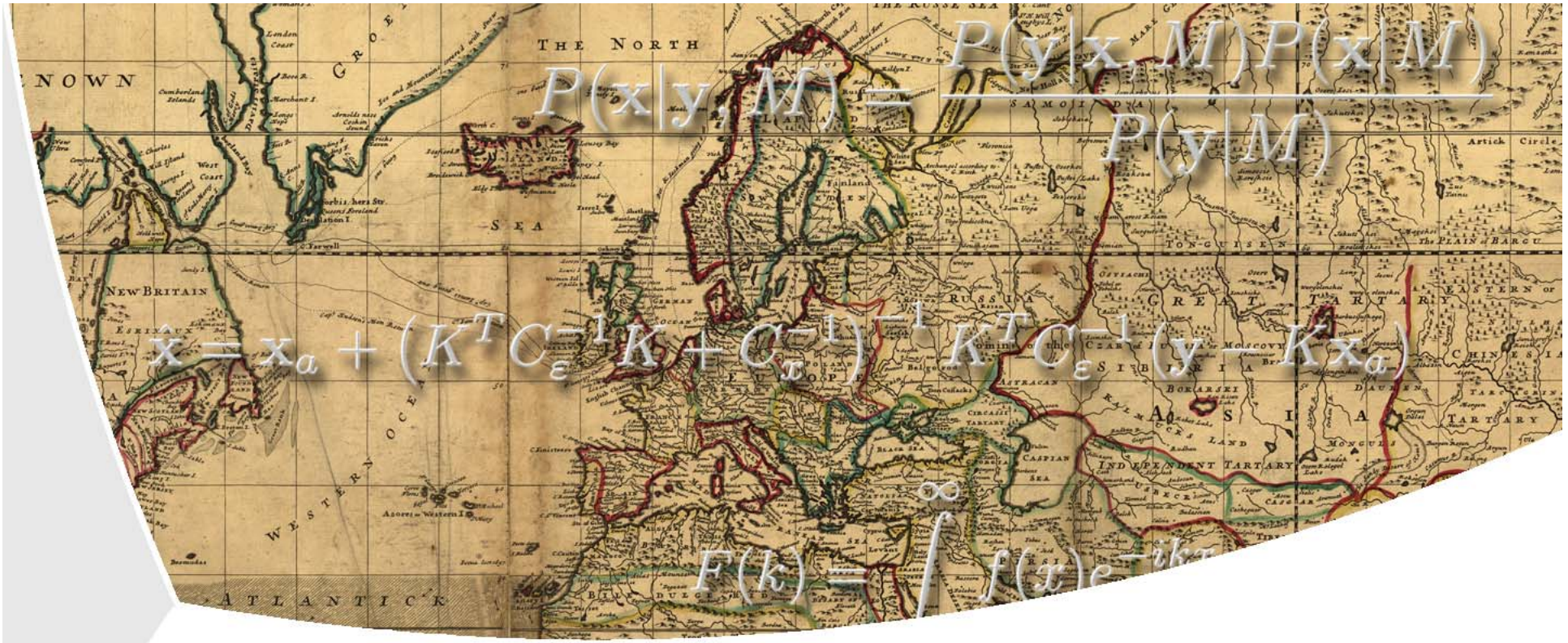

Sea State Measurements by ENVISAT ASAR and TSX Data

Susanne Lehner

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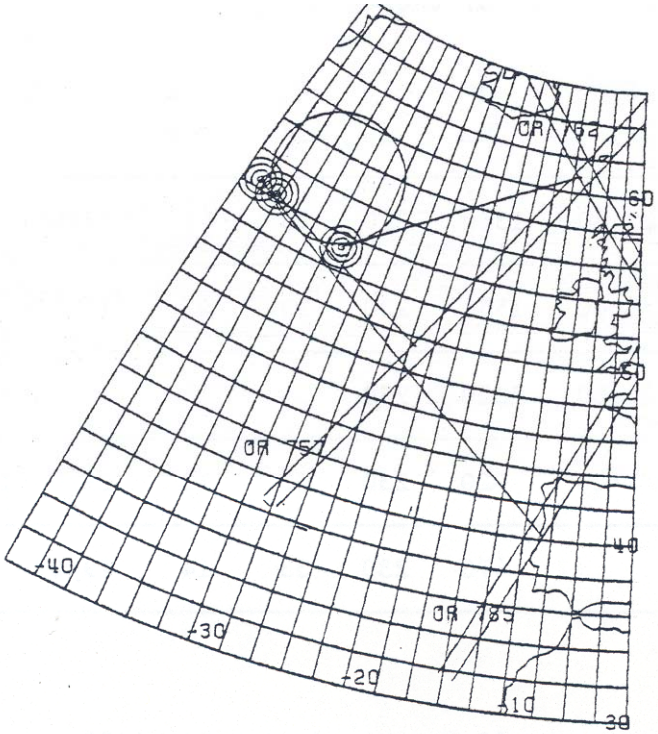
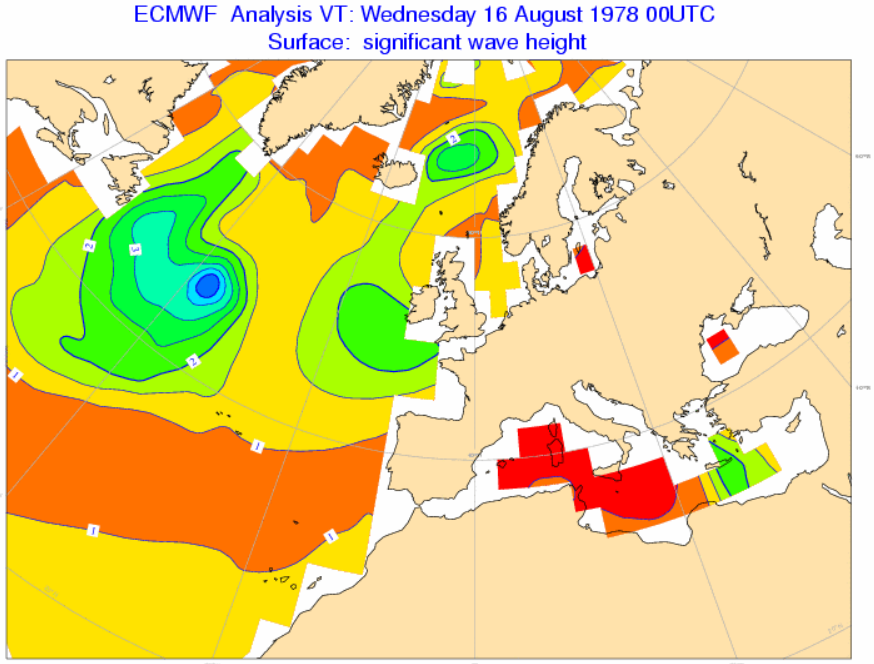
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Swell Tracking from Seasat



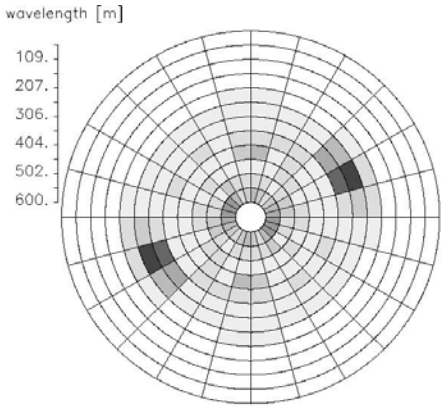


e 36. Map of orbits 757,762 and 785. The solutions for the parameter model are indicated as range rings.

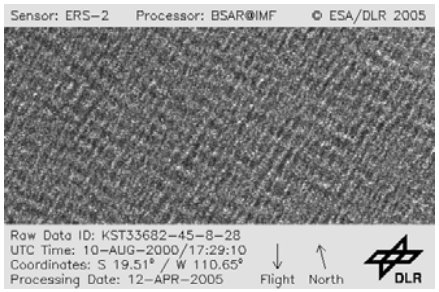
Motivation

Global sea state statistics with SAR wave mode data—Wave Climate

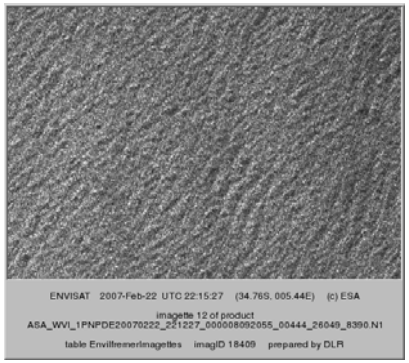
- ERS-1/SAR wave mode data (1991~1995)
- ERS-2/SAR wave mode data (1995~)
- ENVISAT/ASAR wave mode data (2002~)
- oncoming Sentinel satellite wave mode data



ERS-1/2 UWA spectra



Reprocessed ERS-2/SAR wave mode complex data



Standard ESA ENVISAT product--WVI

Outline

❖ CWAVE - Empirical Algorithm development and validation

- ➢ Empirical algorithm (CWAVE) developed to derive integral ocean wave parameters without use of first guess
- ➢ CWAVE_ENV algorithm validation with models and buoy data
- ➢ Global Statistics of Hs based on ERS and ASAR global wave mode data

❖PARSA - Inversion Algorithm using WAM First Guess

- ➢ Validation against ECMWF, DWD
- ➢Investigation of Spectral Shape

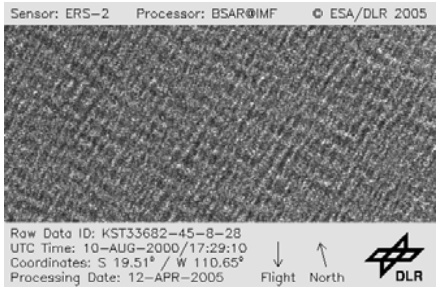
❖ TSX Coastal Wave Measurements

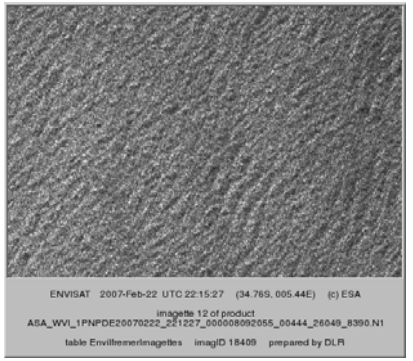
- ➢ Wave generation
- ➢ Wave Shoaling

Empirical Algorithm ---CWAVE

developed for ERS/SAR and ENVISAT/ASAR wave mode data

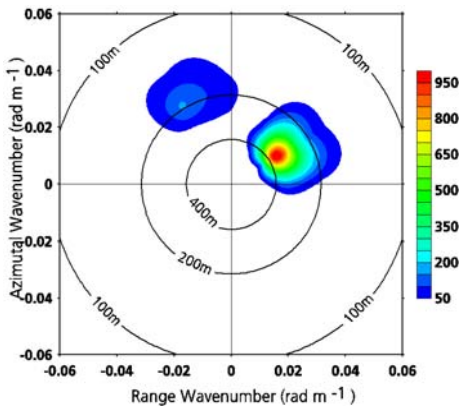
$s_1, \ldots, s_N$





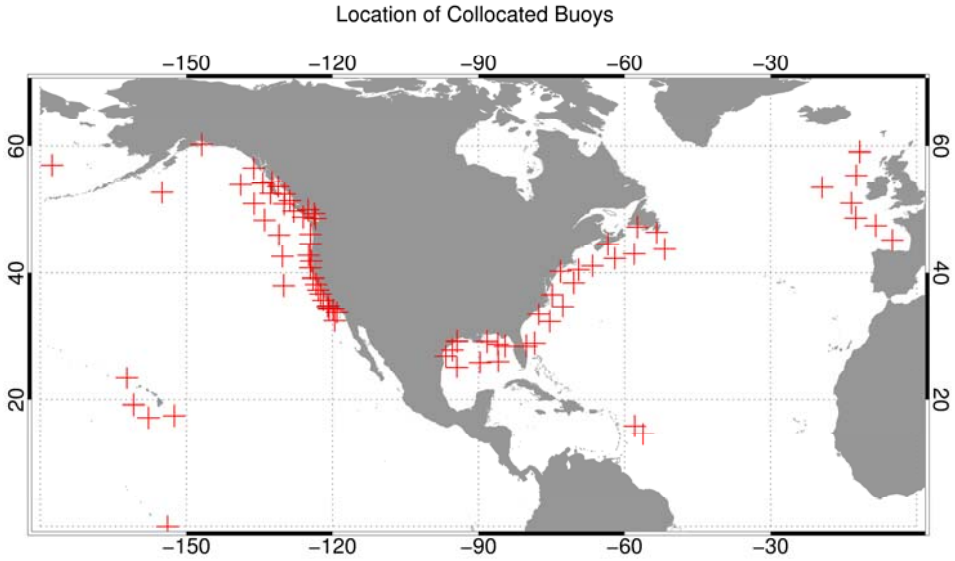
$$H_s = a_0 + \sum_{i=1}^{N} a_i \, s_i + \sum_{i=1}^{N} \sum_{j=1}^{i} a_{i,j} \, s_i \, s_j$$

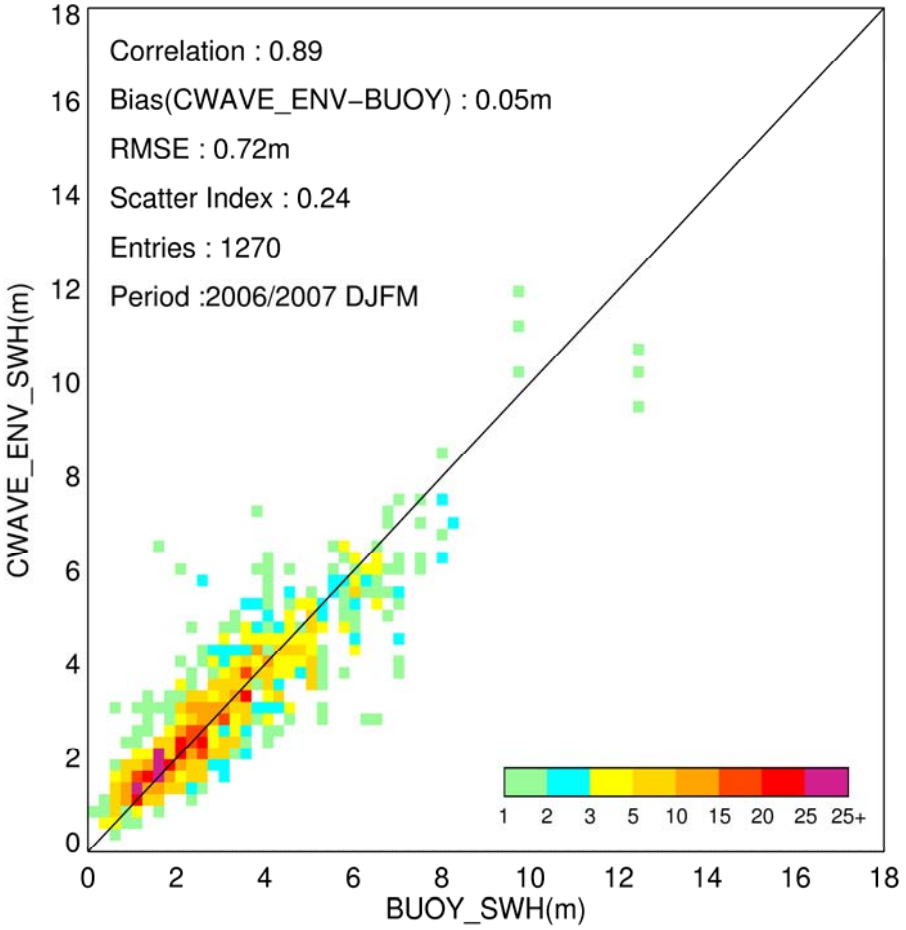
The Parameters $a_0, \ldots, a_N, a_{1,1}, \ldots, a_{N,N}$ are fitted using a training data set of SAR wave mode data and colocated ECMWF wave spectra



Validation of CWAVE_ENV

➢ CWAVE_ENV vs. Buoy

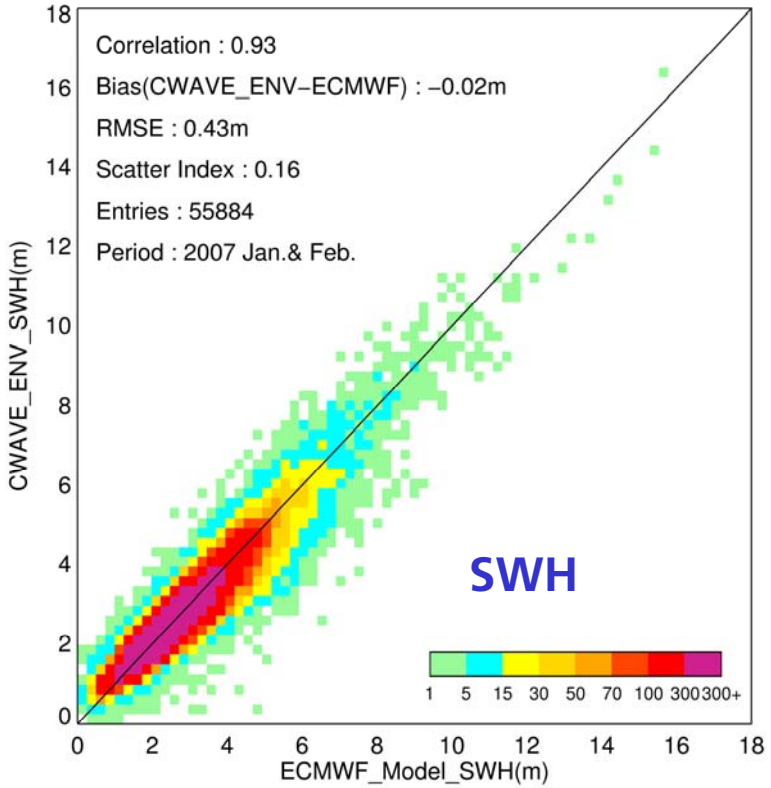


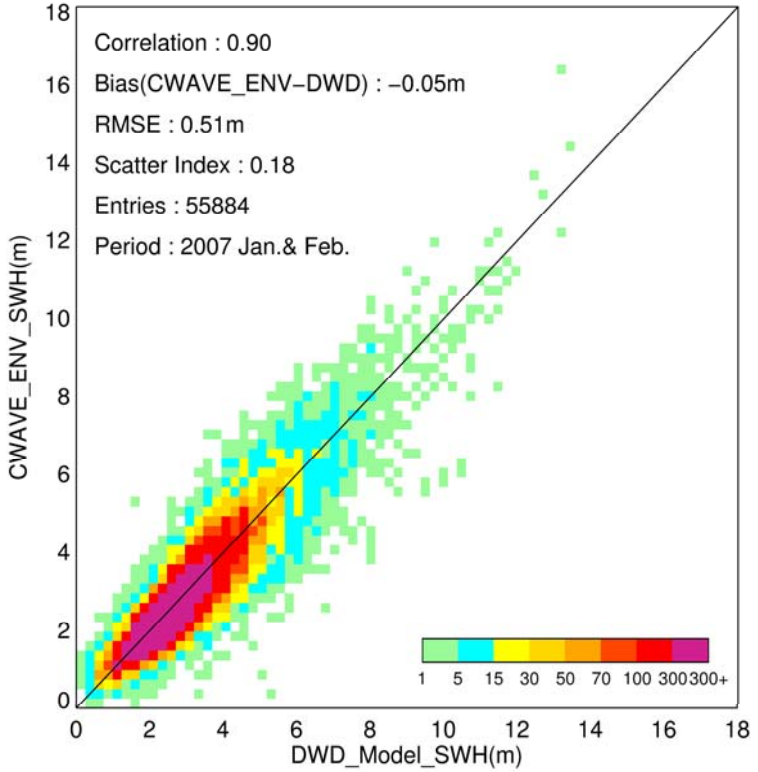


X. Li, S. Lehner, Th. Bruns, sub. 2009

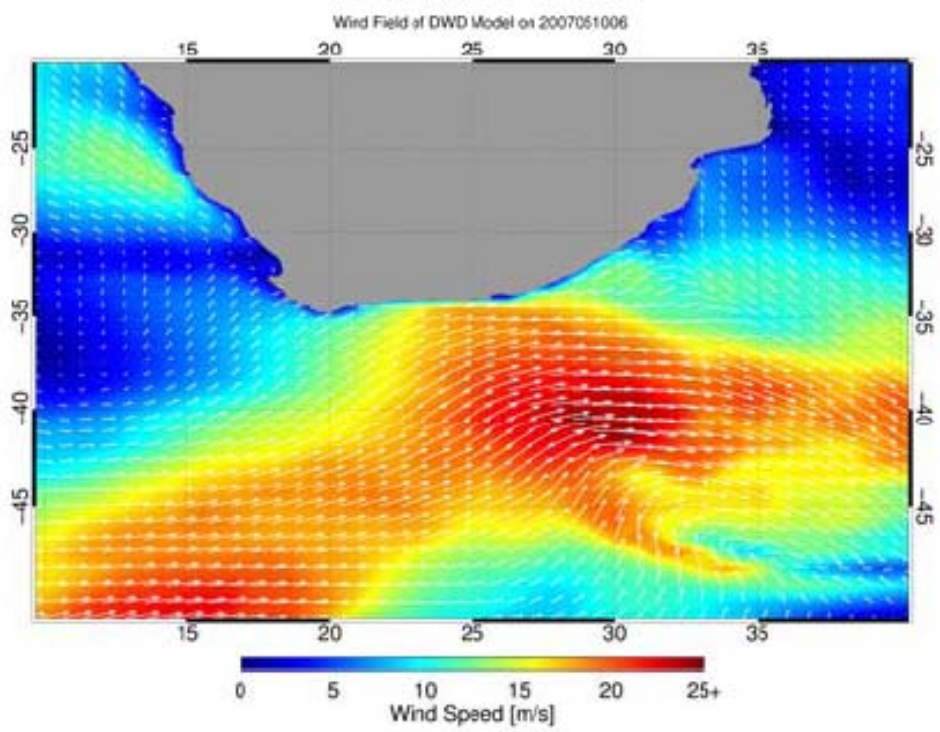
vs. ECMWF_WAM -- reanalyzed

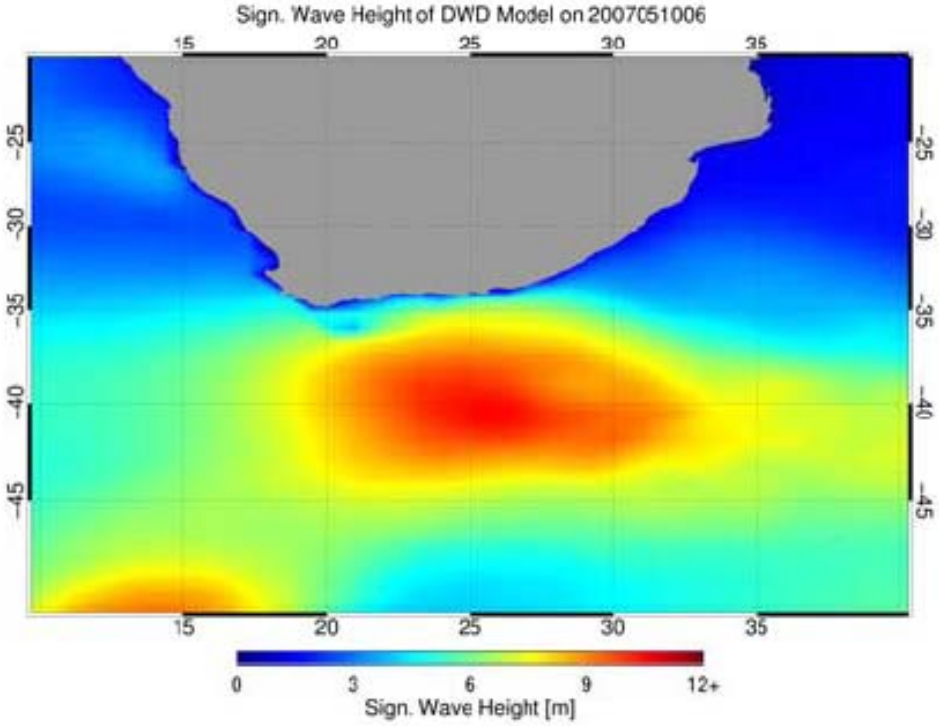
- 2D spectra are achieved at 00, 06, 12 and 18 UTC
- spatial resolution 0.5 degree
- 24 direction bins and 30 frequency bins from 0.03452Hz, log. increment of 1.1Hz.



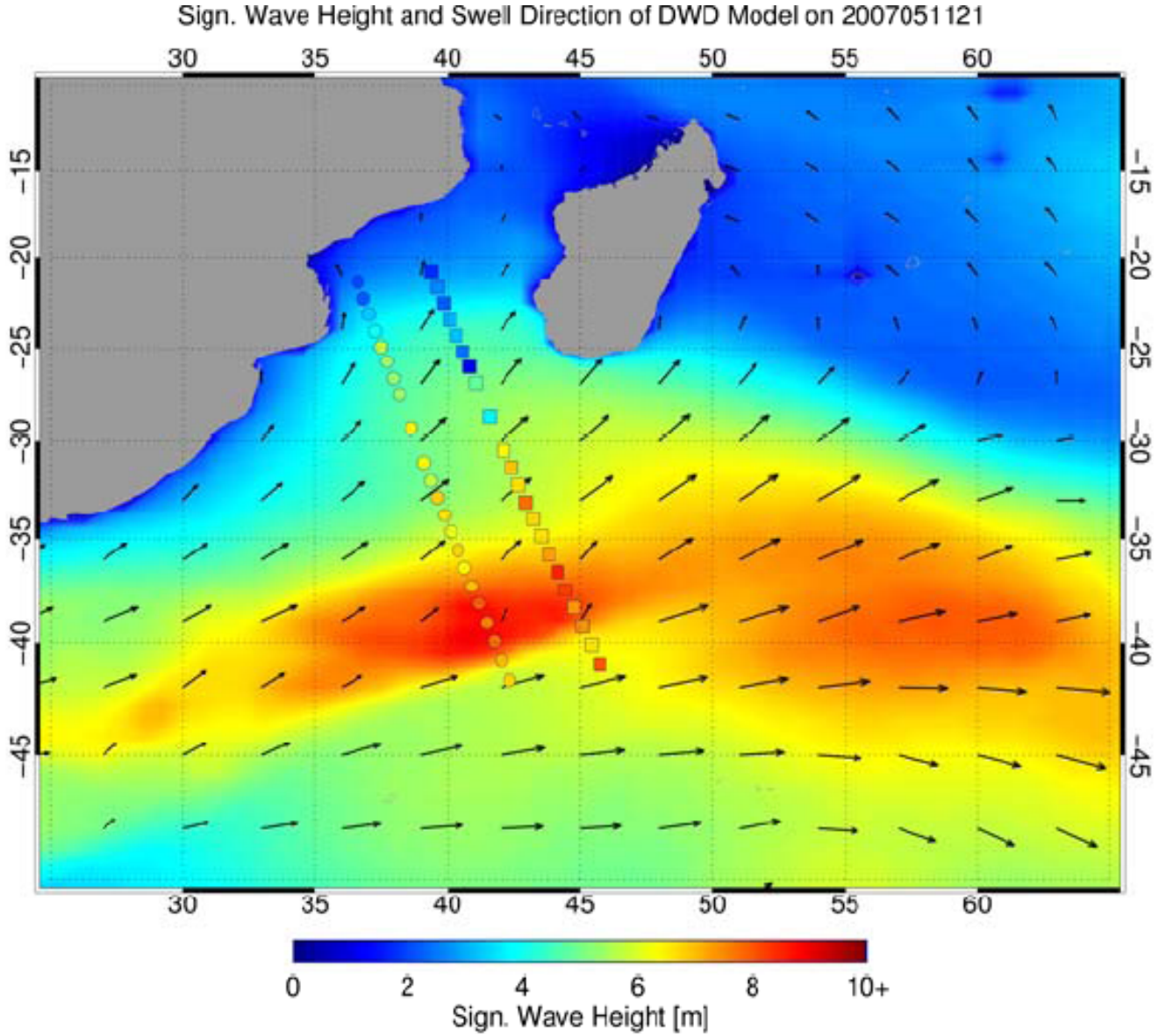


La Reunion Storm

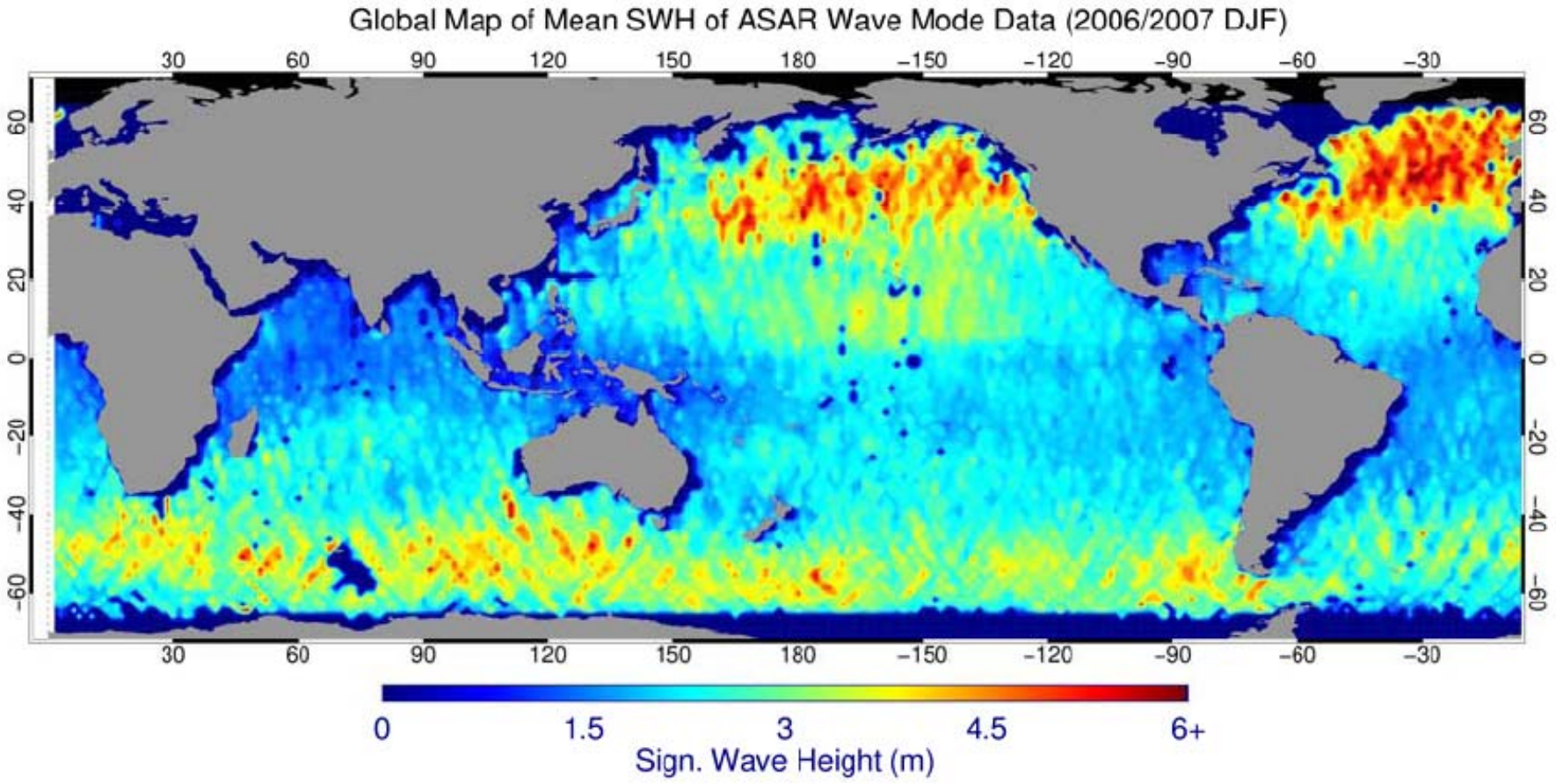




La Reunion Case

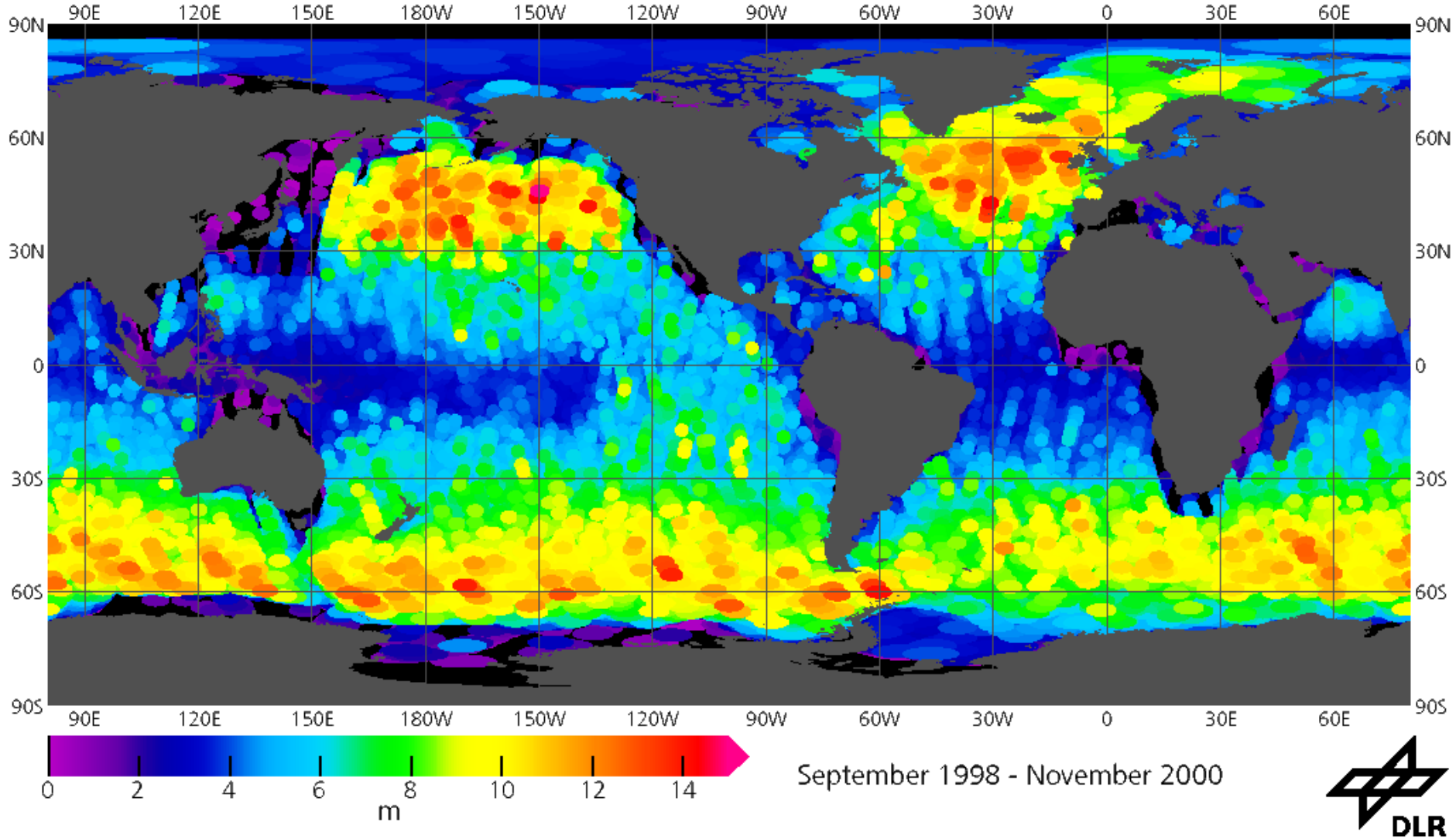


Global Statistics from ENVISAT ASAR only



X. Li, S.Lehner, Oceans 2009

Global Maximum Significant Wave Height (CWave 1.0, modified) of Imagettes in 200 km Surrounding



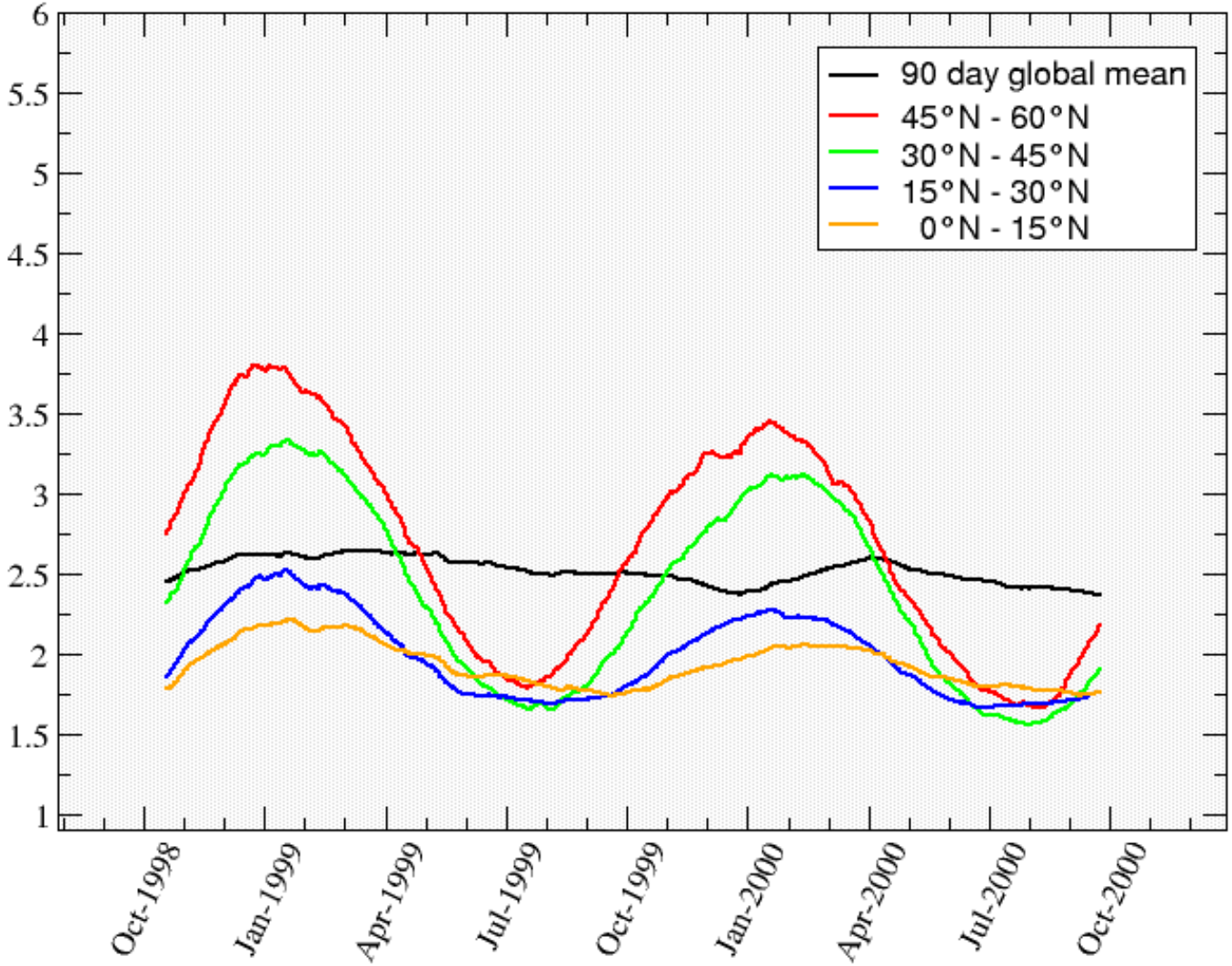
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Th König, S.Lehner, 2004

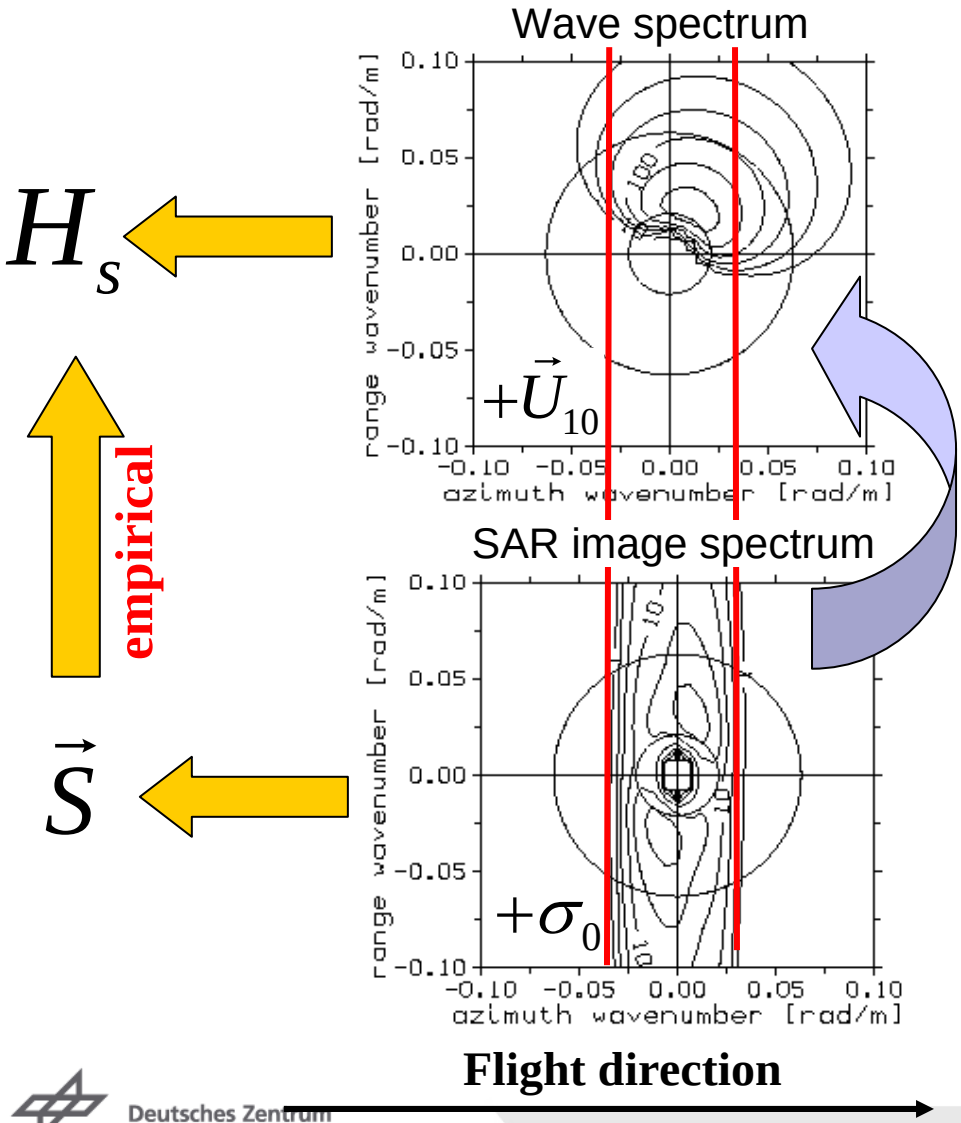
Remote Sensing Technology Institute

90-Day Zonal Mean Significant Wave Height

Northern Hemisphere



Sea State Prameters – 2D Spectra



Retrieve complete 2d wave spectrum using prior information

-MPI scheme (power spectra)

-PARSA scheme (cross spectra)

Retrieve longer waves only using minimum prior information

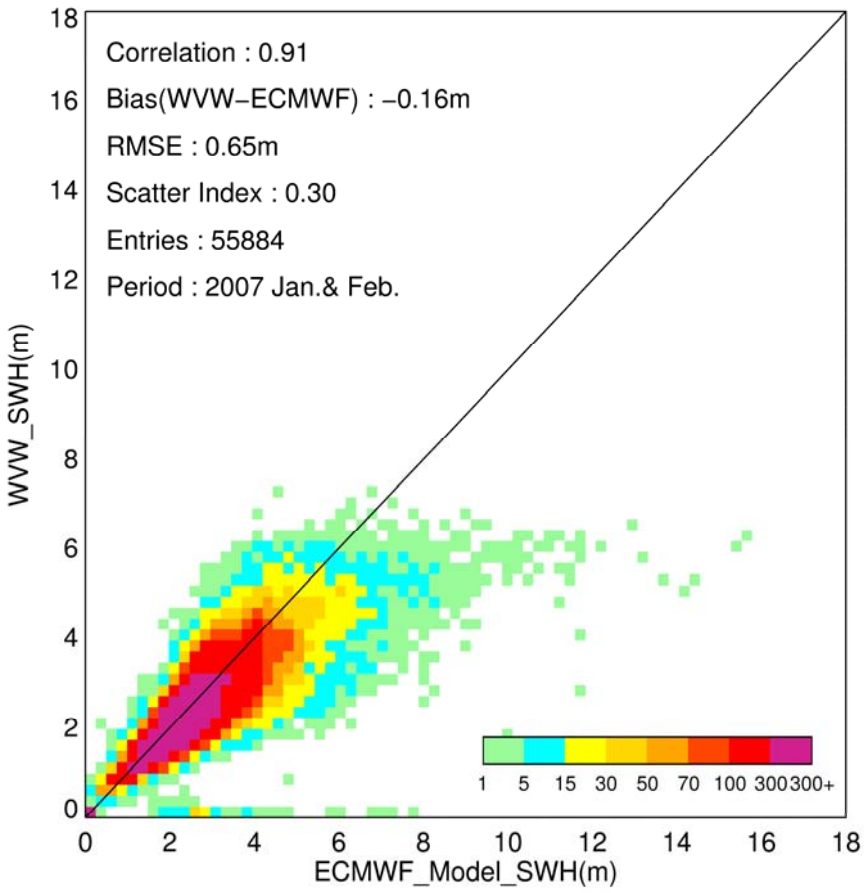
- ESA algorithm

Only integral wave parameters, no prior information

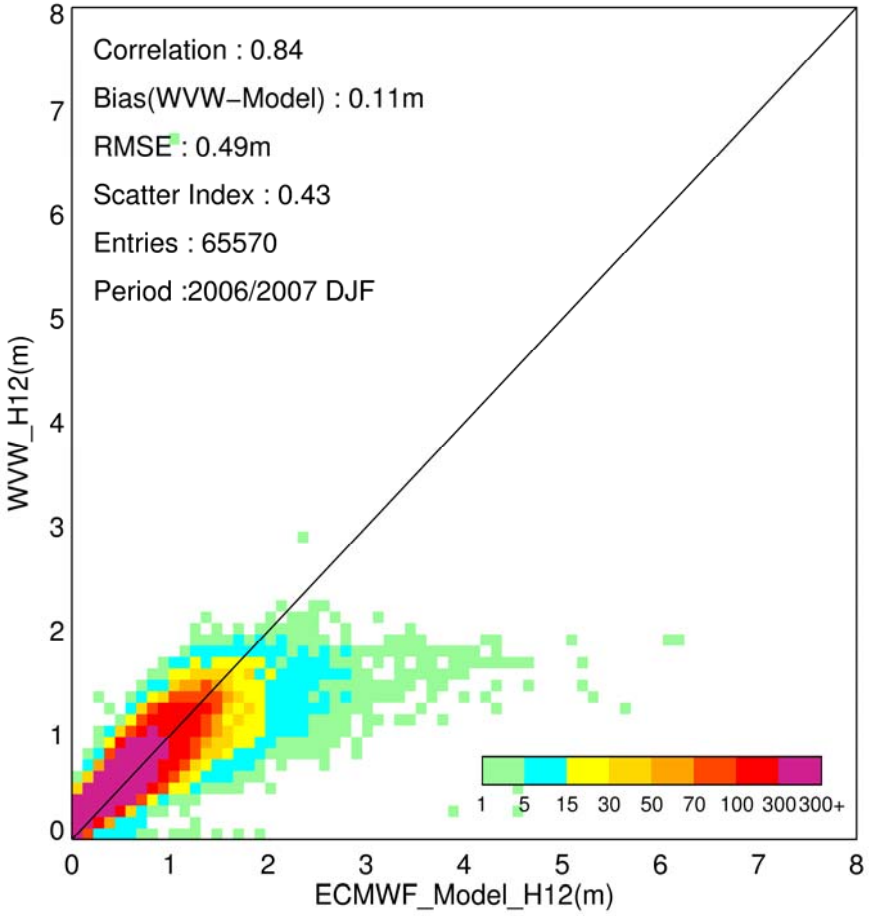
- CWAVE model

ENVISAT Level 2 Product

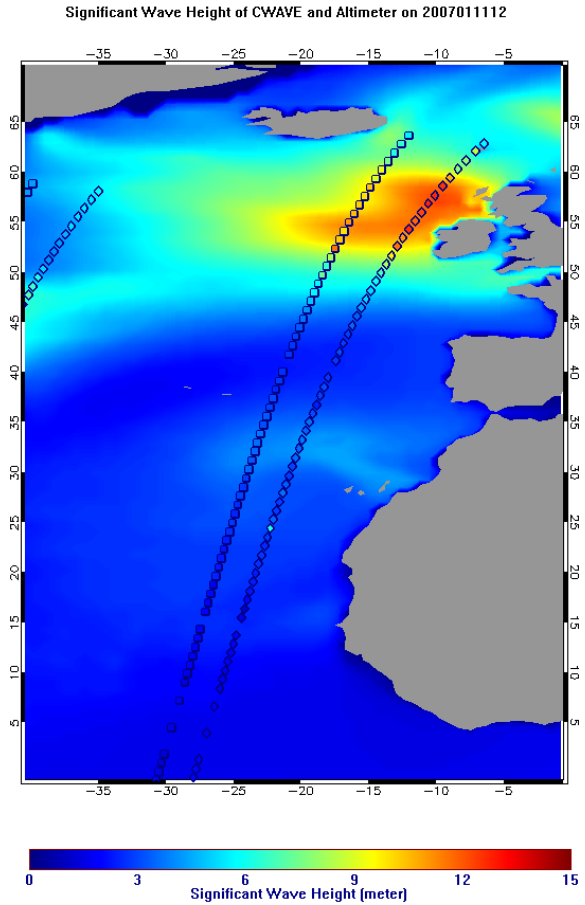
Significant wave height H_s against ECMWF



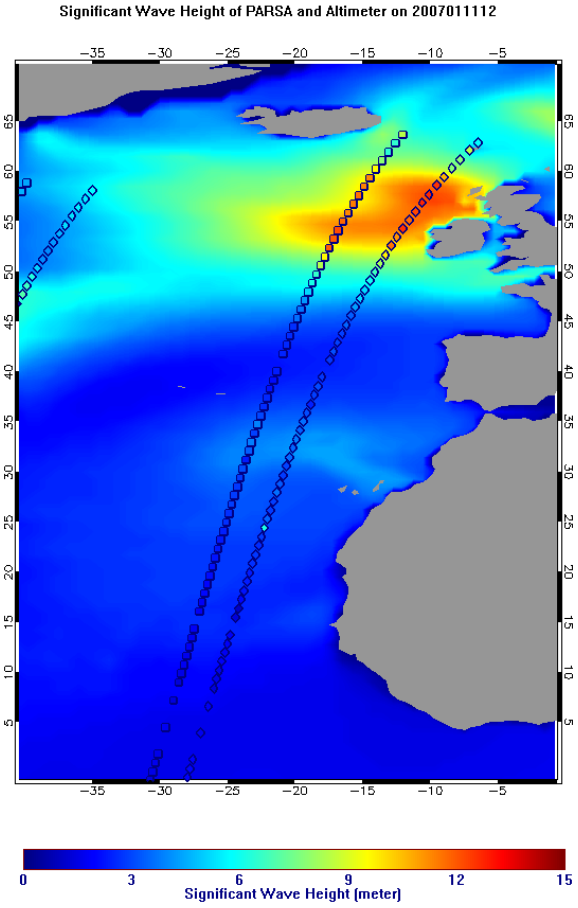
Swell wave height H_{12} against ECMWF



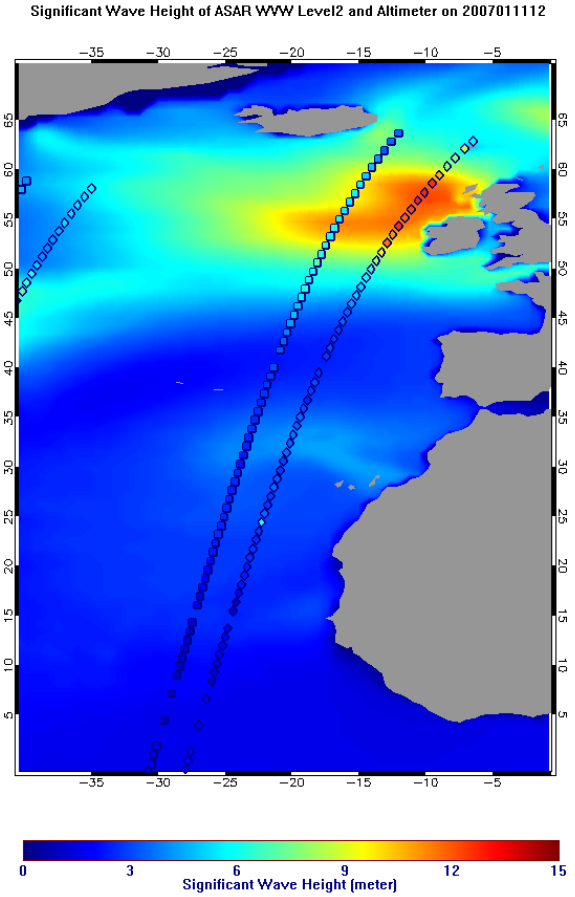
SAR and Altimeter Hs on DWD Model



CWAVE and RA-2



PARSA and RA-2

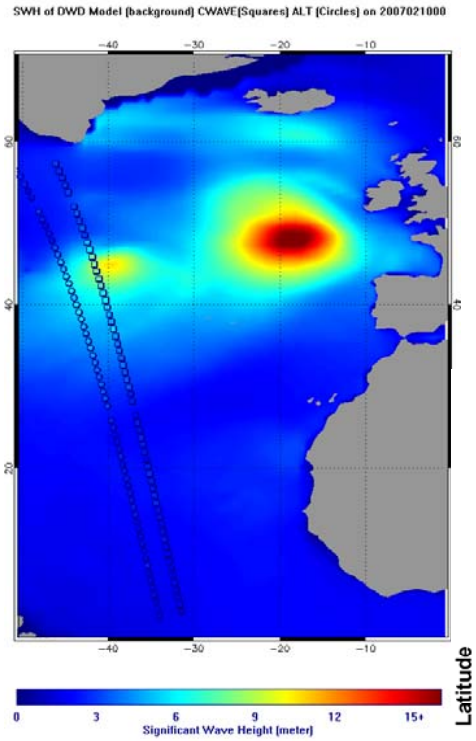


WVW and RA-2

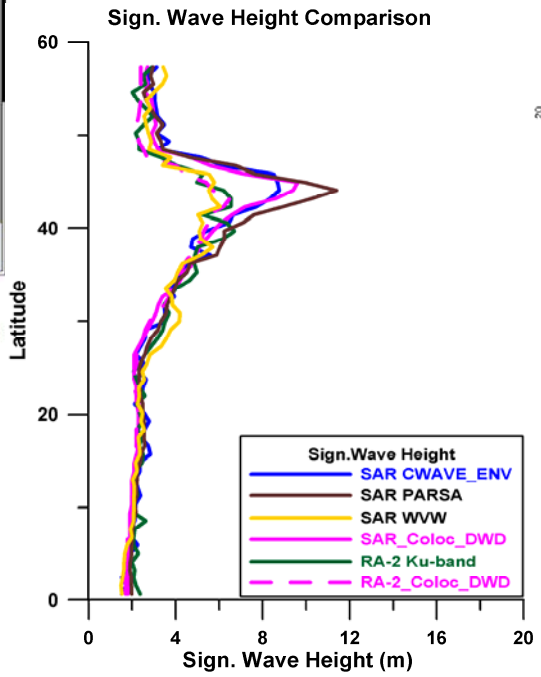
Storm on 2007 Jan. 11 UTC 12:00 at NA

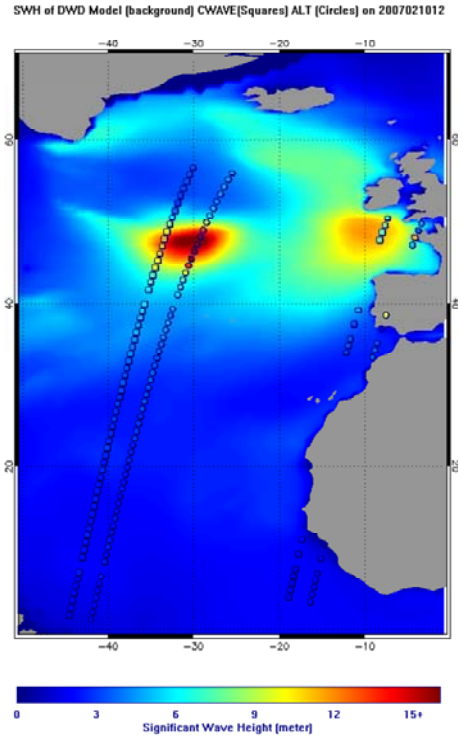
Squares : ASAR Diamonds: RA-2

ASAR + RA altimeter – double tracks for strom investigation

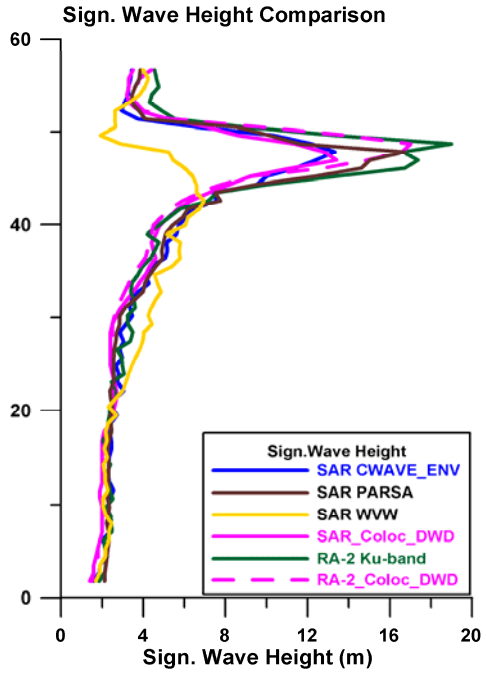


0:00 UTC





12:00 UTC



Storm on 2007 Feb. 10 at NA

Squares : ASAR Diamonds: RA-2

Conclusion and Outlook

The empirical algorithm CWAVE yields ocean wave measurements with SAR Wave Mode data without first guess information.

CWAVE results have been validated both for ERS and ENVISAT wave mode with scatter index below 24 percent against buoys for significant wave height

Long time series ERS-2/SAR and ENVISAT/ASAR wave mode data are being processed with the CWAVE algorithm. Wave mode data are available since 1991 and thus contribute to global wave climate analyses.

A two year statistical analysis has been performed on ERS data

Table 1 Statistical results of different SAR ocean wave algorithms for SWH compared to *in situ* buoy measurements and numerical wave models

	Vs. buoy			Vs. ECMWF			Vs. DWD		
Algorithm	Bias (m)	RMSE (m)	SI	Bias (m)	RMSE (m)	SI	Bias (m)	RMSE (m)	SI
PARSA	0.09	**0.64**	**0.21**	0.01	**0.25**	**0.09**	-0.01	**0.46**	**0.16**
WVW	-0.19	0.88	0.36	-0.16	0.65	0.30	-0.19	0.67	0.31

Table 2. Statistical results describing the performance of CWAVE_ENV for Hs in different sea state

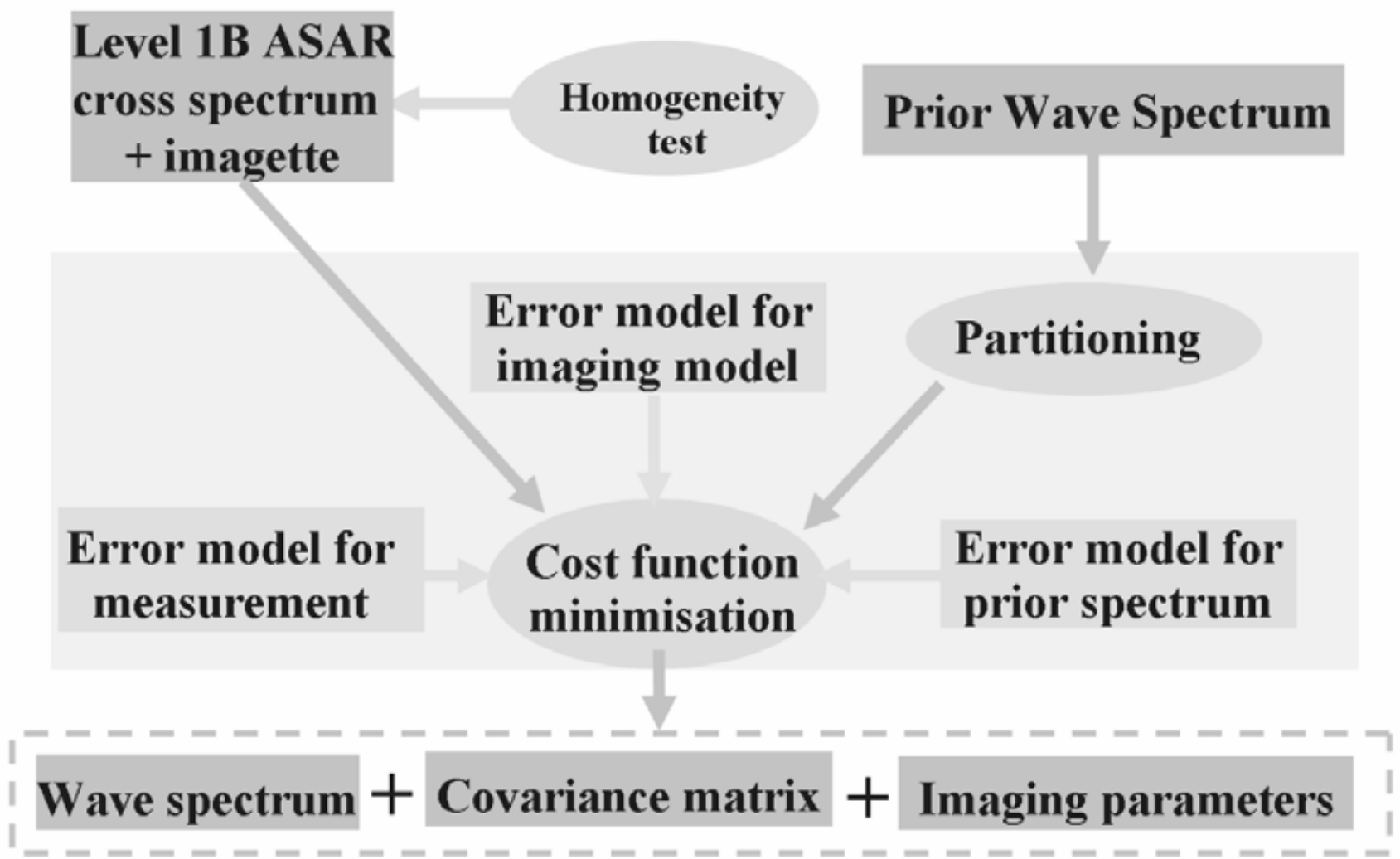
SWH (m)	Data Pairs	Bias (m)	EP (100%)	RMSE (m)	SI
(0,1.25]	170	0.45	47.6%	0.60	0.43
(1.25, 2.5]	456	0.20	10.0%	0.63	0.31
(2.5,4]	370	0.07	2.0%	0.69	0.21
(4,6]	208	-0.34	7.0%	0.77	0.14
>6	66	-0.91	12.6%	1.41	0.15

Additional Schemes using first guess, Yielding 2 D wave spectra

- At DLR PARSA scheme available, implemented at UK Met Office
- Should be used at weather centers, where first guess is available
- Improve the model, but depend at the present stage on the first guess
- Validated in the OSIRIS project

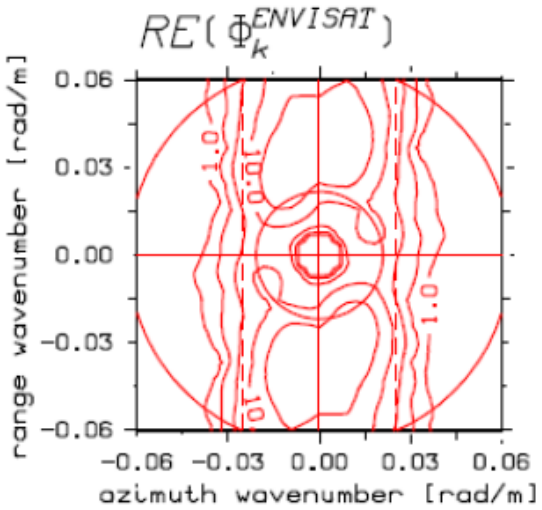
In preparation: first guess from SAR image itself

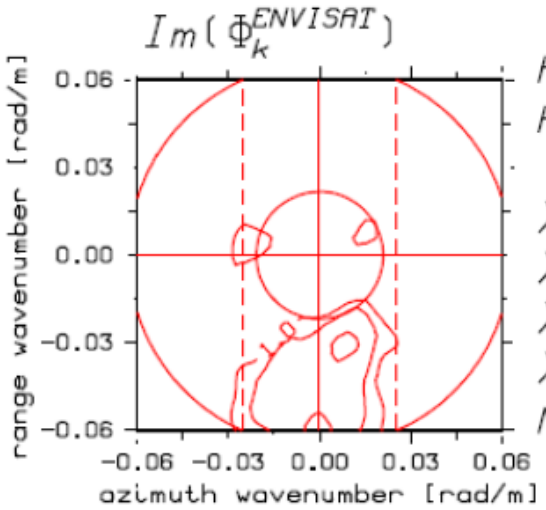
Block Diagram of PARSA Scheme



Schulz-Stellenfleth, Hoja, Lehner, JGR, 2005

Parsa Example, Part 1

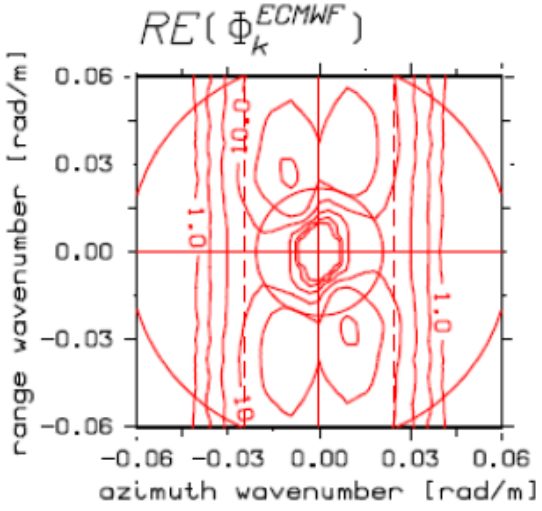


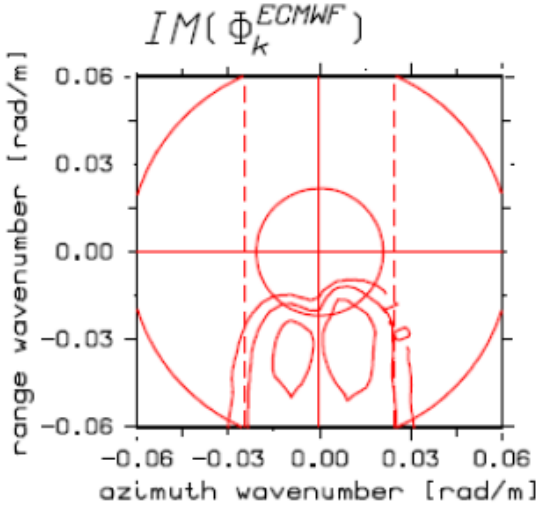


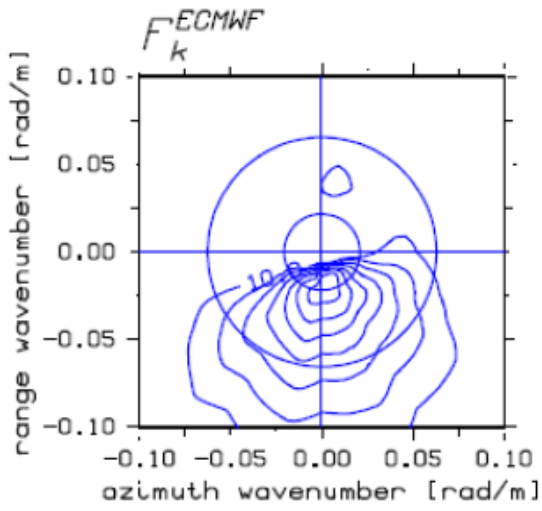
H_s^{PARSA} [m]: 3.62
H_s^{ECMWF} [m]: 4.57

10.1

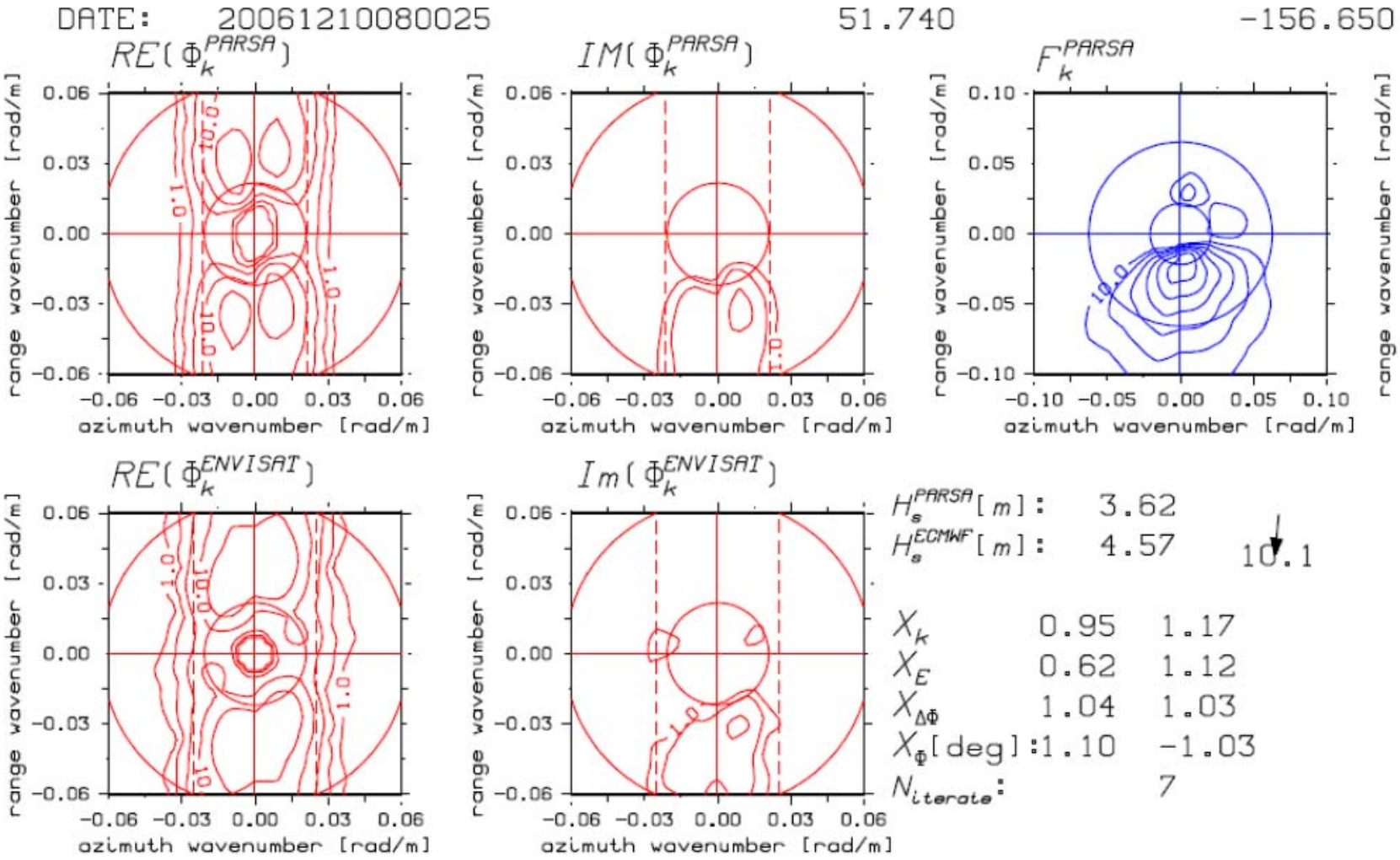
X_k	0.95	1.17
X_E	0.62	1.12
$X_{\Delta\Phi}$	1.04	1.03
X_Φ [deg]:	1.10	−1.03
$N_{iterate}$:		7



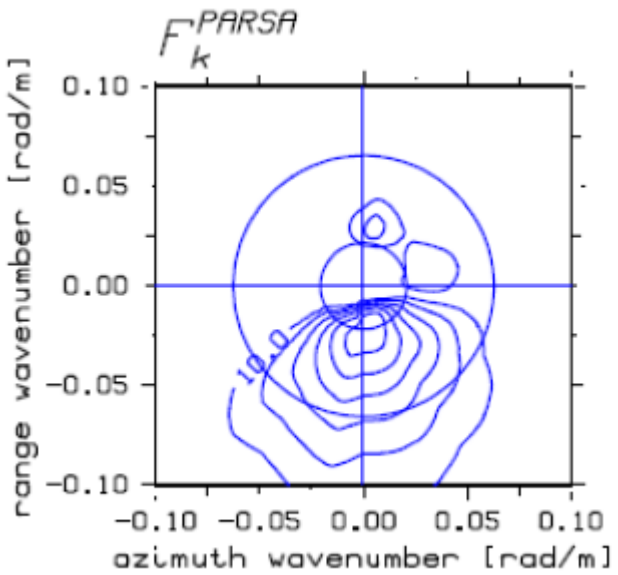


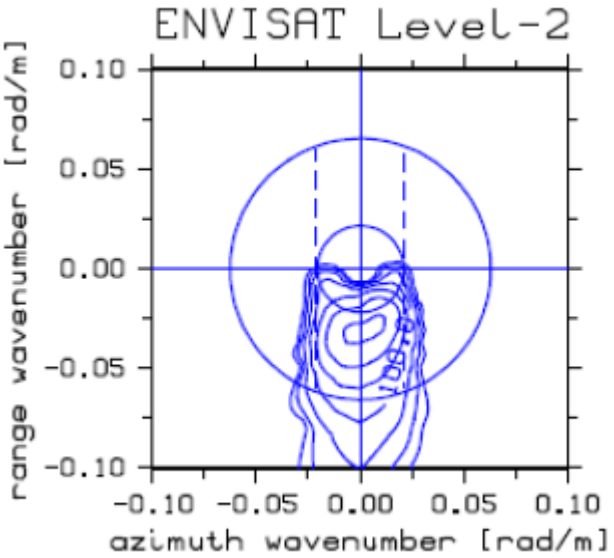


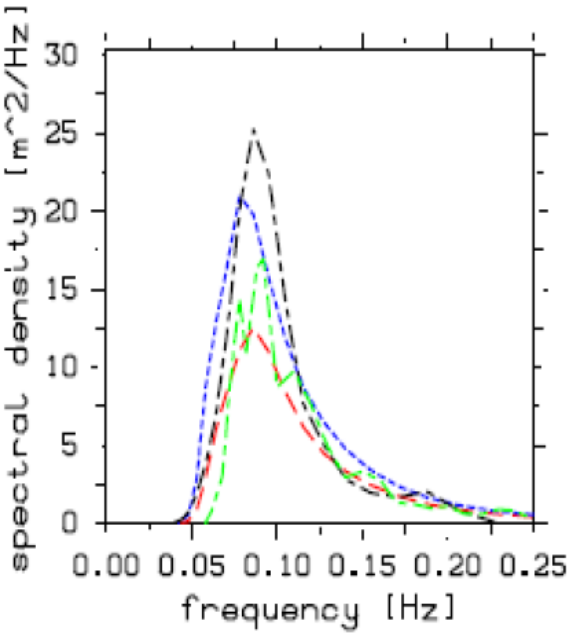
Parsa Example, Part 2



Parsa Example, Part 3







H_s^{PARSA} [m]: 3.62
H_s^{ECMWF} [m]: 4.57

H_s^{L2} 4.37
H_s^{BUOY} 3.70

RED: PARSA
BLUE: WAM
BLACK: L2
GREEN: BUOY

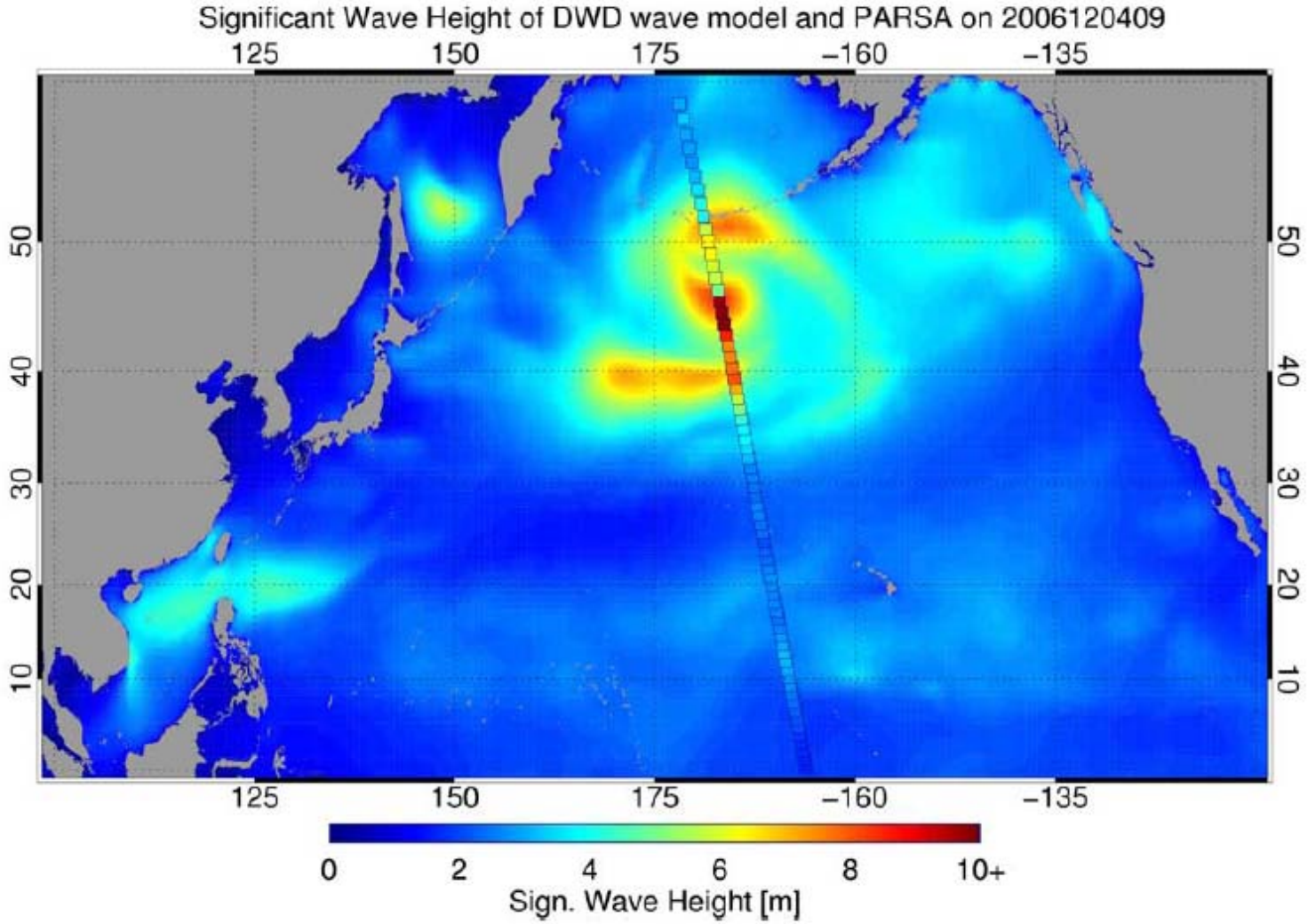


Figure 4. SWH of DWD forecast wave model on Dec.4th, 2006 at 09: 00 UTC superimposed with SWH derived from ASAR wave mode data by the PARSA scheme

Algorithms and Examples published in:

- Lehner, S., Schulz-Stellenfleth, J., Schättler, J. B., Breit, H., and Horstmann, J. (2000): Wind and wave measurements using complex ERS-2 wave mode data. *IEEE Trans. Geosci., and Rem. Sens.*, **38**, 2246-2257.
- Schulz-Stellenfleth, J., S. Lehner and D. Hoja (2005): A parametric scheme for the retrieval of two-dimensional ocean wave spectra from synthetic aperture radar look cross spectra, *J. Geophys. Res.*, 110, doi: 10.1029/2004JC002822.
- Schulz-Stellenfleth, J., Th. Koenig and S. Lehner, An Empirical Approach for the Retrieval of Integral Ocean Wave Parameters from Synthetic Aperture Radar Data, J.Geophys. Res., vol. 112, doi:10.1029/2006JC003970,2007
- Lehner, S., J.Schulz-Stellenfleth, Th. König, X. Li, Sea State Statitics observed by satellite, Proceed. Of the OMAE 2008, June 2008, Estoril Portugal, 2008
- Li, X.-M., Lehner, S., M.-X.HE, (2008) :Ocean wave measurements based on satellite synthetic aperture radar (SAR) and numerical wave model (WAM) data - extreme sea state and cross sea analysis, *Int. J. Remote Sensing*, 29 (21), 6403 - 6416, doi: 10.1080/01431160802175546.
- Li, X.-M.,S. Lehner and Th. Bruns, Ocean Wave Integral Parameter Measurements Using ENVISAT ASAR Wave Mode Data, under submission, 2009