The relevance of ocean surface current in the ECMWF analysis and forecast system

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Thanks to: Anton Beljaars, Peter Janssen, Magdalena Balmaseda, Tim Stockdale, Frederic Vitart, Saleh Abdallah, Mats Hamrud

Introduction:

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

- **For monthly 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: there may be an effect on swell propagation**

This presentation will discuss some first assessment of the effect of ocean currents on the ECMWF atmosphere and ocean-wave component.

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

How to provide ocean current as atmospheric boundary condition

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

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

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

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

- (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 ($\varphi_D = 1$):

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

  $z_0 = \alpha_{\text{M}} \frac{\nu}{u_*} + \alpha_{\text{ch}} \frac{u_*^2}{g} \sim 0.01$ 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

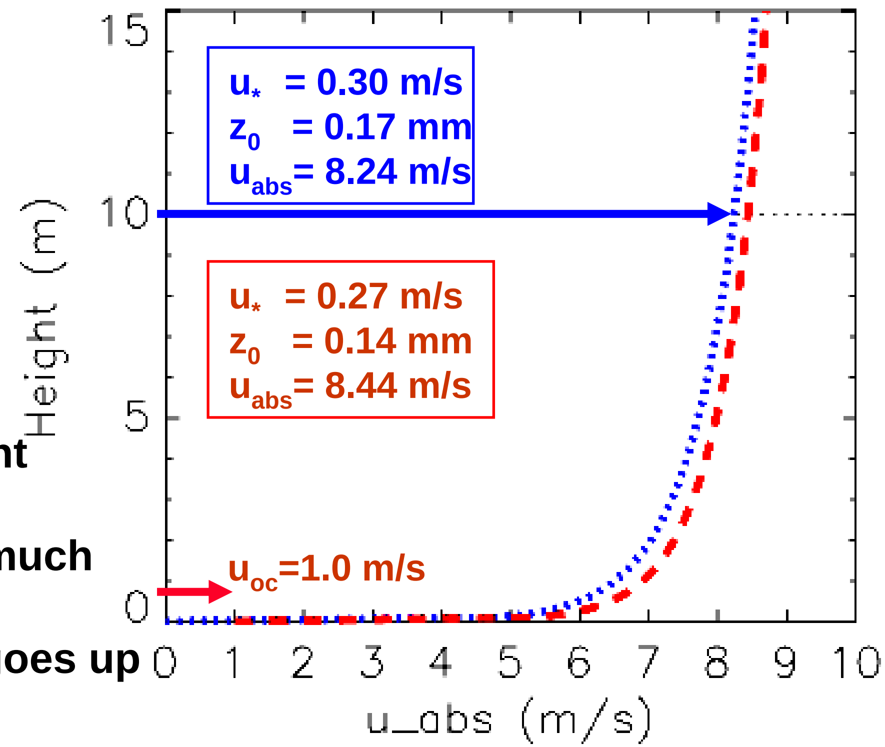
The effect of ocean current on 10m wind

ECMWF 10m wind (in absolute frame) is a popular product

- Since ocean currents are not incorporated in the operational ECMWF model usually, 10m relative winds are constructed as:

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

- How would ECMWF absolute 10m wind change after currents are incorporated?



Due to the small roughness length over sea:

- 10m is relatively close to geostrophic height
- In free atmosphere, the effect will be small
- ❖ 10m absolute wind would not change too much
  About 10-20%?
- ❖ Note: when stress goes down, abs. wind goes up

Some available ocean current products

TOPAZ 3 system from NERSC :

- ✓Modified HYCOM ocean model.
- ✓Horizontal resolution between 8-12 km, Atlantic
- ✓Data assimilation: Ensemble Kalman Filter (100 members).

Sea level, sea surface temperature, sea ice concentration and sea ice drift.

Atmospheric forcing is from ECMWF.

MERCATOR surface currents from the global PSY3V1 system:

- ✓NEMO ocean model (ORCA025)
- ✓Horizontal resolution: 1/4° but global data only available on 1/2°.
- ✓Data assimilation system: OI, since April 2008: Kalman - Seek

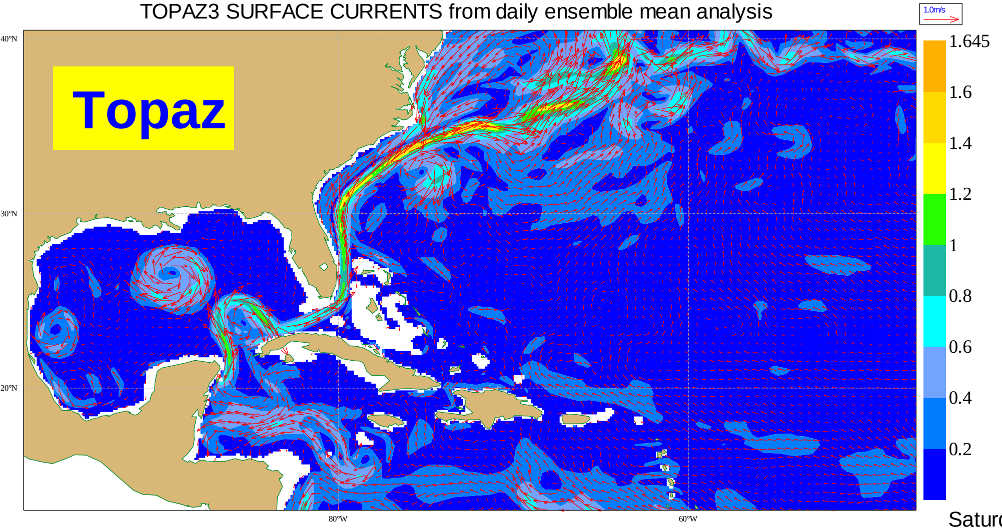
Atmospheric forcing is from ECMWF.

ECMWF system 3:

- ✓Hope ocean model
- ✓Variable horizontal resolution: 1.0°x1.0° in mid latitude, enhanced in tropics
- ✓Data assimilation system: based on OI, temperature, salinity, altimetry

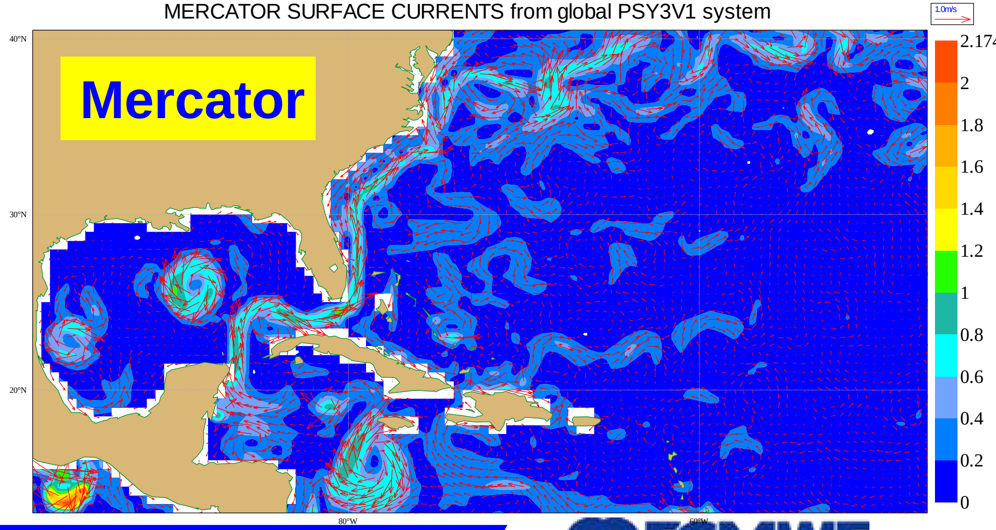
Topaz versus Mercator ocean current

Saturday 3 November 2007 00UTC Analysis t+ VT: 00UTC Surface: U velocity/V velocity
Saturday 3 November 2007 00UTC Analysis t+ VT: 00UTC Surface: **U velocity
TOPAZ3 SURFACE CURRENTS from daily ensemble mean analysis

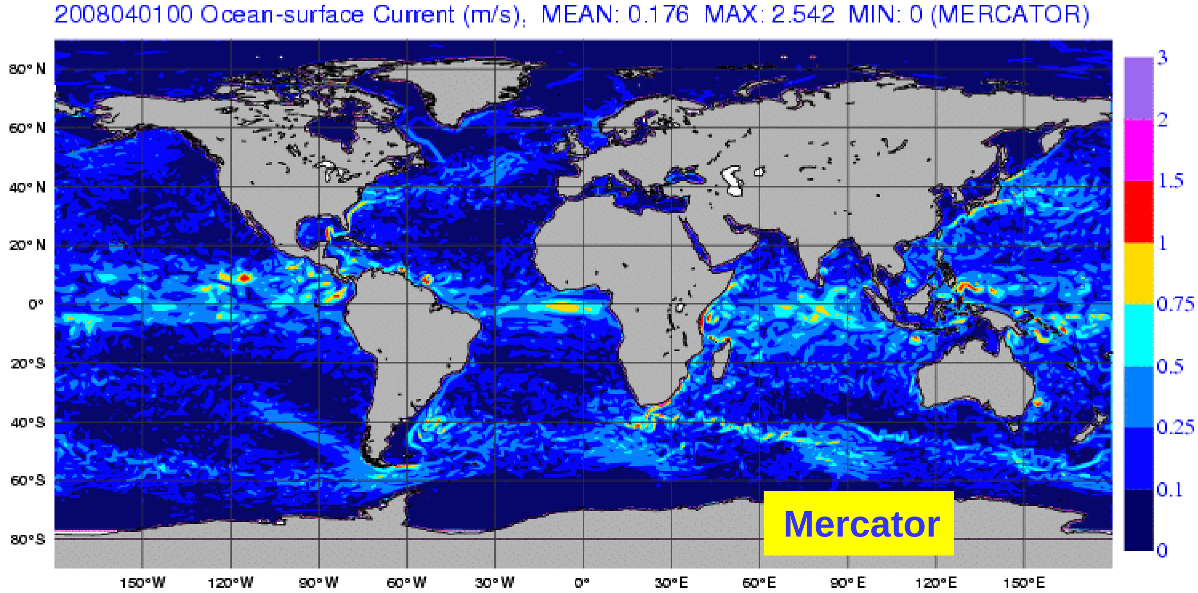


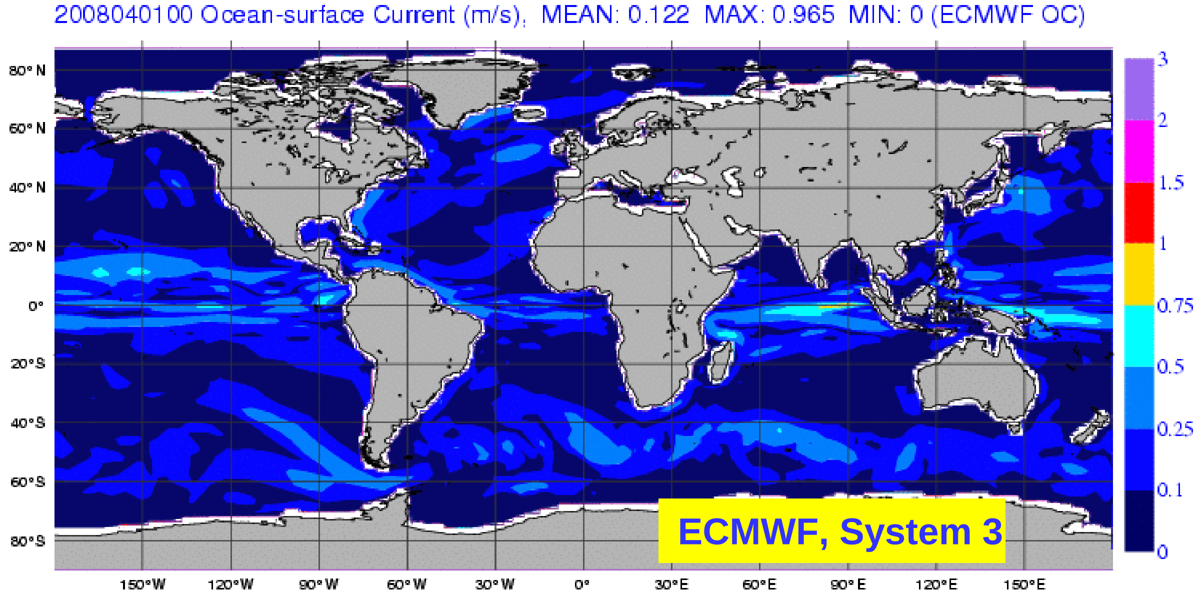
Both products show realistic features, there are some differences, though

Saturday 3 November 2007 00UTC Analysis t+ VT: 00UTC Surface: V velocity/U velocity
Saturday 3 November 2007 00UTC Analysis t+ VT: 00UTC Surface: **U velocity
MERCATOR SURFACE CURRENTS from global PSY3V1 system



ECMWF





Mercator vs ECMWF (system 3)

Mercator:

- **More small-scale structure**
- **About 40% stronger**
- **Realistic?**

ECMWF (system 3):

- **Larger response to instantaneous wind field**

Ocean-wave experiment, using simple approach

Uncoupled, hindcast mode

- Use prescribed ECMWF analysis winds
- Global WAM model (55km horizontal resolution)
- 17 March – 20 April 2008

Ingest ocean currents from Mercator

- Force wave model with relative wind:

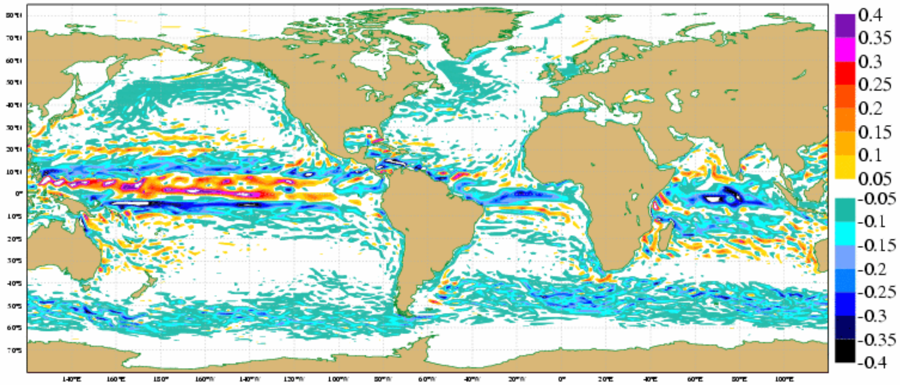
$$\vec{\mathbf{u}}_{\mathrm{rel}}(10) = \vec{\mathbf{u}}_{\mathrm{ECMWF}}(10) - \vec{\mathbf{u}}_{\mathrm{oc}}.$$

- Also assess effect of ocean currents on waves themselves (energy bunching, refraction,..)

Stand alone wave model hindcasts: effect of relative winds and current refraction

$$||\vec{\mathbf{u}}_{\mathrm{ECMWF}}(10) - \vec{\mathbf{u}}_{\mathrm{oc}}|| - ||\vec{\mathbf{u}}_{\mathrm{ECMWF}}(10)||$$

Mean hindcast parameter 245 difference (f3af wave - f2dv wave)
from 20080317 0Z to 20080420 18Z



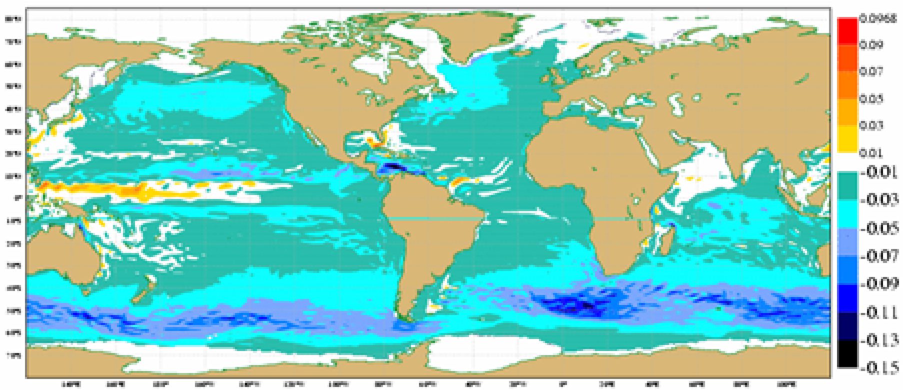
Difference in wind forcing (m/s)

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

(for left-hand experiments only)

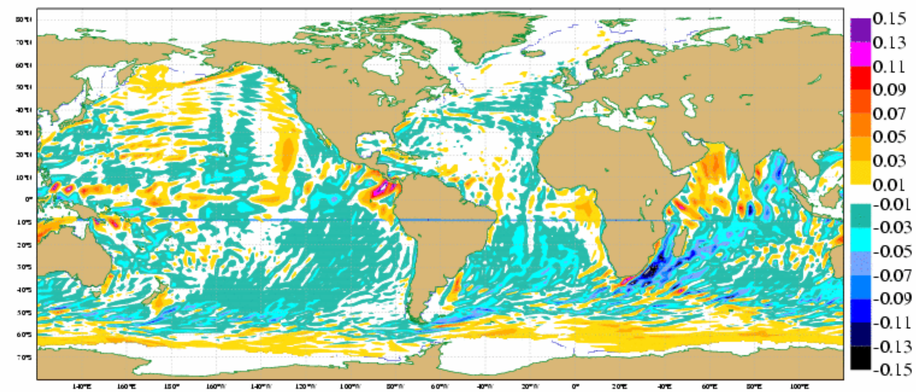
- **Currents and counter currents clearly visible**
- **Wave height decreased over ACC**
- **Swell propagates information**

Effect of forcing relative wind



Difference in Sign. Wave height (m)

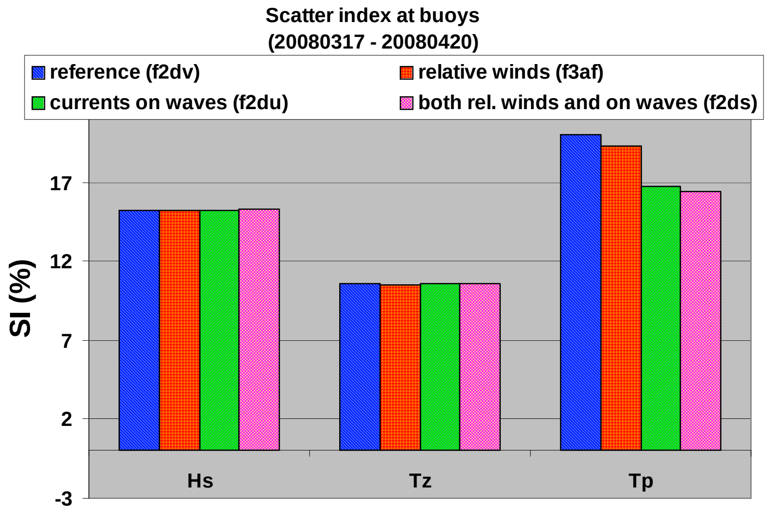
Effect of currents on waves

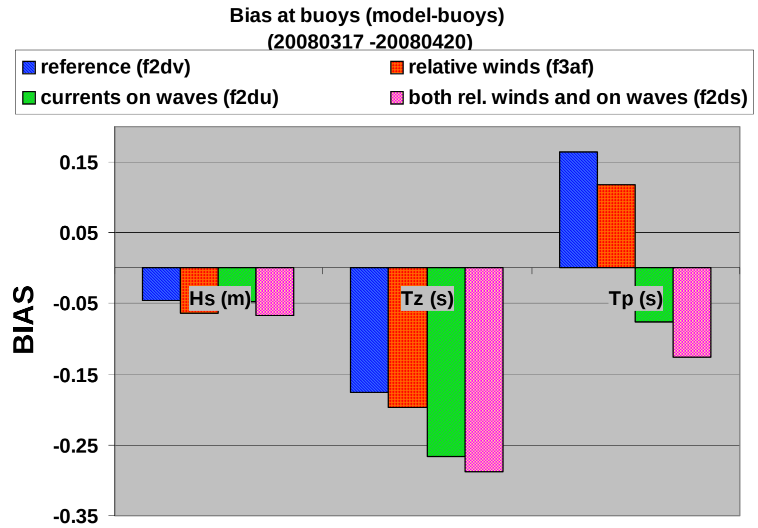


Difference in Sign. Wave height (m)

ECMWF

Stand alone wave model hindcasts: comparison to buoy Hs, Tz, Tp





Currents on waves:

- **Improves peak period**

Scatter index: normalized standard deviation of the difference

Data source: US (NDBC, Scripps, etc), Canada (MEDS), European buoys (UK, Irish, French, Icelandic, Spanish, Norwegian), North Sea and Norwegian platforms.

Ingestion of ocean current in the ECMWF assimilation/forecast system

Surface analysis (SSA):

- **Interpolate current from Topaz, Mercator, system 3,… Like SST and sea ice.**

Forecast system (FC):

- **Read ocean current, like SST and sea ice from previous (SSA)**
- **Keep the current fixed during the (10-day) forecast**

- **Use the current to provide the proper boundary condition:**

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

- **Pass on $u_{rel}=u_{abs} - u_{oc}$ to (coupled) ocean-wave model**

Ingestion of ocean current in the ECMWF assimilation/forecast system

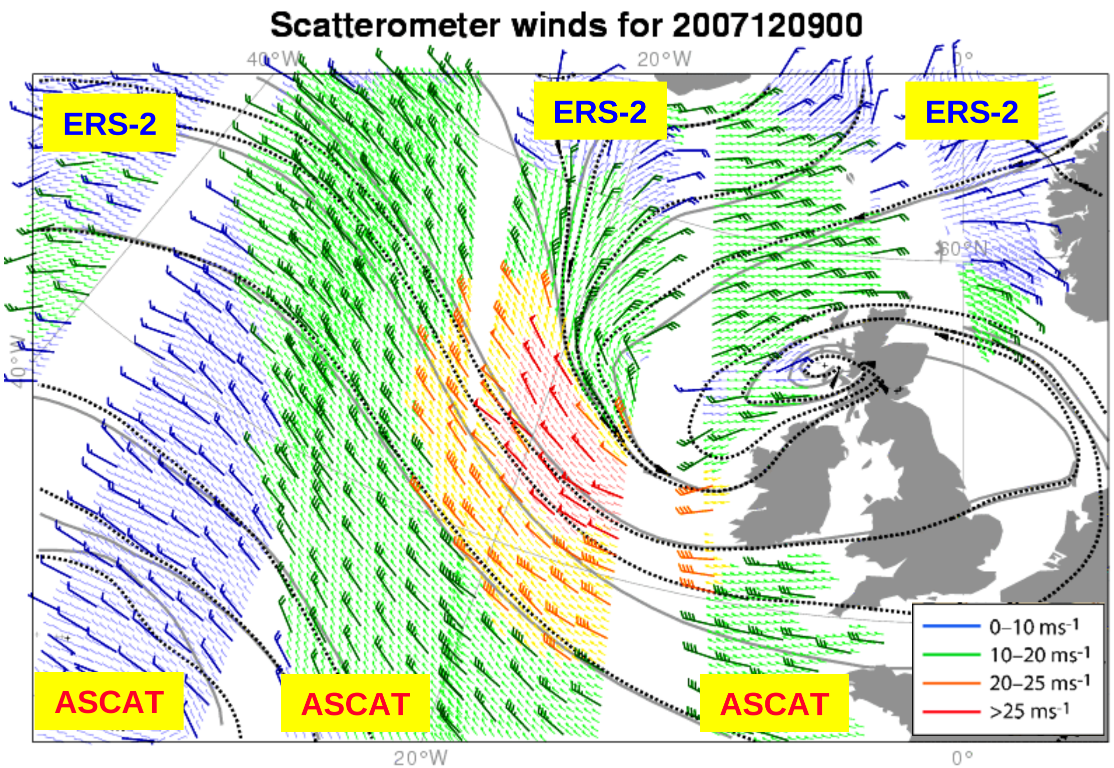
Analysis system (AN):

- **Minimize 4D-Var cost function**

$$J(\mathbf{x}^{\mathrm{mod}}_{\mathbf{t=0}}) = J_b(\mathbf{x}^{\mathrm{mod}}_{\mathbf{t=0}}) + \sum_{t=0}^{12\mathrm{h}} J_o(\mathbf{x}^{\mathrm{mod}}_{\mathbf{t}}, \mathrm{obs}_{\mathrm{t}})$$

- **The ocean current needs to be supplied to the traje $\mathbf{x}^{\mathrm{mod}}_{\mathrm{t}}$ y**
- **Read, like SST and sea ice from previous FC**
- **Adapt observation operators, where necessary**
  scatterometer, buoy, ship, …,

Usage of Scatterometer data at ECMWF



6-hour window

Surface-wind streamlines:
ECMWF analysis
ECMWF First-Guess

Dark barbs: used
Light barbs: not used

Operational assimilation:

- **Coverage almost every 6 hours**
- **Noon/Night: ERS-2 and ASCAT**
- **Morning/evening: QuikSCAT**

Observation operator:

- **As vector wind at 10m height**
- **As wind in absolute frame**

Scatterometer measures stress

- **Stress is related to relative wind** ***(Kelly et. al. 2001)***
- **Adapt observation operator**

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

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

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

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

The combined effect of ocean current and assimilation of scatterometer wind

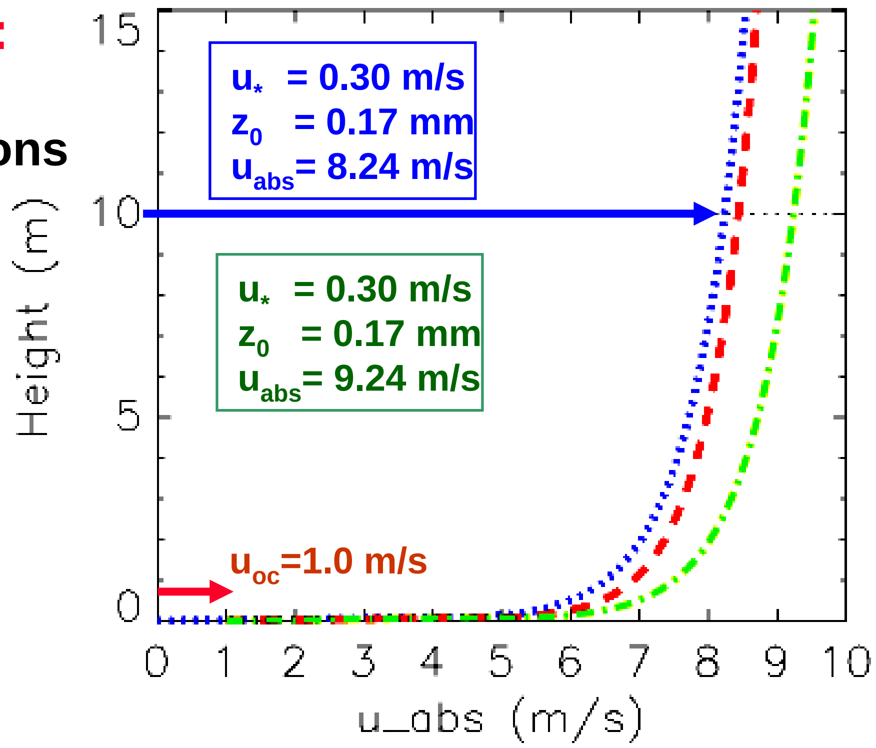
Denote the original 10m ECMWF absolute wind by: $u_{ECMWF}(10)$

Small adjustment for $u_{abs}(10)$, due to:

- **'Forcing' of winds in free atmosphere**
- **Usage of moored buoy, ship observations**
- ✓ **Confirm value of $u_{ECMWF}(10)$**

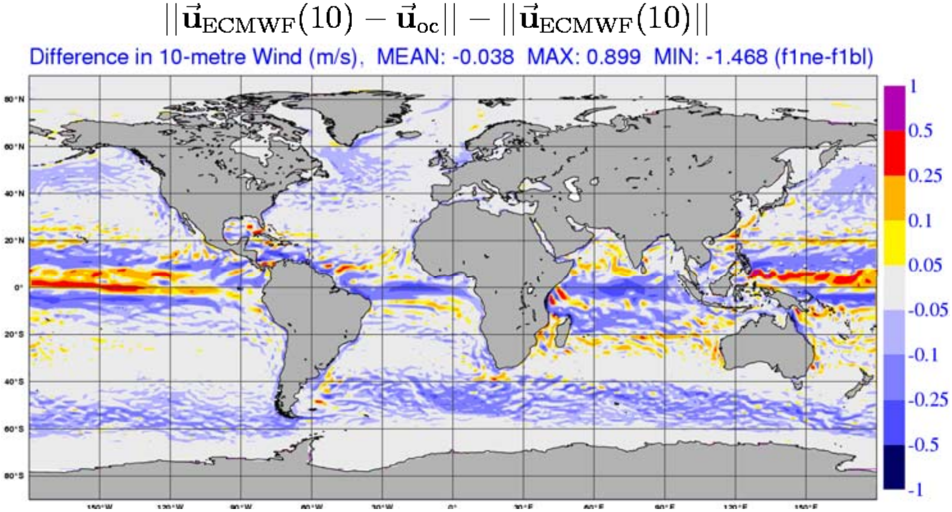
Small adjustment for $u_{rel}(10)$, due to:

- **Usage of scatterometer data**
- **Enforcing stress at surface**
- **$u_{ECMWF}(10)$ appears relative wind**



ECMWF

Average effect on surface winds

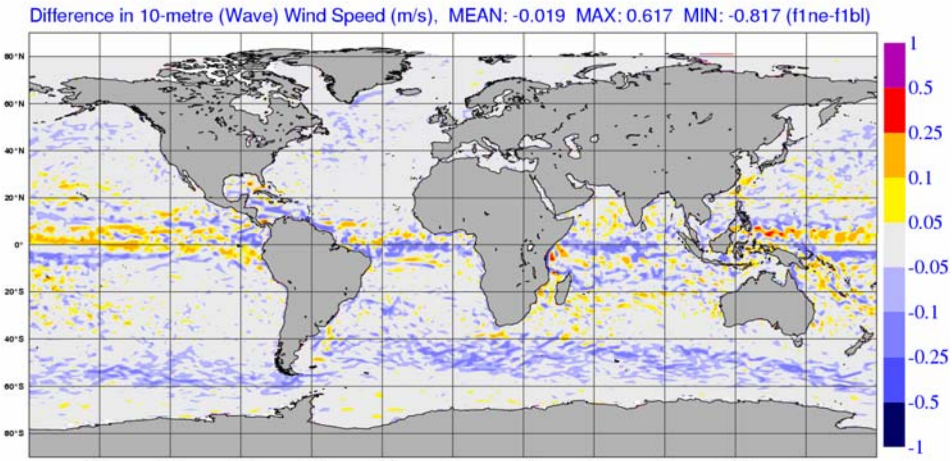


T511 (40km) assimilation impact stud
ocean waves 55km

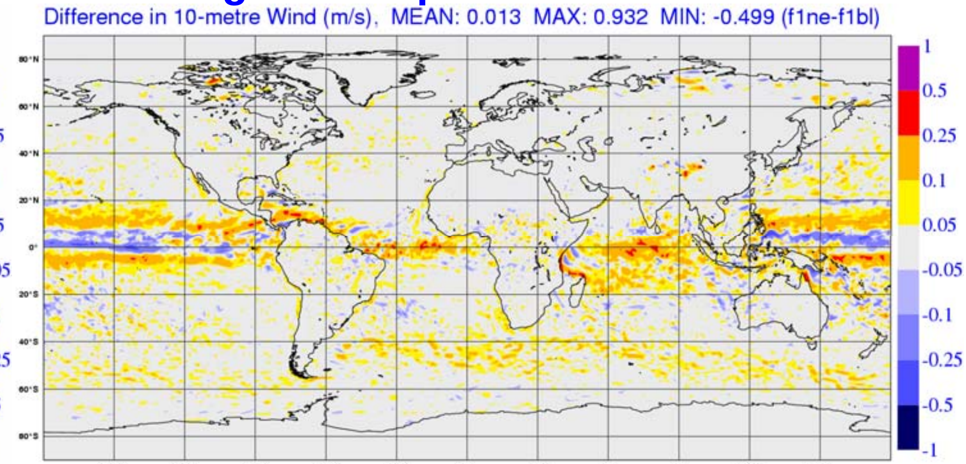
✓**Use Mercator currents**
✓**17 March – 30 April 2008**

- **Effect on relative winds limited**
- **Absolute winds receive about 50% from ocean currents**
- **Forecast score neutral to slightly nega**

Average wind speed in relative frame

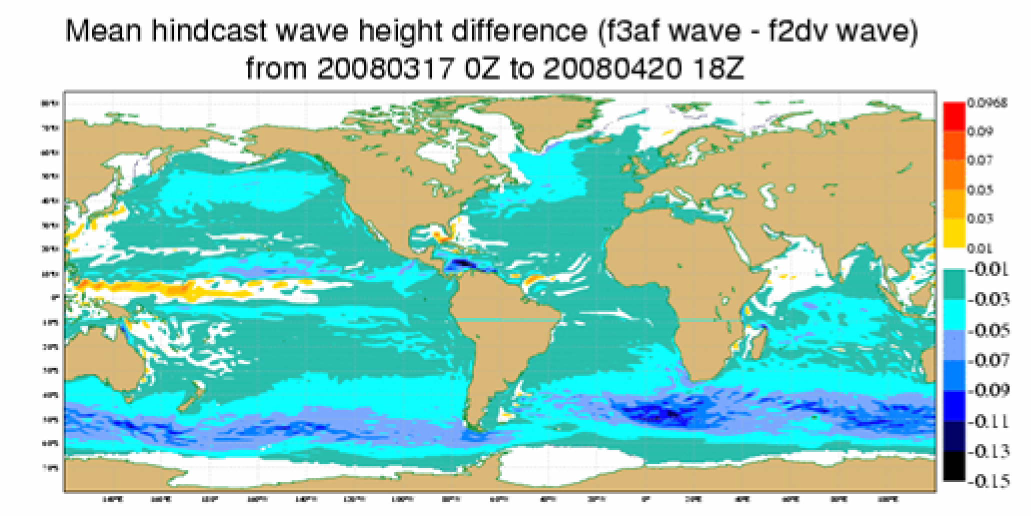


Average wind speed in absolute frame



ECMWF

Coupled runs:
effect of relative winds on ocean waves

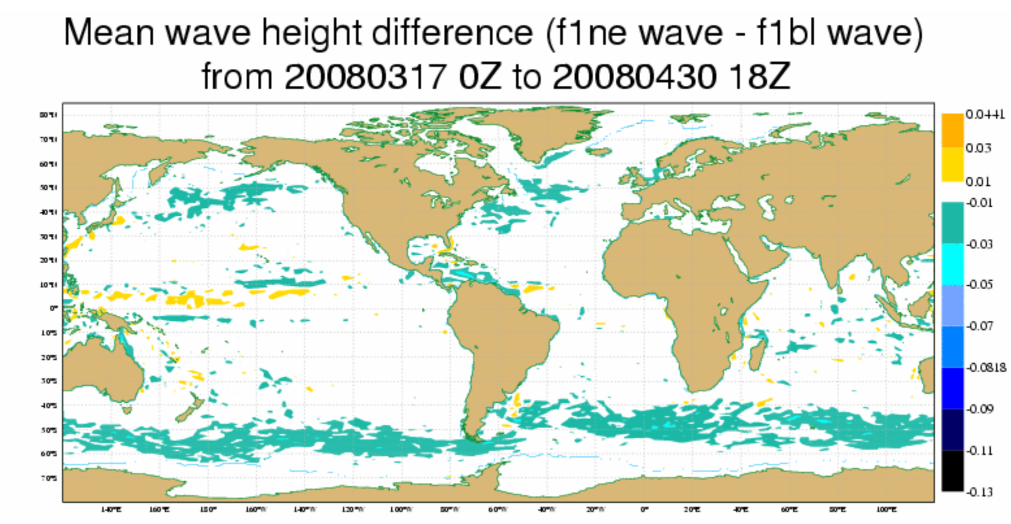


Impact of coupled system much lower

- ➢ **Due to smaller difference in rel. wind**

Effect of current on waves was omitte

- ✓ **This effect should still be present**



ECMWF

Conclusions and final remarks:

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

- Currents could in future be ingested from a (OASIS) coupler

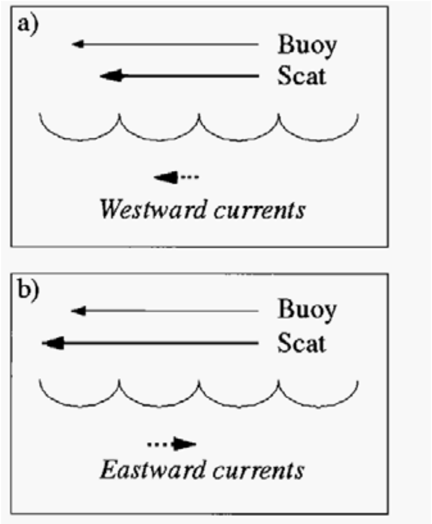
The 10m winds in the absolute frame are more affected than expected

- In present system, scatt data try to make absolute winds relative.
- The effect on ocean waves is smaller than initially expected.
- The ingestion of ocean current is the proper way forward
- Conclusions are preliminary, though

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?
- …..

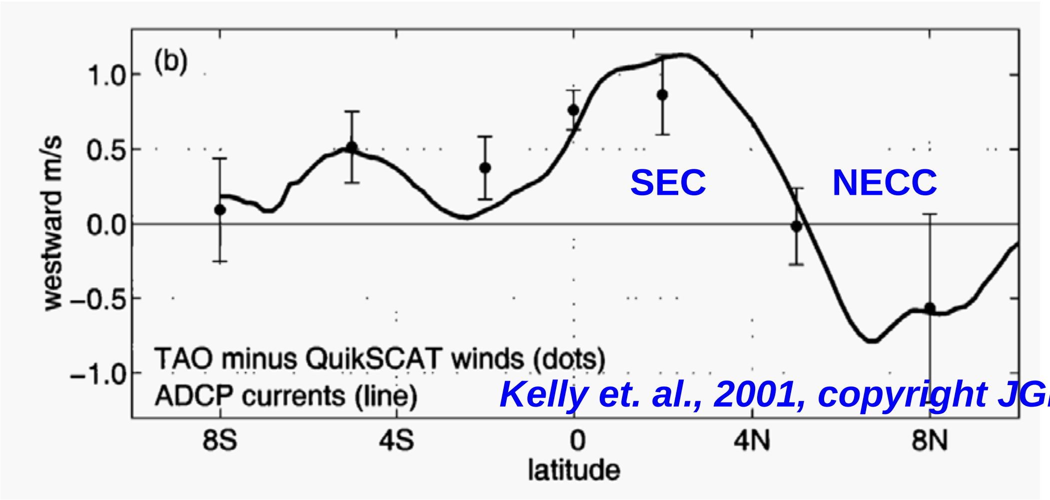
Scatterometer measures stress



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

Stress is related to relative wind,

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

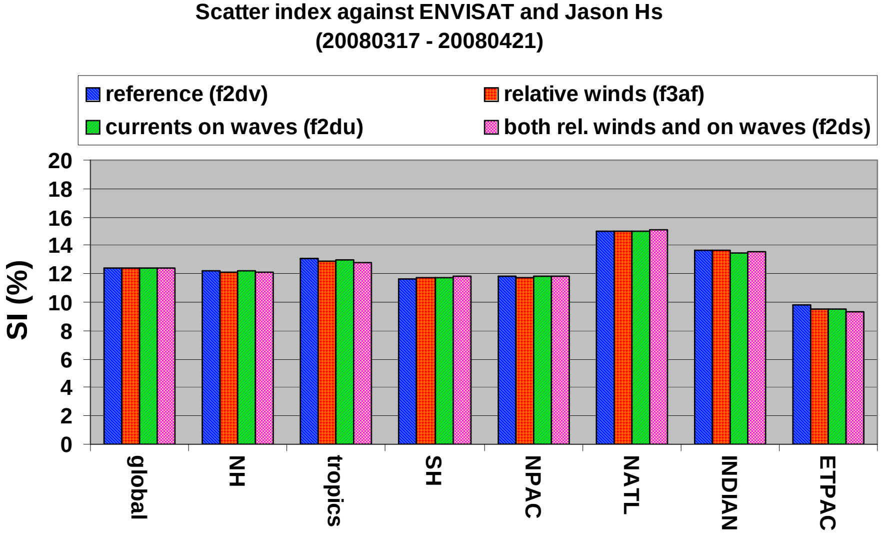


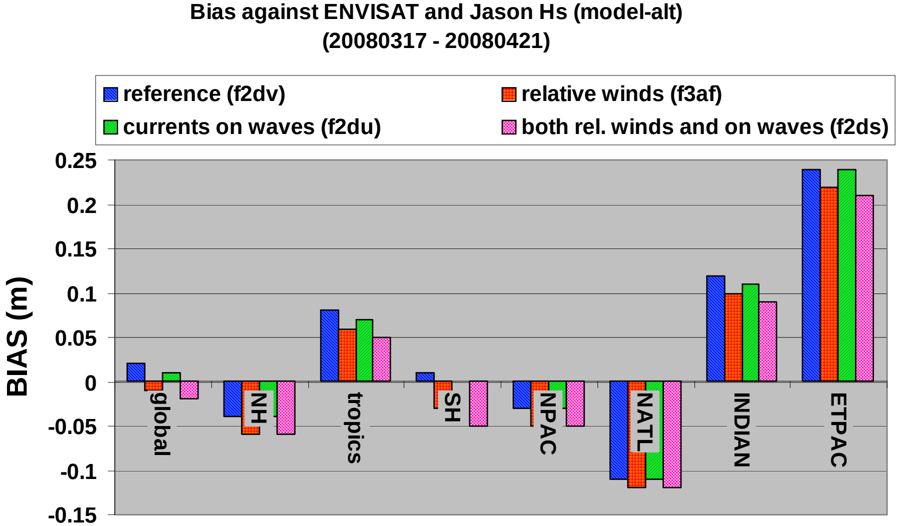
Kelly et. al., 2001, copyright JGR

Moored buoy/ship, measure absolute wind,

- **Observation operator remains to act on these**

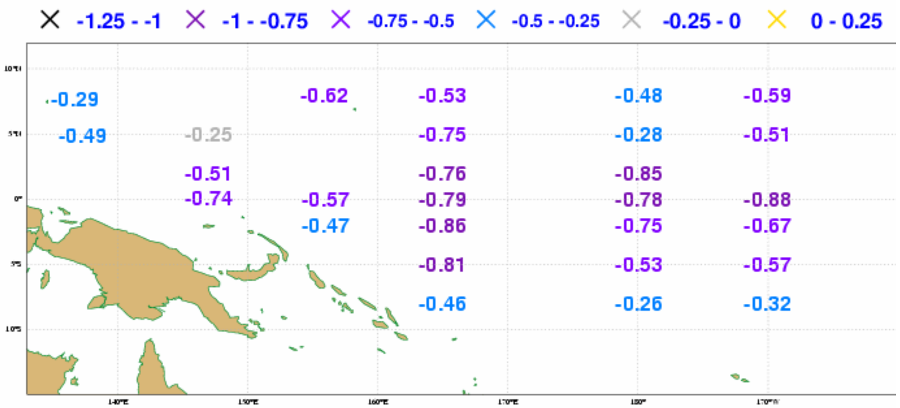
Stand alone wave model hindcasts : comparison to altimeter Hs from ENVISAT and Jason

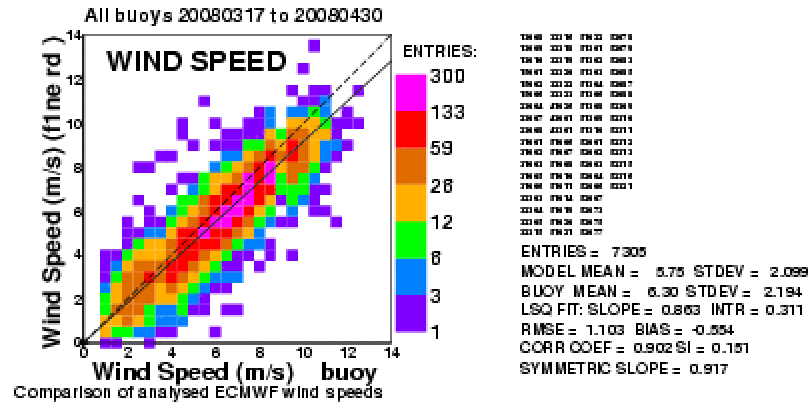




Winds coupled runs:

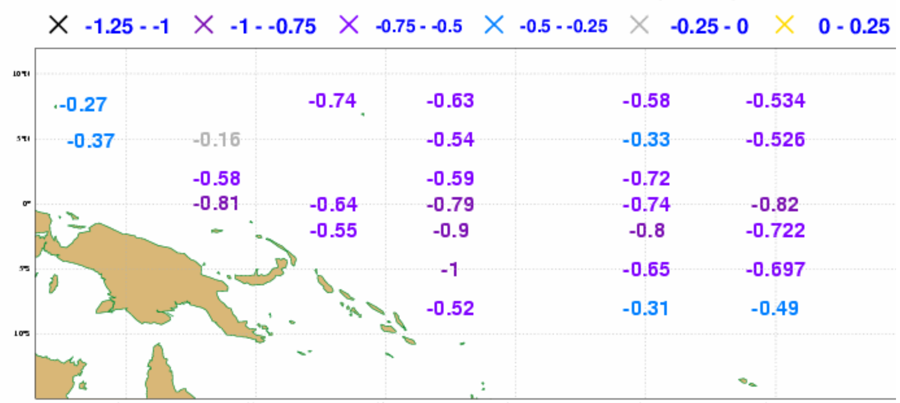
10m wind speed bias with respect to buoy data
20080317 - 20080430
new: with currents (f1ne)

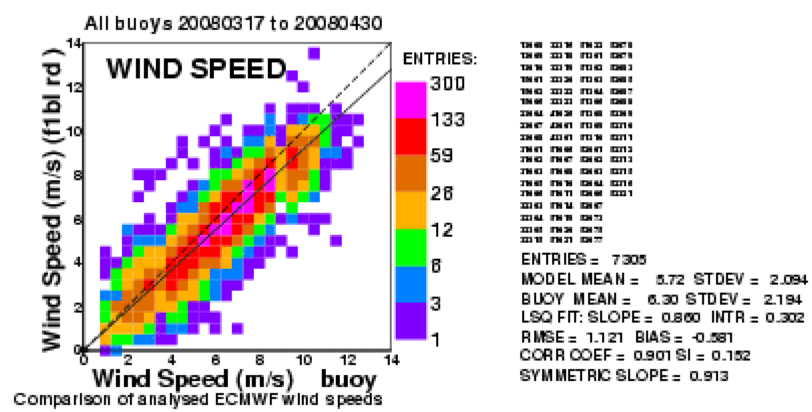




Comparison of analysed ECMWF wind speeds with height corrected averaged buoy data.

10m wind speed bias with respect to buoy data
20080317 - 20080430
control: no current effect (f1bl)





Comparison of analysed ECMWF wind speeds with height corrected averaged buoy data.

ECMWF