CFOSAT
Wind and wave observations from space: A French-Chinese mission

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Globwave Workshop, Brest, September 2007

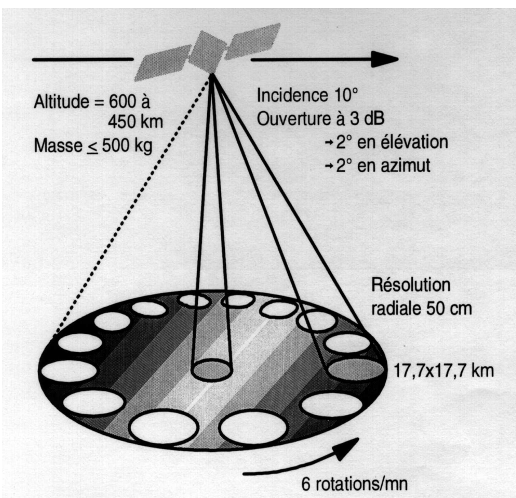
The Chinese French Oceanographic Satelllite CFOSAT

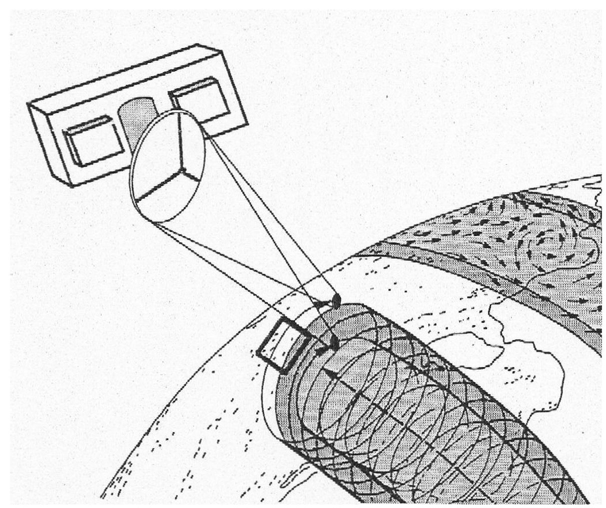
- Dedicated to ocean wind and waves obervation

Two payloads

- Directional wave spectrum form SWIM (France)

- Wind scatterometer SCAT (China)





- SWIM: ≈similar to the former SWIMSAT proposal to ESA in 2002

Outline

- Mission objectives
- Overall mission description
- Wave measurements
    - Scientific requirements
    - Proposed instrument (SWIM)
    - Principle of measurements
    - Preparation studies
- CFOSAT in the context of GLOBWAVE

CFOSAT Objectives

1) Monitor at the global scale the wind and waves at the ocean surface

⇒Improve **wind and wave prediction and sea-state monitoring**

=> improve knowledge and modeling of sea-surface processes

- **sea-state evolution**
- **role of waves in the atmosphere and ocean**,
- **sea-ice** properties and evolution in marginal ice zones,
- **coastal** processes
- determination of ocean surface parameters by **remote sensing**.

2) Opportunity for additional estimates of land surface parameters (in particular soil moisture and soil roughness)

3) Opportunity for studying **polar ice sheet** characteristics

Overall mission characteristics

-Recently agreed between China and France

-Launch planned in 2012-2013

-Platform and launcher under Chinese responsibility

-Ground segment shared between China and France

-SWIM designed and built by France

-SCAT designed and built by China

-Polar orbit (inclination ≈ 97°)

-Altitude 500 km approximately

-Near Real time transmission of data (within 3 hours)

Scatterometer on CFOSAT (Chinese part):

-Ku-Band

-Almost global coverage in one day

Two alternatives under study

- Quickscat type (2 rotating pencil beams, with incidence around 50°)

- intermediate between Quickscat and ERS (or Ascat): rotating fan-beam with incidence from about 20 to about 55° .

SWIM Scientific requirements

•Measurement of directional wave spectrum at global scale with a 70x70 km spatial resolution

• Revisit better than 10 to 13 days (TBC) for latitudes > 35°

• Wavelengths to be measured : ↑ ~ [70 - 500] m

• Variation of backscattering coefficient from 0 to 10° incidence with absolute accuracy < 1dB

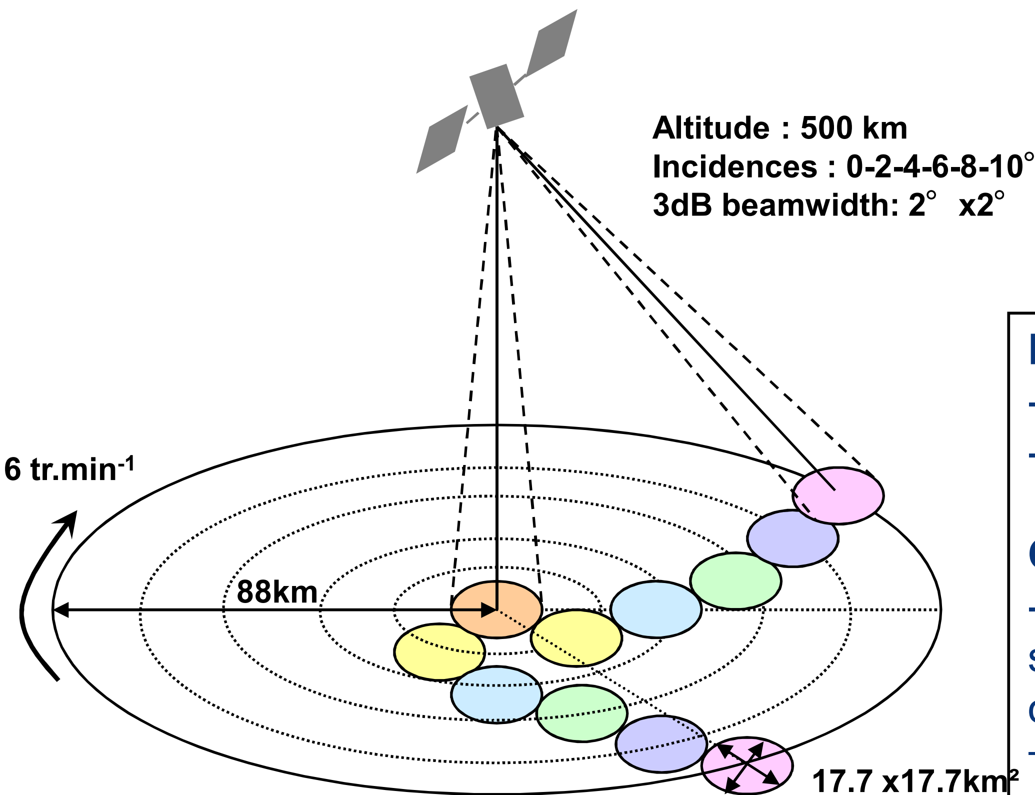
• Sea surface parameters to be derived :
  - Significant Wave Height
  - Wind speed
  - Radial wave spectrum every 15° in azimuth
  - Directional wave spectrum over scales of about 70 x 70 km
  - Mean square slope of short waves and tentatively other parameters of the slope pdf

Instrument SWIM

Ku-Band radar(13.6 GHz)

- –1 nadir beam (altimeter-type)
- –5 off-nadir beams (2 to 10°), rotating over 360° , real-aperture

} Sequential in time

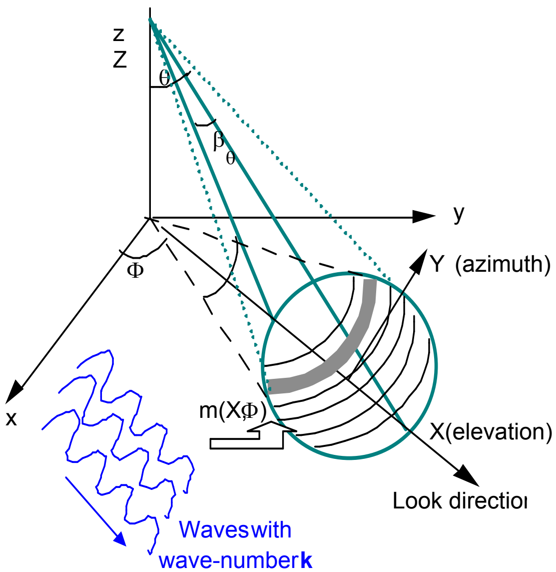


Expected products

Nadir :
-Hs
-Normalized Radar Cross-Section σ^0

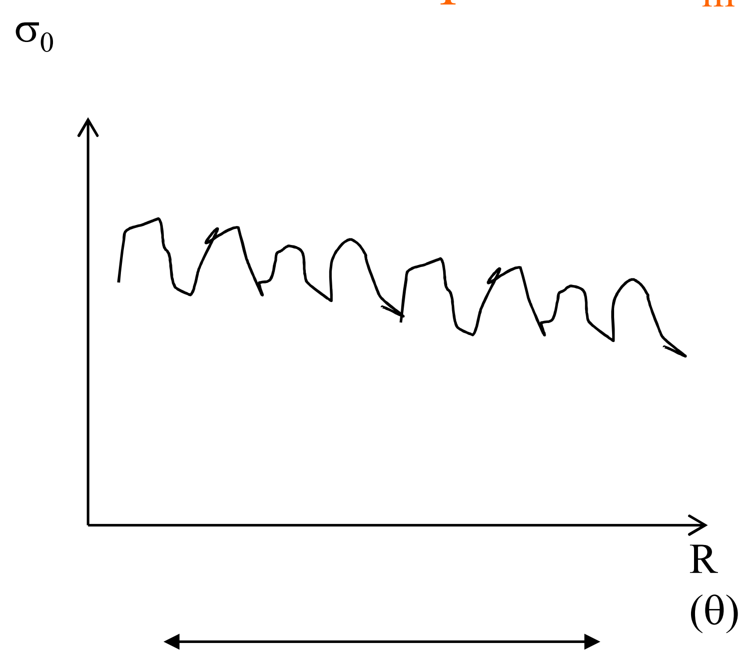
Off-nadir :
- Each 15° in azimuth, wave slope spectrum from the modulation spectrum of σ^0
- σ^0 for each incidence θ. $\sigma^0(\theta)$ => pdf of surface slopes

Principle for estimating wave spectra => similar to STORM/RESSAC



- In each azimuth direction, the normalized radar cross-section σ_0 is modulated by the tilt of the long waves

=> Measurement of these modulations $m(x,\phi)$, calculation of their spectrum $P_m(k,\phi)$



Swath covering 2° incidence range

• Linear relationship between modulation spectrum $P_m(k,\phi)$ and wave slope spectrum $k^2F(k,\phi)$

$$P_m(k,\phi) = \frac{\sqrt{2\pi}}{L_y}\alpha^2 k^2 F(k,\phi)$$

Ly: azimuth footprint dimension

$$\alpha = \cot\theta - 4tg\theta - \frac{1}{\cos^2\theta}\frac{\partial \ln p}{\partial(\tan\theta)},$$

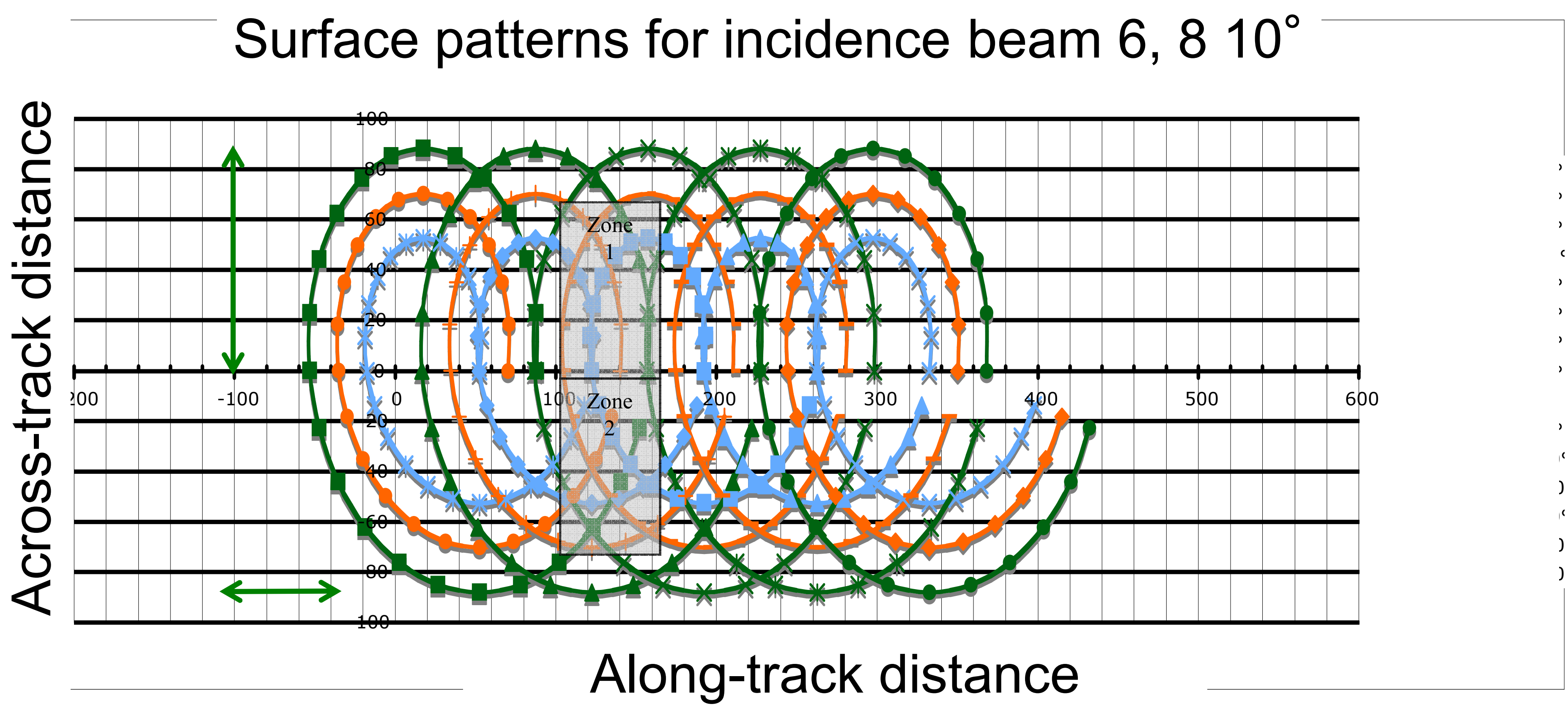
where p is the slope pdf

• Complete directional information using the 360° scans

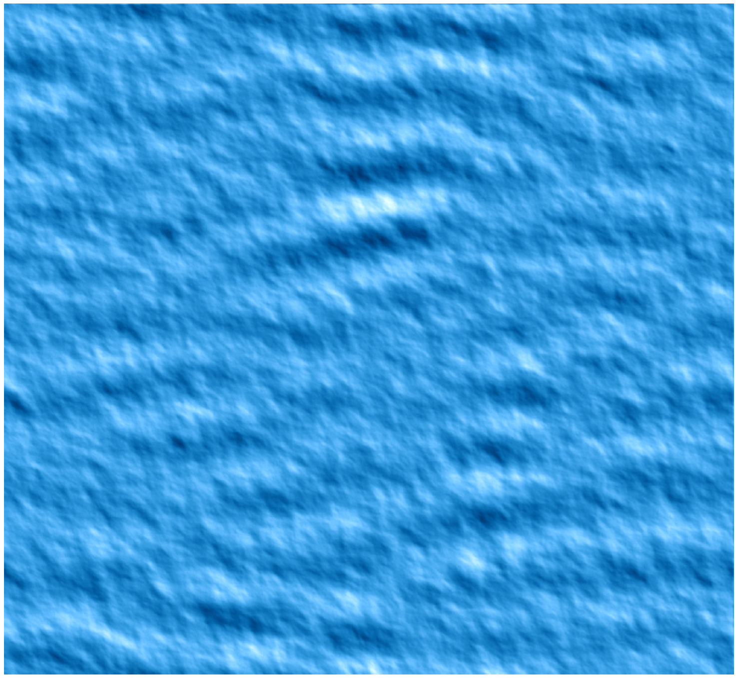
Scale at which directional spectra will be retrieved

90 x 90 km for 10° incidence

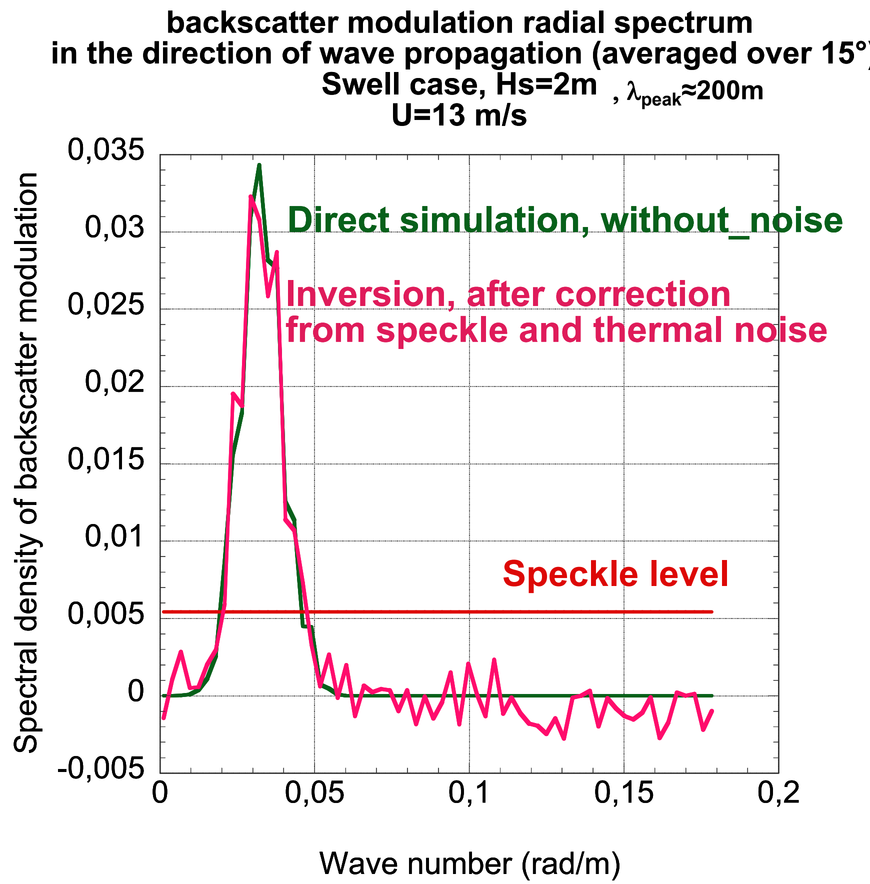
70 x 70 km by combining 3 incidences



Preparation studies (1): simulations of observations and inversions



Example of simulated wave field (4x4 km ; res 1m)
wind waves + swell
Simulator developed through a CNES/CETP cooperation

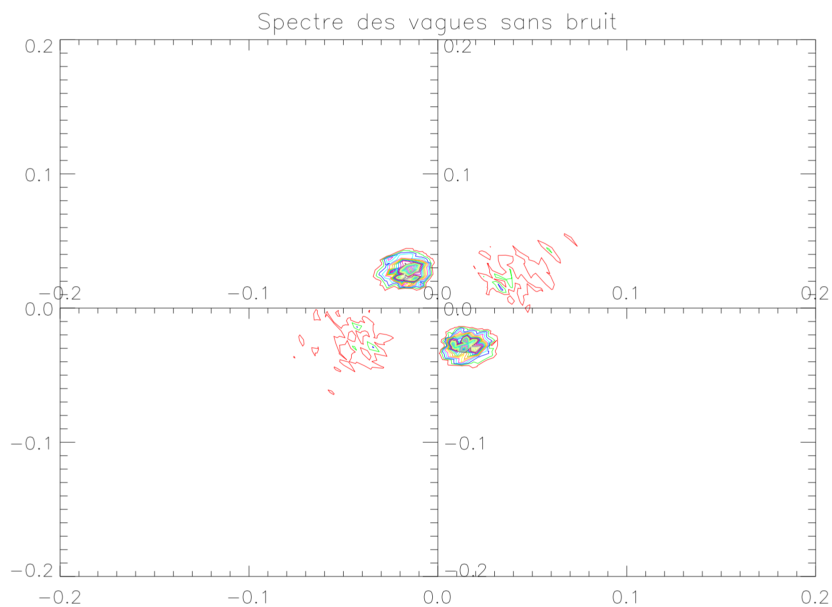


Objectives :

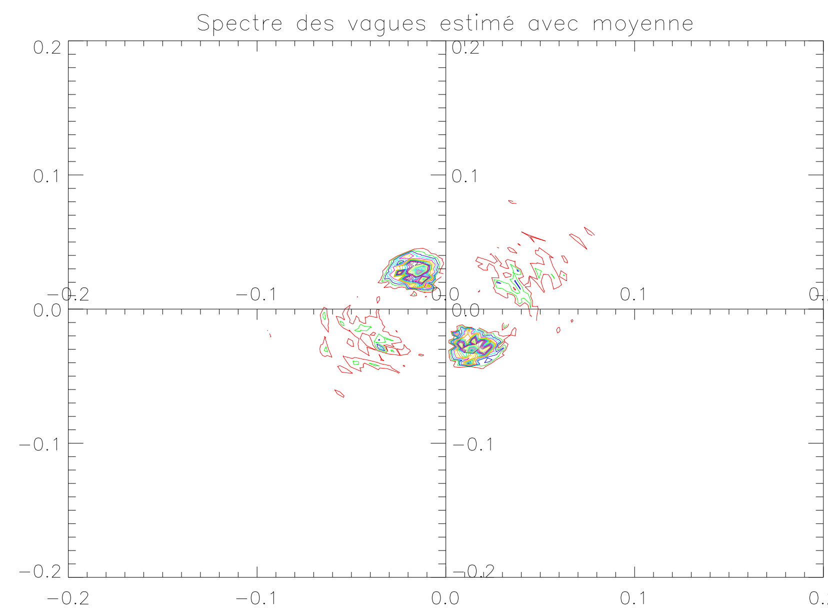
- extraction of directional wave spectrum
- instrument performance & optimization

Other illustration: 2D plot mixed sea case with swell Hs=4m, λ_{peak}=200 m, wind sea with U = 3 m/s, 90° angle between swell and wind sea propagation

Direct simulation
of the 2D modulation spectrum



2D modulation spectrum
after inversion



Preparation studies (2): development of assimilation schemes, study of assimilation impact

Two kind of studies (**Meteo-France**, CETP, BOOST, SHOM, IFREMER):

- simulation of SWIM-like data (observations simulated with perturbed analyzed fields)
- assimilation of data from the ENVISAT SAR wave mode

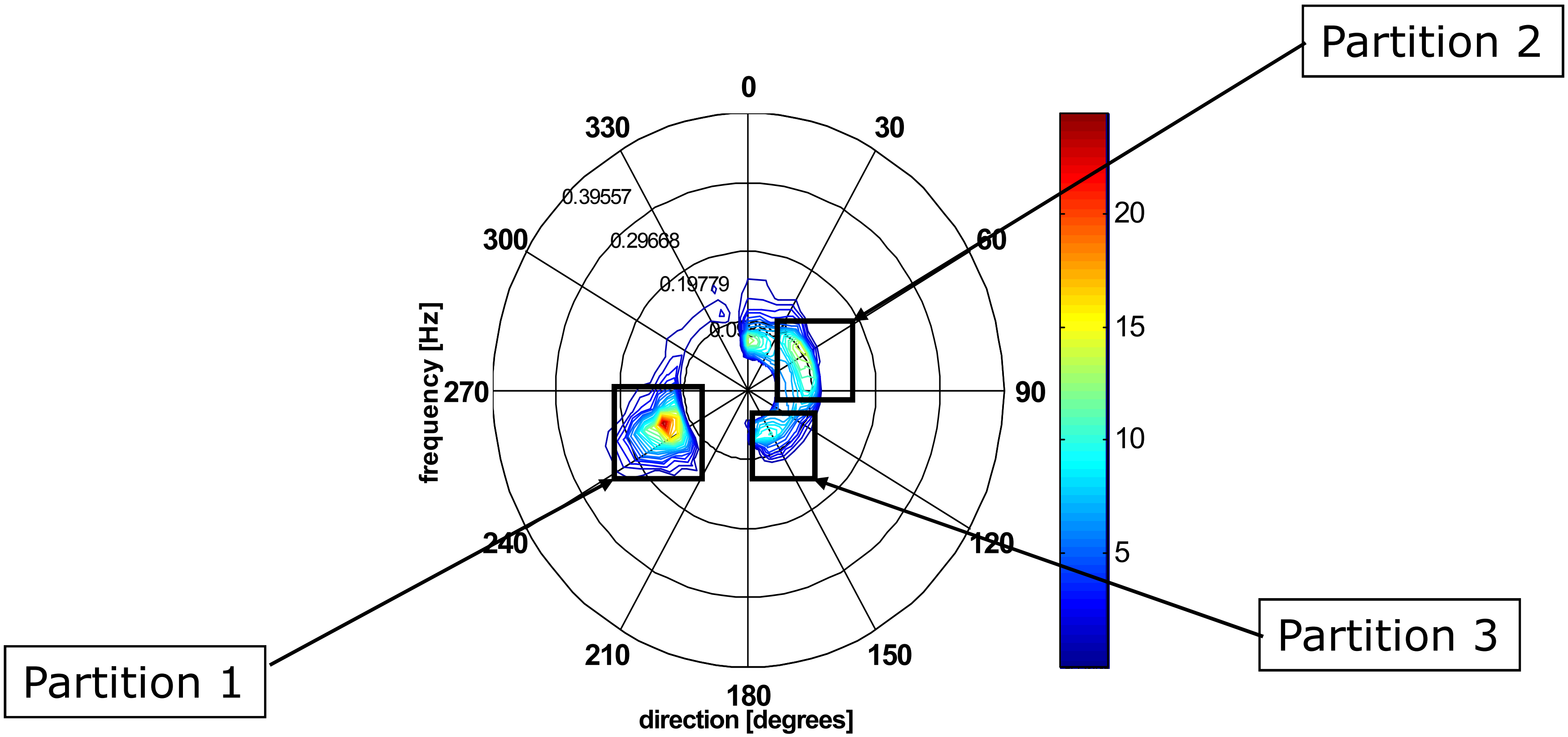
Spectral data: assimilation of main parameters (significant wave height, mean direction, mean frequency) of partitions of the 2D spectrum

Model: WAM, cycle 4, global (1 x 1 °), 25 frequencies (0.04-0.41 Hz), 24/36 directions, 6 hourly analyzed ECMWF wind-fields

Assimilation scheme: Optimal Interpolation

Description of the assimilation scheme

- Decomposition in partitions of the wave spectrum (first guess and observation)



Each partition is described by Its mean parameters

SWIMSAT synthetic case

See also Aouf et al, JAOTech, 2006

-Simulation of a reference case (forecast without assimilation for a period of 8 days)

-Simulation of synthetic “noisy” SWIM observations along the orbit, including noise

-First guess perturbed wave field

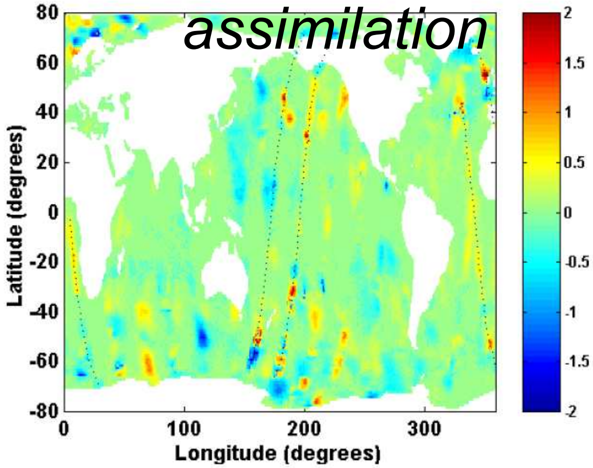
-Assimilation for a period of 4 days, every 3 hours, then forecast without assimilation

-Comparison between runs with and without assimilation

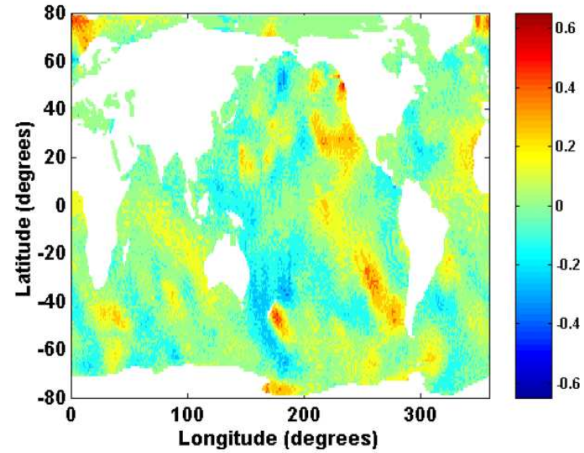
Main results of the simulations

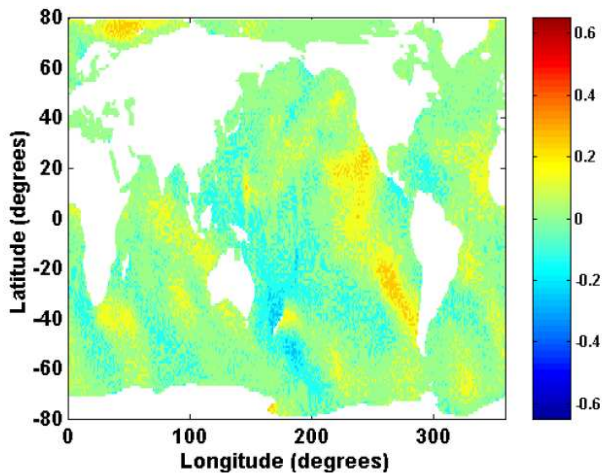
Difference in H_s between runs with and without assimilation of SWIMSAT synthetic data

1 day after beginning of assimilation



1 day of forecast after end of assimilation

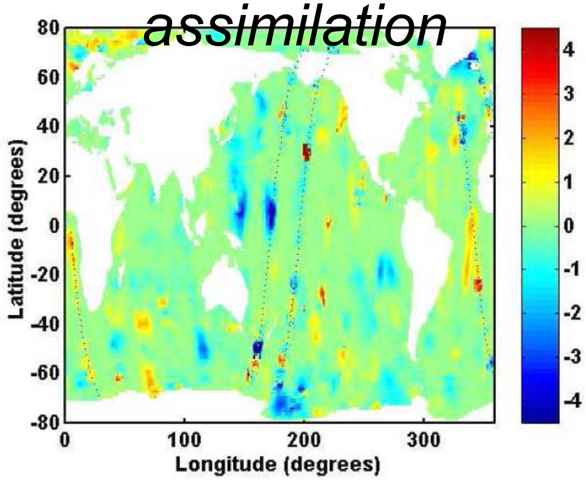




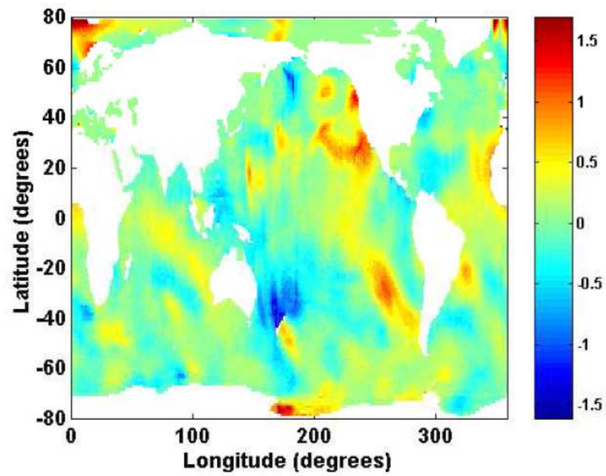
2 days after end of assimilation

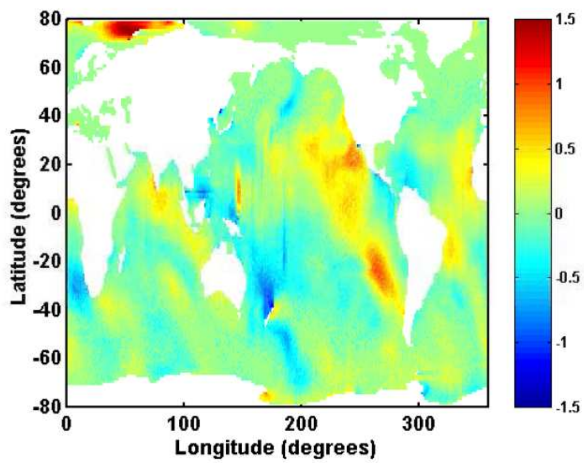
Difference in mean wave period between runs with and without assimilation of SWIMSAT synthetic data

1 day after beginning of assimilation



1 day of forecast after end of assimilation



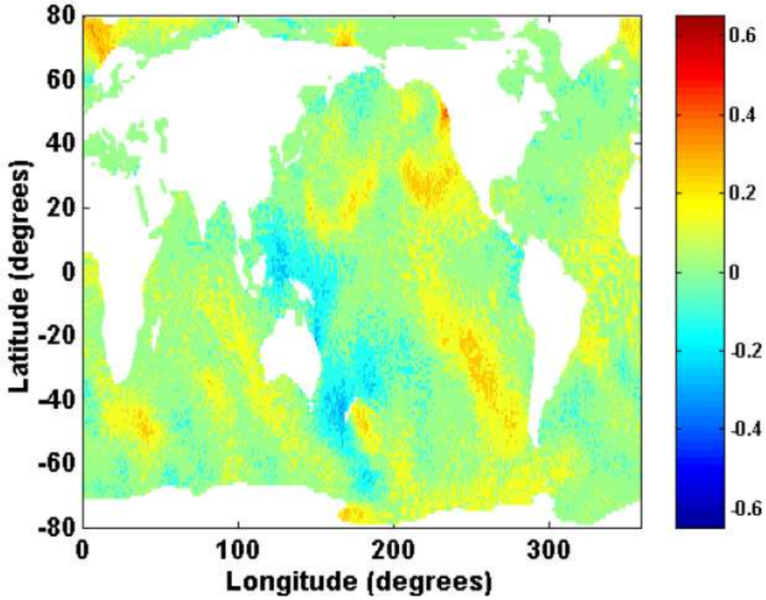


2 days after end of assimilation

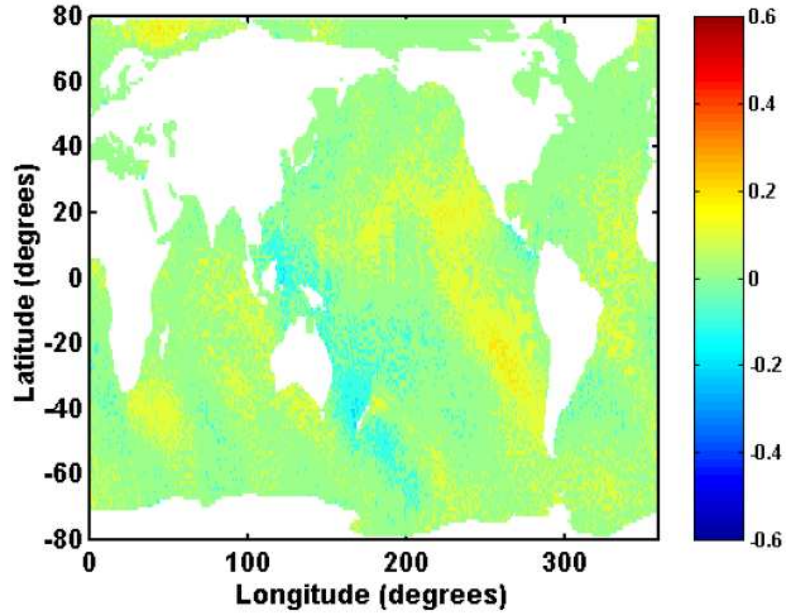
Comparison to assimilation of H_s only (case of an altimeter)

Difference of H_s , 2 days after end of assimilation, between runs with and without assimilation of:

Spectral data
(SWIMSAT case)



Non spectral data
(altimeter case)



Summary on efficiency of assimilation

- Use of the assimilation index: quantifies the reduction due to assimilation, of rms error between model and observations

- On H_{10} (waves with periods longer than 10 s): 6% 1 day after assimilation) , larger than on Hs and larger for spectral data (SWIM) than for non spectral data

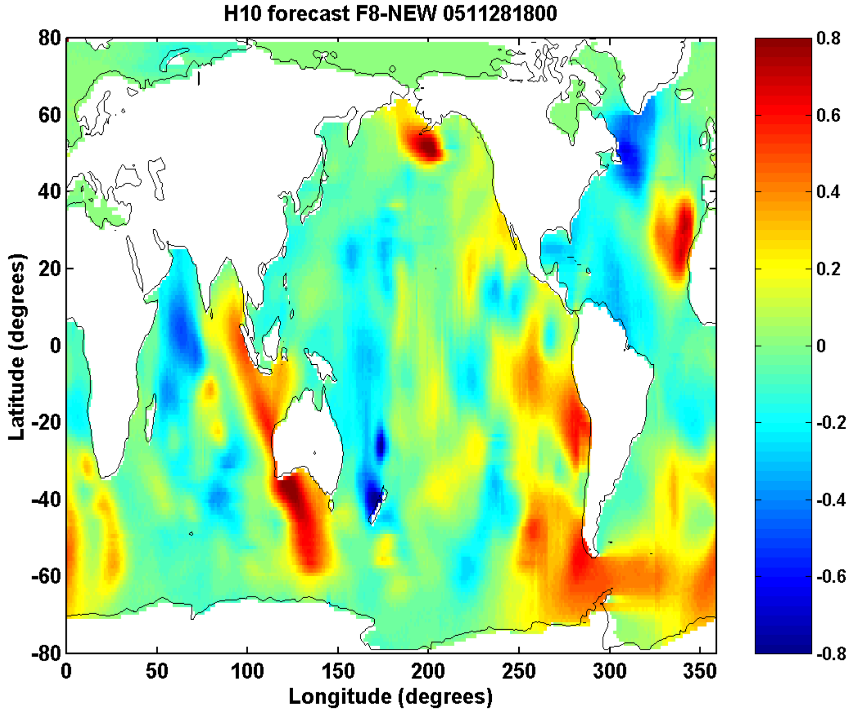
- On mean wave frequency and mean direction: larger for spectral data (about 9% and 4%, respectively) than for non-spectral (5% and 2% respectively)

- Efficiency decreases significantly when the cutoff is larger than 150 m (case of a SAR)

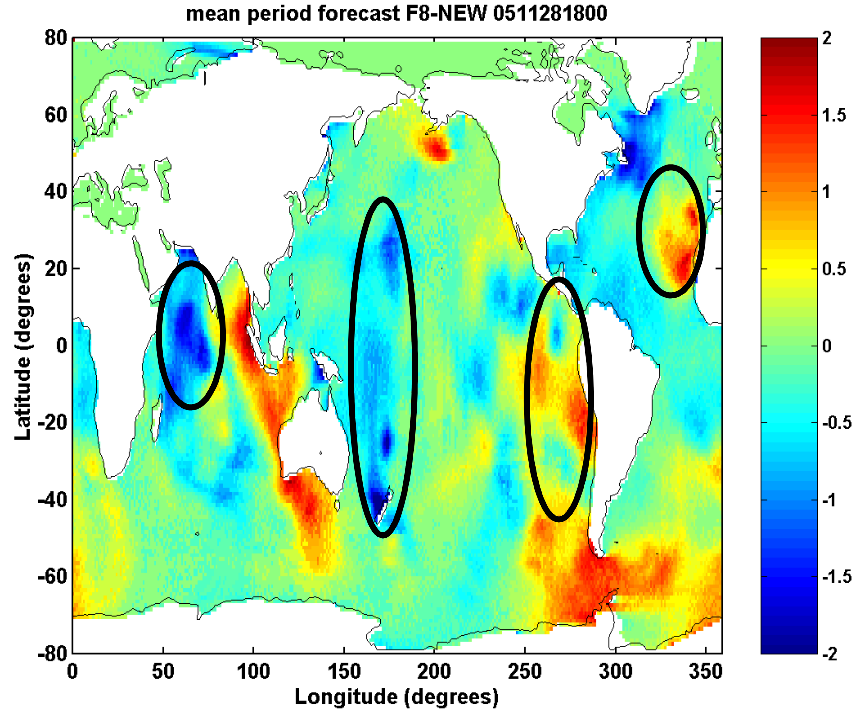
Spectral data (SWIMSAT case) brings more information in the assimilation than standard altimeter data (H_s), efficiency of assimilation larger than for SAR data (less cutoff effect)

Impact of the assimilation of upgraded ASAR wave spectra (cut-off de 244 m) in forecast mode

Wave height H10 (for waves with period > 10 s)



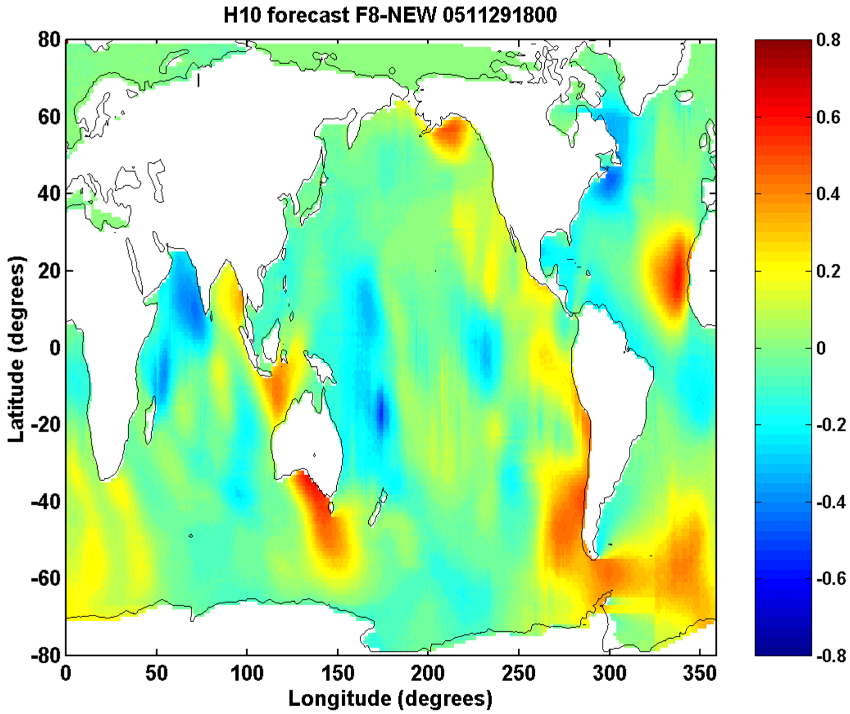
Mean wave period



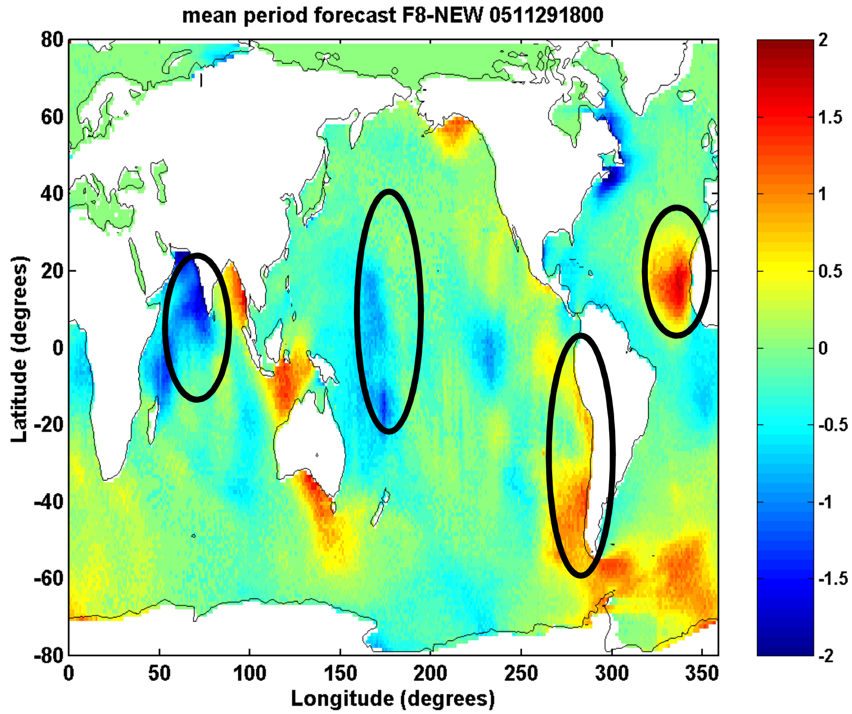
28 November 2005 at 18:00 (UTC)
1-day forecast

Impact of the assimilation of upgraded ASAR wave spectra (cut-off de 244 m) in the forecast mode

Wave height H10 (for waves with period > 10 s)



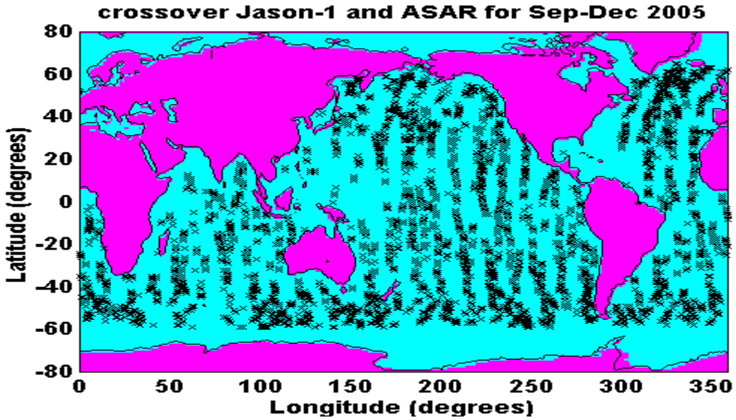
Mean wave period



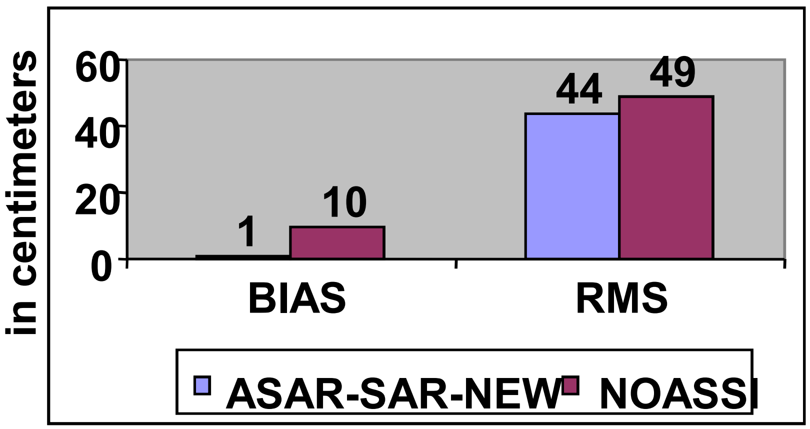
November 29 2005, 18:00 (UTC)
2-day forecast

Using Jason-1 and GFO altimeter data as independent verification data set at crossovers points

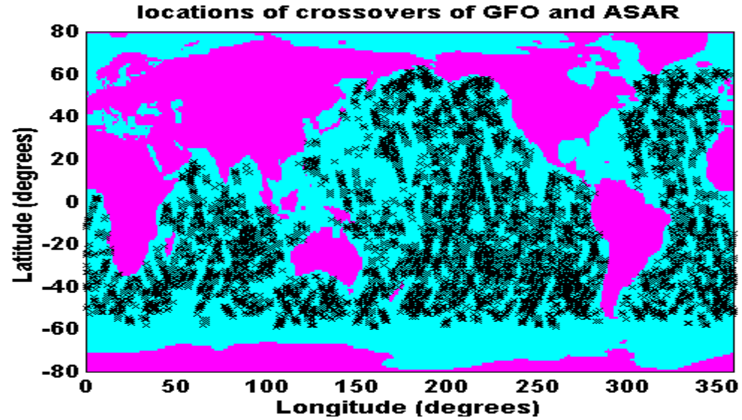
JASON-1



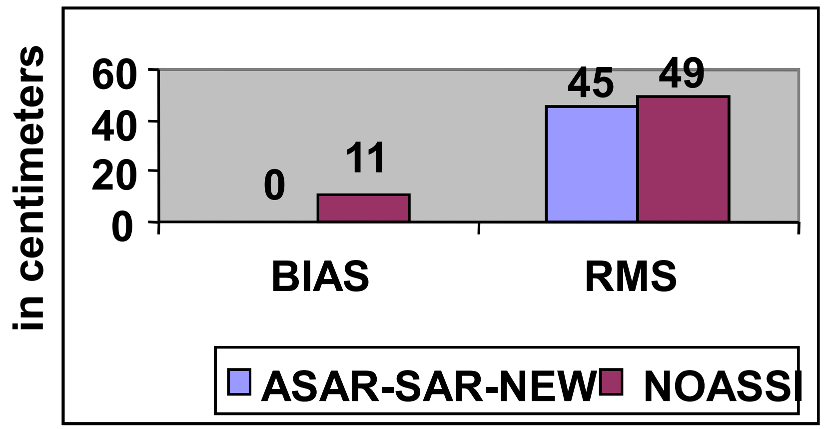
Nb crossovers: 4421



GFO



Nb crossovers: 7806



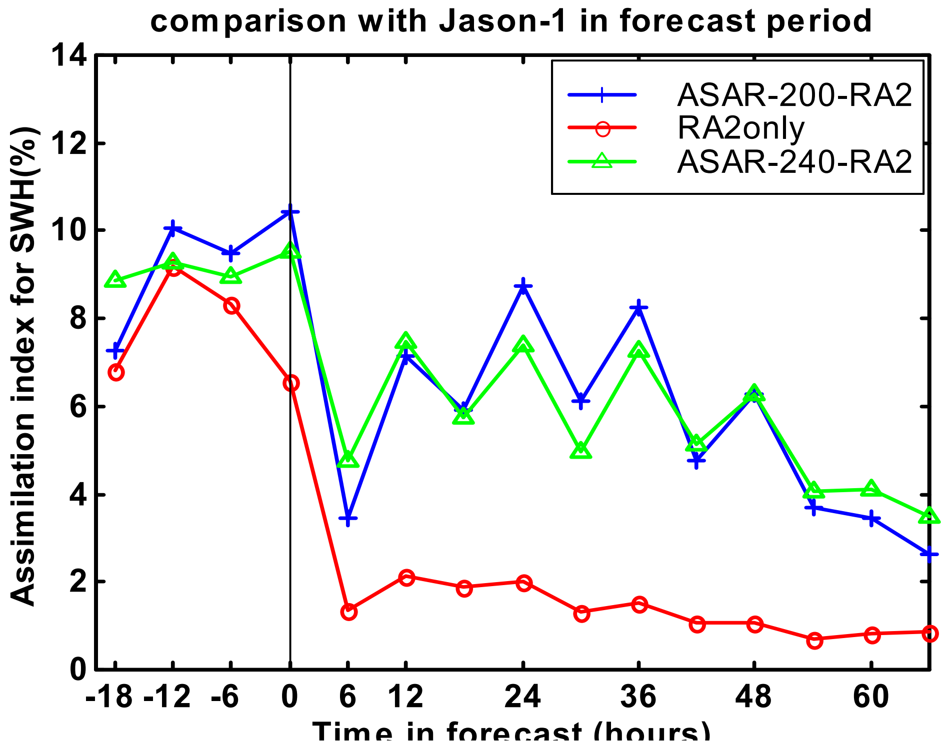
→ **Significant reduction of RMS error (AI) by 10.2 % and 7.6%**

Sep-Oct-Nov-Dec 2005

Effect of combined assimilation (ASAR+RA2) in the forecast period

Comparison of Significant wave heights at Jason-1 orbit tracks

reduction of RMS error in %



After two months of assimilation (Jan et Féb 2004) forecast period of three days

→ **The spectral information induces a longer impact in the period of forecast**

Concluding remarks on assimilation studies

→ SWIM simulation : positive impact for H10, mean period, direction; larger impact than in case of non-spectral assimilation (Hs from altimeter)

→ WAM with ASAR : positive impact for significant wave height as shown by comparison with independent wave data (Jason-1, GFO and NDBC buoys)

→Need for long term studies combining assimilation of ASAR wave spectra and altimeter Ra-2 in WAM model

→Need for better knowledge of correlation functions of spectral parameters

→Need for independent data for validation, scores,…

CFOSAT in the context of a "Globwave system"

-CFOSAT will provide ocean winds and spectral characteristics of surface waves (starting 2012-2013)

- coverage for wind should be global almost daily

- coverage for waves will be global over 10 to 13 days (to be confirmed)

⇒CFOSAT must be used as one element of a « virtual » constellation, with complementary characteristics :

- other altimeter missions (Sentinelle 3, Jason3, SARAL/AltiKa,…)
- SAR missions (Sentinelle 1) with wave mode or image mode over the ocean, Radarsat2, …
- Scat missions (METOP/ASCAT, Chinese HY2B??, other missions of Quickscat type??)

CFOSAT in the context of a "Globwave system", (2)

-Real-time aspects will be under space agencies responsibility

-In addition: need for easy data access for science and applications (not real-time)

-Need for in situ observations (wind, spectral characteristics of waves) for validation of retrieval algorithms, assimilation scores,..

-Need for models as observation integrating systems (assimilation), as tool for open ocean forecast, as boundary conditions and tool for coastal processes forecast and analysis.

Personal recommandation

Wind and waves from various sources (satellites, buoy, ships,..) in the same data base or via same interface

For remote sensing: radar cross-sections also archived

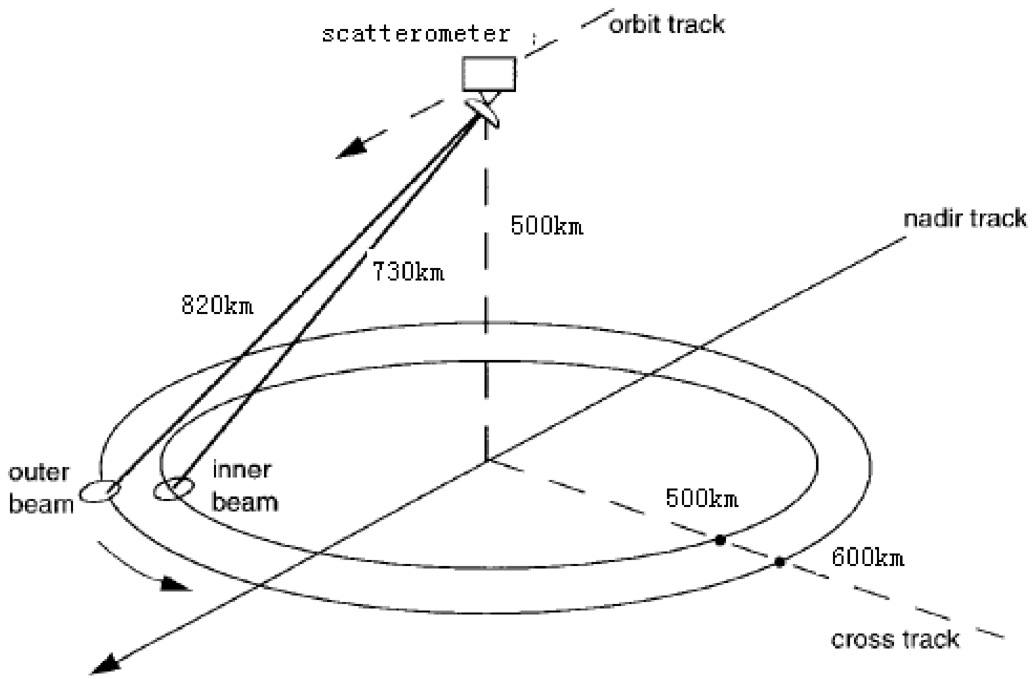
Ancillary useful data: rain, current, SST,…

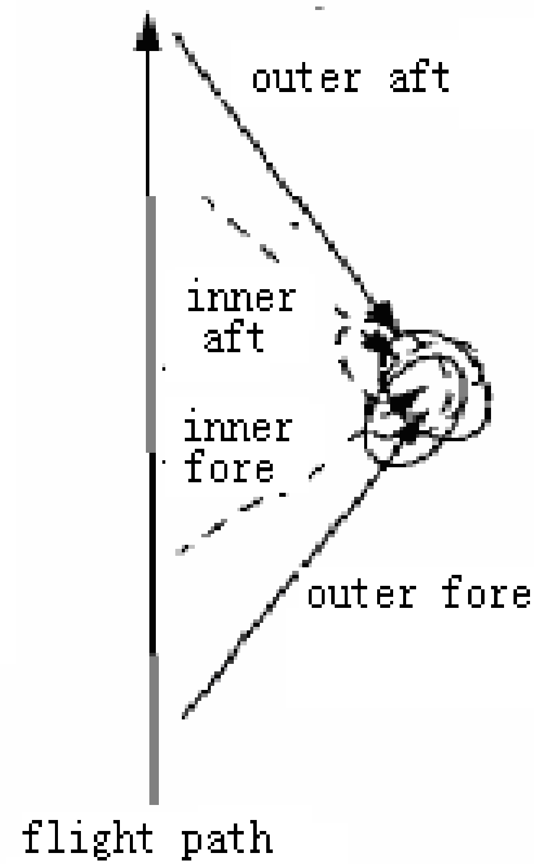
Need for more in situ observations of spectral properties of waves.

Even wit the present 1D buoy network : access to the 1D spectrum rather than to the parameters of a the spectra would be useful

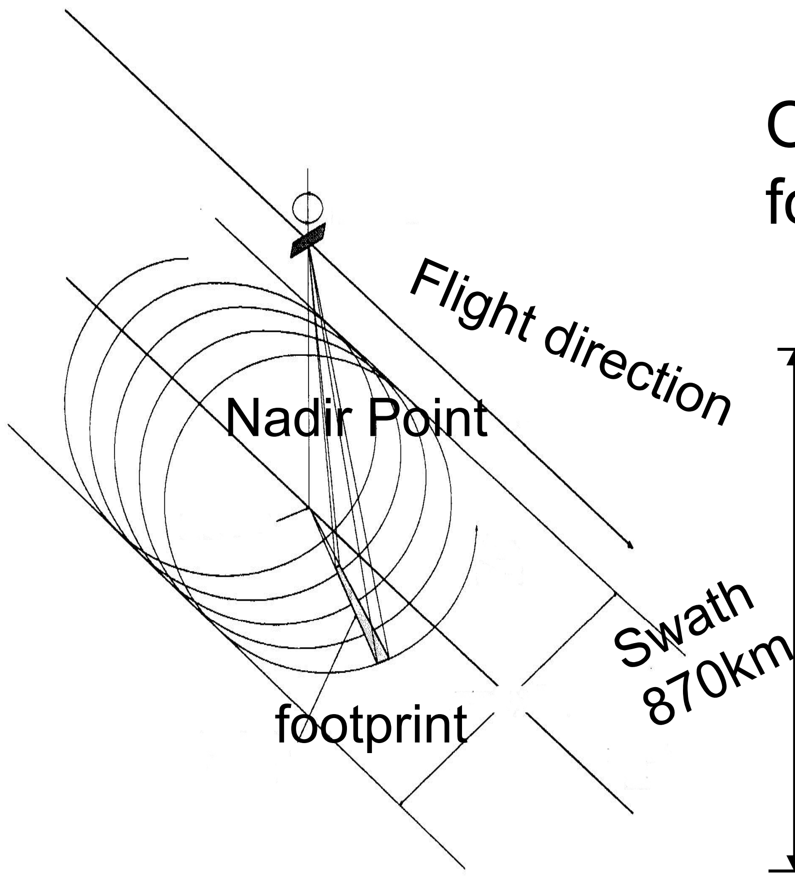
Need for more 2D spectra

First option (pencil-beam, Quickscat type)

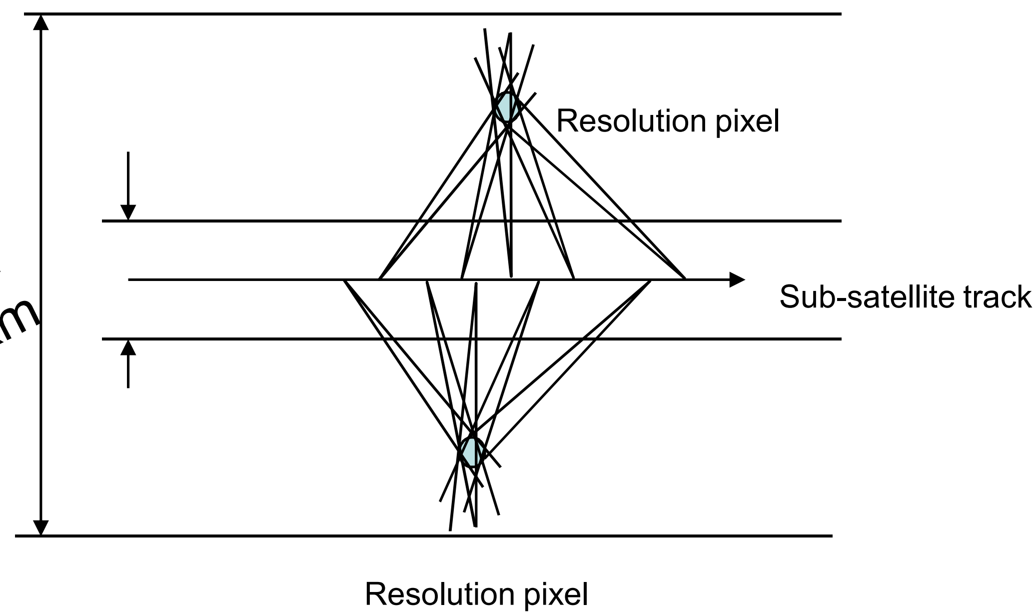




Second option: rotating fan-beam



Overlap between adjacent scans for large number of azimuth view for each pixel

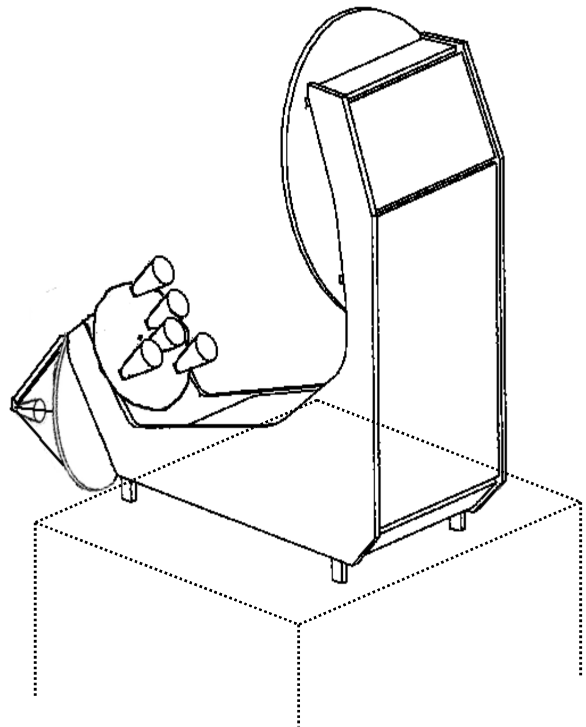


Tentative specifications (to be confirmed)

Radio-Frequency part	
Frequency	13.575 GHz
Peak RF power (TWTA)	120-150 Watt
Waveform	Chirp (frequency modulated)
Bandwidth	200 to 320 MHz depending on incidence
Pulse duration	50 µs
PRF	2 to 6.5 kHz, depending on incidence
Antenna part	
Incidence	0, 2, 4, 6, 8, and 10°
Polarisation	HH (TBC)
3 dB beamwidth	2° x 2°
Rotation	6 rotations/minute (TBC)
Design	80 cm diameter passive offset parabole with six rotating feeding horns
On-board Processing Unit	
Range Compression	Deramp technique (TBC)
Range resolution after compression	0.47 to 0.75 m depending on incidence
Time integration	17 to 48ms (depending on incidence with correction of the advection using tracking-loop)
Real time processing	- nadir beam: distance, radar cross-section and significant wave height - off-nadir beams: backscatter power versus distance, time integration accounting for migration due to satellite displacement
Data transmission	
Data rate/data Link	8 Mbits, X-Band

Tentative design of the antenna part

Offset antenna (80 cm) for the 5 offset beams + small antenna (40 cm) for nadir beam



$$P_m(k,\phi) = \frac{\sqrt{2\pi}}{L_y}\alpha^2 k^2 F(k,\phi)$$

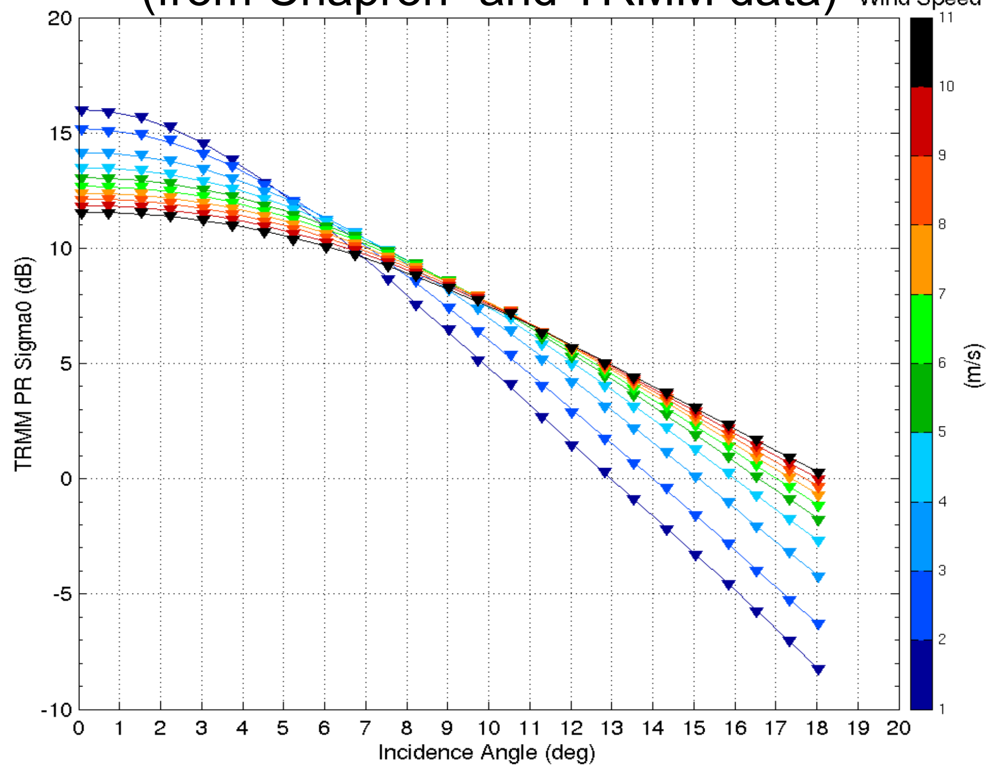
$$\alpha = \cot\theta - 4tg\theta - \frac{1}{\cos^2\theta}\frac{\partial \ln p}{\partial(\tan\theta)}$$

$$\frac{\partial \ln p}{\partial(\tan\theta)}\ related to\ \frac{1}{\sigma_0}\frac{\partial\sigma_0}{\partial \tan\theta},$$

α is wind dependent

$\sigma_0(\theta)$ for different wind speeds

(from Chapron- and TRMM data)



Coverage for 4 days of assimilation (preliminary specification)

Observation locations for 4 days assimilation of SWIMSAT synthetic