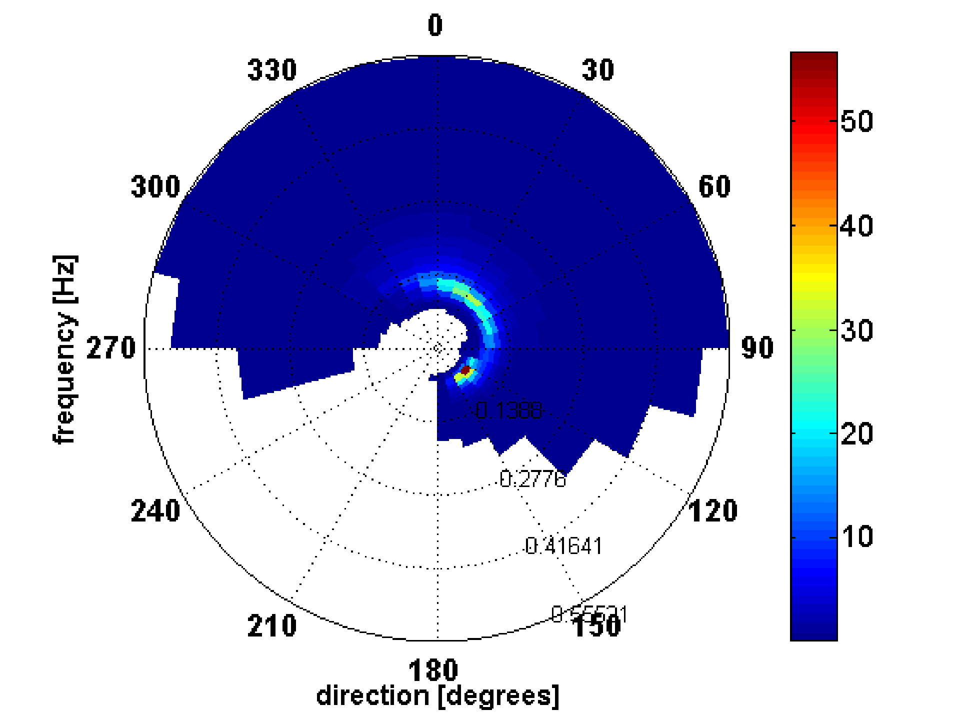
The impact of the assimilation of altimeters and ASAR L2 wave data in the wave model MFWAM



Lotfi Aouf [1], Jean-Michel Lefèvre [1]

1) Météo-France, Toulouse

12th Wave Hindcasting and Forecasting, Big Island
3 November 2011

METEO FRANCE
Toujours un temps d'avance

Motivation

→ Assessement of the assimilation system in the new wave model MFWAM (improving the wave forecast)

→ Satellite wave observations (Jason-1,Jason-2, Envisat Ra2 and ASAR, Cryosat-2) are available and are very helpful to correct the model errors

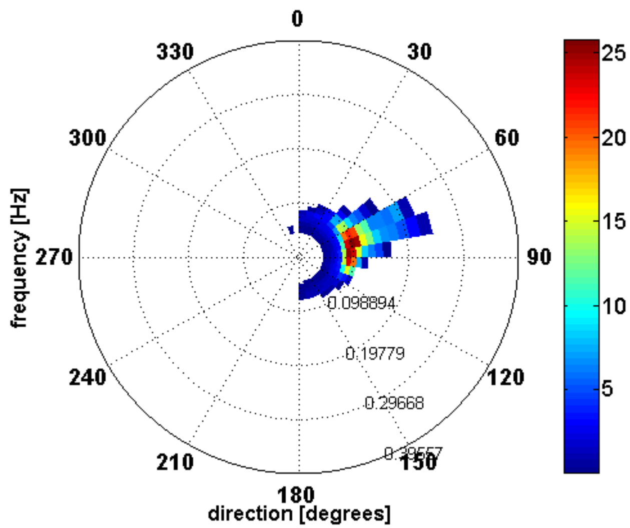
→ Preparation to future satellite missions CFOSAT, Altika, Jason3)

→ → complementary use of different instruments

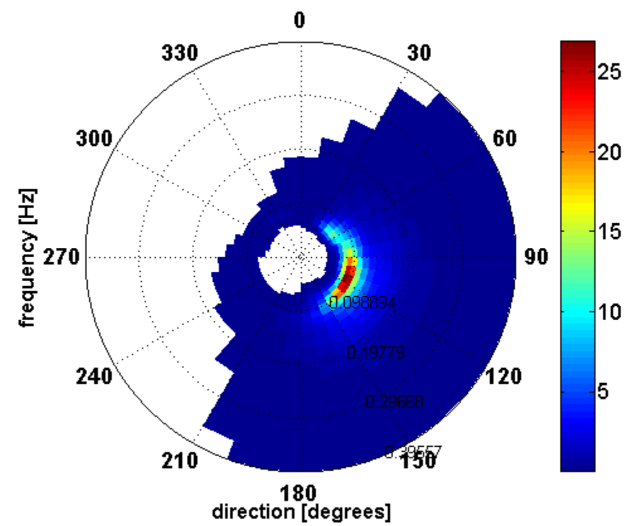
Assimilation of satellite data (Altimeters, SAR) to improve Off shore Sea-state analyses and predictions

→ Provide more accurate boundary conditions to coastal wave models

ENVISAT ASAR (only long waves are detected if travelling in the azytmutal direction)



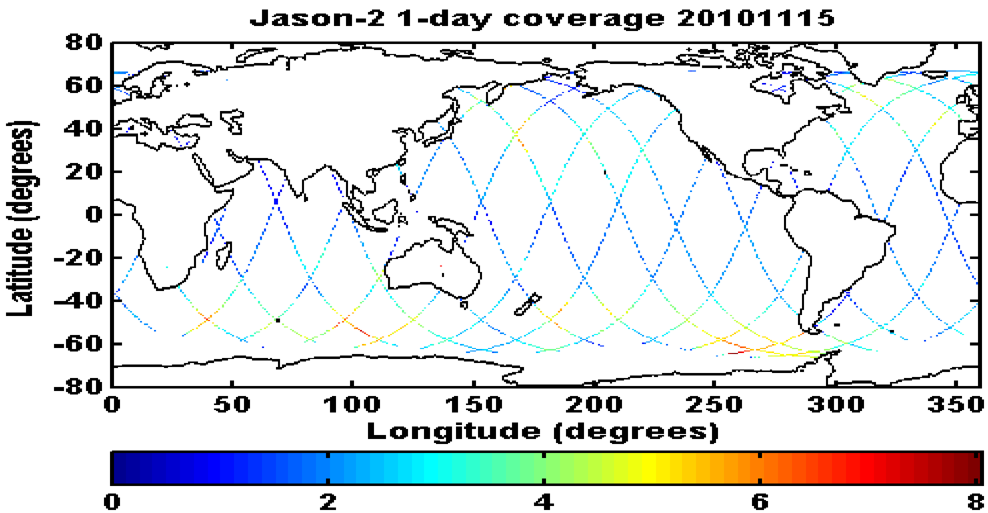
MFWAM (3G global Model)



→Differences between wave directions from model and observation (ENVISAT/ASAR)
→Simple OI scheme is used to correct the model mean wave direction, energy and frequenc
then the model wave spectrum is corected according to the new mean parameters
→ Altimeter data (from ENVISAT and JASON) are also used to correct the energy spectr

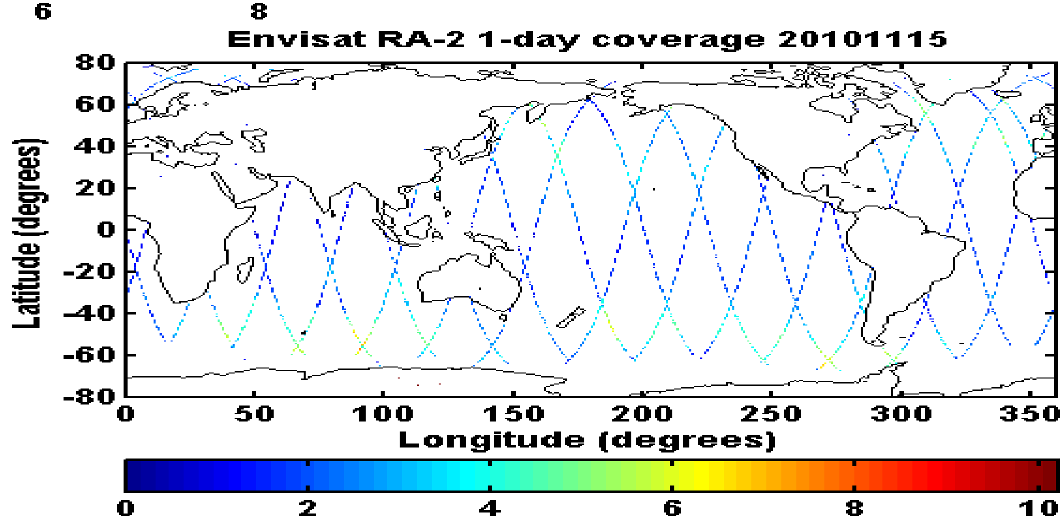
Altimeters wave data (Jason-2 and Envisat-RA2

Jason-2



Example of 1 day global coverage of total wave height

ENVISAT RA-2



~ 2500 data/altimeter

METEO FRANCE
Toujours un temps d'avance

Methodology

1- Implementation of the assimilation system

- Preparation of the wave data : Quality control procedure

- The assimilation technique (distribution of covariance errors of model and observation, partitioning and optimal interpolation)

2- Investigating different scenarios of assimilation runs (altimeters or directional wave spectra)
→ quantifying the contribution of each instrument

3- Validation with independent wave data

Conclusions

--> How efficient the assimilation is

--> The contribution of each instrument for the impact

--> positive impact of the assimilation in case of high waves (huricane season 2011)

--> Ways to optimize the assimilation system

The world's biggest waves (no, not Australia, just across the Channel!)

by **Michael Hanlon**

THEY called it La Belharra — Basque for 'The Gigantic One' — a series of three gigantic waves which appeared out of nowhere, three miles off the Atlantic coast on the French-Spanish border. Such monsters are seldom found, even at the world's most extreme surfing spots off the coasts of Mexico and Hawaii, where the Pacific allows true giants to form.

But in the Bay of Biscay, breaking rollers off St-Jean-de-Luz normally average 8-12ft. This time they were nearly ten times that. On June 2, locals noticed a larger-than-normal swell building up about two miles offshore. The waves had been getting larger all day, drawing surfers to the beach, and now the offshore swell was so huge it was visible from the bars that line the spectacular coastline between Hossegor, Biarritz and St Jean. Yet the weather was clear and there had not been the type of tropical storm in the Atlantic that could generate such water mountains.

Soon, local surfers led by professional Fred Basse, seen in these extraordinary pictures by photographer Eric Chauche, were scampering out to tackle the incoming giants. To catch the wave, Fred and his fellow surfers had to hitch a ride on jetskis — using arm-power alone, they could not move fast enough.

It is impossible to overstate how dramatic — or dangerous — a wave 70-100ft high can be. It contains enough kinetic energy to power a small town. Should one break on your body, you would be subjected to a force of 120 tons — similar to being run over by a tank. And should a surfer get it wrong, he would be crushed and hauled along the seabed for four minutes. But if he gets it right, it is a once-in-a-lifetime thrill.

When the surfer reaches a high point in the face of the wave, he will pull away from the jetski — which continues safely over the top. Only the very best can hope to surf a wave as big as a ten-storey office block and live. The trick is to stay ahead of the surf, and avoid being 'dumped' as the crest topples over. So how was this extraordinary series of waves created? The seabed on this part of the French coast is is fairly shallow — but offshore from Hossegor, a surfing town 20 miles north of Biarritz, is an underwater channel, two miles deep, leading from the Atlantic floor. This acts as a funnel, forcing the water over huge sand dunes on the seabed, where the waves build and break. Until recently, 70ft waves were thought impossible. It was believed that only an under-sea earthquake or volcanic eruption could create a truly giant breaker — a tsunami.

But the cause here was something that has been recognised only recently: the rogue wave. Yet while rogue waves may be a mariner's nightmare, they are a dream come true to surfers. But only for the most brave.

What a high: Professional surfer Fred Basse displays his skill — and his bravery

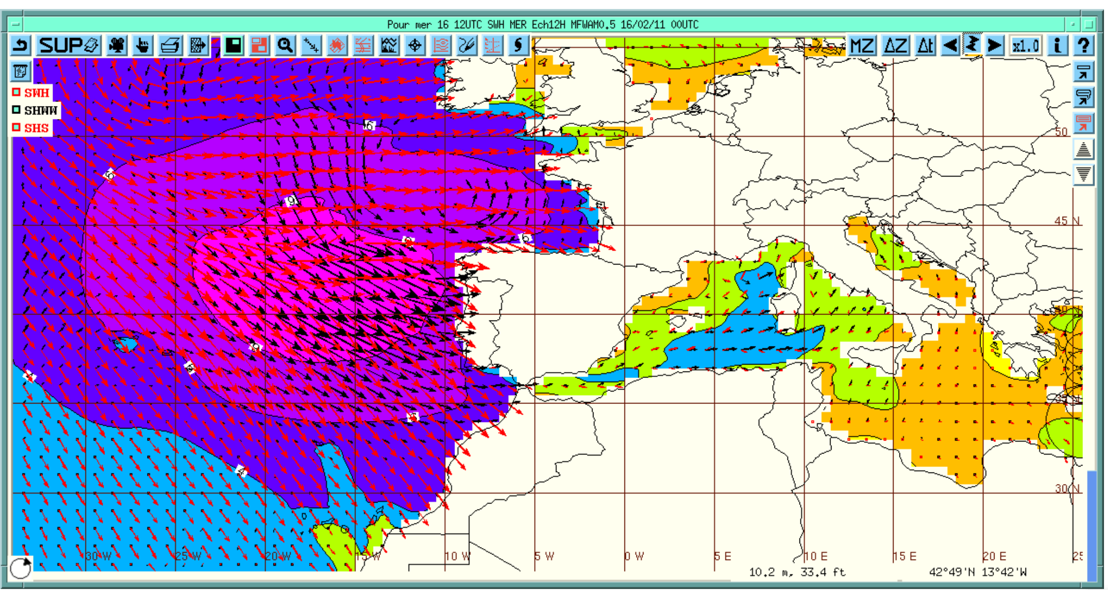
Thrill of the chase: The massive waves can be as big as a ten-storey office block

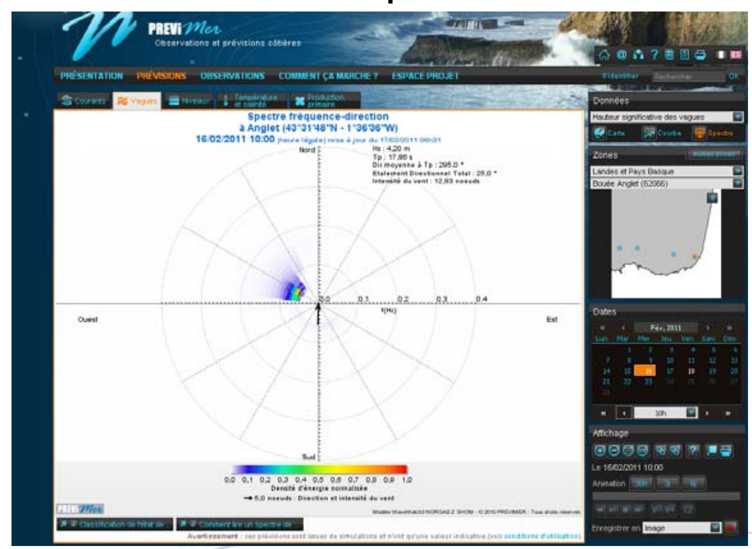
Meteo-France is responsible for issuing marine forecasts (wind and sea-state) at national level (Safety of people and goods, Navy, …) and international level (GMDSS: Global Maritime Distress and Safety System)

Setting a new warning system for coastal innundation and high waves

Need for improving global and coastal wave predictions

Belharra wave





METEO FRANCE
Toujours un temps d'avance

New Wave model: MFWAM
improvement and validation partly thanks to Altimetry

Based on ECWAM code with new physics for dissipation: (Ardhuin et al. 2010, JPO)

- Non isotropic dissipation:
  -> Better adjustment of the mean direction and angular spreading

- Threshold mechanism from the saturation spectrum , instead of mean wave steepness dependency
  Breaking term:
  -> avoid too strong dissipation of swell and too strong generation of wind sea for mixed wind sea-swell situations

- New term for swell damping due to air friction

Global version running at 55 km resolution (Gaussian grid, irregular in longitude)

Regional version at 0.25 ° resolution running over South Indian Ocean

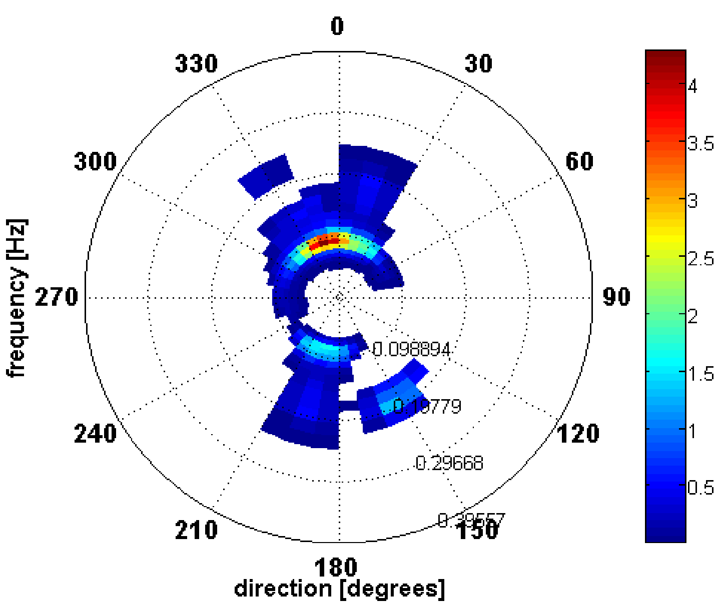
Regional versions for European Aera at 10 km resolution

METEO FRANCE
Toujours un temps d'avance

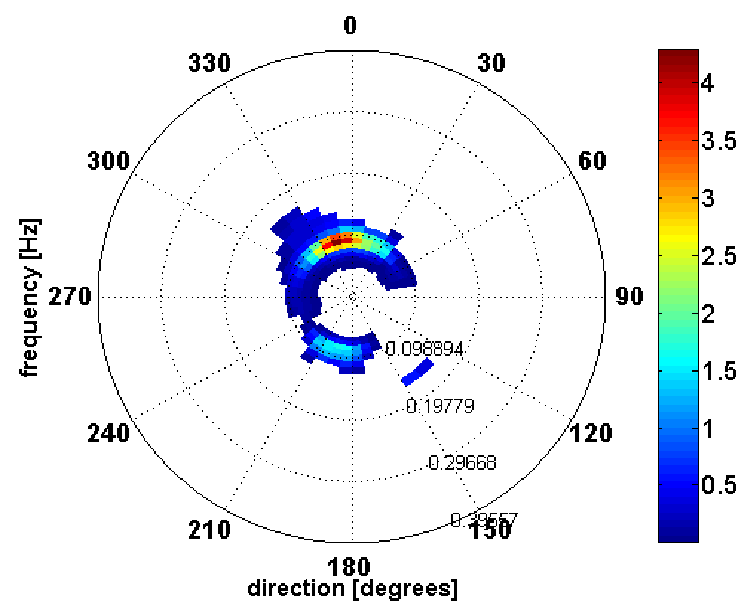
The ASAR level 2 wave mode provides:

- Quality control procedure for ASAR wave spectra has been assessed in our previous studies (Aouf et al. 2008) (Threshold intervals for signal parameters ratio of signal to noise (3<r <30), normalised variance of ASAR imagettes (1-1.6))
- Use of a variable cut-off for SAR wave spectra depending on the azimuthal cut-off, the orbit track angle and the wave direction from the model

ASAR wave spectrum (before cut-off)



After using variable cut-off



Description of the assimilation system

- Assimilation of altimeters RA2 and Jason-1
  - → Optimal interpolation on SWH (Significant wave height)
  - → Correction of wave spectra using empirical laws and assumptions

- Procedure for the assimilation of ASAR directionnal wave spectra

  → **Partitioning** principle (collecting different wave trains)

  → **Cross assignement** between partitions of first guess and ASAR (km-ko < 2)

  → **Optimal interpolation (OI)** on mean wave energy and the components of wave number of the selected partitions

  → **Reconstruction** of the analysed wave spectra

METEO FRANCE
Toujours un temps d'avance

Optimal interpolation

$$X^a = X^f + \sum_{i}^{N} W_i (X_{i^o} - HX_{i^f})$$

Where Xa and Xf stand for the analysed and first-guess wave parameters (energy, wave umber)

The corrected weights depend on the covariance error matrix :

$$W = PH^T \left[HPH^T + R \right]$$

P and R are respectively the background and observations covariance errors. While H is location operator

$$P = \sigma_i^f \sigma_j^f \exp\left(- \left(\frac{d_{ij}}{\lambda_c} \right) \right)$$ and $$R = \sigma_o^2$$

σ indicates the standard deviation and d is the distance between the observations and affected grid points (~1200km). While l stands for the λ correlation length (300 km).

Description of runs : from Sep 2010 to Mar 2011 (7 months)

- **Test runs set-up**
  - Wave model MFWAM 441 (global coverage 0.5x0.5° irregular grid), wave spectrum in 24 frequencies (starting 0.035 Hz) et 24 directions
  - ECMWF analysed winds every 6 hours
  - Assimilation timestep 6 hours

→ EXP1 : **Assimilation** of **ASAR** wave spectra and altimeters Ra-2 and Jason-2

→ EXP2 : **Assimilation ASAR** wave spectra and altimeter Ra-2

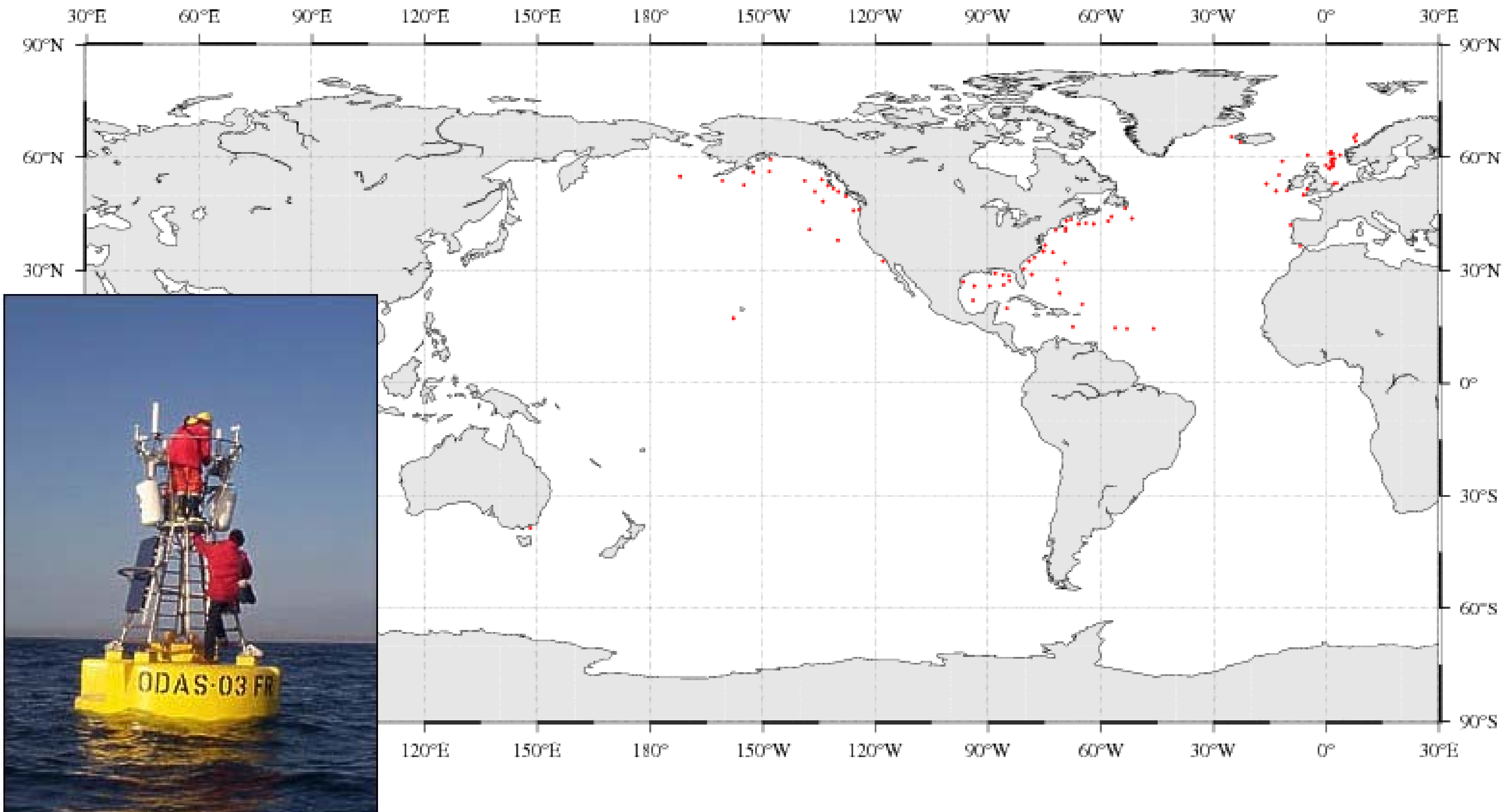
→ EXP3 : **Assimilation ASAR** wave spectra only

→ EXP4 : **Assimilation** altimeters RA2 and Jason-2 only

→ **Baseline** run without assimilation

Location of common Automatic Weather Stations AWS (wind + waves), all real time and on GTS

AWS located not very far from the coast and mainly in the northern hemisphere → partial model validation



Bouée 03FR le 16 mars 1999

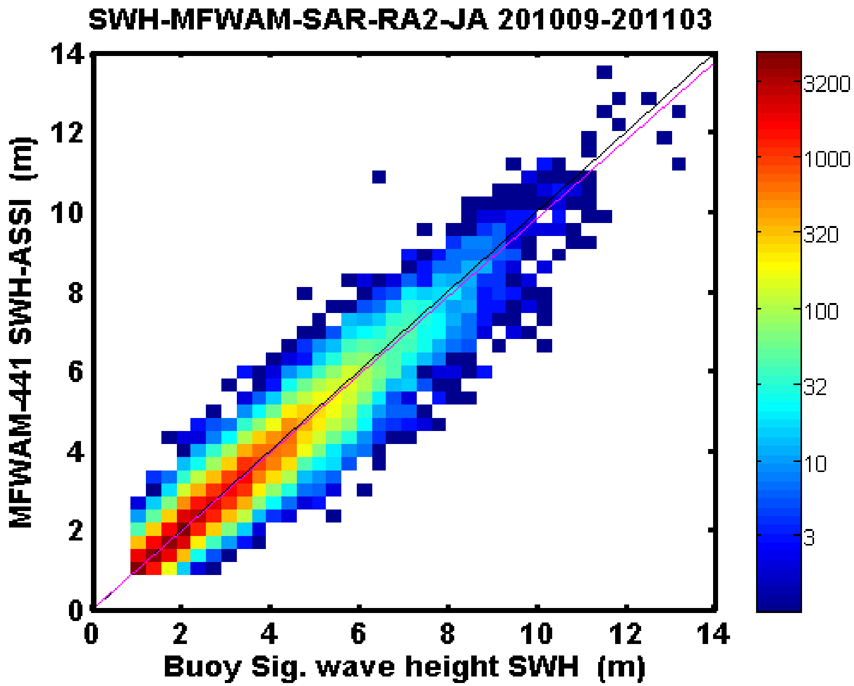
Photo Météo-France

METEO FRANCE
Toujours un temps d'avance

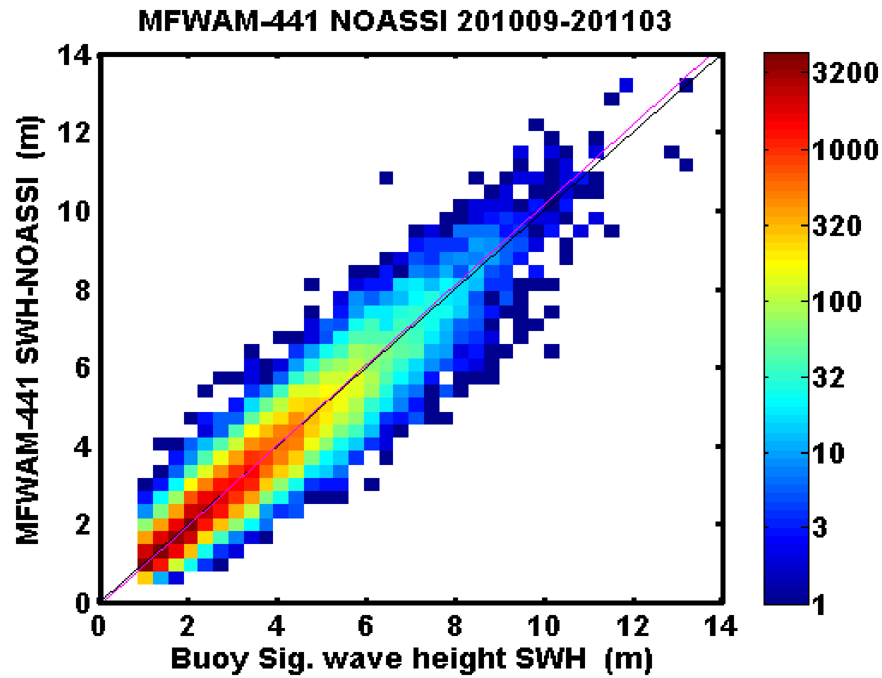
VALIDATION OF EXP1 WITH BUOY DATA (buoy data not assimilated)

MFWAM with assimilation of both altimeters and ASAR (jason-2, Envisat-Ra2 and ASAR)

With assimilation



Without assimilation



Bias = -0.03
SI = 14.2%
NRMS = 14.3%
Slope = 0.98
Intercept = 0.02

Significant wave height

Collected = 64880

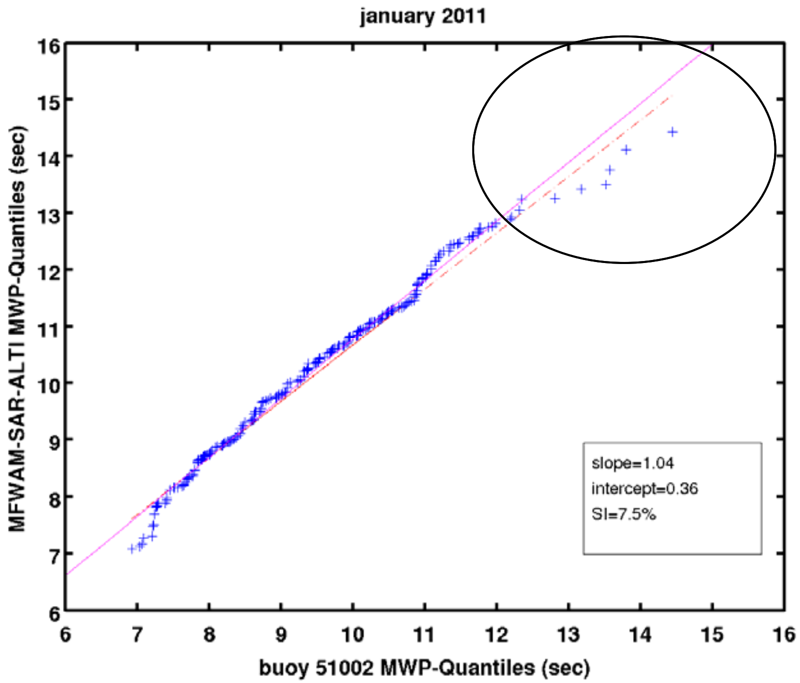
Bias=-0.02
SI=15.6%
NRMS=15.6%
Slope=1.02
Intercept=-0.08

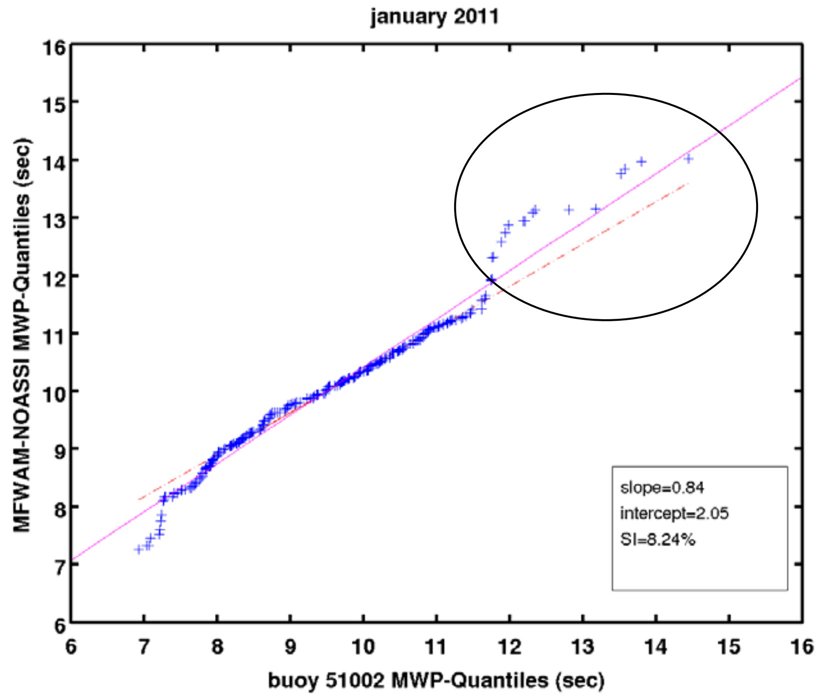
validation with Buoys data Sep 2010 to march 2011(7 months)

METEO FRANCE
Toujours un temps d'avance

Validation of the assimilation for mean period vs Buoy 51002

January 2011





Bias=0.24
RMSE=8%
SI=7.5%
Slope=1.04
Intercept=0.36

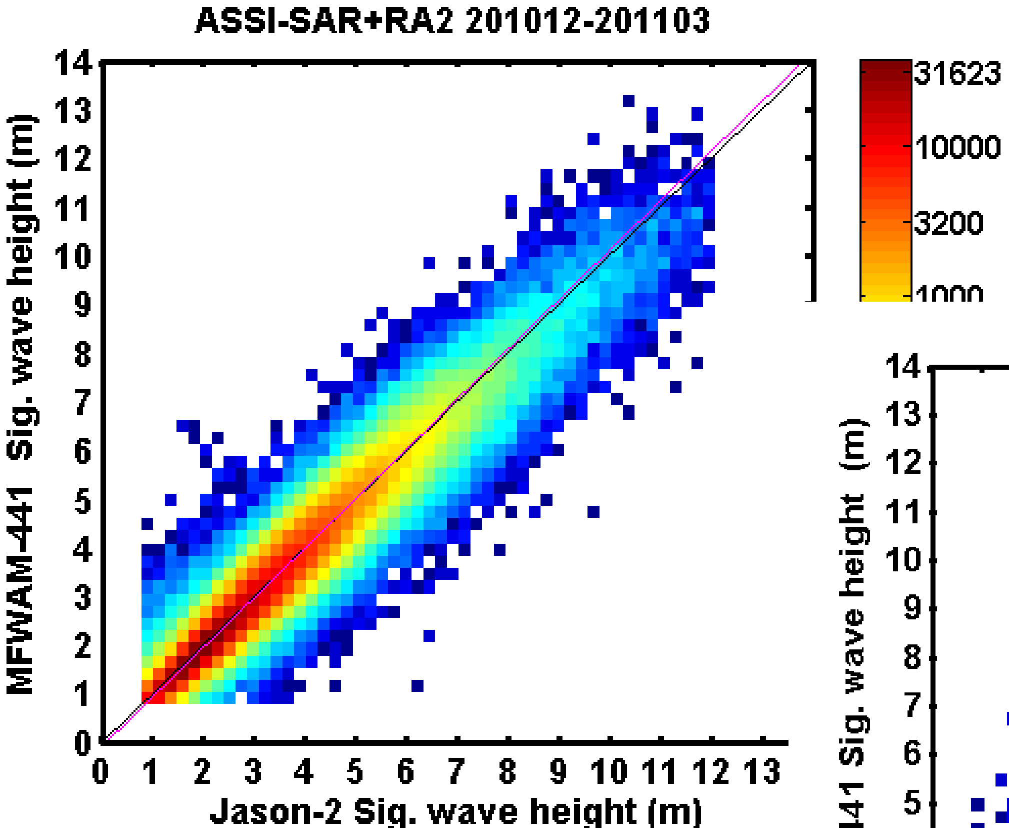
Bias=0.38
RMSE=8.8 %
SI=8.24 %
Slope=0.84
Intercept=2.04

METEO FRANCE
Toujours un temps d'avance

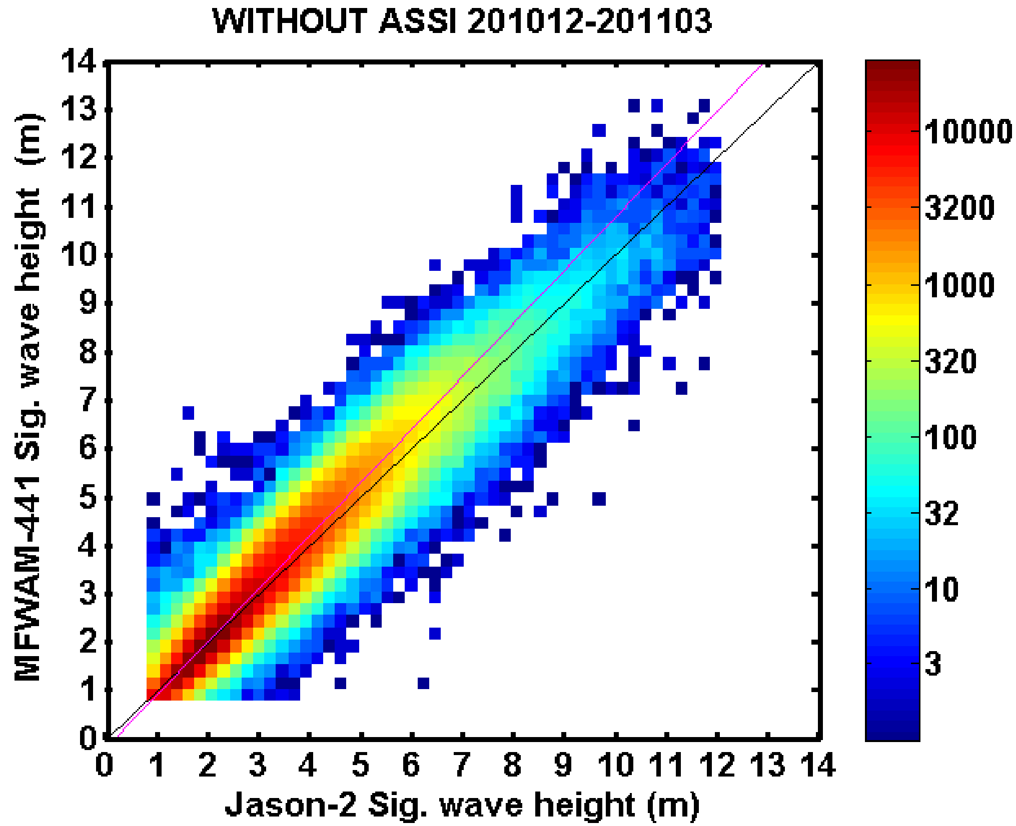
VALIDATION OF EXP2 WITH JASON-2 (Jason-2 data not assimilated

MFWAM 441 with assimilation of ASAR and RA-2 comparison with Jason-2 wave heights

Bias = 0.10
SI = 15.1%
NRMS = 15.5%
Slope = 1.09
Intercept=-0.16



Bias = -0.03
SI = 12.1%
NRMS = 12.1%
Slope = 1.02
Intercept = -0.09
Density = 879589

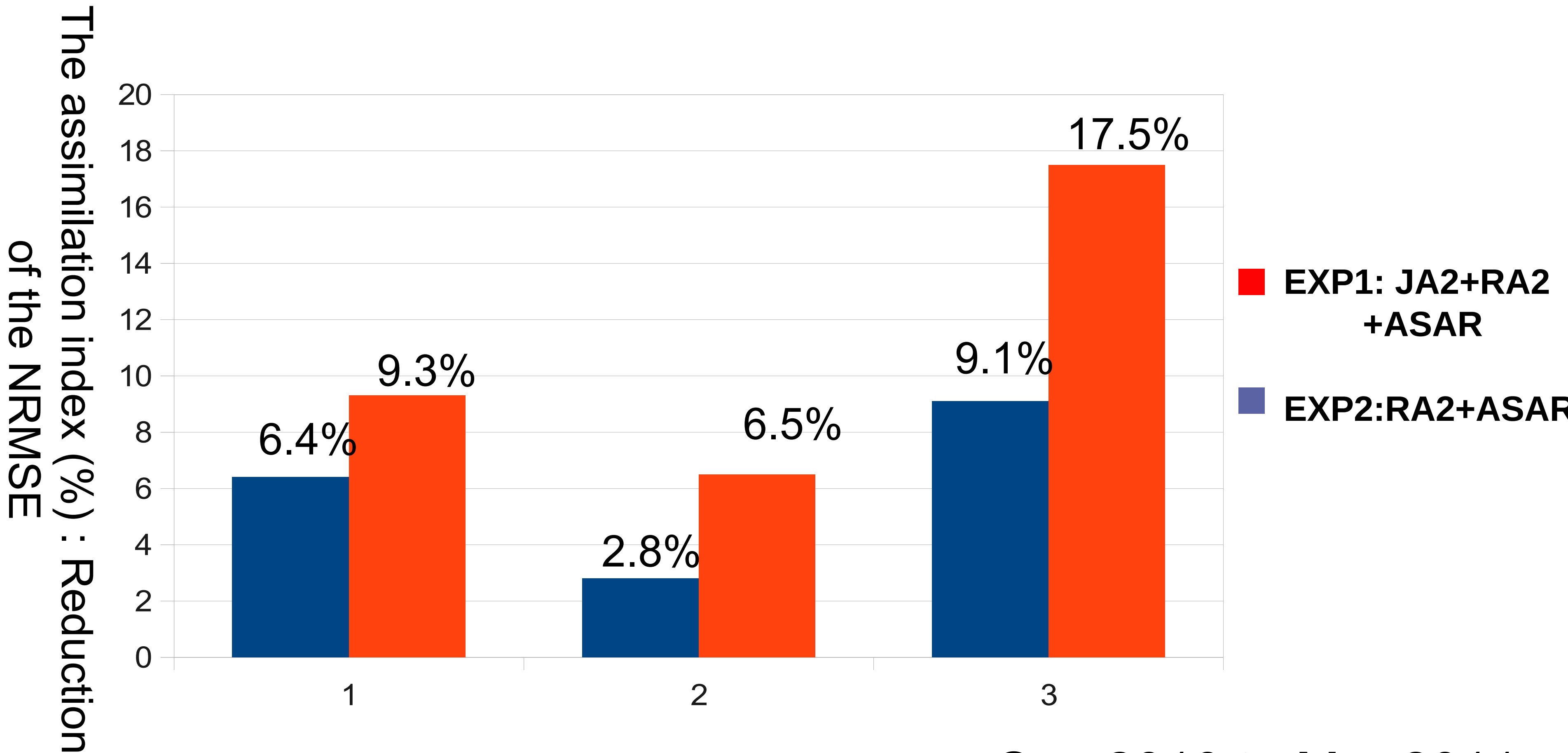


winter season Dec 10 to Mar 11

METEO FRANCE
Toujours un temps d'avance

COMPARISON EXP2 VS EXP1 REGARDING TO BUOYS

Comparison between EXP1 and EXP2 (Ra-2+ASAR) Validation with Buoys (Sig. Wave Height)



Sep 2010 to Mar 2011

1 : High latitudes North Atlan |Φ|>50°

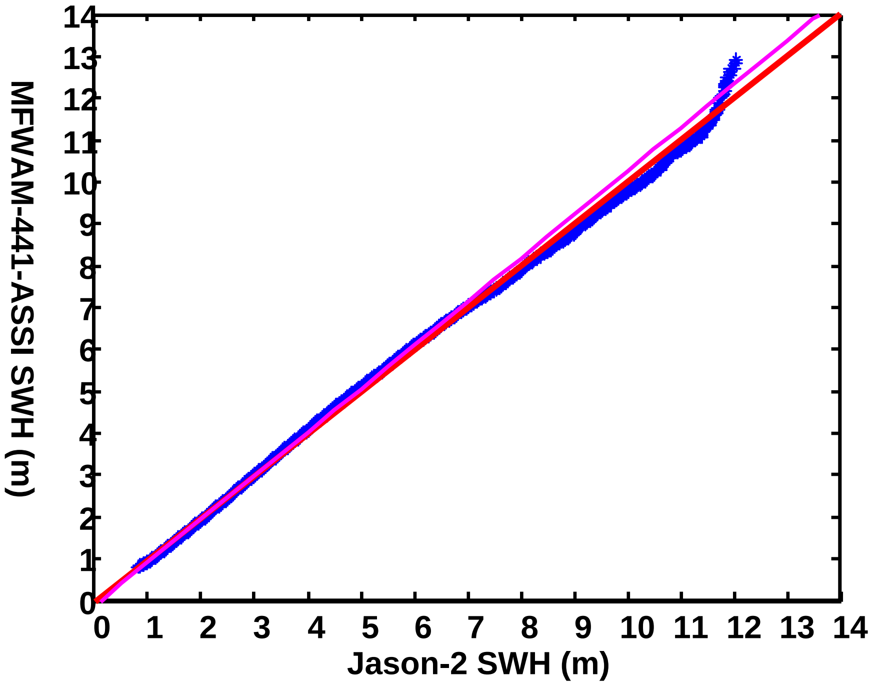
2 : Intermediate basin 20°<|Φ|<50°

3 : Tropics |Φ|<20°

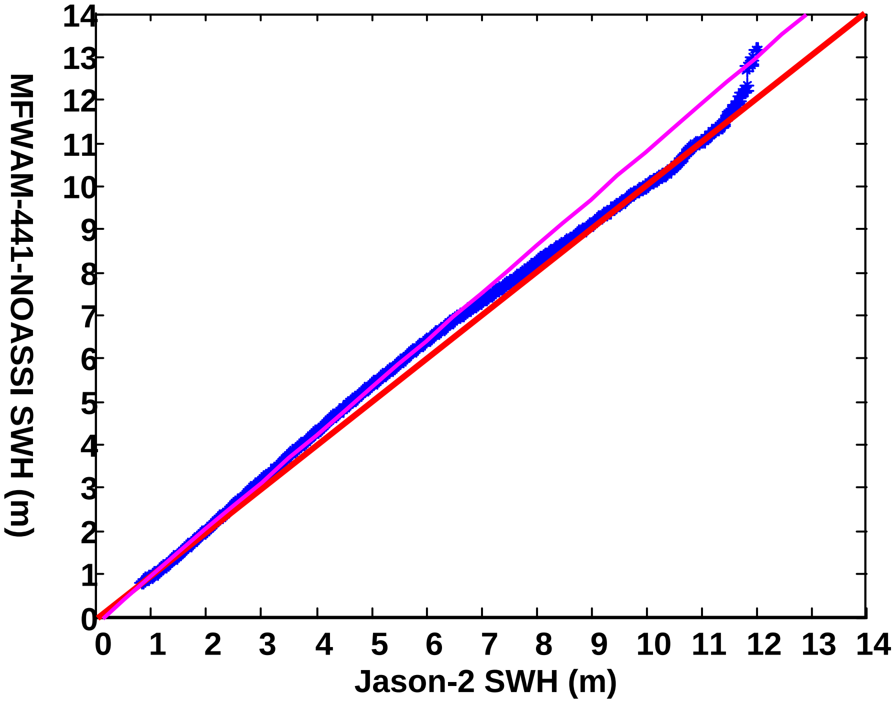
METEO FRANCE
Toujours un temps d'avance

MFWAM 441 with assimilation of ASAR wave spectra only comparison with Jason-2 Sig. wave heigth

MFWAM with assimilation of ASAR



MFWAM without assimilation



Bias=-0.04
SI=14.0%
Slope=1.04
Intercep=-0.14

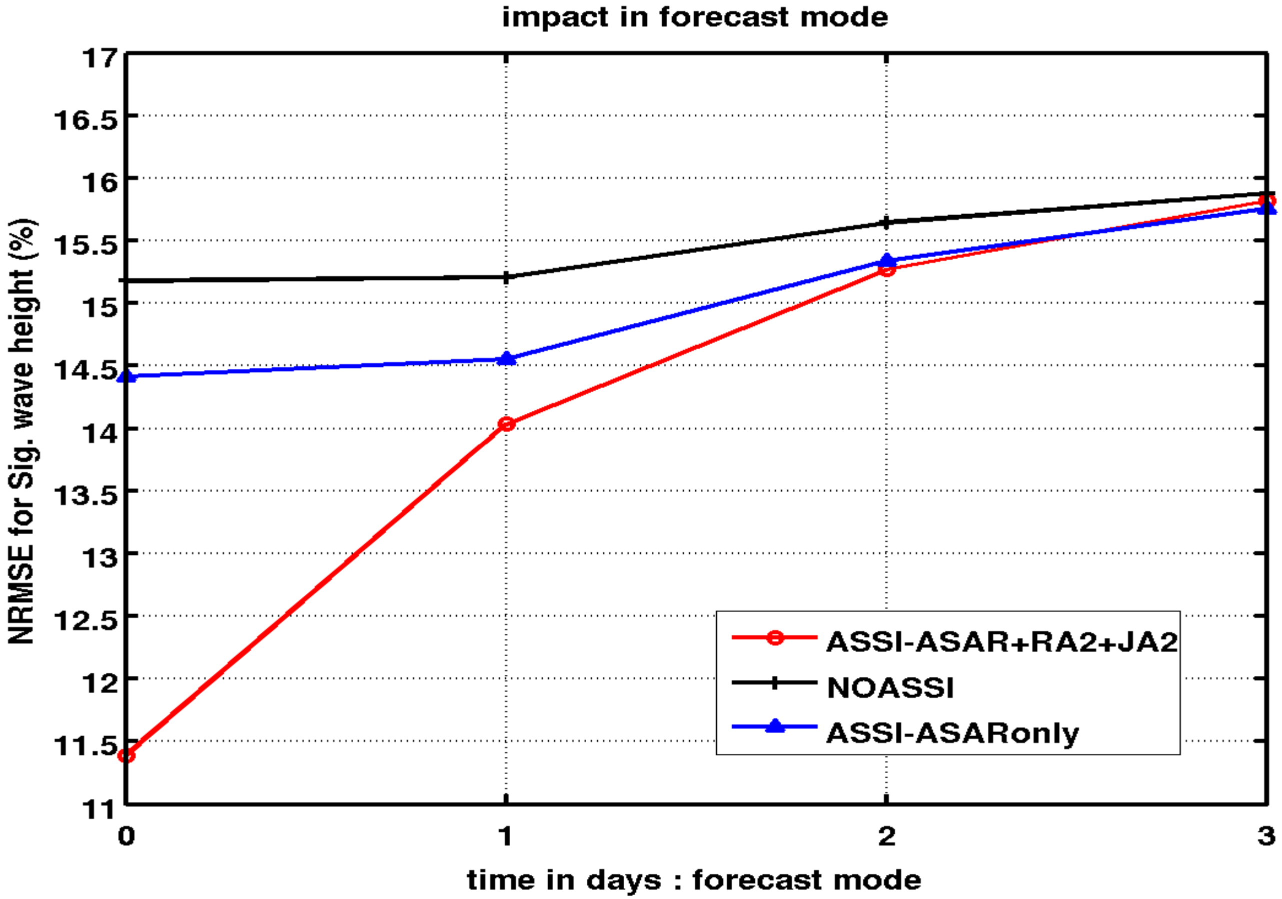
Bias=0.10
SI=15.1%
Slope=1.09
Intercep=-0.16

Sep. 2010 to March 2011

Impact of the assimilation of Altimeters and ASAR wave data
Period of forecast

→ Positive impact for the significant wave height

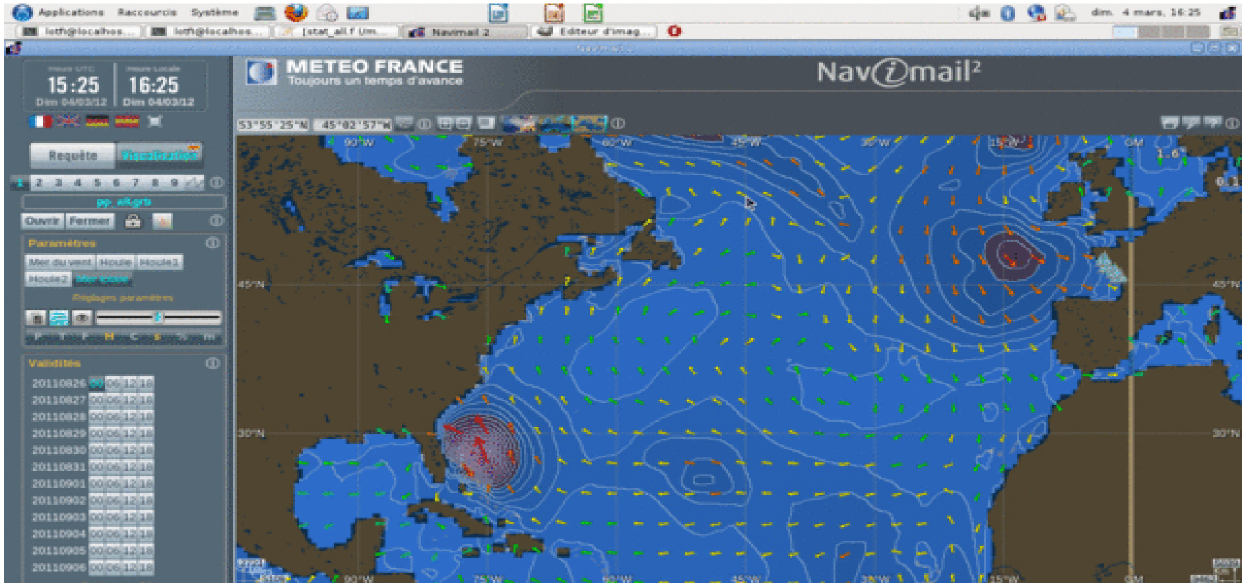
4-day forecast



1 is 0-24h average period, 2 is 24-48h,….
Comparison with Jason-2 and Envisat Ra-2 in the period of forecast

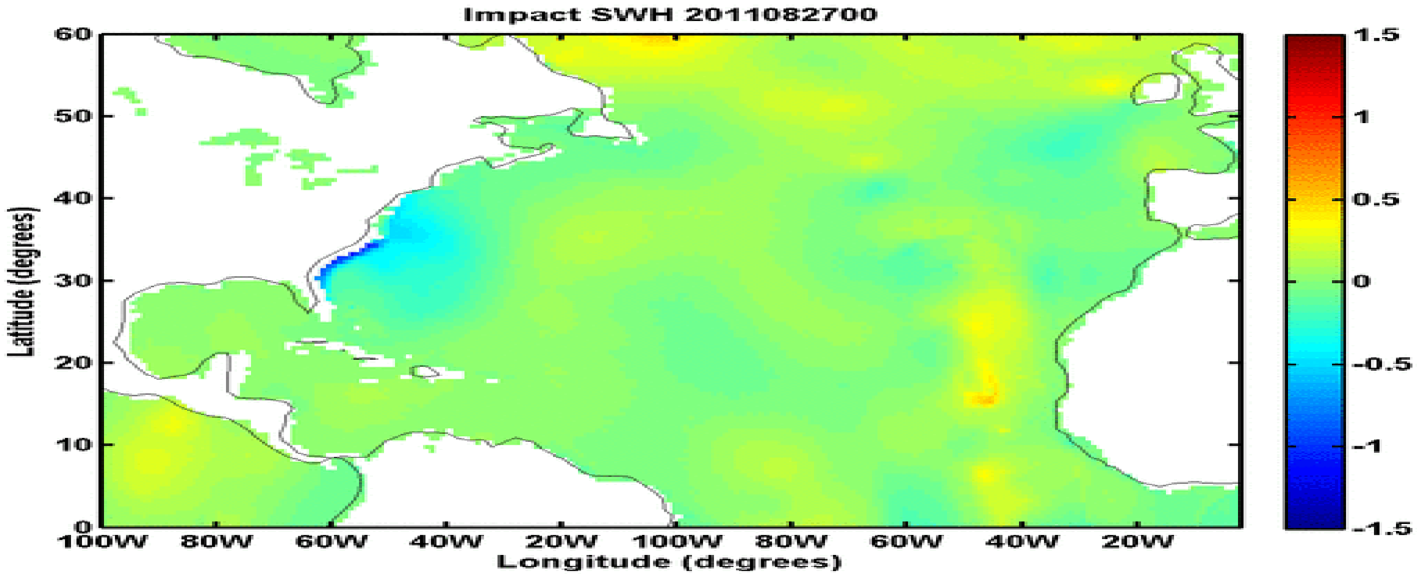
Impact of the assimilation in hurricane season 2011 (Hurricane Katia)

Snapshot of SWH operational MFWAM



From August 26 to Sep 6, 2011

Increment induced by the assimilation (Analyses-without assimilation) with a step of 6 h

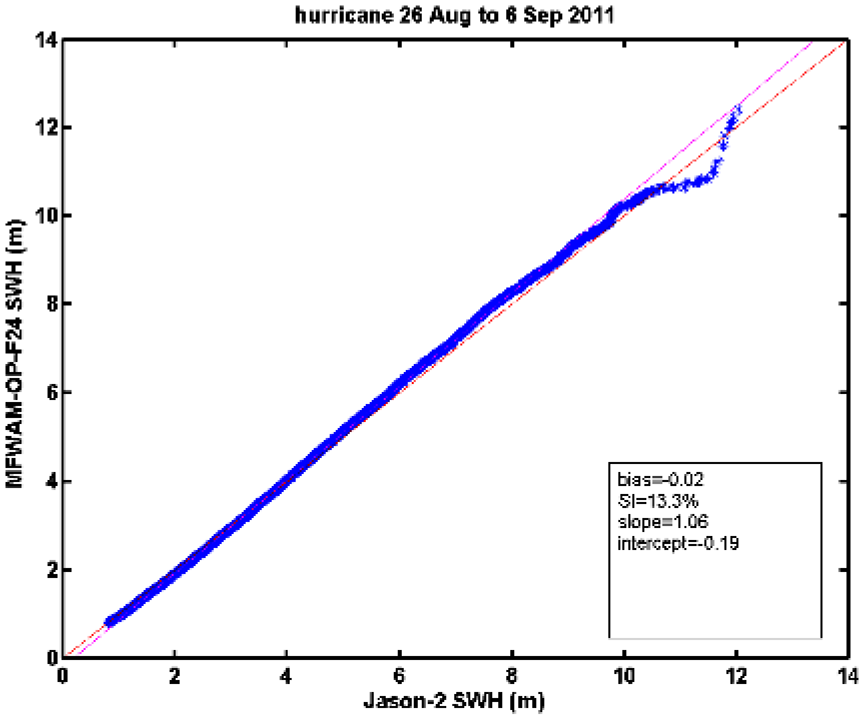


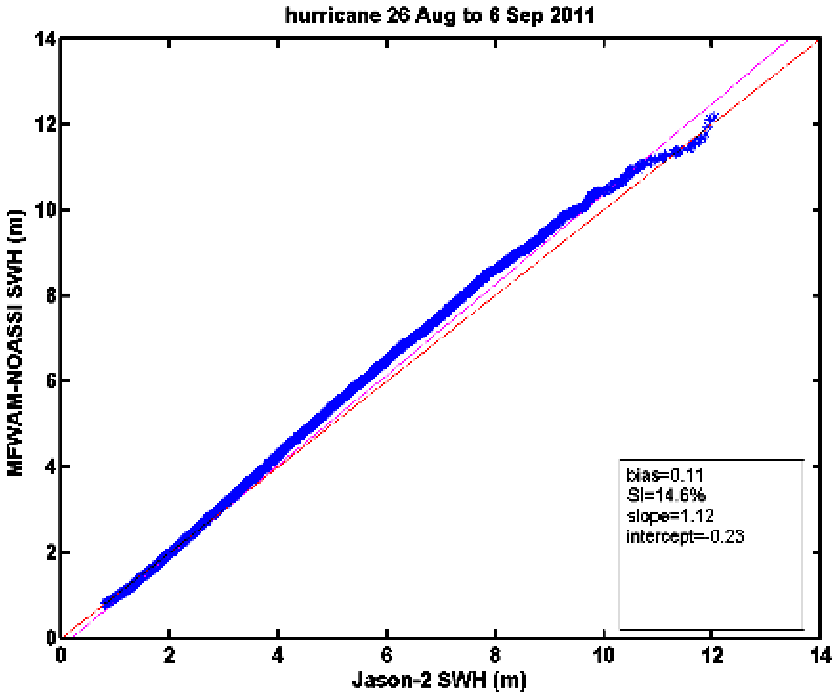
EO FRANCE
un temps d'avance

Impact of the assimilation in case of hurricanes validation of SWH with Jason-2

Forecast 24hours of the operational MFWAM with assimilation

Analyses of MFWAM without assimilation





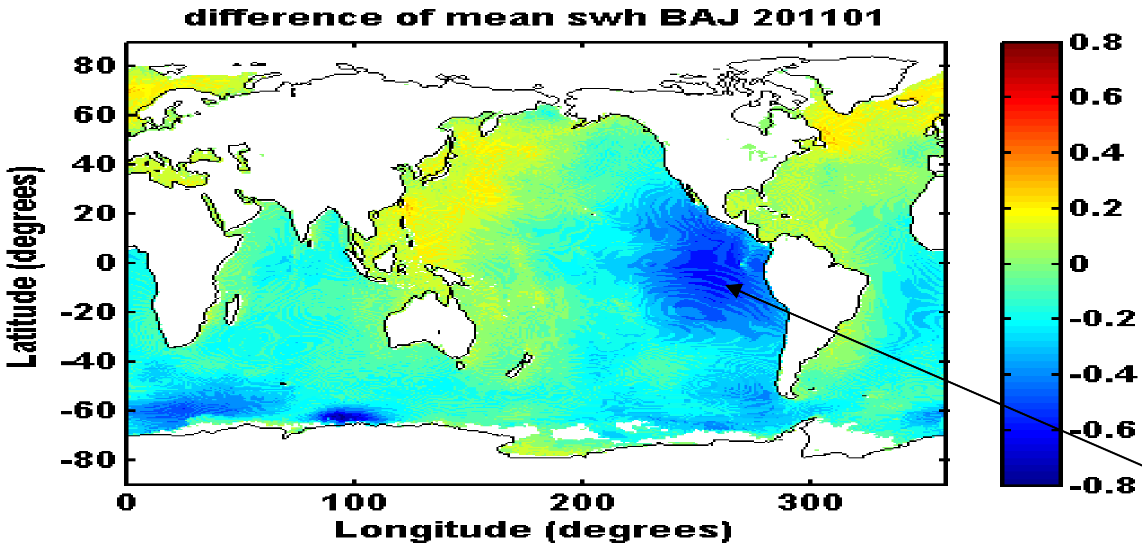
Bias=-0.02
SI=13.3%
Slope=1.06
Intercep=-0.19

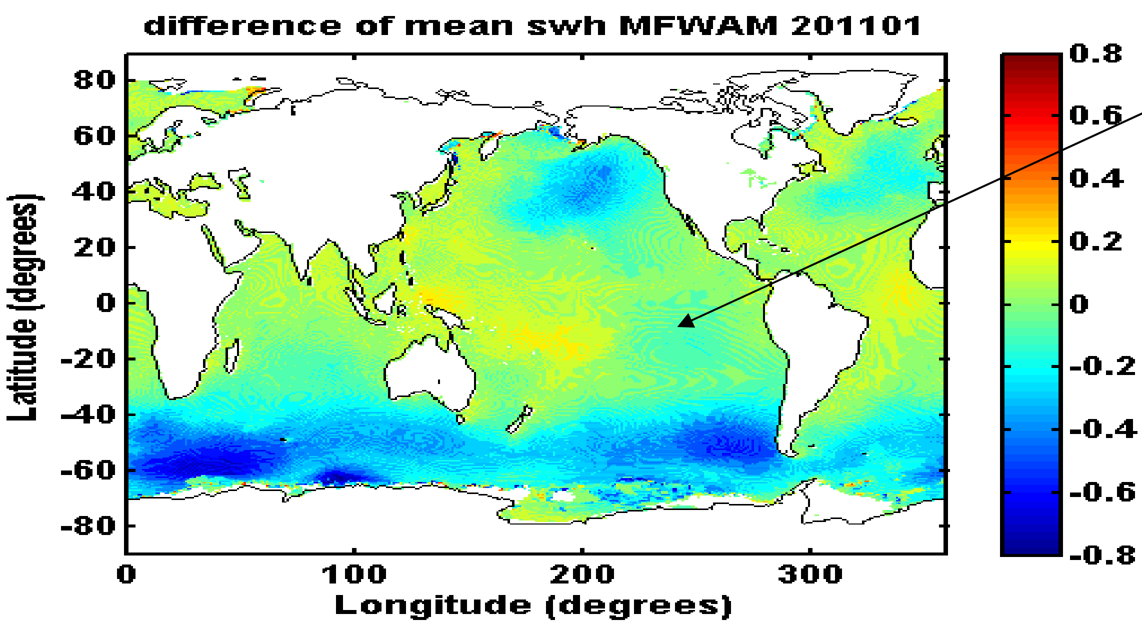
Bias=0.11
SI=14.6%
Slope=1.12
Intercep=-0.23

Aug. 26 to Sep. 6, 2011

METEO FRANCE
Toujours un temps d'avance

How about the ECWAM (BAJ dissipation) ?
Experiment for January 2011





Mean SWH Difference
(with and
without assimilation)

Improved
dissipation

--> less impact induced by the assimilation

METEO FRANCE
Toujours un temps d'avance

Conclusions and future works

→ The assimilation of altimeters Ra-2 and Jason-2 and ASAR wave in MFWAM spectra reveals a significant positive impact (in both forecast and analysis periods).

→ the use of multi source of satellite observations (ASAR+Altimeters) increase the impact (twice stronger in the tropics and intermediate ocean basins

→Even with an improved wave model, data assimilation is still useful to improve the wave forecast (room for model improvments)

→ The assimilation system is already operational at MF since 17 March 2011.

→ Improvment of the assimilation scheme : use of correlation length depending on the wavelength of dominant wave trains, optimization of the correlation error functions

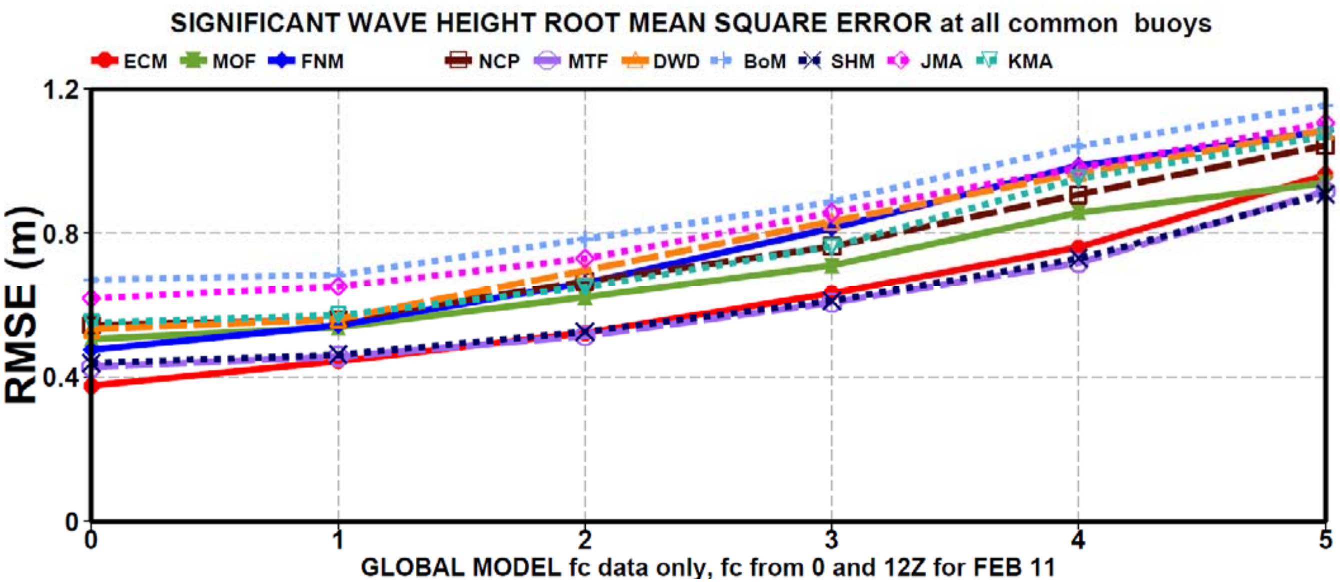
METEO FRANCE
Toujours un temps d'avance

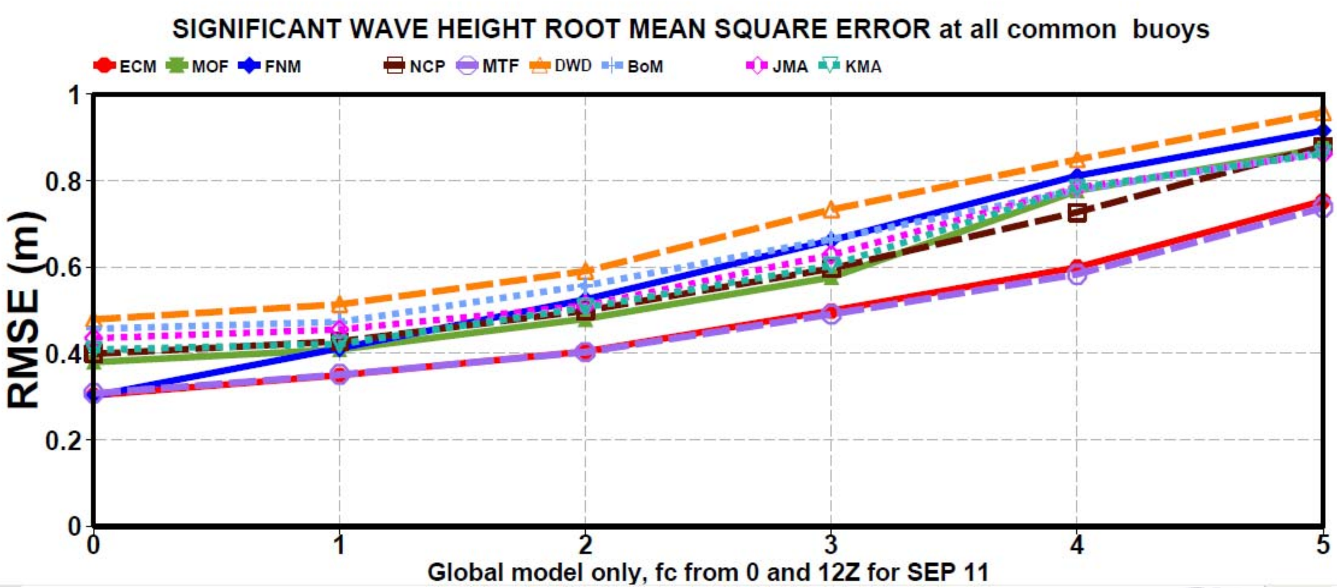
→The use of different ratio between model and observation error for wave height and components of wave number

→ Further investigations are needed to evaluate the impact of ASAR L2 wave spectra with the wave model MFWAM-441

→Impact studies based on future directionnal spectral data from satellite : SWIM instrument on CFOSAT satellite (Chineese-French program, launch 2015), complementary use with the ASAR

Global forecast
Verification at all common buoys





Comparison of several global wave forecasting systems, not waves models themselves, because differences in model implemention (model resolution, wind forcings, data assimilation ….)

ECMWF

MET OFFICE

METEO-France

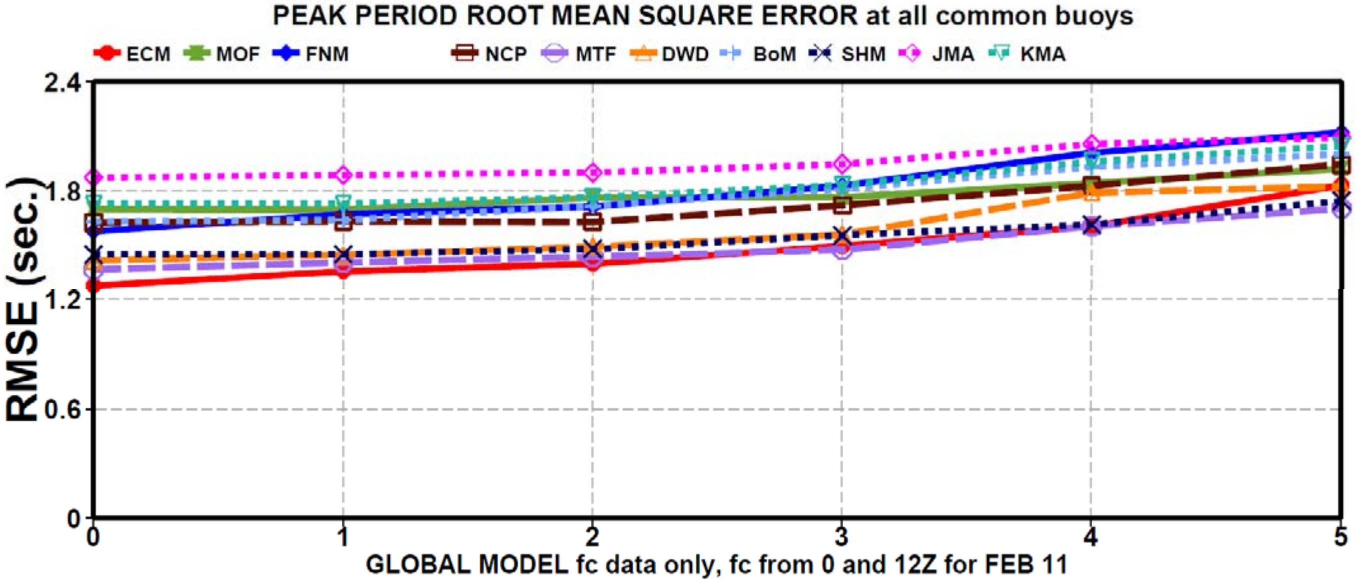
DWD

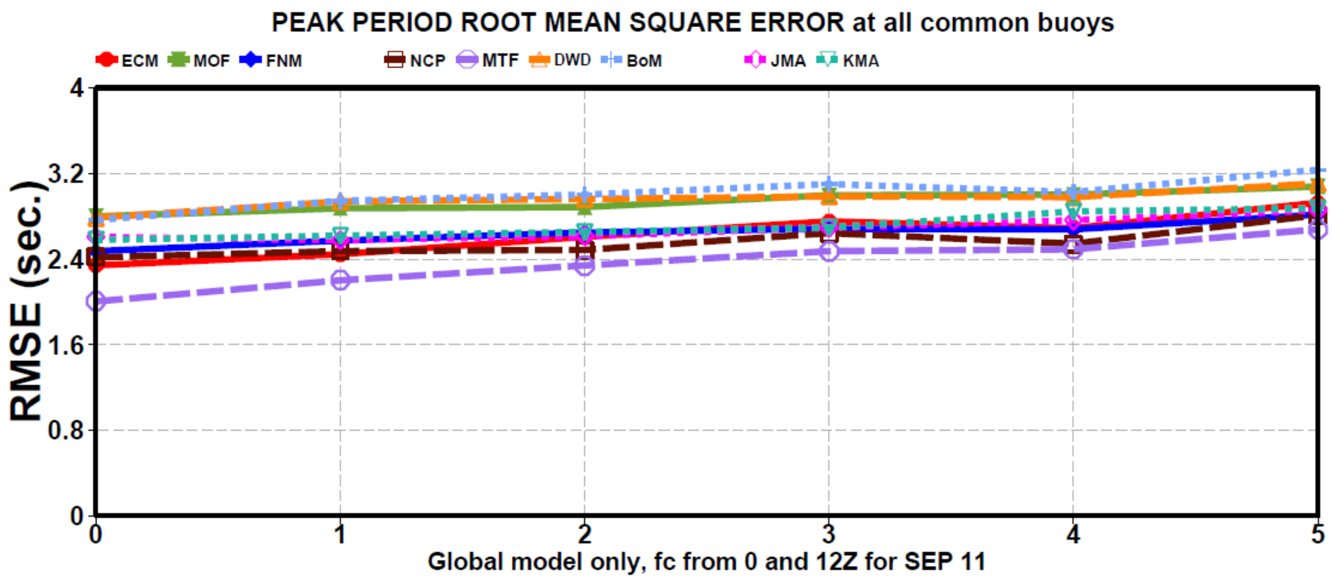
SHOM

JMA

METEO FRANCE
Toujours un temps d'avance

Global forecast
Verification at all common buoys





Comparison of several global wave forecasting systems, not waves models themselves, because differences in model implemention (model resolution, wind forcings, data assimilation ….)

ECMWF

MET OFFICE

METEO-France

DWD

SHOM

JMA

METEO FRANCE
Toujours un temps d'avance