Latest developments in Wave in Data Assimilation

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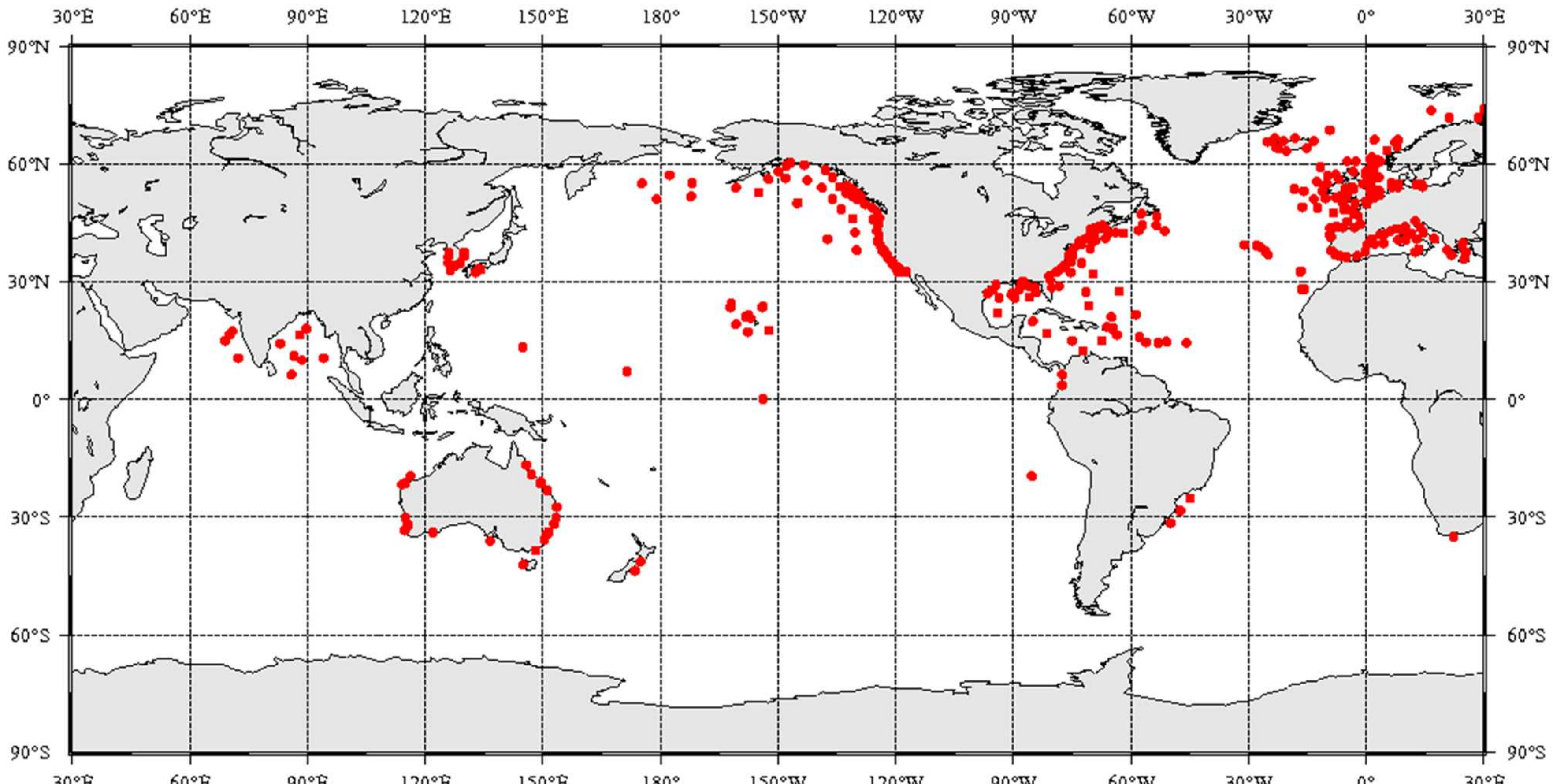
Outline

- Introduction
- Techniques and Background
- Data Quality Control/Data Preparation
- Impact
- Perspectives

Introduction

ECMWF/WFVS (Wave Forecasting Verification System) based on Marine Automatic Weather Stations (MAWS)



Most of data are near the coast--> Assimilation of buoy data not efficient for global forecast

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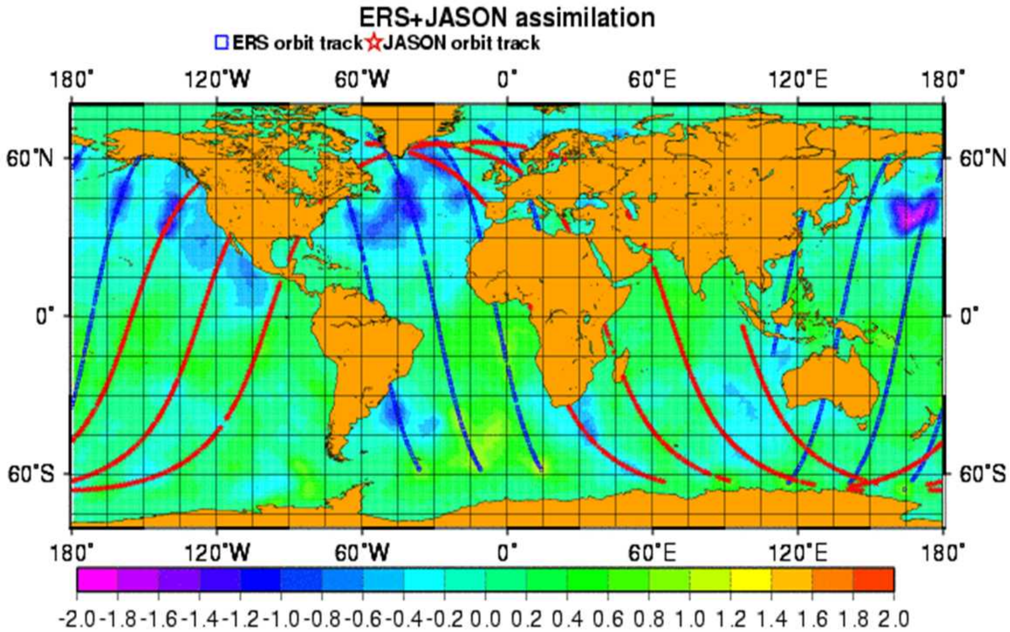
Radar Altimetry + SAR from space

Data from space: global coverage--> Data Assimilation
is an optimal way to distribute information over space and time



Analysis errors are amplified in the forecast period by NWP models (initial value pb), not by wave models (forcing pb)

Motivation for developping wave data assimilation

Past: SEASAT, GEOSAT

ERS-1, ERS-2, ENVISAT

TOPEX

Present: JASON-1, JASON-2

CRYOSAT

Future: SENTINEL-3, 1, CFOSAT, SARAL-ALTIKA, JASON-CS

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Data Assimilation Methods

BG=True+ε_b assumptions: no bias, uncorrelated errors

Obs=True+ε_o ε_b^2=E(ε_b^2), E(ε_b)=0, E(ε_o^2), E(ε_b ε_o)=0

Principle: Combine Background (First Guess) with Observation in an optimal way:

An=αBG+βObs

when $\alpha = \varepsilon_o^2 / (\varepsilon_b^2 + \varepsilon_o^2)$ and $\beta = \varepsilon_b^2 / (\varepsilon_b^2 + \varepsilon_o^2)$, the analysis error is mimimum and

E(ε_a)=0, $1/\varepsilon_a^2 = 1/\varepsilon_o^2 + 1/\varepsilon_b^2$

the error of the analysis is smaller than the error of the first guess, whatever the error of observation is!

Data Assimilation Methods

- • Sequential: large interest for operational applications (cheap) related to waves

- **Optimum interpolation**
  - Thomas 1988 (Altimeter)
  - Janssen et al.1989 (Altimeter-Global)
  - Lionello et al. 1990, 1992 (Altimeter-Global)
  - Lefevre 1994 (Altimeter-Regional)
  - Le Meur et al. 1995 (Altimeter+SCATT, Regional)
  - Greenslade 2001, et al. 2004, 2005 (Altimeter, Global)
  - Hasselman et al. 1997. (SAR, level1, Global)
  - Voorrips et al., 1997 (picth roll buoys, Regional)
  - Skandrani et al. 2004, 2005 (Altimeter, global)
  - Aouf et al., 2006, 2008, 2012 (SAR, level2, Global)
- **Successive corrections**
  - Breivik and Reistad 1994 (Altimeter-Regional)
  - Breivik et al. 1998 (SAR, level 1, Regional)

- **Kalman filter**
  - Voorrips et al. 1999 (Regional)

- Variational (operational in NWP models)
- **Adjoint technique**
  - De la Heras and Janssen 1992 (1Point Model)
  - De Valk 1994, in Komen 1994 (Syntetic Observations)
  - Voorrips and De Valk 1997 (pich rolls buoys, regional)
-
- **Green functions**
  - Bauer et al. 1996 (SAR level1)

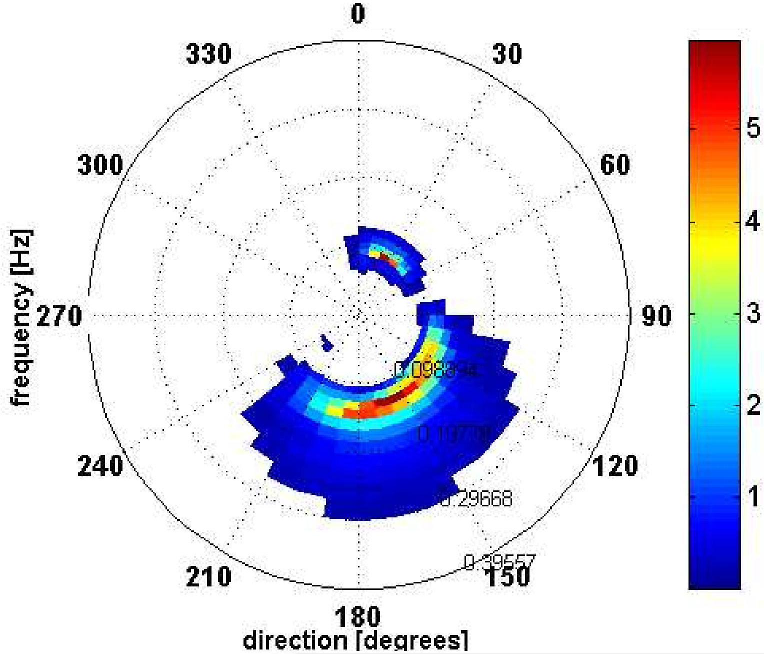
  - -Kalman very expensive in term of computer ressource (memory)
  - -4D var- need to maintain 3 sources code: direct, linear tangent, adjoint model, expensive in term of computational time (iterative method with N runs…)

Spectral Wave Modeling

- $\partial E/\partial t + C_g.\mathrm{grad}(E) = $ Source terms

- $E(f,\theta)$ energy directional spectrum is THE PRONOSTIC VARIABLE
  - not measured by Altimeters
  - Partially by SAR

→ Assumptions are required to convert the analysed total energy in a wave spectrum



Data quality control and preparation

1. Perform basic quality control on the raw data

   -RMS_SWH

   -Signal to Noise Ratio

   -Normalyzed Variance of Imagette

   - ....

2. Perform consistency checks on the remaining data

   - observations (altimeters) are grouped in sequences of several observations

3. Apply data bias correction to get zero bias between model and observation

4. Estimate random errors for model FG and observations

   use multiple collocation method (Janssen 2003, Abdalla 2005)

5. Estimate EFCM (Error Forecasting Correlation Matrix)

How to correct the SWH model value at a given grid point if you get an observation of SWH in another place and same time (or close)?

To do so, you need to know the spatial correlations of the model forecasting errors. The simplest way to represent the background correlation matrix is to assume **homogeneity** and **isotropy**.

But :

- May depend on location (not homogeneous)
- May depend on directions (not isotropic)
- May depend on time

Estimation using Model-Obs or Forecast24-Forecast0 (NMC method) for OI, small ensemble forecast for 4D var,

Estimated with Kalman Filter …..

Estimation of the Error Forecasting Covariance Matrix in the O-I case

$$X^a = X^f + \sum_{i}^{N} W_i \, (X_i^{\,o} - HX_i^{\,f})$$

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

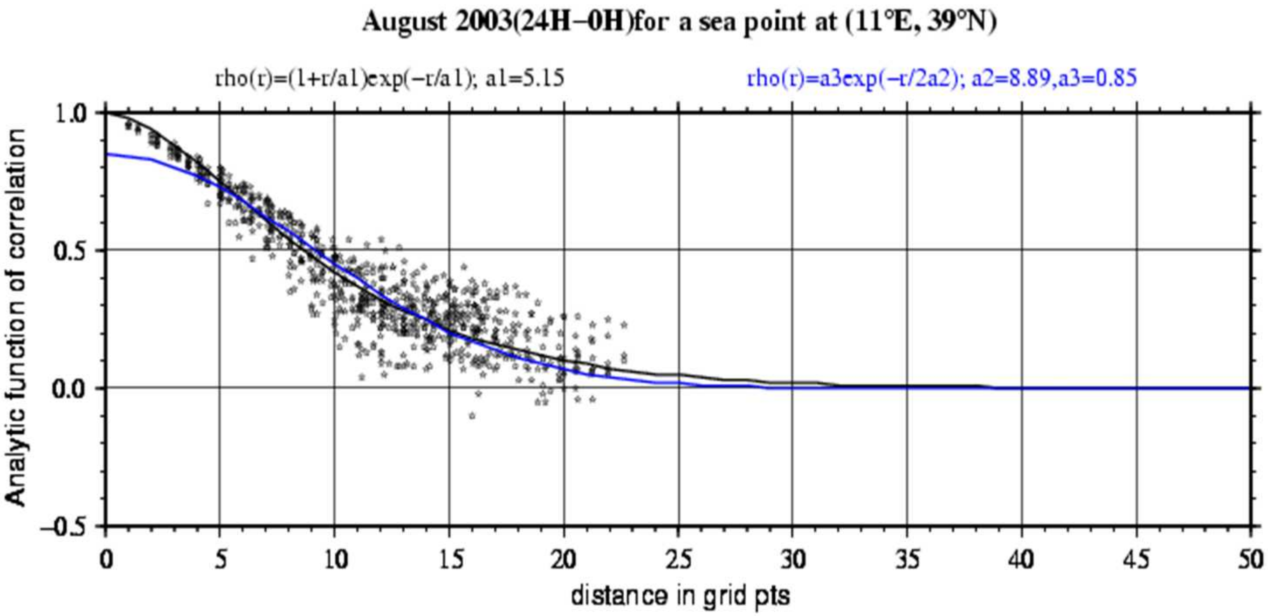
The corrected weights depend on the covariance error matrix :

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

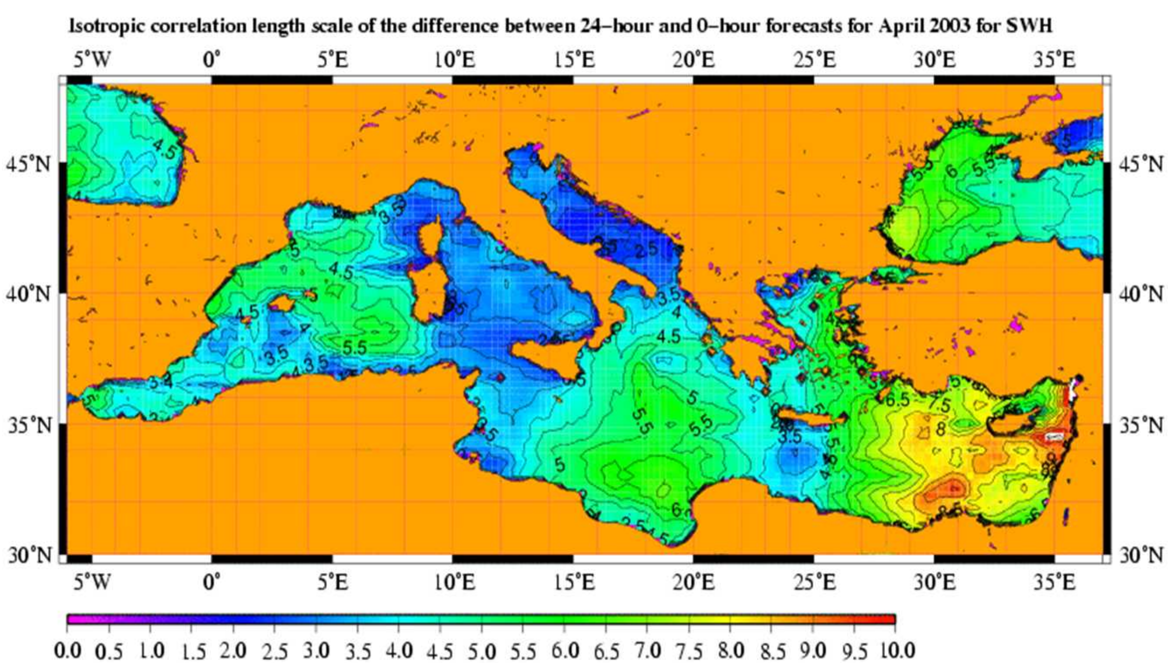
P and R are respectively the background and observations covariance errors. While H is location operator

$$P = A(r,\theta)\exp B(r,\theta) \qquad\qquad R = \sigma_o^2$$

Estimation of the correlation functions



$$P(r) = a_2\left(1 + \frac{r}{a_1}\right)\exp\left[-\frac{r}{a_1}\right]$$



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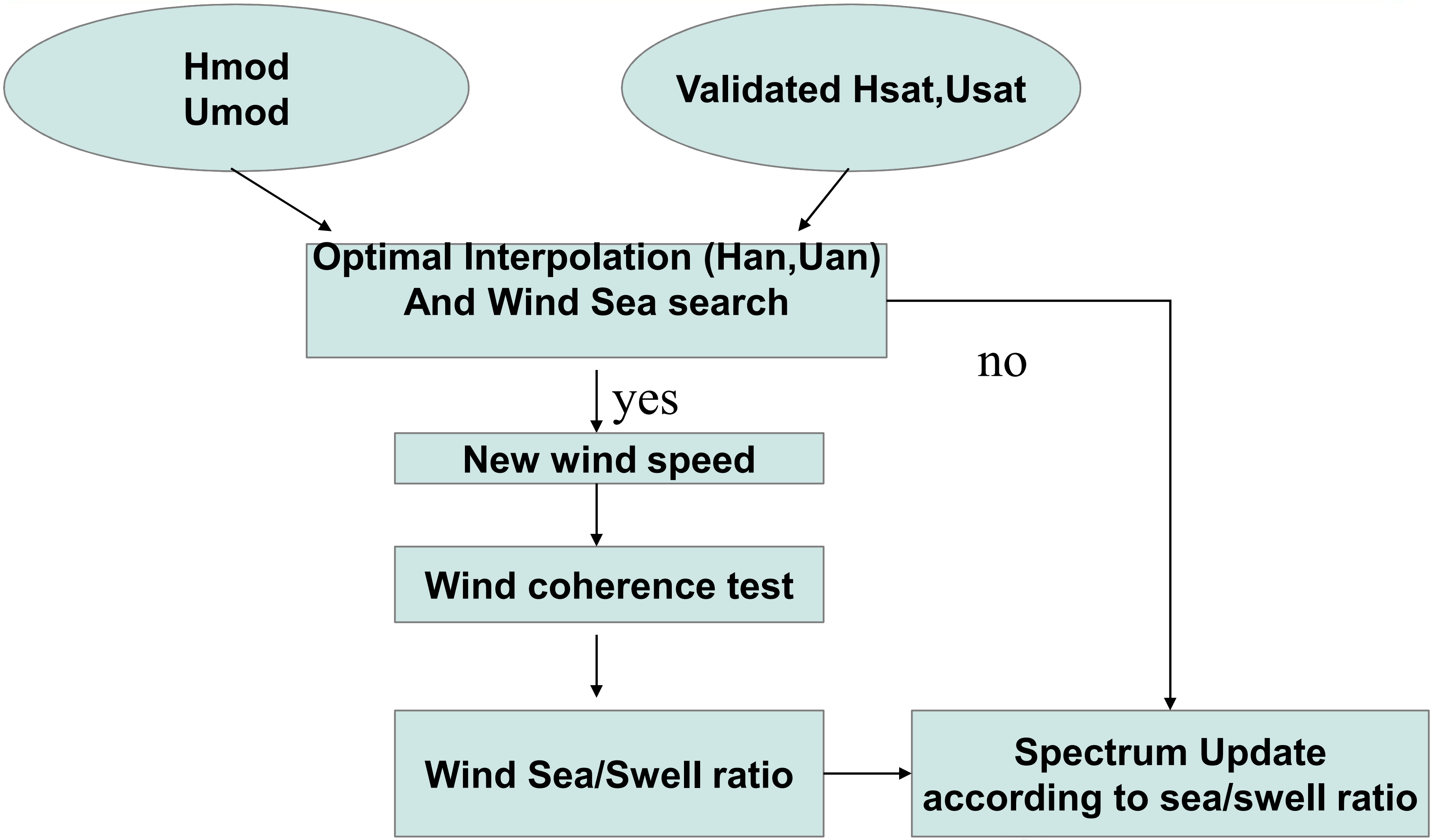
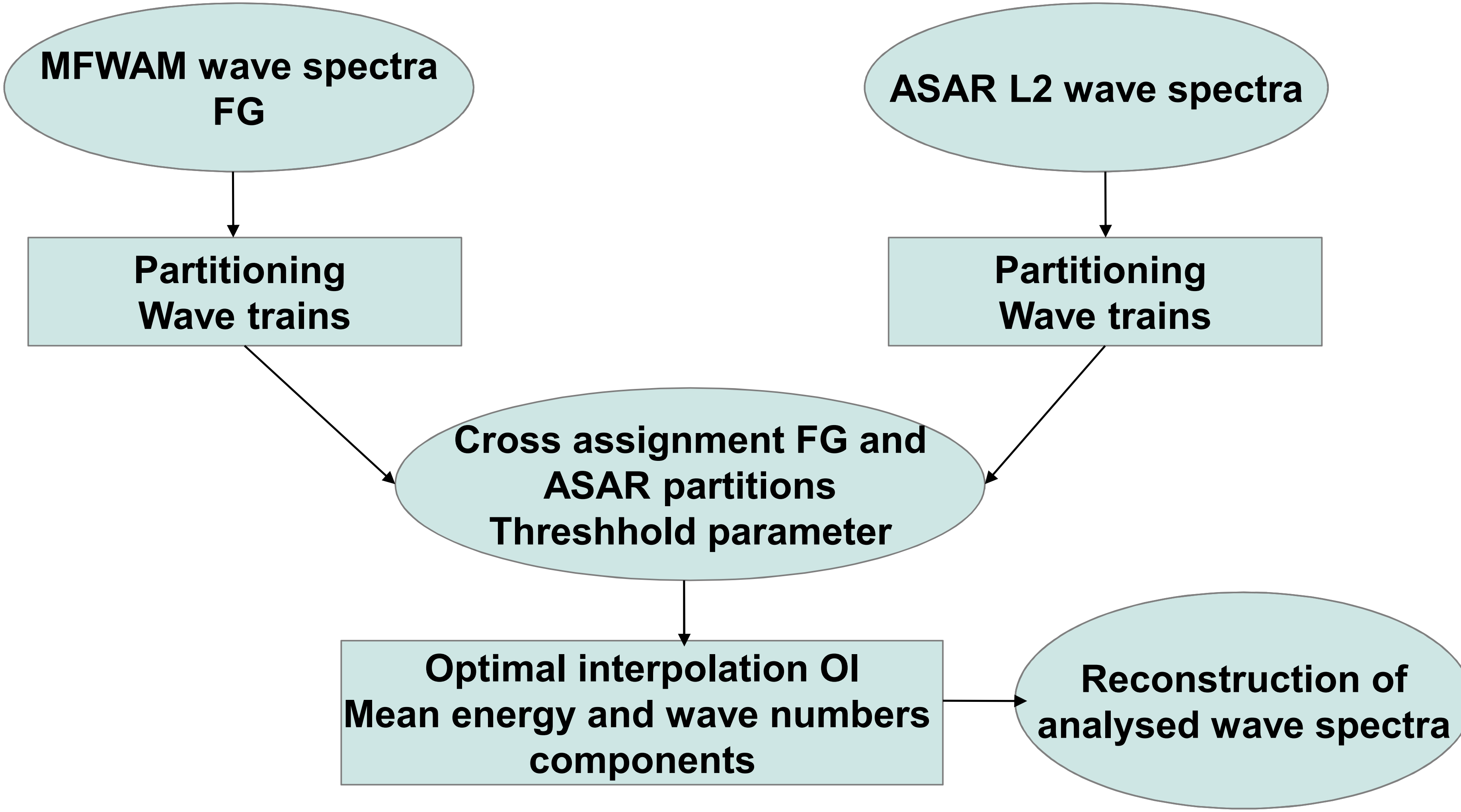
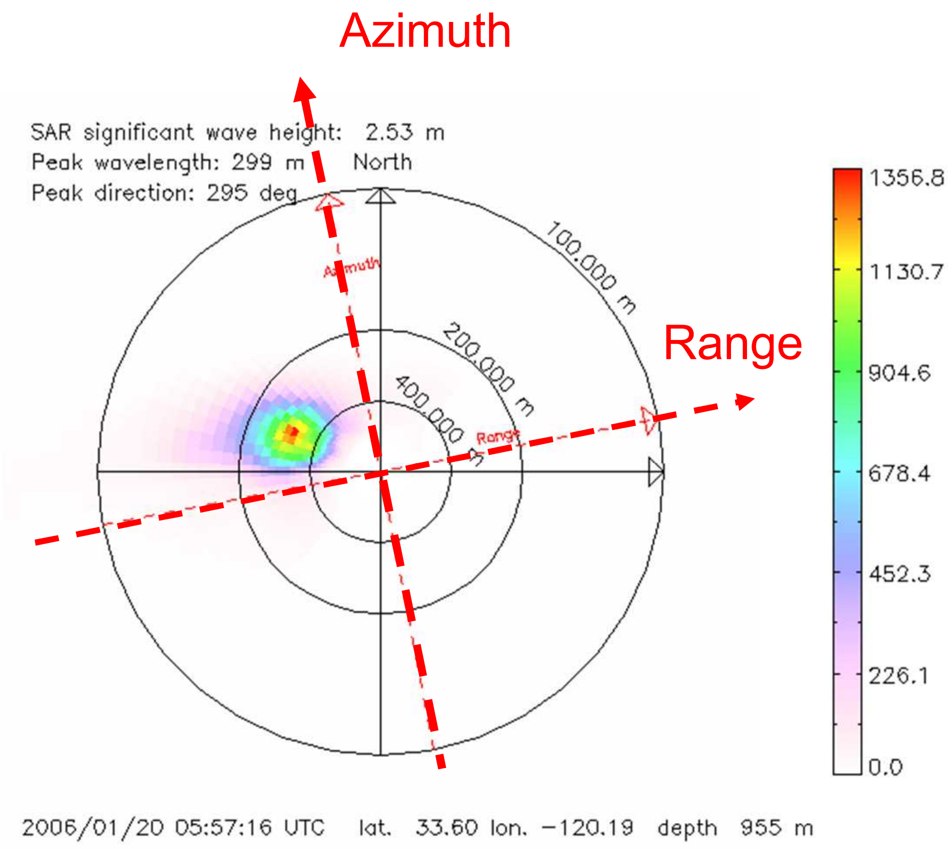
Description of the assimilation of Altimeter data



Description of the assimilation of ASAR L2 wave spectra



SAR variable cut-off applied to model data

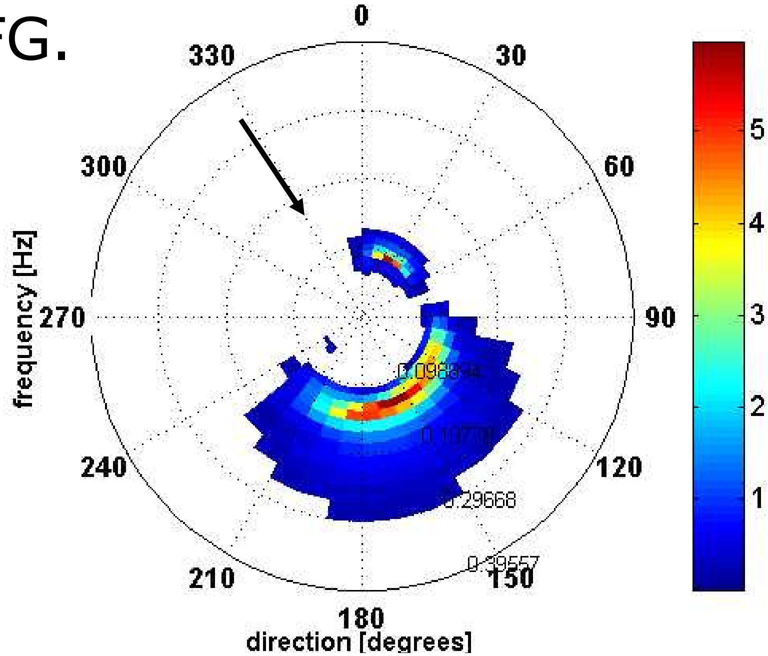


The azimuthal cut-off is provided by the level 2 Algorithms, but in the range direction SAR can see smaller wavelengths (including wind sea)

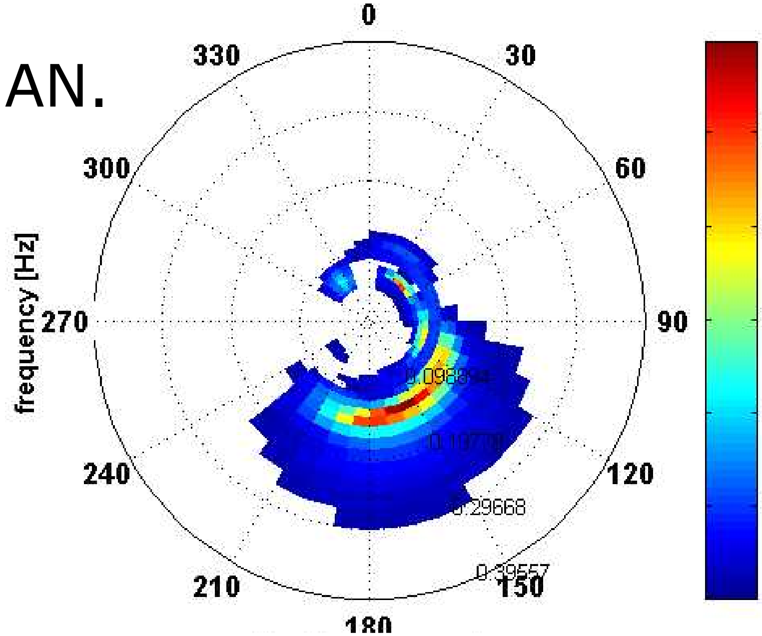
$$\lambda r = \lambda a * \cos(\Phi + \alpha)$$

λa : azimuthal cut-off
λr : minimum cut-off (range)
ϕ : orbit track angle
α : wave direction from the model

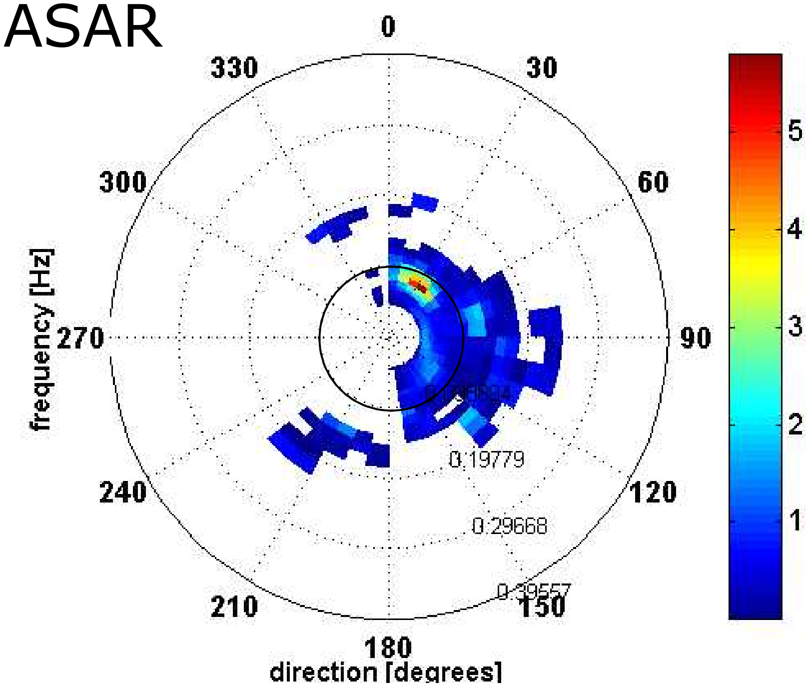
FG.

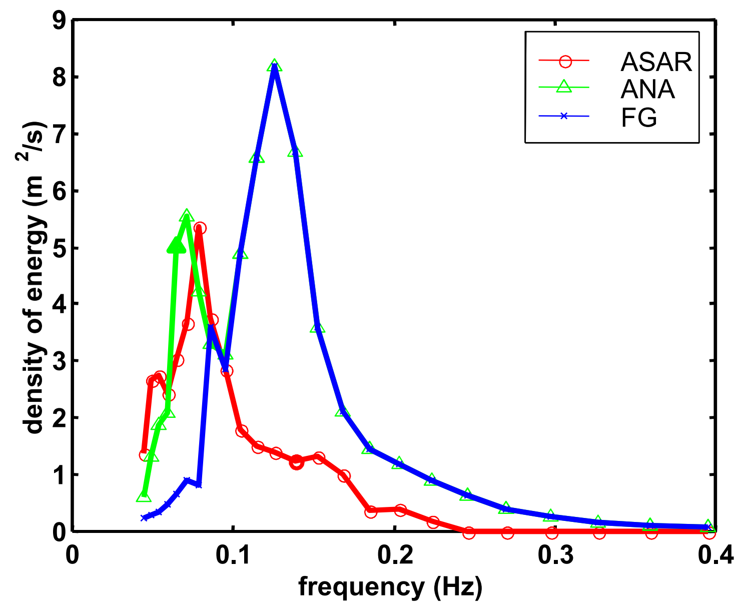


AN.



ASAR





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The new wave model MFWAM

-Based on ECWAM code with alternative physics for dissipation: (Ardhuin et al. 2010, JPO, TEST441)

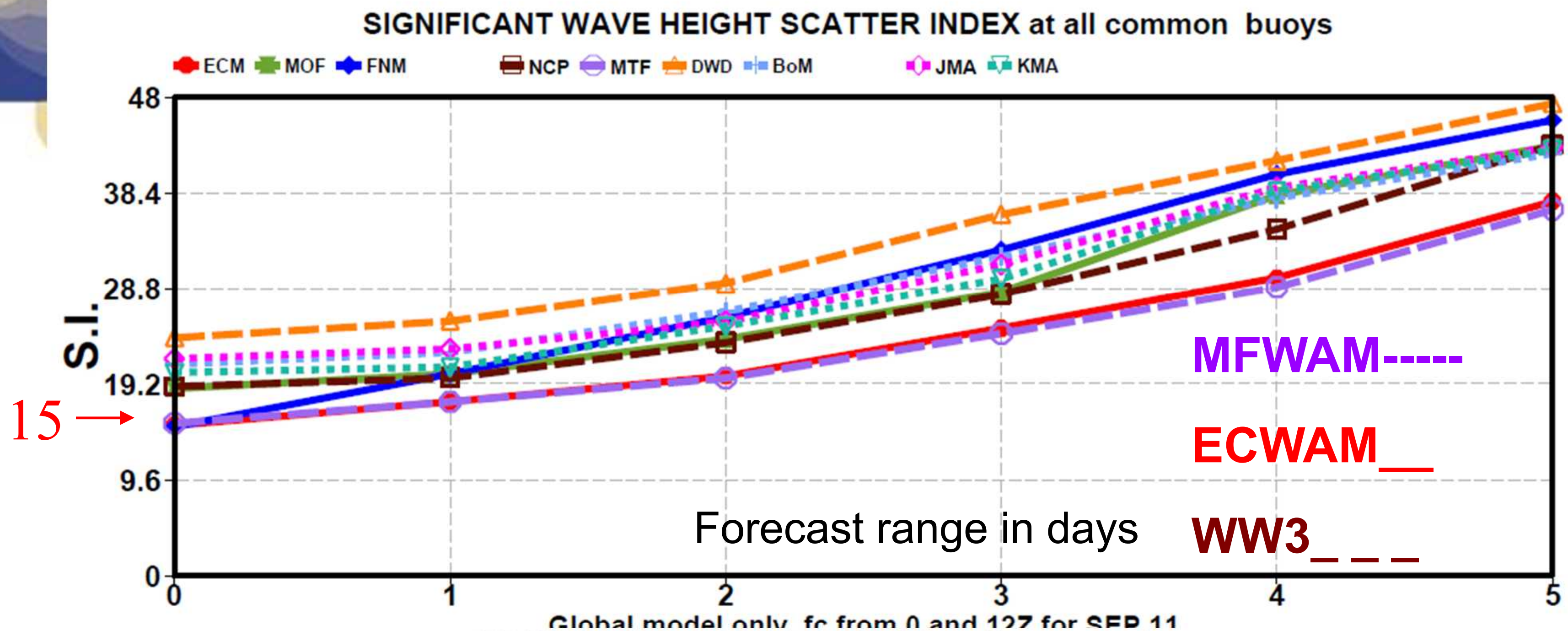
- Non isotropic dissipation:
  -> Better adjustment of the mean direction and angular spreading

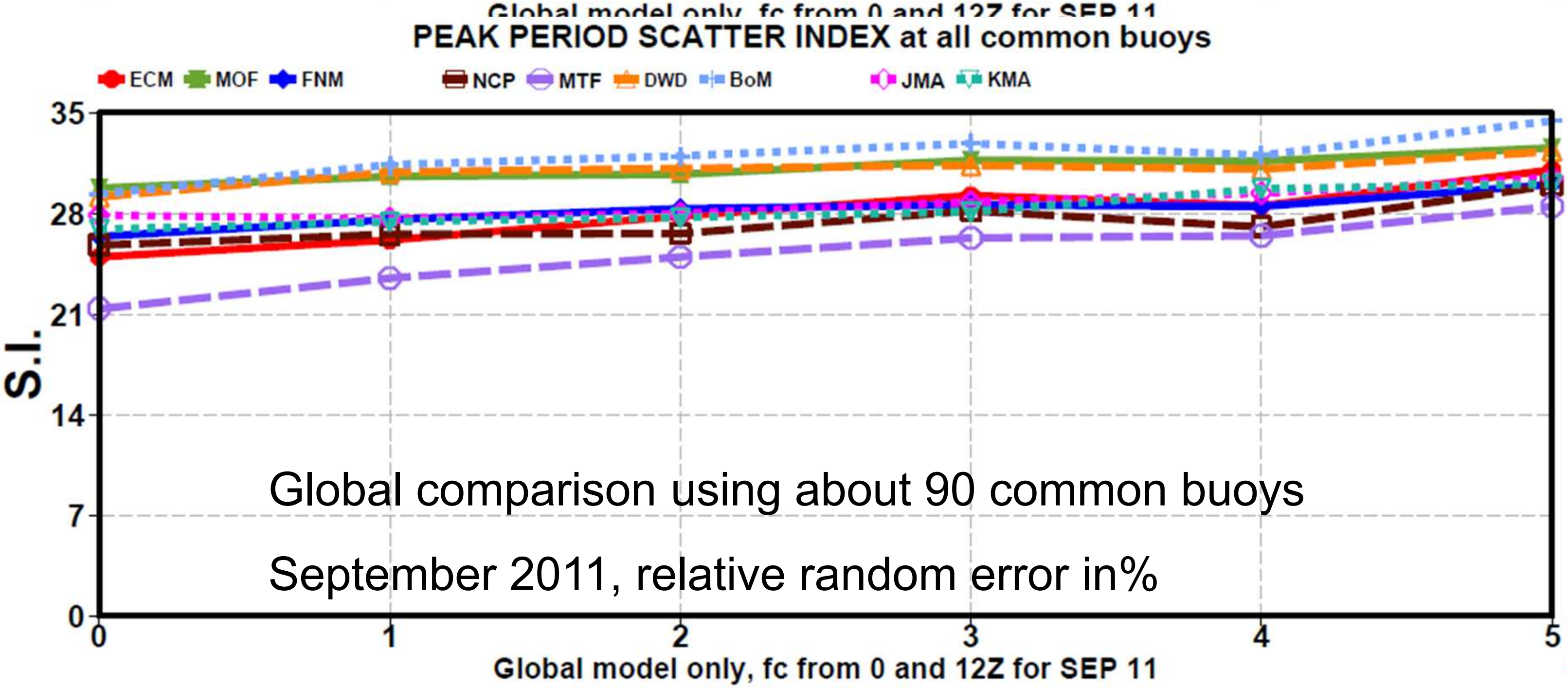
- Threshold mechanism from the saturation spectrum , instead of mean wave steepness dependency Breaking term:

- New term for swell damping due to air friction

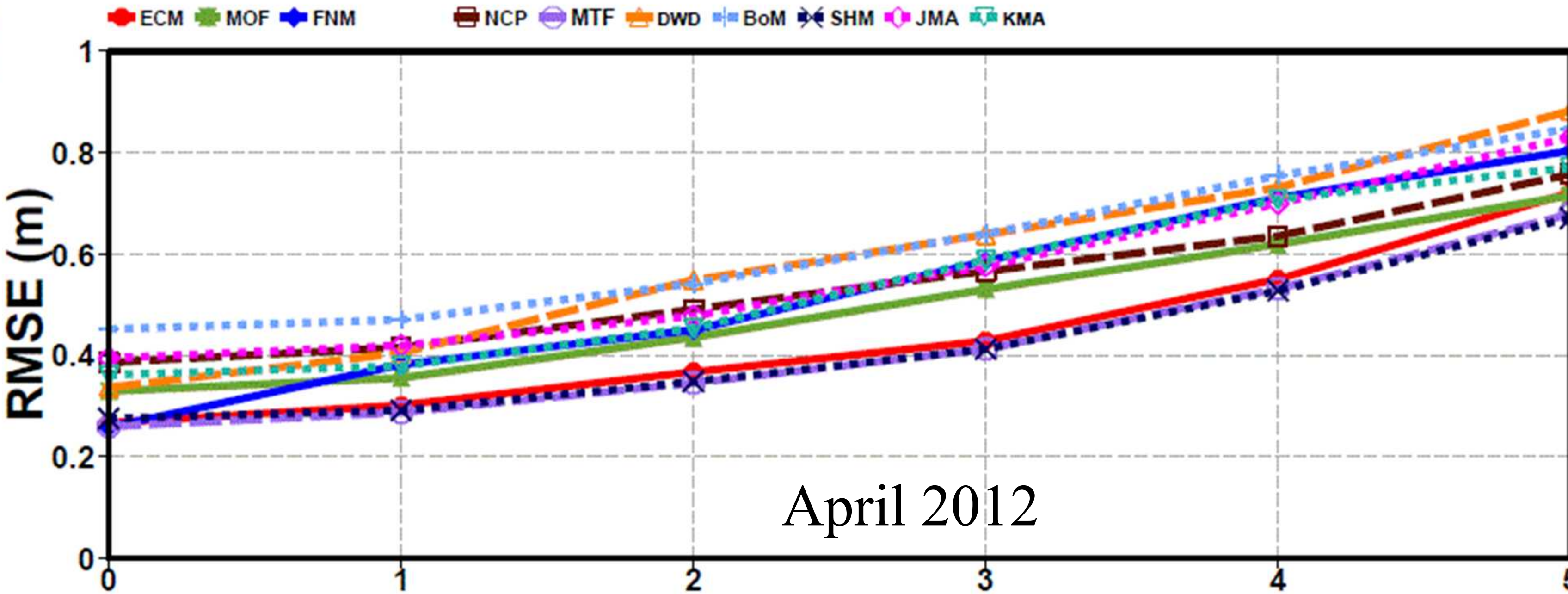
- Global versions 55 km resolution

- 24 directions , 30 frequencies


SIGNIFICANT WAVE HEIGHT SCATTER INDEX at all common buoys
ECM MOF FNM NCP MTF DWD BoM JMA KMA
S.I.
48
38.4
28.8
19.2
9.6
0
15
MFWAM-----
ECWAM__
WW3_ _ _
Forecast range in days
0 1 2 3 4 5

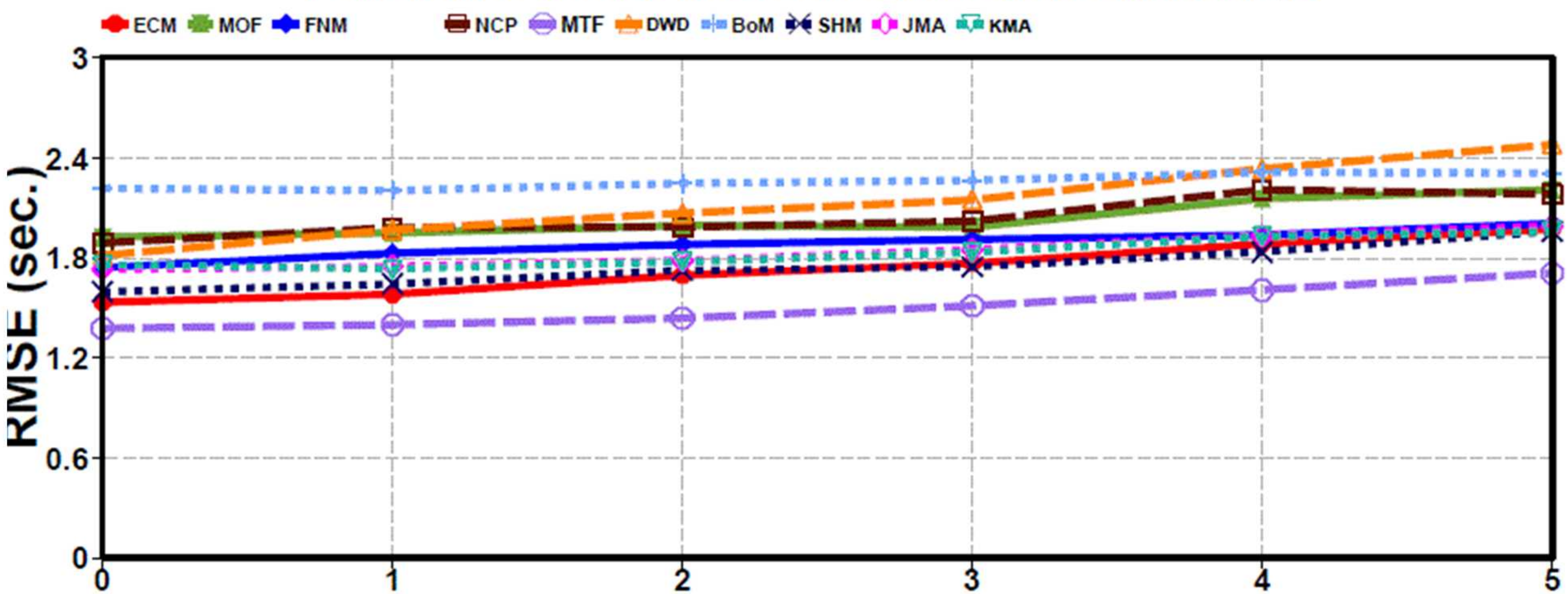

PEAK PERIOD SCATTER INDEX at all common buoys
ECM MOF FNM NCP MTF DWD BoM JMA KMA
S.I.
35
28
21
14
7
0
Global comparison using about 90 common buoys
September 2011, relative random error in%
0 1 2 3 4 5
Global model only, fc from 0 and 12Z for SEP 11

SIGNIFICANT WAVE HEIGHT ROOT MEAN SQUARE ERROR at all common buoys



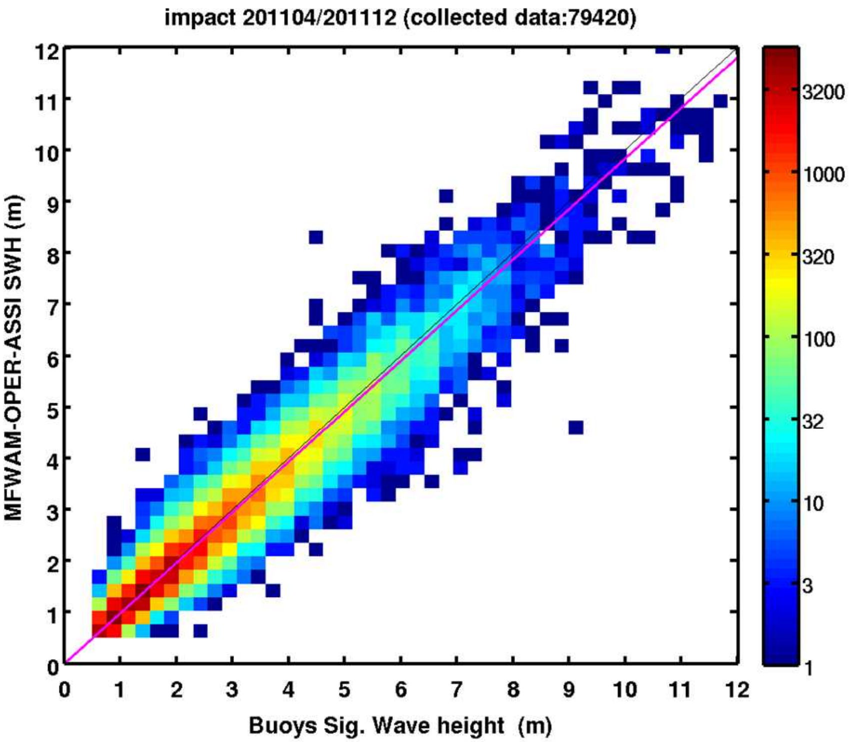
GLOBAL MODEL fc data only, fc from 0 and 12Z for APR 12

PEAK PERIOD ROOT MEAN SQUARE ERROR at all common buoys

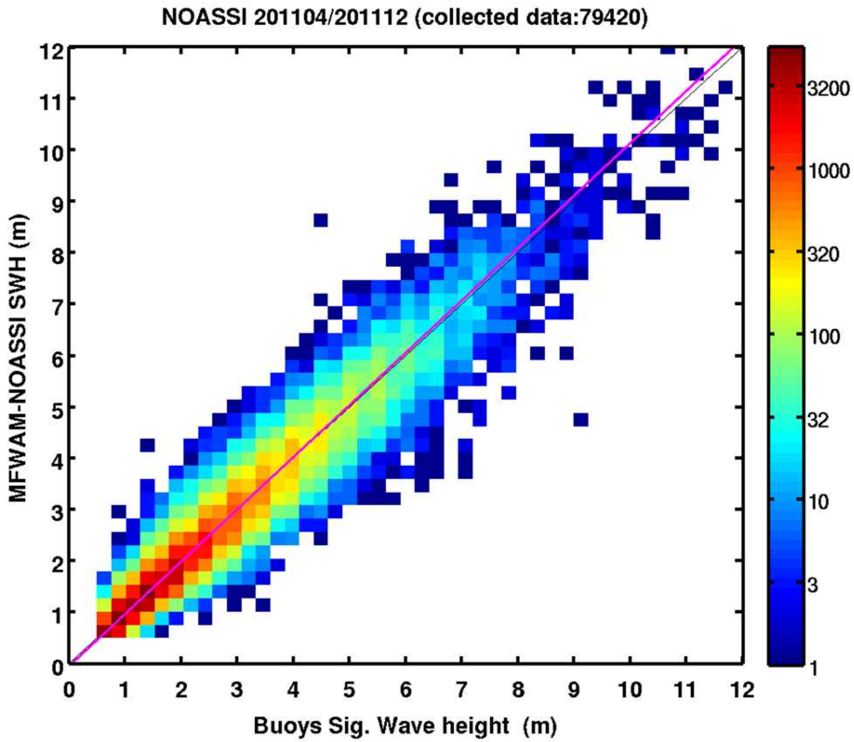


Hs Validation against buoys

OPER ASSI Jason 2 RA2 and ASAR



NOASSI



Bias = -0.04
SI = 15.1%
NRMS = 15.3%
Slope = 0.98
Intercept = -0.01

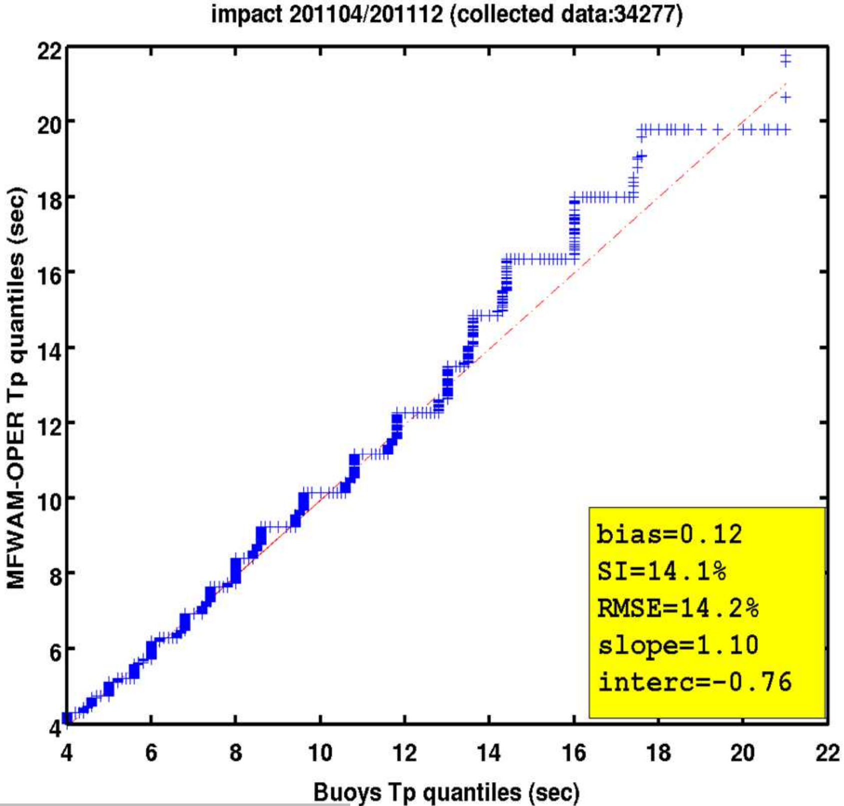
Data Nb :79420

Bias=-0.01
SI=16.1%
NRMS=16.4%
Slope=1.02
Intercept=-0.05

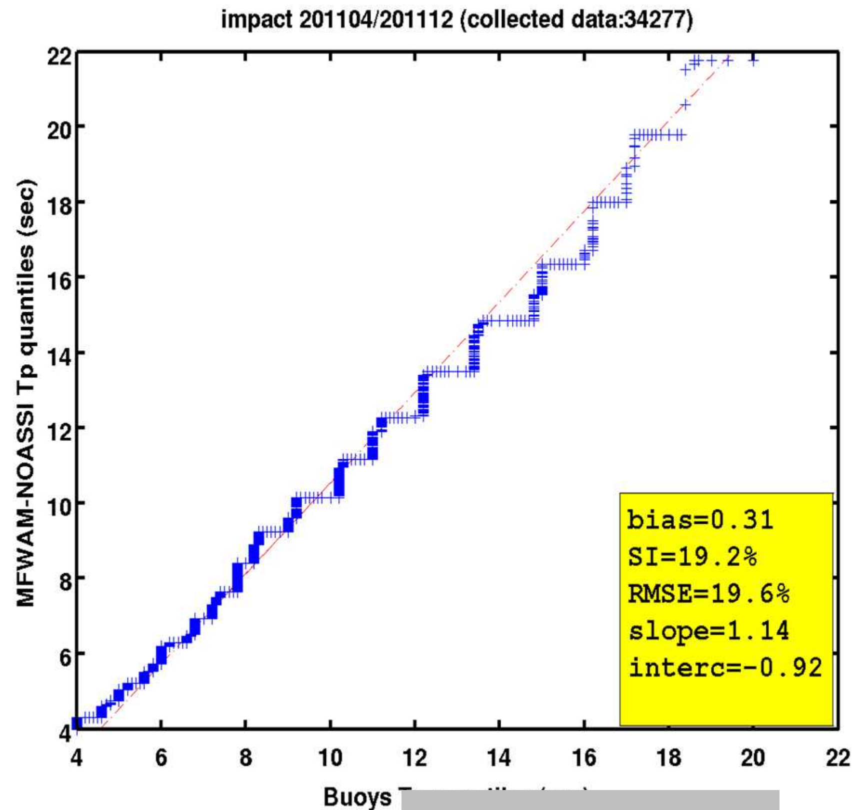
April to December 2011

Tp validation against Buoys

OPER ASSI Jason 2 RA2 and ASAR



NOASSI



Bias = 0.12
SI = 14.1%
NRMS = 14.2%
Slope = 1.10
Intercept = -0.76

Data collected : 34277

Bias=0.31
SI=19.2%
NRMS=19.6%
Slope=1.14
Intercept=-0.92

April to December 2011

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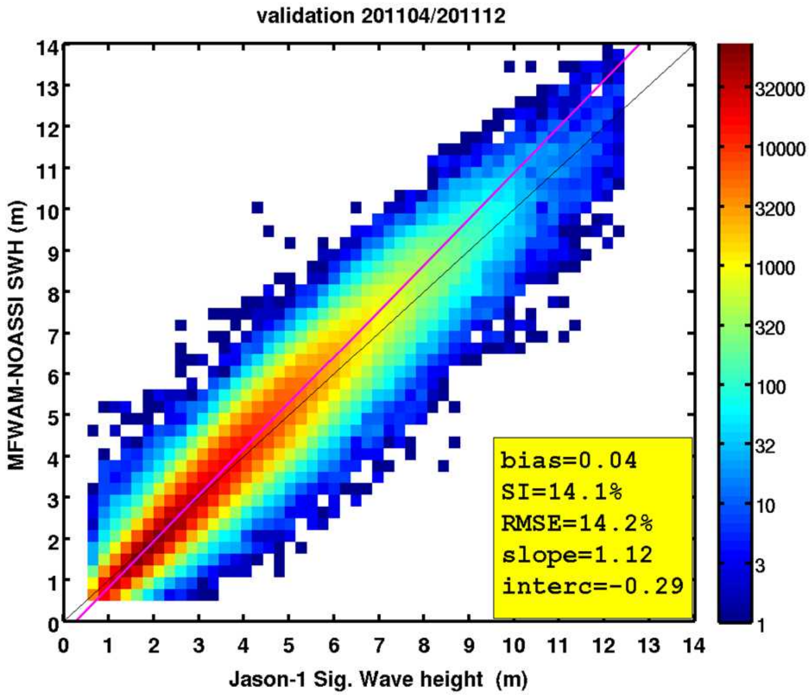
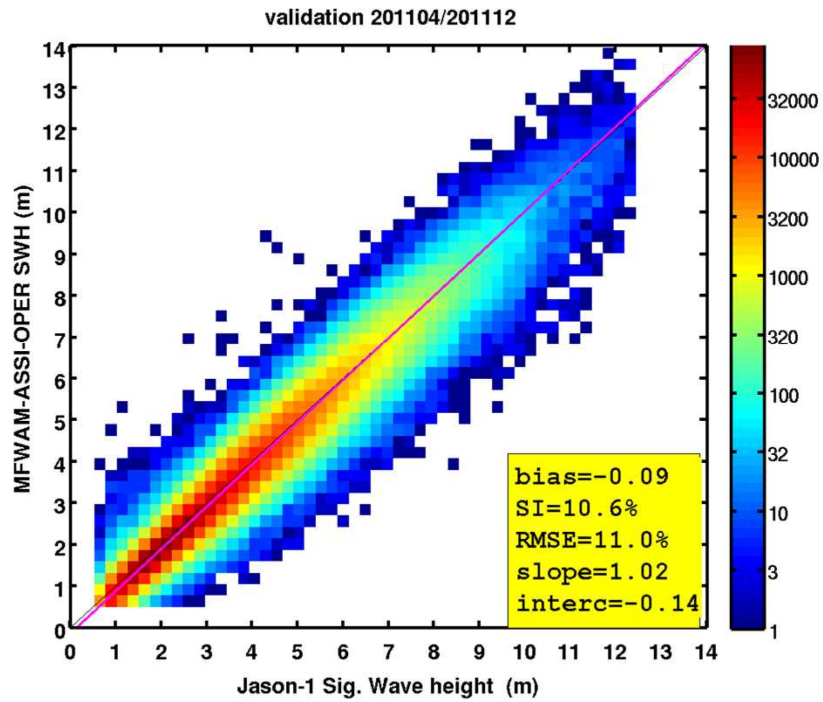
Validation against Altimeters (Jason-1)

NOASSI



ASSI Jason2-RA2+ASAR



Bias=0.04
SI=14.1%
NRMS=14.2%
Slope=1.12
Intercept=-0.29

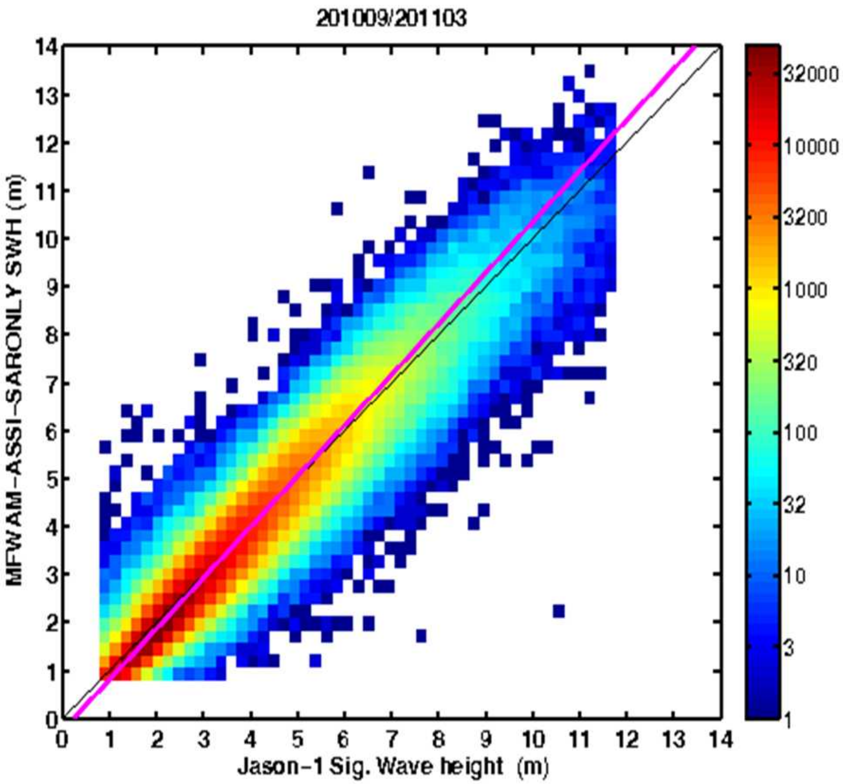
Data Nb 170942

Bias = -0.09
SI = 10.6%
NRMS = 11.0%
Slope = 1.02
Intercept = -0.14

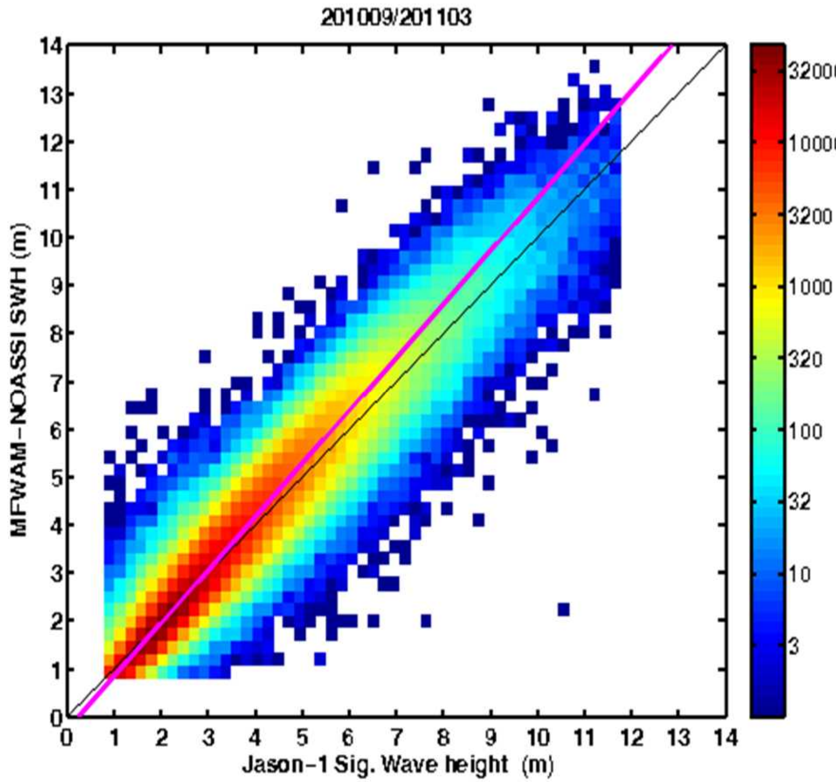
April to December 2011

Impact of the assimilation of ASAR wave spectra only comparison with Jason 1 wave heigths

ASSI-SAR



NO ASSI



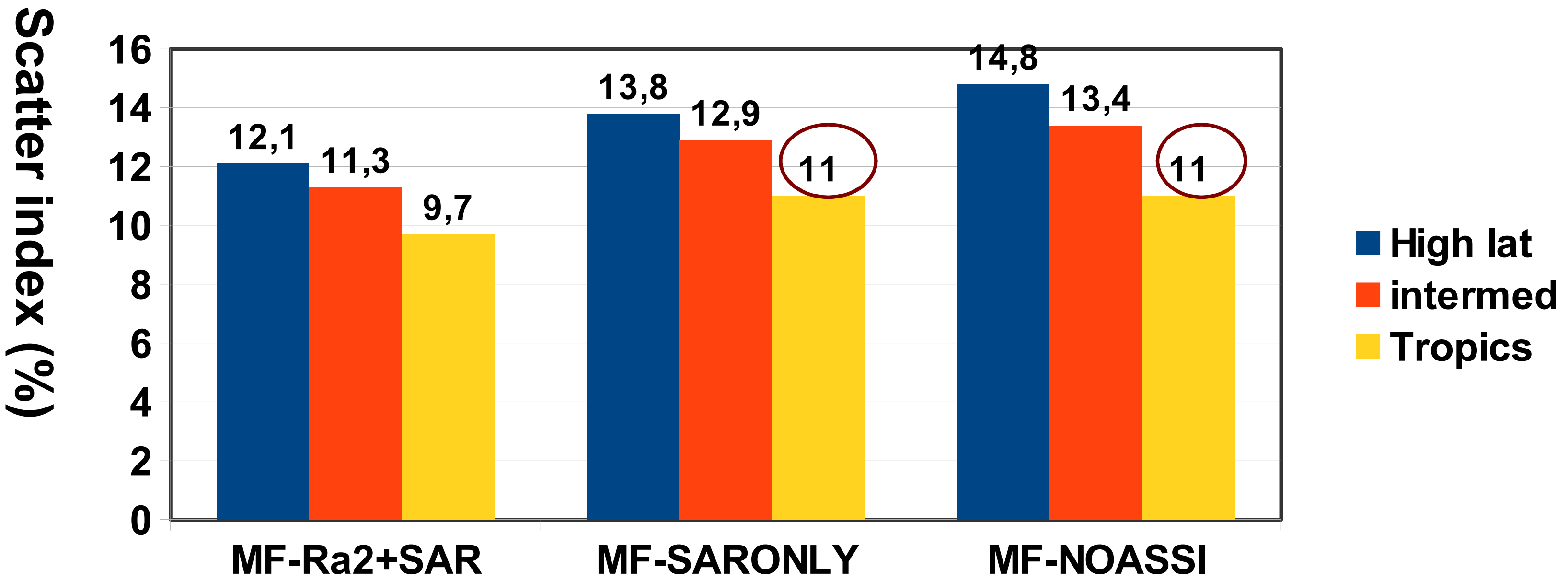
Bias = -0.08
SI = 13.7%
NRMS = 13.9%
Slope = 1.06
Intercept = -0.25

Data collected
1327786

Sep. 2010 to March 2011

Bias = 0.05
SI = 14.7%
NRMS = 14.8%
Slope = 1.11
Intercept = -0.27

Hs Impact of SAR, SAR+ALTI against Jason 1 & 2



->No significant impact in the tropics probably due to the new Physics

7 months: Sep. 2010 to March 2011

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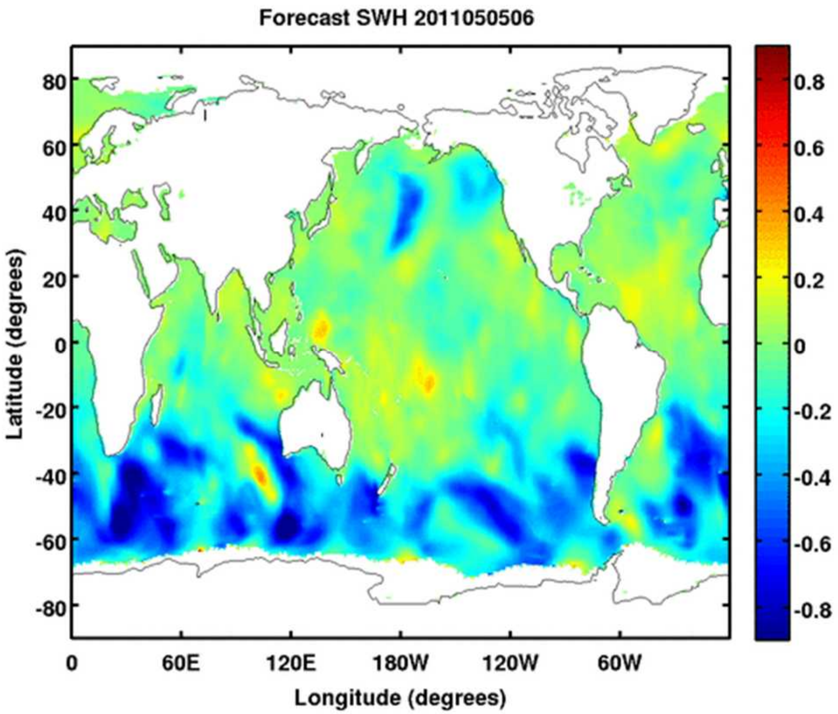
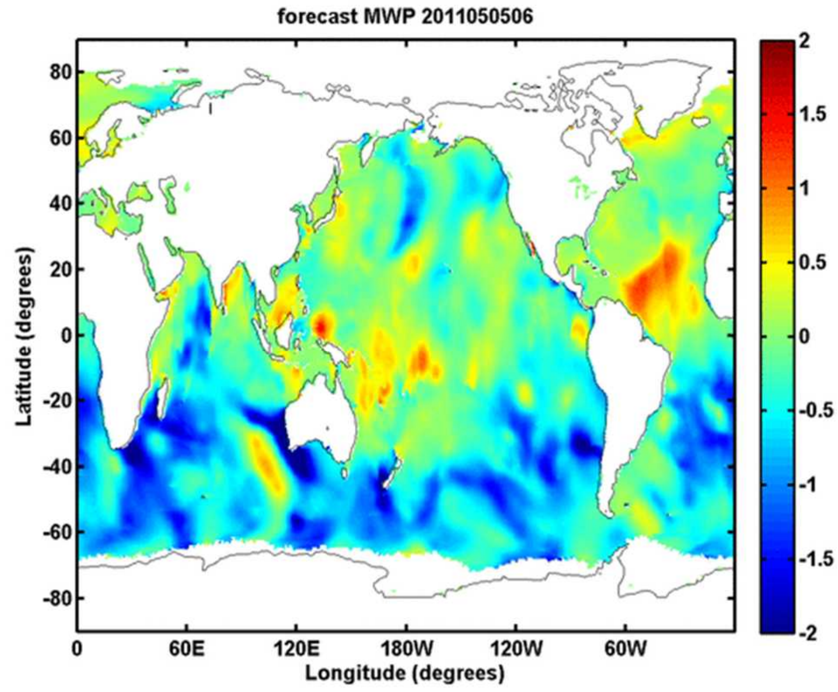
« Impact » of the assimilation in the forecast period

SWH



Mean Wave Period

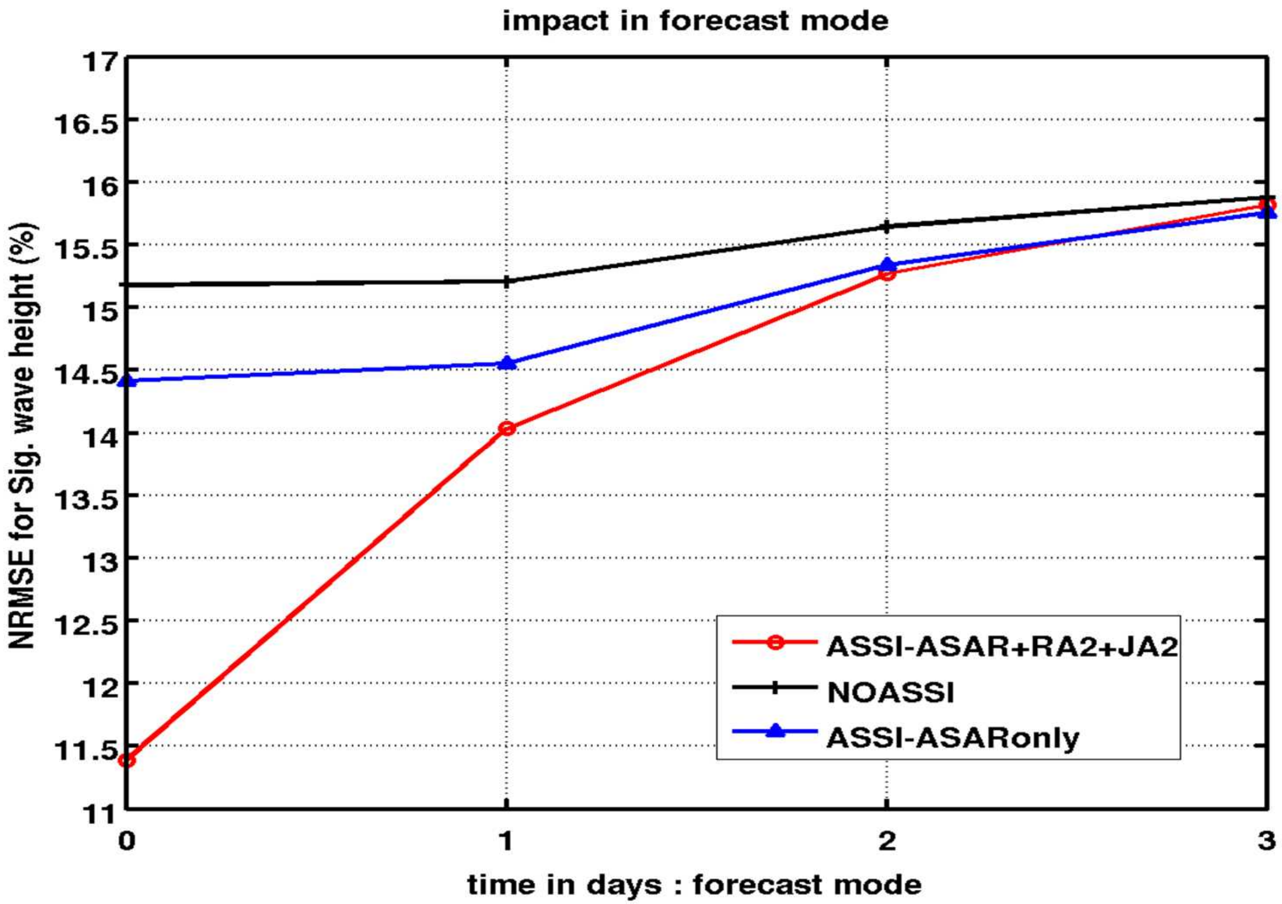


Difference between runs of MFWAM with and without assimilation

3-day forecast starting from 5 May 2011, by step of 6 hours

Impact of ASAR +Altimeters according to forecast range

→ Positive impact for the significant wave height



Comparison with Jason-2 and Envisat Ra-2 in the forecast period

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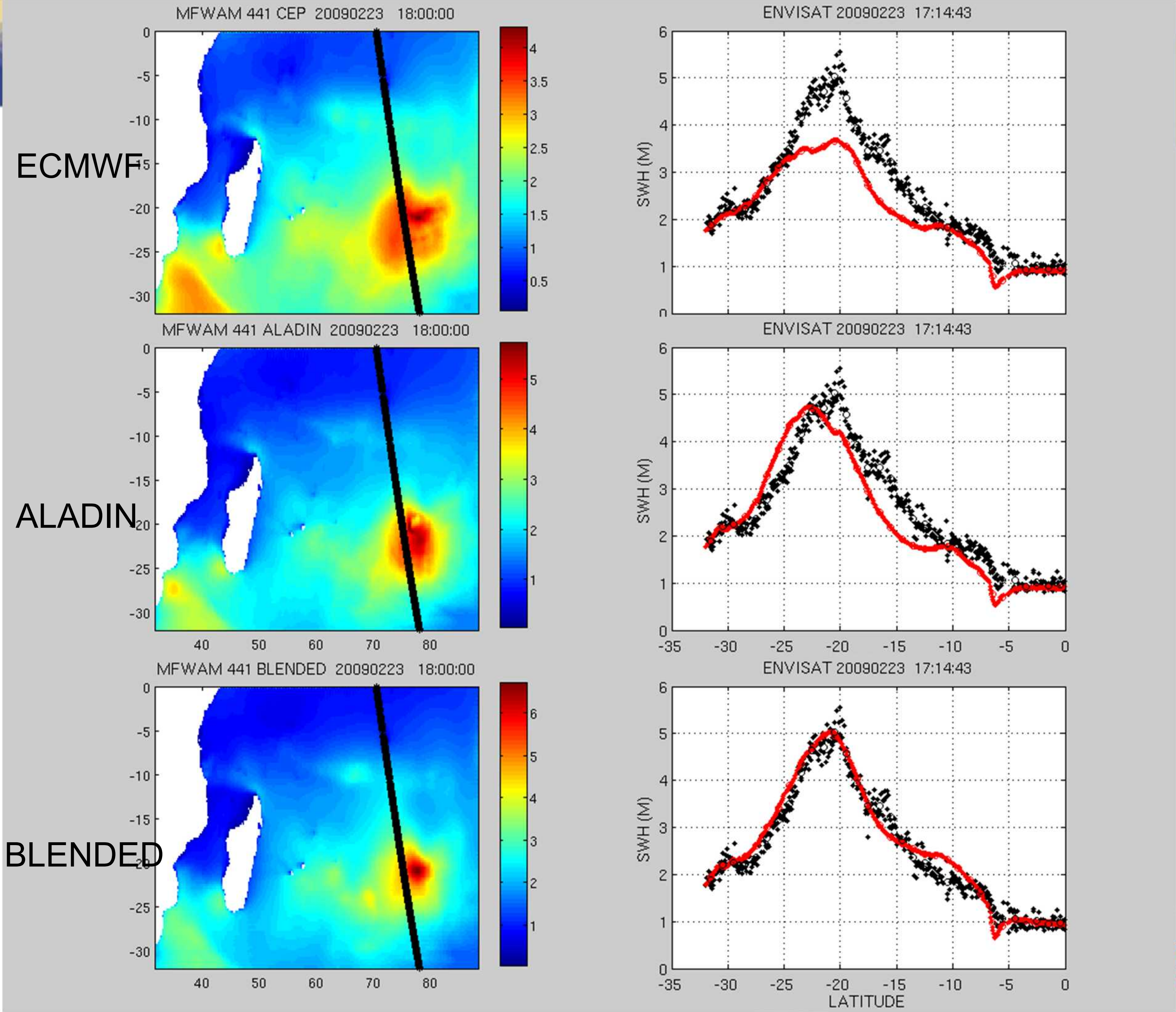


Large biais

Small biais but shifted position ---> increases rmse

No bias right position

Recent tuning the assimilation scheme

- Adjustment of the correlation length and of the distance of influence of the ASAR wave spectra

- Adjustment of threshhold level for combining two peaks of partitions when they are close to each other

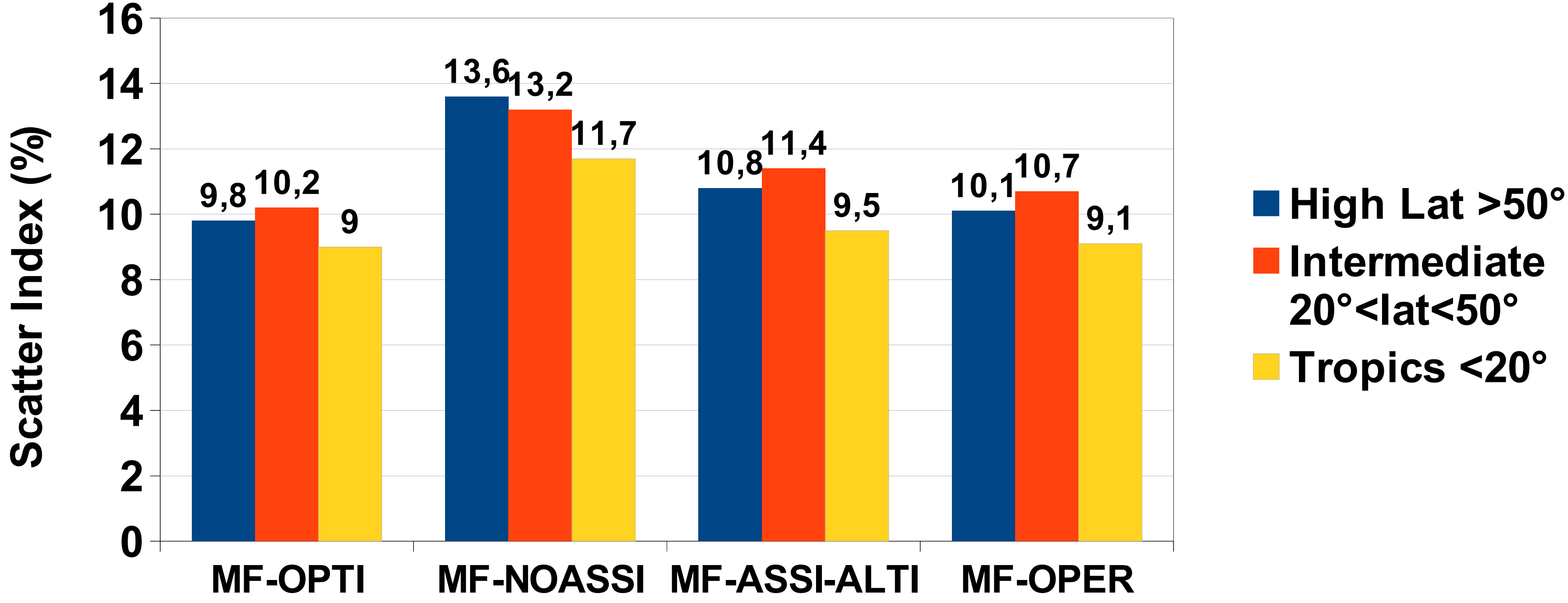
- Smoothing of the filling gaps between the analysed partitions in order to reconstruct the analysed wave spectrum

- Rejection of the partitions with too low energy

- Introduction of a frequency cut-off in addition to the variable SAR cut-off

→ test over 3 months (April to June 2011)

Impact of tuning the assimilation scheme
Validation against Jason-1 Sig. Wave Height (not assimilated)



MFWAM-OPTI and MFWAM-OPER : ASSI of SAR , Ja2 and Envisat

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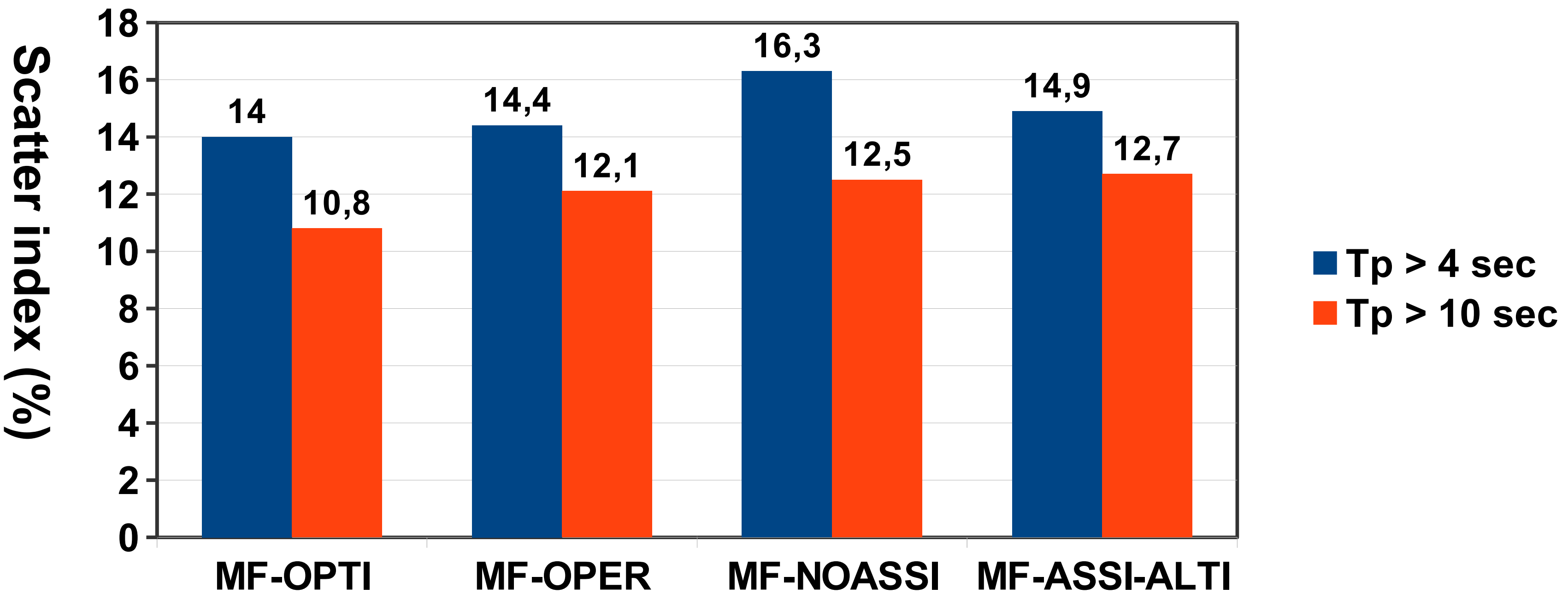
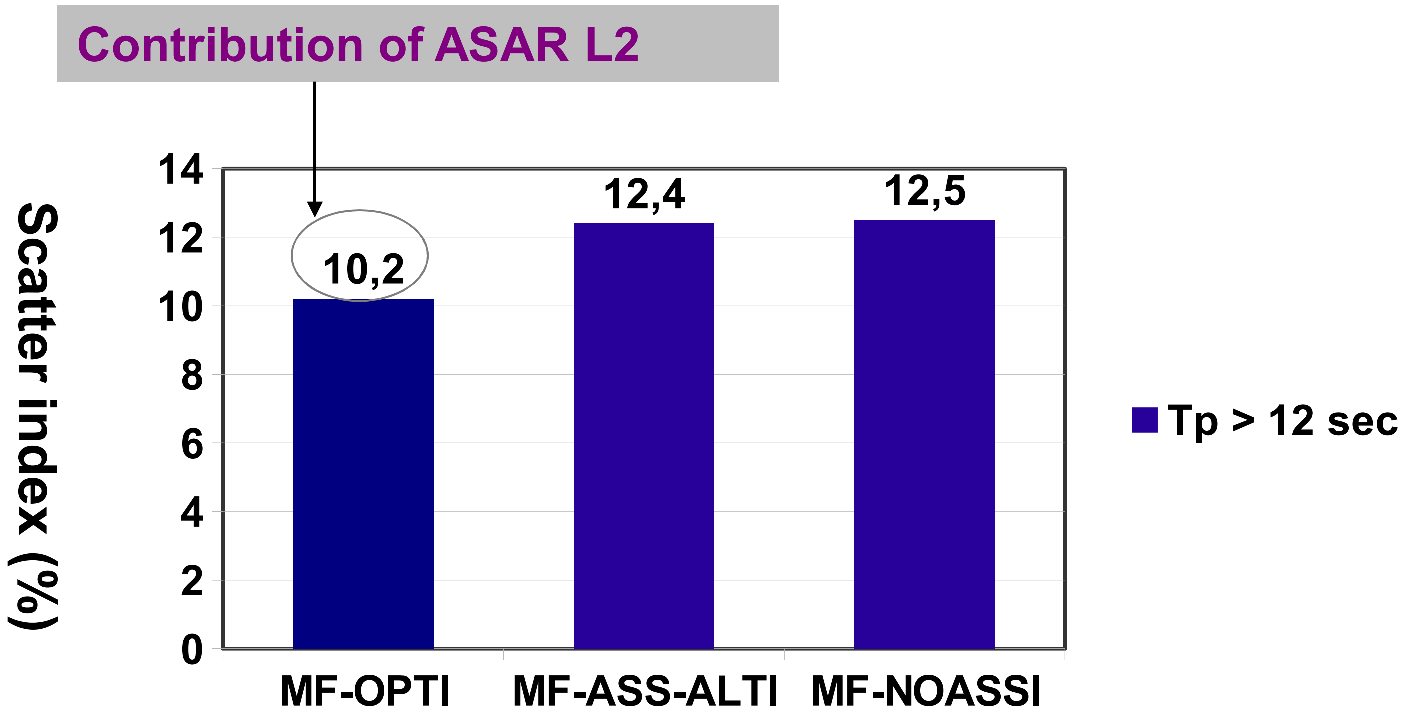
Verification against buoys (peak period))



MFWAM-OPTI and MFWAM-OPER : ASSI of SAR , Ja2 and Envisat

- **error reduction with new tuning (MFWAM-OPTI)**

impact of the ASAR in addition to altimeter on the Peak Wave Period (Tp>12 sec)



Conclusions

→MF and ECMWF have been assimilating operationally ESA/ASAR (L2 for MF, Level 1 for ECMWF) and Altimeters products for months or years

→The impact of the assimilation of Altimeter data, SAR alone, SAR + Altimeters has been evaluated:

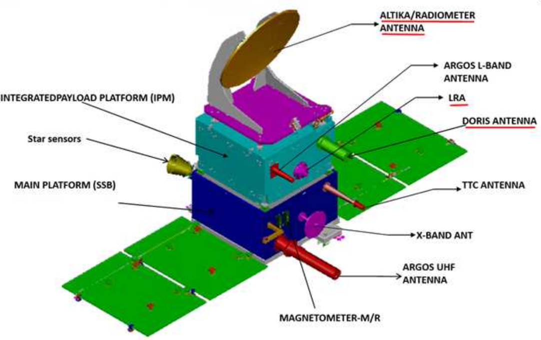
the reduction of the RMSE in the wave model analysis is of

- 10% and 25% when estimated with swh and Tp from buoys
- 25% when estimated with altimeter swh

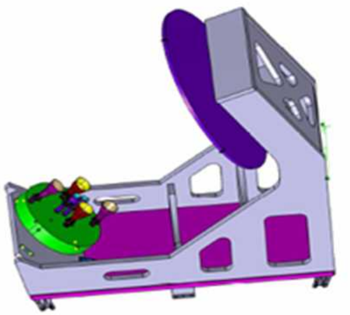
→The contribution of ASAR in the assimilation is clearly showed for the peak period Tp>12 sec : only the use of ASAR improves the analyses by more than 20%

→The assimilation of ASAR L2 products alone improves the estimate of Sig. Wave height by about 10% in comparison with altimeters (mainly in high and intermediate latitudes)

→ Impact in the forecast is however deacreasing quite quickly; depending on the area and parameter



Perspectives/Issues

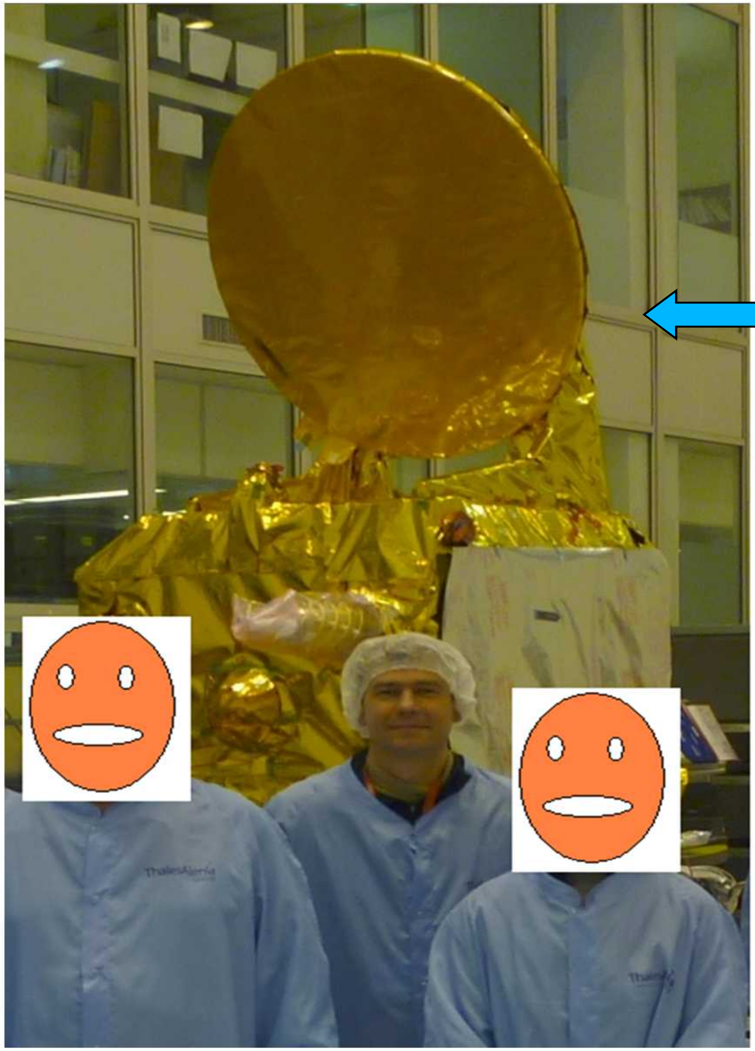


→ Impact studies based on synthetic wave spectra from SWIM instrument on CFOSAT satellite (Chineese-French program, launch 2015) and performances combining additional instruments (ASAR and altimeters)

→Improvement of the assimilation scheme to better deal with several source of information (Altimeter and SAR assimilation precedures are performed successively), modify error covariance functions-that are not isotropics

→ Revisiting more sophisticated techniques to better combine all source of information (in near future Jason1, Jason2, Cryosat, Sentinel 3, Saral/Altika could fly together) ? Operational forecasting is not the only issue: better knowledge of the sea-state is important for many applications such as Wave statistics, Climate, sediment transport…

THANK YOU



SARAL/ALTIKA

Ka band Altimeter