On the improvements of wave forecasting in the Atlantic ocean

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Workshop Atlantic from Space,
Southampton, UK, 23-25 January 2019

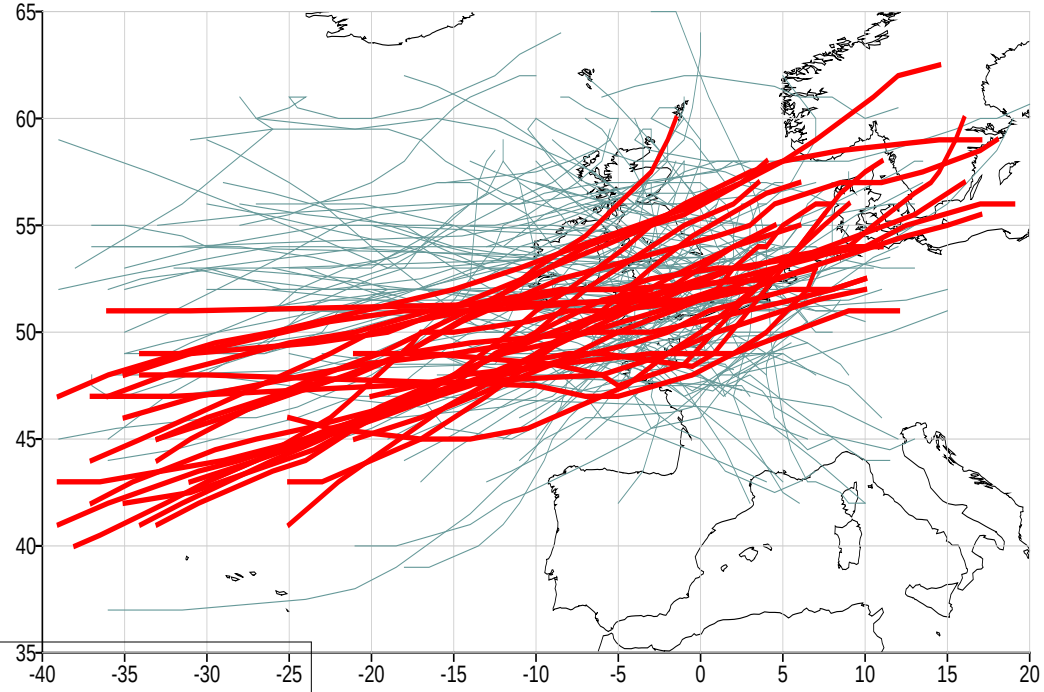
Consequences of storm Petra 2014 : submersion

Saint Guénolé (Finistère) with max tide wednesday 5 february at 08h00 2014

Historical storm cases
INCREO FP7 project : Winds, waves, storm surges

From records from 1924 until 2010

- Availability of data
- High intensity of the event in terms of known damages
- Other specific selection criteria for each coasts:



Storm tracks on western European coasts

ATLANTIC

- Total sea level (= tide + storm surge) > High Atmospheric Tide + 20cm (Atlantic coast)
- Storm surge > threshold defined by station
- Instantaneous storm-surge > 1.75 * previous threshold
- Large geographical extent

  Large variety of situations

Motivation

☐**Relevance of wave forecasting progress for the Atlantic ocean :**

➢ **Wave submersion warning (VVS) for the french coasts**
North Atlantic storms and hurricane season for the west indies

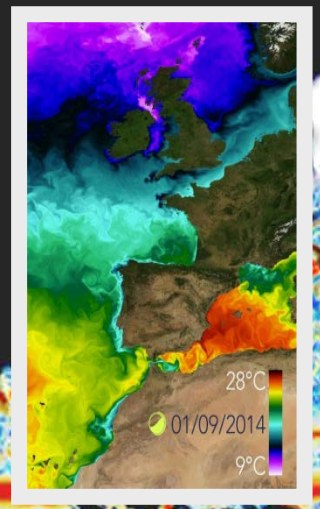
➢ **Better wave products for CMEMS users**

☐**Implementation of earth system with coupling between ocean, Waves and Atmosphere (NEMO/MFWAM/ARPEGE models)**

☐**Innovating with the assimilation of new satellite wave data (CFOSAT, SWOT, SKIM,...)**

#1: Monitoring the Earth CMEMS

IBI zone



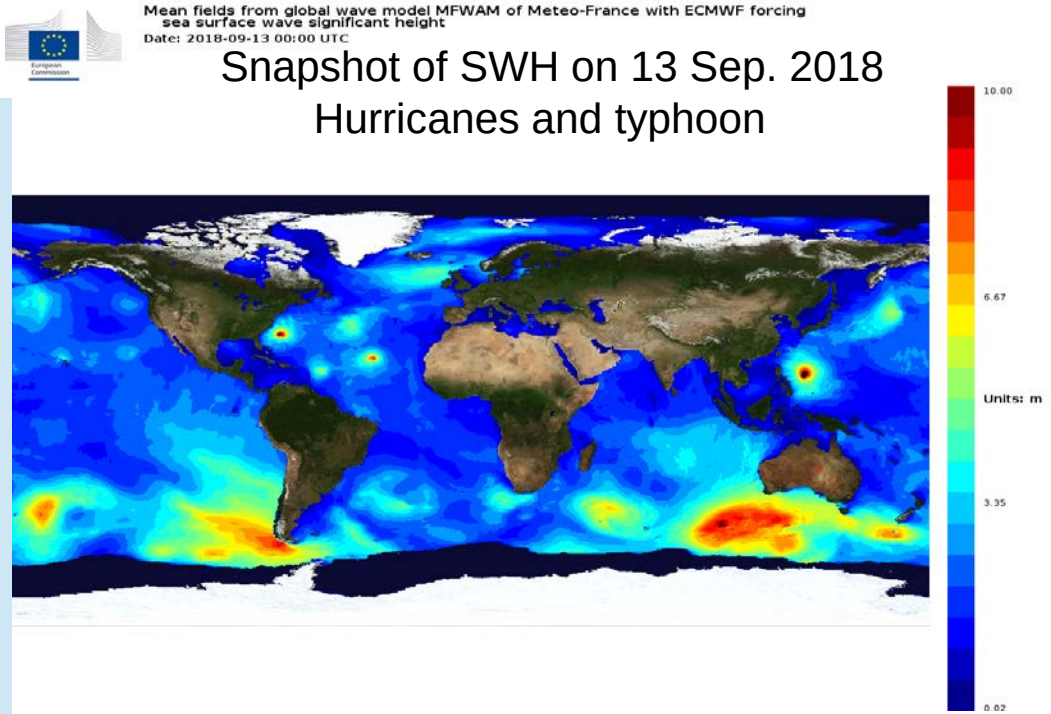
Real-time bulletins (2 to 10 days) + Multi-year Simulations (10 to 45 years), combining satellite, in situ and models

Assessment Reports prepared by world-class European experts

System availability : 99%
Data Timeliness : 98%
User satisfaction : 4,75/5

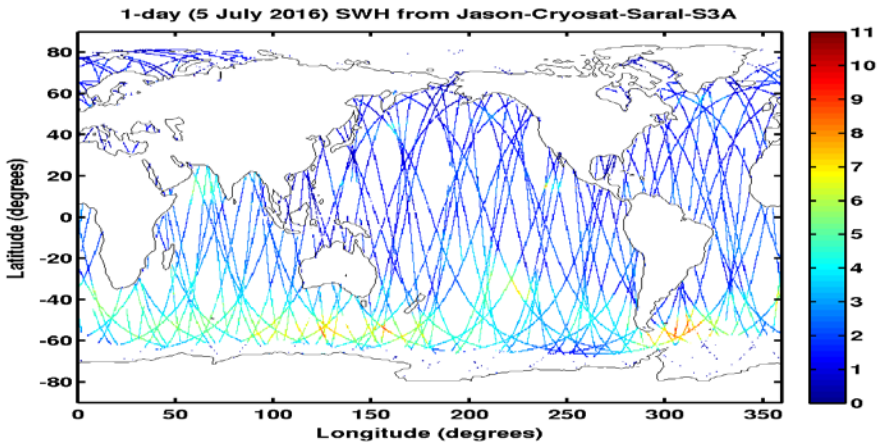
The current operational wave system MFWAM for CMEMS-GLO waves (marine.copernicus.eu)

☐Global grid of 10 km
3-hourly atmospheric forcing from IFS-ECMWF.
☐Improved wave physics for better surface stress for the coupling with ocean
☐Daily surface currents forcing from CMEMS global ocean system
☐3-hourly assimilation of 5 altimeters in operations (Jason 2 & 3 Saral, Cryosat-2, Sentinel-3A) and Sentinel-1 wave spectra since December 2018



Snapshot of SWH on 13 Sep. 2018
Hurricanes and typhoon

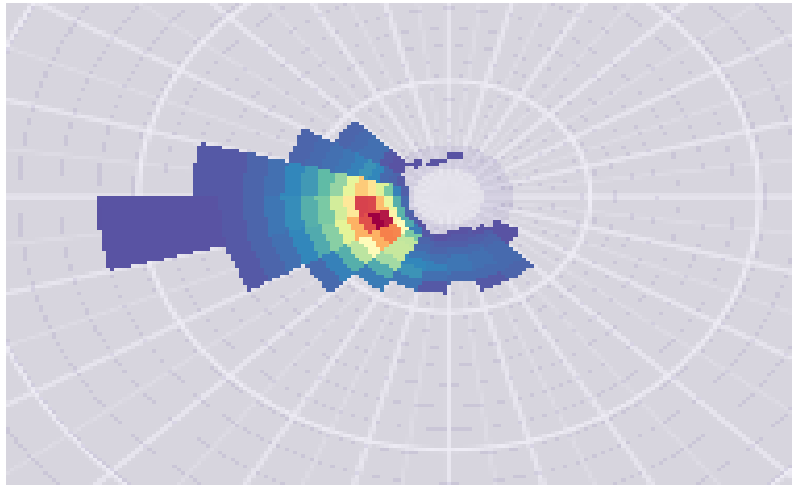
Relevance of satelite wave data : Combined assimilation (altimeters and SAR wave spectra



Current daily coverage (Jason-2 & 3, Cryosat-2, Saral and S-3A)

Complementary use between Altimeters SWH and directional Wave spectra
Altimeters corrects total wave height, while SAR Spectra corrects directly the directional properties of partitions

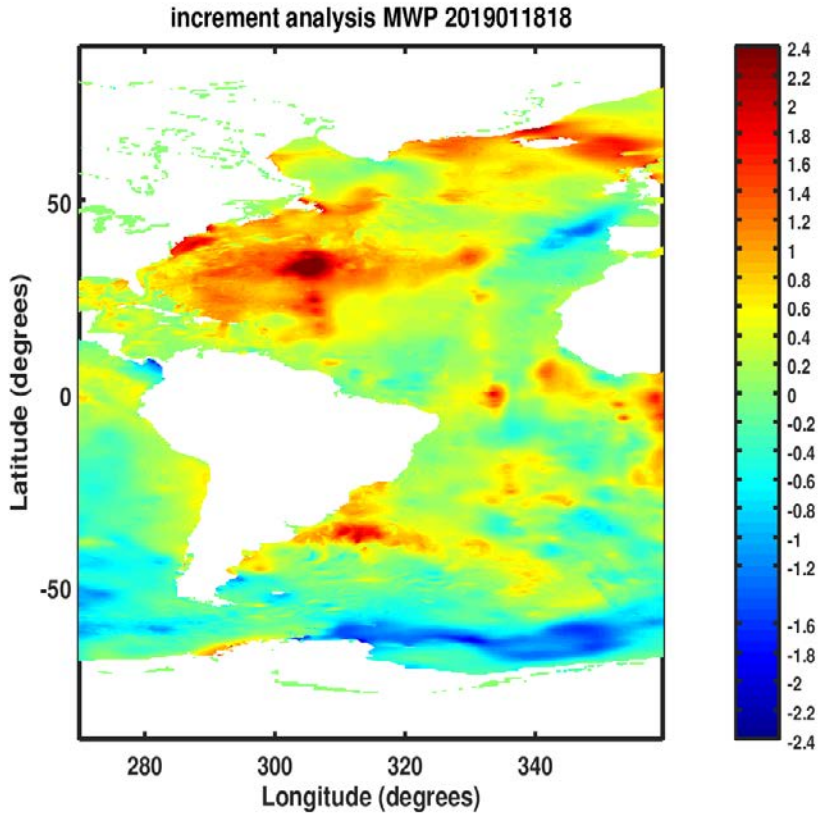
Sentinel-1 SAR spectra



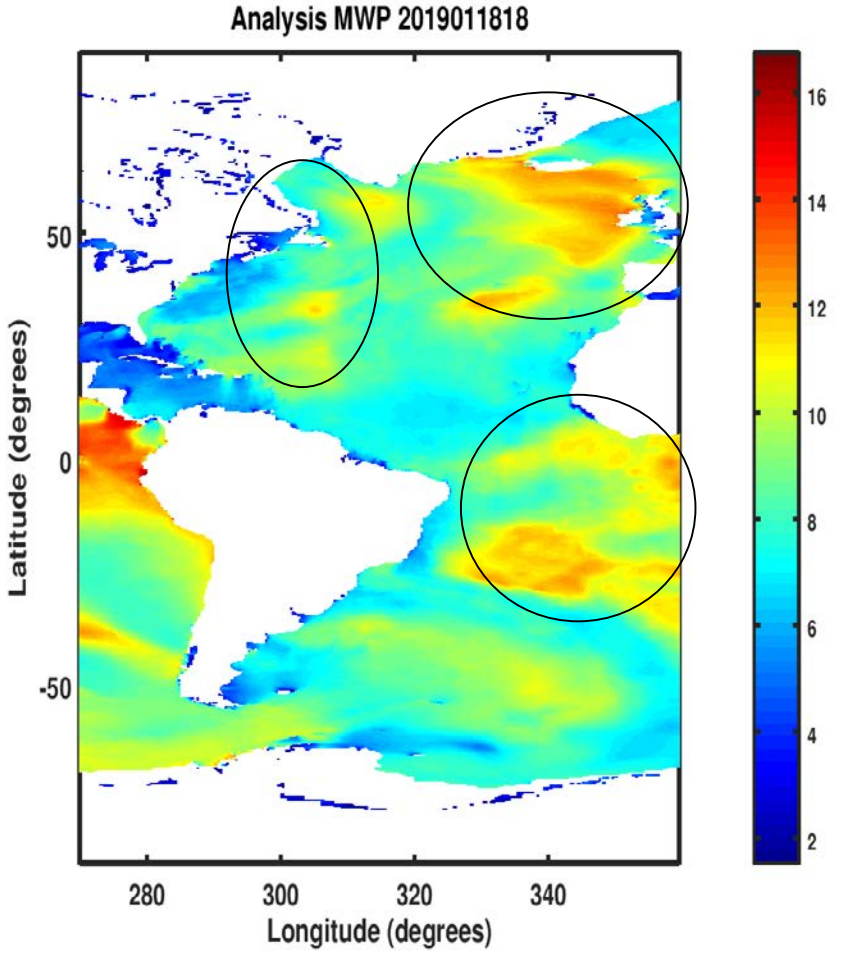
Good retrieval of 3 to 5 wave systems
Limited to long waves with azimuthal cut-off of -200 m

Operational CMEMS-Global waves : Combined assimilation Impact on mean wave period

Corrections mean wave period induced by the assimilation of altimeters and SAR in CMEMS-Global



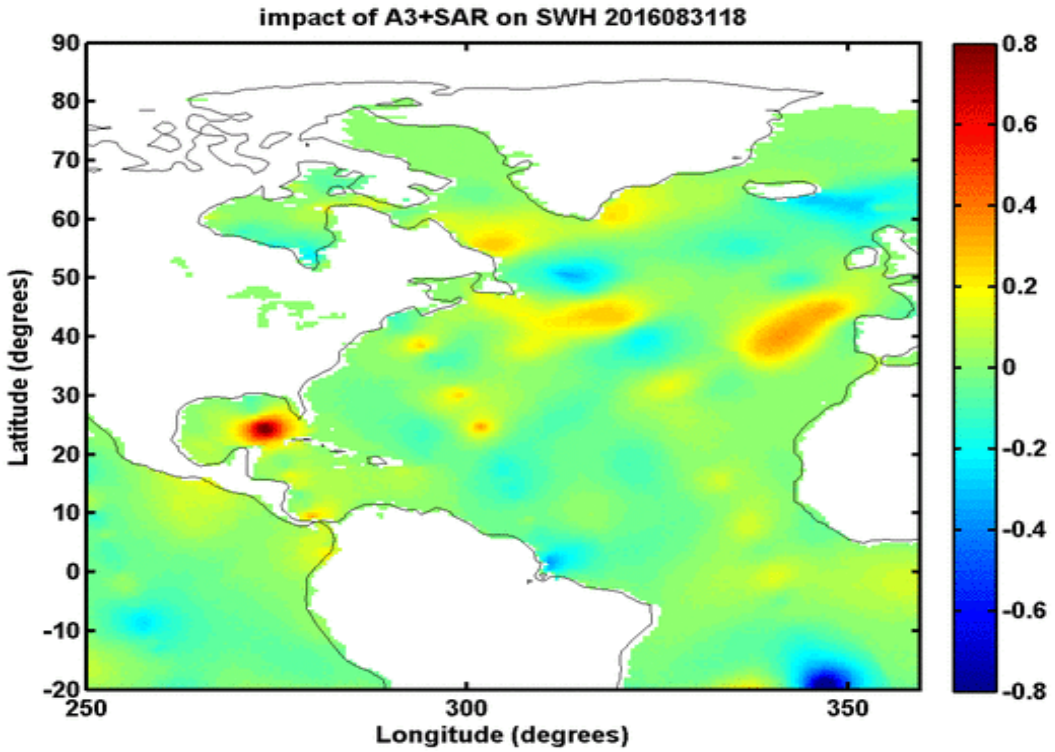
Long swell tracks MWP>12 sec



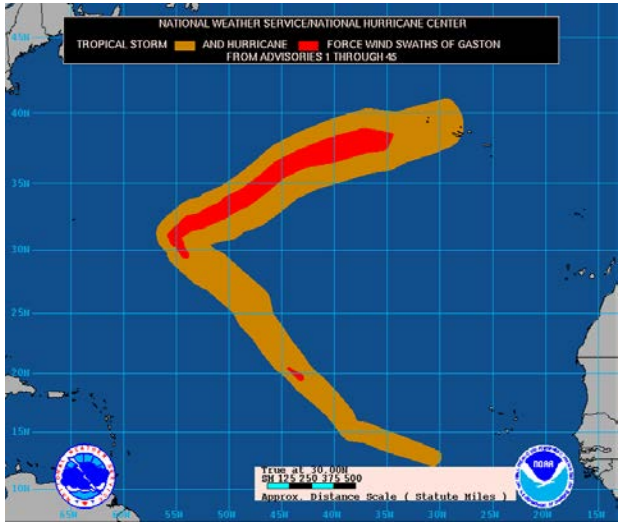
18 January 2019 at 18:00 UTC

Impact of the assimilation of 3 altimeters and SAR of S1A : Forecast period during GASTON

Ja2-Saral-CR2-Sentinel-1A



Tropical storm GASTON (Atlantic)

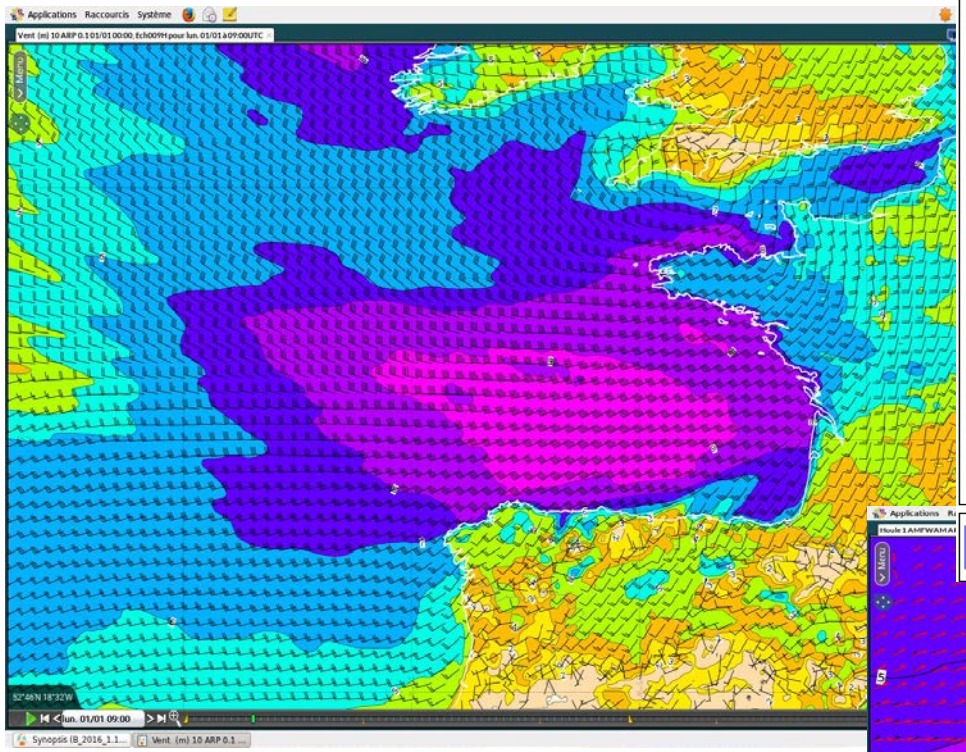


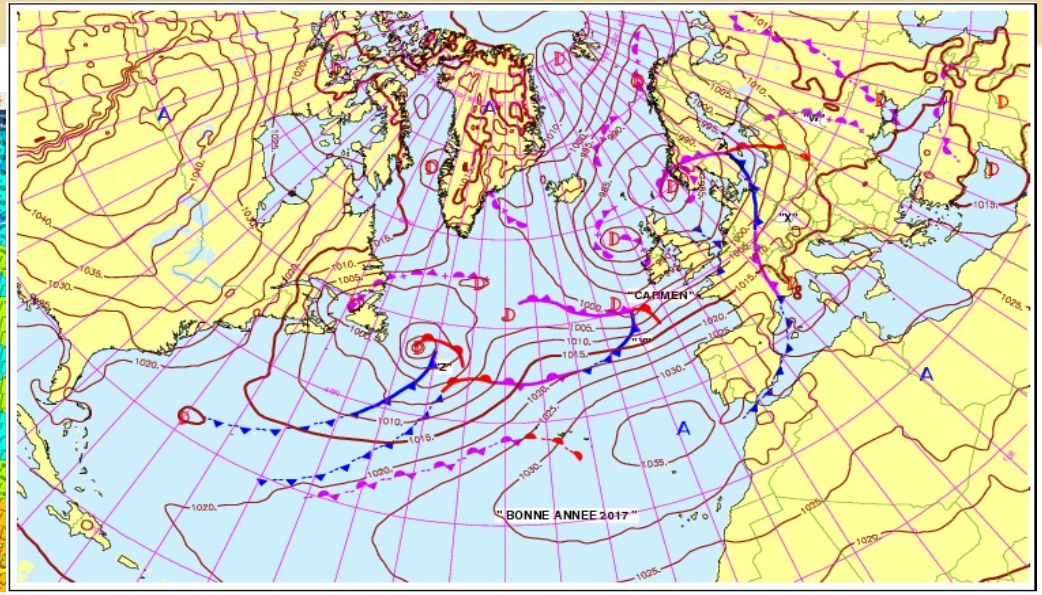
Difference between runs of MFWAM with and without assimilation

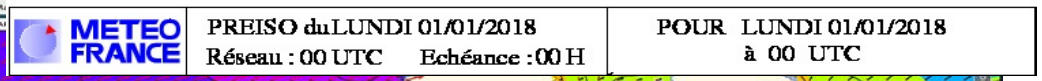
1-day forecast starting from 31 Aug. 2016 at 18:00, by step of 6 hours

Storm CARMEN (1 january 2018)

Winds on 01/01/2018 at 09:00UTC





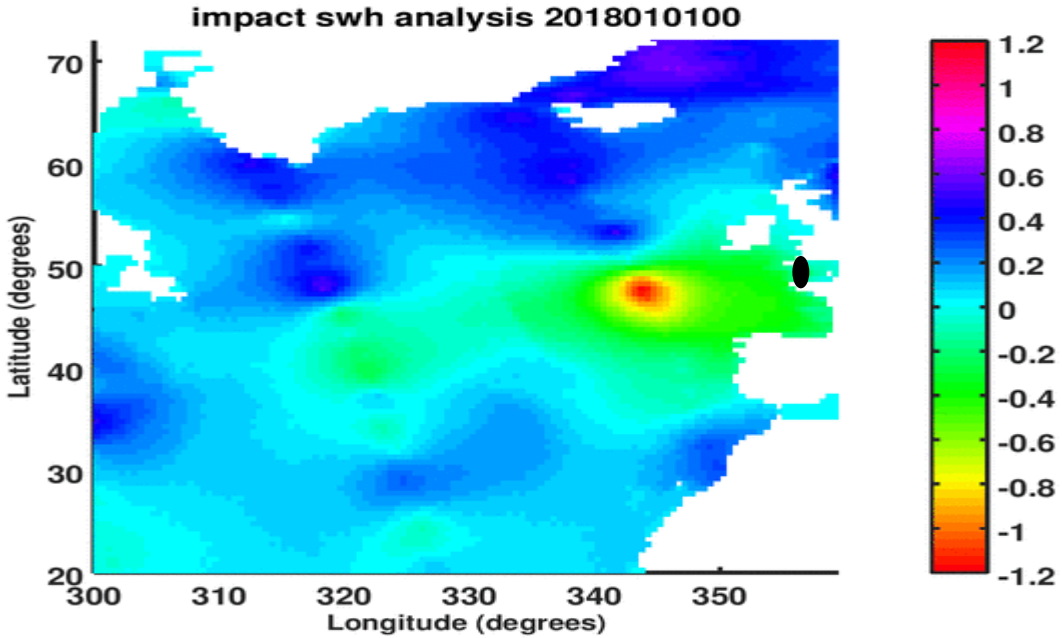


Winds of more 140km/h
High waves french coasts (Brittany and Channel)

SWH from MFWAM 01/01/2018 at 09:00UTC

Impact of S3A during North-Atlantic Storm CARMEN (Jan 2018)

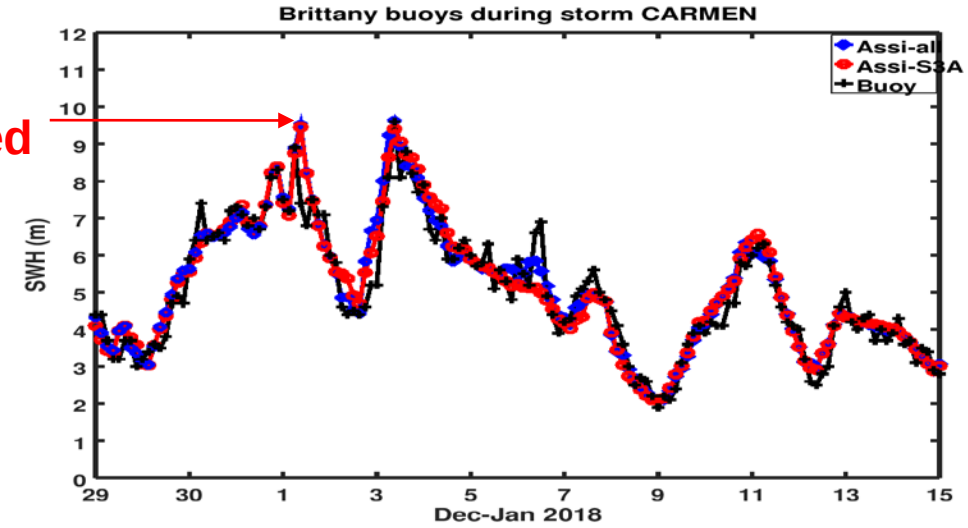
Analysis increment induced by S3A on SWH from 1 to 3 Jan (step 6h)



Scatter index of SWH is significantly reduced when using 5 altimeters Comparison with brittany buoy

Scatter index of SWH (%)		
S3A	V4	Noassi
10,1	9,7	12,2

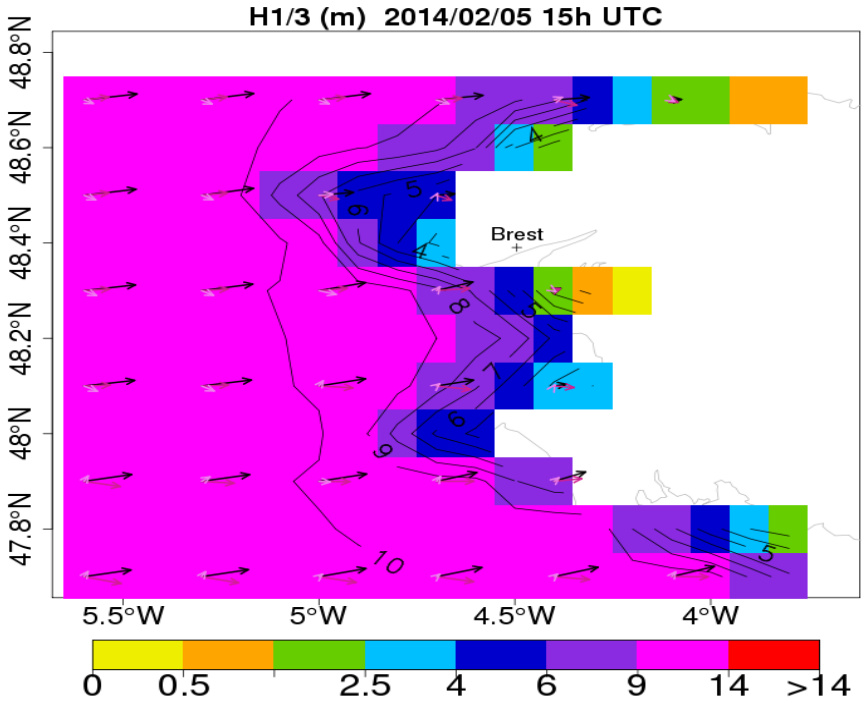
Peaks are well captured After the assimilation



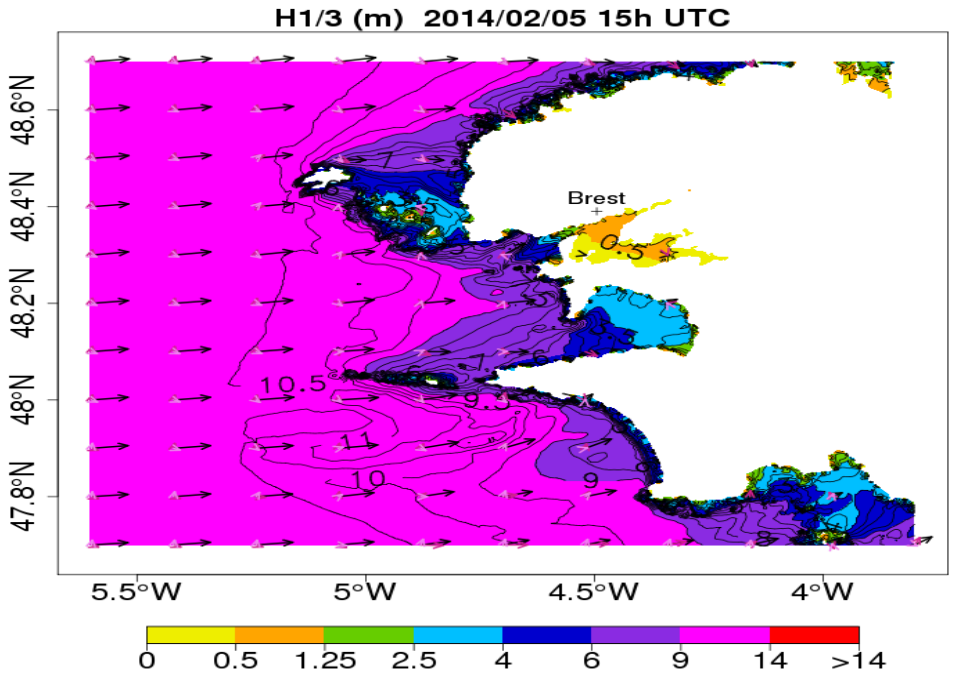
Times series of SWH :
Black line : brittany buoy
Red line : Assimilation of S3A
Blue line : Assimilation of All

Better resolved coastlines (grid size)
Petra storm 5 february 2014

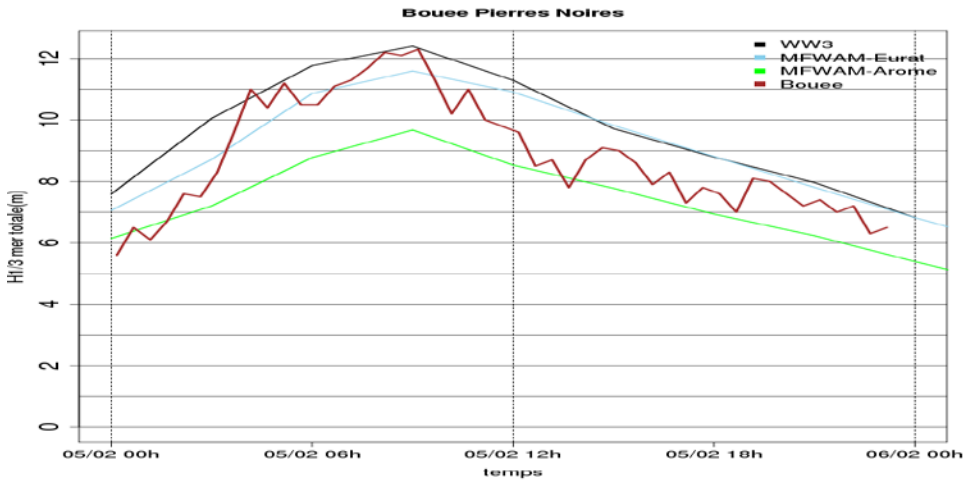
MFWAM 10 km



Coastal unstructured grid up to 200m



AROME high Resolution wind Induces an under-estimation of SWH Coastal model fits better the peak of event

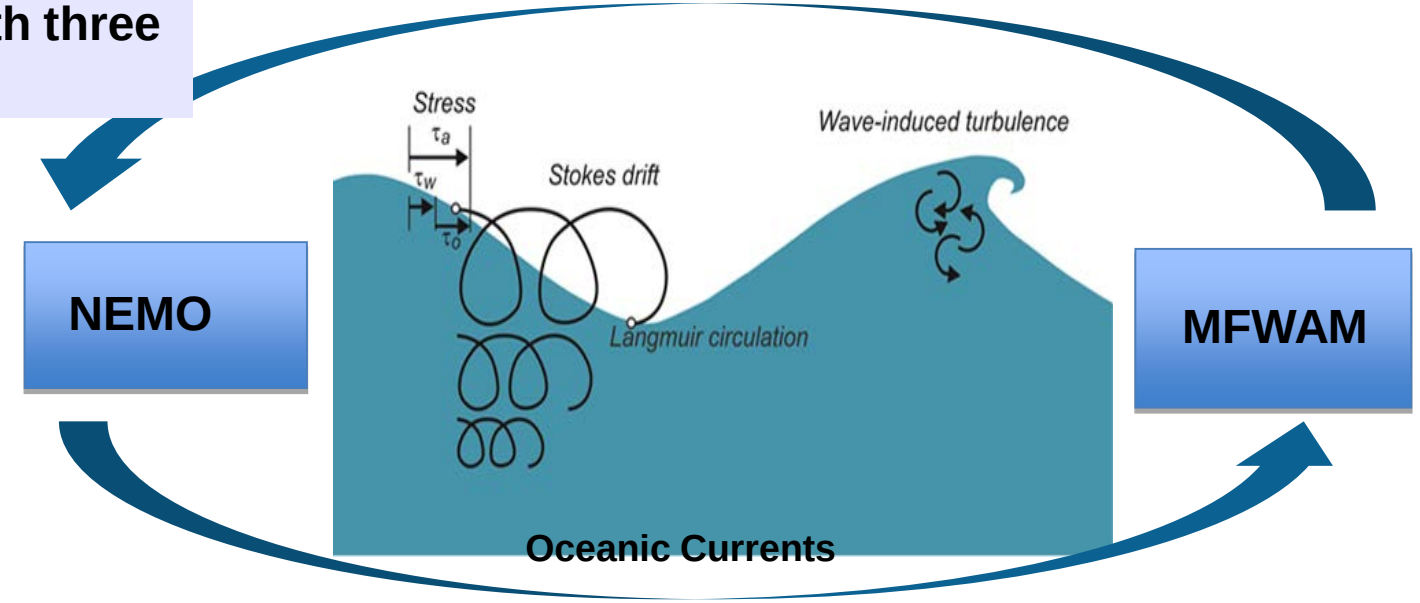


Comparison with Pierres noires Coastal buoy

Better waves = better Ocean/waves coupling
Development in CMEMS-IBI system

MFWAM-IBI 10km grid size
NEMO-IBI 1/36° grid size
1-year (2014) run with three coupling processes

Coupling NEMO ocean model and the wave model MFWAM)



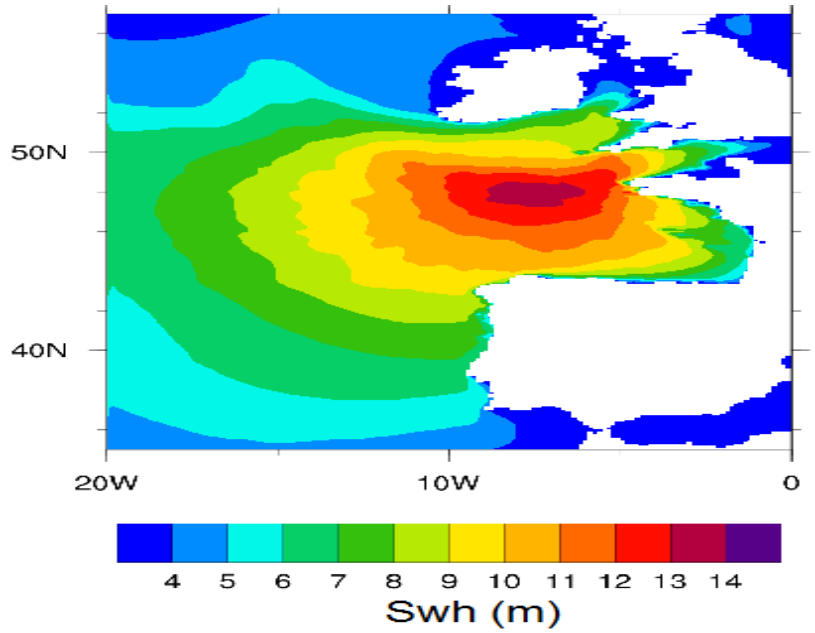
Three coupling forcing computed by the wave model MFWAM

- **Momentum flux modified by the waves**
- **Stokes-Coriolis forcing**
- **Wave breaking inducing turbulence in the ocean mixed layer**

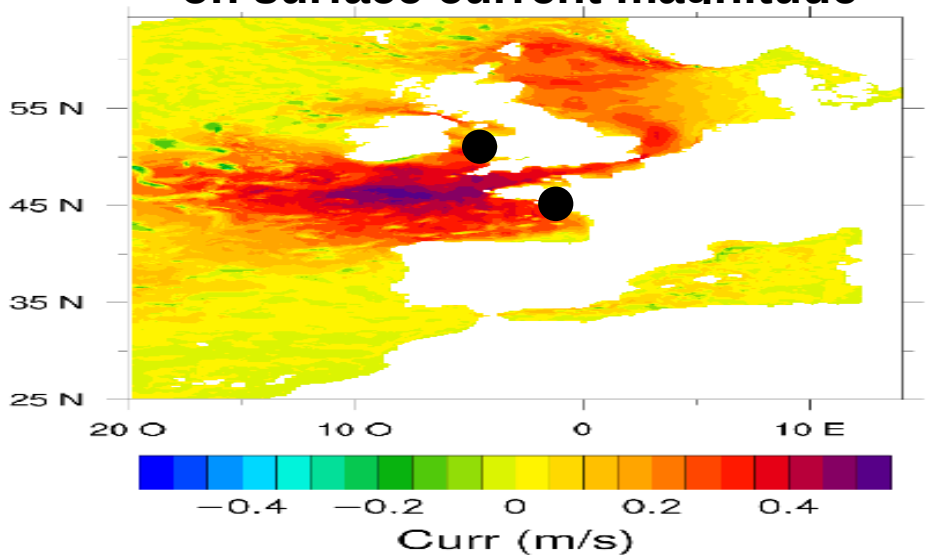
Storm consequences

Spanish cargo « *Luno* » pushed to the coast at Anglet (biscay bay) entrance of Adour estuary wednesday 5 february 2014 10:00 UTC.

Ocean/waves coupling during storm Petra on CMEMS-IBI (5 February 2014)

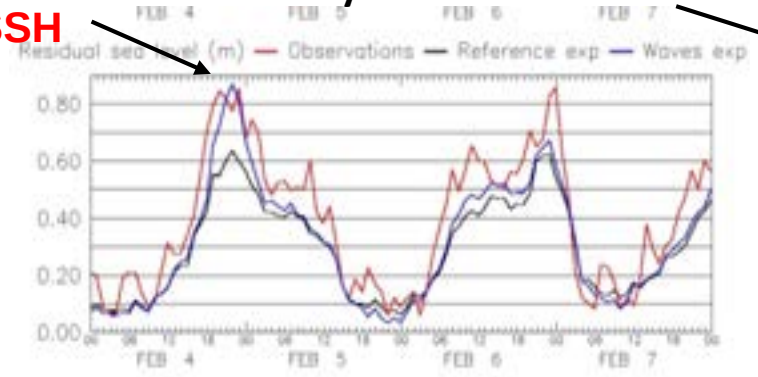


Impact of the wave coupling on surface current magnitude

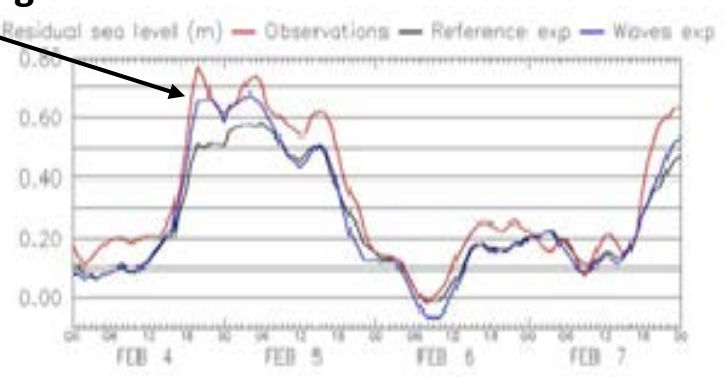


Sea surface height
The coupling captured better the peaks of SSH at Le Crouesty and Fishguard locations

Le Crouesty



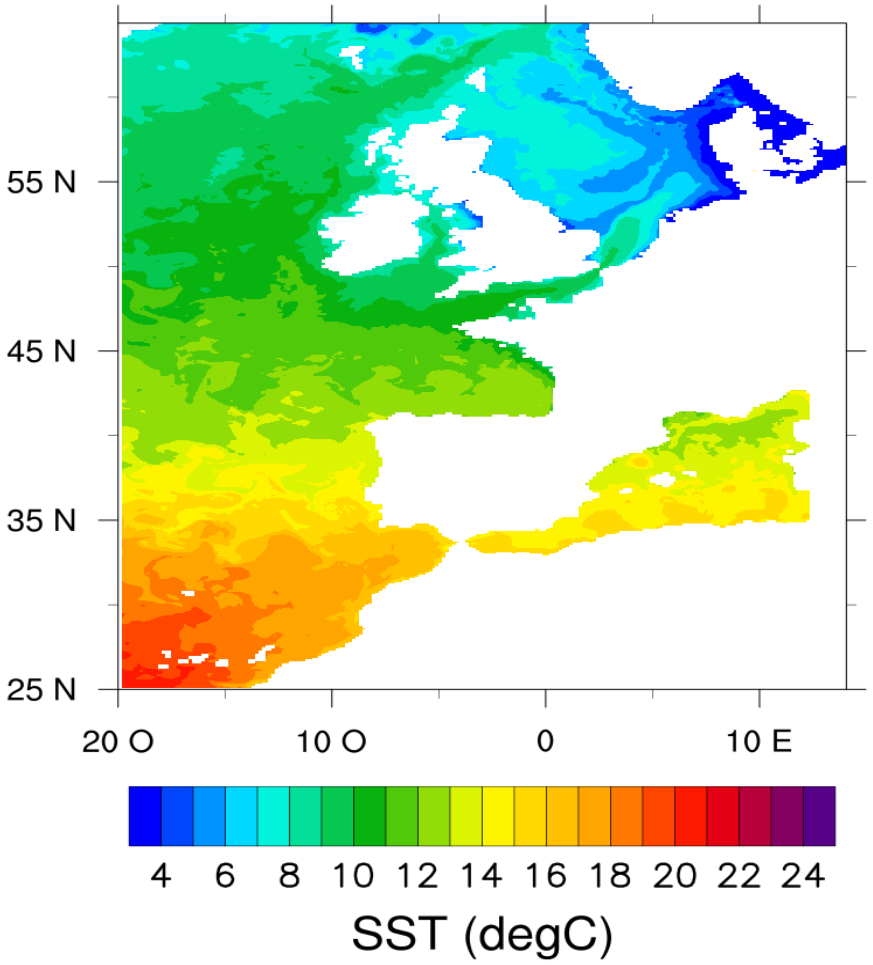
Fishguard



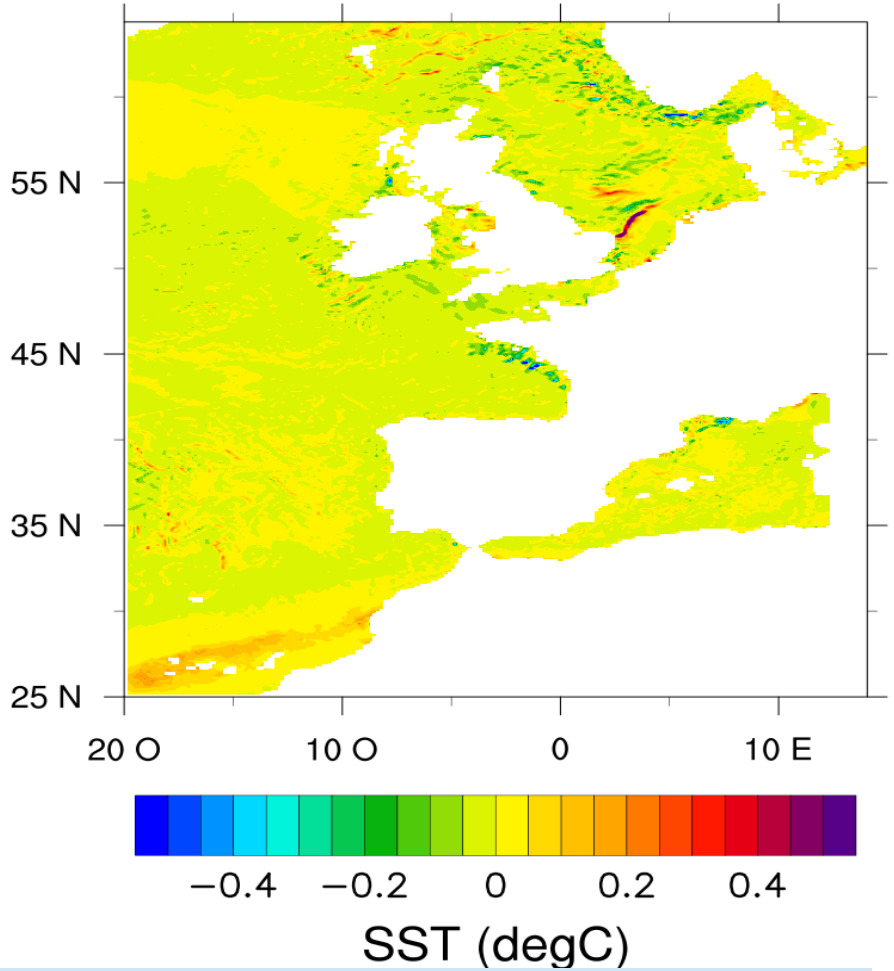
Red : tide gage
Blue : with waves
Black : w/o waves

Coupling MFWAM/NEMO
Wave forcing impact on SST : storm Petra 05/02/2014

SST NEMO



Difference ofSST
NEMO Waves – Ref



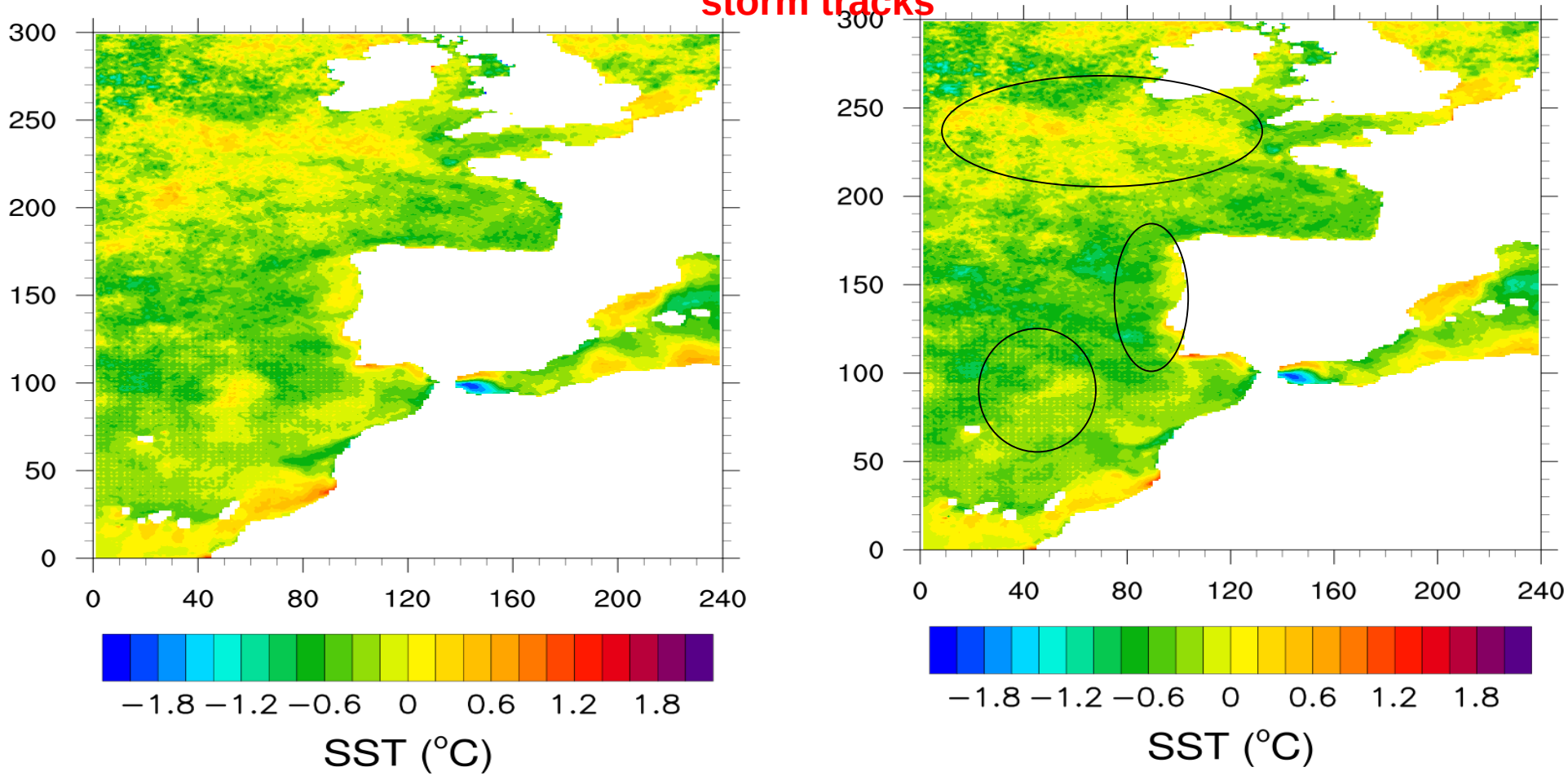
The wave forcing enhances the ocean mixing at the upper ocean :
Cooling is observed at the french coastal areas

Impact of wave forcing for 2014
Mean difference

NEMO without waves

Better SST on Atlantic storm tracks

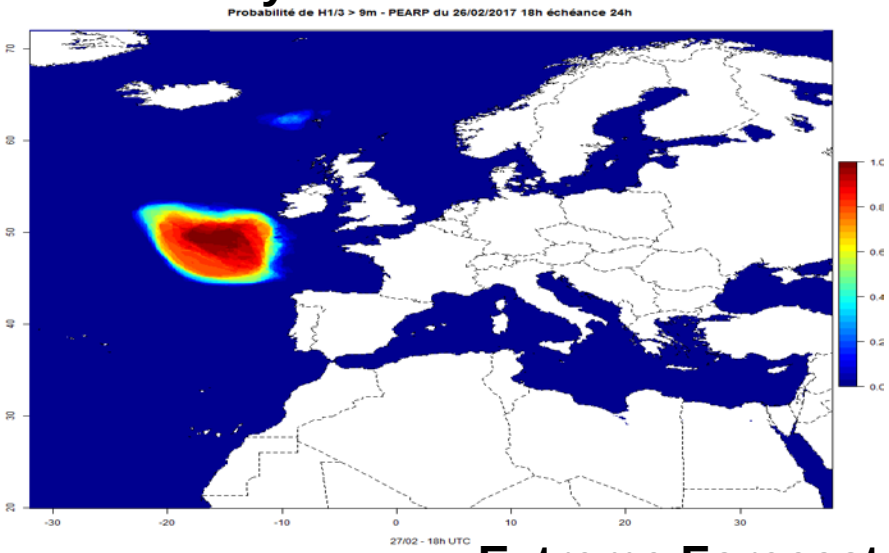
NEMO with waves



Validation with satellite SST L3S

Ensemble wave forecast (PEARP, PE-AROME)

Probability of SWH > 10 m forecast-24h

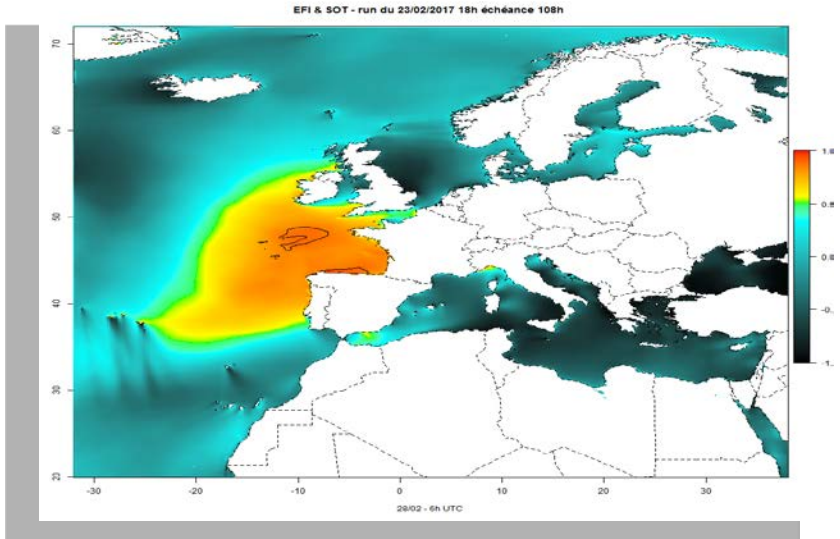


Implementing PEARP (35 members)
Global ensemble wave forecast MFWAM
With 3 different wave physics (3x35)

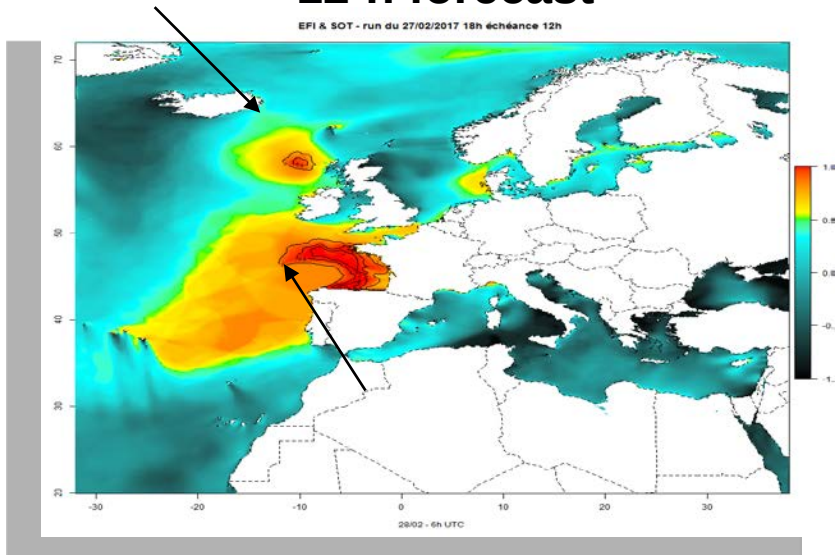
Implementing diagnostic index
EFI, Shift Of Tail,...

Extreme Forecast index (SWH) 27 February 2017

108h forecast

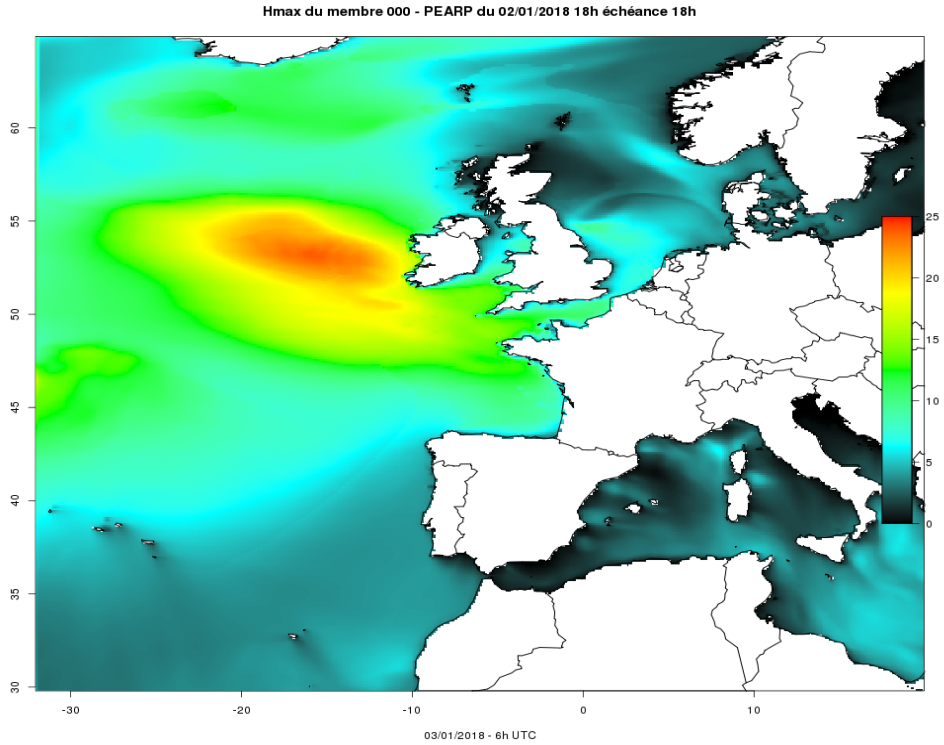


12-h forecast



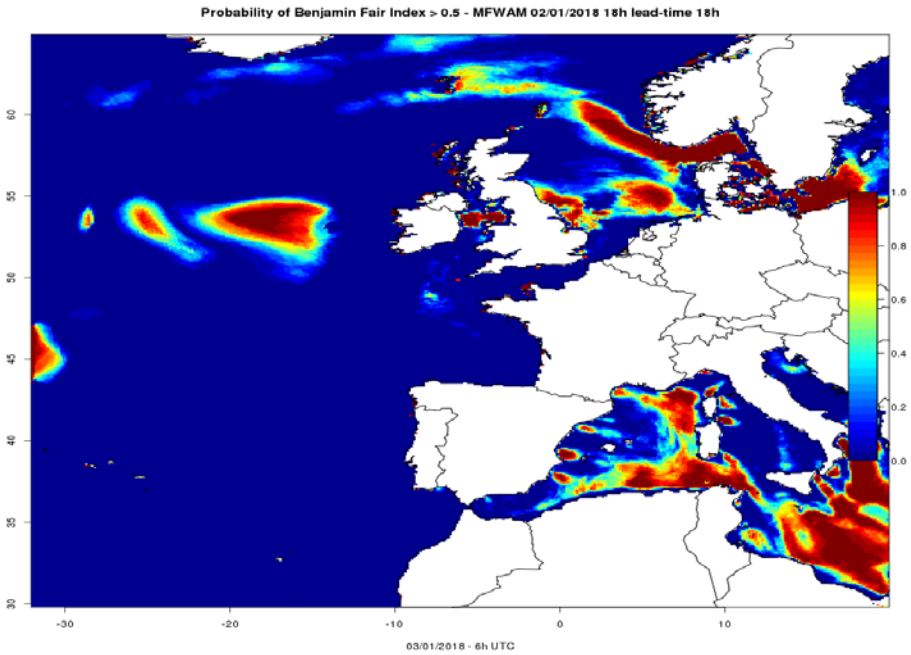
Freak waves prediction with ensemble wave forecast storm Eleonor (janvier 2018)

Maximum wave height



Forcing the wave model MFWAM with PEARP atmospheric ensemble system (35 members)

---> Probability of BFI >1



1 means 100 % of freak waves risk (in red)
Applications for ship routing

Conclusions

☐The operational wave forecast in the Atlantic ocean has improved significantly thanks to the assimilation of satellite wave data.
marine.copernicus.eu

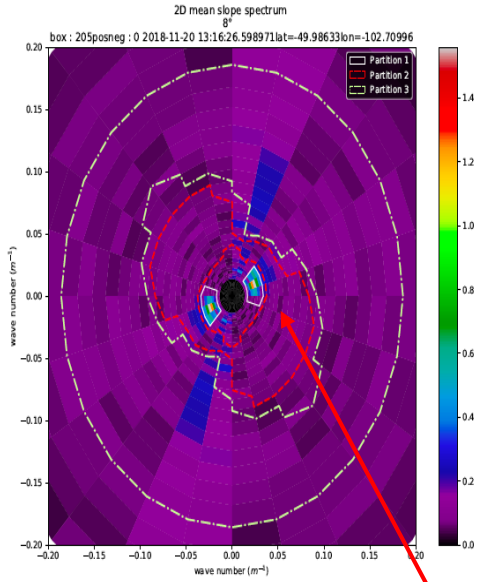
☐Ensuring reliable wave submersion warning systems and accurate wave products for CMEMS users

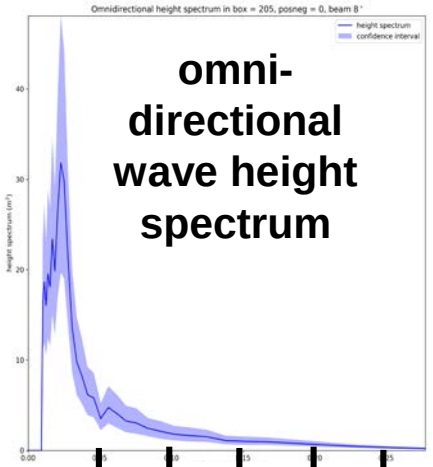
☐Waves in the atlantic ocean play a key role for the coupling between Ocean and atmosphere systems (storms and hurricanes in the tropical atlantic, Challenges for warming pool impact on lower layer of the atmosphere)

☐Use of ensemble wave forecasting to provide extreme indicators in the Atlantic ocean

Case of 20 November 2018, 2018: wave spectra from

2D wave slope pectrum in wave cell of ≈ 70 km x70 km

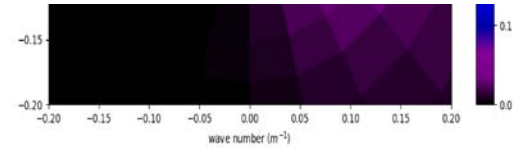




omni-directional wave height spectrum

0.05 0.10 0.15 0.20 0.25
wave number (rad/m)

MF-WAM-converted in wave number slope spectrum

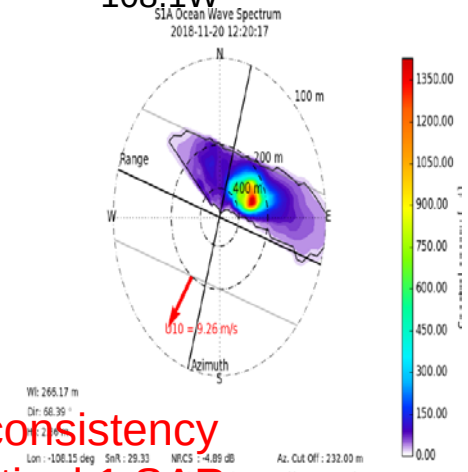


WW3, 12 UTC)

Sentinel-1 49.1S, 108.1W

waves

first partition: direction 250° ±180° wavelength 260 m, Hs 2.2m



very encouraging consistency SWIM/models/Sentinel 1 SAR