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Toujours un temps d'avance

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Ifremer

A new 3rd Generation wave model at Meteo-France

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Motivation

- Improve Meteo-France's Sea-State Forecasting System
- Main deficiencies
  - In complex seas (Lefevre et al. Isope 2003, Lefevre et al. 8th Wave H&F workshop 2004)→ Hasselmann/Komen Dissipation → improved by
  - Swell dissipation
- Benefit for applications such as
  - High sea states prediction
  - Unexpected waves (Spectral shape)
  - Wave Setup warning (beach slope, $HsxT^2$)

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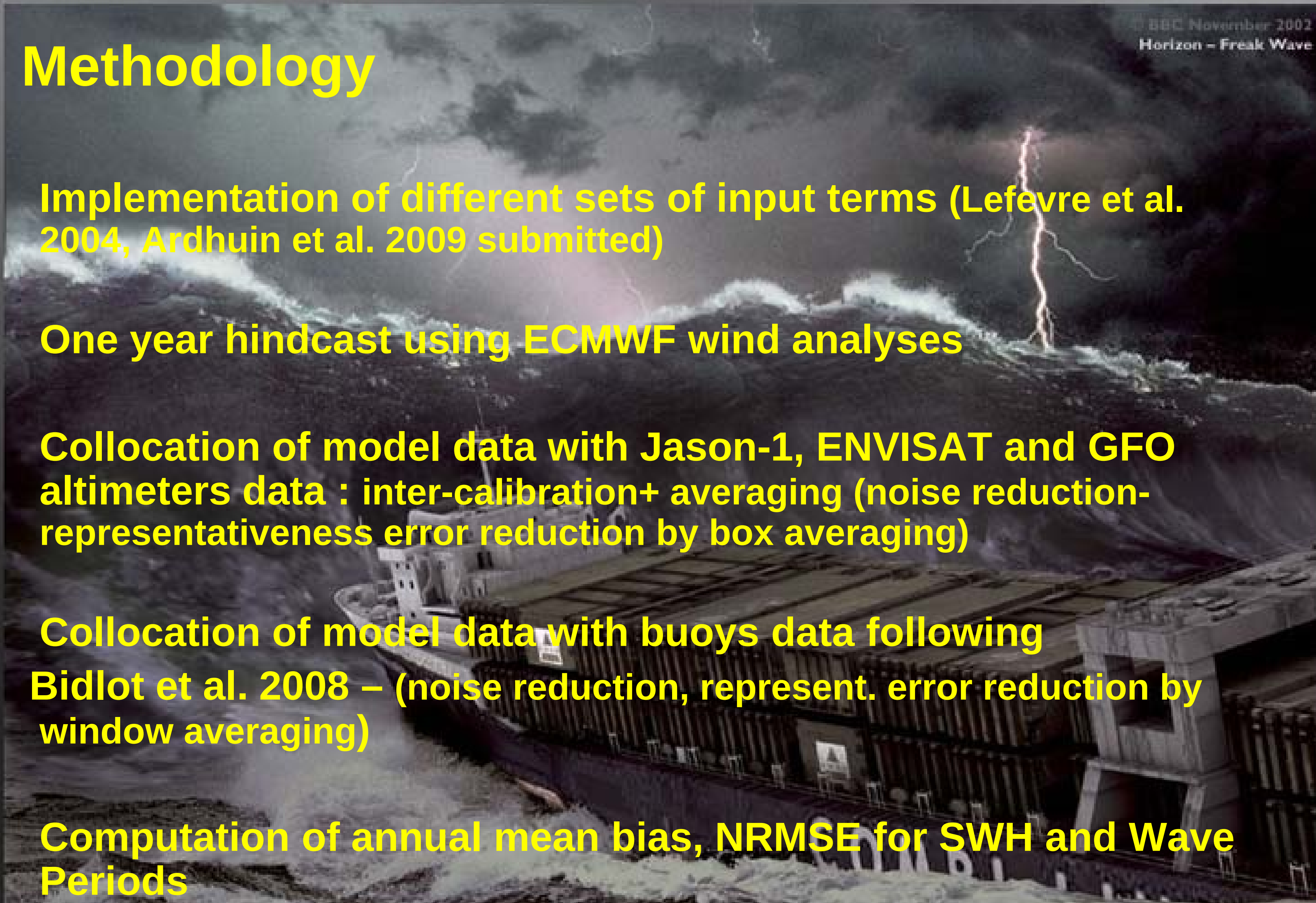
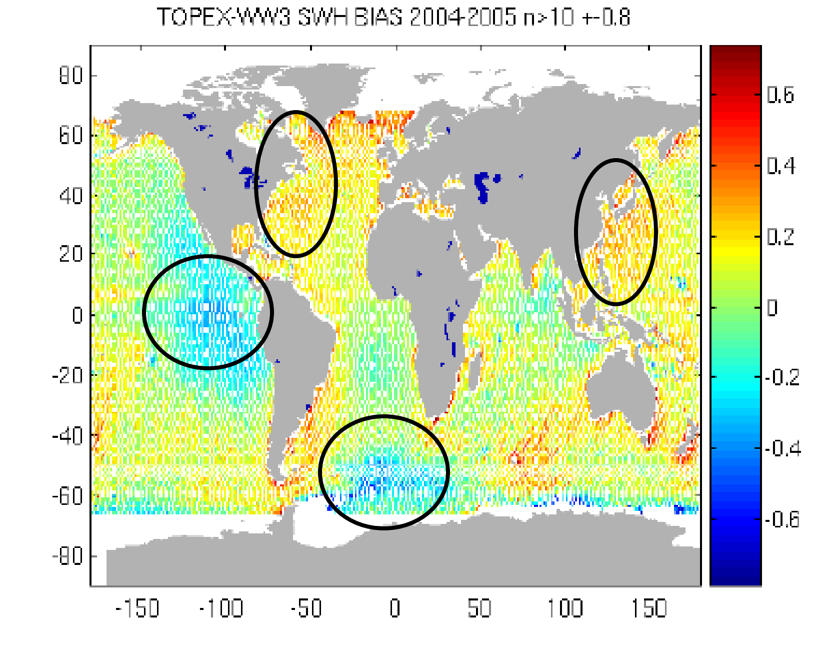
Methodology

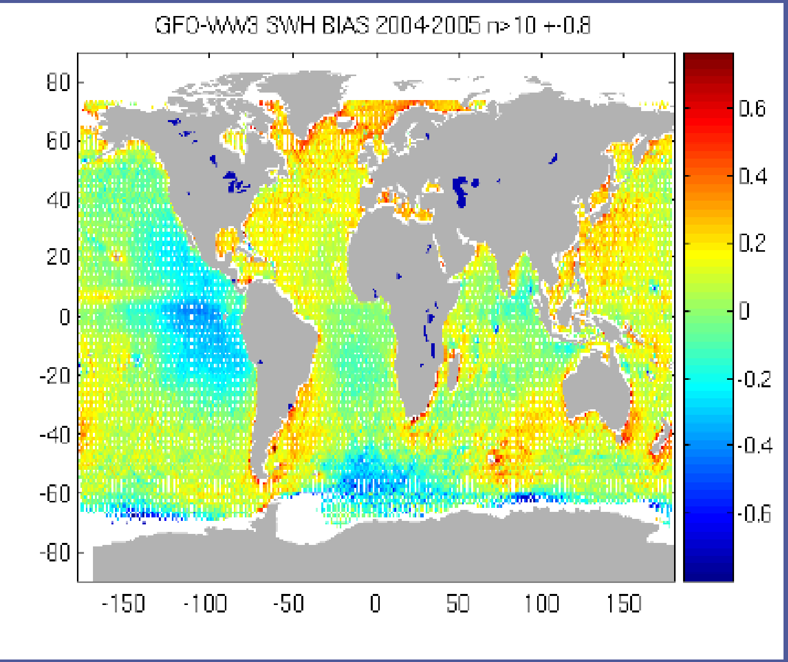


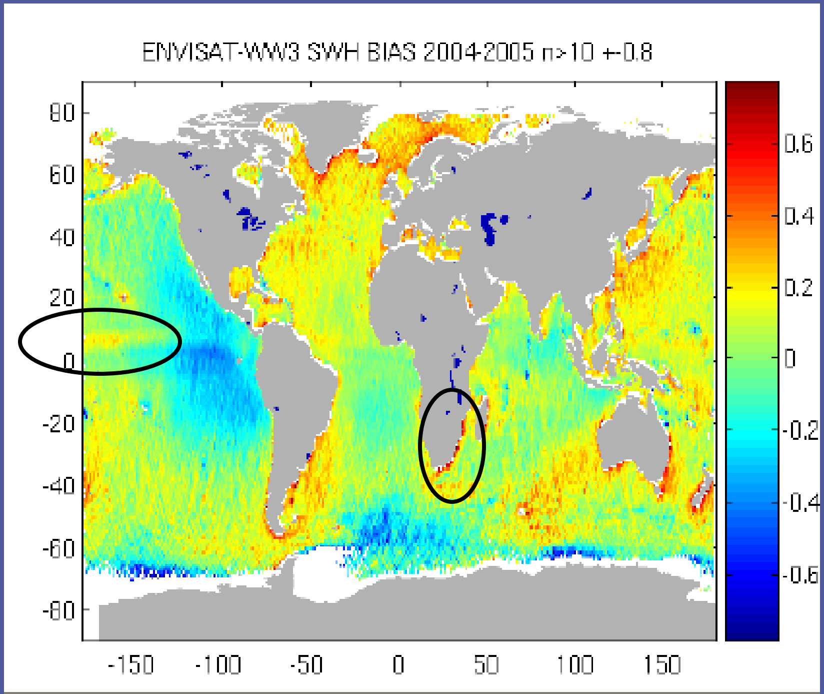
- **Implementation of different sets of input terms (Lefevre et al. 2004, Ardhuin et al. 2009 submitted)**
- **One year hindcast using ECMWF wind analyses**
- **Collocation of model data with Jason-1, ENVISAT and GFO altimeters data : inter-calibration+ averaging (noise reduction-representativeness error reduction by box averaging)**
- **Collocation of model data with buoys data following Bidlot et al. 2008 – (noise reduction, represent. error reduction by window averaging)**
- **Computation of annual mean bias, NRMSE for SWH and Wave Periods**

Summary and Conclusions

- Significant reduction of model bias and RMSE in most parts (15% on average on Hs, 25 % on Tp, relative to BAJ) with TEST441
- The addition of a swell dissipation term together with the introcucution of a local saturation crietira for wave breaking has corrected the underestimation of Hs in Generation areas, and the overestimation in the inter-tropical zone.
- However TEST 441 produces large biases for high sea states (more than BAJ for Hs>8 m, 2m for Hs=14m), whereas TEST437 and BAJ has similar rmse for Hs in the range 2-8 and TEST437 has almost no bias up to 14 m)
- Much more details in Ardhuin et al. 2009, submitted to JPO







-WW3-BAJ -TOPEX, GFO end ENVISAT patterns are very similar

-Model SWH are overestimated (blue, up to 0.4 m) over the intertopical eastern Pacific and in the southern Atlantic

-Model SWH are underestimated (red) in the north-west side of Atlantlic and Pacific oceans, and is some narrow bands (currents effects?)

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Wind input from BAJ (ECWAM)

$$S_{in}(f,\theta) = \beta\omega F(f,\theta)$$ Exponential growth

$$\beta = \varepsilon m_\beta \left(\frac{u_*}{c}\right)^2 \cos^2(\theta-\phi), |\theta-\varphi| \langle \pi/2$$

ε *air-water density ratio, c wave speed*

θ direction of wave propagation, φ *wind direction*, u_* friction velocity, m_β is the Miles parameter, positive if u_*/c > *threshold*

$$\tau = \rho_a u_*^2 = \tau_v + \tau_w + \tau_{turb}$$

Wave induced stress, computed from the input source term → $\tau_w = \int_0^{2\pi}\int_0^{\infty} d\vec{k}.\vec{k} S_{in}$

$$u_* = \frac{\kappa U}{\ln\left(10/z_0\right)} \qquad z_0 = \frac{\alpha . u_*^2}{g\sqrt{1-\frac{\tau_w}{\tau}}}$$

=> Then compute u_*

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Modifications by par Makin et Stam (WAM_MA)

$$Sin = \varepsilon m_\beta R \left(\frac{u_*}{c}\right)^2 \cos(\theta - \theta_\omega) \left|\cos(\theta - \theta_\omega)\right| \omega F(\omega)$$

if $R>0$, otherwise $\cos^2$

$$R = 1 - m_c \left(\frac{c}{u_{10}}\right)^{n_c}$$

Negative input in presence of swell or with opposing winds

$$m_\beta = 0.045, m_c = 0.3, n_c = 5$$

$$\tau = \rho_a u_*^2 = \tau_v + \tau_w + \tau_s$$

The friction velocity is obtained through a modern theory taking account air-flow separation by dominant waves (Kudrastiev and Makin). The Drag coefficient depends on the wind sea age (Cp/u_{10}).

New term for swell damping from Ardhuin et al. (2009)

→Due to friction at the air-sea interface. 2 formulations depending on the boundary layer state: laminar or turbulent. Depends on the Reynolds number (R_e).

$$R_e = 4u_{orb}a_{orb} / \nu_a$$

(u_{orb}) significant surface orbital velocity
(a_{orb}) significant surface displacement amplitudes .

$$S_{out}(f,\theta) = -1.2\varepsilon\left\{2k\sqrt{2\nu\omega}\right\}F(f,\theta)$$ laminar

$$S_{out}(f,\theta) = -\varepsilon\left\{16 f_e \omega^2 u_{orb} / g\right\}F(f,\theta)$$ turbulent

$$f_e = 0.7 f_{e,GM} + [0.015 - 0.018\cos(\theta - \varphi)]u_* / u_{orb}$$

Empirical adjustments from SAR data (see poster P3)

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Dissipation term in BAJ (ECWAM)

(whitecapping)

$$S_{dis}(f,\theta) = \gamma \langle \omega \rangle \alpha^{2m} \left[(1-a)\left(\frac{k}{\langle k \rangle}\right)^2 + a\left(\frac{k}{\langle k \rangle}\right)^4 \right] F(f,\theta)$$

γ, a and m are constants to be adjusted

$$\langle \omega \rangle = \int F d\omega \Big/ \int F d\omega / \omega$$

Mean frequency : foam pressure proportional to wave amplitudes

$$\sqrt{\langle k \rangle} = \int F d\omega \Big/ \int F d\omega / \sqrt{k}$$

Mean wave number: dumping of short waves by dominant waves

$$\alpha^2 = \langle k \rangle^2 \int F d\omega$$

Mean steepness: foam coverage depends on the mean wave steepness.

Problem in mixed seas conditions: sea + swell

swell→ mean steepness decreases → less dissipation→ growth of wind sea too strong (trade wind area for instance)

Sea → mean steepness increases → more dissipation→ too much swell dissipatiion → underprediction of large swell events

Modification proposed by Alves and Banner implemented in WAM_MA (Lefèvre et al. 2004)

$$S_{ds\,\mathrm{MA(k)}} = -C_{dis}^{b}\left(\frac{\alpha}{\alpha_{PM}}\right)^{m}\left(\frac{B(k)}{B_r}\right)^{p/2}\left(\frac{k}{\langle k\rangle}\right)^{n}$$

$$B(k) = \frac{1}{2\pi}F(f)c_g k^3$$

Introduction of the saturation spectrum

$$p = \frac{p_0}{2} + \frac{p_0}{2}\tanh\left\{10\left[\left(\frac{B(k)}{B_r}\right)^{1/2} - 1\right]\right\}$$

When $B(k) > B_r$, *then* : $p = p_0$ and dissipation governed mainly by the ratio $B(k)/B_r$ (wind sea). For $B(k) < B_r$, p=0 and the dissipation is governed by the mean wave steepness.

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Modifications from Ardhuin et al. (2009)

Non isotropic dissipation :

$$B(f) = 2\pi \int_0^{2\pi} k^3 F(f,\theta)/C_g \mathrm{d}\theta, \qquad B'(f,\theta) = 2\pi \int_{\theta-\Delta\theta}^{\theta+\Delta\theta} k^3 F(f,\theta')/C_g \mathrm{d}\theta',$$

-> Better adjustment of the mean direction and angular spreading
-> Breaking: threshold mechanism from the saturation spectrum

$$S_{\mathrm{ds}}(f,\theta) = \sigma C_{\mathrm{ds}} \left\{ \delta \left[\max\left\{ \frac{B(f)}{B_r} - 1, 0 \right\} \right]^2 + (1-\delta) \left[\max\left\{ \frac{B'(f,\theta)}{B_r} - 1, 0 \right\} \right]^2 \right\} F(f,\theta).$$

$$-c_3 F(f,\theta) \int_0^{0.7f} \int_0^{2\pi} \frac{56.3}{\pi}.\max\left\{\sqrt{B(f',\theta')} - \sqrt{B_r}, 0\right\} \frac{\Delta C}{C_g'}.d\theta' df'$$

Last term for the dumping of short waves by dominant waves

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Hs Bias Hs from altimeters

Model-Observations

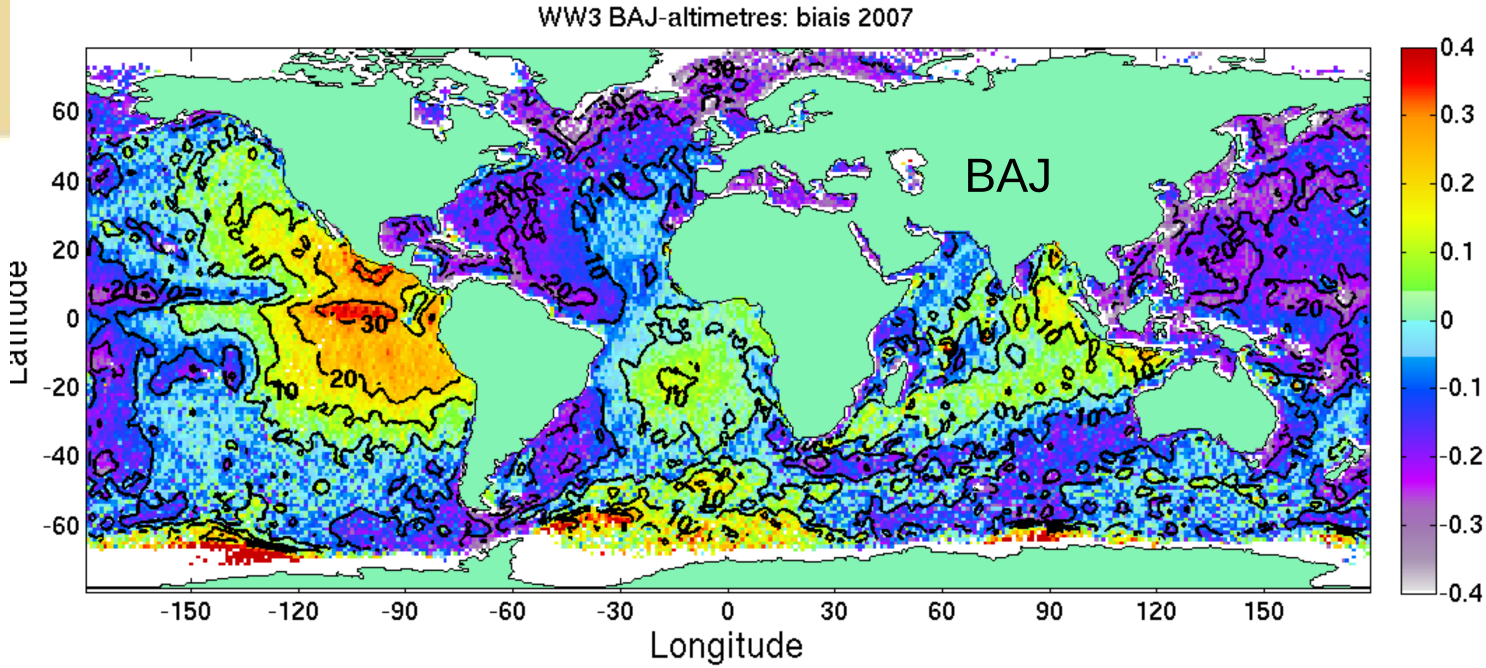
Jason

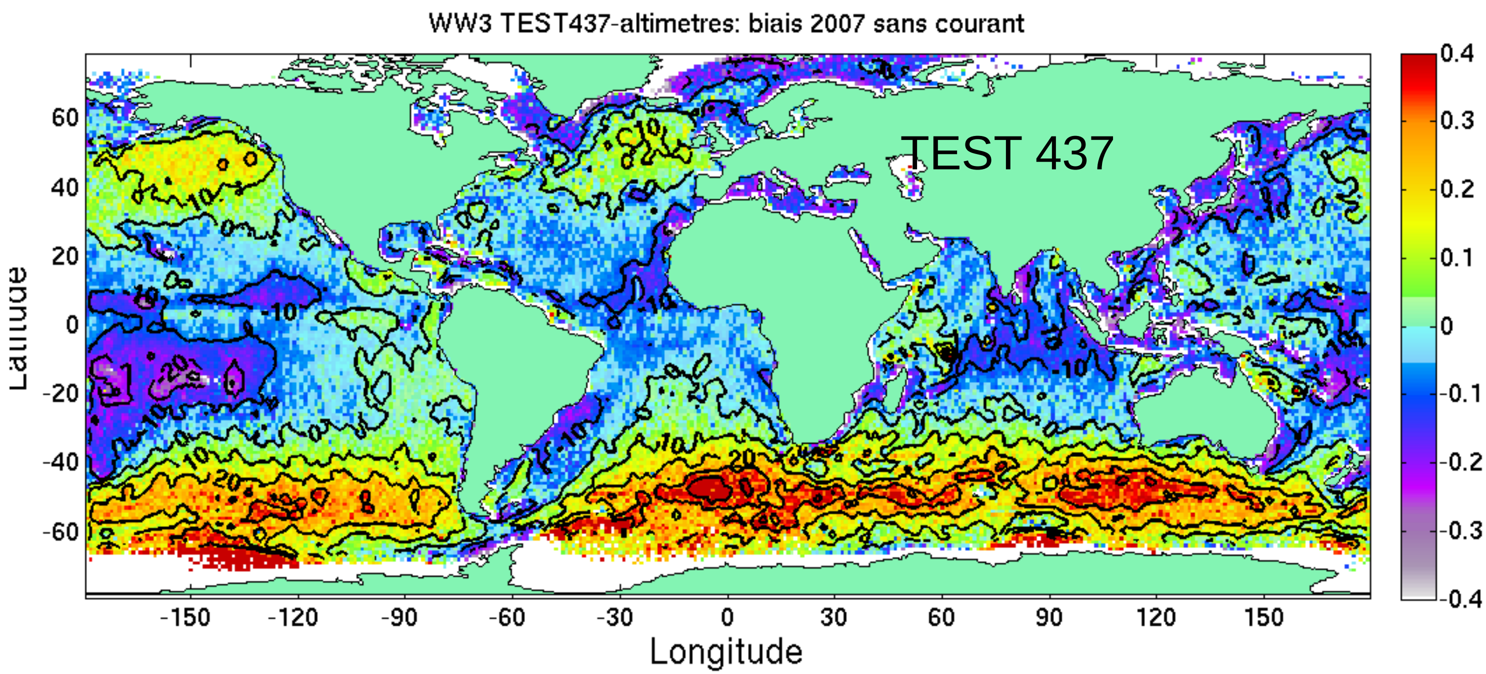
ENVISAT

GFO

Year 2007, ECMWF wind analyses

reg grid 0.5x0.5





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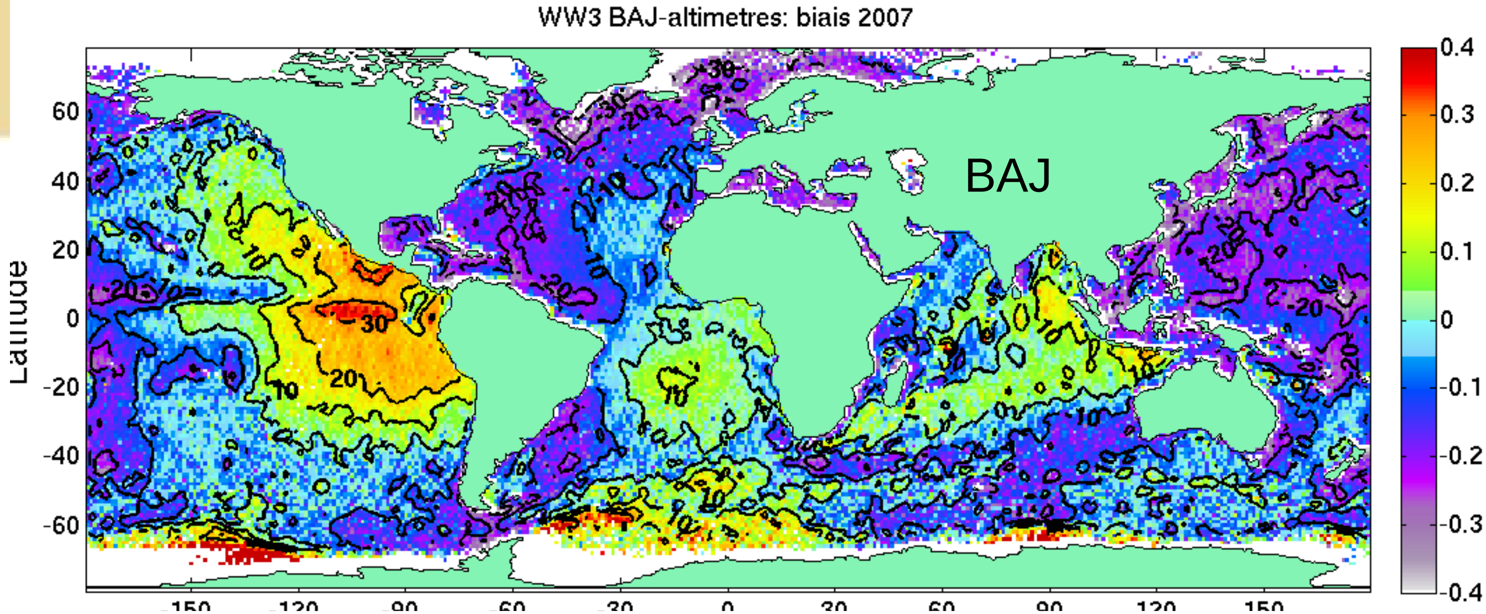

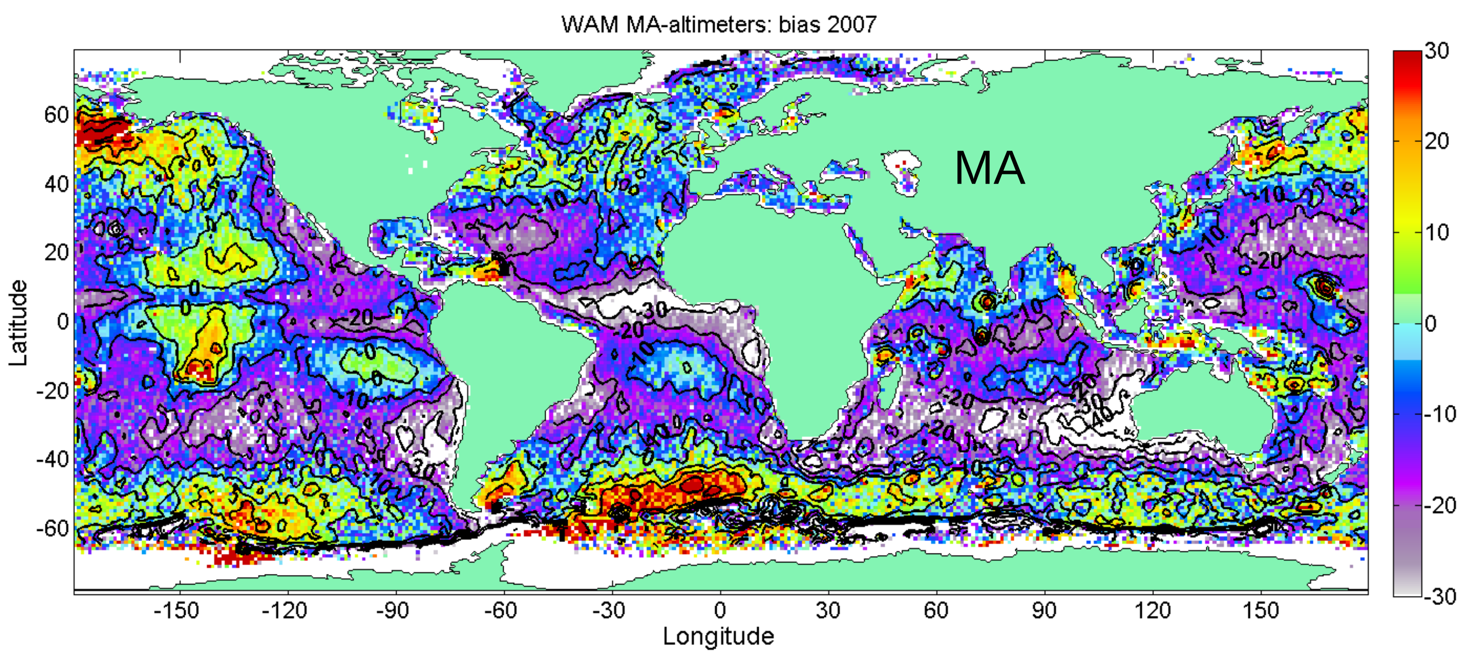

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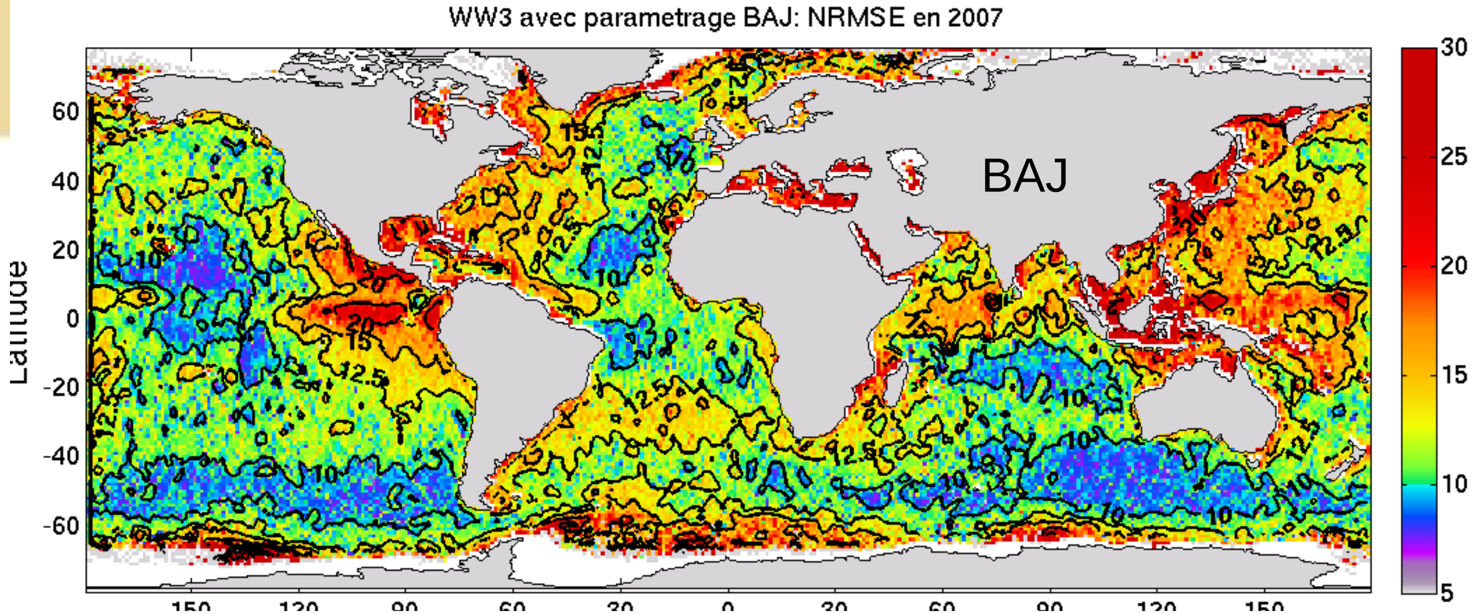
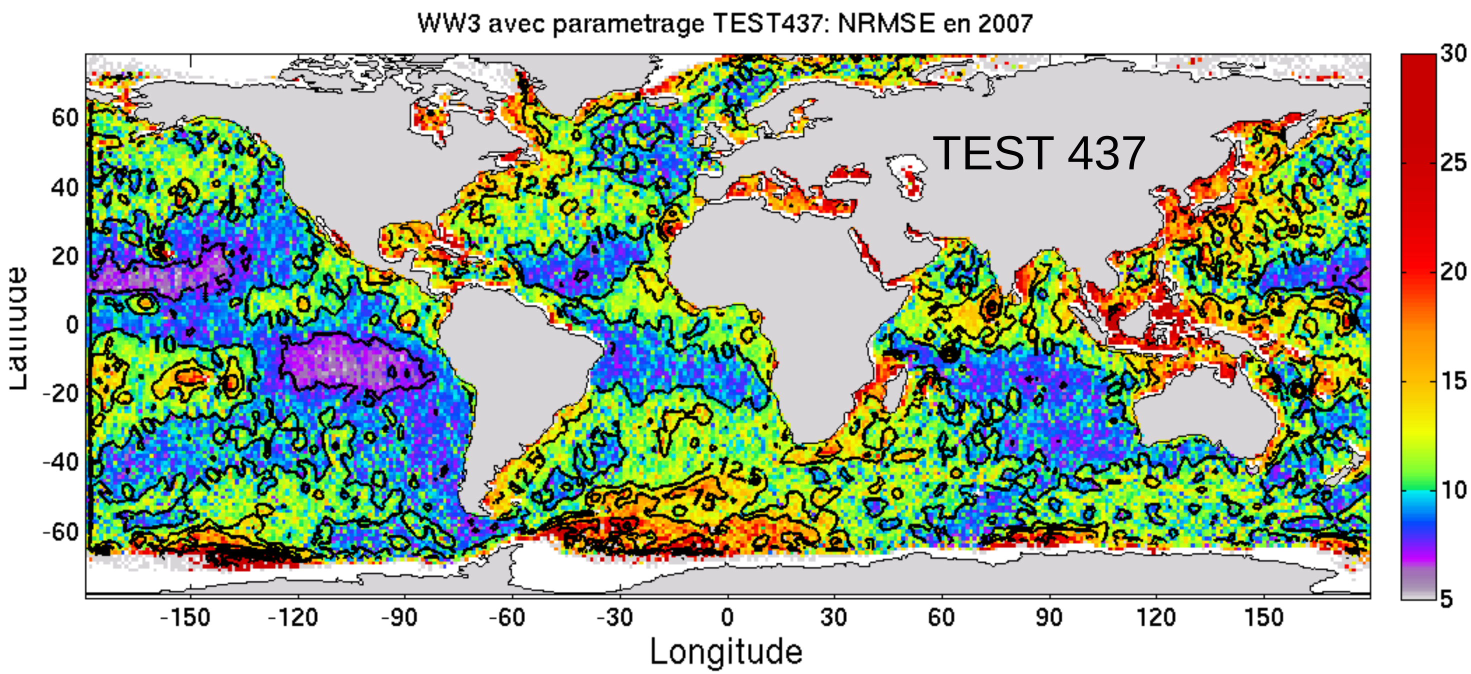
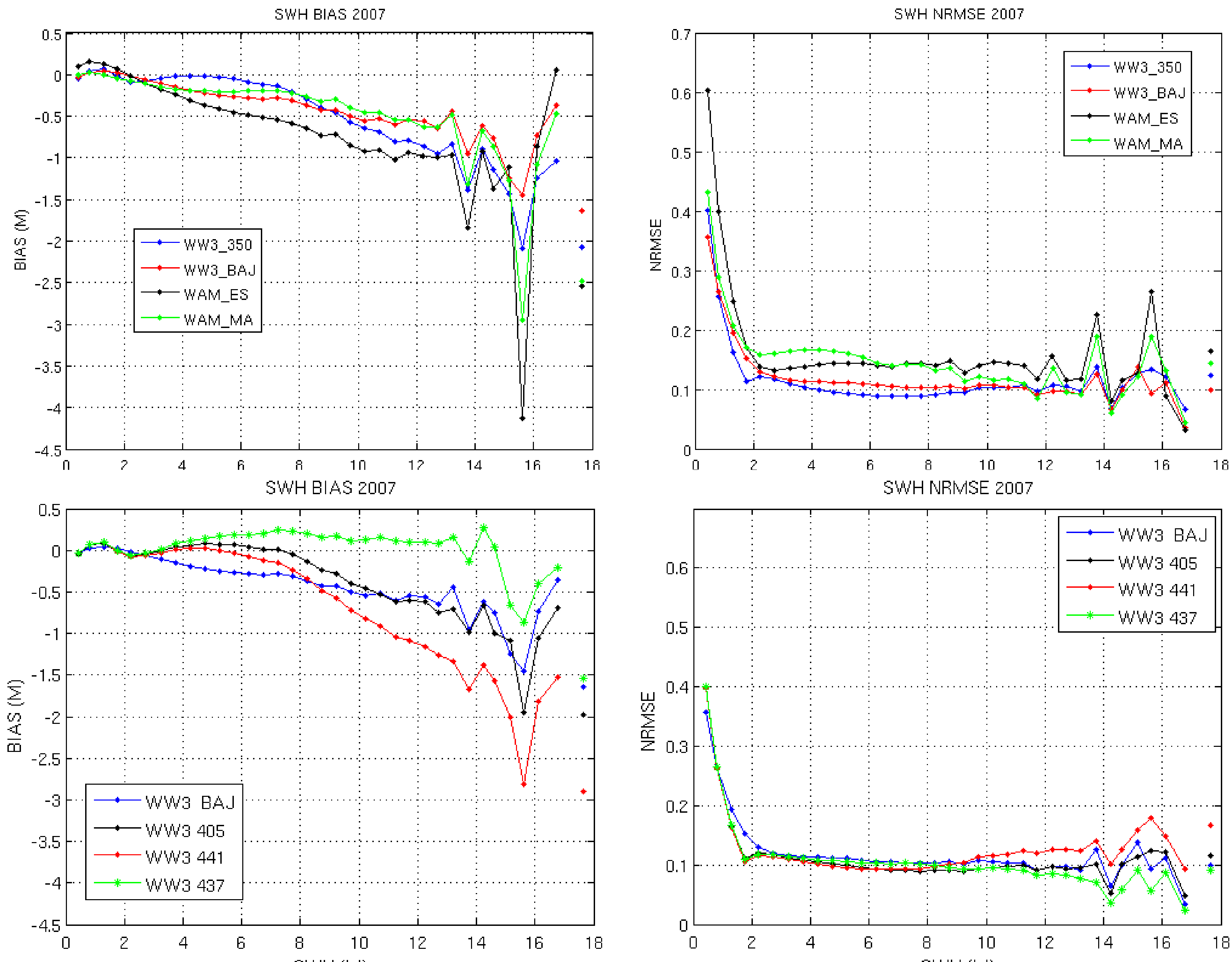
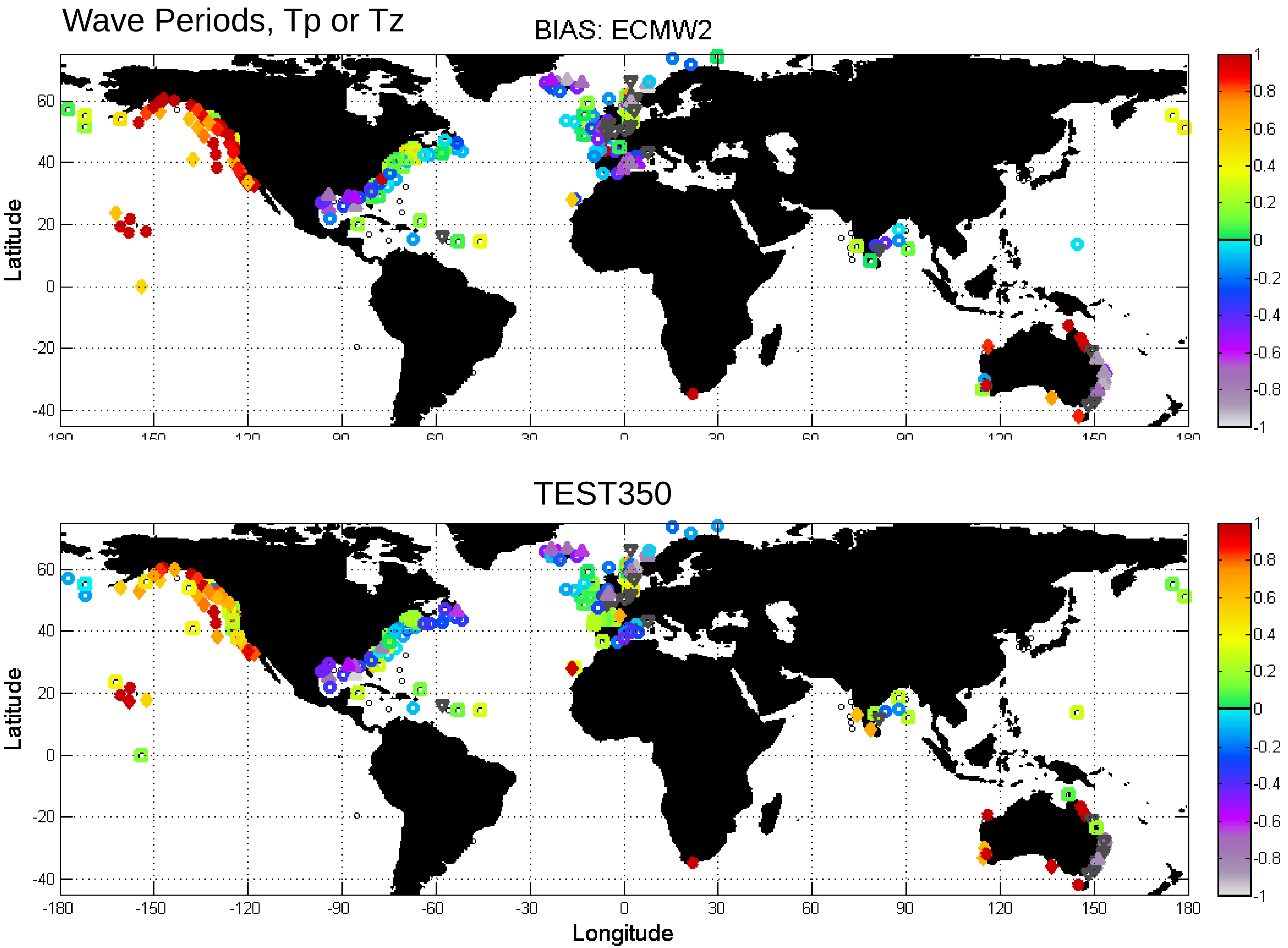


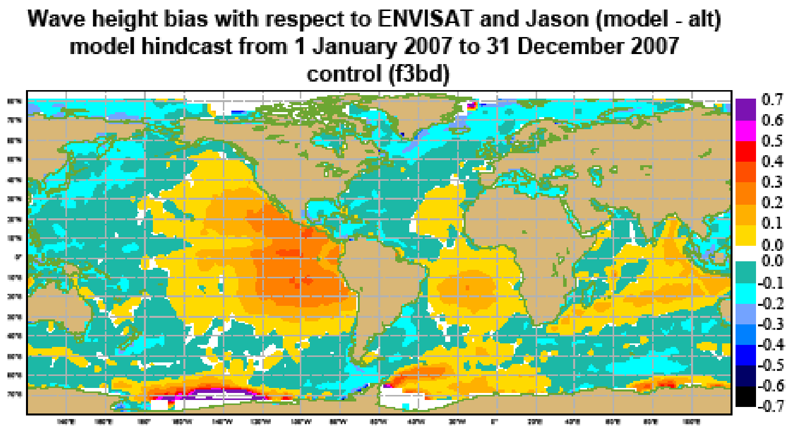




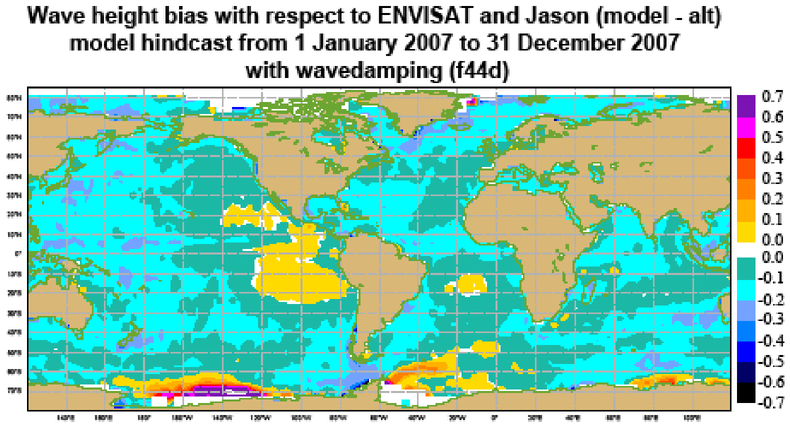
SWH BIAS 2007
BIAS (M)
WW3_350
WW3_BAJ
WAM_ES
WAM_MA
SWH NRMSE 2007
NRMSE
WW3_350
WW3_BAJ
WAM_ES
WAM_MA
SWH BIAS 2007
BIAS (M)
WW3 BAJ
WW3 405
WW3 441
WW3 437
SWH (M)
SWH NRMSE 2007
NRMSE
WW3 BAJ
WW3 405
WW3 441
WW3 437
SWH (M)



Wave Periods, Tp or Tz
BIAS: ECMW2
TEST350
Latitude
Longitude
60
40
20
0
-20
-40
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1



2. One year simulation (2007) with validation with ENVISAT and Jason



Janssen and Bidlot, 2009

Concluding remarks

ecause of their global coverage, importance of satellite data for validation nd calibration of model parametrizations (Altimeter and SAR), in situ data e however crucial (calibration of satellite data, 1D spectra with omemtum, Directional information…)

gnificant reduction of model errors (bias and rmse) with new arametrizations (Ardhuin et al. 2009), for Hs and Periods

- in the tropics (swell reduction)
- In wave growth areas (continent’s east coasts)

owever, preliminary calibrations (!) because TEST441 not suitable for high e state forecast, and TEST 337 too strong in the SH.

ompare BAJ+ Swell dissipation (RDT) with TESTXXX