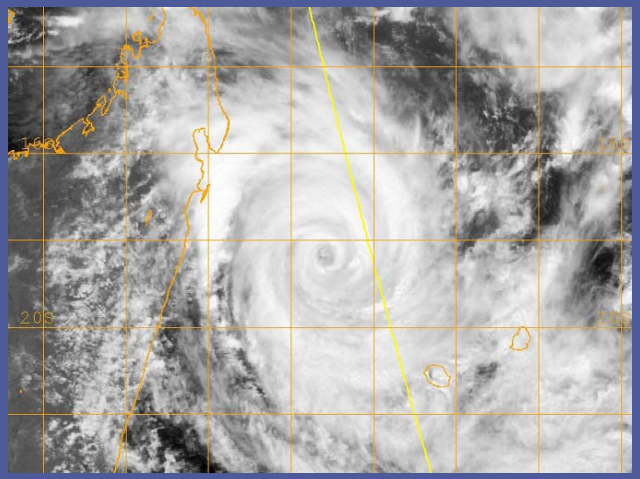
OPERATIONAL WAVE FORECASTING FOR TROPICAL CYCLONES CONDITIONS



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Pierre Queffeulou[2], Abderrahim Bentamy[2], Yves Quilfen[2]

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with support of CNES, and ANR funding (HEXECO project)

Ifremer

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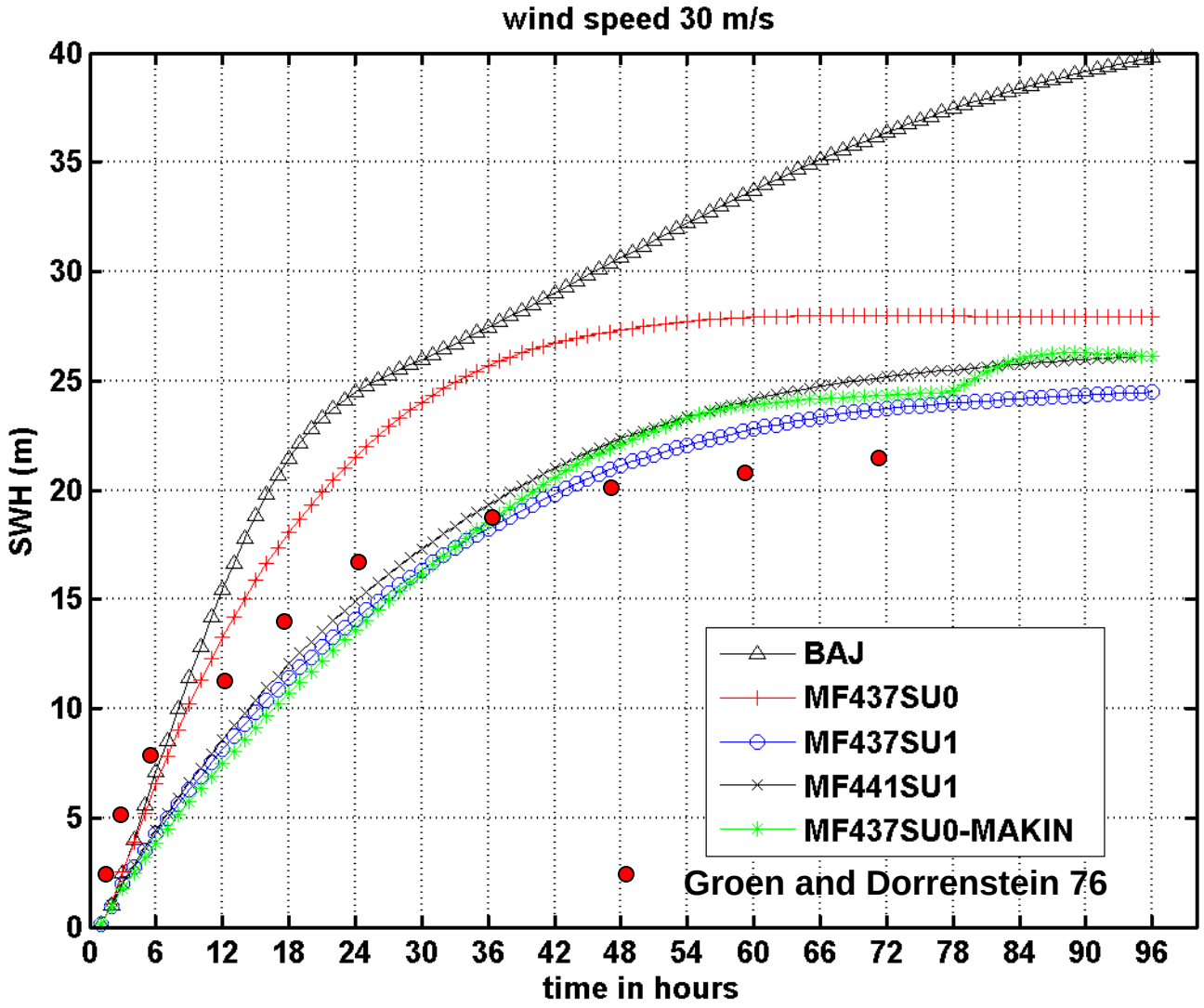
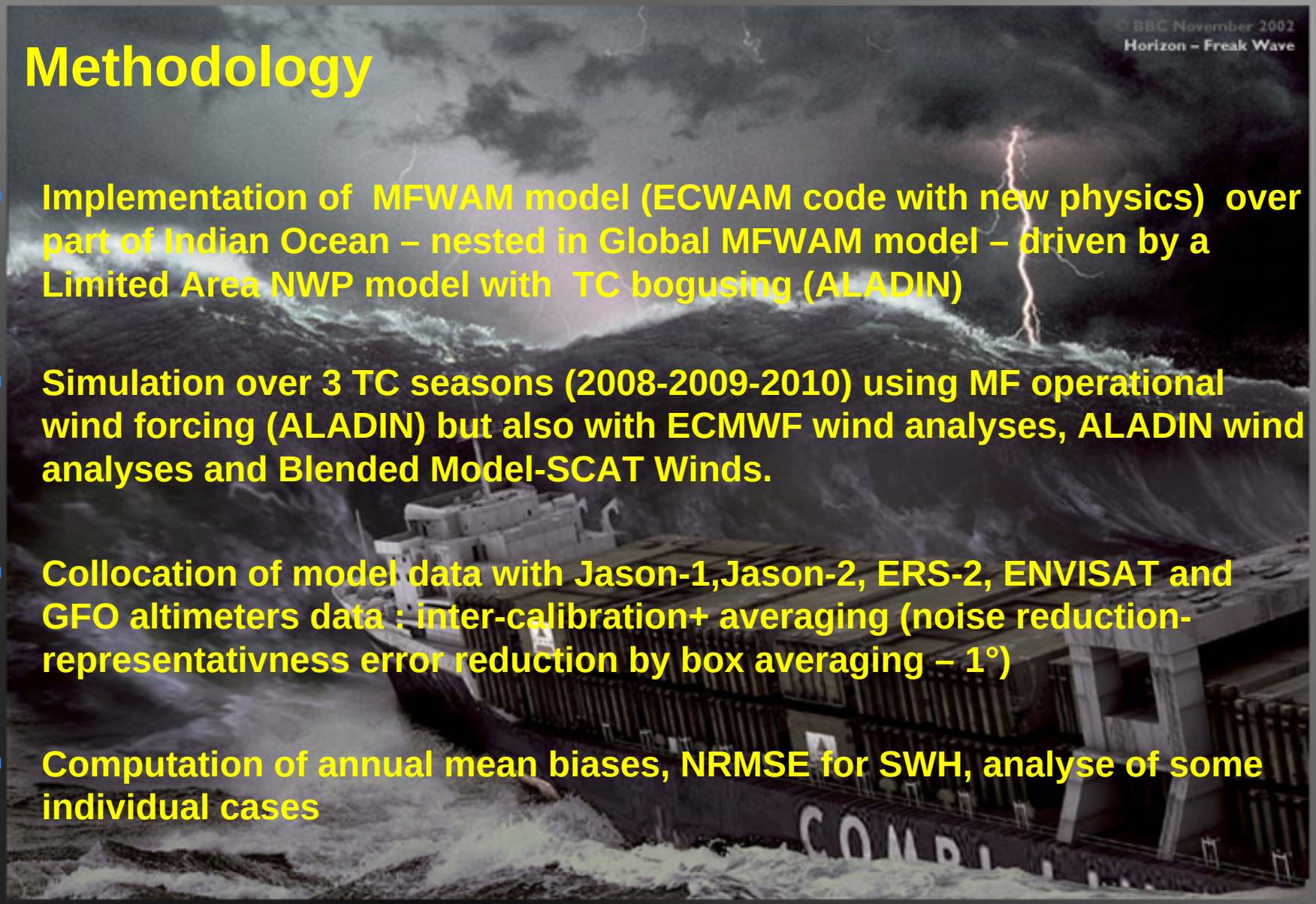
Motivation

- **Meteo-France's Responsibilities**
  - **International: GMDSS and RMSC**
  - **National: Warning System recently extended**
- **New Wave Forecasting System: MFWAM**
  - **Global – Validation through JCOMM/WFVS**
  - **Regional – Validation using data from JCOMM/WFVS**
  - **Tropical Cyclone – Validation- Errors estimation**
- **Benefit for applications such as**
  - **High sea states prediction**
  - **Unexpected waves (Spectral shape)**
  - **Wave Setup warning (beach slope, $HsxT^2$)**

Challenge: errors due to "unknown" growth curves, **Snl approximation** (**use of DIA**, Hendrik talk), **underestimated maximum wind speed- TC location**.uncertainty



Methodology



- Implementation of MFWAM model (ECWAM code with new physics) over part of Indian Ocean – nested in Global MFWAM model – driven by a Limited Area NWP model with TC bogusing (ALADIN)
- Simulation over 3 TC seasons (2008-2009-2010) using MF operational wind forcing (ALADIN) but also with ECMWF wind analyses, ALADIN wind analyses and Blended Model-SCAT Winds.
- Collocation of model data with Jason-1,Jason-2, ERS-2, ENVISAT and GFO altimeters data : inter-calibration+ averaging (noise reduction-representativness error reduction by box averaging – 1°)
- Computation of annual mean biases, NRMSE for SWH, analyse of some individual cases

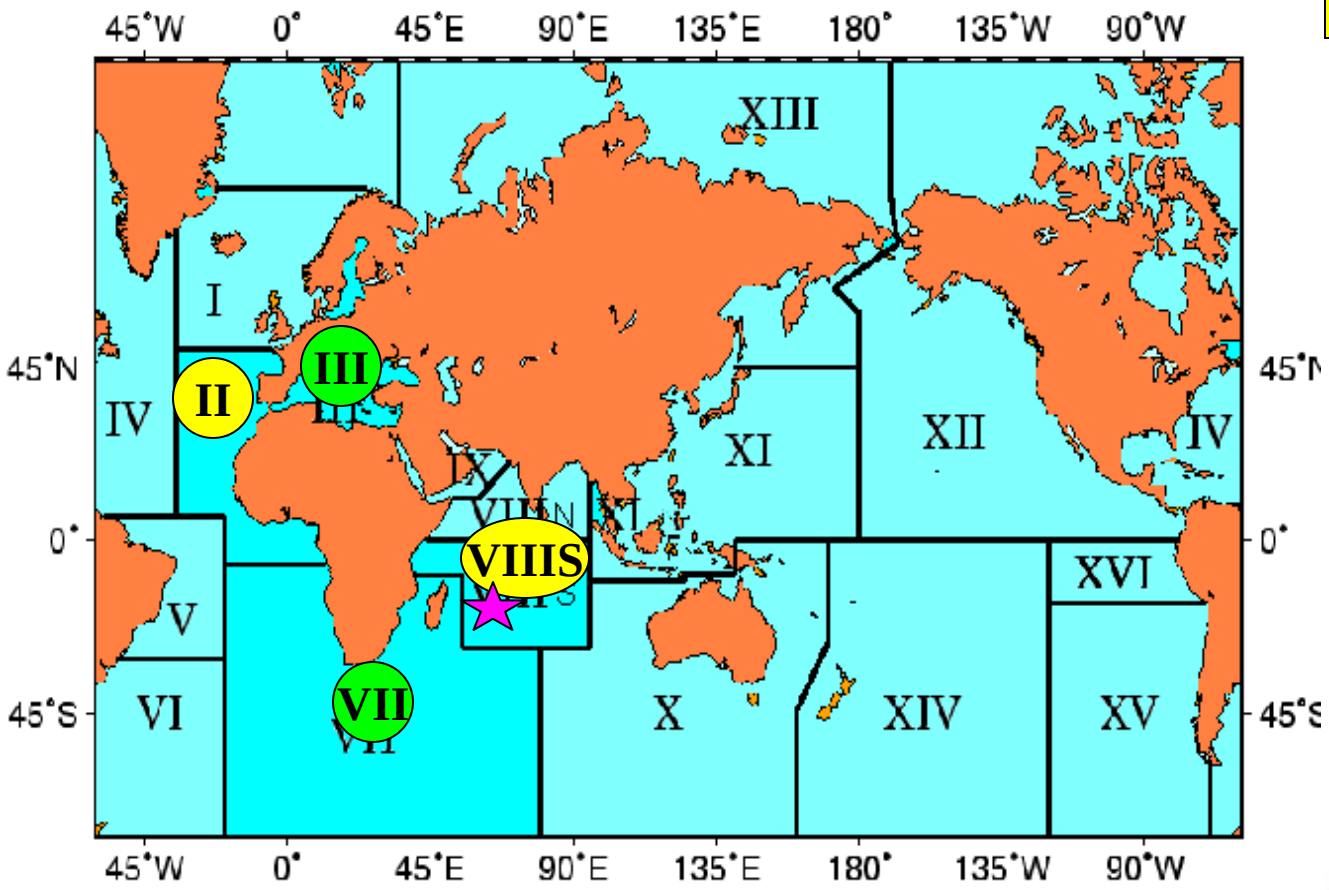
BBCi

Summary/Conclusions

- MFWAM-437 underestimates wave heights for TC conditions when driven with LAM ALADIN and ECMWF winds.
- MFWAM-441 produces unbiased SWH for high winds conditions, including TC conditions, when driven by ALADIN, ECMWF and Blended winds (SCATT+model first guess)
- All wind forcings produce relatively accurate sea-state estimates (typically 10% random error up to 7m SWH) with very small biases (< 5%)
- Improvement when using Blended winds→ Closer to scatt winds than model analyses: more spatial variability in blended winds

International duties:France within the GMDSS

Global Marine Distress and Safety System
RMSC La REUNION



✓Issuing Service for Metarea II and Metarea VIII(S)

✓Preparation Service for Metarea III (W), Metarea VII

MF LA REUNION: Regional Specialized Met Center (RMSC):

Tropical Cyclone Monitoring

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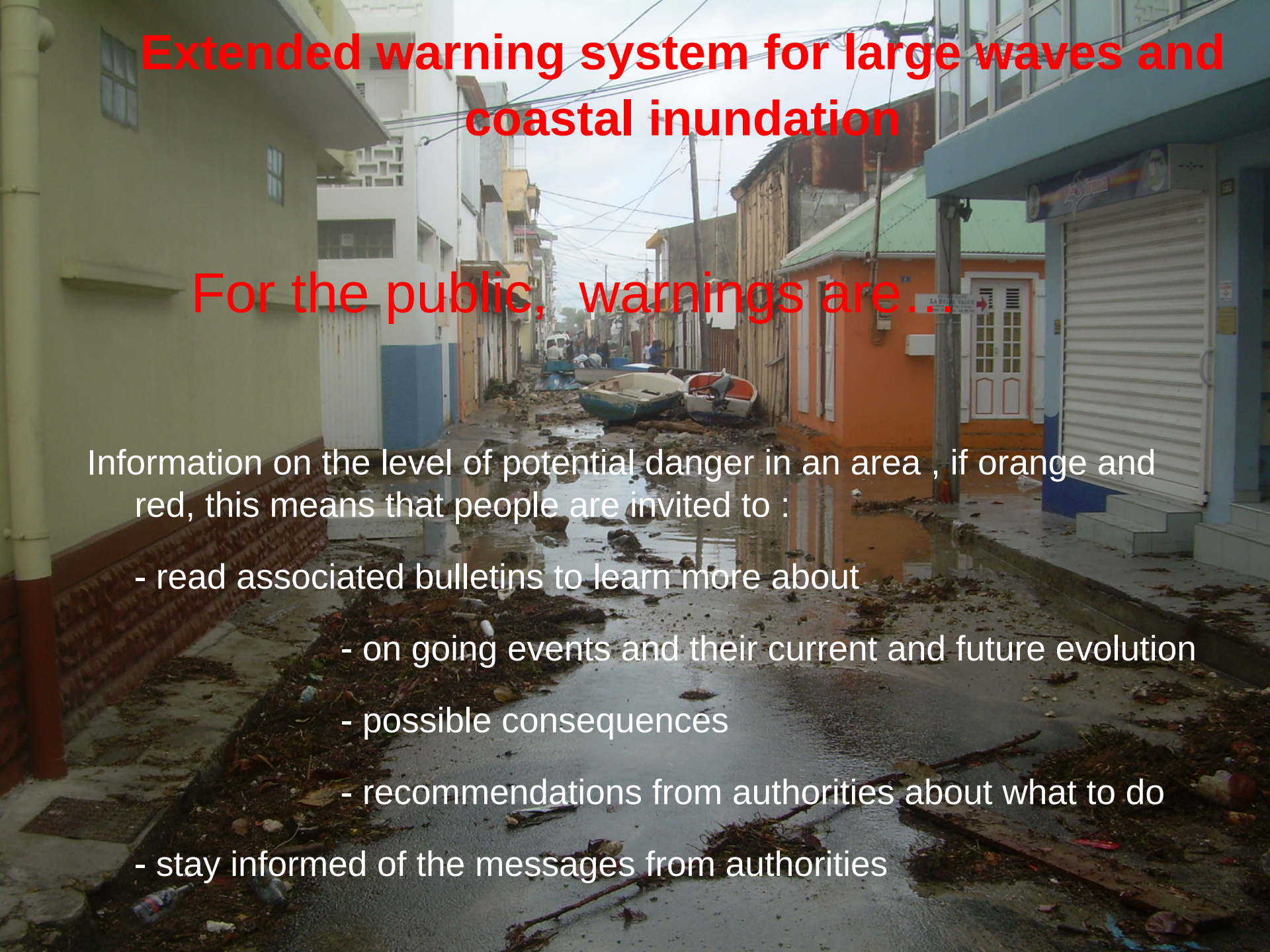
Extended warning system for large waves and coastal inundation

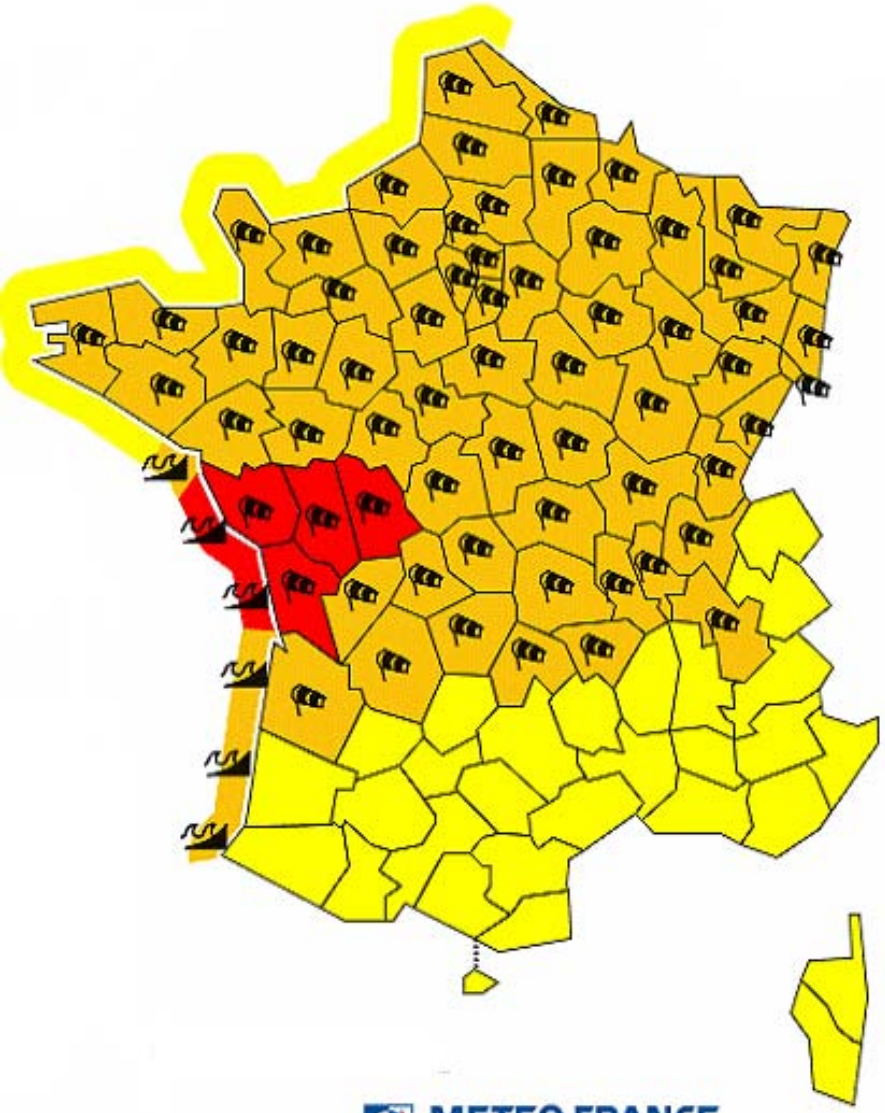


For the public, warnings are…

Information on the level of potential danger in an area , if orange and red, this means that people are invited to :

- read associated bulletins to learn more about
  - on going events and their current and future evolution
  - possible consequences
  - recommendations from authorities about what to do
- stay informed of the messages from authorities

Example of Warning Map



- High waves and coastal flooding warning system operational since october 3 rd this year.

- Decision to speed up the setting taken after Xynthia storm which was associacted with dramatic coastal flooding

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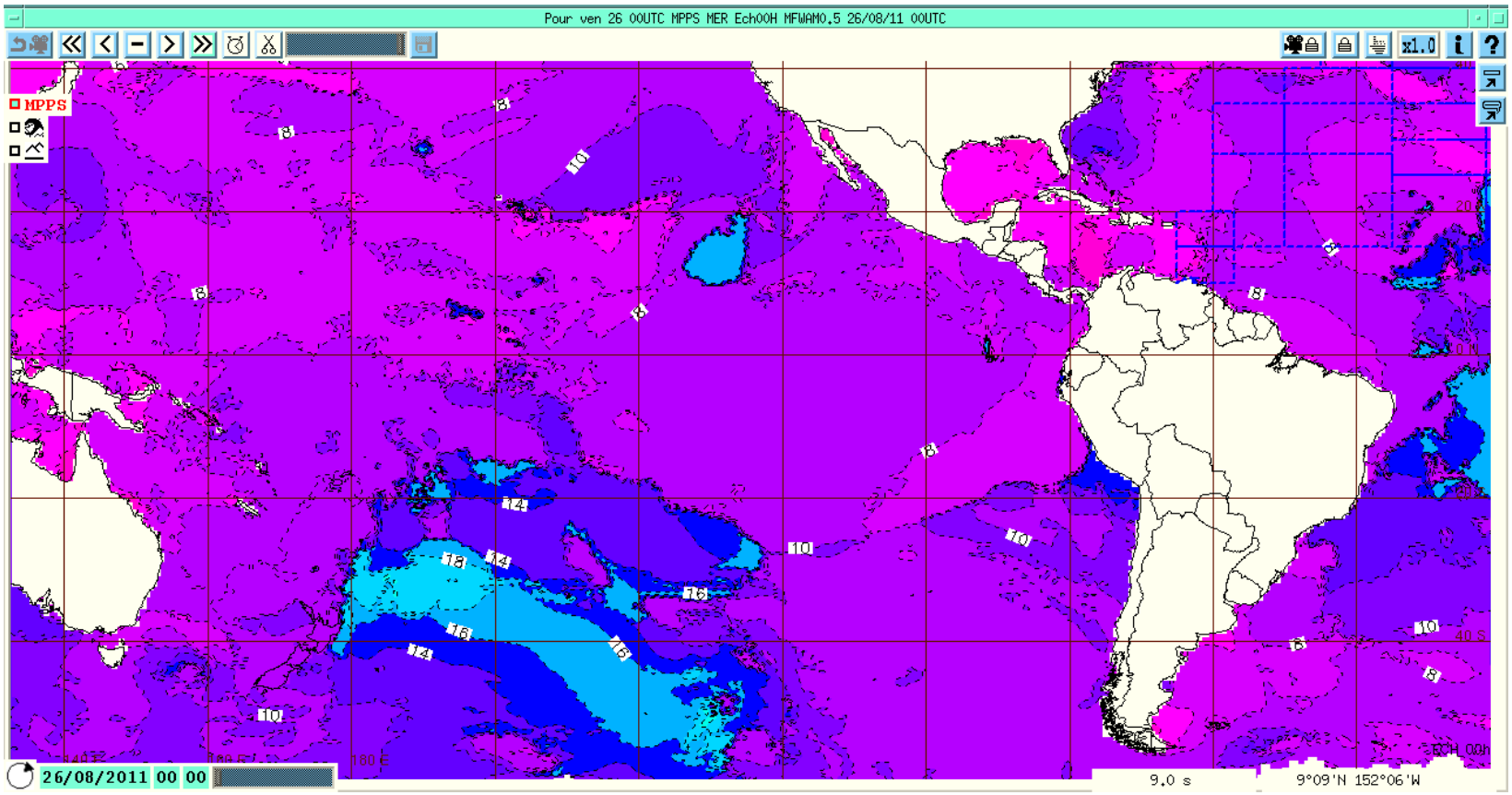
Example of event that activated the warning system in French Polynesia:



5 m and **18s** (wave length 500 m) swell

Expected wave set up, locally more than 1.5 m

No buoy data, only data from space

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New wave forecasting system of Meteo-France: MFWAM, thanks to joint efforts with :

- ECMWF (source code-validation with buoy data)
- SHOM (Physics)
- IFREMER (Validation with Altimeter data)
- CNES (Data assimilation-Validation)

-MFWAM based on ECWAM source code modified for new wave physics- mainly the dissipation term (Ardhuin et al . 2010)

-Introduction of ASAR LP2 and Altimeter data (Aouf et al. 2010)

-Implementation of Multi-grid nesting: from Global to Regional models

-Introduction of a partitioning scheme for swell components

New Dissipation terms from Ardhuin et al. (2010)

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 (term cumulative term, C3=0.4 in 441 C3=1 in 437)

Modification of the input source term (Ardhuin et al.2010)

$$U_{10} = \frac{u_\star}{\kappa} \log\left(\frac{z_u}{z_1}\right)$$

$$z_0 = \max\left\{\alpha_0 \frac{\tau}{g}, z_{0,\max}\right\}$$

Drag limitation

$$z_1 = \frac{z_0}{\sqrt{1-\tau_w/\tau}}.$$

stress reduction for MFWAM-441 to adjust with new dissipation based on saturation spectrum

$$(u'_\star)^2 = u_\star^2 (\cos\theta_u, \sin\theta_u) - |s_u| \int_0^k \int_0^{2\pi} \frac{S_{in}(f',\theta)}{C} (\cos\theta, \sin\theta)\, \mathrm{d}f'\mathrm{d}\theta,$$

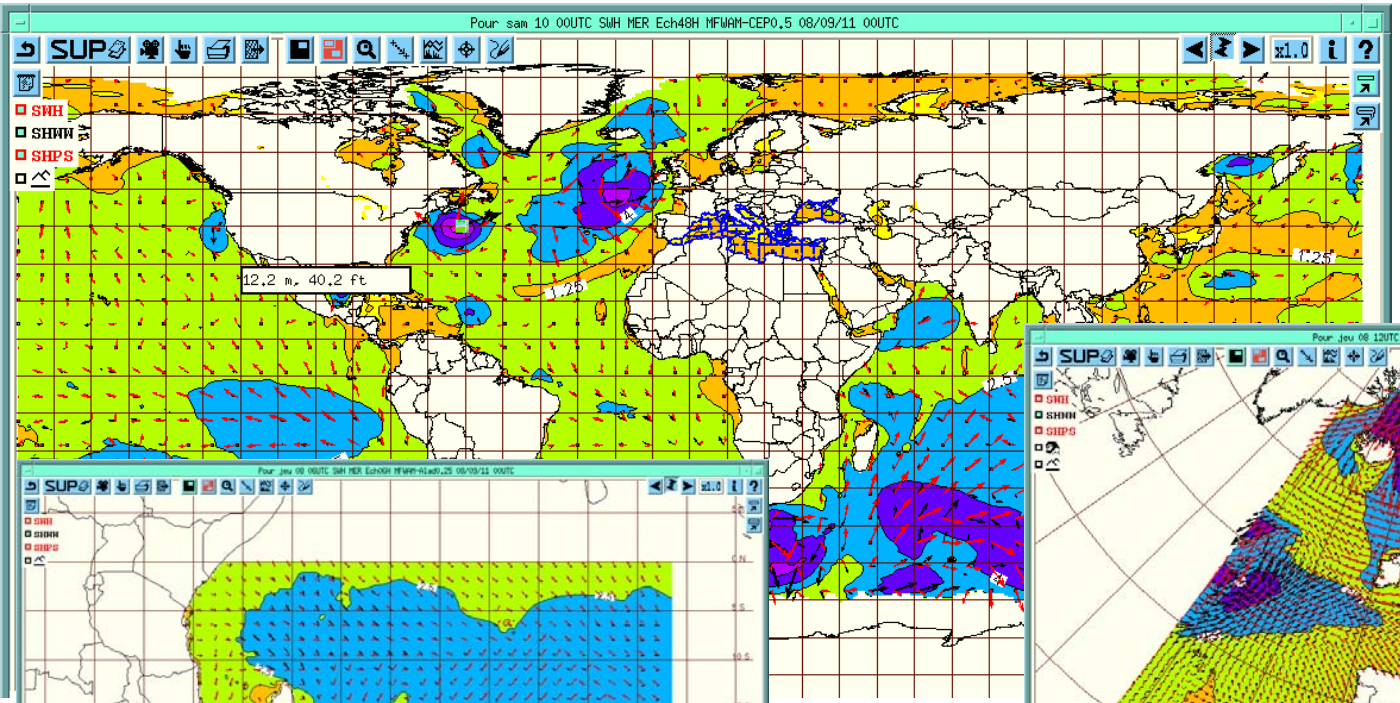
Su=1 for MFWAM-441

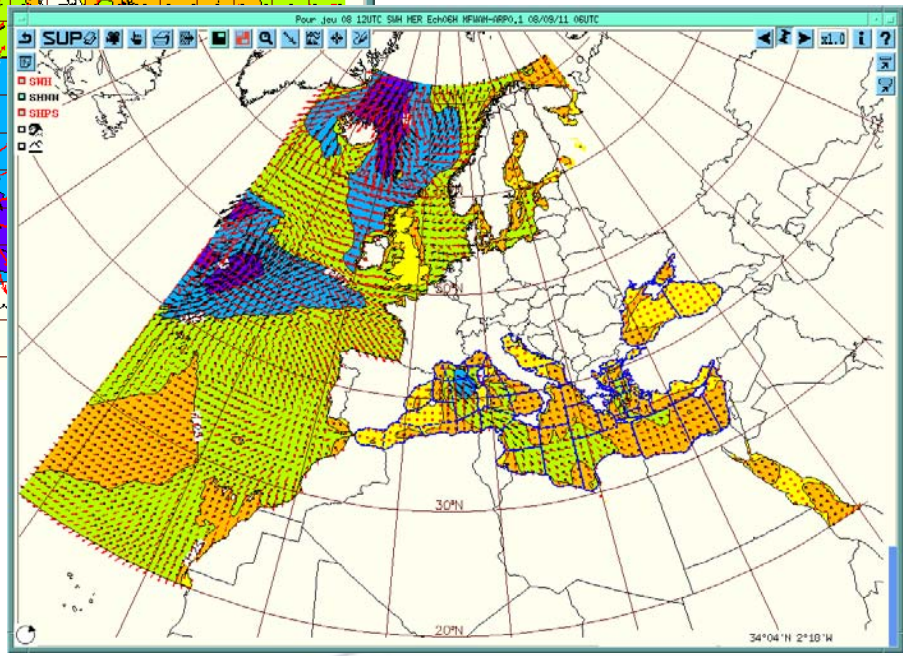
Su=0 for MFWAM-437

New wave forecasting system of Meteo-France:

2 global wave models MFWAM driven by different wind forcings: ECMWF and ARPEGE/IFS - resolution 55km

1 regional wave model MFWAM resolution 10km driven by ARPEGE winds soon with ECMWFwinds aswell





MFWAM-ALADIN-REUNION resolution 0.25°

Wind forcing ALADIN-REUNION –grille 0.1 km- 3hourly winds with TC bogusing

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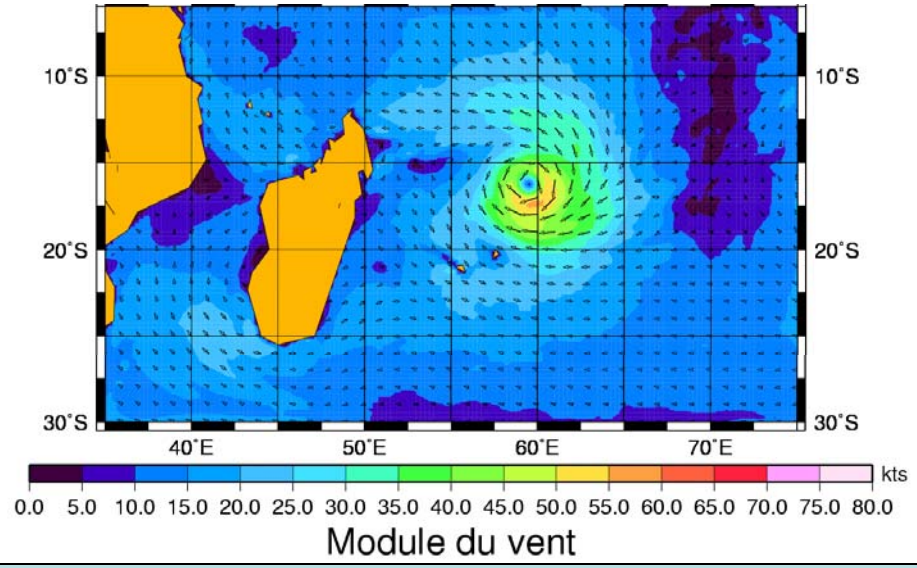
ALADIN-Réunion Model



- **Operational since nov. 2006**
- **10km** horizontal résolution
- **3D Var** assimilation scheme
- a 6h window (4/day)
- 60 vertical levels
- **2-day leadtime** forecast (at 0
- and 12h UTC). 3-day very soo
- BC from Arpege model.

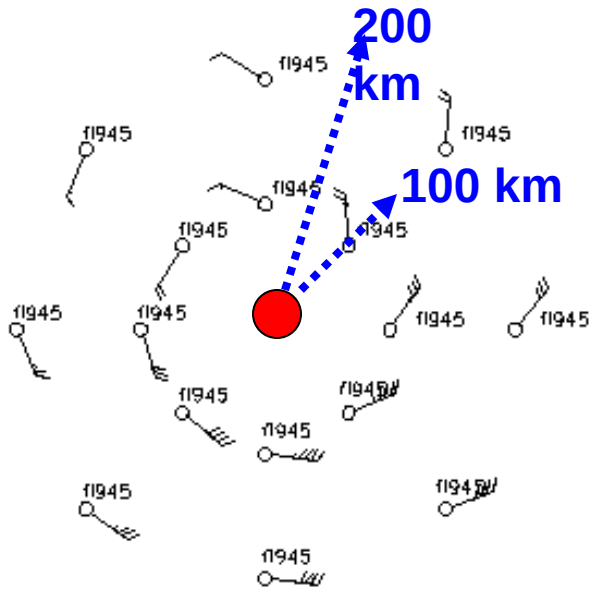
Observation dataset

- **SYNOP/SHIP/BUOY, Radiosondes, Profilers, Aircra**
- **Cloud winds (METEOSAT 7, 9)**
- **Scatterometer winds (QuikScat, ERS-2 and METOP**
- **ATOVS HIRS, AMSU-A, AMSU-B (NOAA 15,16,17,18**

AQUA ; METOP-A), AIRS (AQUA)

- **SSMI in clear-sky conditions (DMSP F13, F14)**
- **Satellite GPS**

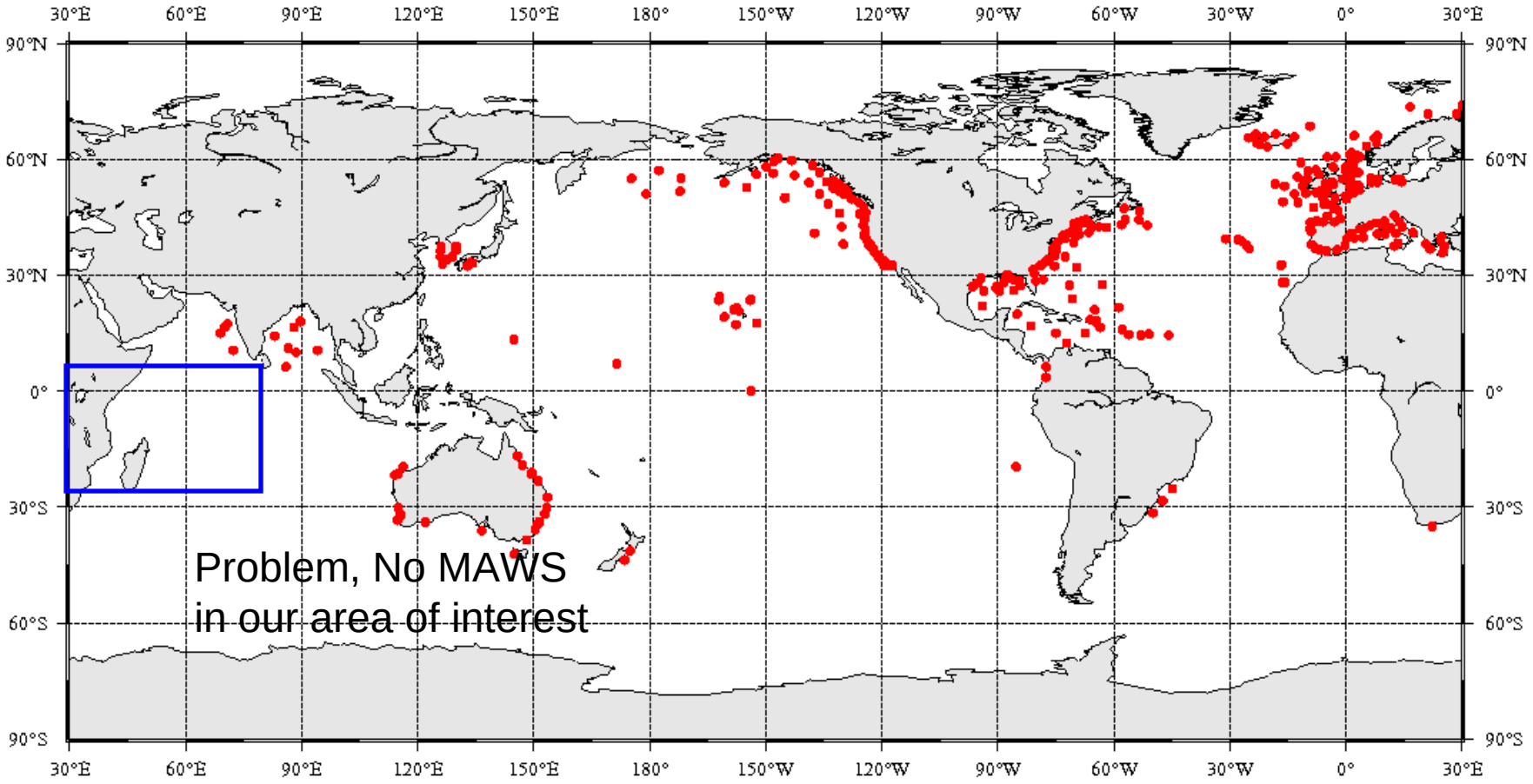
But Lack of observation in the Hurricane



pseudo-

Systematic Verification of the Wave Forecasting System:

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



2. ESA/GlobWave Pilot System to extend the WFVS to **altimeter data** Following WMO/JCOMM recommandation

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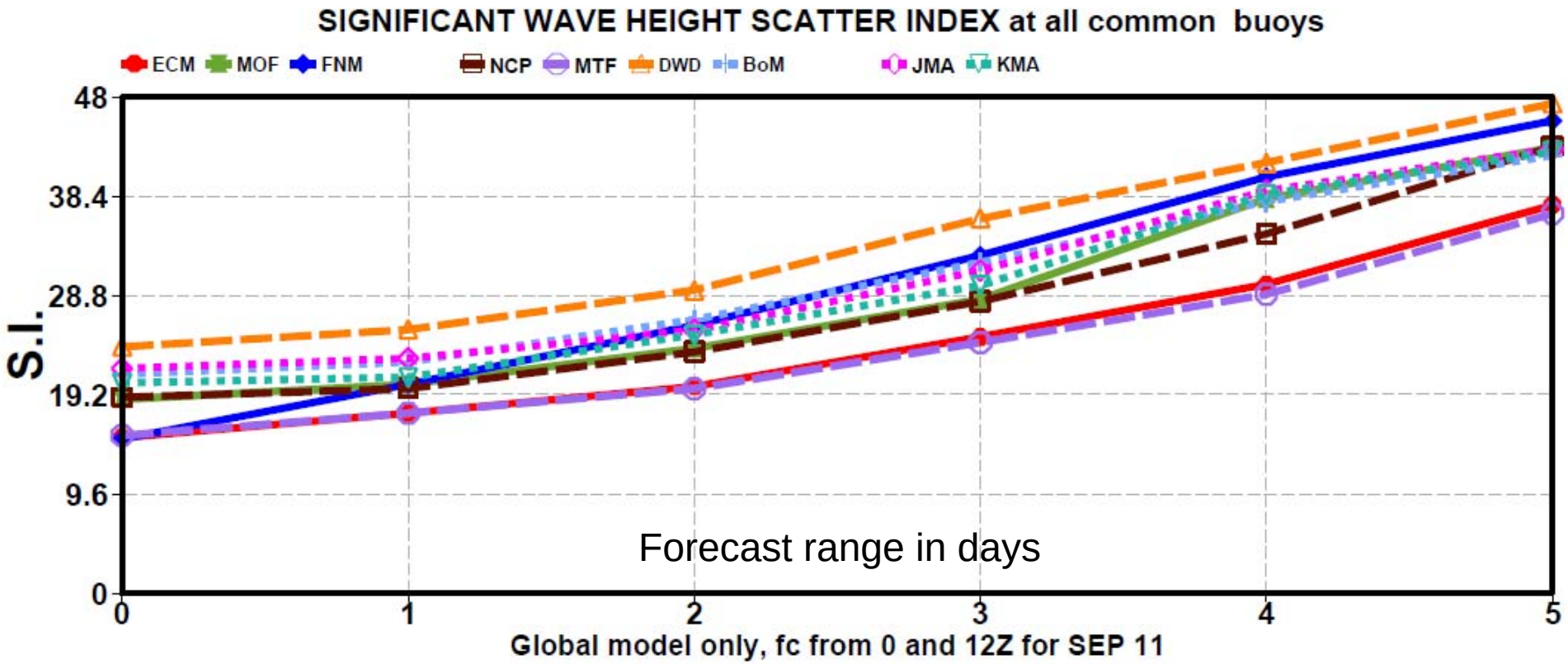
Monthly WFVS reports from JCOMM web site



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ECMWF__

NCEP_ _ _

September 2011

Relative error in %

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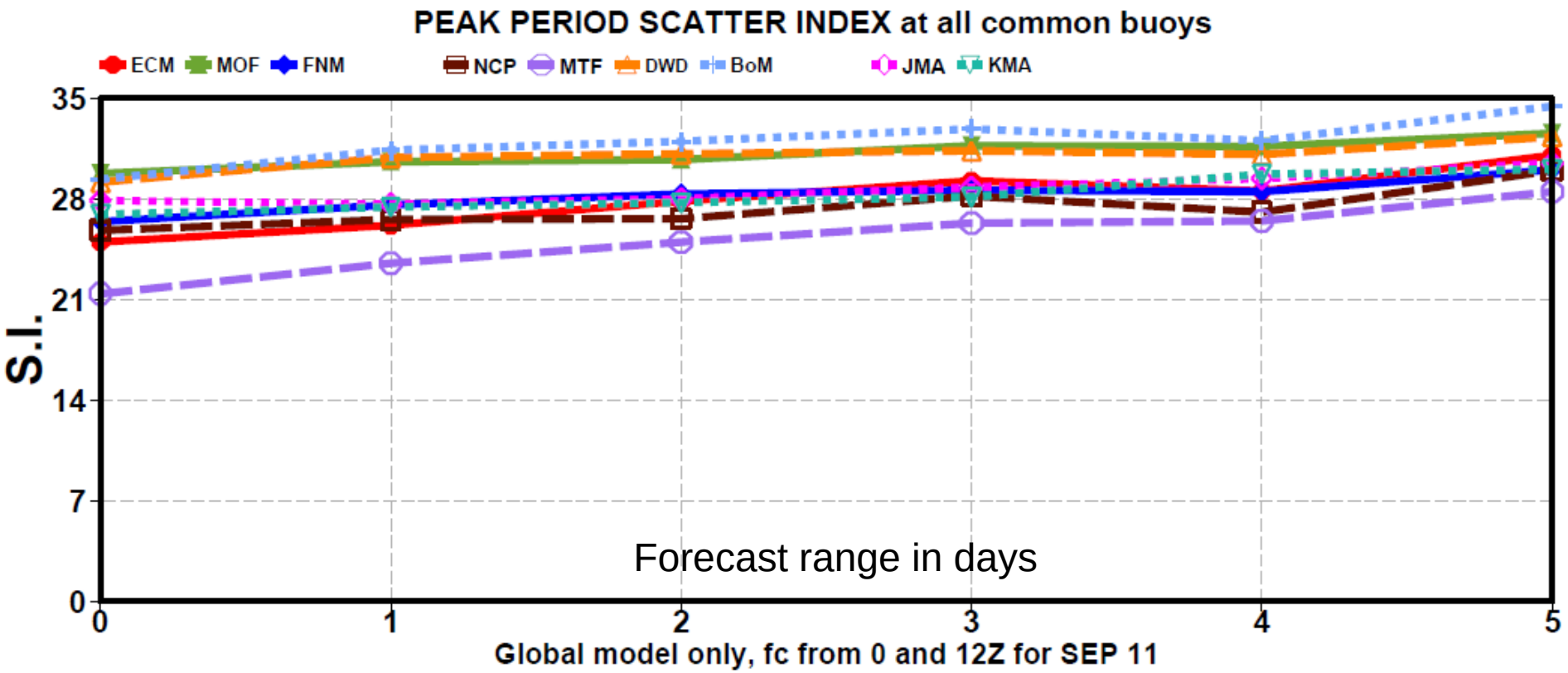

MF-----

ECMWF__

NCEP_ _ _

September 2011

Relative error in %

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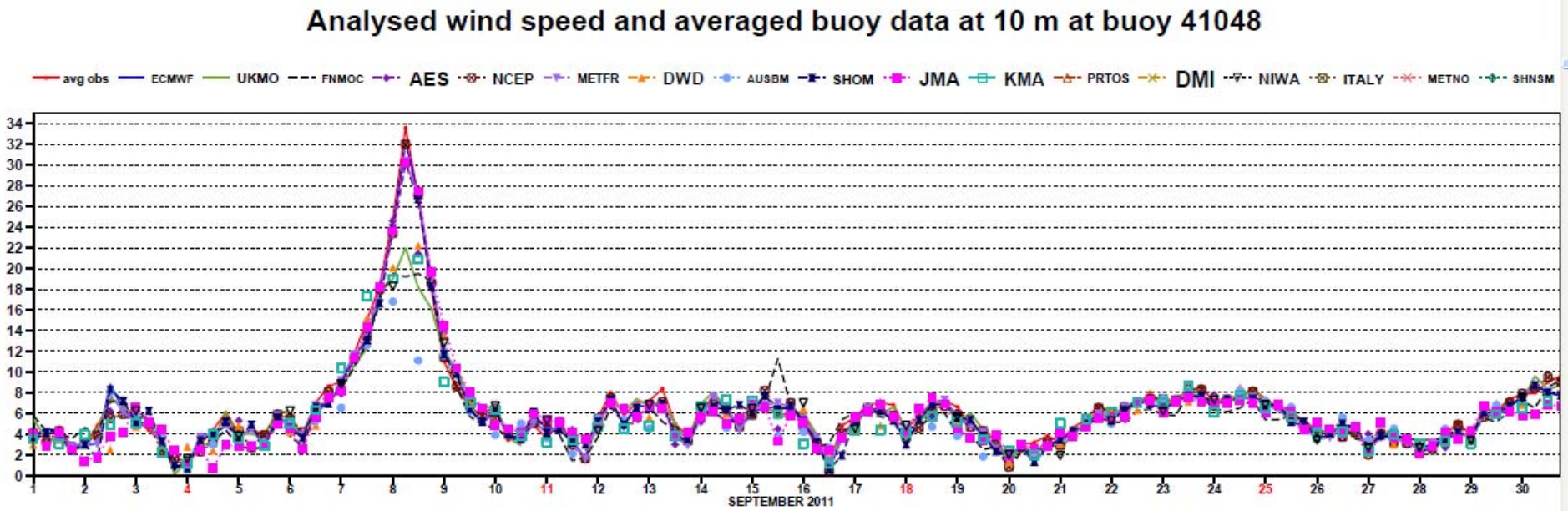
Hurricane Katia, september 2011



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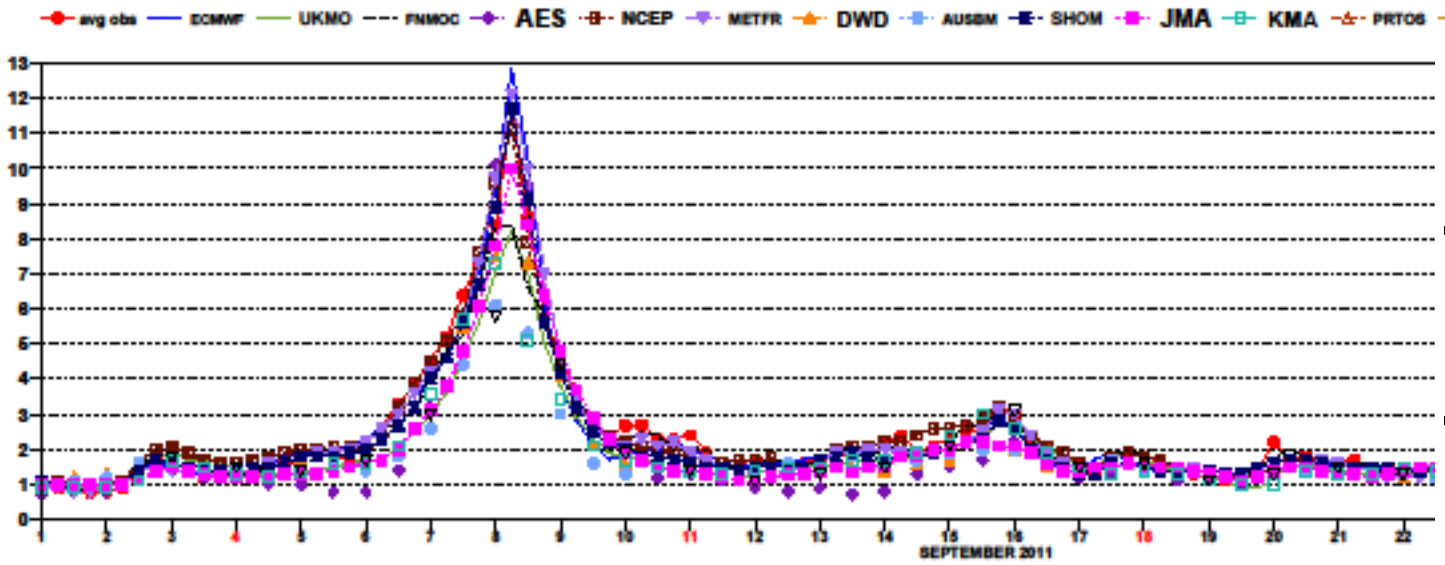
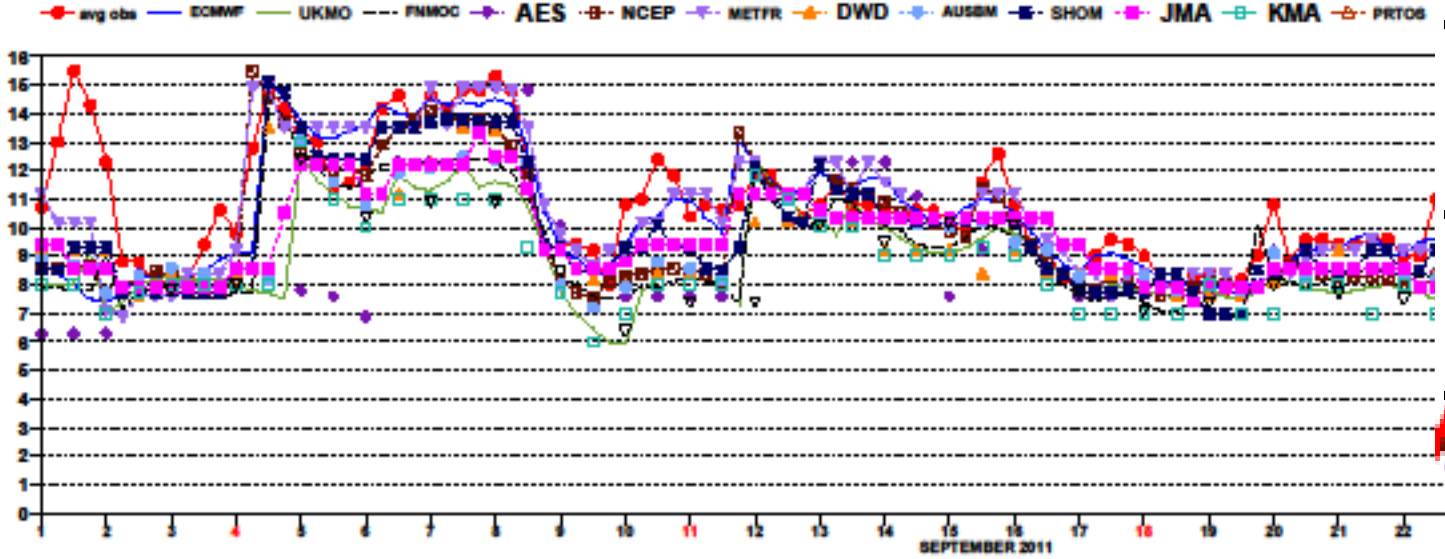
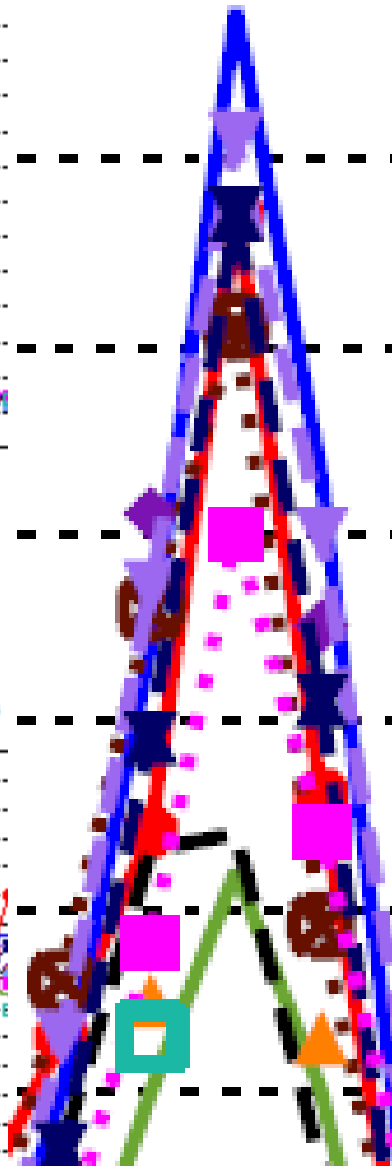
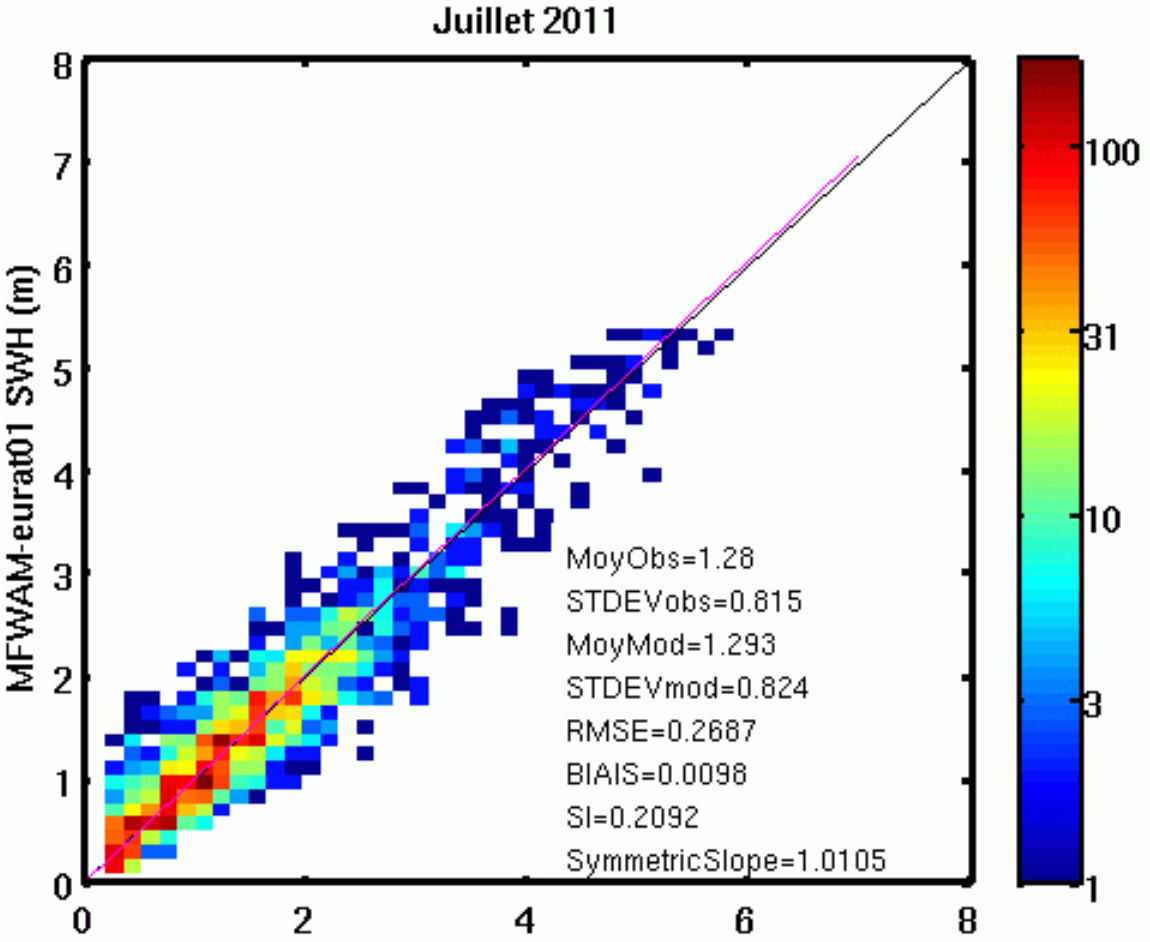
Analysed significant wave height and averaged buoy data at buoy 41048

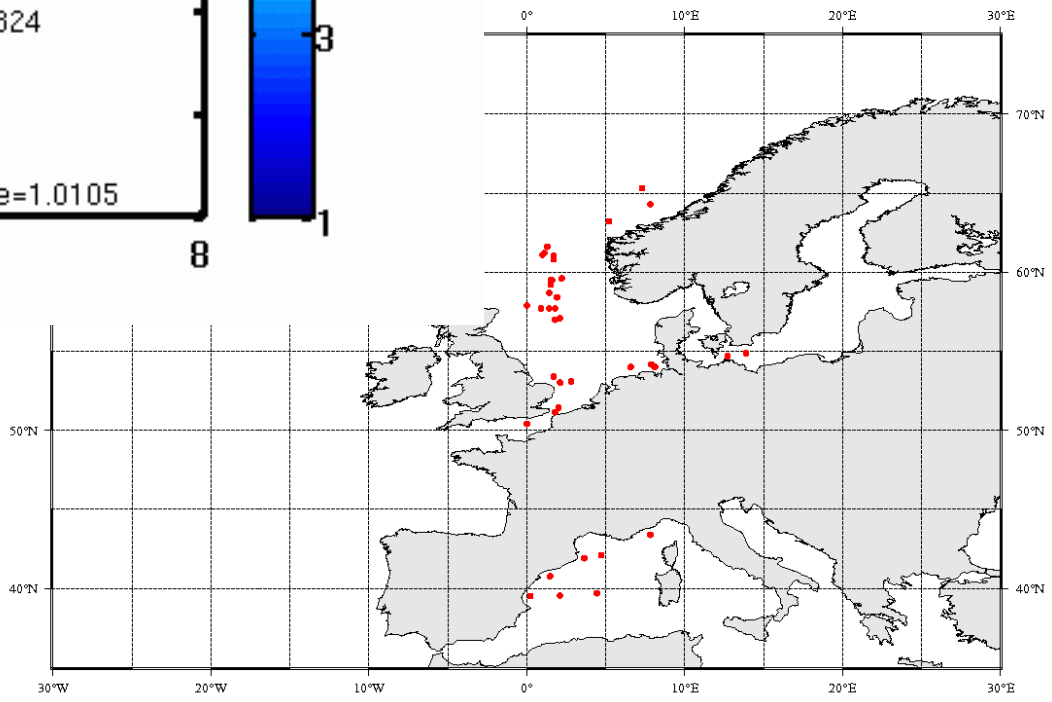


Analysed Tp and averaged buoy data at 41048





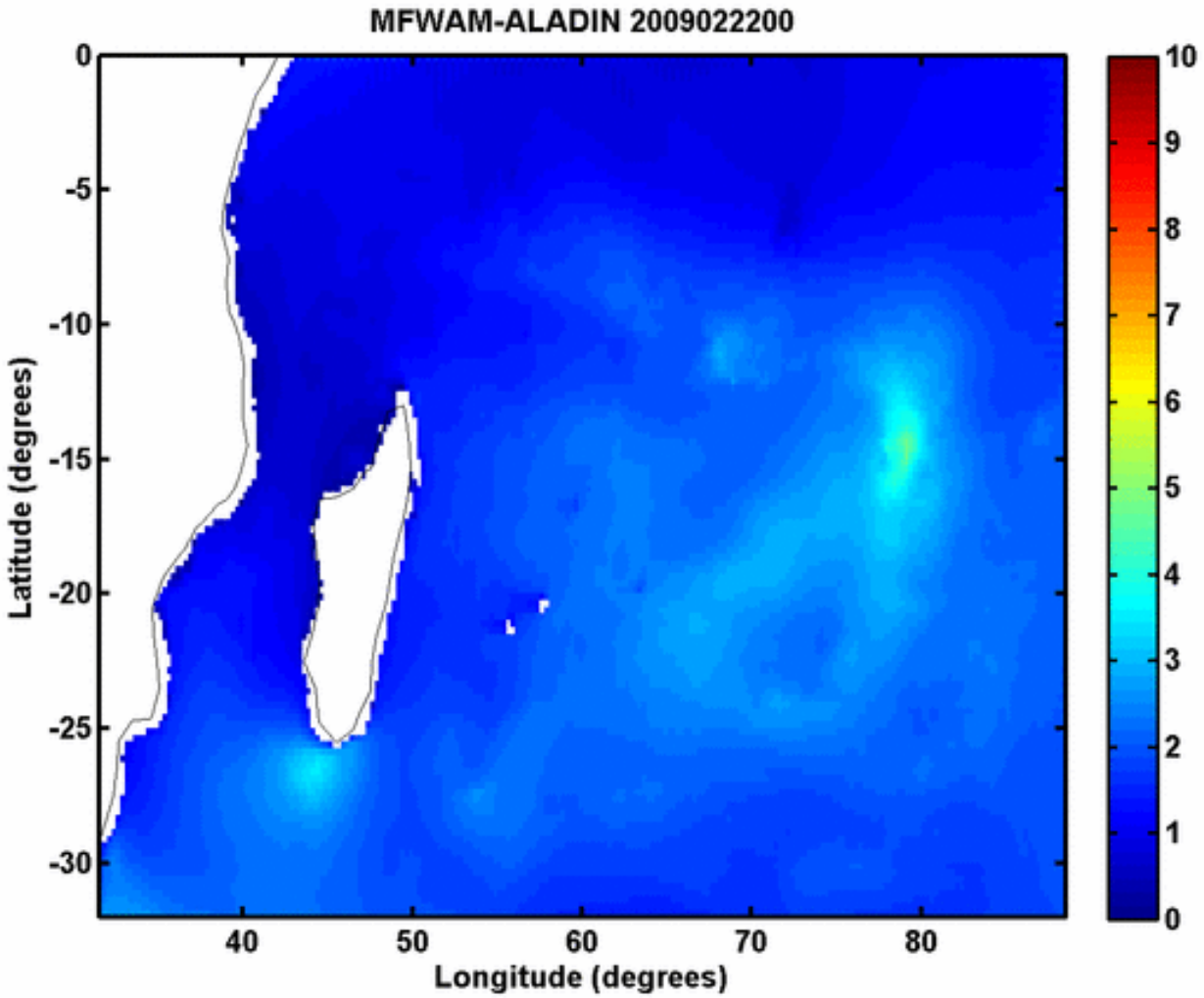




Regional Europe
MFWAM 11 km
resolution

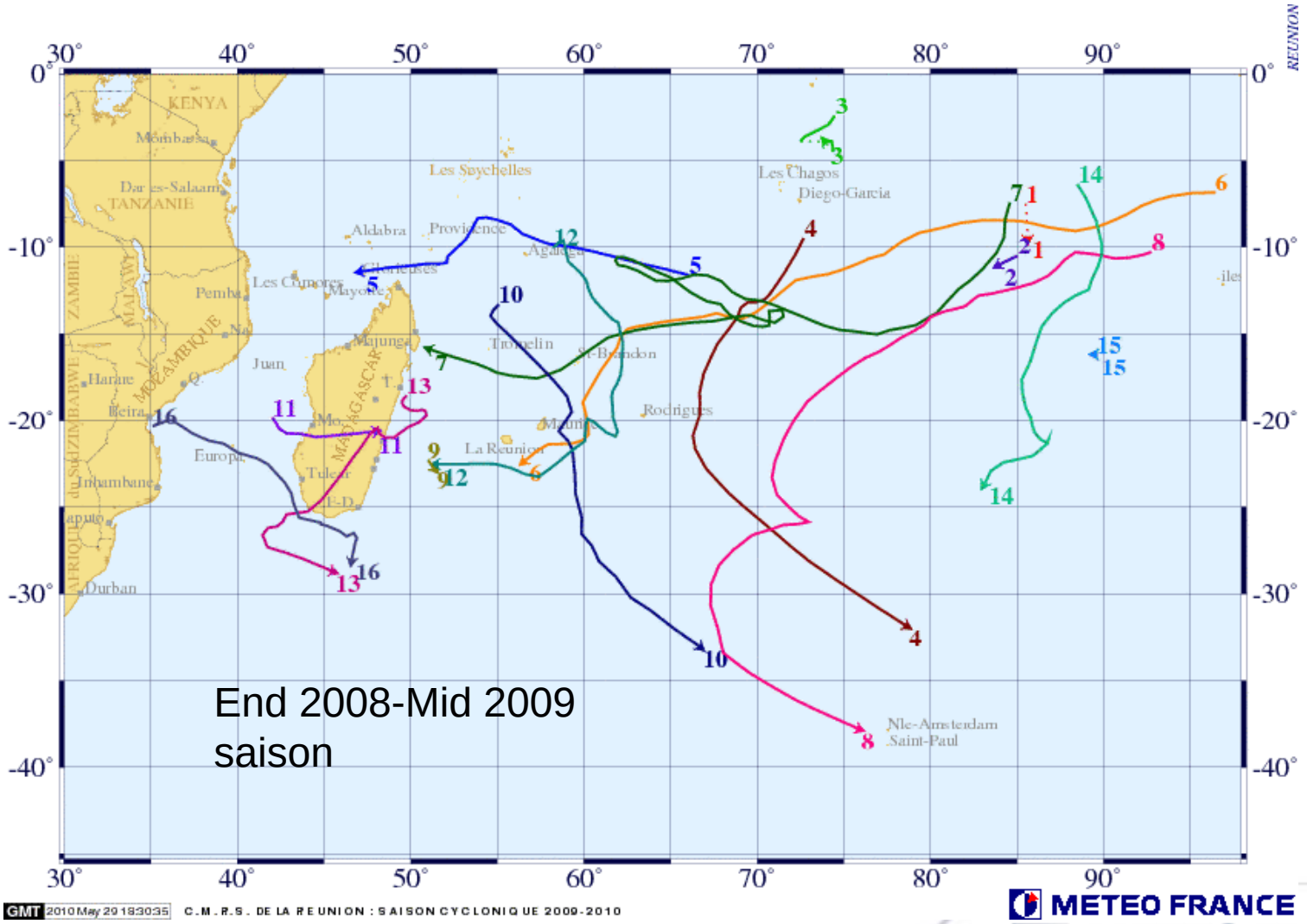
Modelling Waves from TC requires appropriate wind forcing and Wave model:

- realistic winds at typical scale of 10-25 km
- realistic wave growth at high winds



MFWAM-ALADIN

Validation over seasons 2008 and 2009 done, 2010 ongoing



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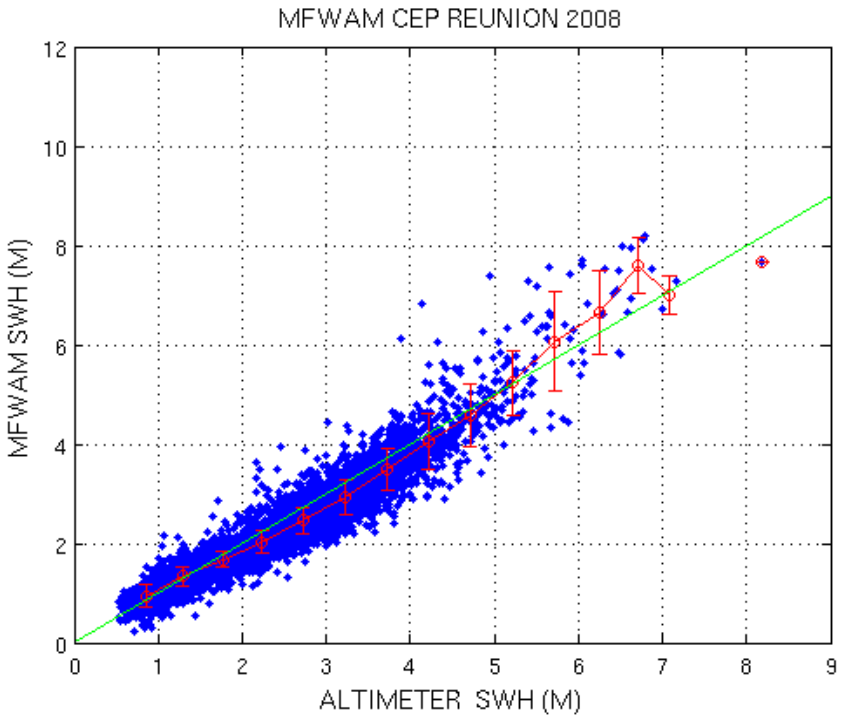
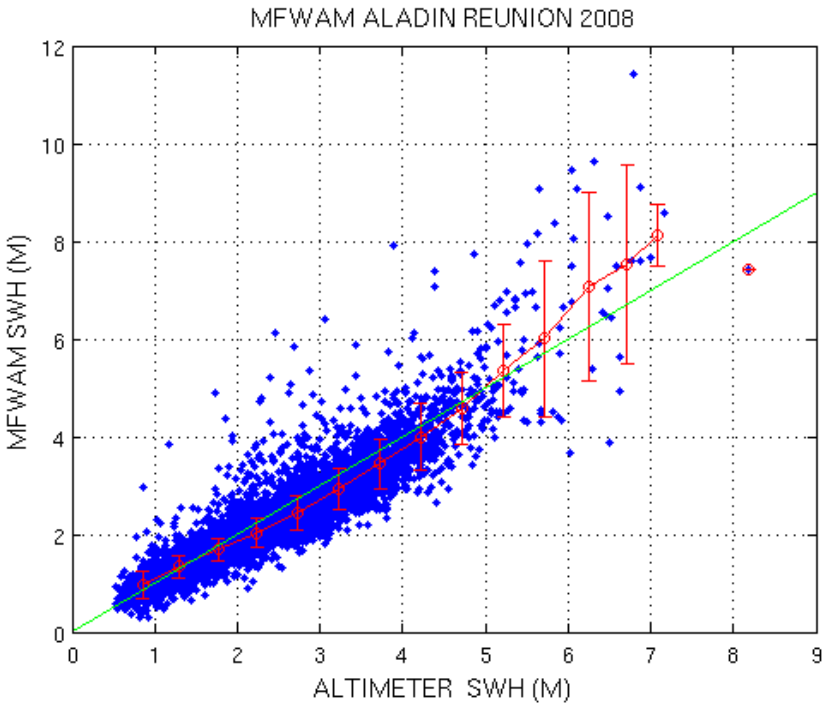
Altimeter data → Model improvment



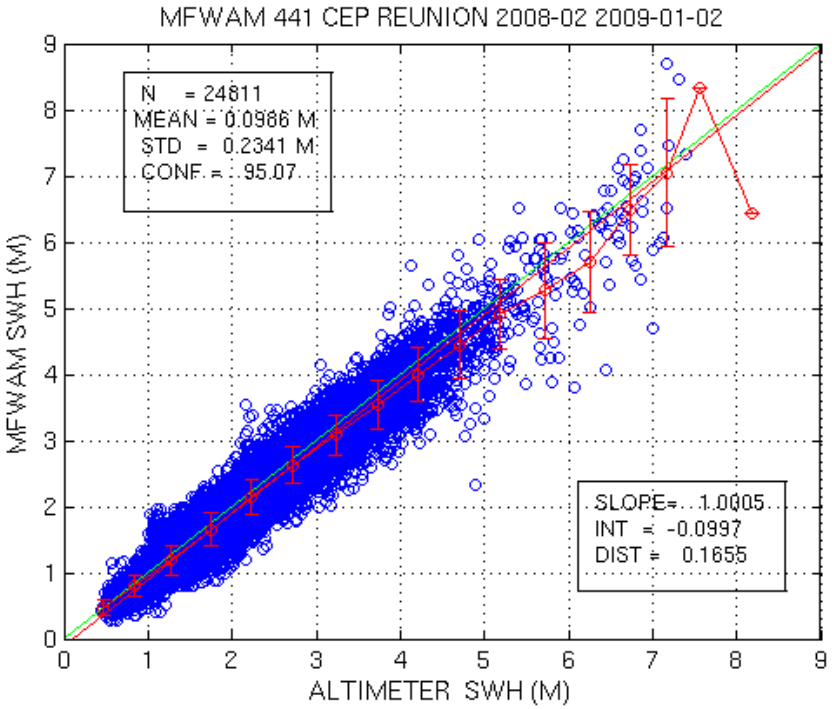


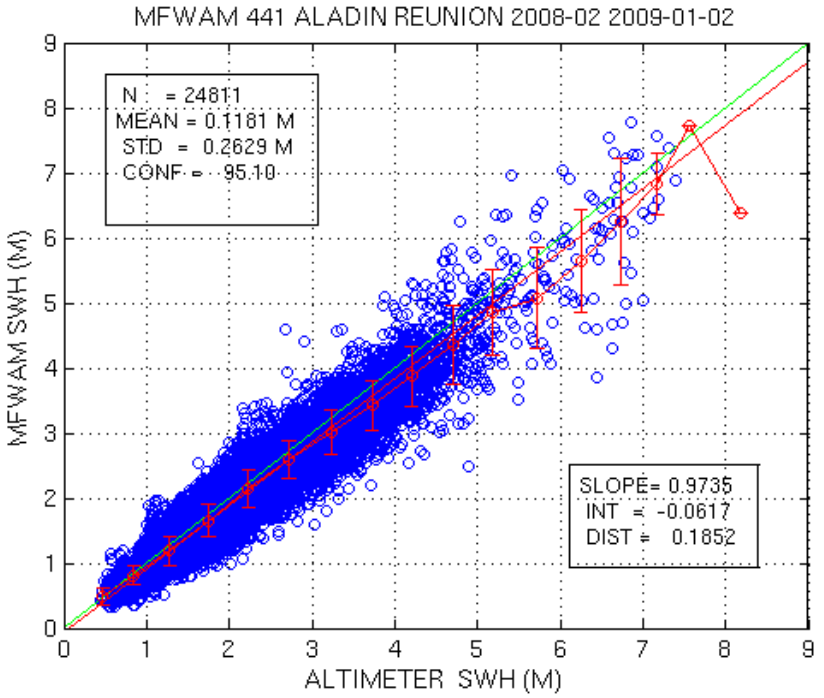
ALTIMETER DATA BASE: IFREMER

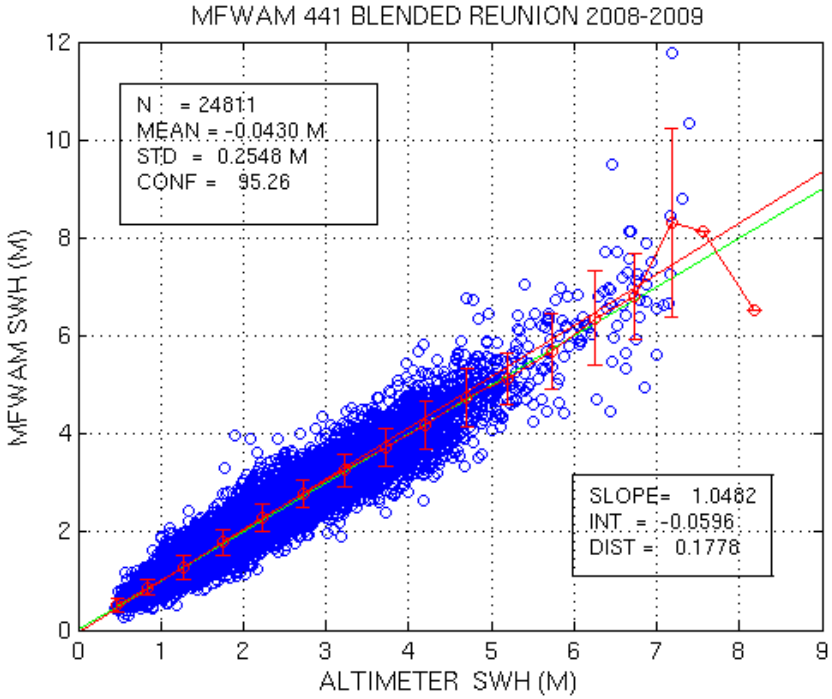
ERS-2 ENVISAT JASON1-2 GFO

Intercalibrated data averaged along track over 1° in latitude

First Version of MFWAM (437, see Ardhuin et al. 2010,JPO): overestimation of high waves with all wind forcings







Implementation of MFWAM-441 (see Ardhuin et al. 2010, JPO)

- Drag Limitation (Zo max)
- Shelter term added in the input source term
- Dissipation rate modified
- Tested with 3 sources of wind:
  - **. Aladin**
  - **. ECMWF**
  - **. Blended (Scatt + ECMWF guess)**

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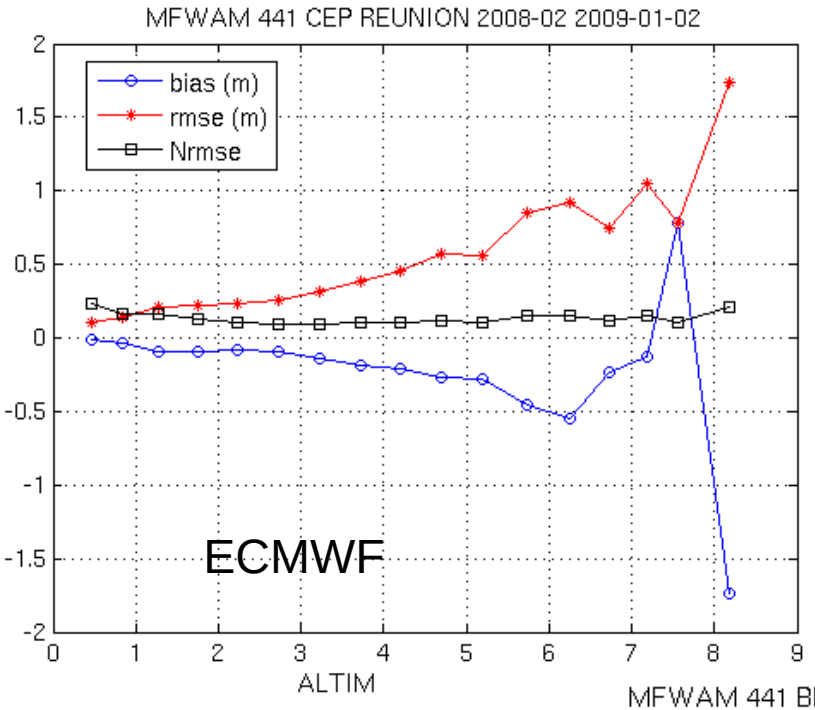

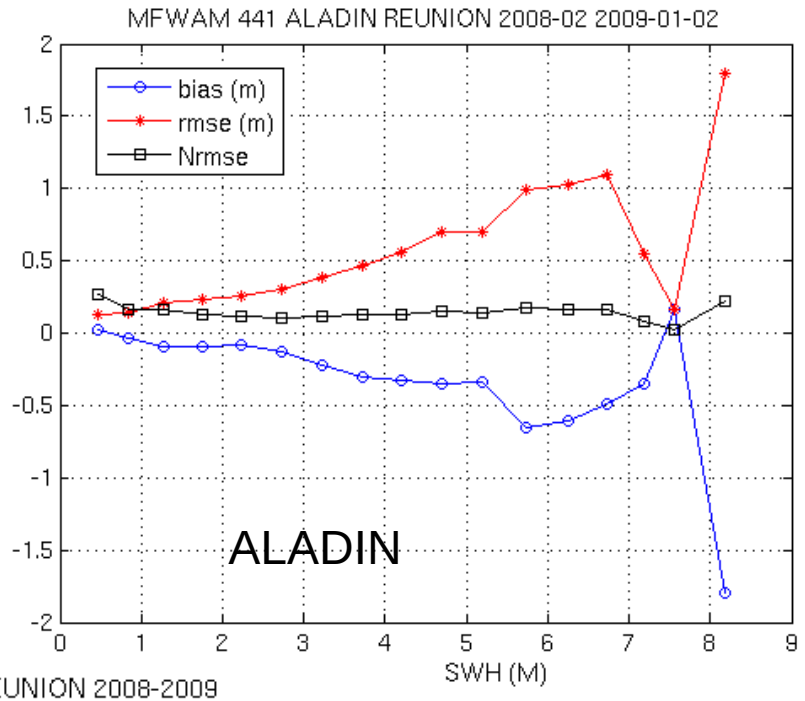

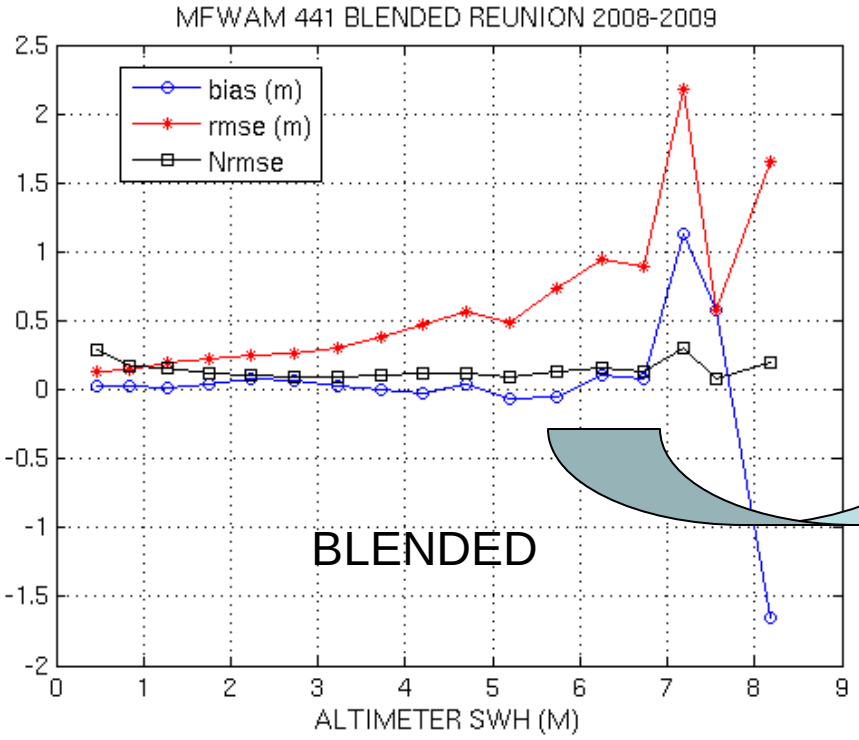

Biais reduction
(blue curve)

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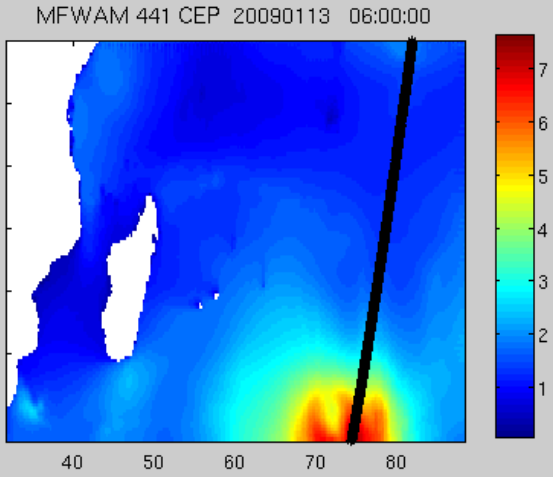
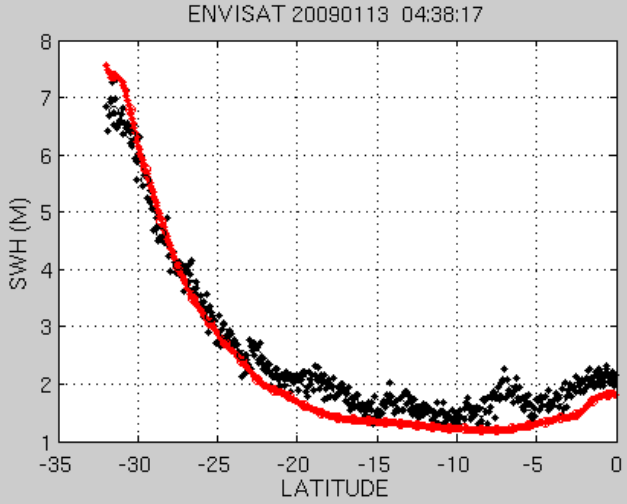
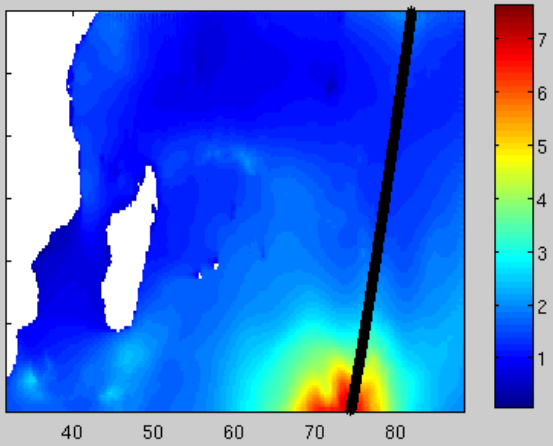
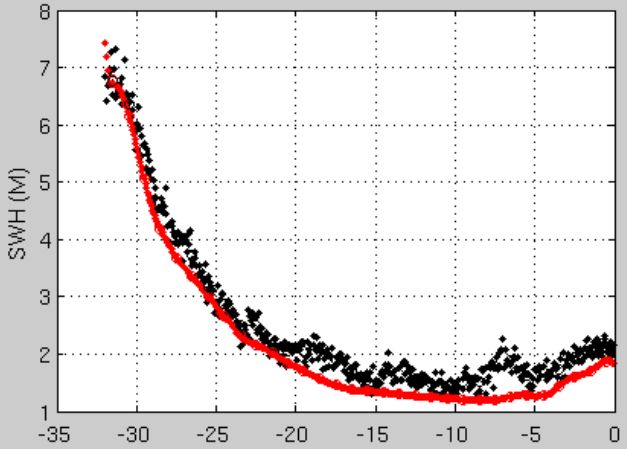
ECMWF



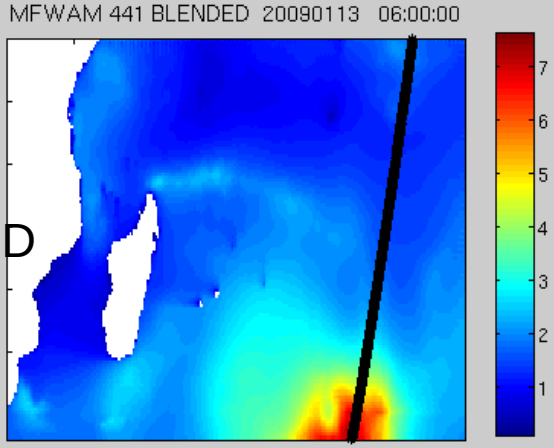


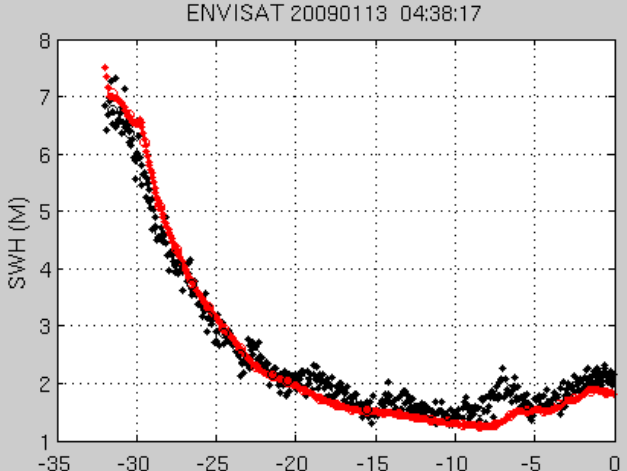
ALADIN





BLENDED





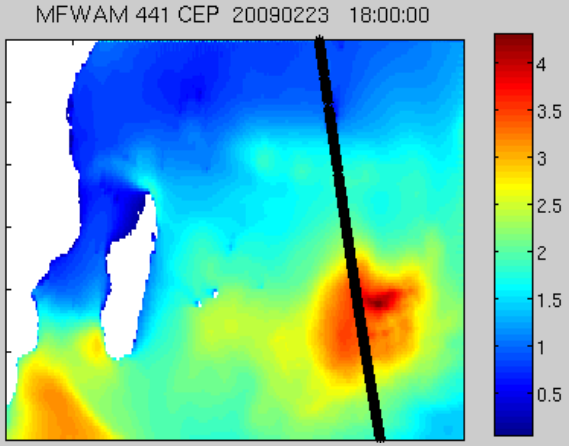
Case with small differences

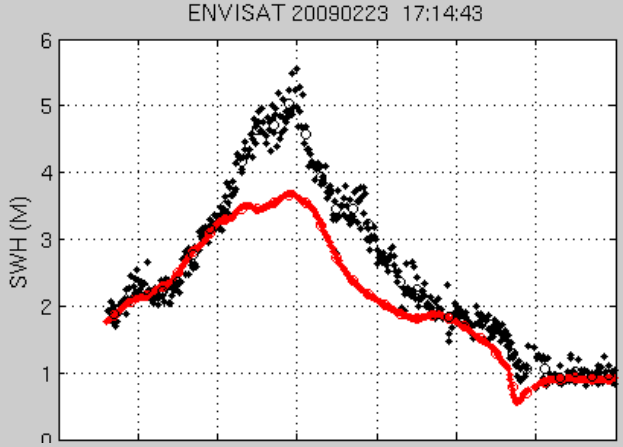
however

Blended better

FRANCE
emps d'avance

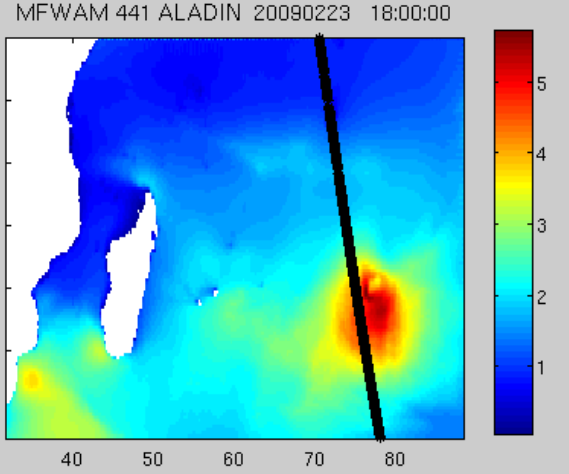
ECMWF

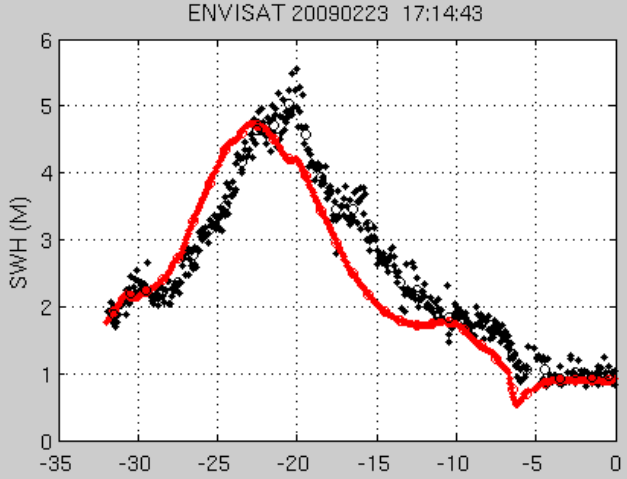




Large bias

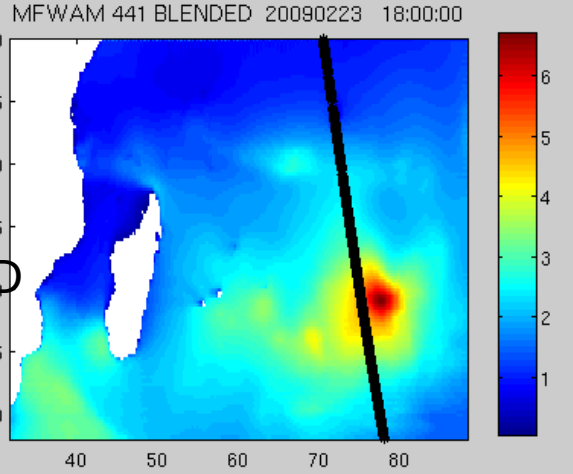
ALADIN

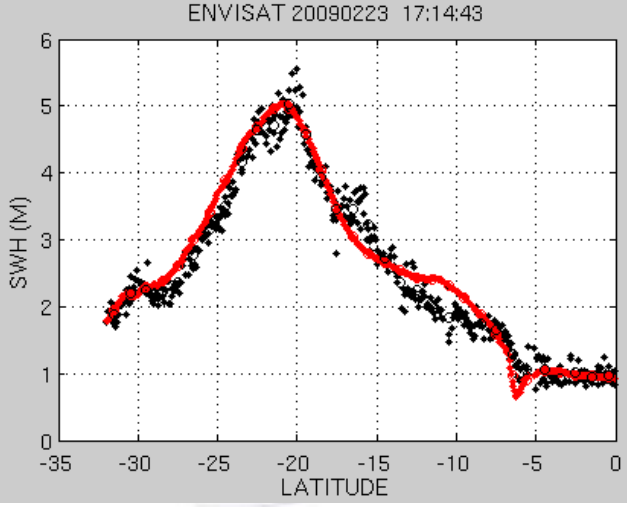




Small bias but shifted position ---> increases rmse

BLENDED





No bias right position

FRANCE
emps d'avance

Concluding Remarks/Perspectives

- Importance of satellite data for validation, calibration of model parameterizations –> ESA/GlobWave Pilot System to extend the WFVS to **altimeter data** Following WMO/JCOMM recommandation

- Need to extent the comparisons to other periods (2010 and 2011) and other areas (Northern Atlantic) in order to study more cases with larger wave heights and Compare NWP winds with winds derived from altimetry (IFREMER wind Algorithm, see F. Ardhuin's presentation)

- Use of SAR data to validate peak periods and directions (and Significant Wave Heights – CWAVE algo. From DLR, see T. Bruns's presentation)

- Regional models for the Caribbean, French Polynesia and New Caledonia areas will be implemented in 2012. For most of those areas no in situ data are available. Use of a 2.5 km resolution NH NWP model (AROME) currently tested over La Reunion Area