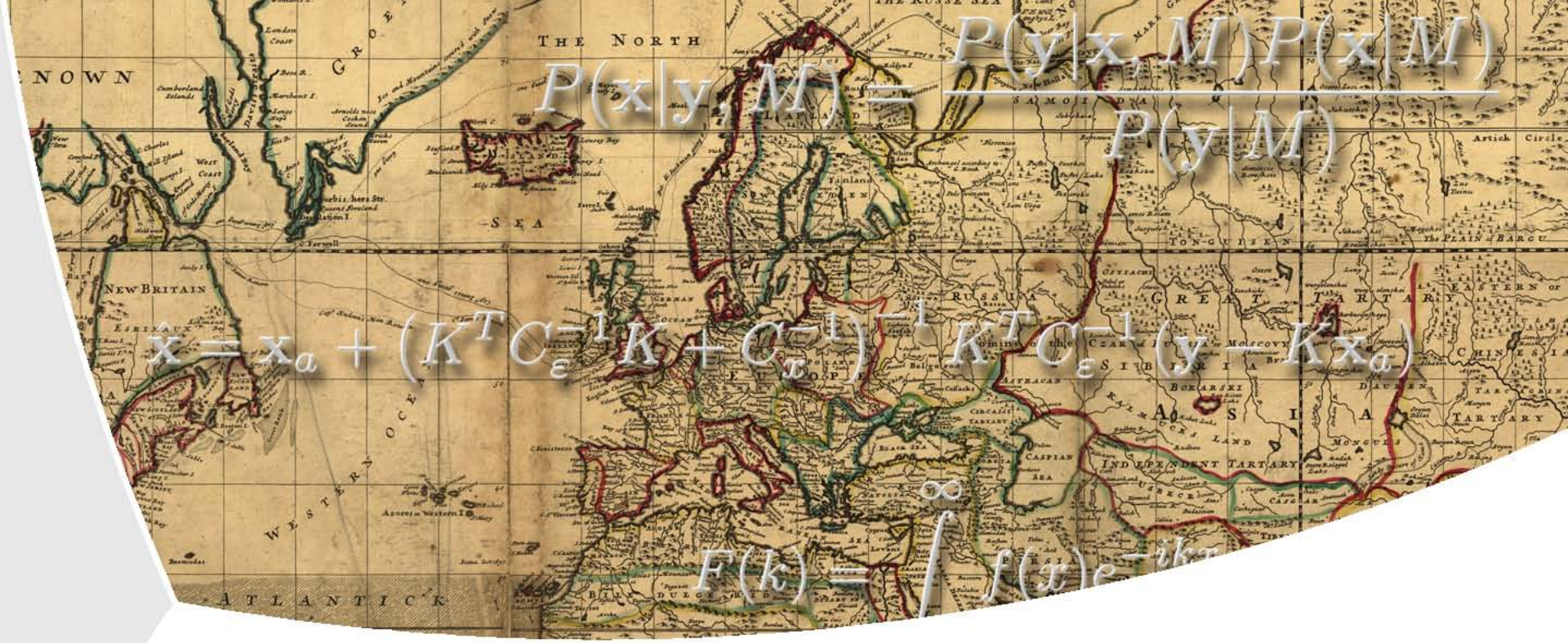


Extraction of Wind and Wave Field from SAR data

S. Lehner, X. Li, Th. Bruns, W. Rosenthal

German Aerospace Center (DLR), Oberpfaffenhofen

Motivation

➢Derive integrated Wave Parameters (e.g. SWH, mean period) from satellite SAR data by an empirical algorithm without using a first guess: CWAVE (= make the SAR to measure like an altimeter on a parallel track)

➢ Thus develop global data set of SWH and mean period for assimilation into models and global statistics (altimeter and SAR, available since 1991)

➢ Derive 2D Spectrum from SAR using model first guess

➢ Observation of coastal wave variations using high resolution TerraSAR data

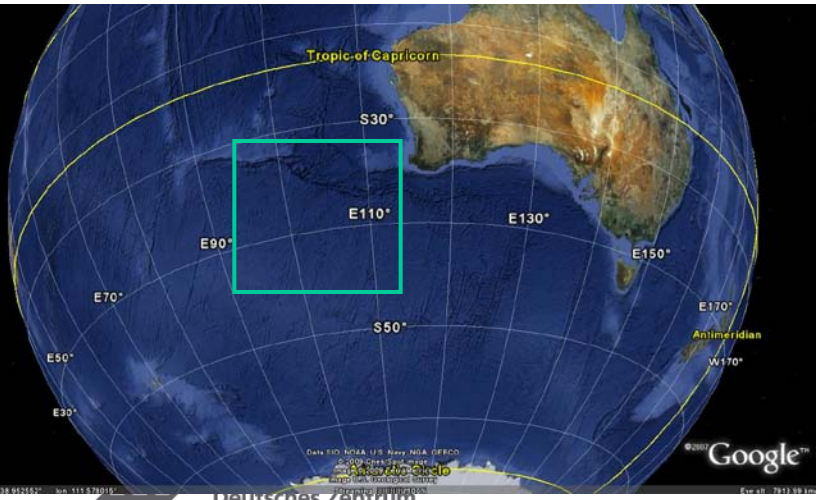
➢ Validation of TSX image spectra to measurements of marine radar and model data

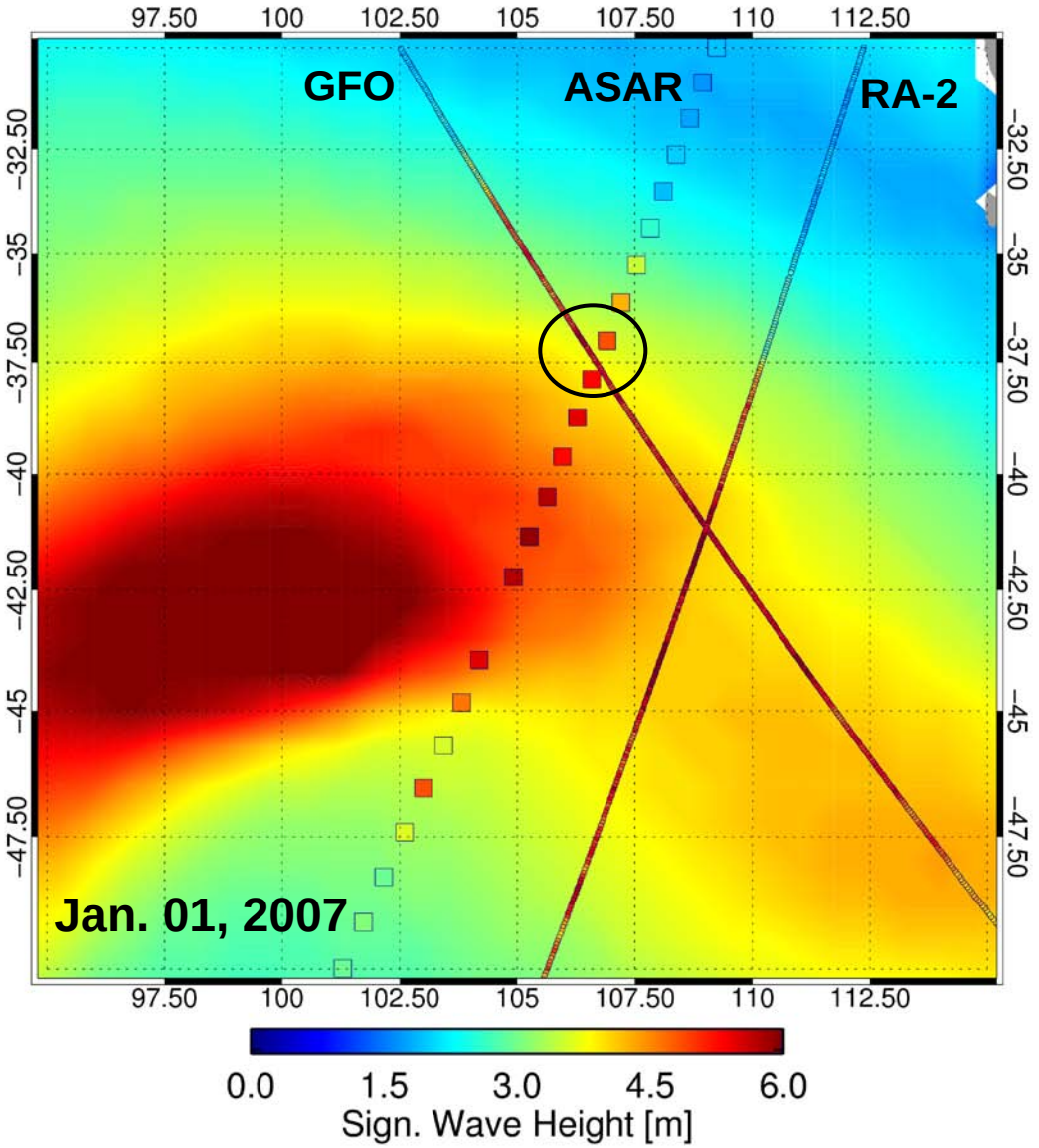
Motivation example:

Sea State Measurements in Storms

SAR vs. Radar Altimeter cross over measurements On DWD model

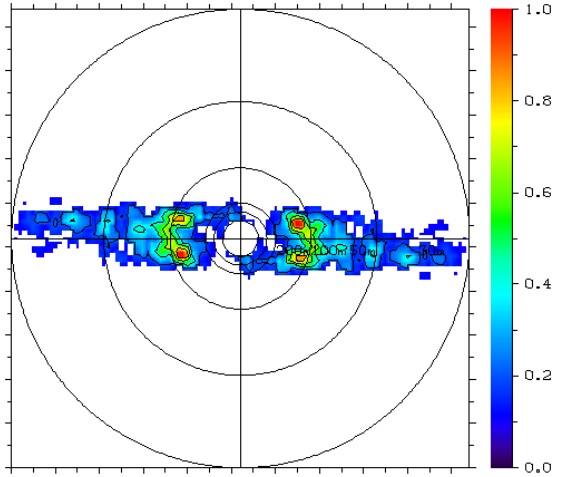
DWD model is not assimilated With RA information.

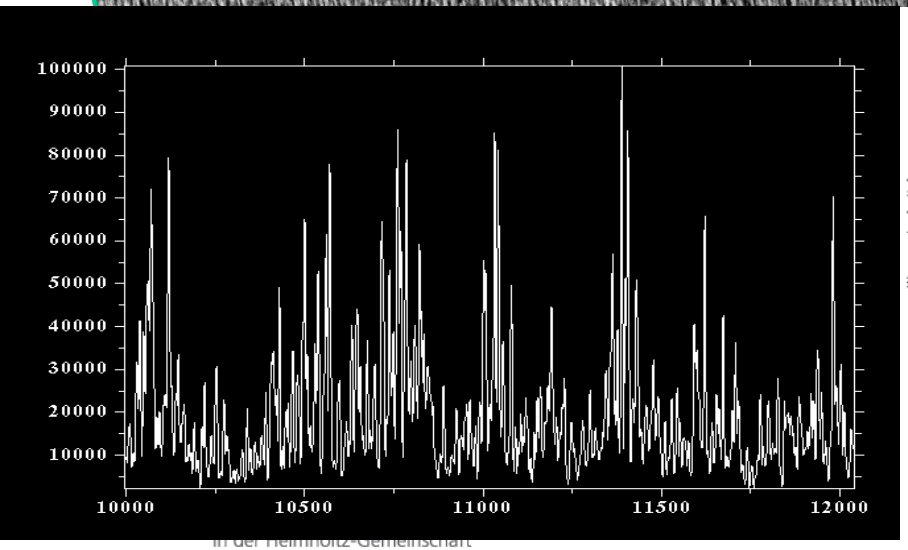


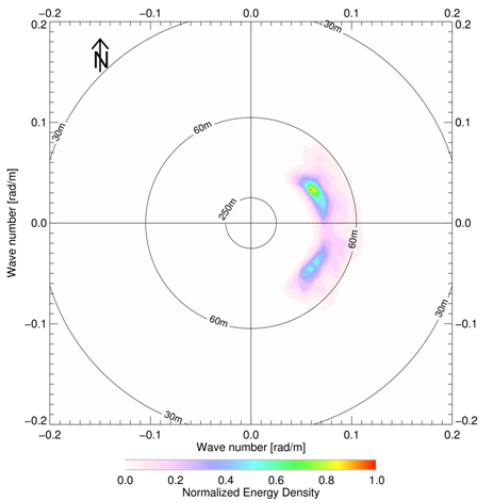


TSX Spotlight mode image acquired on May 15, 2009 at 17:19 UTC over Ekofisk oil platform

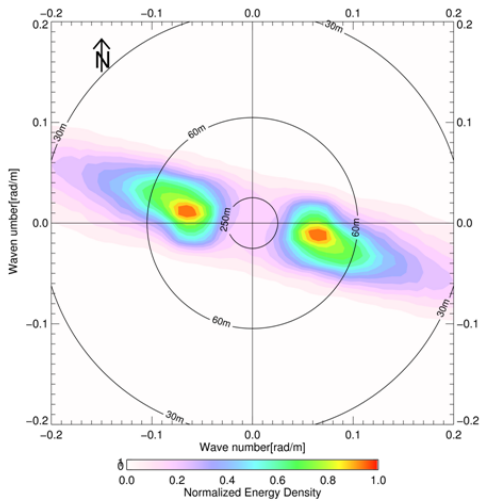
	Hs(m)	Tp(s)	Dir(°)
WaMoS	3.8	8.1	87
TSX	3.8	8.5	60







WaMoS spectrum



TSX image spectrum

Methodology

- **Derive sets of parameters from SAR images (e.g. mean intensity, spectral parameters)**

- **use SAR parameters in an empirical algorithm tuned by sea state parameters from ECMWF model : CWAVE (named analog to CMOD for wind speed)**

- **Cross validate SAR, altimeter and buoy sea state measurements with models**

- **Derive 2D Spectrum from SAR using model first guess – use cross spectrum and inversion algorithm**

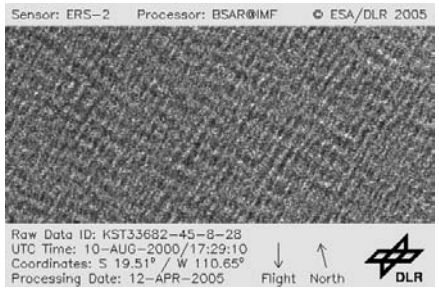
- **Validation of TSX image spectra to measurements of marine radar and model data**

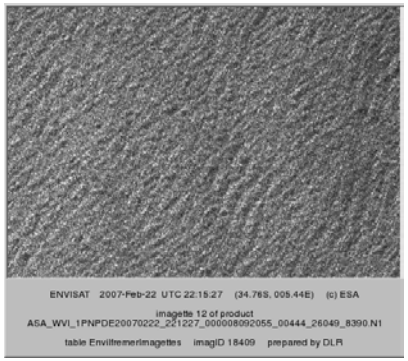
Empirical Algorithm ---CWAVE

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

22 Image and spectral parameters

$$s_1, \ldots, s_N$$

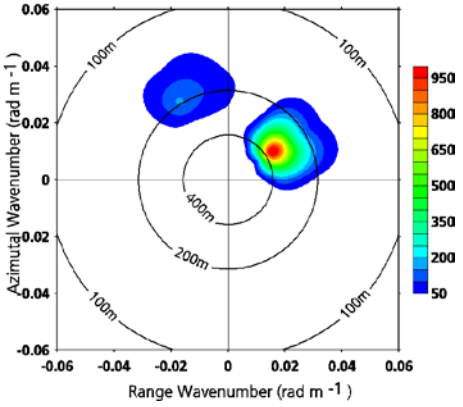




Since 1991

Since 2002

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



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

J. Schulz-Stellenfleth, Th, König, S.Lehner, JGR, 2007
X. Li, S. Lehner, Th. Bruns , JGR 2009

Conclusions (1)

- The empirical algorithm **CWAVE_ENV** yields ocean wave measurements with ASAR wave mode d without first guess information. Accuracy of retrieved SWH using CWAVE_ENV algorithm has the quality of the RA measurements and is near to in situ buoy measurements.

	vs. Buoy				vs. ECMWF model				vs. DWD model				vs. Radar Altimeter			
Statistical Para.	Cor.	Bias	RMSE	SI	Cor.	Bias	RMSE	SI	Cor.	Bias	RMSE	SI	Cor.	Bias	RMSE	SI
SWH	0.90	0.06	0.70	24%	0.93	-0.02	0.43	16%	0.90	-0.05	0.51	18%	0.93	-0.11	0.51	13%

- The empirical algorithm **CWAVE_ENV** also can yield accurate mean wave period measurements.

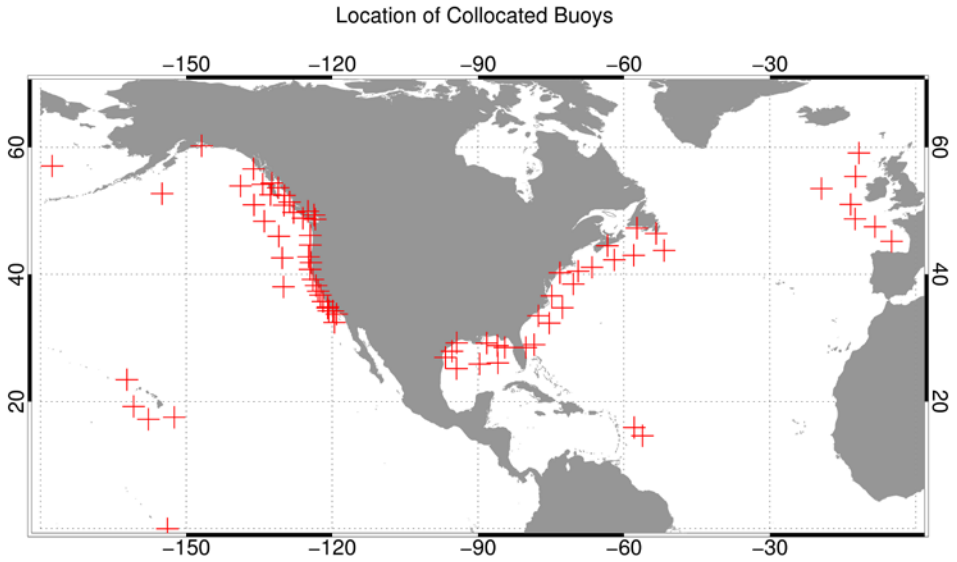
	vs. ECMWF model			
Statistical Para.	Cor.	Bias	RMSE	SI
$\mathbf{T_{m02}}$	0.87	-0.05 s	0.60 s	0.08
$\mathbf{T_{m-10}}$	0.85	-0.06 s	0.74 s	0.08

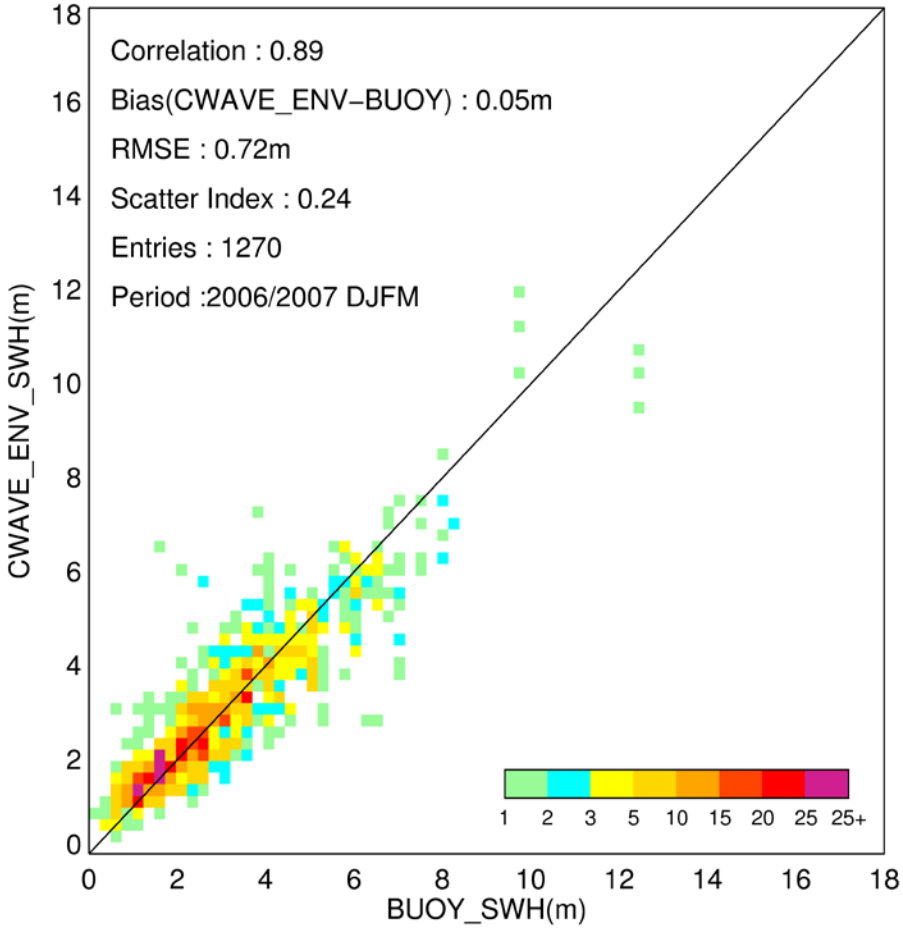
- Using the algorithm **CWAVE_ENV,** ASAR WM data can be used for global wave statistical analys the sampling issue needs to be considered.

From X. Li, S. Lehner, Th. Bruns

Validation and intercomparison of CWAVE_ENV

CWAVE_ENV vs. Buoy





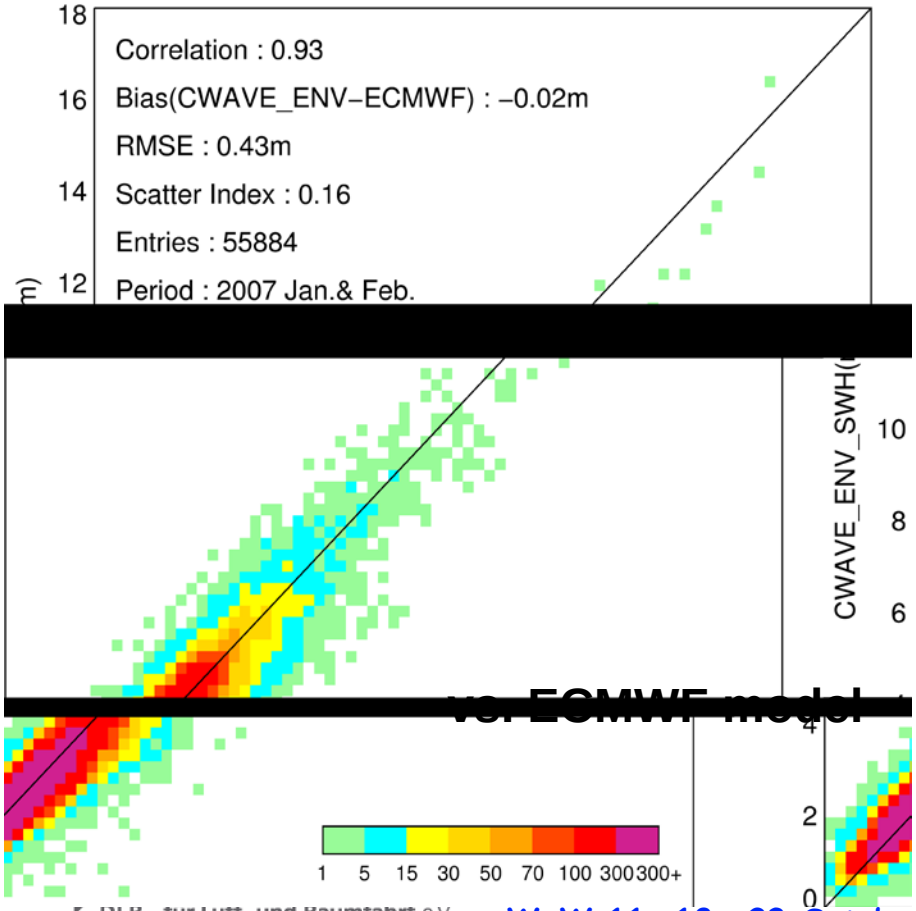
$$bias = \overline{Y_i} - \overline{X_i}$$

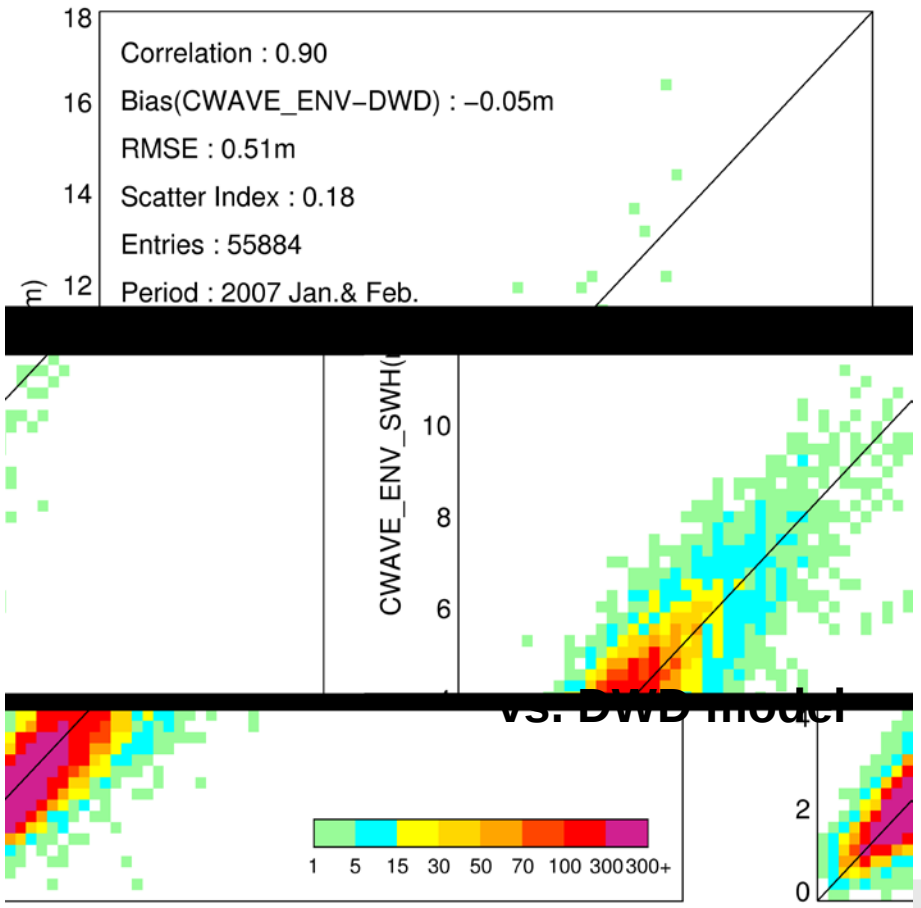
$$rmse = \sqrt{\frac{\sum (Y_i - X_i)^2}{n}}$$

$$SI = \frac{1}{\overline{X_i}} \sqrt{\frac{1}{n} \sum \left[\left(Y_i - \overline{Y_i} \right) - \left(X_i - \overline{X_i} \right) \right]^2}$$

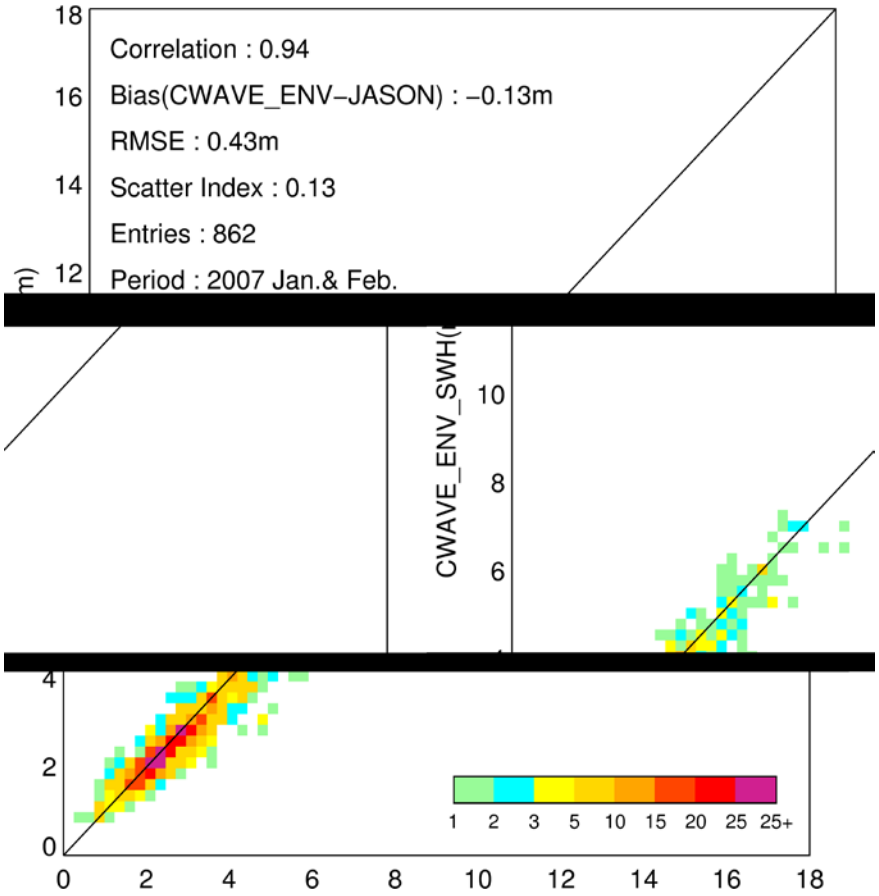
vs. ECMWF_WAM – reanalyzed, DWD_WAM -- forecast

- temporal resolution : ECMWF model : **6 hours** ; DWD model : **3 hours**
- spatial resolution: ECMWF model: **0.5 degree** ; DWD model : **0.75 degree**

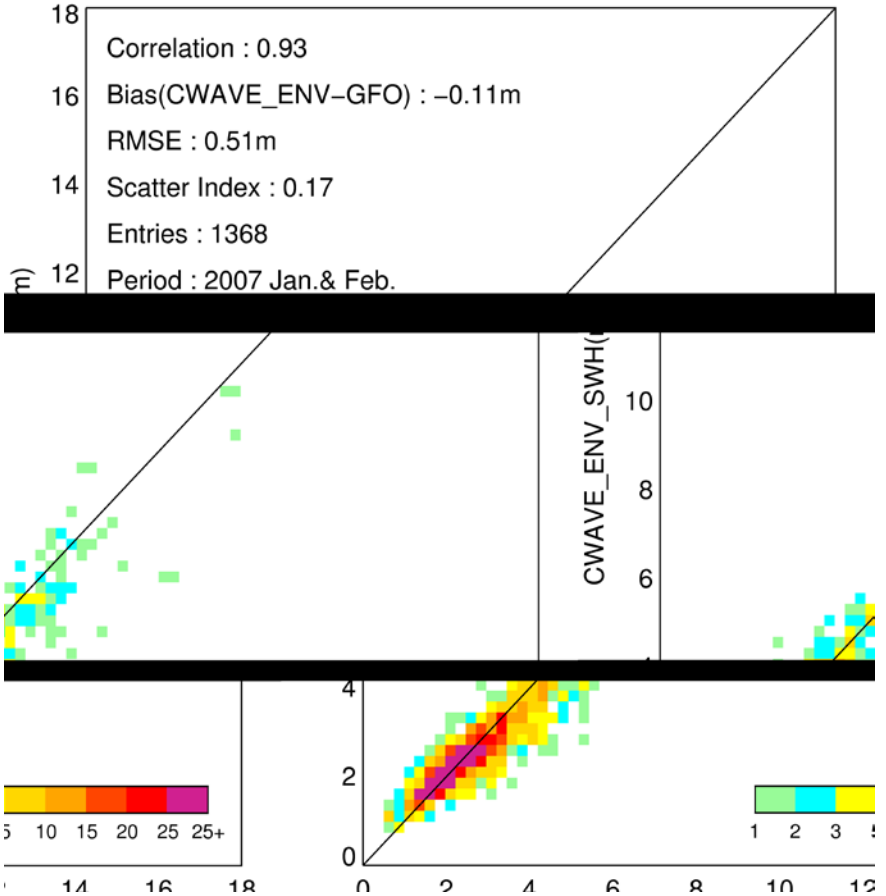




Crossover with altimeters

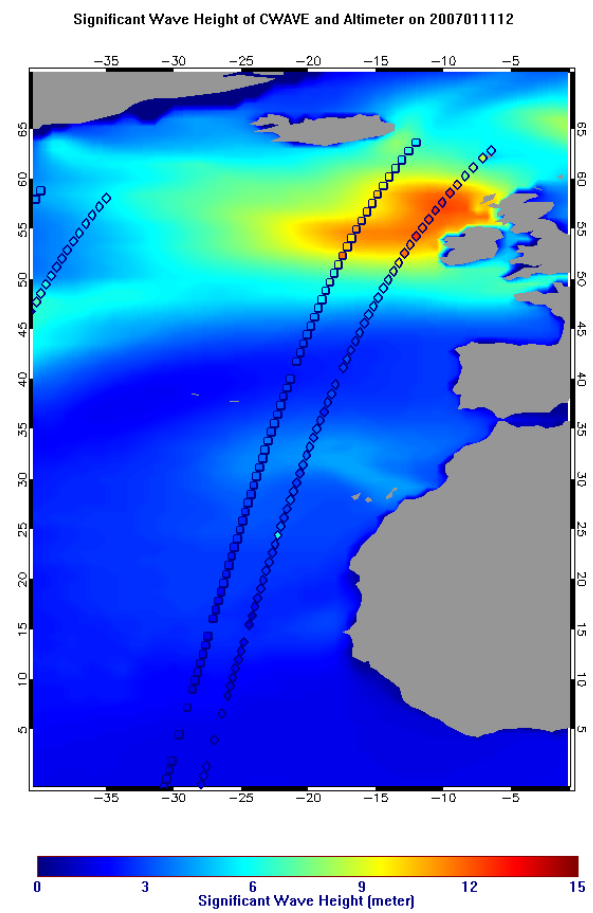


RA: JASON

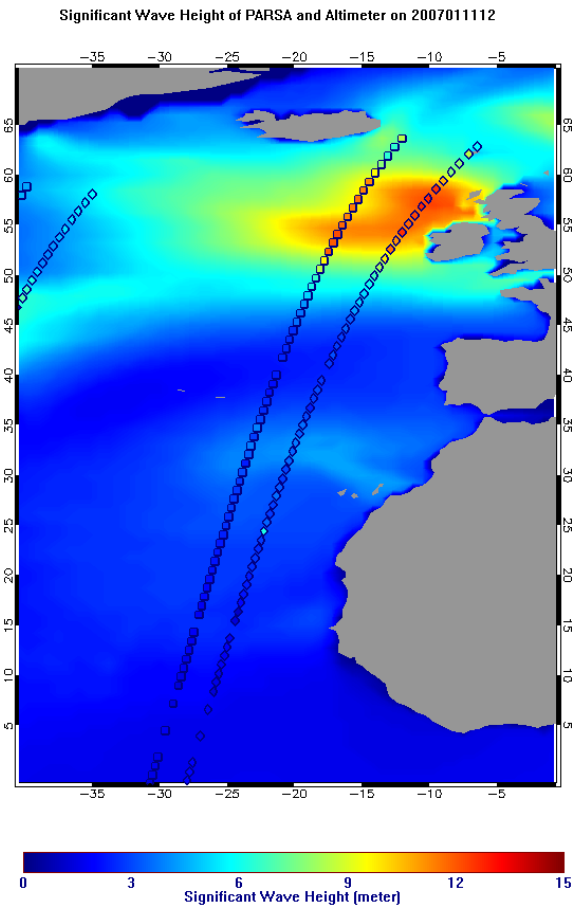


RA: GFO

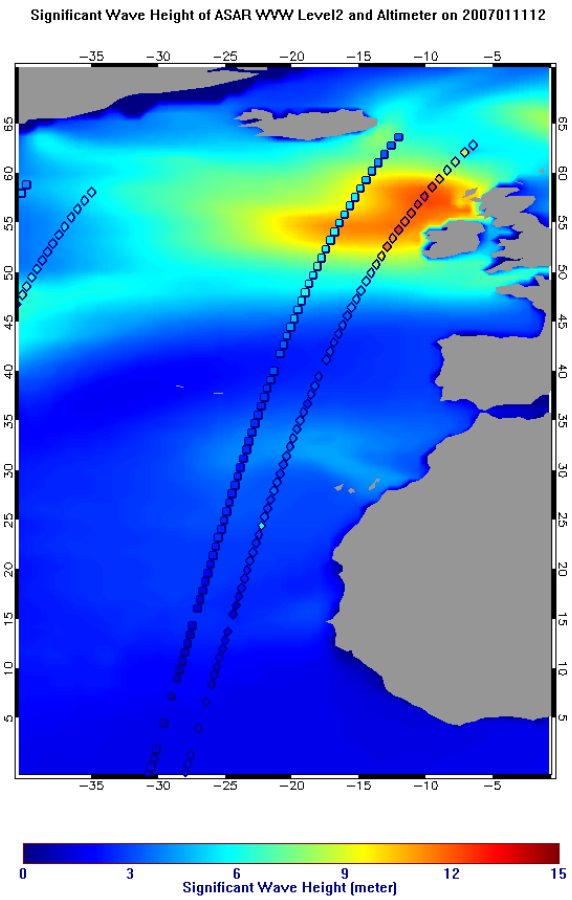
SAR and Altimeter Hs on DWD Model



CWAVE and RA-2



PARSA and RA-2



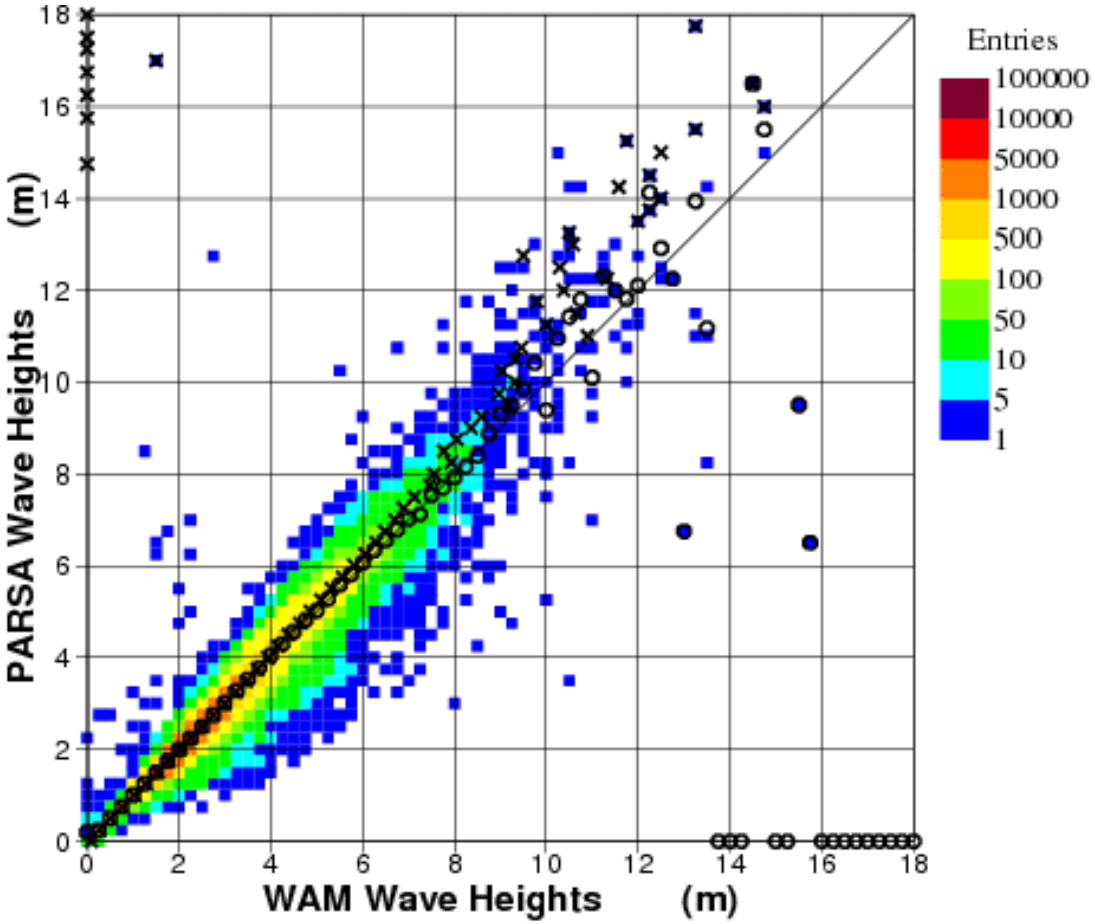
WVW and RA-2

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

W+W 11 -18 -23 October Halifax

Squares : ASAR Diamonds: RA-2

Global Significant Wave Height from PARSA (first guess

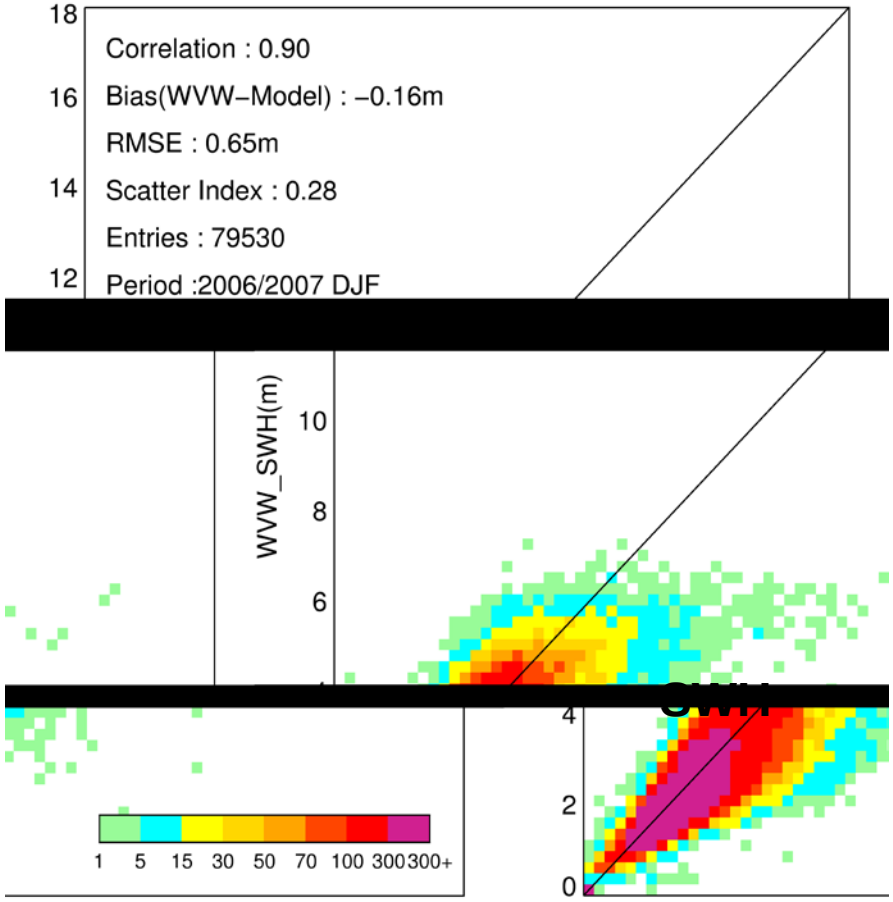


STATISTICS	
ENTRIES	115618
MEAN WAM	2.6298
MEAN PARSA	2.6394
BIAS (PARSA - WAM)	0.0096
STANDARD DEVIATION	0.2694
SCATTER INDEX	0.1024
CORRELATION	0.9792
SYMMETRIC SLOPE	1.0098
REGR. COEFFICIENT	1.0137
REGR. CONSTANT	-0.0266

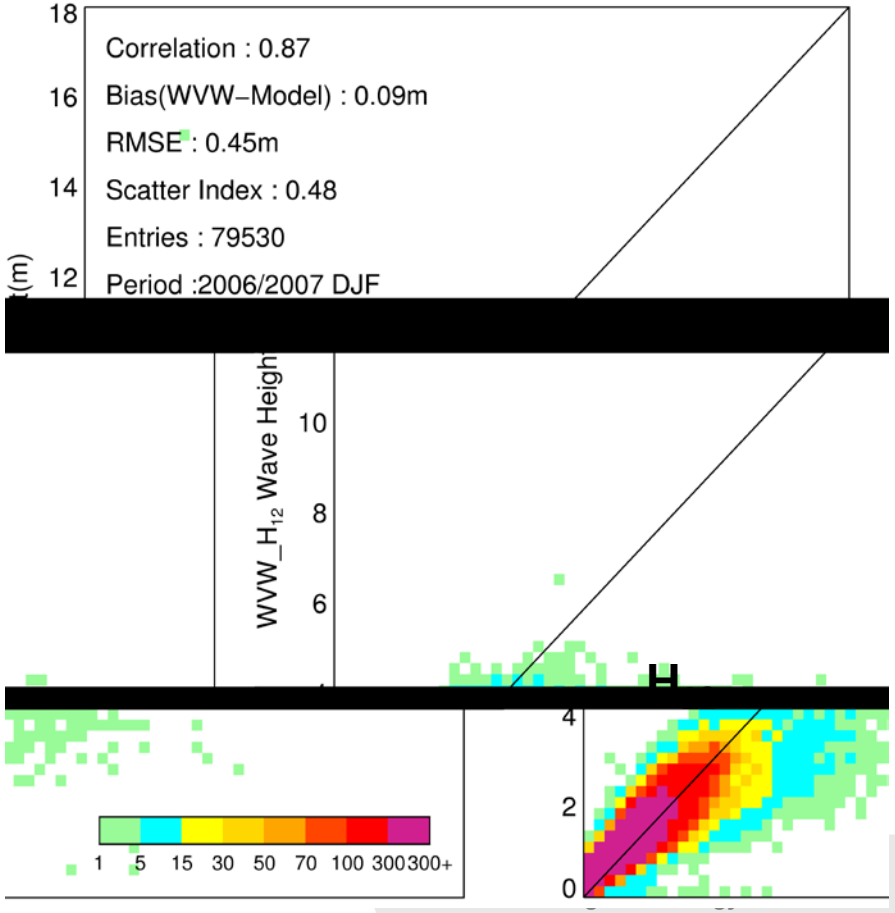
Figure 1. Comparison between ASAR-PARSA and ECMWF WAM Significant Wave Heights (Global)

From S. Abdallah

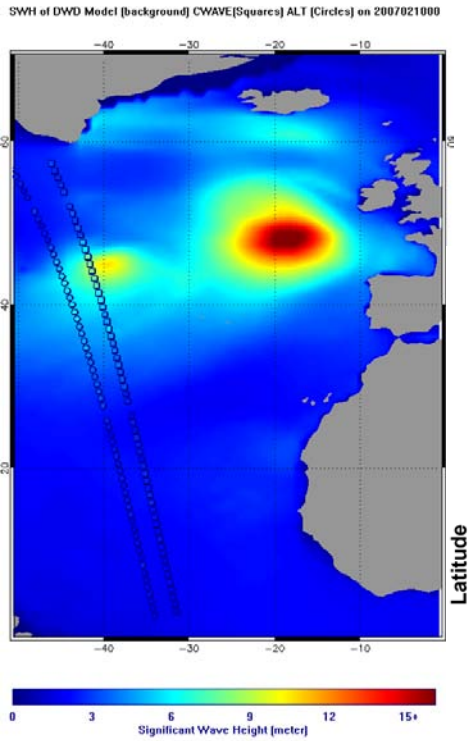
ENVISAT ASAR Level2 Product (WVW)



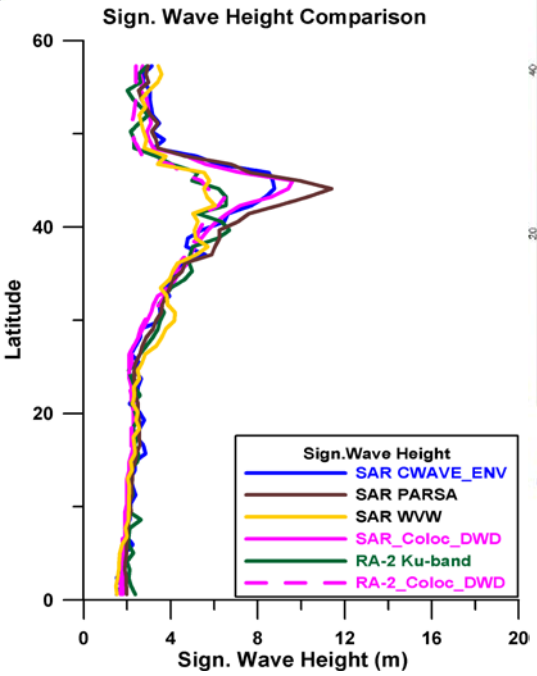
$$H_{12} = 4\sqrt{\int_{f<1/12s} E(f,\theta)\,df d\theta}$$

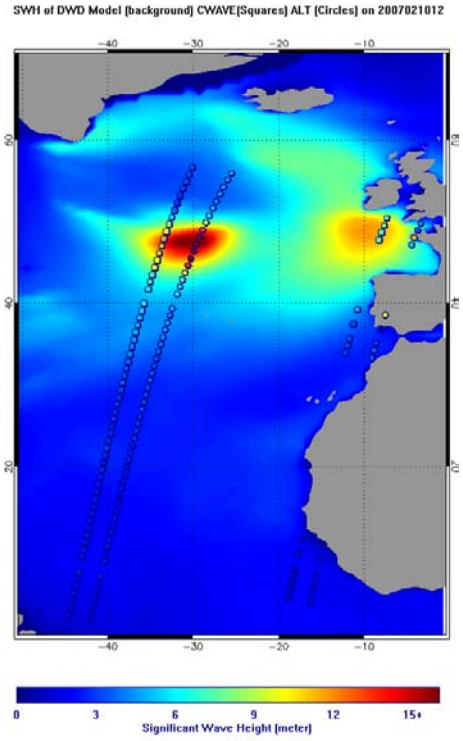


ASAR + RA altimeter – double tracks for strom investigation

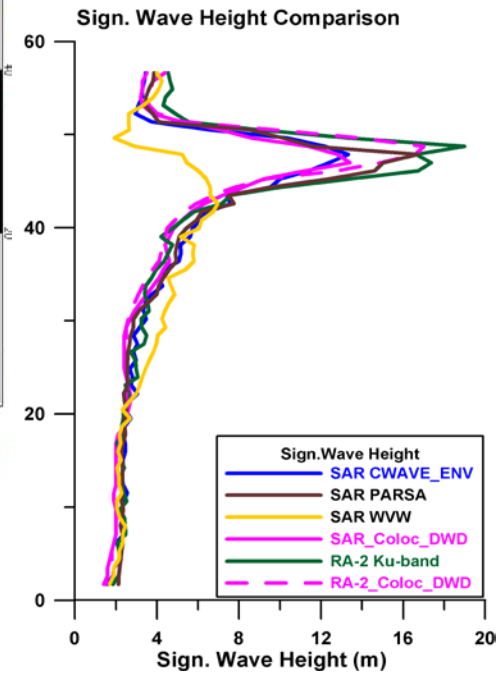


0:00 UTC





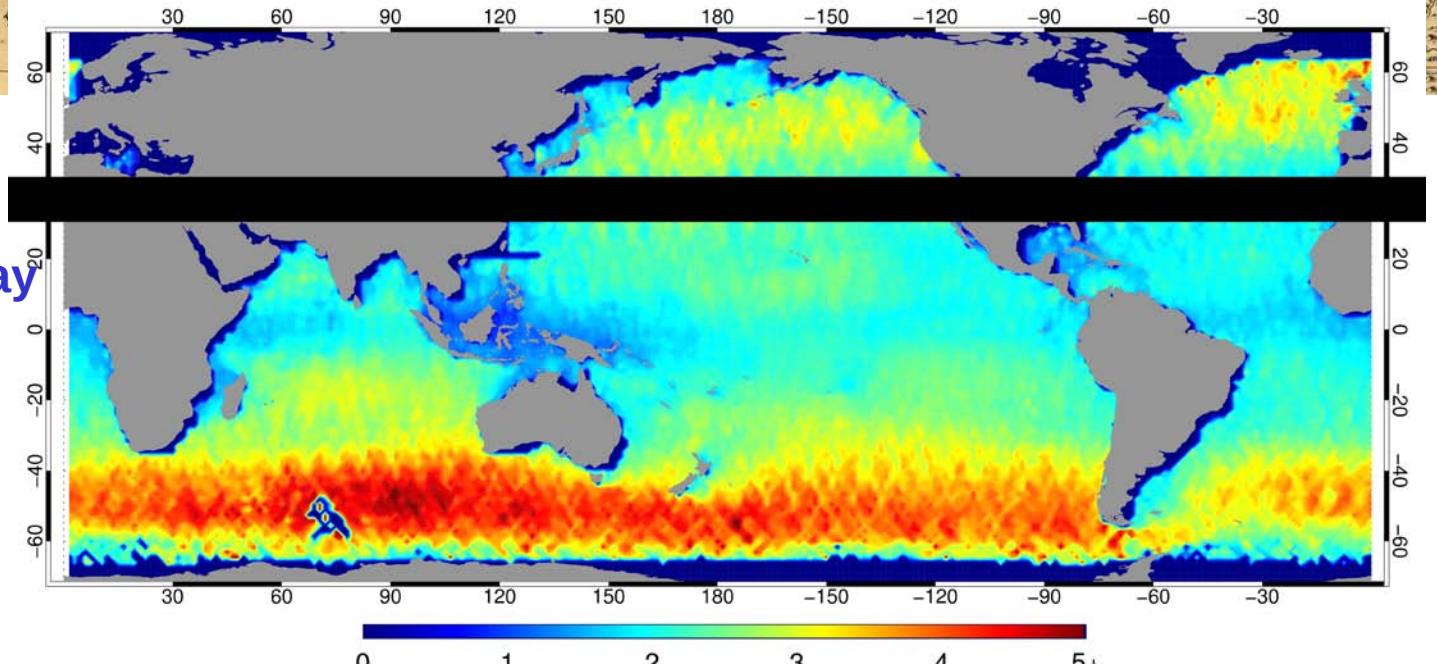
12:00 UTC



Storm on 2007 Feb. 10 at NA

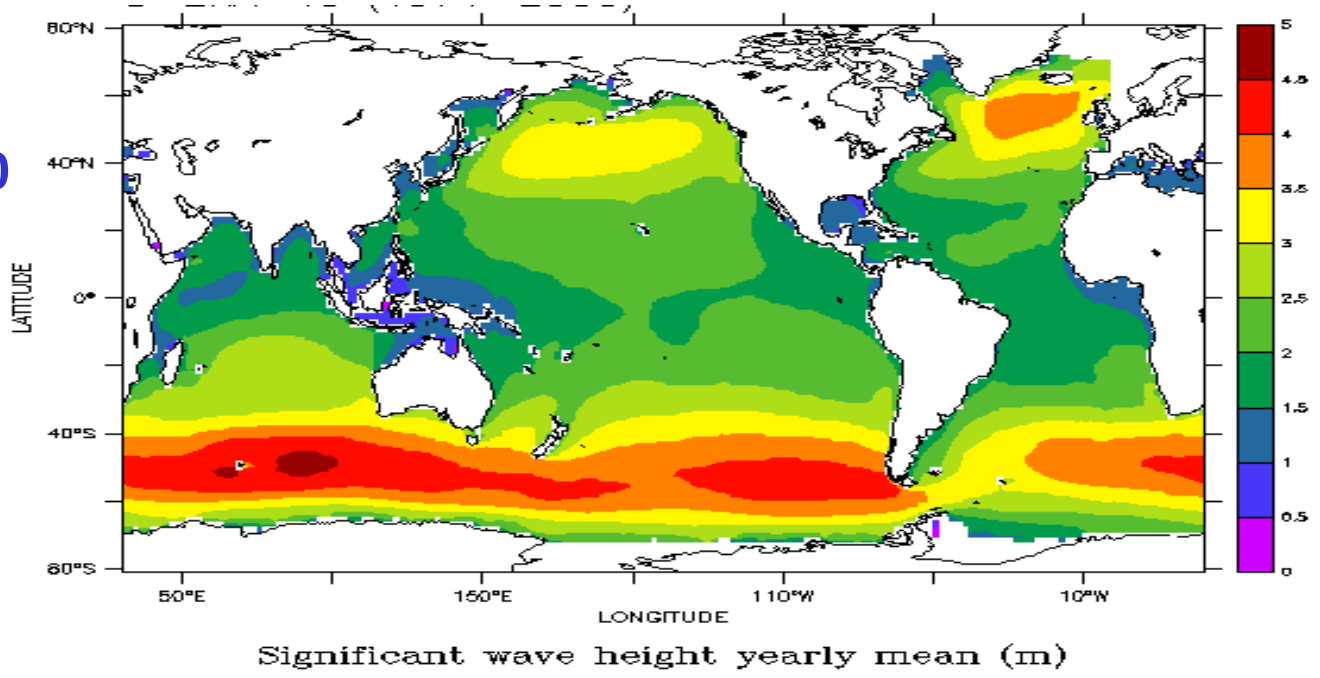
Squares : ASAR Diamonds: RA-2

CWAVE
2006 June~ 2007 May



C-ERA-40, 1971-2000

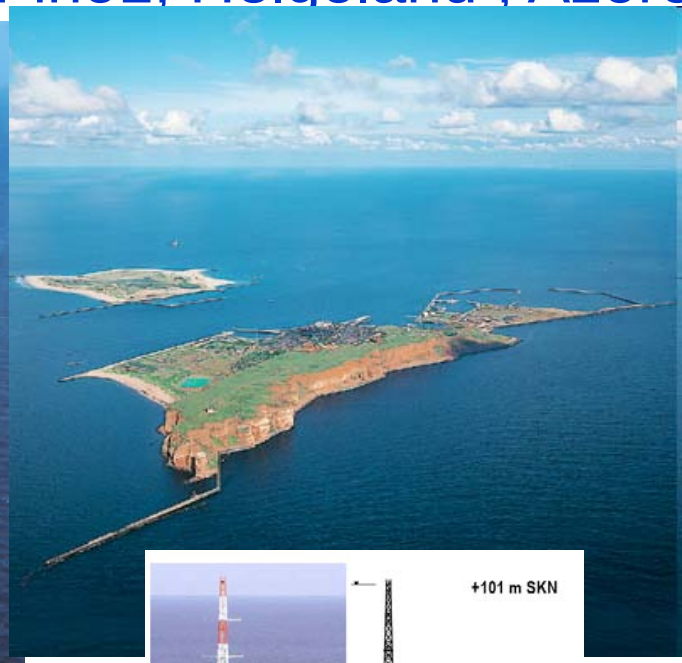
KNMI

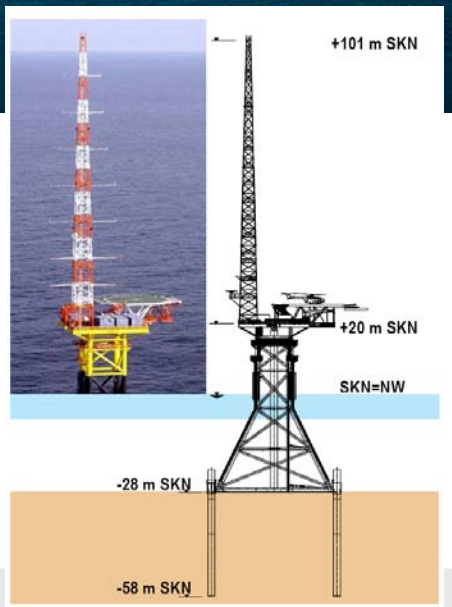


W+W 11, 18 -23 October, Halifax

Comparison of TSX image spectra to measurements of marine radar --WaMoS

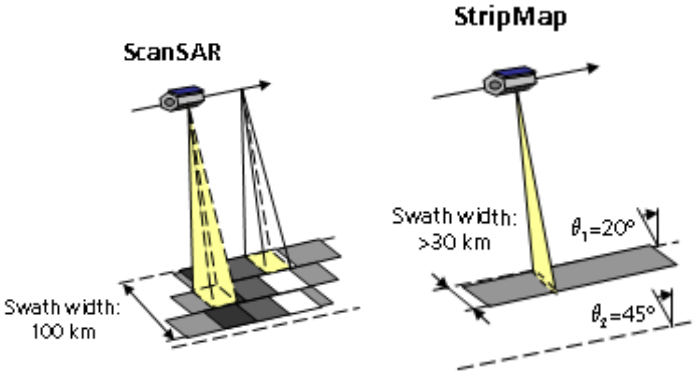
Sites: Ekofisk, Fino1, Helgoland , Azore





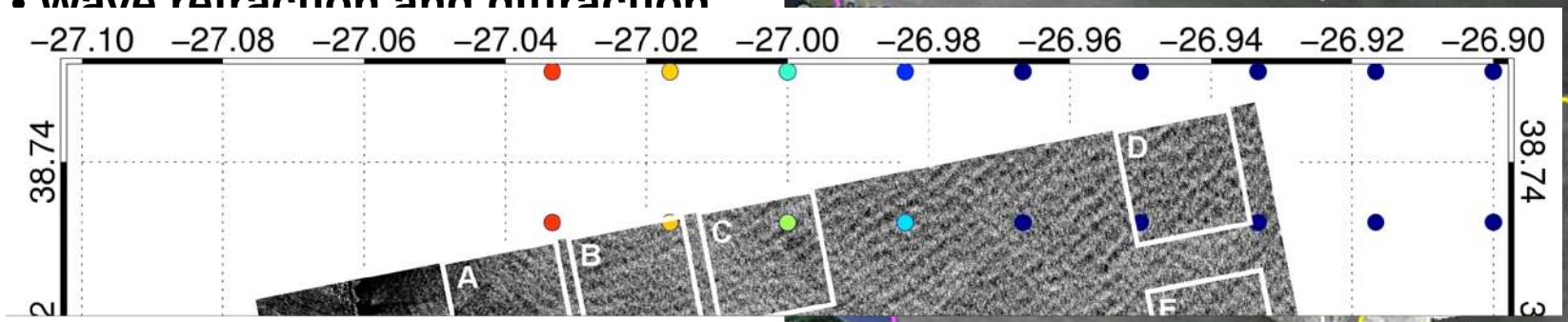
Seastate Observations using TerraSAR-X

TSX images
Scan SAR, stripmap, spotlight
Terceira

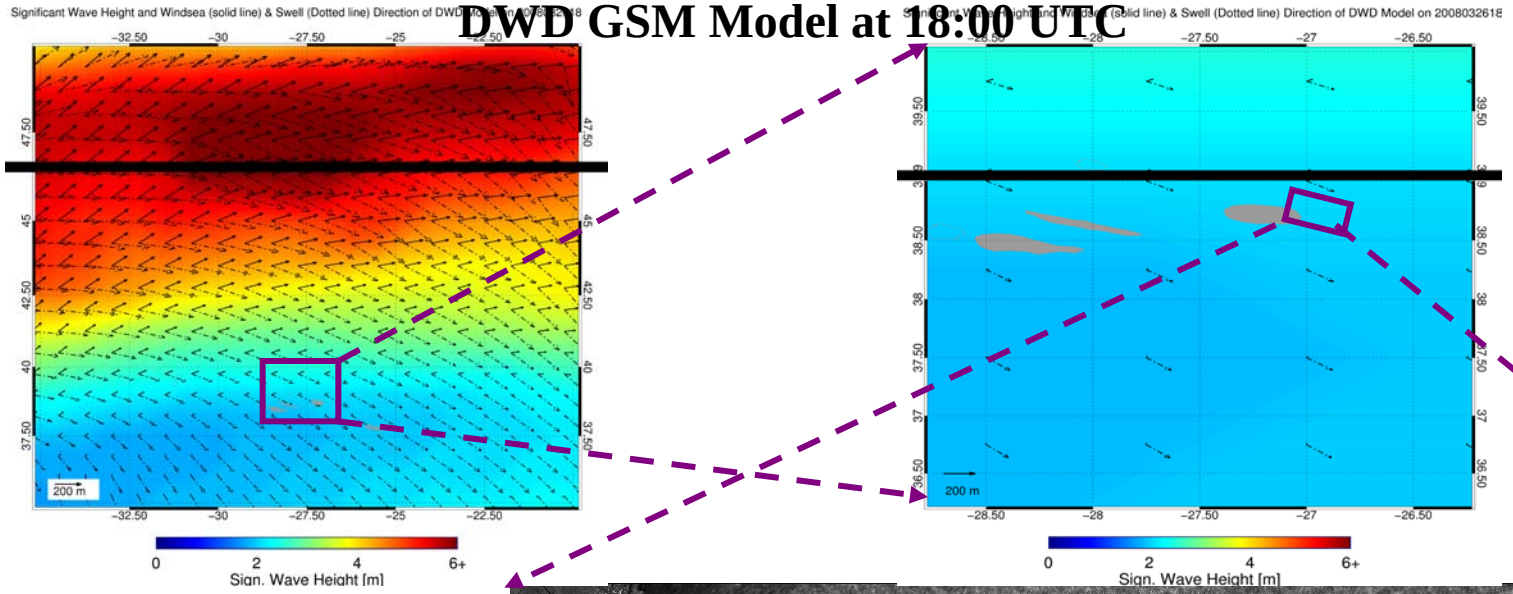


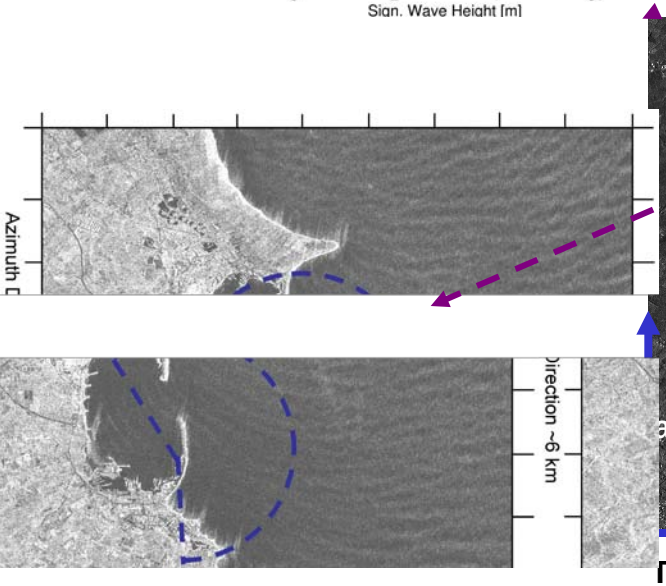
X. Li et al,
sub to IEEE TGARS

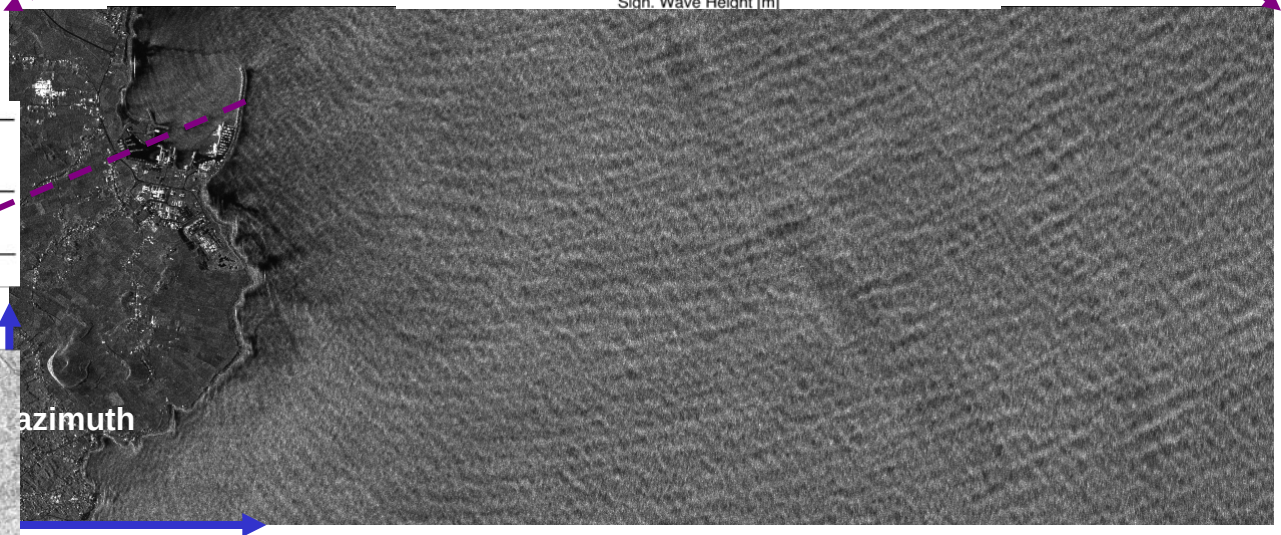
Observation of coastal wave variations using TSX data on the Portuguese island Azores.



DWD GSM Model at 18:00 UTC

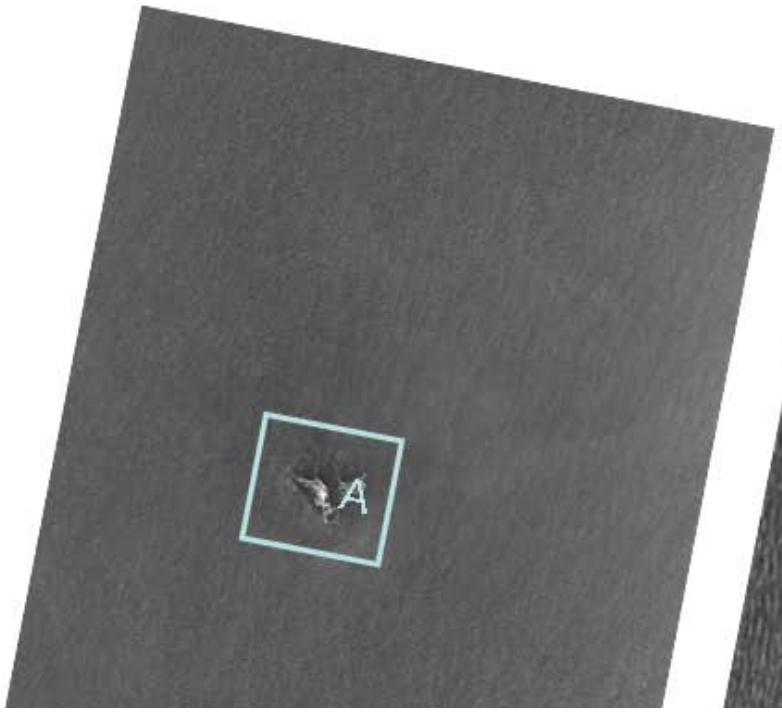


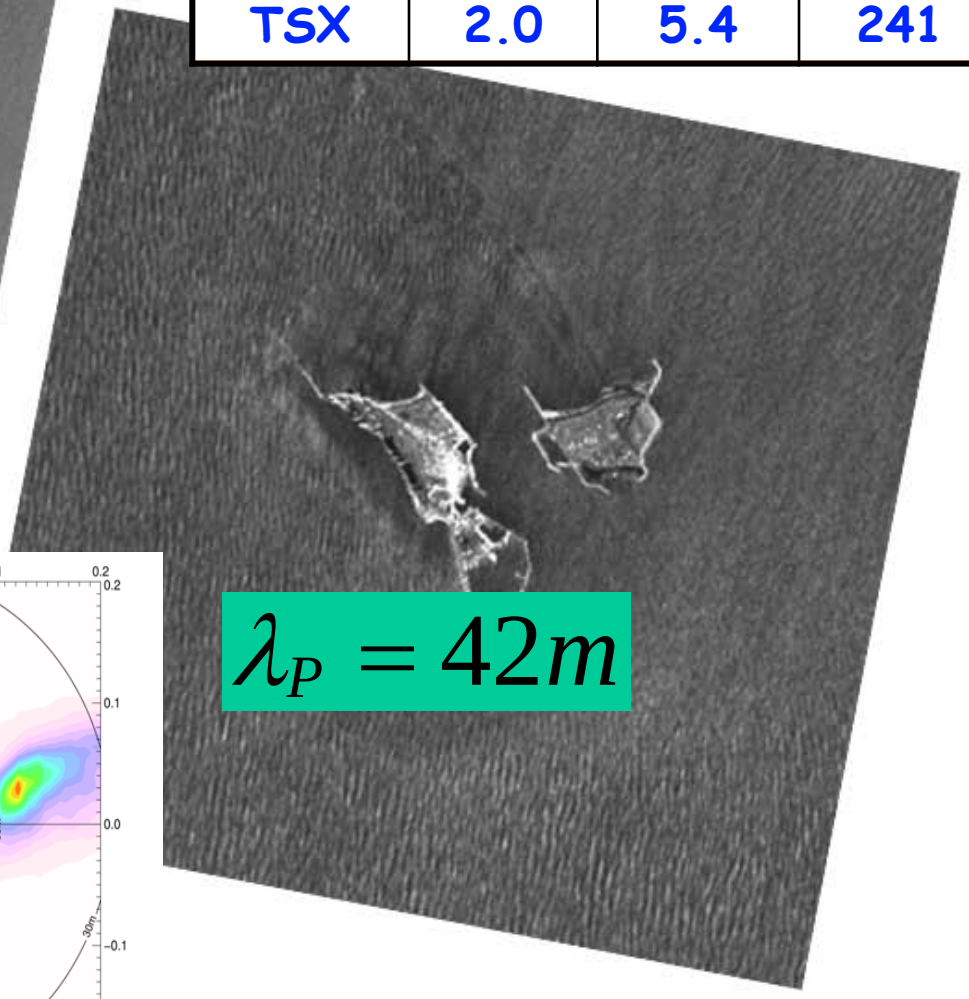




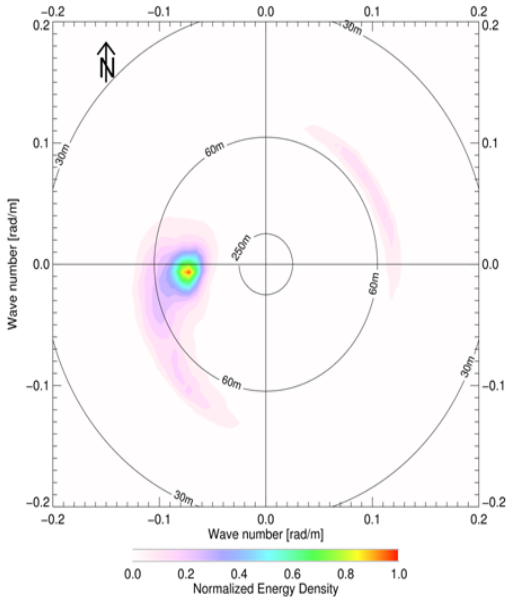
TerraSAR-X Spotlight data acquired on Mar.26th, 2008 at 19:32 UTC with ascending orbit with HH polarization, azimuth resolution: 2.8m, range resolution: 3.5m

	Hs(m)	Tp(s)	Dir(°)
WaMos	1.8	8.1	274
TSX	2.0	5.4	241

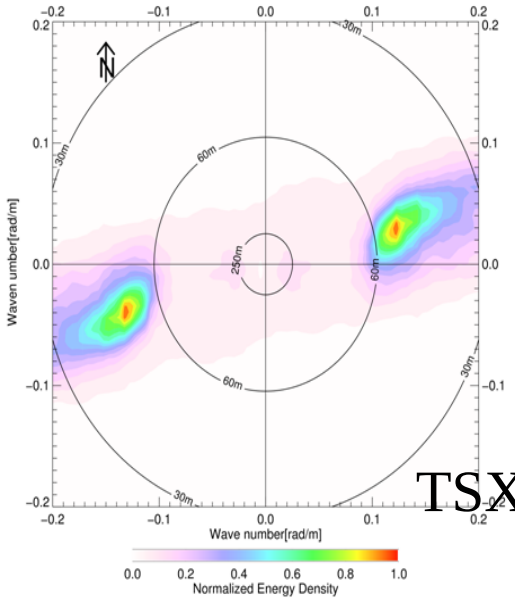




$\lambda_P = 42m$



WaMoS spectrum



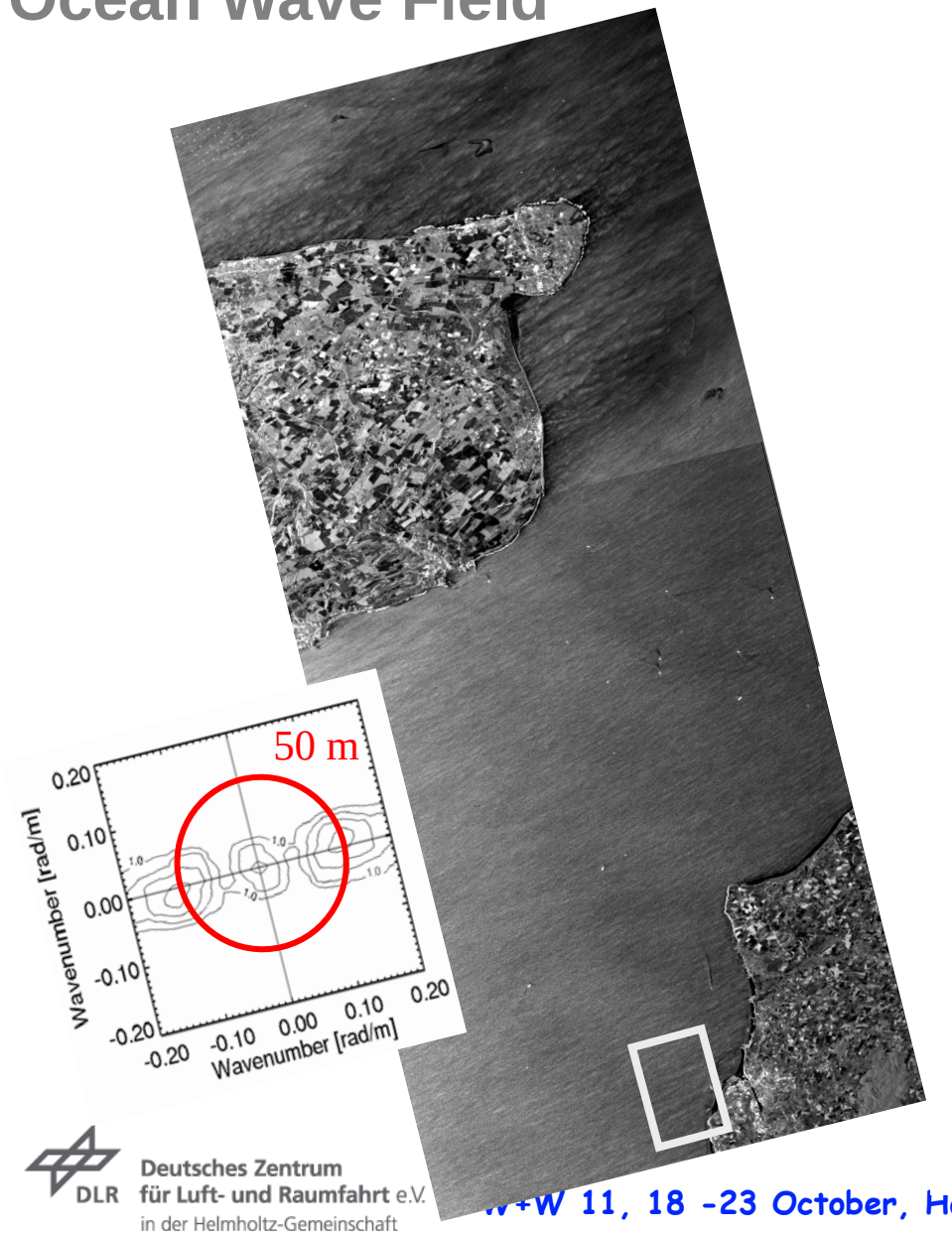
TSX image spectrum

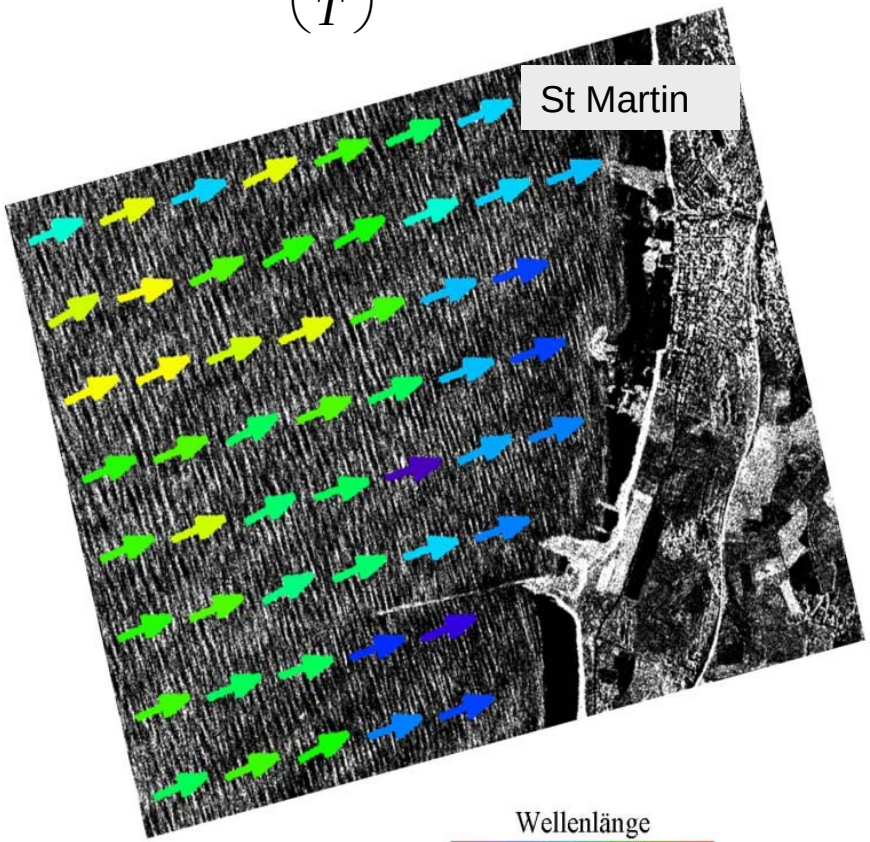
TSX StripMap image (a) and subscene A (b) acquired over Helgoland on Nov.28, 2008 at 5:50 UTC

Ocean Wave Field

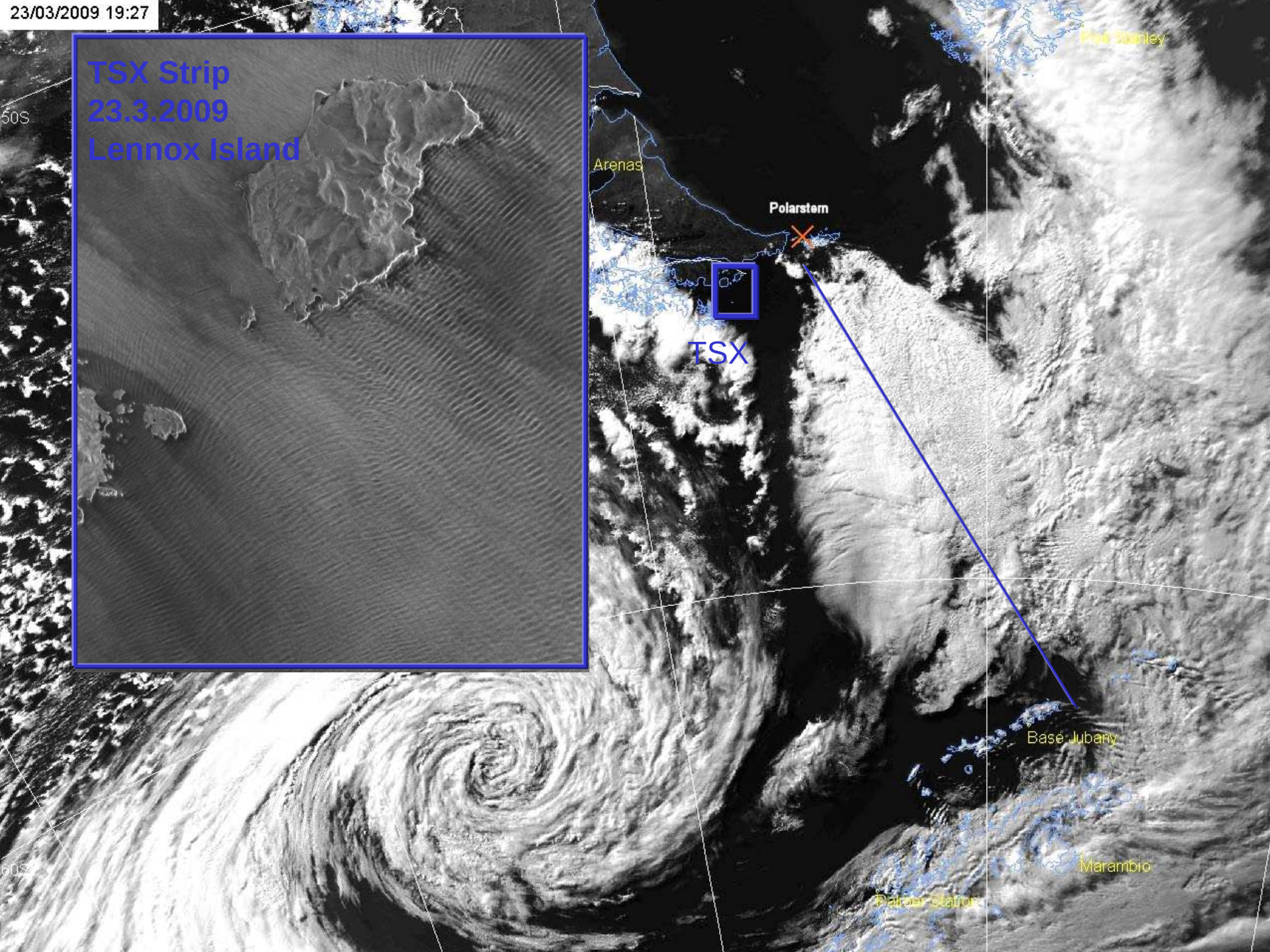
shallow water

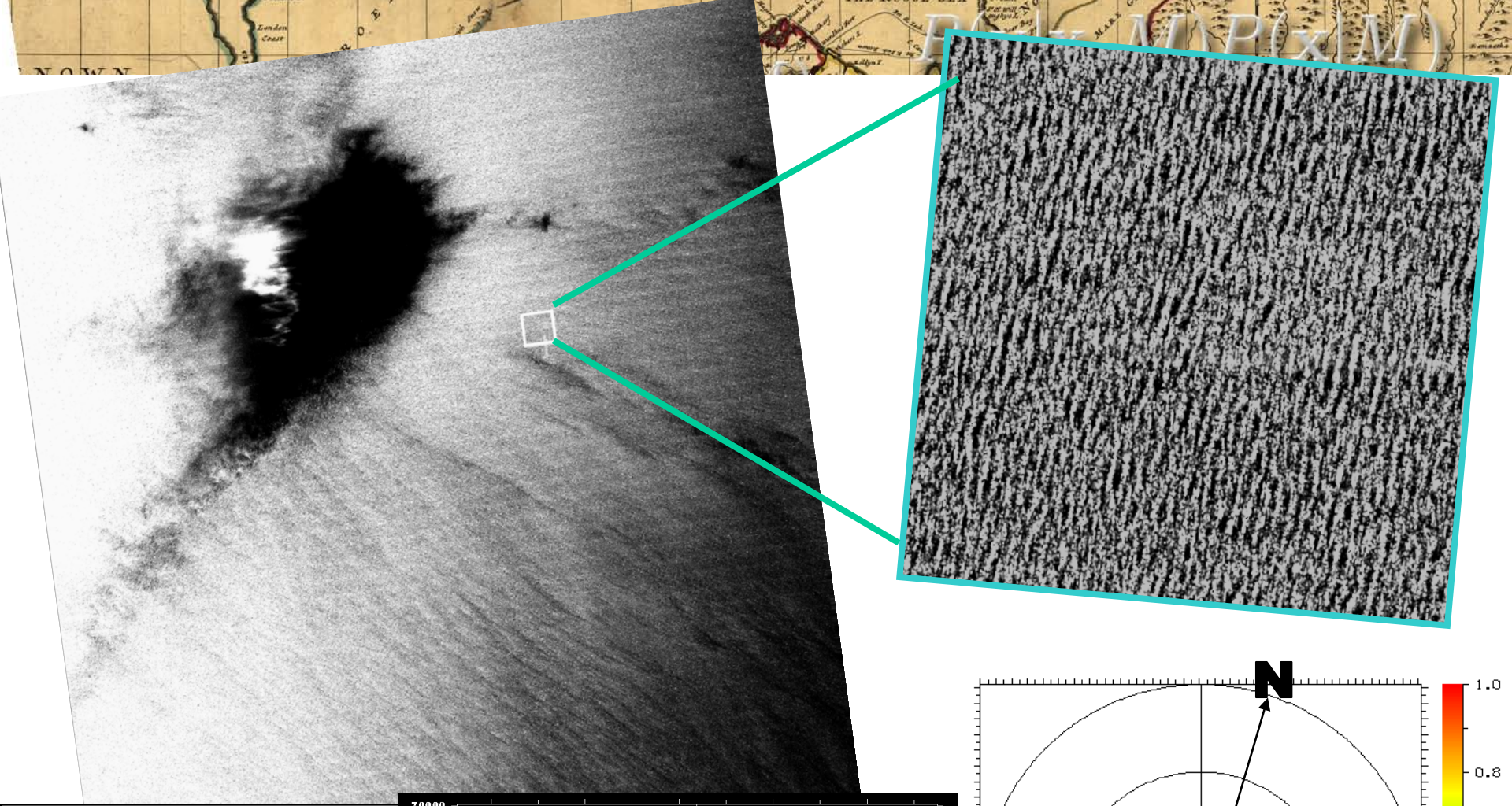
$$\left(\frac{\lambda}{T}\right)^2 = g * h$$



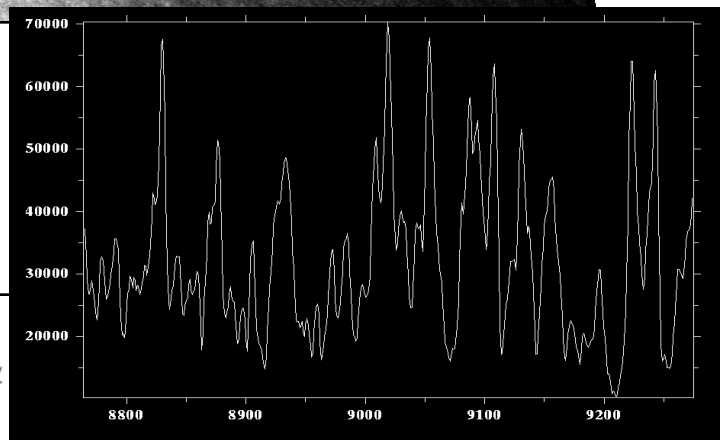


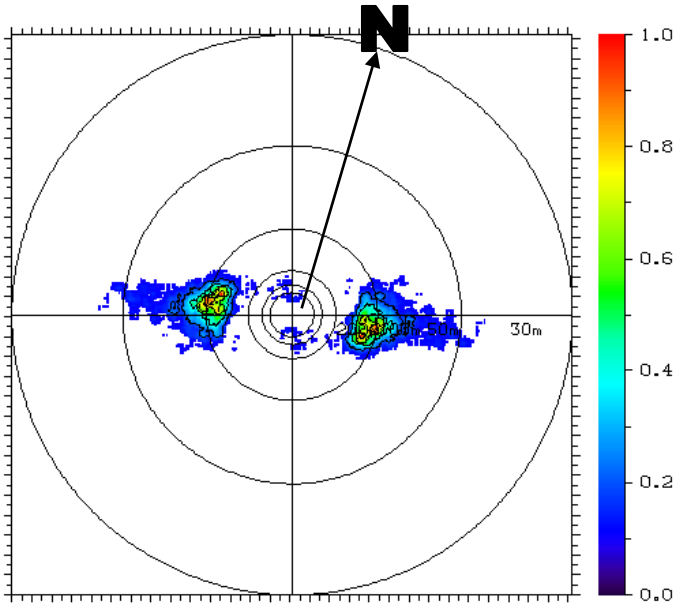
W+W 11, 18 -23 October, Halifax


23/03/2009 19:27
TSX Strip
23.3.2009
Lennox Island
50S
Arenas
Polarstern
TSX
Port Stanley
Base Jubany
Marambio
Palmer Station



Hs =4.9 m
Tp = 7.5 s
dir = 267 (87)
Hurricane FRED





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

Algorithm development for deriving SWH from TSX data

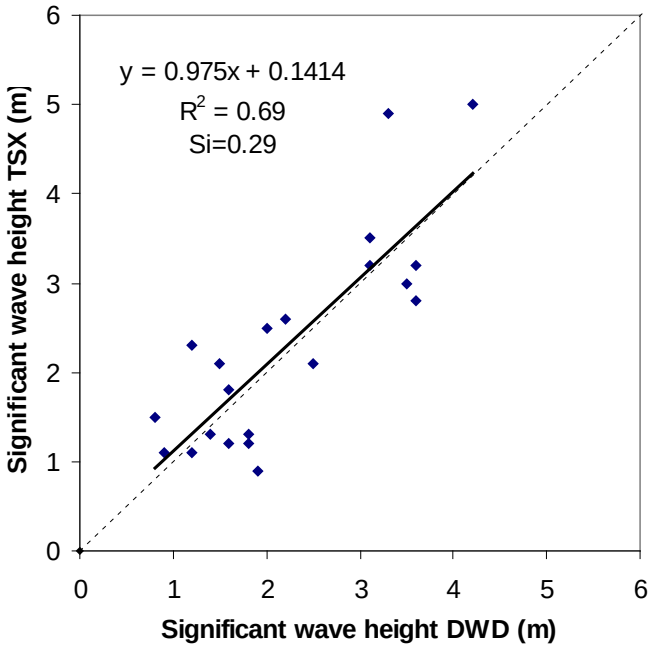
Linear relation between SWH and TSX image energy, assuming!

$$SWH \propto F(E_{SAR\_image\_spectra}, \alpha)$$

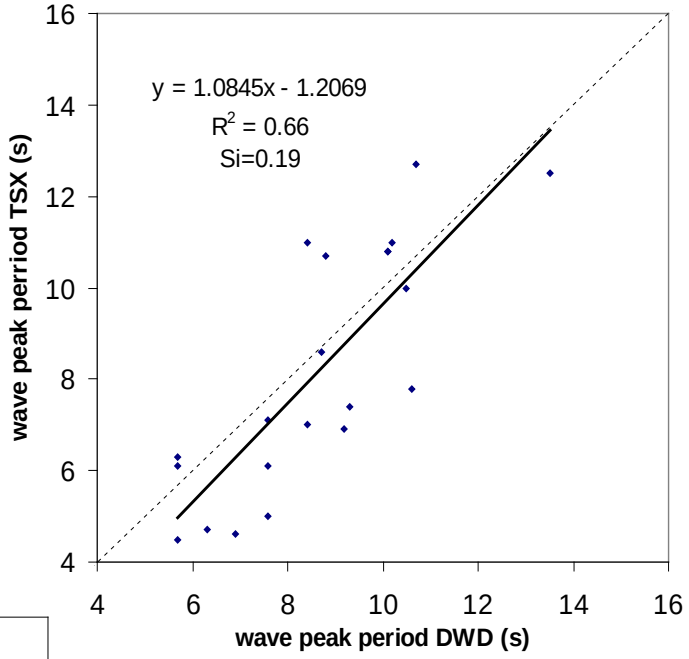
α is peak wave direction relative to azimuth (satellite flight) direction

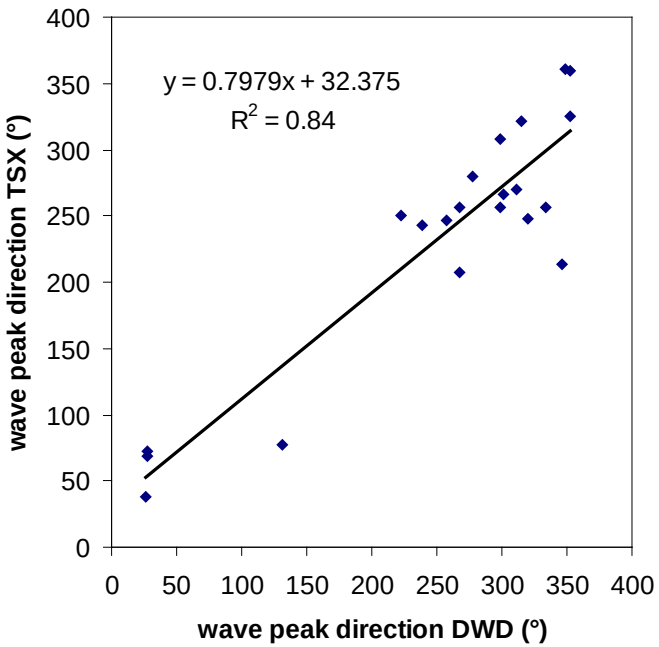
$$Hs = a * 4\sqrt{E(1.0 + \cos(\alpha))} + b$$

Coefficients are determined by linear fitting with **hindcast** DWD model results



Number of measurements:21





Summary Coastal Measurements

• A preliminary result of the XWAVE algorithm shows good agreement with the numerical wave model from DWD, marine radar WAMOS , as well as the shipborne altimeter.

• Further validation and comparison to buoy measurements is being done (we acquired lots of images over buoys)

• TerraSAR X data can be used as a tool to observe wave reflection, wave refraction.

•Global statistics are not possible

•TerraSAR X data can be used for the observation of individual wave behaviour