OPERATIONAL WAVE FORECASTING FOR TROPICAL CYCLONES CONDITIONS

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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, HsxF^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-representativeness error reduction by box averaging – 1°)

- Computation of annual mean biases, NRMSE for SWH, analyse of some individual cases
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
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

- ongoing 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 3rd this year.

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

$$B(f) = 2\pi \int_{0}^{2\pi} k^3 F(f, \theta)/C_g d\theta, \quad B'(f, \theta) = 2\pi \int_{\theta-\Delta\theta}^{\theta+\Delta\theta} k^3 F(f, \theta')/C_g d\theta'.$$

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

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

Last term for the dumping of short waves by dominant waves (term cumulative term, \(C_3=0.4\) in 441, \(C_3=1\) in 437).
Modification of the input source term (Ardhuin et al. 2010)

\[ U_{10} = \frac{u_*}{\kappa} \log \left( \frac{z_u}{z_1} \right) \]

\[ z_0 = \max \left\{ \alpha_0 \frac{\tau}{g} z_{0,\text{max}} \right\} \]

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

\[ (u'_*)^2 = u_*^2 (\cos \theta_n, \sin \theta_n) \]

\[ -|s_u| \int_0^k \int_0^{2\pi} \frac{S_{in} (f', \theta)}{C} (\cos \theta, \sin \theta) \, df' \, d\theta. \]

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

MFWAM-ALADIN-REUNION resolution 0.25°

Wind forcing ALADIN-REUNION –grille 0.1 km-

1 regional wave model MFWAM resolution 10km driven by ARPEGE winds soon with ECMWF winds as well
ALADIN-Réunion Model

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

Observation dataset
• SYNOP/SHIP/BUOY, Radiosondes, Profilers, Aircrafts
• Cloud winds (METEOSAT 7, 9)
• Scatterometer winds (QuikScat, ERS-2 and METOP-A)
• 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
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 recommendation.

Problem, No MAWS in our area of interest.
Monthly WFVS reports from JCOMM web site

**SIGNIFICANT WAVE HEIGHT SCATTER INDEX** at all common buoys

- ECM
- MOC
- FN
- NCP
- MTF
- DWD
- BoM
- JMA
- KMA

**Forecast range in days**

- **MF-----**
- **ECMWF__**
- **NCEP__**

Relative error in %

September 2011
PEAK PERIOD SCATTER INDEX at all common buoys

Forecast range in days

Global model only, fc from 0 and 12Z for SEP 11

Relative error in %

September 2011

MF-----
ECMWF___
NCEP_ _ _
Hurricane Katia, September 2011

Analysed wind speed and averaged buoy data at 10 m at buoy 41048
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
Validation over seasons 2008 and 2009 done, 2010 ongoing

End 2008-Mid 2009 saison
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)
Biais reduction (blue curve)
Case with small differences however Blended better
ECMWF

Large bias

ALADIN

Small bias but shifted position
--->
increases rmse

BLENDED

No bias right position
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