IMPLEMENTATION OF NEW SOURCE TERMS IN A 3G WAVE MODEL

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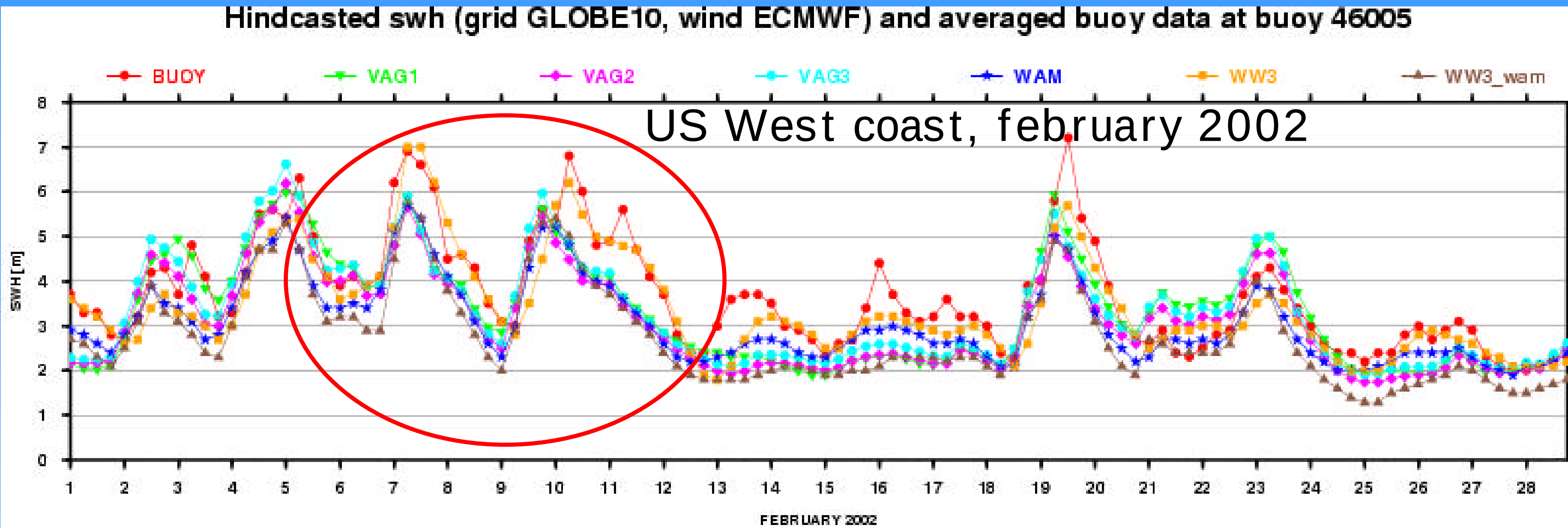
Motivations

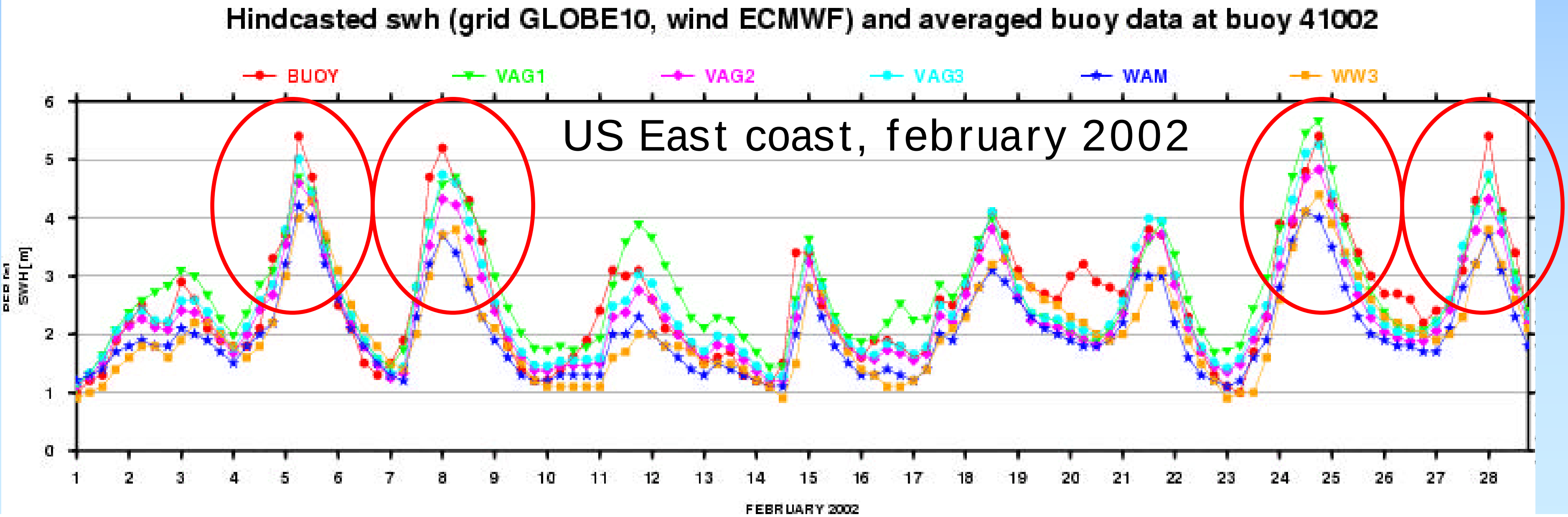
In a recent intercomparison study (Lefèvre et al. 2003, Isope conference, WISE 2003 meeting) with VAG (2G model), WAM and WW3, it has been found that:

- VAG and WAM are **under predicting high swell systems** (often, wind sea and swell are mixed for such cases). **WW3 performs very well to predict high swells** due to the source terms (no significant impact of the WW3 propagation scheme)

- **In small to moderate fetch conditions** (typical distance from US coast to buoys locations 100-400 km), **WAM and WW3 underpredict** wave heights by about **15%** in winter. For smaller fetch (< 100 km, in the Med Sea for instance, Cavaleri et al., WISE meeting 2003), the **underprediction** is even **larger** for **WW3.**

Motivations (Cont.): Typical examples





Motivations (Cont.)

- An explanation for such WAM4 behaviour can be found in **Banner and Young 94 and Alves and Banner 2002** : the WAM4 dissipation formulation results in the dissipation rate at the spectral peak that is too low during very young sea growth and too strong for old wind seas.

- The dissipation formulation as it is implemented in WAM4 is very **sensitive on the occurrence of swell or wind sea in mixed sea-swell** situations as shown by Ardhuin et al. (WISE 2003) in a SHOWEX study.

- A modern WOWC theory was recently developed by Makin and Kudryastsev (1999, 2001, 2002)

- This theory based on the direct coupling of waves of all scales to the wind accounts for stress **due to the separation of the airflow (AFS)** from short and dominant waves and also for the **wave-induced stress**.

- The parameterization of the surface stress **(sea drag**) is based on this theory and it accounts for the **wind speed**, wave age (and finite bottom dependencies of the surface stress in shalow water).

Motivations (Cont.) and Content

- New formulations of wind input and dissipation due to the wave breaking, based on the new understanding of physics of the processes, have been implemented by Makin and Stam (2003) in NEDWAM, calibrated and tested in the **North Sea** (with shallow water conditions!).

- **Need for an Assessment in a global wave model with deep water conditions**: Implementation in WAM

Content

- **The new sea drag parameterization and wind input and dissipation source terms formulations introduced in the WAM model**
- **Description of the models and buoy data**
- **Sensitivity and intercomparison study**
- **Conclusions and perspectives**

The new dissipation source term introduced in the wave model

Additional term compared to WAM3 introduced in WAM4 to balance WOWC input source term from Jansen 91

The dissipation source term :

$$S_{ds} = \gamma_{dis}\omega F$$

- Janssen (1994) → WAM 4.0:

$$\gamma_{dis} = -C_{dis}\frac{\langle\omega\rangle}{\omega}\left(\frac{\alpha}{\alpha_{PM}}\right)^2\frac{k}{2\langle k\rangle}\left(1+\frac{k}{\langle k\rangle}\right)$$

with $C_{dis}=9.4\ 10^{-5}$

$$\alpha = E\langle k\rangle^2$$

integral spectral steepness

- Alves and Banner (2003) → new formulation:

$m=2$, $n=1$, $C_{dis}=2.5\ 10^{-5}$, $Br=4\ 10^{-3}$

$$\gamma_{dis} = -C^b_{dis}\left(\frac{\alpha}{\alpha_{PM}}\right)^m\left(\frac{B(k)}{B_r}\right)^{p/2}\left(\frac{k}{\langle k\rangle}\right)^n$$

with

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

local saturation parameter

and

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

- **p = 0 when B(k)<Br (Br is a threshold saturation parameter), corresponds to the background diss. rate of swell. The A&B formulation is then very similar to WAM3 (ω in A&B instead of < ω >, leading to a slightly smaller dissipation of swell and a stronger dissipation of sea.**

- $p=p_0=6$ otherwise (steep waves)

The new sea drag parameterization and wind input source terms

The wind input source term : $S_{in} = bwF$

- Janssen (1991) $\rightarrow$ WAM 4.0.

$$b = \frac{r_a}{r_w} m_b \left(\frac{u_*}{c} + z_a\right)^2 \cos^2(q - q_w)$$

u_* is the sea-state dependant friction velocity

$$m_b = \frac{1.2}{km} \ln^4 m \quad k = 0.4$$

$$m = \frac{g z_0}{c^2} \exp\left(\frac{k}{u_* / c + z_a}\right)$$

$$z0 = 0.009 u_*^2 / g$$

- Makin and Kudryavtsev (1999) $\rightarrow$ new formulation:

$$\beta = \frac{\rho_a}{\rho_w} m_\beta R \left(\frac{u_*}{c}\right)^2 \cos(\theta - \theta_w) |\cos(\theta - \theta_w)|$$

Cb

$$m_b = 0.045$$

$$m_c = 0.3$$

$$n_c = 5$$

With $R = 1 - m_c \left(\frac{c}{u_{10}}\right)^{n_c}$ $\quad u_* / c$ is the wave age parameter

This is an extension of Plant (1982) relation for fast moving waves :

- R~1 for slowly moving waves, R~0 for fully dev. seas
- R is negative for fast moving waves or waves travelling against wind
- Cb=max(-20,Cb) (tests with Cb=max(-100,Cb))

Description of the models and buoy data

Models:

- VAG (2G)
- WAM
- WW3

- Different configurations of the WAM model were considered, depending on the wind input and dissipation formulations and the value of some thresholds used in the wind input source term for cb and in the dissipation term (p):

  - WAM_MM Makin input source term and Alves and Banner Diss.
    p=0, p=6, p=0t6

  - WAM_M3 Makin Input source term, WAM3 Diss term
  - WAM_M4 Makin Input source term, WAM4 Diss term

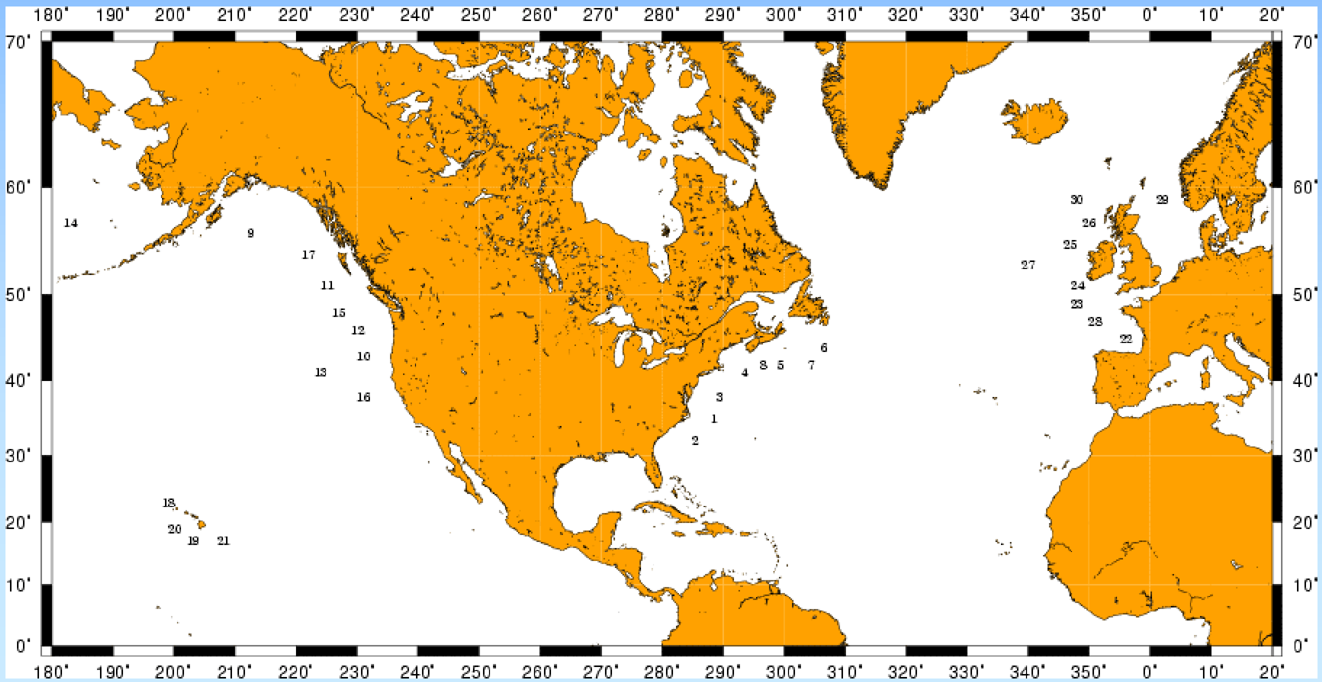
- 2 periods of 1 month: February and July 2002
- Global grid : 1° x 1°
- Wind input every 6h for all wave models from IFS/ECMWF NWP model

Buoy data:

- Wind speed and direction, swh and mean or peak period.

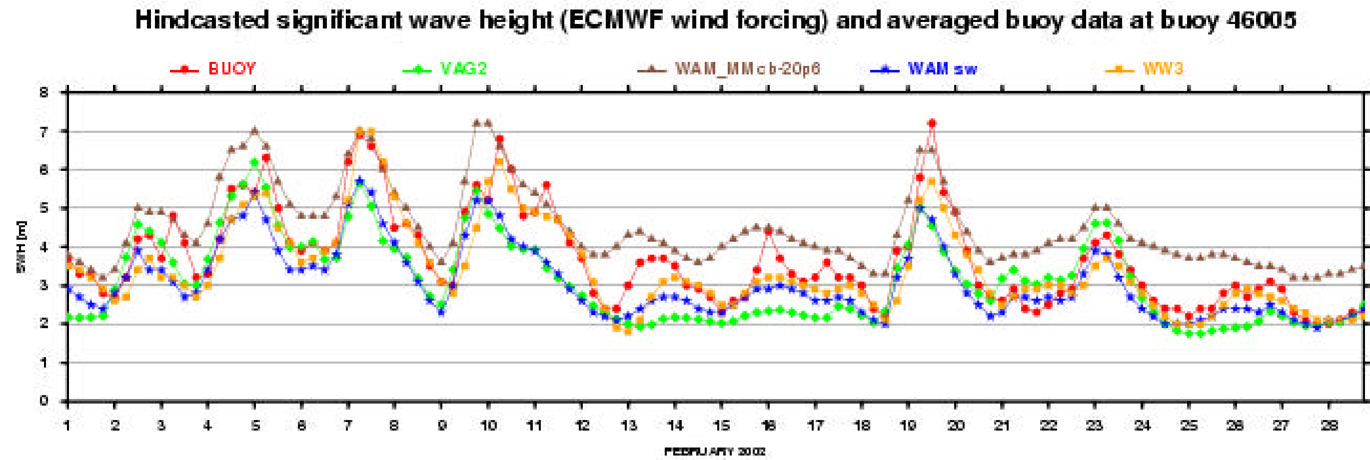
- Quality control and Averaged measurements available every hour (Procedure from the verification exchange centralized at ECMWF)

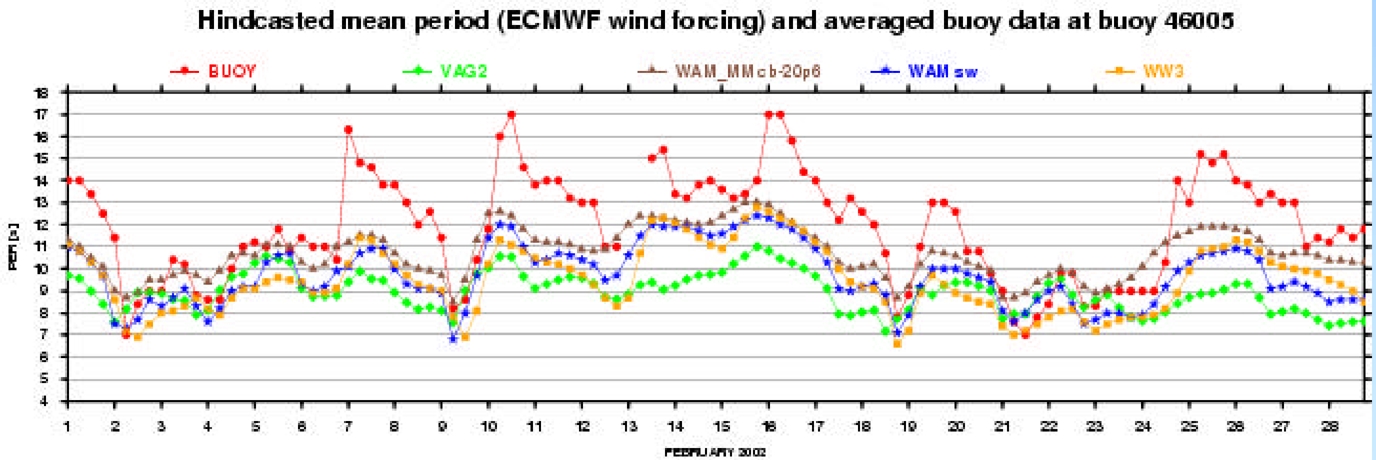
- Data from 30 moored buoys located in Northern Hemisphere



Sensitivity and intercomparison study

- Makin and Stam (2003) proposed cb=max(-20,cb) and a constant value for p, namely 6. The experiments showed that the swell dissipation is too small for *WAM_MM (p=6)* .





Sensitivity and intercomparison study

- The experiments made with *WAM_M4* showed swh values close to those obtained with WAM 4.0→ weak impact of the new input term

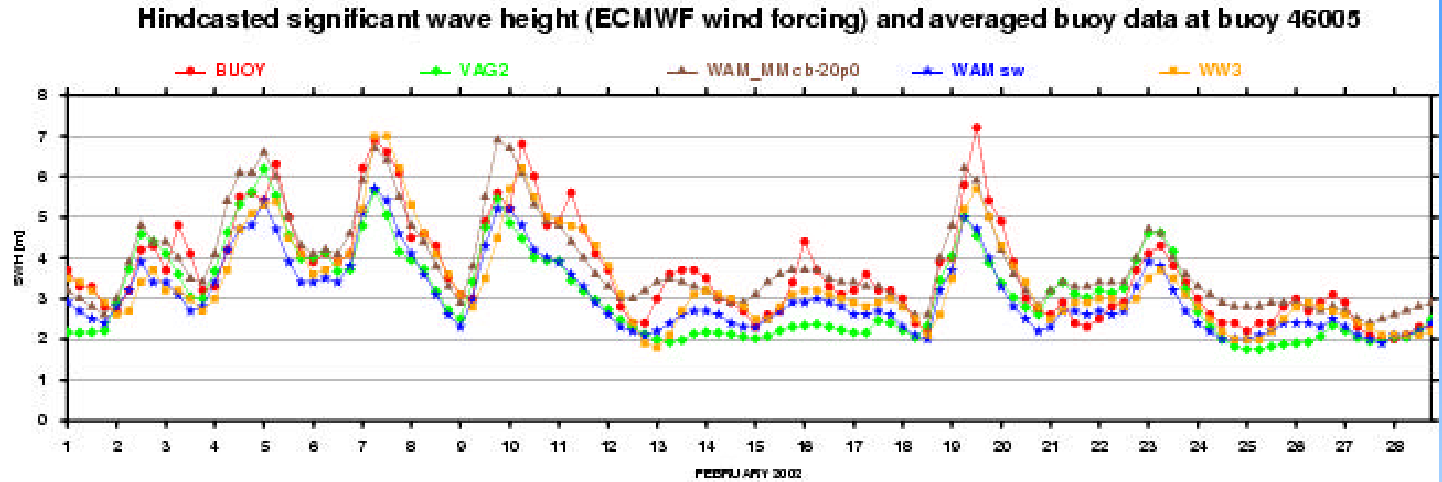
- By setting p=0, the results obtained with *WAM_MM (p=0)* are rather close to that ones obtained with *WAM_M3 as expected since A&B and WAM3 dissipation are then very similar.*

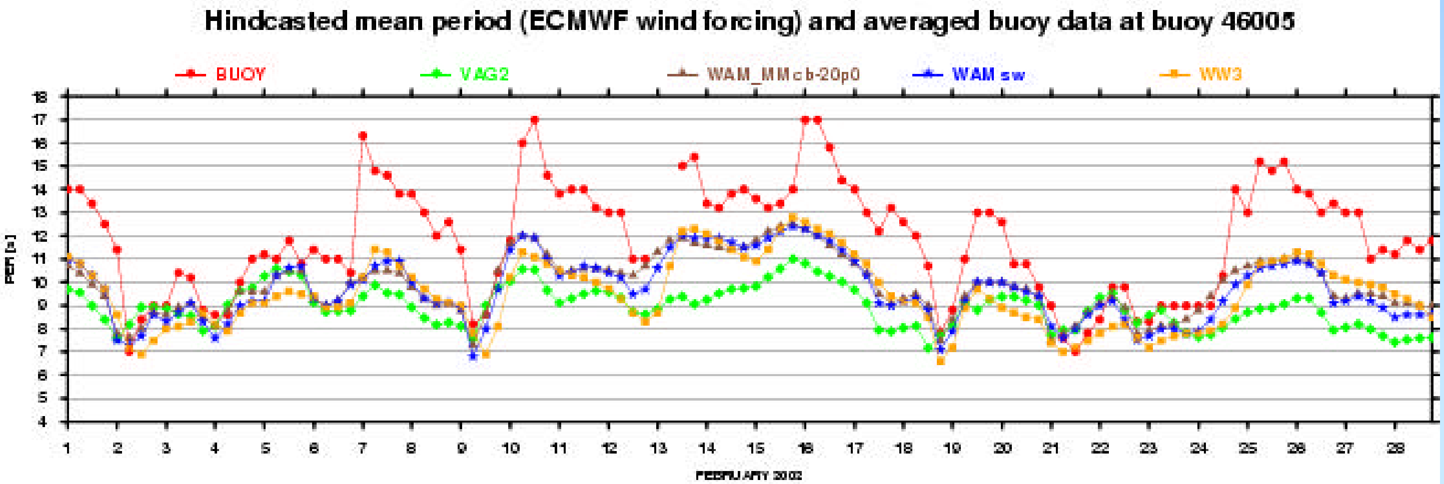
- p=0 works well for high swell prediction as WAM_M3 (not the case for WAM3), so there is an impact of Makin input term when WAM3 dissipation is used, unlike with WAM4 dissipation.

- Alves and Banner (2003) suggested that $(B(k)/B_r)^{(p/2)}$ should approach assimptotically 1 in case of spectral components with reduced local steepness, like swell (p=0).

Sensitivity and intercomparison study

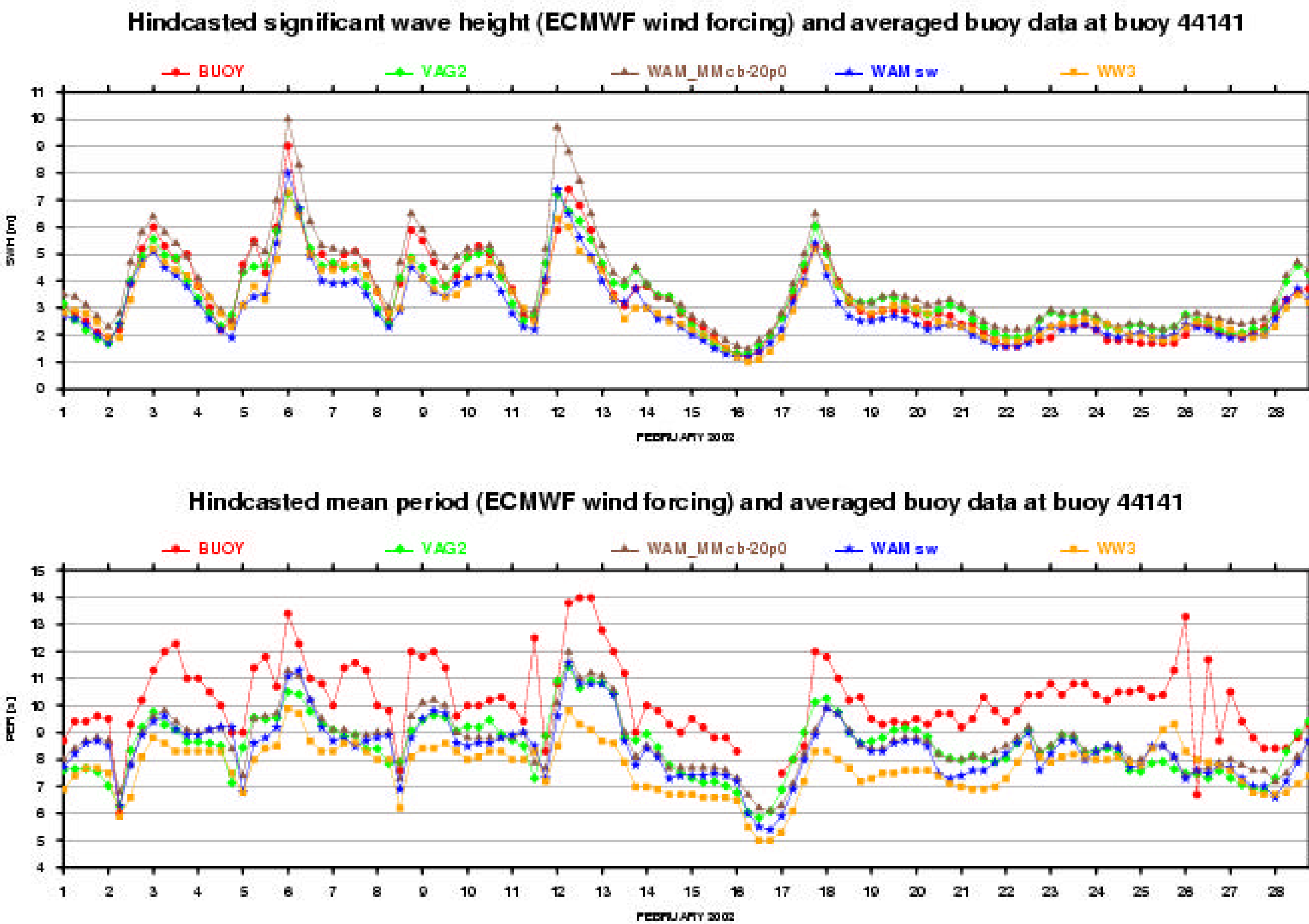
- Experiments showed that the swell dissipation is well described when p is set to 0 in *WAM_MM*.





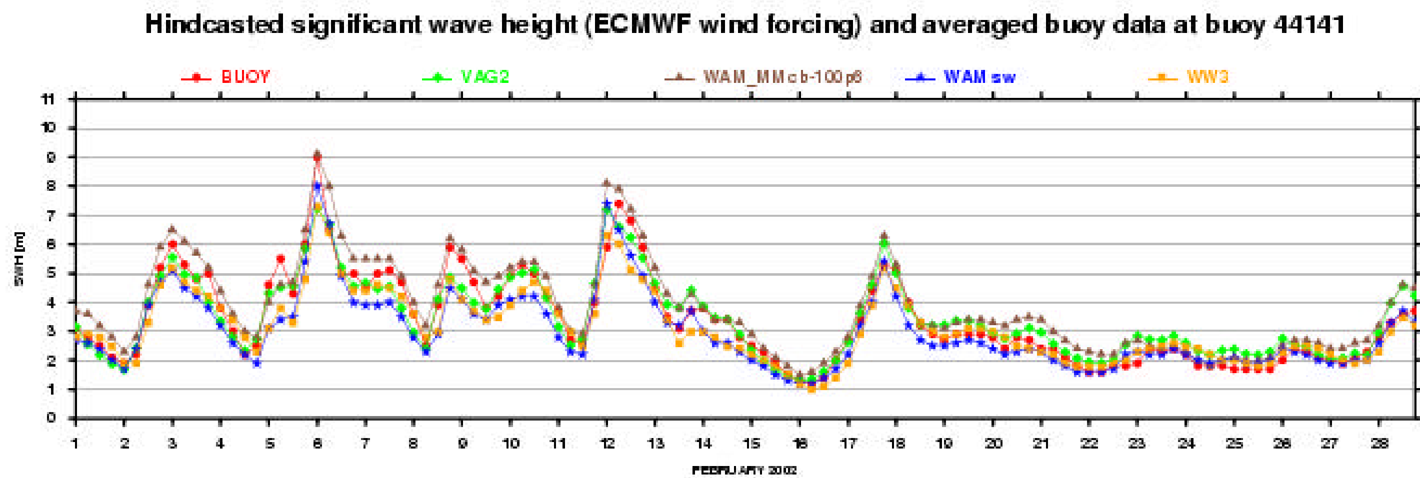
Sensitivity and intercomparison study

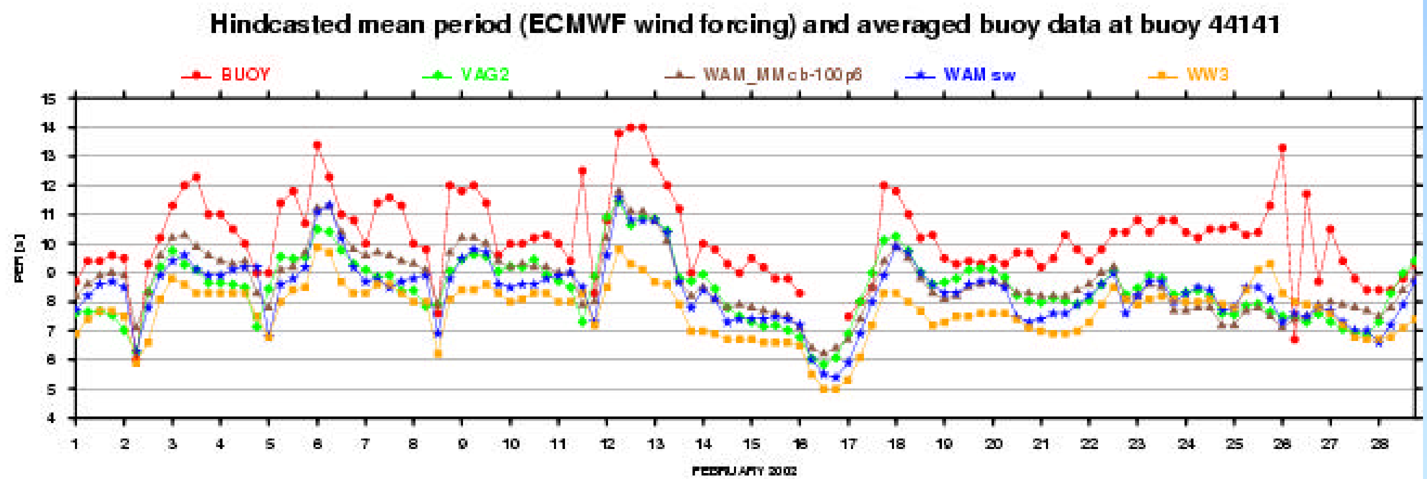
- But, for windsea situations, swh peaks are significantly overestimated in case of setting p=0 (the dissipation is too small)



Sensitivity and intercomparison study

- For waves with large local steepness ($(B(k)/B_r) > 1$), a constant value of p (p=6) gives good result with WAM_MM (sea dominant situations, Cb=max(-100,Cb).





Sensitivity and intercomparison study

- By decreasing the cb threshold from –20 to –100, when p=6 it is possible to improve the “mean behaviour” of the model but high swells are underpredicted (not shown).

- Therefore, and as expected, it appears that it is not appropriate to use a constant value for p in case of mixed windsea-swell situations, unlike in Makin and Stam implementation (2003).

- Alves and Banner (2003) suggested to define p as a function of the ratio ($B(k)/B_r$).

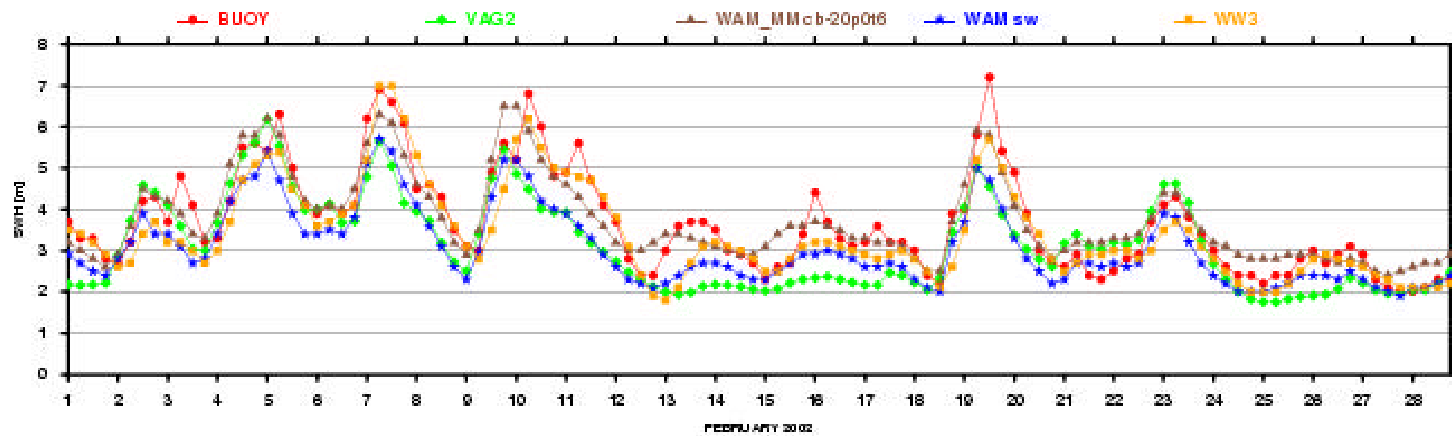
- In this way, p is equal to 0 for waves with a reduced local steepness (swells) and it takes a constant value p_0 (6 in our experiments) for waves with large local steepness (sea).

- The experiments made with *WAM_MM cb-20 p0t6* showed that the **improvements in swell dissipation are still kept**, while the **overestimation of the windsea peaks is removed**.

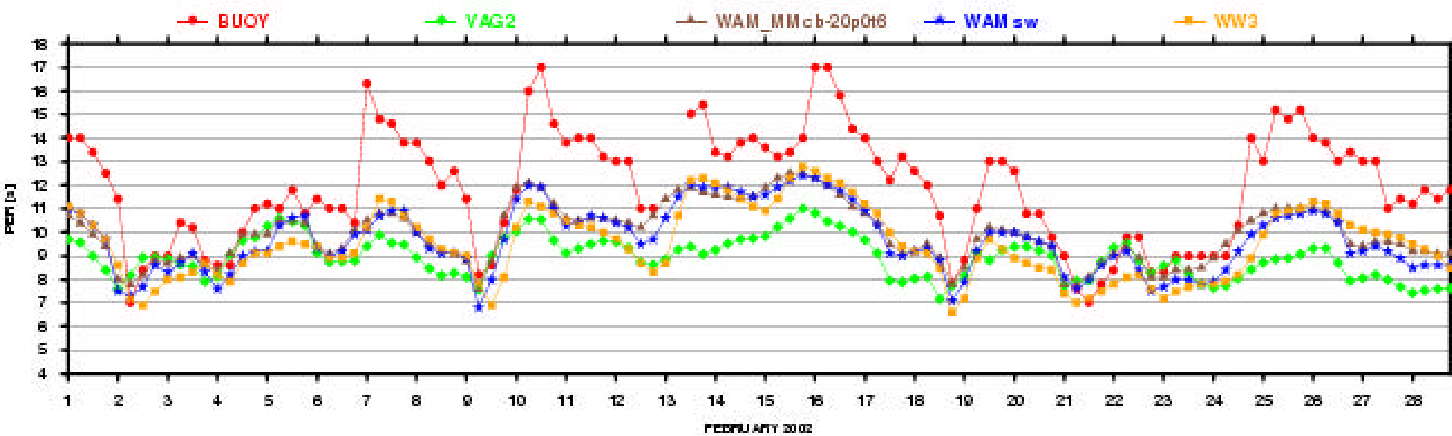
Swell cases

Sensitivity and intercomparison study

Hindcasted significant wave height (ECMWF wind forcing) and averaged buoy data at buoy 46005



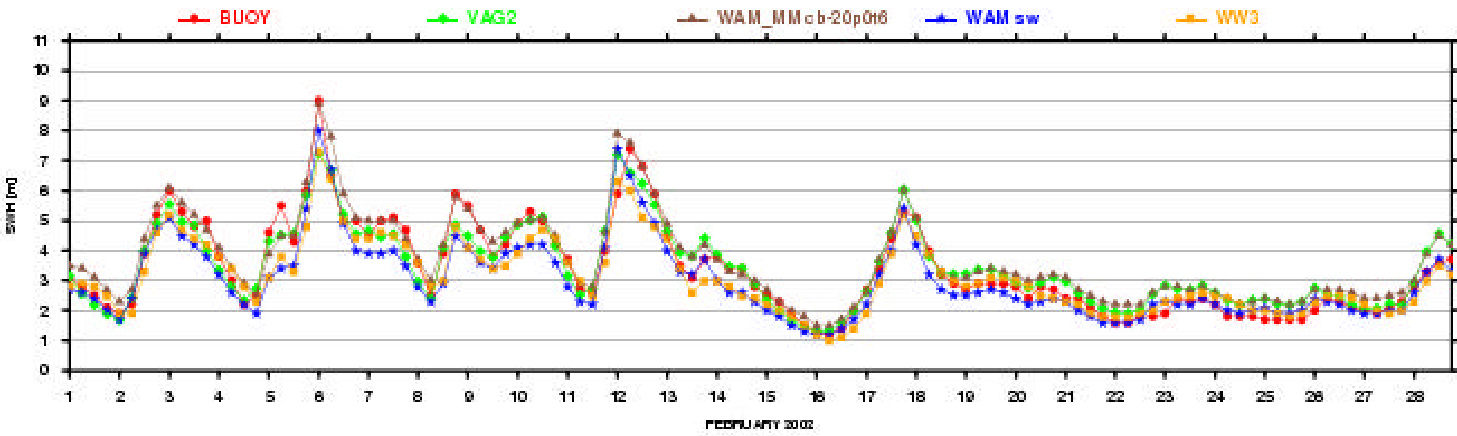
Hindcasted mean period (ECMWF wind forcing) and averaged buoy data at buoy 46005



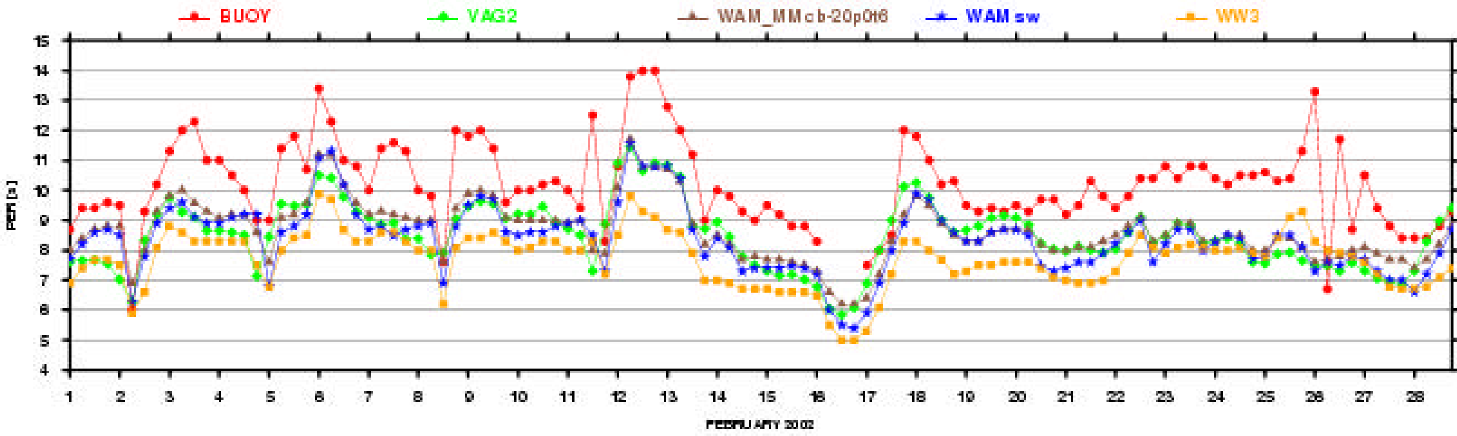
wind sea cases

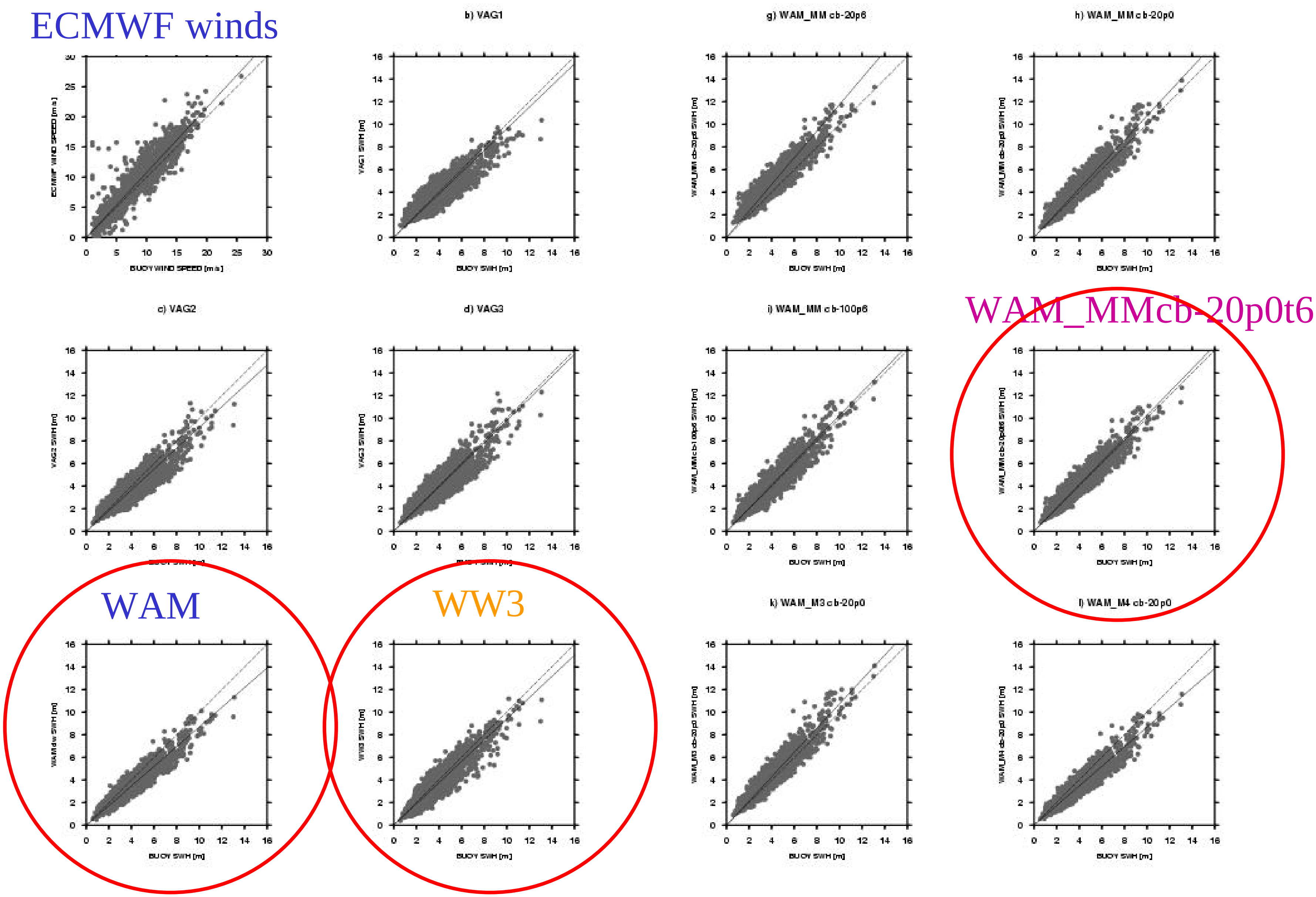
Sensitivity and intercomparison study

Hindcasted significant wave height (ECMWF wind forcing) and averaged buoy data at buoy 44141



Hindcasted mean period (ECMWF wind forcing) and averaged buoy data at buoy 44141




ECMWF winds
b) VAG1
g) WAM_MM cb-20p6
h) WAM_MMcb-20p0
BUOY WIND SPEED [m s]
BUOY SWH [m]
c) VAG2
d) VAG3
i) WAM_MM cb-100p6
WAM_MMcb-20p0t6
WAM
WW3
k) WAM_M3 cb-20p0
l) WAM_M4 cb-20p0

Sensitivity and intercomparison study

➢ Visual findings with SWH time series at different buoys locations are confirmed by global statistics for February 2002 (30 buoys):

Model	ECMWF	VAG1 dw	VAG2 dw	VAG3 dw	WAM dw	WW3 dw
No. of entries	2010	2490	2490	2490	2490	2490
Buoy mean	8.87	3.69	3.69	3.69	3.69	3.69
Bias	0.61	-0.08	-0.26	-0.05	-0.46	-0.24
Rms error	1.74	0.77	0.74	0.70	0.74	0.67
Scatter index	0.18	0.21	0.19	0.19	0.16	0.17
Symmetric slope	1.08	0.96	0.92	0.98	0.87	0.94

Model	WAM sw	WAM_MM sw (cb-20 p6)	WAM_MM sw (cb-20 p0)	WAM_MM sw (cb-100 p6)	WAM_MM sw (cb-20 p0t6)	WAM_M3 sw (cb-20 p0)	WAM_M4 sw (cb-20 p0)
No. of entries	2490	2490	2490	2490	2490	2490	2490
Buoy mean	3.69	3.69	3.69	3.69	3.69	3.69	3.69
Bias	-0.48	0.79	0.32	0.09	0.16	0.30	-0.49
Rms error	0.75	0.99	0.65	0.64	0.57	0.65	0.75
Scatter index	0.16	0.16	0.15	0.17	0.15	0.16	0.15
Symmetric slope	0.87	1.18	1.07	1.03	1.03	1.07	0.87

Sensitivity and intercomparison study

- Global statistics for July 2002:

Model	ECMWF	VAG1 dw	VAG2 dw	VAG3 dw	WAM dw	WW3 dw
No. of entries	2398	3316	3316	3316	3316	3316
Buoy mean	6.19	1.68	1.68	1.68	1.68	1.68
Bias	0.12	0.17	0.08	0.17	-0.02	-0.07
Rms error	1.08	0.41	0.36	0.40	0.34	0.31
Scatter index	0.17	0.23	0.21	0.22	0.20	0.18
Symmetric slope	1.02	1.08	1.02	1.08	0.97	0.96

Model	WAM sw	WAM_MM sw (cb-20 p6)	WAM_MM sw (cb-20 p0)	WAM_MM sw (cb-100 p6)	WAM_MM sw (cb-20 p0t6)	WAM_M3 sw (cb-20 p0)	WAM_M4 sw (cb-20 p0)
No. of entries	3316	3316	3316	3316	3316	3316	3316
Buoy mean	1.68	1.68	1.68	1.68	1.68	1.68	1.68
Bias	-0.05	0.81	0.33	0.08	0.30	0.26	-0.11
Rms error	0.33	0.89	0.45	0.33	0.43	0.39	0.31
Scatter index	0.20	0.23	0.19	0.19	0.19	0.17	0.18
Symmetric slope	0.95	1.43	1.17	1.05	1.15	1.13	0.92

- thought the SI is also smaller for WAM_MM in summer, SWH are overestimated: some tuning has to be performed.

Conclusions and perspectives

- A new parameterization of the sea drag as well as new formulations of wind input and dissipation source terms have been implemented in WAM and tested on a global grid.

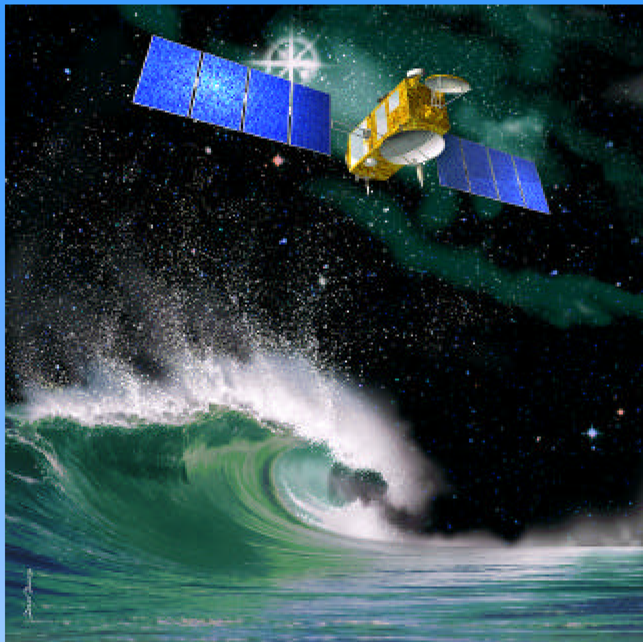
- Different configurations of WAM have been investigated, depending on the wind input and dissipation formulations and the value of some coefficients (but only for the threshold for negative cb, finally set as in NEDWAM and p finally set as in Alves and Banner)

- Improvements for predicting high waves for various conditions (dominant wind sea, dominant swell, mixed) have been found for ***WAM_MM cb-20 p0t6*** configuration with in many cases some reduction of bias and rms error of SWH parameter.

- A refinement of the coefficients for a better balance of the new physical parameterizations, together with an assessment of the wave periods, spectral shapes, directional spreads is on going.

  - → we also plan to use altimeter wind/wave data (SWH, Mean wave period):

    JASON-1, ENVISAT



•Since July 2003, Meteo-France has been putting wind/wave JASON/OSDR products on the WMO GTS, making them available in near real-time (less than 3 hours) to the international meteorological community.

JASON-1

•Since May 2004, these data have been introduced) into Meteo-France's sea-state forecasting systems.