

Impact of
Ocean Surface Currents
on the ECMWF Forecasting System for
Atmospheric Circulation and Ocean Waves.

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Introduction:

ECMWF has an operational coupled ocean-atmosphere system for seasonal and monthly forecasting.

- **It is only coupled from day 10 onwards (at lower resolution)**
- **So far the coupling does not include ocean currents.**

At first sight, the importance of ocean currents seems minor?

- **~0.15 m/s, compared to ~ 7.8 m/s for surface wind.**
- **Although, in tropical areas, the ratio can be 1 m/s vs. 5 m/s.**
- **Ocean waves: current-wave interaction usually not considered for global scale**

This presentation will discuss some assessments of the effect of 'high resolution' ocean currents on the ECMWF high resolution atmosphere and ocean-wave components.

- **Available ocean current products.**
- **Effect on ocean waves using a simple approach.**
- **How to provide them as boundary condition.**
- **Inclusion in the forecast and assimilation system.**

Available ocean current products at ECMWF

TOPAZ 4 system obtained via met.no :

- ✓ Modified HYCOM ocean model.
- ✓ Horizontal resolution of the products: 8-12 km, Atlantic, Arctic and surrounding seas.
- ✓ Data assimilation.

Atmospheric forcing is from ECMWF.

MERCATOR surface currents from the global PSY3V3 system:

- ✓ NEMO ocean model.
- ✓ Horizontal resolution of the products: 1/4°.
- ✓ Data assimilation system.

Atmospheric forcing is from ECMWF.

(we have just started receiving PSY4V1 products 1/4° and 1/12° native)

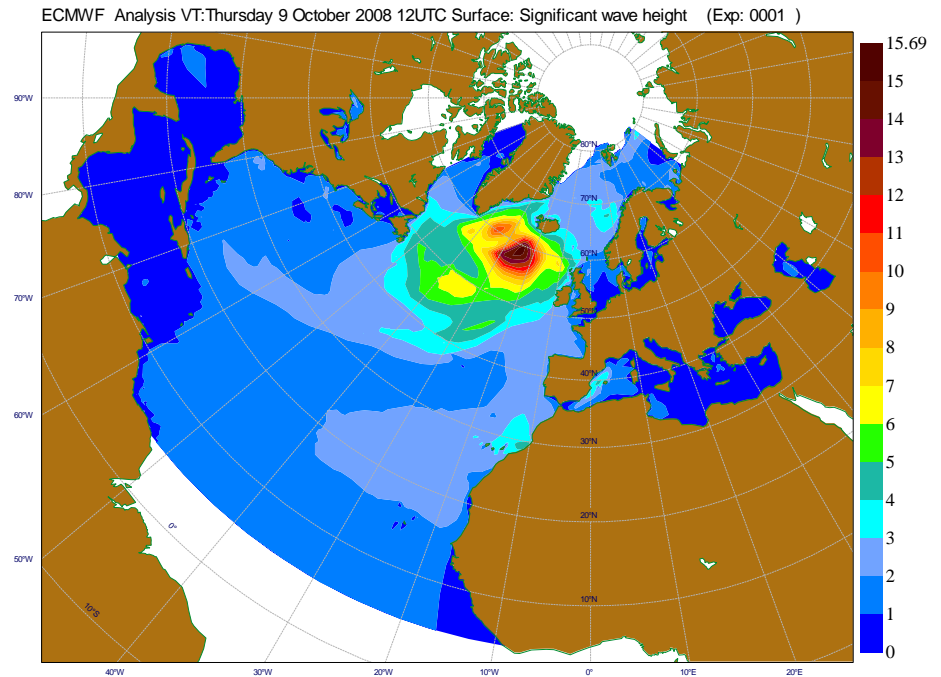
ECMWF system 4 (as of Nov. 2011):

- ✓ NEMO ocean model.
- ✓ Variable horizontal resolution: ~1° with refinement in Tropics.
- ✓ Data assimilation system.

ECMWF Wave Model

1) Limited area Wave model (LAW)

- **ECWAM uncoupled.**
- **From 5°N to 90°N and 98°W to 56°E.**
- **11 km grid spacing.**
- **Forced by 10m neutral wind fields from the global system.**
- **2 daily forecasts (from 0 & 12 Z) extending to day 5.**

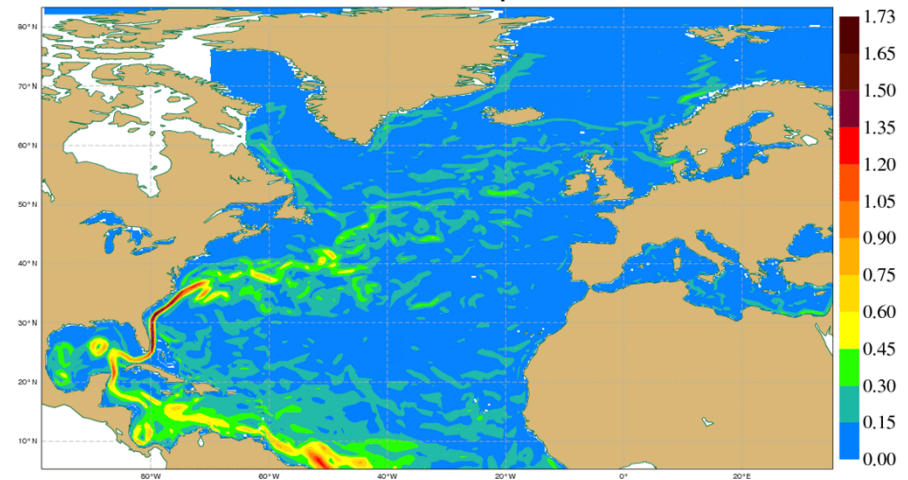


Analysis wave height on
9 October 2008 12UTC.

Limited area wave model with currents:

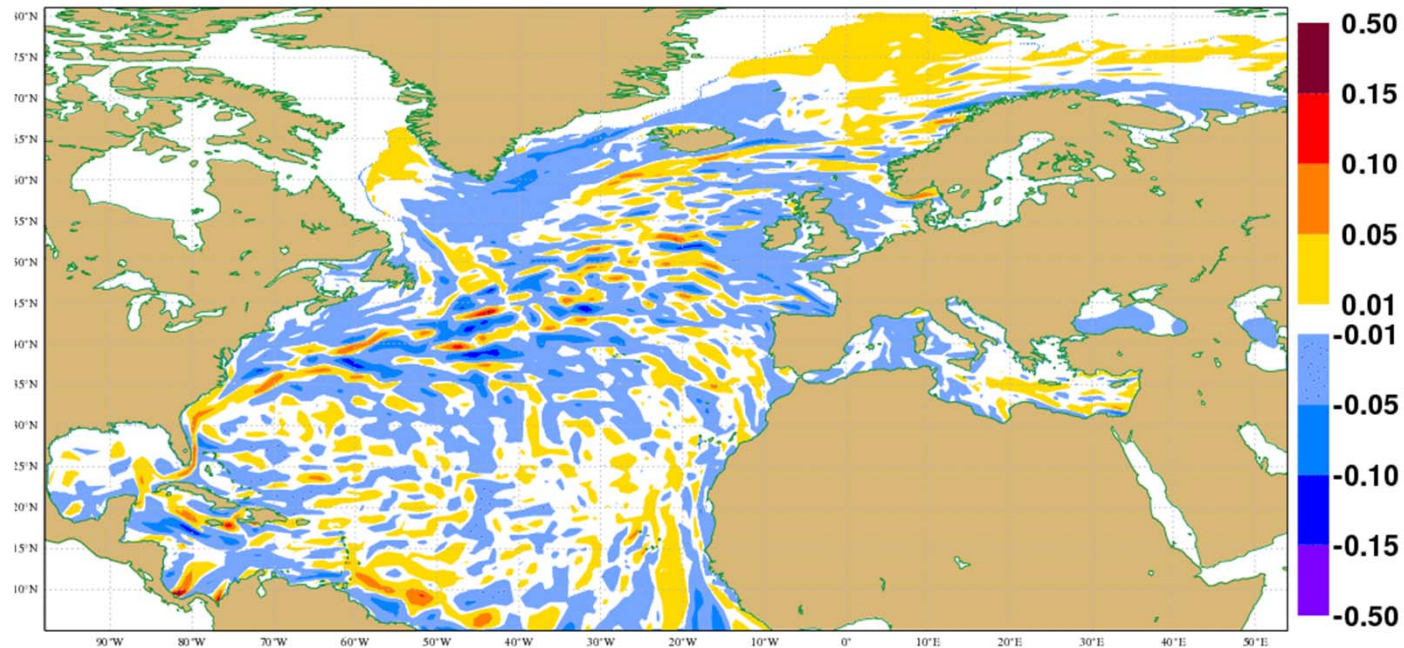
- **Analysis and forecast TOPAZ4 surface currents are averaged in 8 day moving window to retain the slow varying component.**
- **Every day, they are supplied to the wave model modifying the propagations characteristics of the waves (both in geographical and in spectral space).**
- **The wind forcing is NOT modified (i.e. we cannot assume that the waves would feel the relative winds (see later)).**
- **It is now operational.**

Mean surface current speed for January 2012 data from Topaz 4



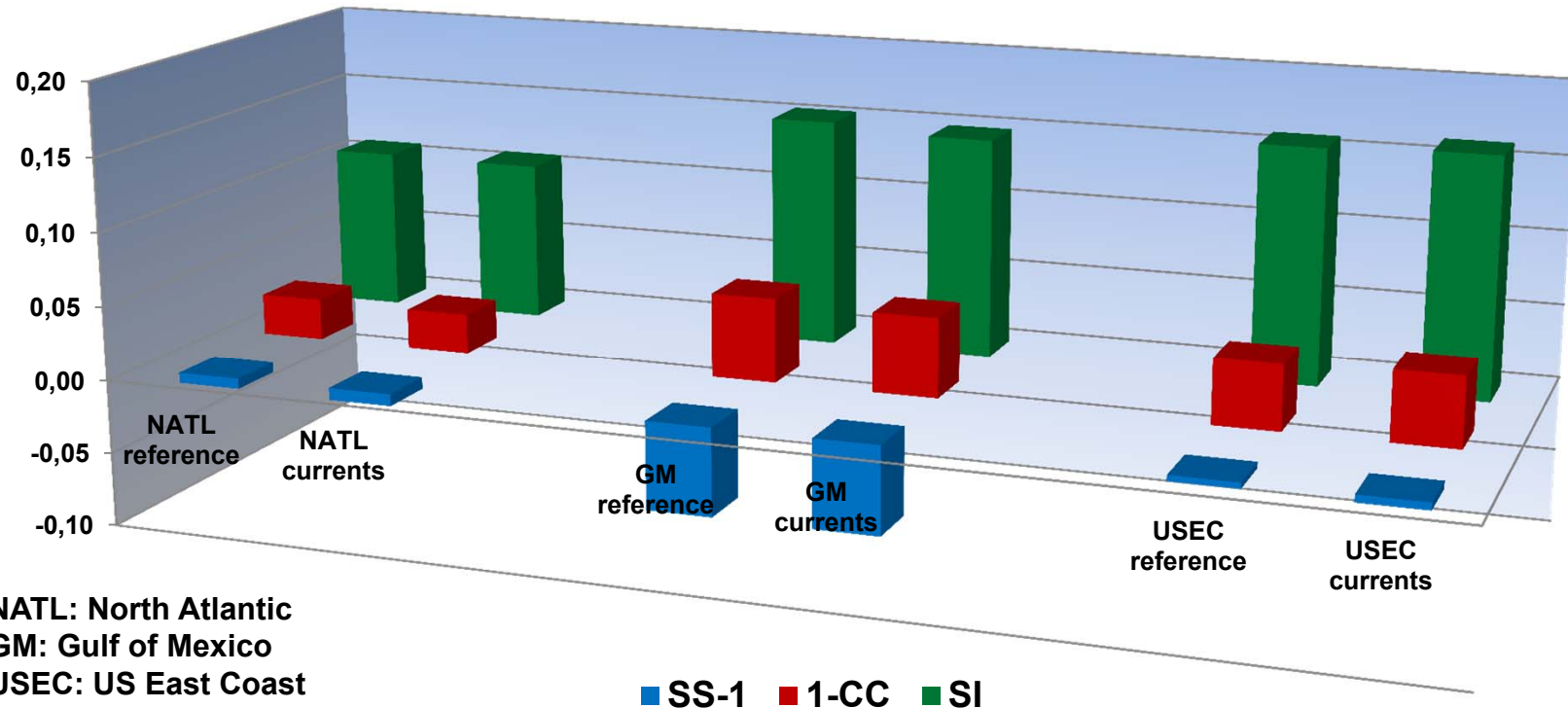
Limited area wave model with currents: Mean Hs difference (current - reference)

Mean significant wave difference (with currents - reference)
from 2012-01-01 0UTC to 2012-01-31 18UTC



Comparison to altimeter wave height data

Comparison against altimeter wave heights (ENVISAT, Jason-2)



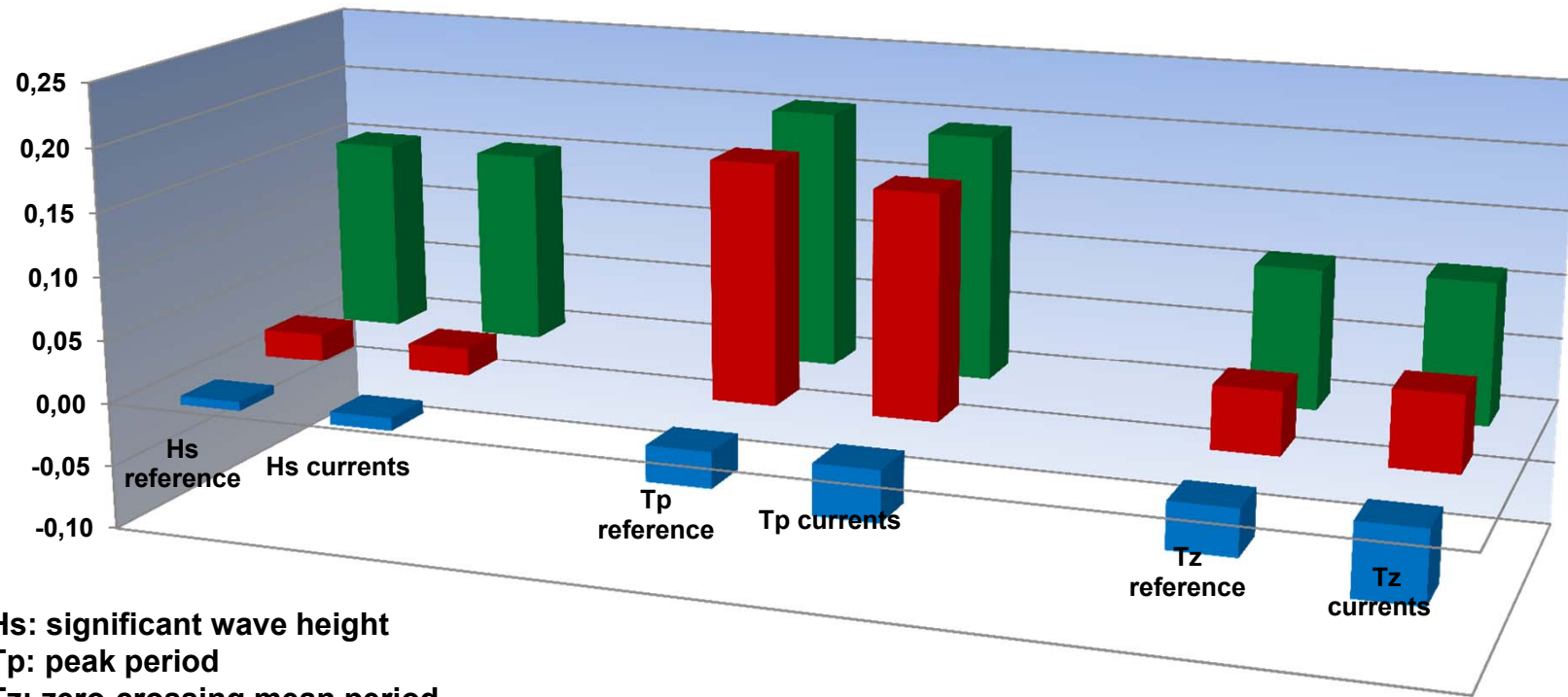
NATL: North Atlantic
GM: Gulf of Mexico
USEC: US East Coast

■ SS-1 ■ 1-CC ■ SI

SS: Symmetric Slope: square root of the altimeter variance to model variance.
CC: Correlation Coefficient.
SI: Scatter Index: normalised standard deviation of the difference.

Comparison to buoy height data

Comparison against all buoy data (January 2012)



Hs: significant wave height
Tp: peak period
Tz: zero-crossing mean period

■ SS-1 ■ 1-CC ■ SI

SS: Symmetric Slope: square root of the altimeter variance to model variance.
CC: Correlation Coefficient.
SI: Scatter Index: normalised standard deviation of the difference.

In a fully coupled system, ocean surface currents are part of atmospheric boundary condition:

In the constant stress layer (Monin-Obukhov), enforce the correct boundary condition:

$$\frac{\partial \vec{\mathbf{u}}_{\text{abs}}}{\partial z} = \frac{\vec{\mathbf{u}}_*}{\kappa(z + z_0)} \varphi_D \left(\frac{z + z_0}{L} \right), \quad \vec{\mathbf{u}}_{\text{abs}}(z = 0) = \vec{\mathbf{u}}_{\text{oc}}. \quad (1)$$

Define $\vec{\mathbf{u}}_{\text{rel}}$ as (1), but with boundary condition: $\vec{\mathbf{u}}_{\text{rel}}(0) = 0$.

Then:

$$\vec{\mathbf{u}}_{\text{abs}}(z) = \vec{\mathbf{u}}_{\text{rel}}(z) + \vec{\mathbf{u}}_{\text{oc}}. \quad (2)$$

- (2) is valid for all values of z in the constant stress layer, including $z = 10\text{m}$.
- $\vec{\mathbf{u}}_{\text{rel}}(z)$ is related to the surface stress $\tau = \rho_a u_*^2$, e.g., for the neutral case ($\varphi_D = 1$):

$$\vec{\mathbf{u}}_{\text{rel}} = \frac{\vec{\mathbf{u}}_*}{\kappa} \ln \left(\frac{z + z_0}{z_0} \right)$$

$z_0 = \alpha_M \frac{\nu}{u_*} + \alpha_{\text{ch}} \frac{u_*^2}{g} \sim 0.01$ to 1 mm is the roughness length.

- It is the stress, so $\vec{\mathbf{u}}_{\text{rel}}$ that should be used to force the ocean-wave model

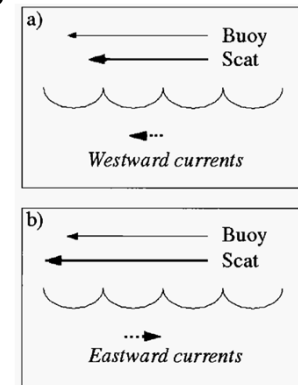
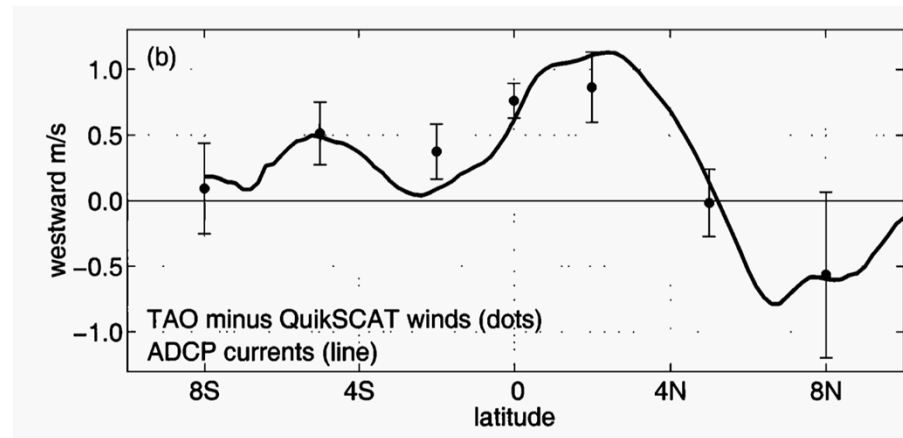
Ingestion of ocean current in the ECMWF assimilation/forecast system

Analysis system (AN):

- Minimize 4D-Var cost function.
- The ocean current needs to be supplied to model forward integration.
- Read, like SST and sea ice from previous forecast.
- Adapt observation operators, where necessary scatterometer, buoy, ship,.

Stress is related to relative wind,

- ❖ the SCATT observation operator should act on relative wind, not absolute wind.



1. Schematic of the buoy wind vectors, scatterometer and ocean currents (a) for currents aligned with the winds and (b) for currents opposing the winds.

Kelly et. al., 2001, copyright JGR

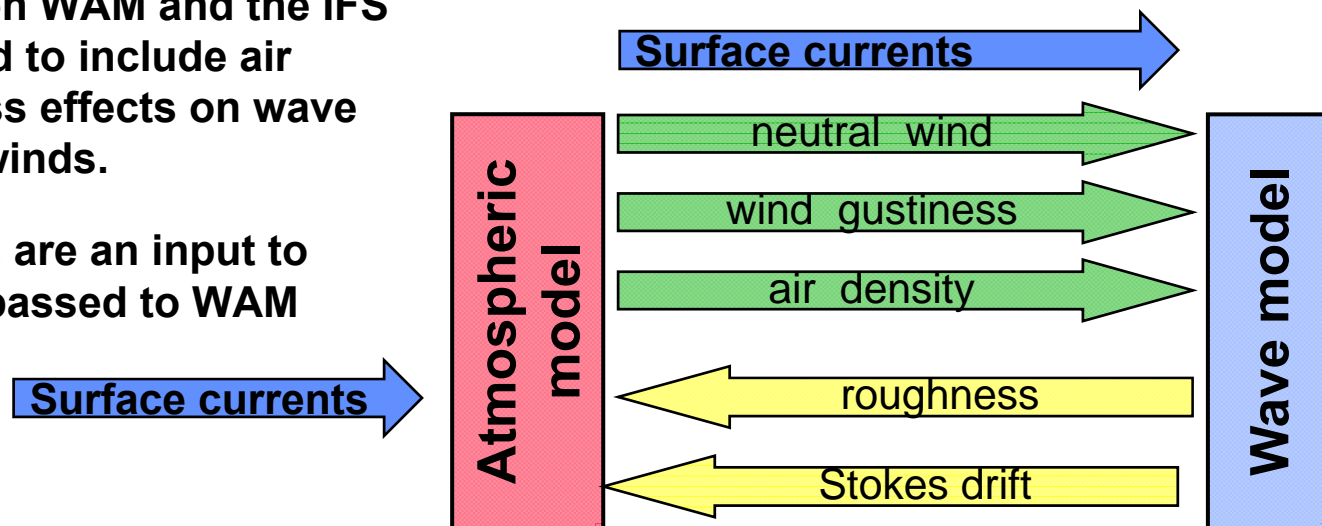
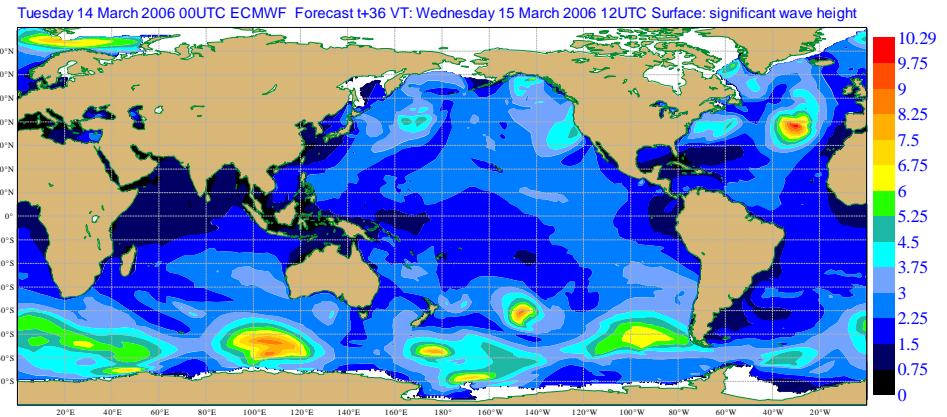
Moored buoy/ship, measure absolute wind,

- ❖ Observation operator remains to act on these.

ECMWF Wave Model

2) Global models

- Global from 81°S to 90°N
- Coupled to the atmospheric model (IFS) with feedback of the sea surface roughness change due to waves. The Stokes drift is also returned for the parameterisation in the skin layer model for the daily cycle of the SST.
- The interface between WAM and the IFS has been generalised to include air density and gustiness effects on wave growth and neutral winds.
- The surface currents are an input to IFS, which are then passed to WAM

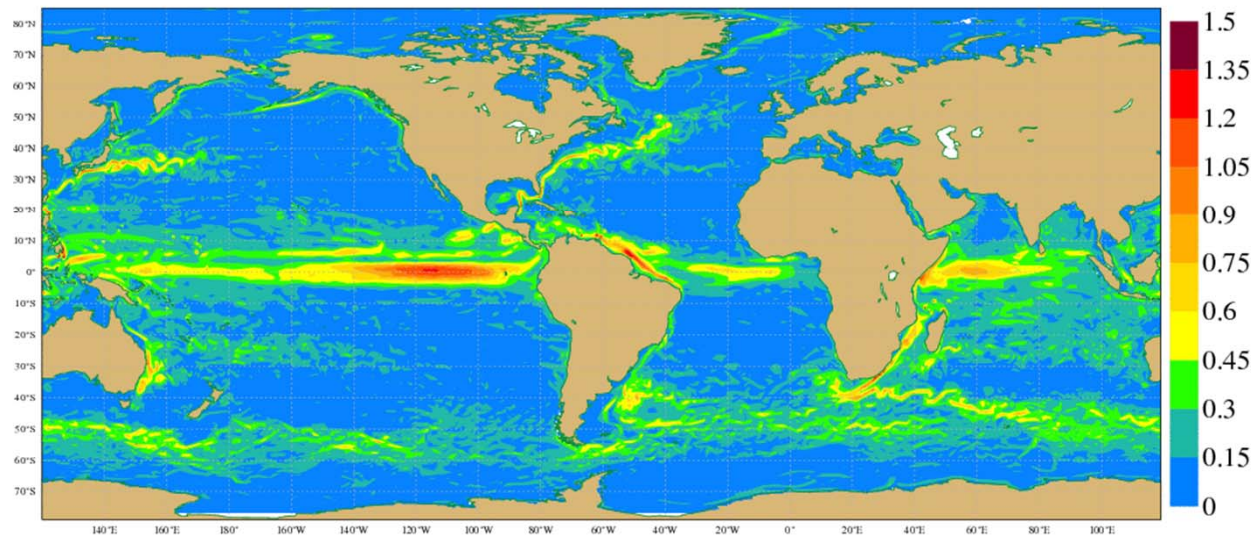


Average effect on surface winds

T1279 (16km) assimilation/forecasts impact study

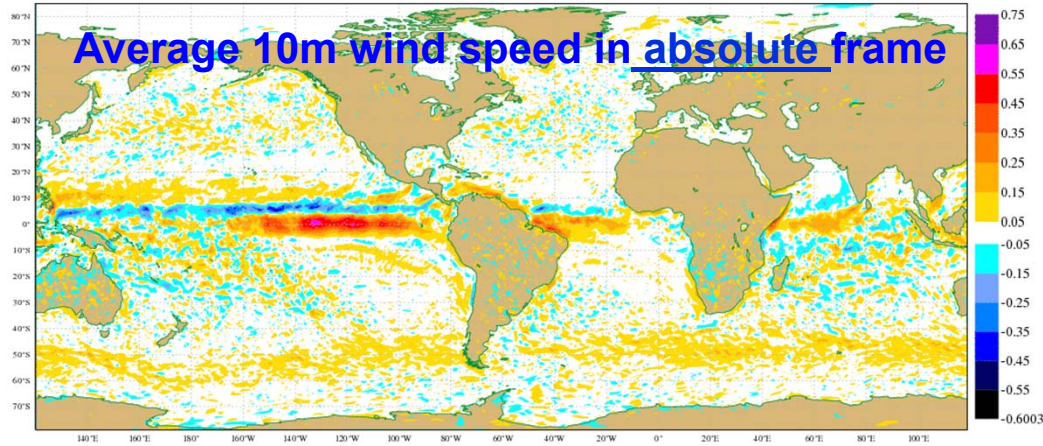
- ✓ Use Mercator currents.
- ✓ 22 December 2009 to 28 February 2010.

Mean analysis surface current speed: rd feb8 dcda
from 20091222 to 20100228

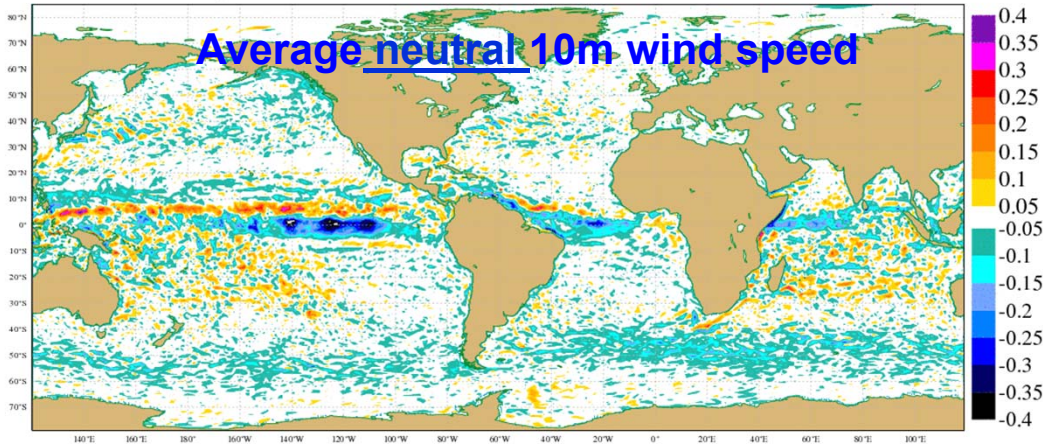


Average effect on surface winds

Mean analysis difference in 10m wind speed: rd feb8 dcda - rd feb8 dcda
from 20091221 to 20100228

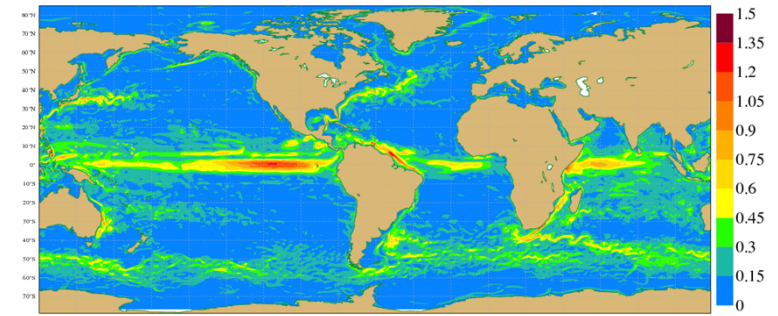


Mean neutral wind speed difference (feb8 dcwv - feb8 dcwv)
analysis from 20091221 0Z to 20100228 18Z



Currents – no currents

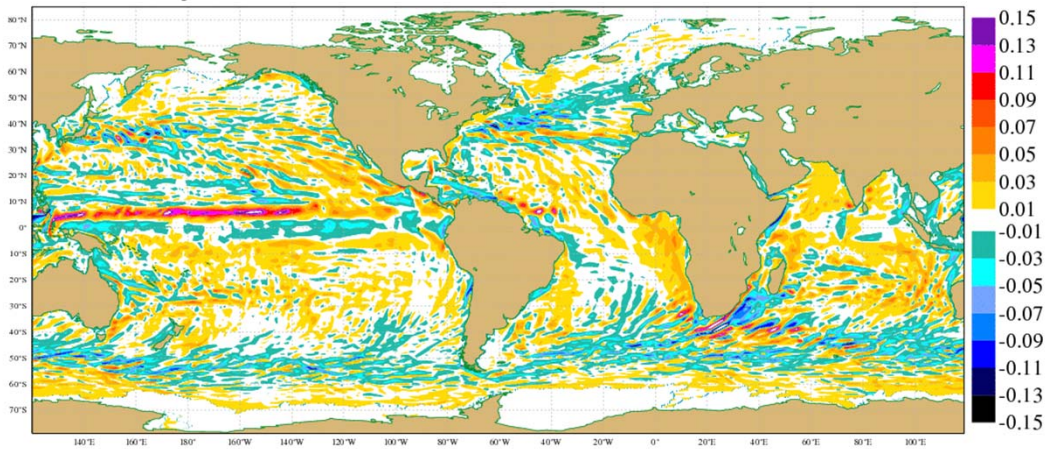
Mean analysis surface current speed: rd feb8 dcda
from 20091222 to 20100228



➤ **Absolute winds receive about 50% from ocean currents**

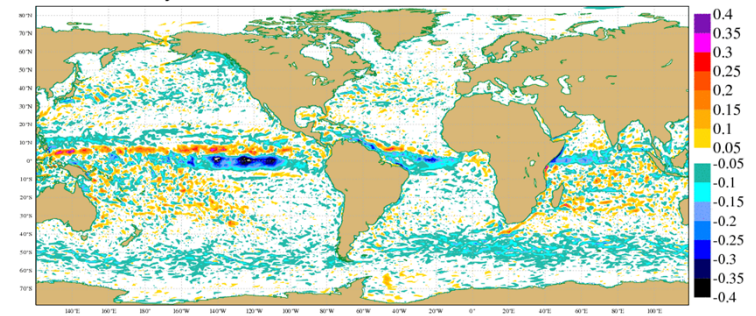
Average effect on ocean waves

Mean wave height difference (feb8 dcwv - febp dcwv)
analysis from 20091221 0Z to 20100228 18Z



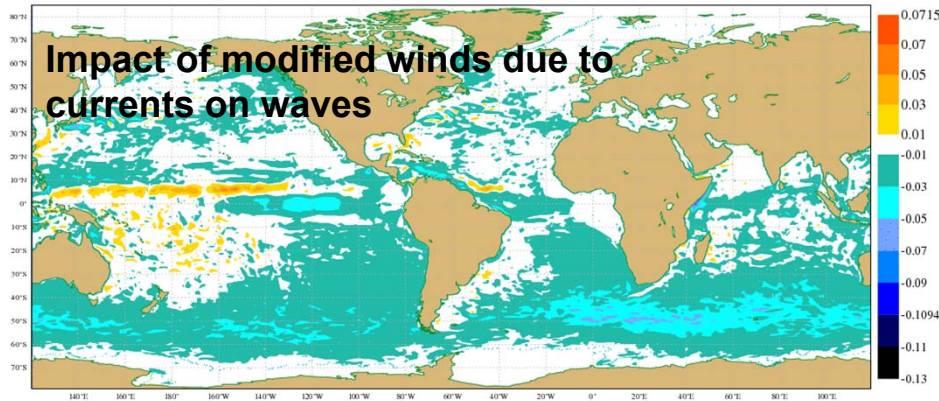
Currents – no currents

Mean neutral wind speed difference (feb8 dcwv - febp dcwv)
analysis from 20091221 0Z to 20100228 18Z



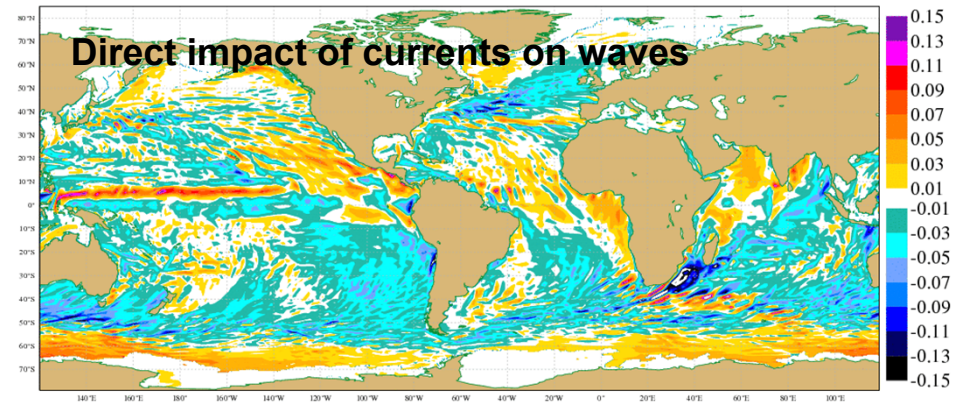
Averaged effect on waves

Mean wave height difference (ffxl wave - ffxd wave)
from 20091228 0Z to 20100228 18Z



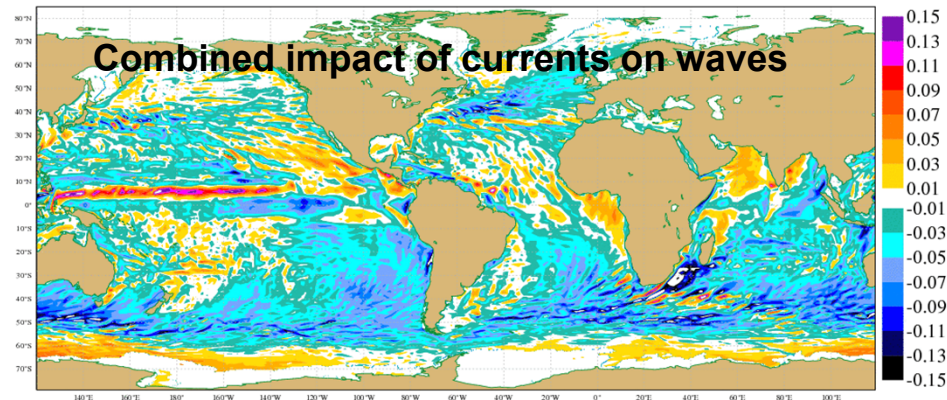
Currents – no currents

Mean wave height difference (ffxa wave - ffxd wave)
from 20091228 0Z to 20100228 18Z



Currents – no currents

Mean wave height difference (ffxk wave - ffxd wave)
from 20091228 0Z to 20100228 18Z

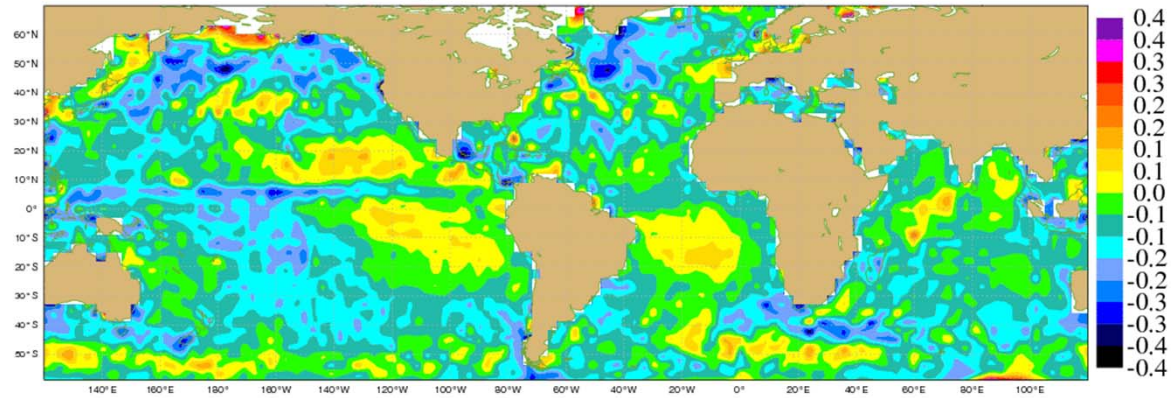


Currents – no currents

Averaged effect on waves

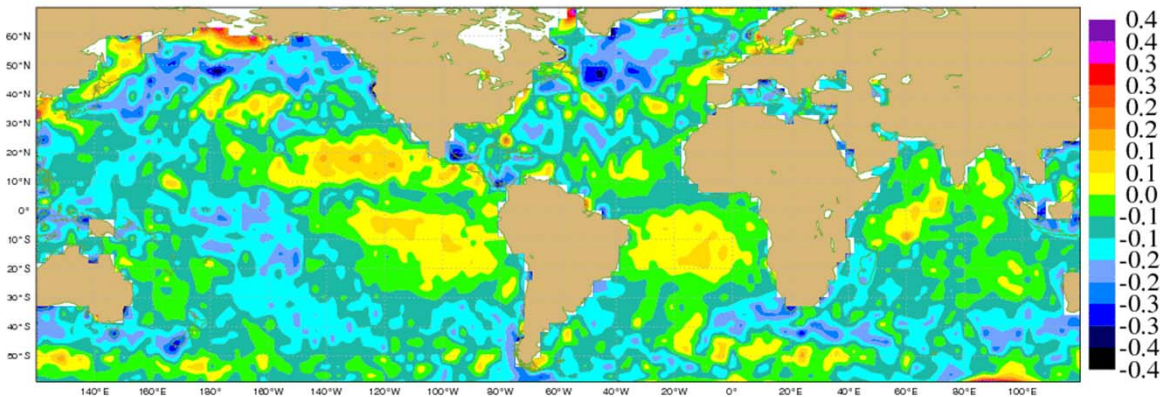
Wave height bias with respect to ENVISAT and Jason's (model - alt)
IFS/WAM T1279 dcda first guess, 2009122-20100228
reference, NO surface currents (febp)

No currents



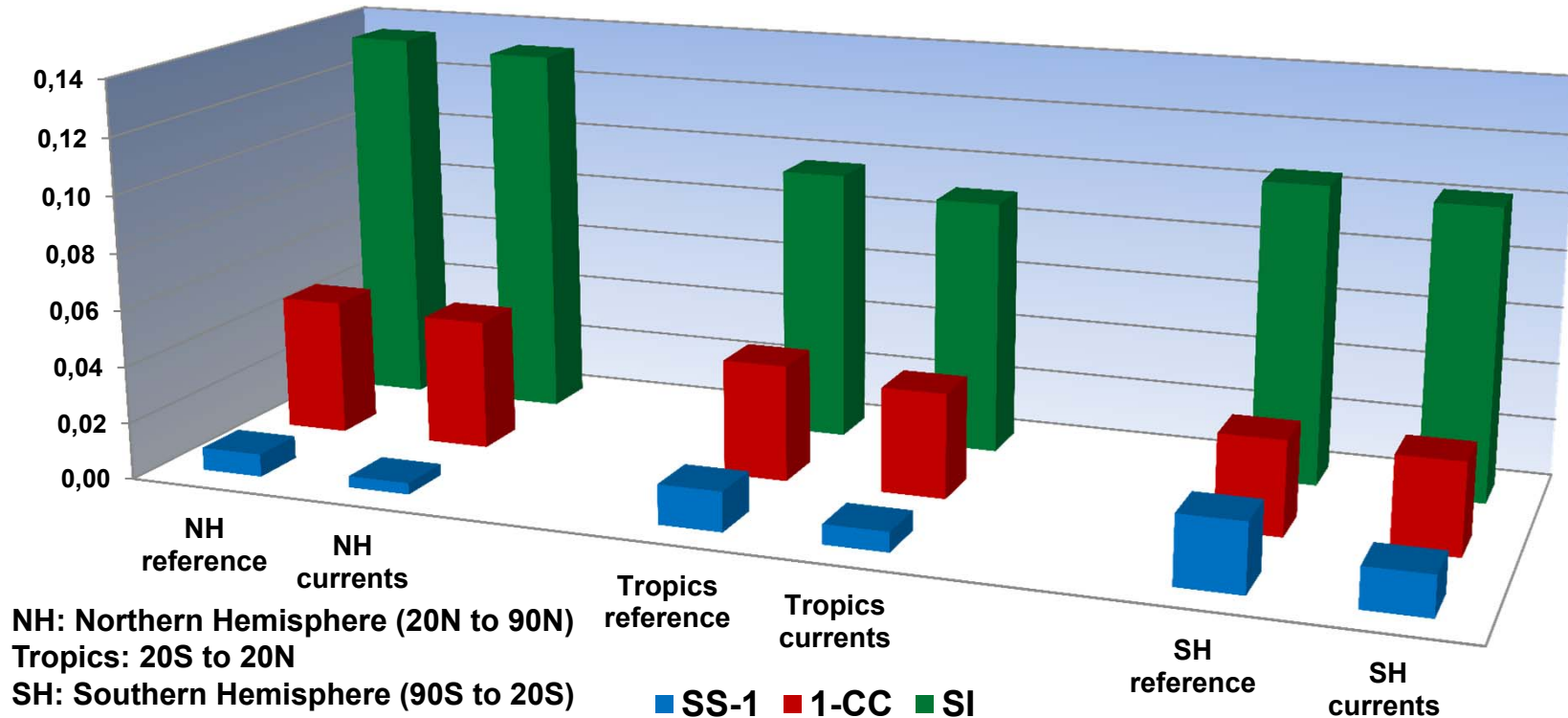
Wave height bias with respect to ENVISAT and Jason's (model - alt)
IFS/WAM T1279 dcda first guess 20091222-20100228
with surface currents (feb8)

With currents



Comparison with altimeter data

Comparison against altimeter wave heights (ENVISAT, Jason-2)



SS: Symmetric Slope: square root of the altimeter variance to model variance.

CC: Correlation Coefficient.

SI: Scatter Index: normalised standard deviation of the difference.

Conclusions and final remarks:

It is now technically possible to include ocean currents in the ECMWF assimilation and forecast system.

The 10m winds in the absolute frame are more affected than expected

- **about 50% goes into the absolute winds and 50% in the surface stress.**
- **The ingestion of ocean current is the proper way forward.**
- **More work is needed. We are currently receiving operationally currents from Topaz and Mercator.**

Emerging questions:

- **Should the currents be smoothed, or time-averaged?**
- **Is it reasonable to keep the current fixed during the 10-day forecast?**
- **Which details should the ocean currents contain, and which not?**
- **How good are the currents. No doubt that it can be improved.**

References :

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>

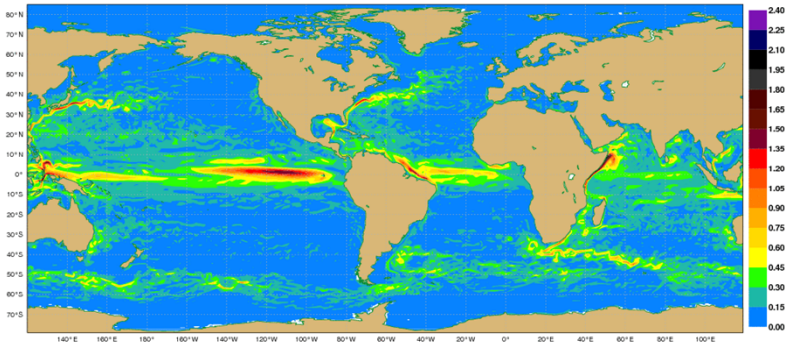
Bidlot J, 2010: Use of MERCATOR surface currents in the ECMWF forecasting system. Research Department Memorandum R60.9/JB/10104. Internal report available on request.

Bidlot J, 2012: Use of MERCATOR surface currents in the ECMWF forecasting system: a follow-up study. Research Department Memorandum R60.9/JB/1228. Internal report available on request.

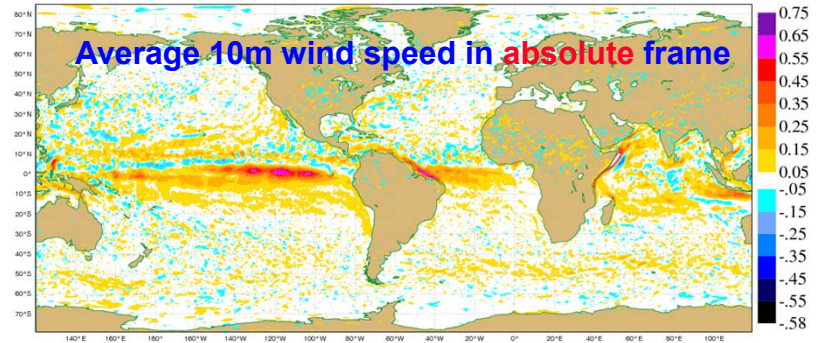
Average effect on surface winds

We also ran a summer case (July-August 2011)

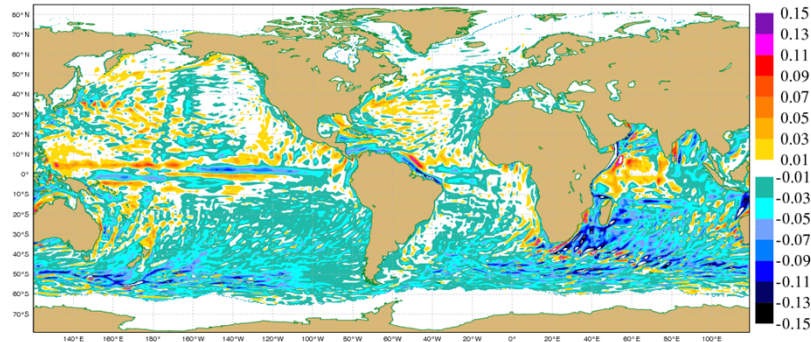
Mean surface current speed: rd fk11 dcwv
from 2011-07-01 to 2011-08-31



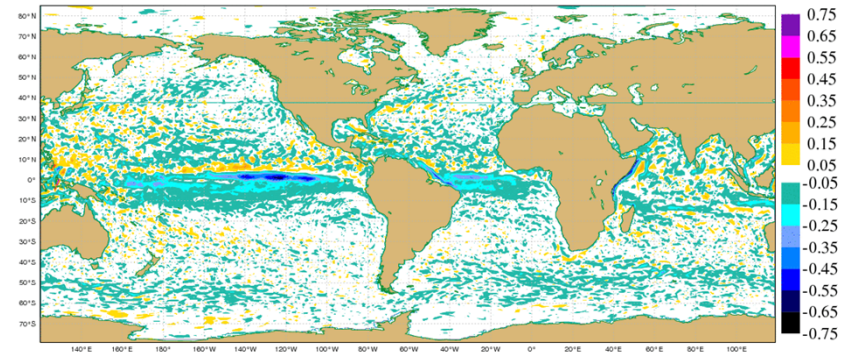
Mean analysis difference in 10m wind speed: rd fk11 dcda - od 0001 dcda
from 2011-07-01 to 2011-08-31



Mean wave height difference (fk11 dcwv - 1 dcwv)
from 2011-07-01 0Z to 2011-08-31 18Z



Mean neutral wind speed difference (fk11 dcwv - 1 dcwv)
from 20110701 0Z to 20110831 18Z

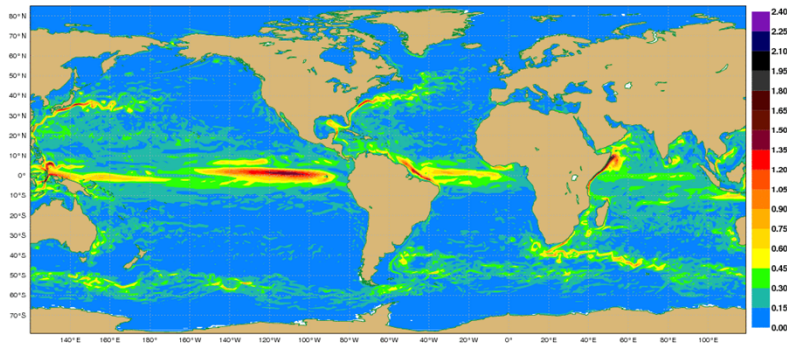


Same conclusions !

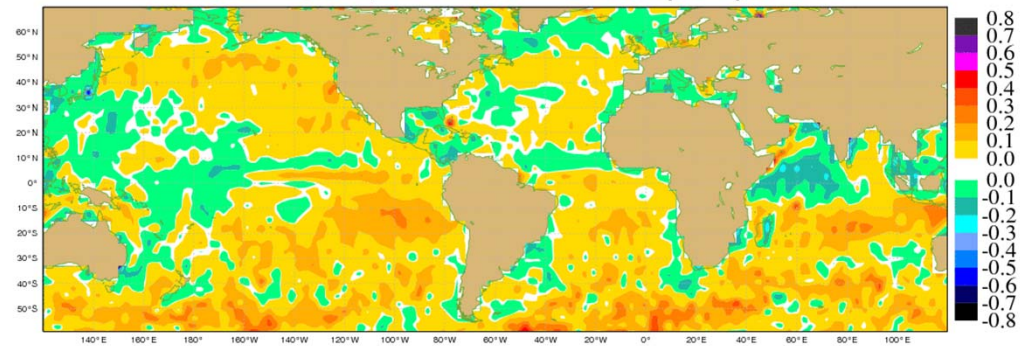
Averaged effect on waves

We also ran a summer case (July-August 2011)

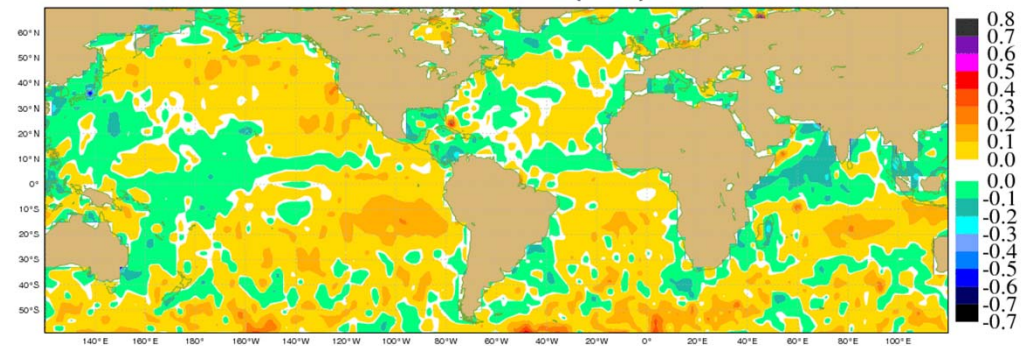
Mean surface current speed: rd fk11 dcwv
from 2011-07-01 to 2011-08-31



Wave height bias with respect to ENVISAT and Jason 2 (model - alt)
IFS/WAM T1279 dcwv first guess 2011-07-01 - 2011-08-31
reference, NO surface currents (0001)



Wave height bias with respect to ENVISAT and Jason 2 (model - alt)
IFS/WAM T1279 dcwv first guess 2011-07-01 - 2011-08-31
with surface currents (fk11)



The effect of ocean current on 10m wind

How would ECMWF absolute 10m wind change if currents were incorporated?

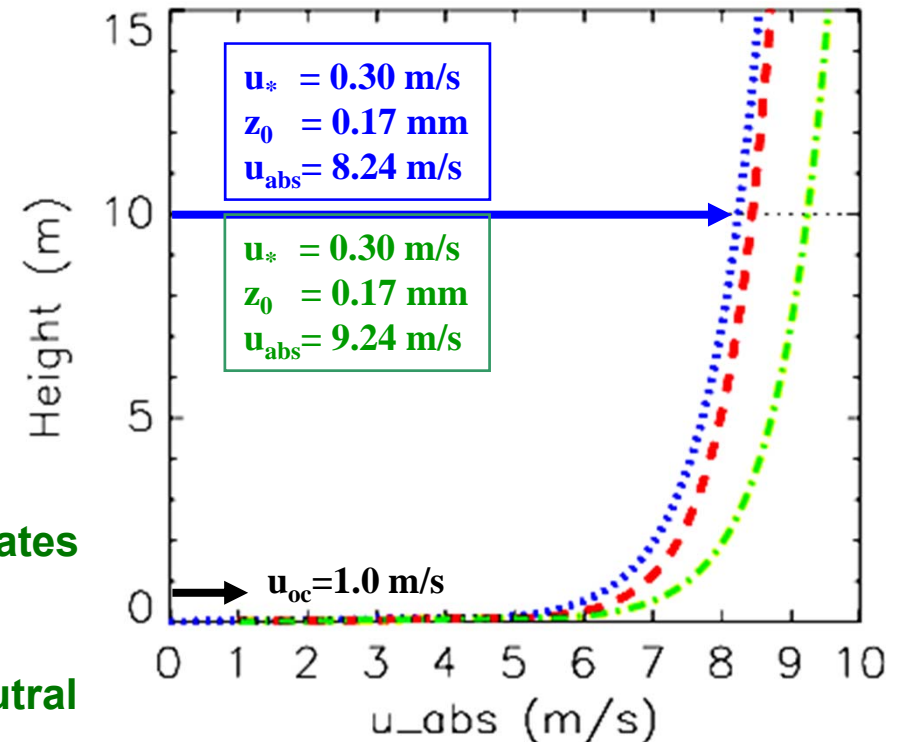
$$\vec{u}_{\text{rel}}(10) = \vec{u}_{\text{ECMWF}}(10) - \vec{u}_{\text{oc}}.$$

Take for instance a simple neutral boundary layer with u^* of 0.30 m/s in the absence of currents (blue dotted curve).

What would happen to the wind profile if a 1 m/s surface current is present:

If the boundary condition at the surface dominates over conditions aloft, then the surface stress stay the same.

- then the relative wind will follow from the neutral profile.
- 10m absolute wind would be shifted by the current (green dash-dot curve)
- ❖ The full wind profile will need to be shifted,
- ❖ including higher up !!?? (doubtful!)



The effect of ocean current on 10m wind

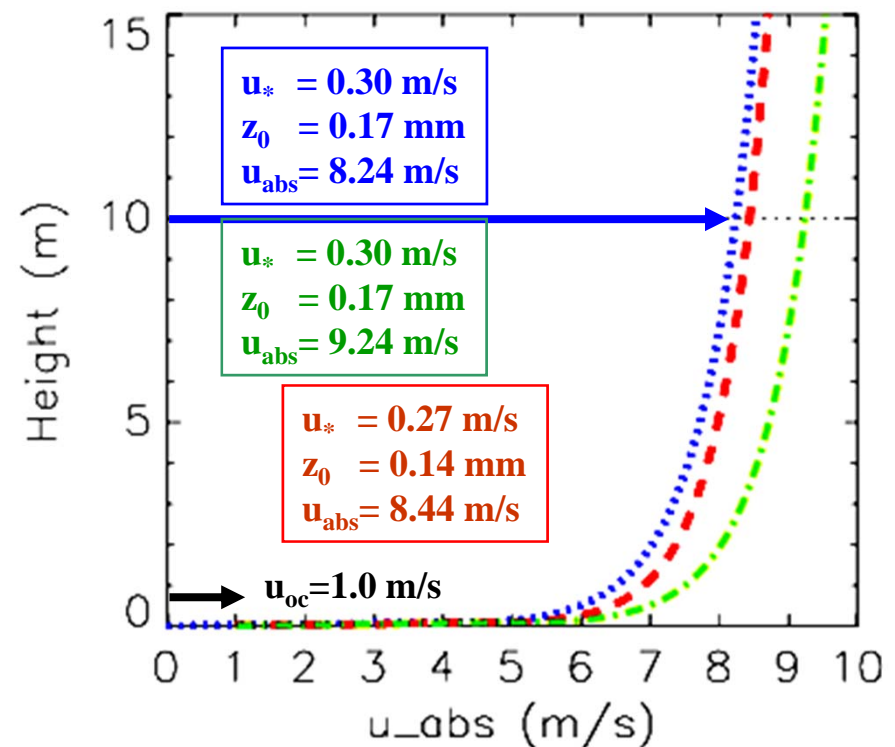
A more plausible assumption is that due to the small roughness length over sea:

- 10m wind is relatively close to geostrophic height
- In the free atmosphere, the effect will be small (here we have assumed unaltered at 100m and reintegrated the boundary layer equation to get the red dash curve)
- ❖ 10m absolute wind would not change too much (about 10-20%?).
- ❖ Note: when stress goes down, the absolute wind goes up

In reality, both boundary conditions at the surface and higher up will play a role.

Thus, one cannot directly guess the effect of surface currents on the operational 10m wind.

Some fraction α of the current will be “absorbed” in the absolute wind, leaving a fraction $(1-\alpha)$ for a change in relative wind and hence the surface stress.



Adaptation of the scatterometer obs operator

Adaptation of the scatterometer cost function:

$$J_o^{\text{scatt}}(\vec{\mathbf{u}}^{\text{mod}}, \text{scatt}) = \frac{\|\vec{\mathbf{u}}^{\text{mod}} - \vec{\mathbf{u}}^{\text{scatt}}\|^2}{\sigma_0^2}$$

Here, $\vec{\mathbf{u}}^{\text{mod}}$ is the scatterometer observation operator.

It is determined from the wind $\vec{\mathbf{u}}_L$ at lowest model level z_L (Geleyn 1988):

$$\vec{\mathbf{u}}_{\text{rel}}(z_{\text{obs}}) = R\vec{\mathbf{u}}_{\text{rel}}(z_L),$$

where

$$R = R(z_{\text{obs}}/z_L, z_0, \text{stability}), \quad R = 1, \text{ for } z_{\text{obs}} = z_L.$$

Since now $\vec{\mathbf{u}}_L = \vec{\mathbf{u}}_{\text{abs}}(z_L)$, rather than $\vec{\mathbf{u}}_{\text{rel}}(z_L)$

$$\begin{aligned} \text{scatterometer :} \quad & \vec{\mathbf{u}}^{\text{mod}} = \vec{\mathbf{u}}_{\text{rel}}(z_{\text{obs}}) = R (\vec{\mathbf{u}}_L - \vec{\mathbf{u}}_{\text{oc}}) \\ \text{buoy/ship :} \quad & \vec{\mathbf{u}}^{\text{mod}} = \vec{\mathbf{u}}_{\text{abs}}(z_{\text{obs}}) = R \vec{\mathbf{u}}_L + (1 - R) \vec{\mathbf{u}}_{\text{oc}} \end{aligned}$$