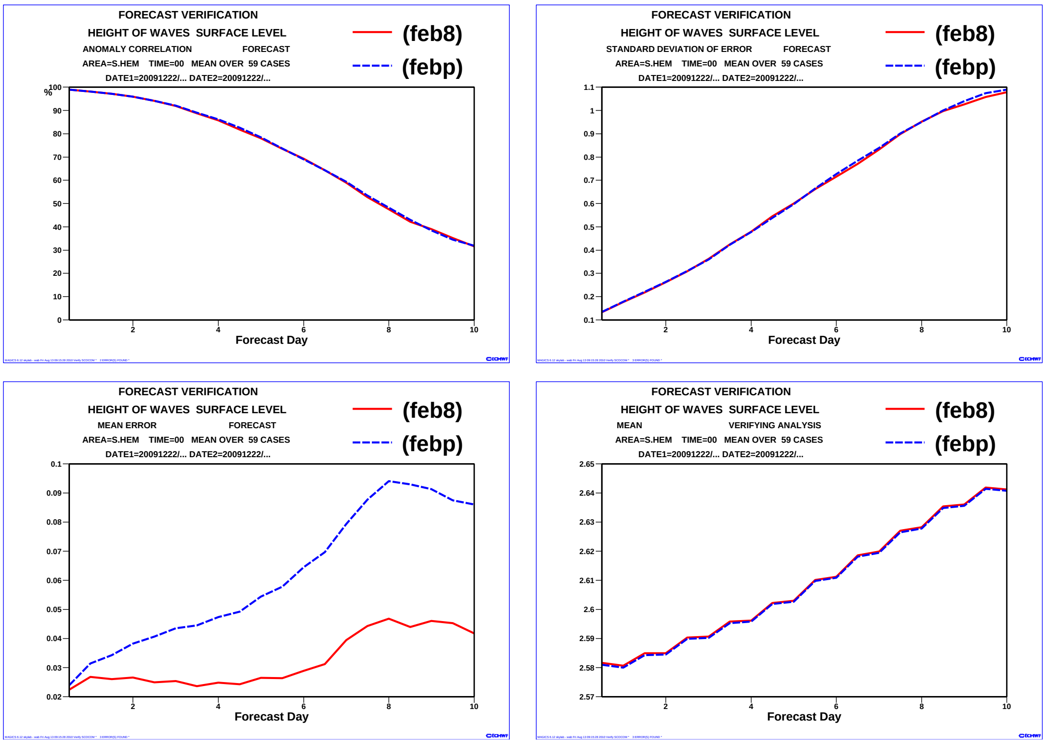


Figure 8: Wave height scores for the Southern Hemisphere against own analysis. The experiment with currents (feb8) is the solid red line and the reference (febp) is the dash blue line.