RESEARCH DEPARTMENT
MEMORANDUM

ECMWF

To:	DR, HPD, Marine Aspects Section, MERCATOR OCEAN	
Copy:	Hans Hersbach, Anton Beljaars	
From:	Jean Bidlot	
Date:	March 14, 2013	File: R60.9/JB/1228
Subject:	**Use of MERCATOR surface currents in the ECMWF forecasting system: a follow-up study**	

Abstract

A follow-up impact study of using MERCATOR surface currents in the ECMWF forecasting system has been carried out. It confirms earlier 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.

This memorandum follows an earlier memorandum (Bidlot, 2010), in which the impact of surface ocean currents in the latest version of operational system was accessed for a winter case (Decmber 2009 to February 2010). Preliminary results from HB08 were indeed confirmed. It was shown that by prescribing the slowing varying surface currents as part of the ocean surface boundary condition, both the surface stress and the surface wind profile 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. Results from a similar study are presented here, albeit for a summer period (July-August 2011).

2 MERCATOR data.

Every Wednesday, Operations receives daily-mean data from the latest run of the operational MERCATOR system, global data on a $1/4°$ grid (product PSY3V3) and also $1/12°$ data for the North Atlantic (PSY2V4). 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, our intention is 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 are 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 are 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, currents from July to August 2011 were used . Figure **??** shows the mean surface currents as obtained by averaging the surface current data that were supplied to WAM 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.

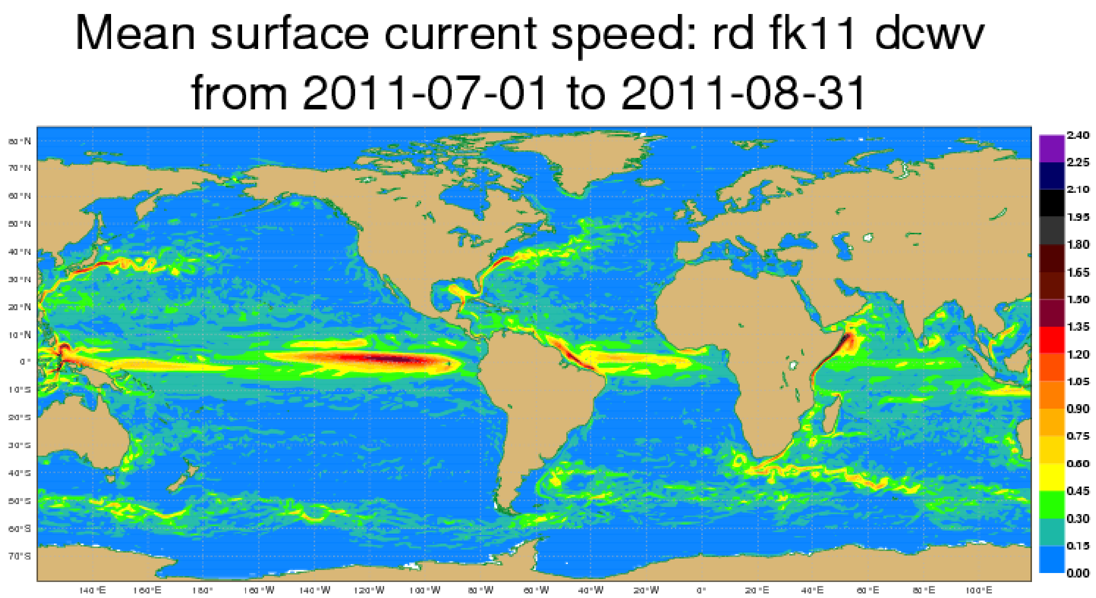


Figure 1: Mean surface current speed as suppied to WAM.

3 Impact of surface currents on the analysis system.

In order to assess the impact of using surface currents, the CY37R2 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 (fk11) was run from June 30, 2011, 12 UTC to September 1, 2011, 00 UTC and can be compared to a reference run, which in this case is the operational run (0001).

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. **??**, 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. **??**, the presence of surface currents reduces 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. **??**, middle panel) with the strength of the current (Fig. **??**), 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,

Table 1: Comparison of the model first guess with assimilated altimeter wave heights from ENVISAT and Jason 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 July 1, 2011, 00 UTC to August 31, 2011, 18UTC. 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	0.217 [0.019]	0.213 [0.013]	101,649
Tropics	0.195 [0.026]	0.183 [0.014]	123,507
SH	0.378 [0.072]	0.367 [0.039]	170,386

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 July 1, 2011 to August 31, 2011, 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).

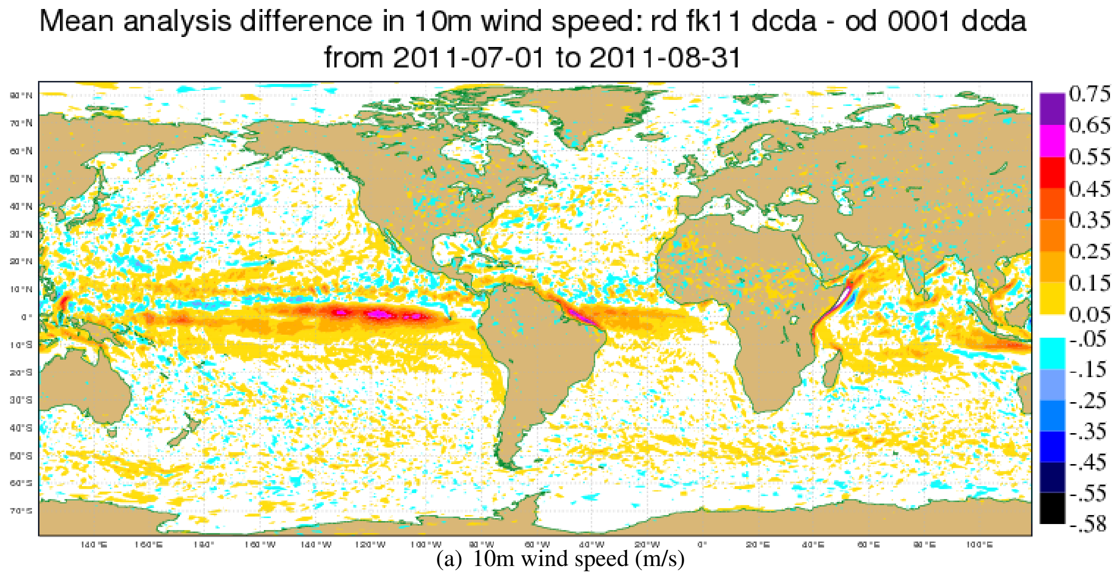
Comparison with buoy data: stdev [bias]			
	no currents	currents	n
H_s (m)	0.213 [-0.020]	0.209 [-0.027]	52,066
T_z (s)	0.611 [-0.535]	0.596 [-0.559]	9,033
T_p (s)	2.075 [0.047]	1.928 [-0.230]	36,062

the whole surface wind profile is adjusting. Areas with increased/decreased surface stress will see a slowing down/speeding up of the absolute winds at 10m.

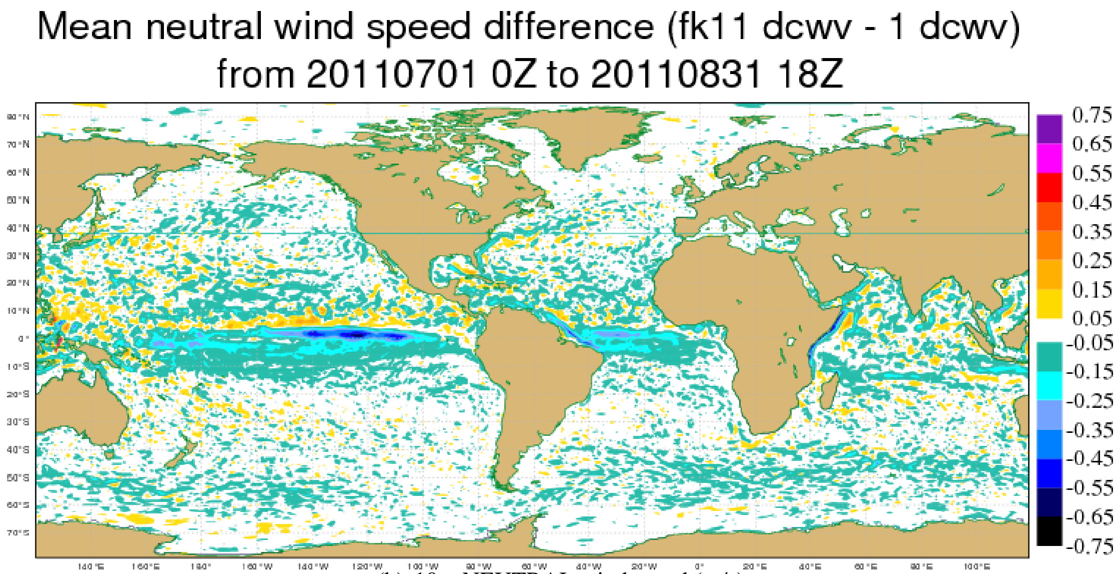
Finally, the net impact of the change in surface stress due to the surface currents and their effect on the wave propagation can be seen in Fig. **??** (bottom panel). Because waves propagate, the pictures is a bit more confused than for the winds. Nevertheless, the signature of the main ocean currents is still visible. In Bidlot (2010), the impact of the currents on wave propagations and the impact of the modified stress on the waves were shown separately. As shown, for most parts, they tend to re-inforce one another.

Global altimeter wave height data from ENVISAT and Jason-2 were used in the wave model analysis. The geographical distribution of model first guess bias with respect to used altimeter wave heights for the reference run without currents is shown in Fig. **??** (top panel). There is a characteristic underestimation of the model in the counter-equatorial current in the Pacific Ocean. On the other hand, the model wave heights are generally a bit too large in the southern ocean and the southern part of the other three main oceans as well as the northern Pacific. These features are reduced in the run with currents (Fig.**??**, bottom panel).

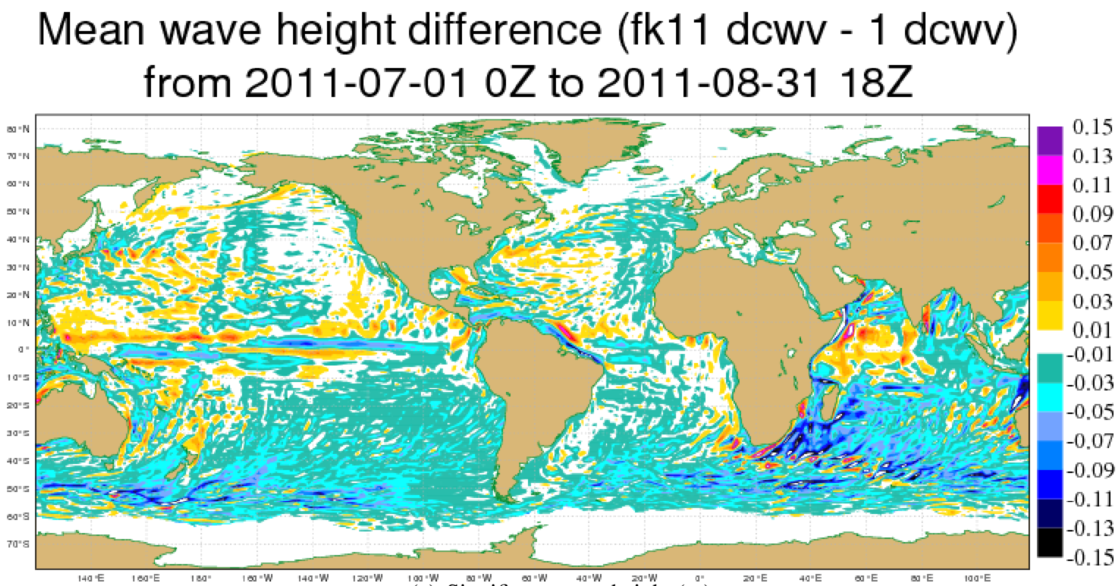
The global impact of using currents on the wave model analysis is summarised in Table **??** for a comparison against global altimeter wave heights and in Table **??** for a comparison against buoy data. Using surface currents is rather beneficial on the wave model results, especially in the Tropics. 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 **??** for a comparison against wind observations at moored buoys. Contrary to wave observing buoys, there are a large number of buoys reporting winds in the Tropics (TAO/TRITON. PIRATA, RAMA), where large currents are present. The model fit to the wind data is however not improved when currents are present, besides a small reduction in bias in the Tropics.



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

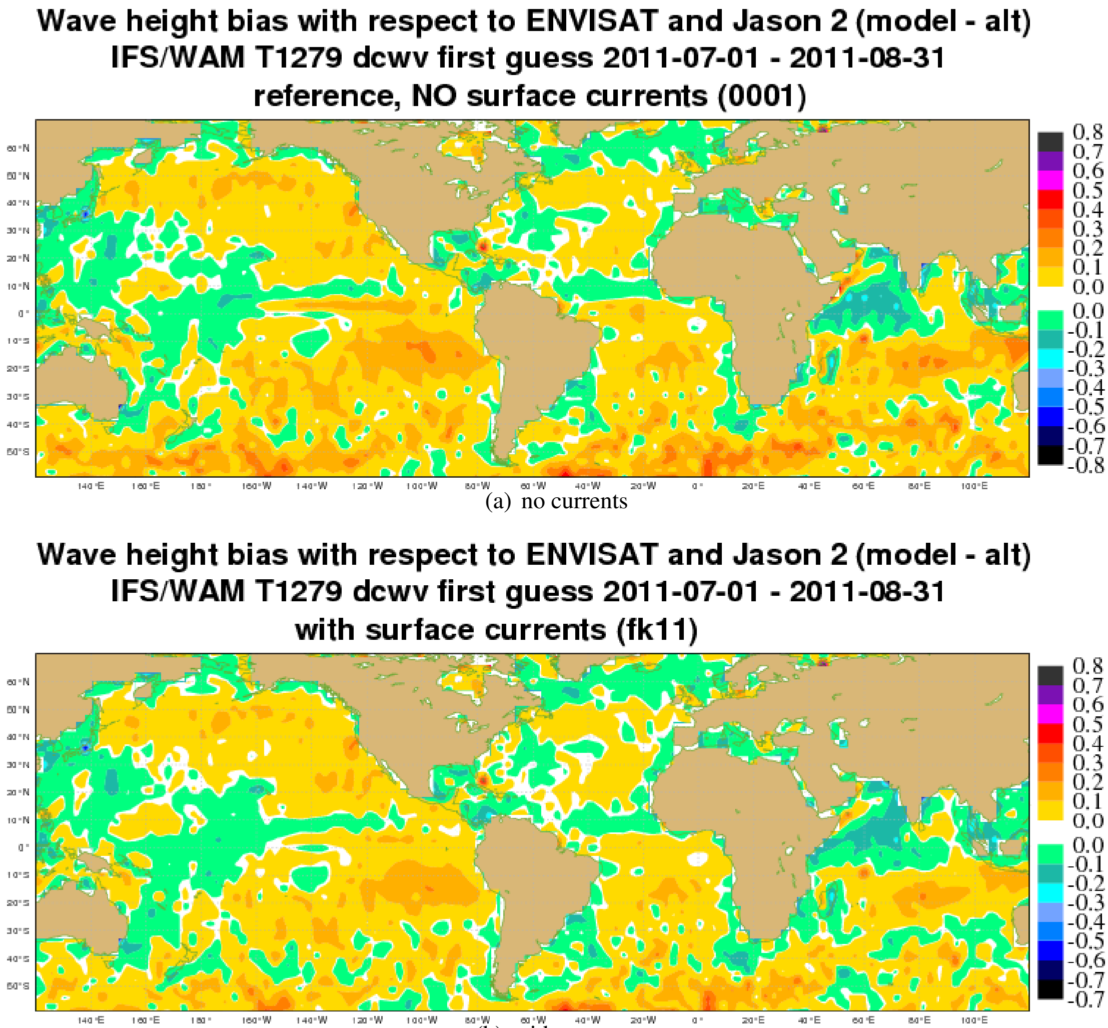


(b) 10m NEUTRAL wind speed (m/s)



(c) Significant wave height (m)

Figure 2: Mean analysis difference between a run with surface current (fk11) and a reference without any current (0001)



(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) and the Tropics (20°S to 20°N) The model data are from the delayed cut-off analysis and the period covered is July 1, 2011 0 UTC to August 31, 2011, 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	1.168 [-0.001]	1.168 [-0.001]	34,792
Tropics	0.985 [-0.230]	0.985 [-0.164]	19,905

4 Forecast scores.

As mentioned earlier, 10 day forecasts were also computed. When averaged over the different areas, standard atmospheric scores were mostly neutral. Fig. **??** shows an example for the 500 hPa geopotential height standard deviation of error of the forecasts for both Northern and Southern Hemispheres.

As seen in Fig. **??**, 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 mirror the surface scores (not shown) with no clear overall gain.

5 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. 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. MERCATOR OCEAN has recently released data from their latest system (PSY4V1). They have noted quite some improvements in the representations of the main ocean currents with respect to the data used in this study (PSY3V3). We have signed a new agreement with them to receive the new global data (including a few extra sea ice parameters) on a $1/4^\circ$ grid but also on the $1/12^\circ$ native grid. A similar study should be carried out to test the impact of the new product on the coupled IFS/WAM, in particular the effect of increased resolution.

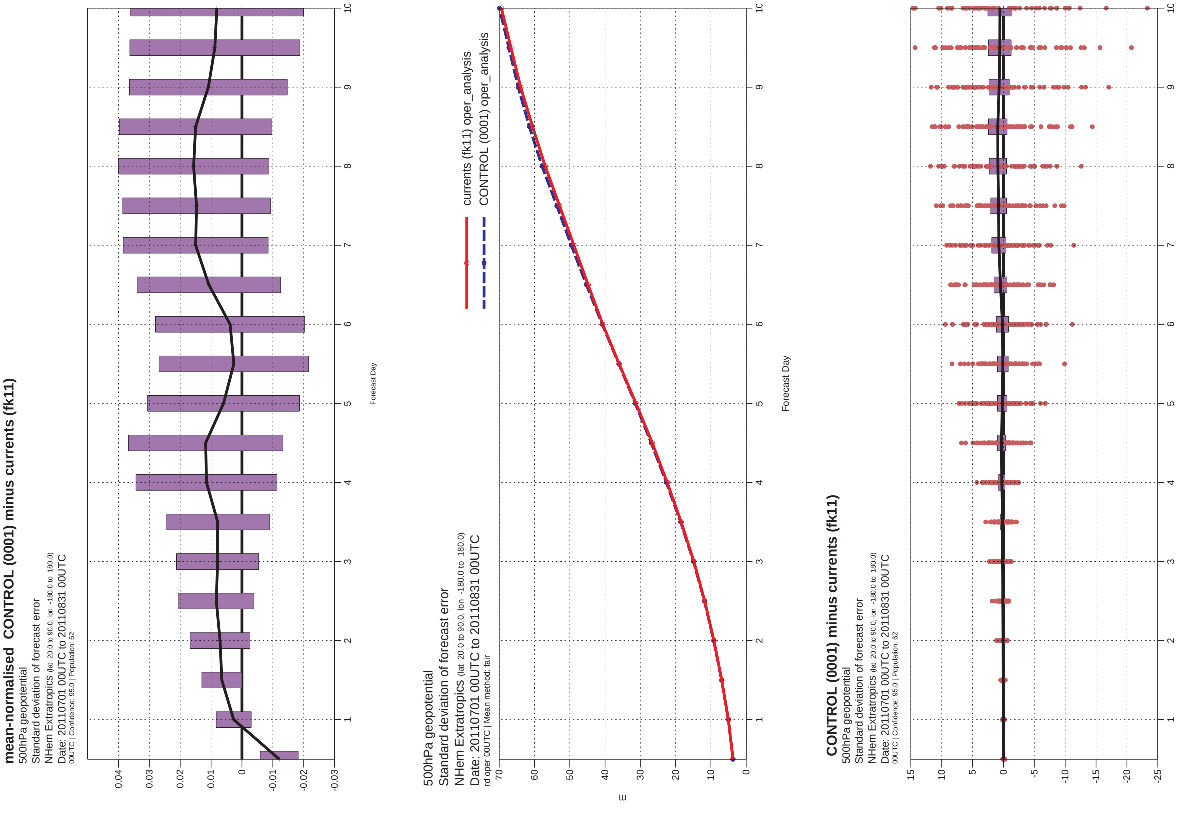
6 Acknowledgments.

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

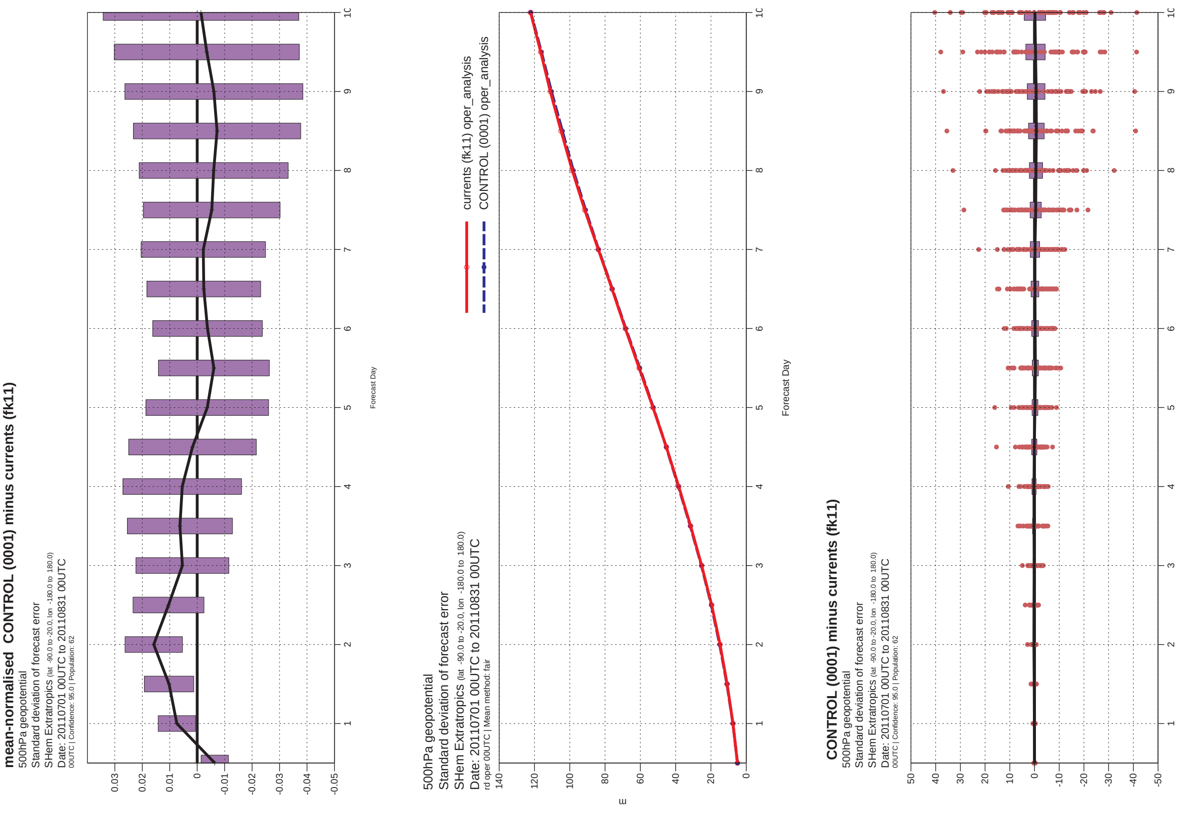
Reference.

Bidlot J, 2010: Use of MERCATOR surface currents in the ECMWF forecasting system. Research Department Memorandum R60.9/JB/10104.

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 4: 500 hPa geopotential height standard deviation of error of the forecasts when compared to the operational analysis. The top panel shows the mean normalised difference (solid line). The difference is defined as reference (0001) minus the experiment with currents (fk11), such that positive values indicate a reduction in errors of the run with currents. The vertical bars are the 95 percents confidence intervals The middle panel is the actual mean standard deviation of error. The bottom panel shows the distribution of the actual differences for all forecasts.

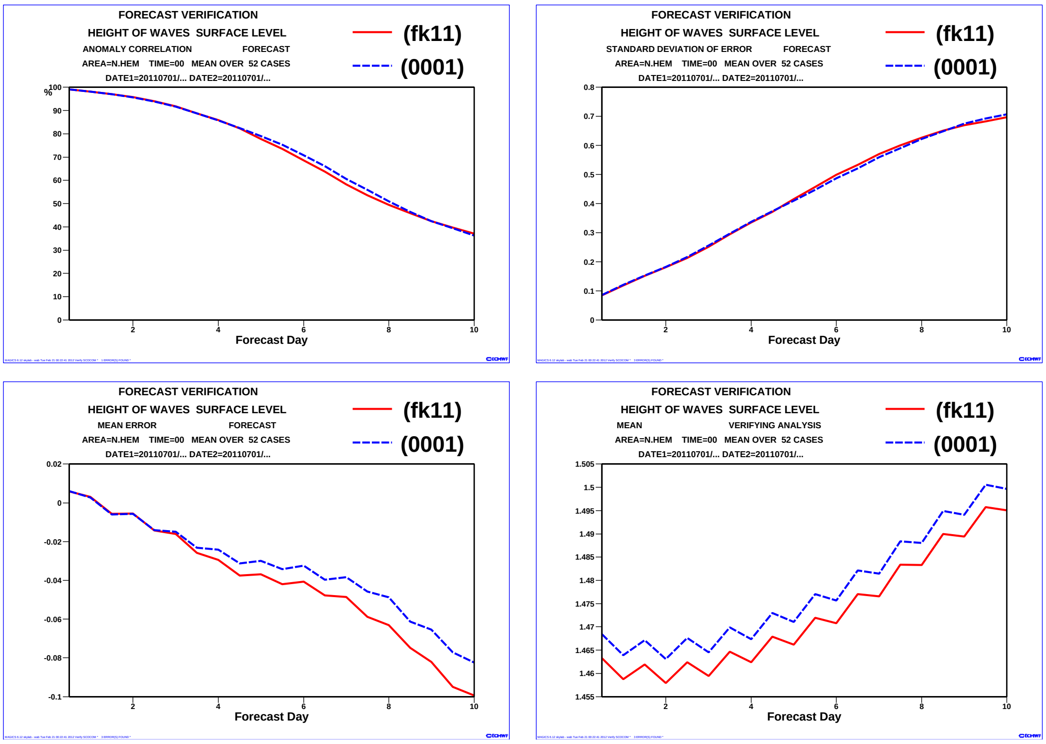


Figure 5: Wave height scores for the Northern Hemisphere against own analysis. The experiment with currents (fk11) is the solid red line and the reference (0001) is the dash blue line.

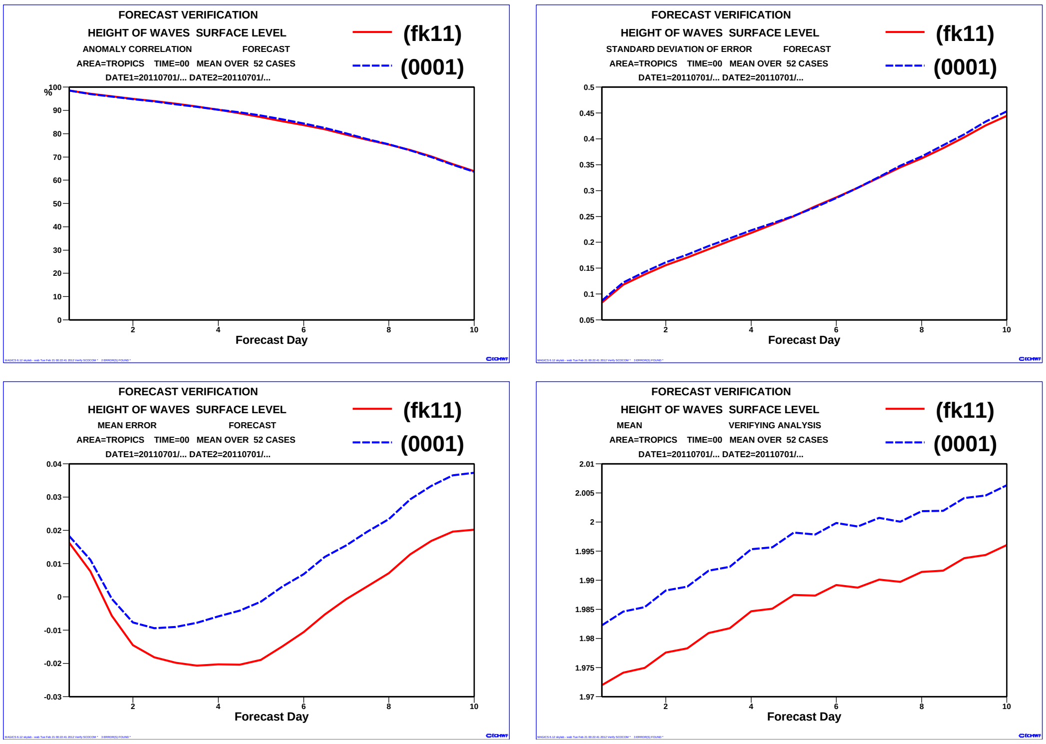


Figure 6: Wave height scores for the Tropics against own analysis. The experiment with currents (fk11) is the solid red line and the reference (0001) is the dash blue line.

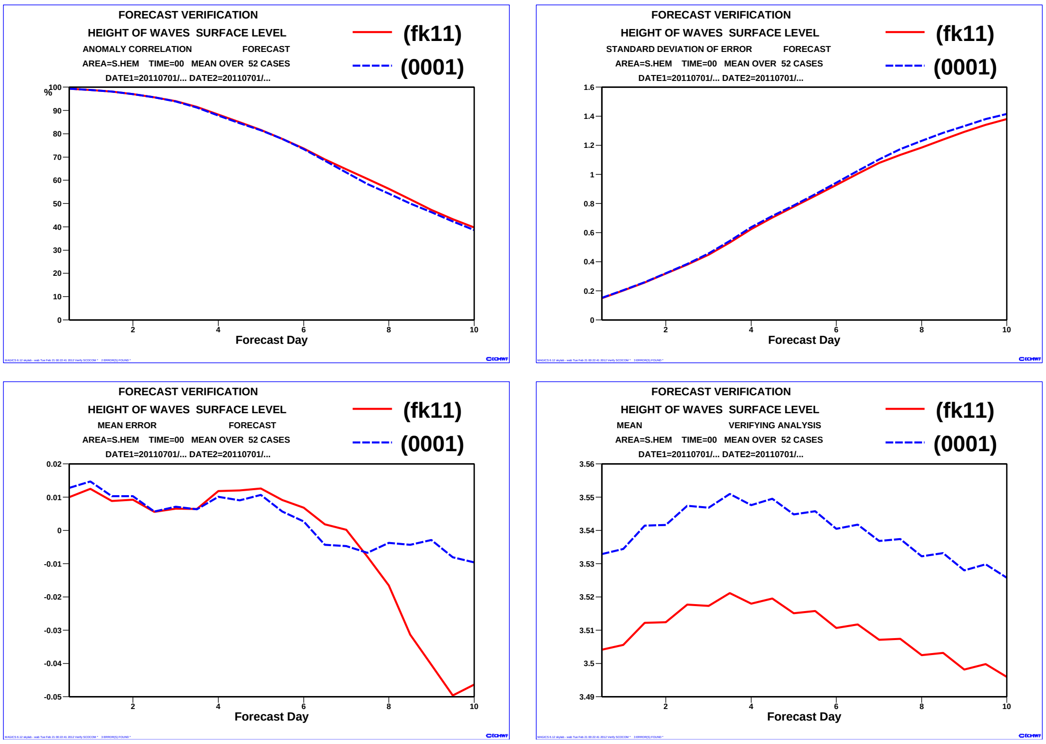


Figure 7: Wave height scores for the Southern Hemisphere against own analysis. The experiment with currents (fk11) is the solid red line and the reference (0001) is the dash blue line.