UNIVERSIDAD SAN FRANCISCO

Wave modelling in the Equatorial Pacific Zone

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Joint ICTP-TWAS Workshop on Climate Change in Mediterranean and Caribbean Seas: Research experiences and new scientific challenges.

Guayaqui, 8-11 May 2012

Outline

- Applications
- The WaveWatchIII™ model
- Model setup
- Input data
  - Bathymetry
  - Wind fields
  - Ice coverage
- Verification data
  - ECMWF reanalysis data
  - Altimeter
  - SAR spectra
  - Seismic noise
- Storm source detection algorithm
- Preliminary results
- Summary, conclusions and further work

Wave modelling in the Equatorial Pacific Zone

APLICATIONS

- **Wave forecasting and hindcasting**
  - Coastal engineering
  - Environmental engineering
  - Offshore structures
  - Navigation / Fisheries
  - Risk assessment
  - Wave energy resource assessment
  - Tourism and Recreation
  - Climate
  - . . .

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The WaveWatchIII™ model

Characteristics

- Third generation wave model
- Stochastic, phase average model
- Open source code
- MPI environment
- Continuous development
- Documentation and support available

Special features

- Multi-grid capabilities
- Sub-grid obstruction resolving

The WaveWatchIII™ model

Basic Equation: The action balance equation

Spectral change

$$\frac{\partial N}{\partial t} + \underbrace{\nabla_x \cdot \dot{\mathbf{x}} N}_{\text{advection}} + \underbrace{\frac{\partial}{\partial k}\dot{k} N}_{\text{shoaling}} + \underbrace{\frac{\partial}{\partial \theta}\dot{\theta} N}_{\text{refraction}} = \frac{S}{\sigma}$$

Source terms

$$N = \frac{E}{\sigma} \quad \textit{wave action}$$

$$S = S_{in} + S_{nl} + S_{wc} + S_{bf} + S_{db} + \ldots$$

S_{in}	*wind input*
S_{nl}	*quadruplet resonance*
S_{wc}	*white capping dissipation*
S_{bf}	*bottom friction*
S_{db}	*depth induced breaking*

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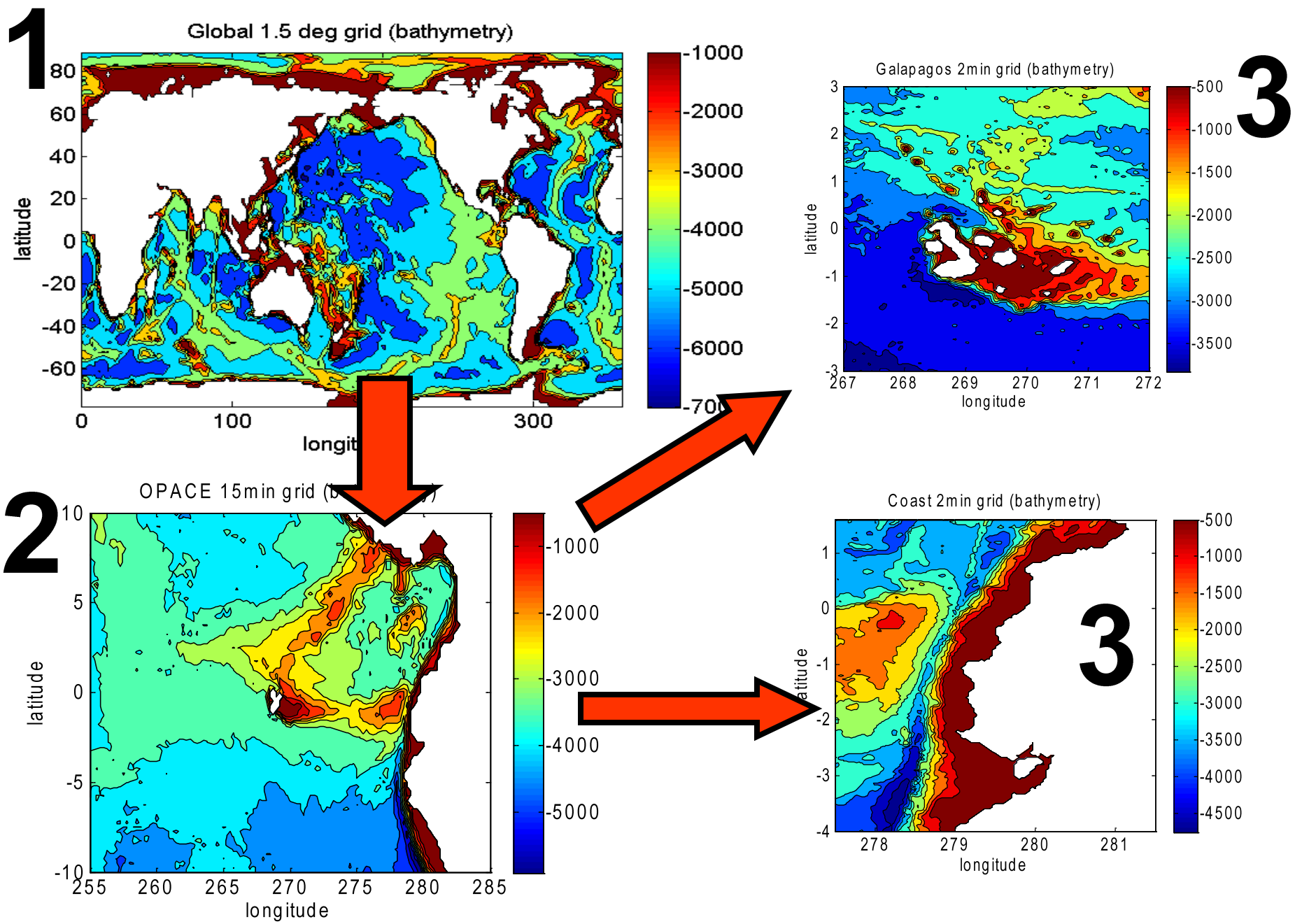
Model Setup

	Resolution	Lat1	Lat2	Lon1	Lon2	level
Global	90min	-77.5	89	0	360	1
OPACE	15min	-10	10	-75	-105	2
Coast	2min	-4	1.6	-78.5	-82.5	3
Galapagos	2min	-3	3	-88	-93	3

Model Setup


1
Global 1.5 deg grid (bathymetry)
latitude
longitude
80
60
40
20
0
-20
-40
-60
0
100
300
-1000
-2000
-3000
-4000
-5000
-6000
2
OPACE 15min grid
latitude
longitude
10
5
0
-5
-10
255
260
265
270
275
280
285
-1000
-2000
-3000
-4000
-5000
3
Galapagos 2min grid (bathymetry)
latitude
longitude
3
2
1
0
-1
-2
-3
267
268
269
270
271
272
-500
-1000
-1500
-2000
-2500
-3000
-3500
3
Coast 2min grid (bathymetry)
latitude
longitude
1
0
-1
-2
-3
-4
278
279
280
281
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500

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Input data

❖ Bathymetry

ETOPO2v2: 2min global relieve data (land and bathymetry)

ETOPO2v2 Global Gridded 2-minute Database, National Geophysical Data Center, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, http://www.ngdc.noaa.gov/mgg/global/etopo2.html.

Smith, W. H. F. and D. T. Sandwell, Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings, Science, 277(5334), 1956-1962, 1997

❖ Wind fields

ECMWF: European Centre for Medium-Range Weather Forecasts

ERA-Interim reanalysis

1.5 deg. resolution every 6h

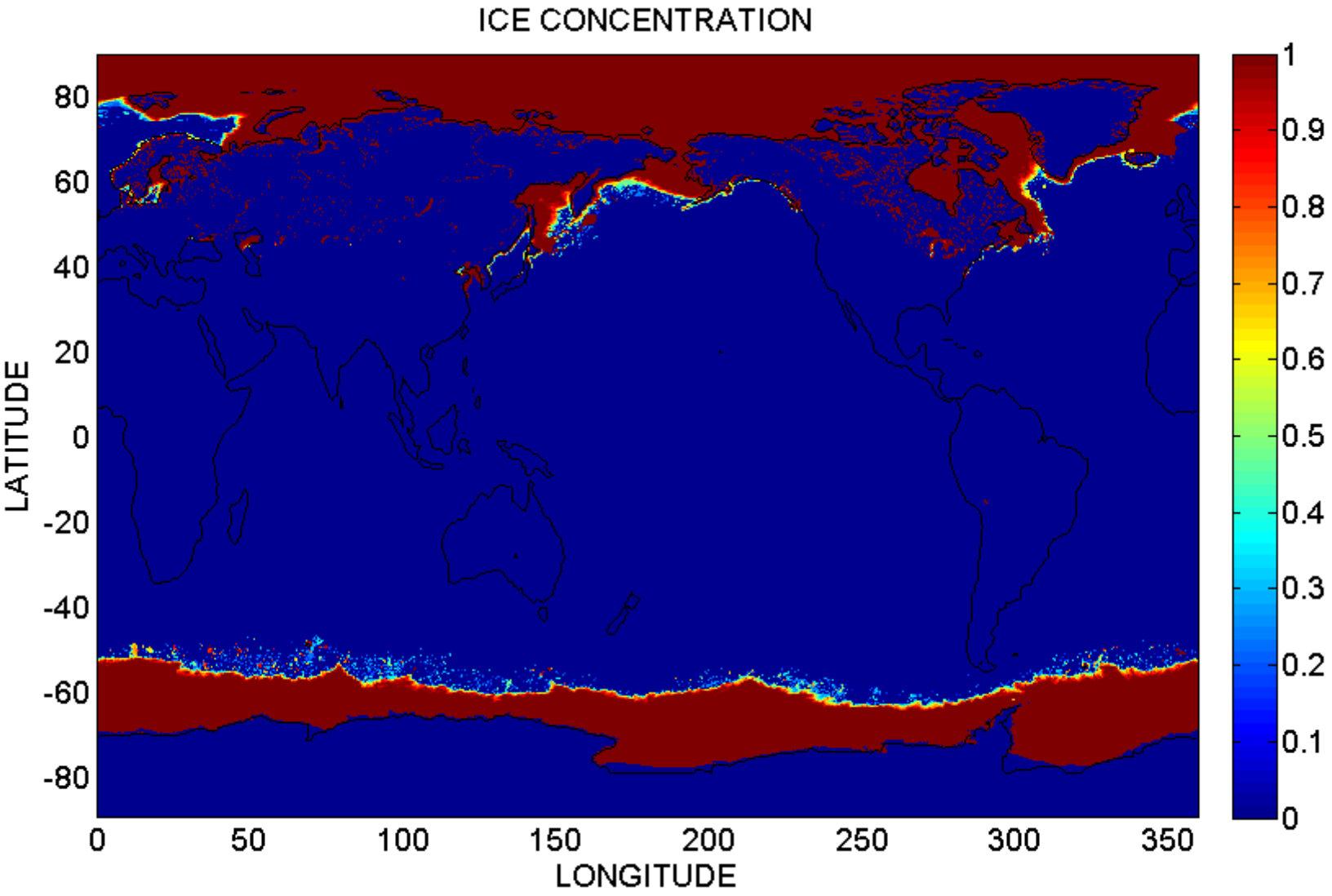
❖ Ice coverage concentration *

MMAB (Marine Modeling and Analysis Branch**) Sea Ice Analysis**

5min resolution

Input data

Ice concentration



Maximum Ice coverage concentration (2004 – 2011) Used for synthetic test run

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Verification data

ECMWF reanalysis data (1 deg resolution)

- Significant wave height
- Mean wave period
- Wave spectra

Altimeter data (several missions)

- Significant wave height

SAR spectra (ENVISAT)

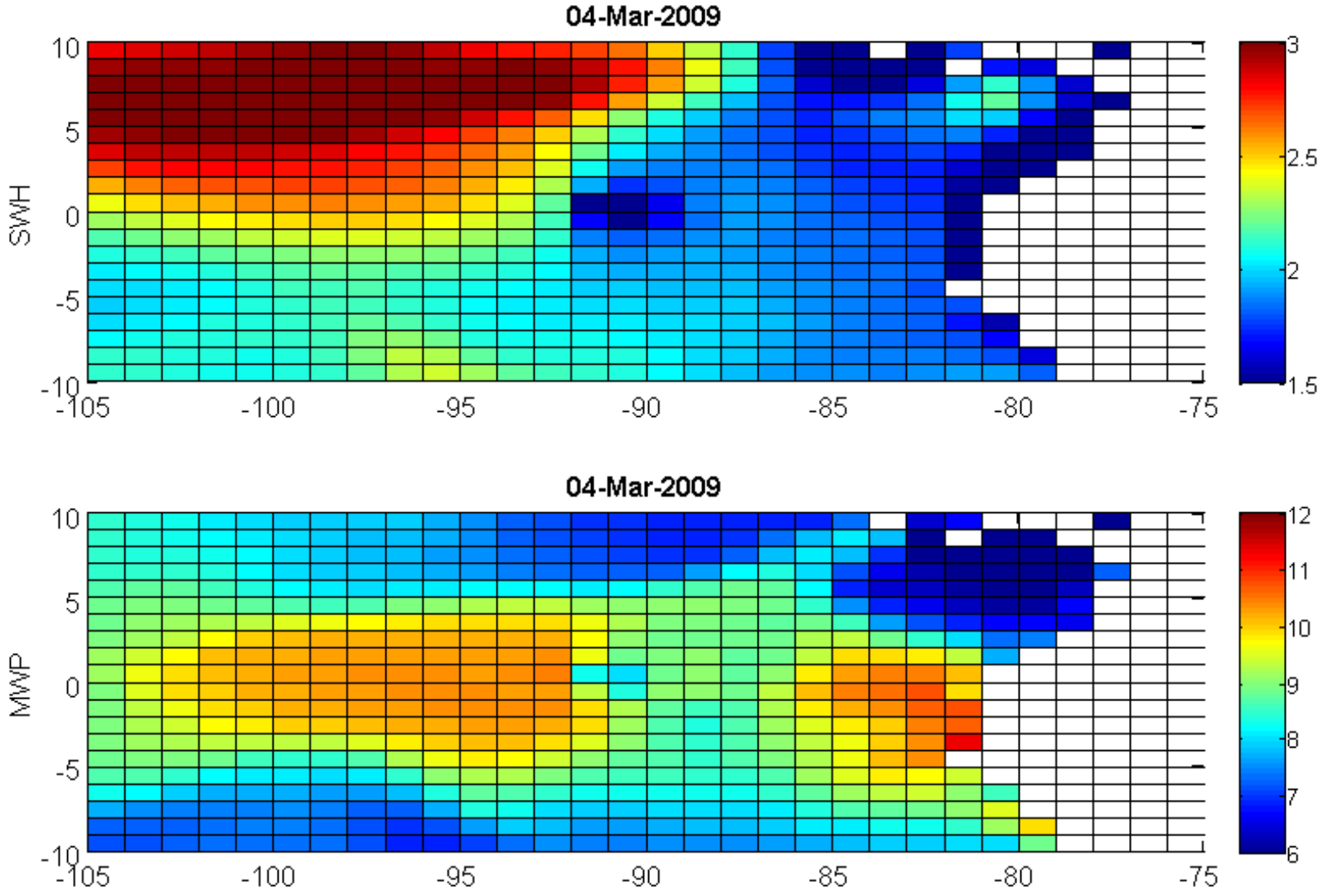
-Wave spectra

Seismic noise (2 seismic stations)

- Noise spectra

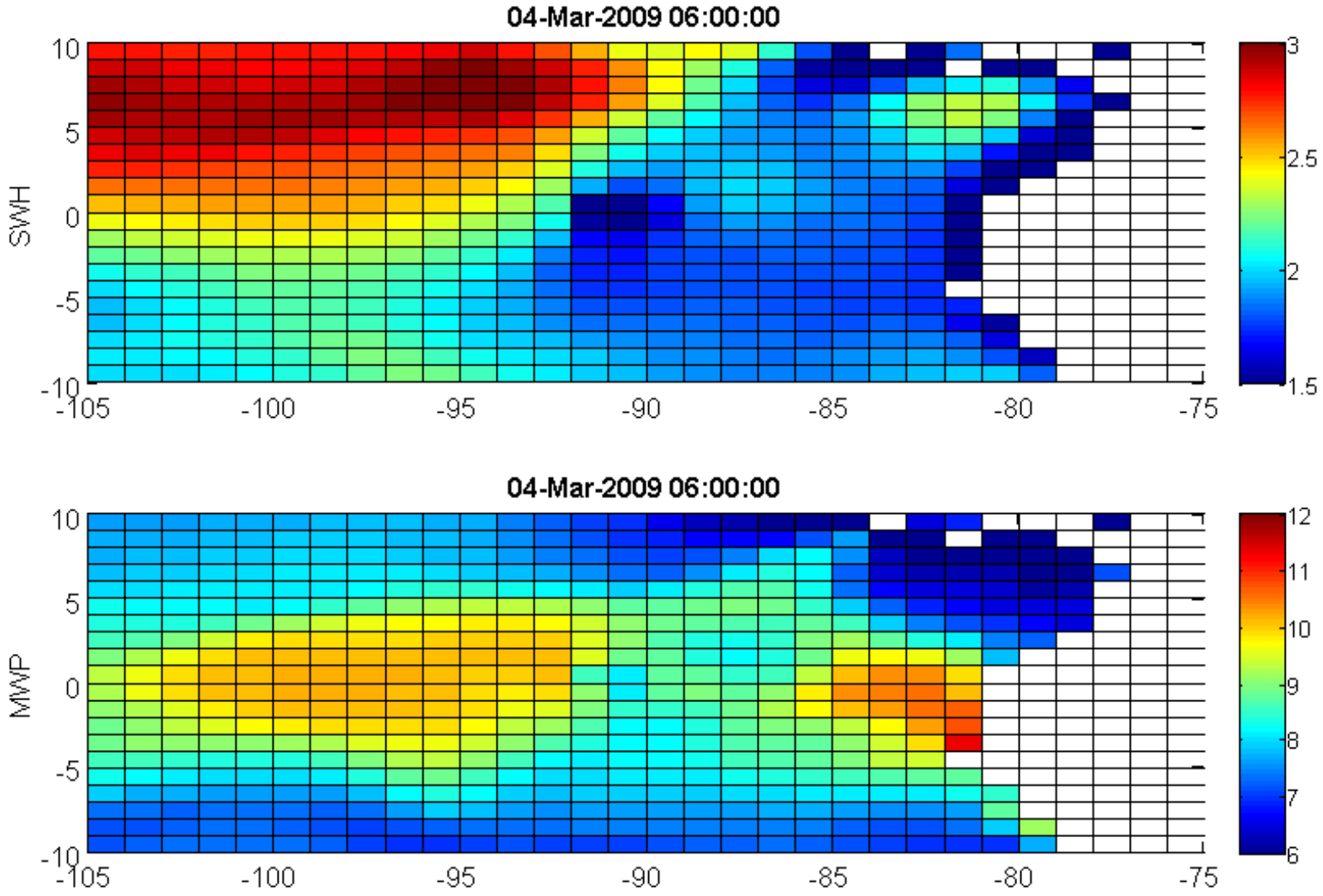
Verification data

ECMWF reanalysis data (ERA Interim)



Verification data

ECMWF reanalysis data (ERA Interim)



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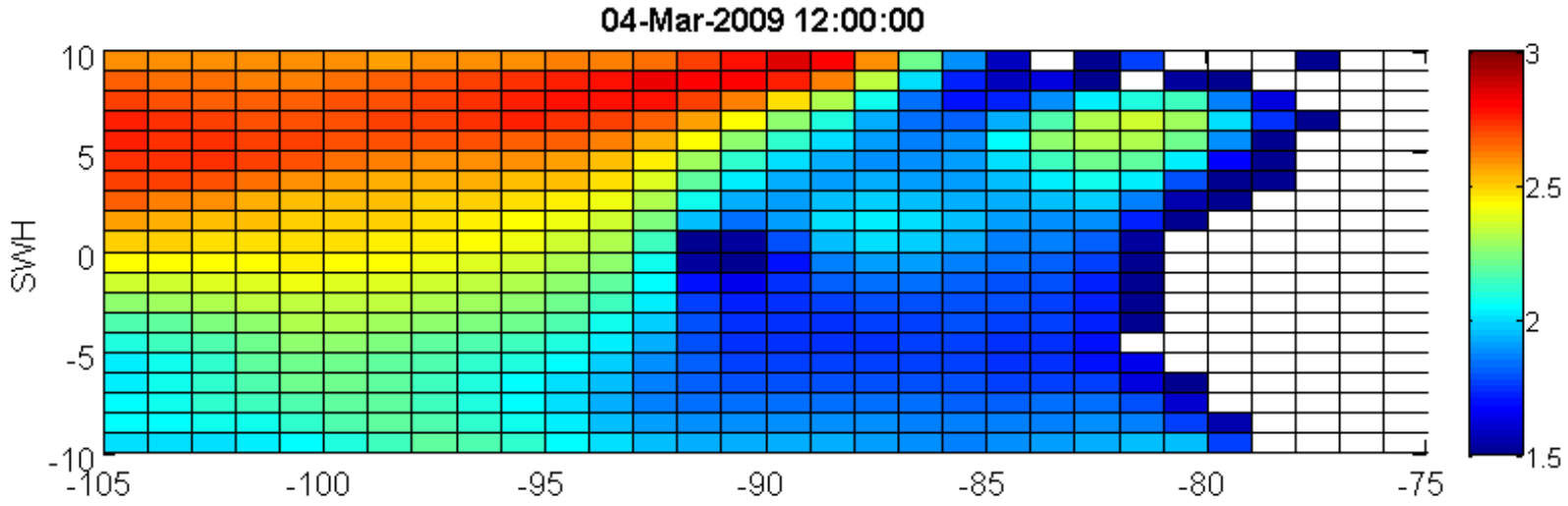

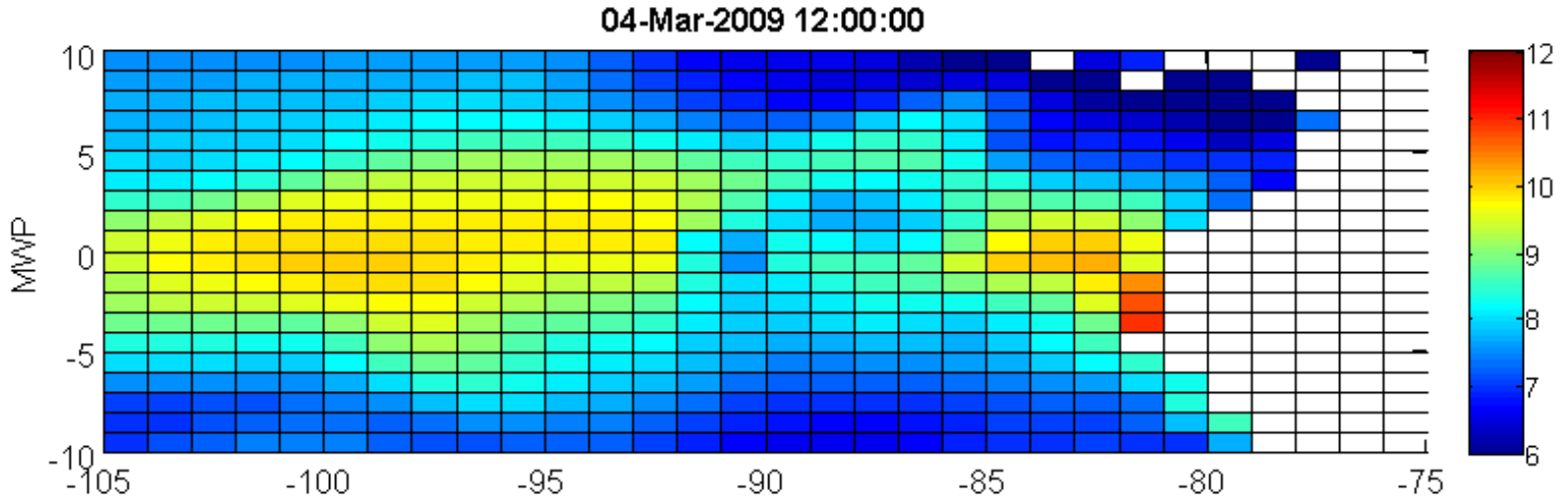

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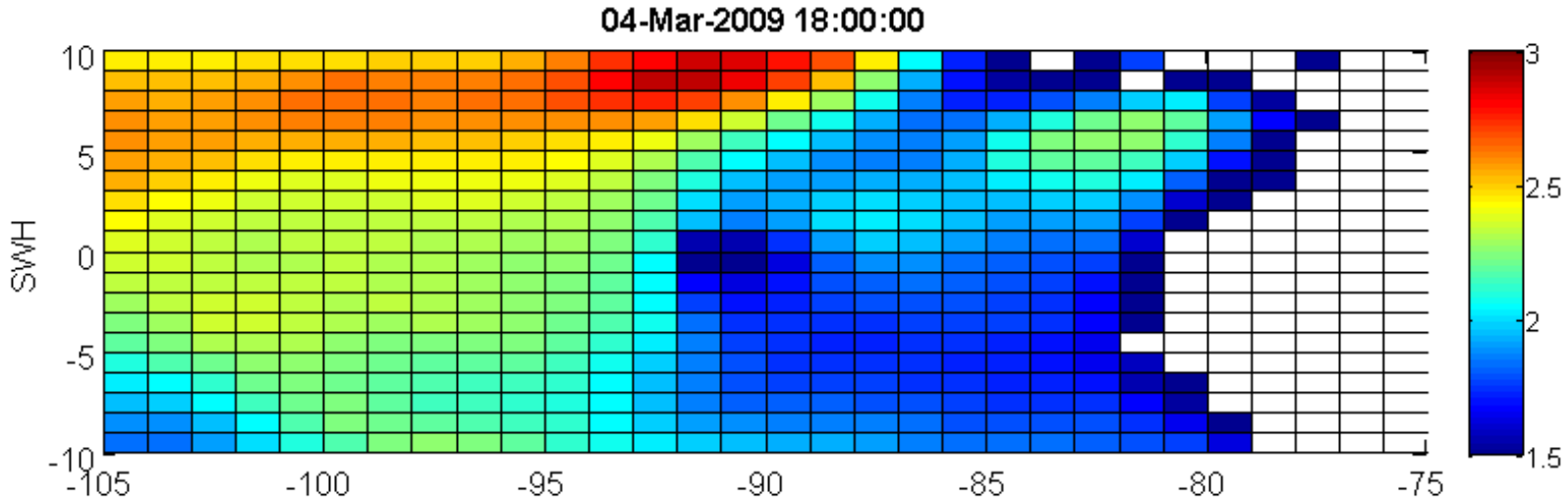

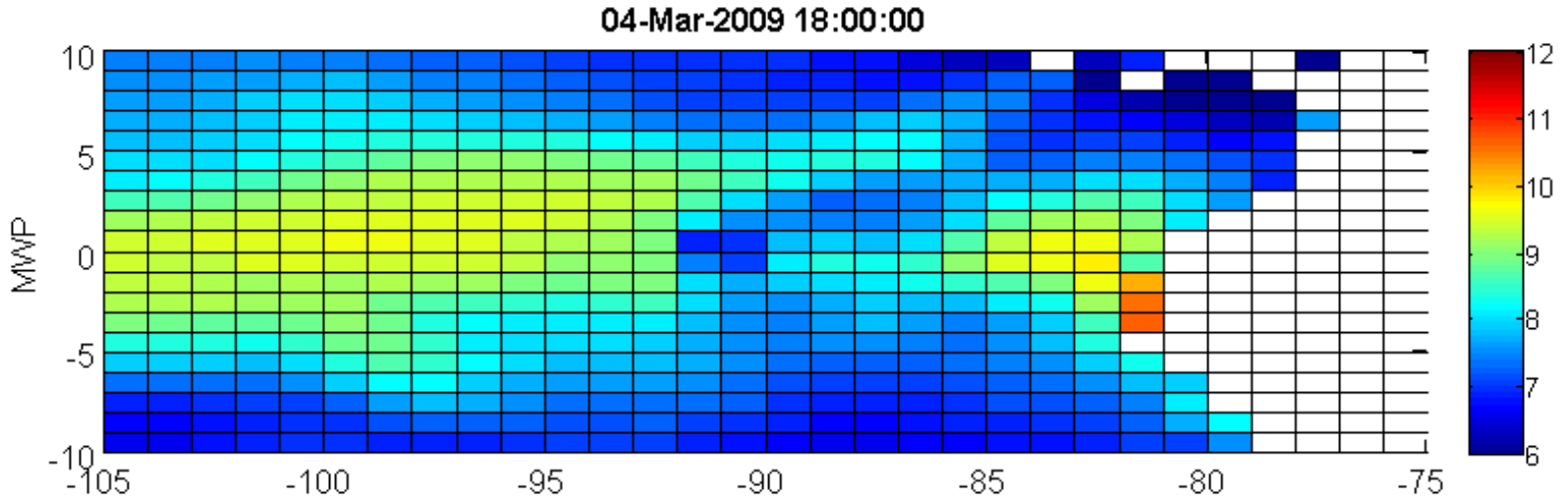

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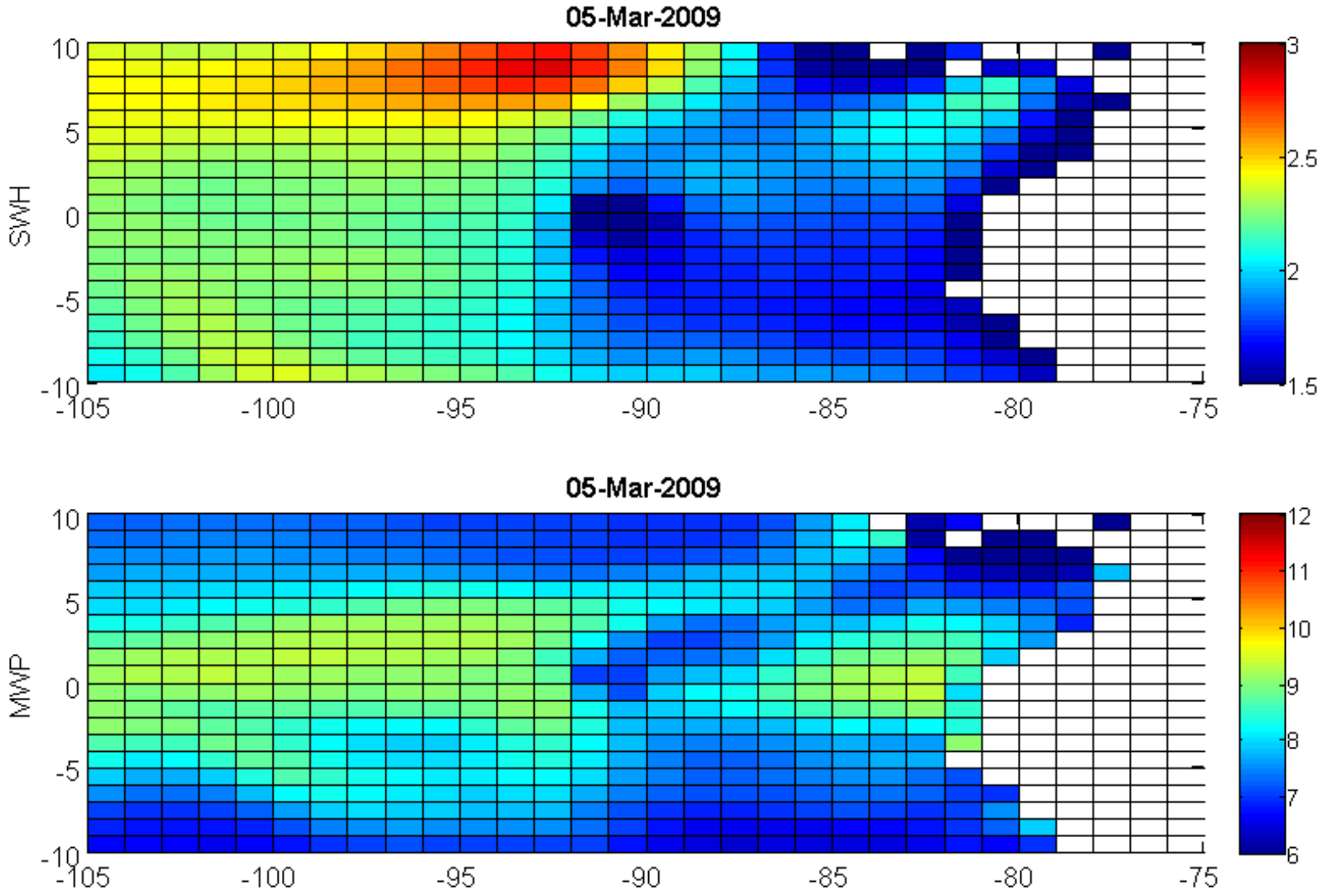

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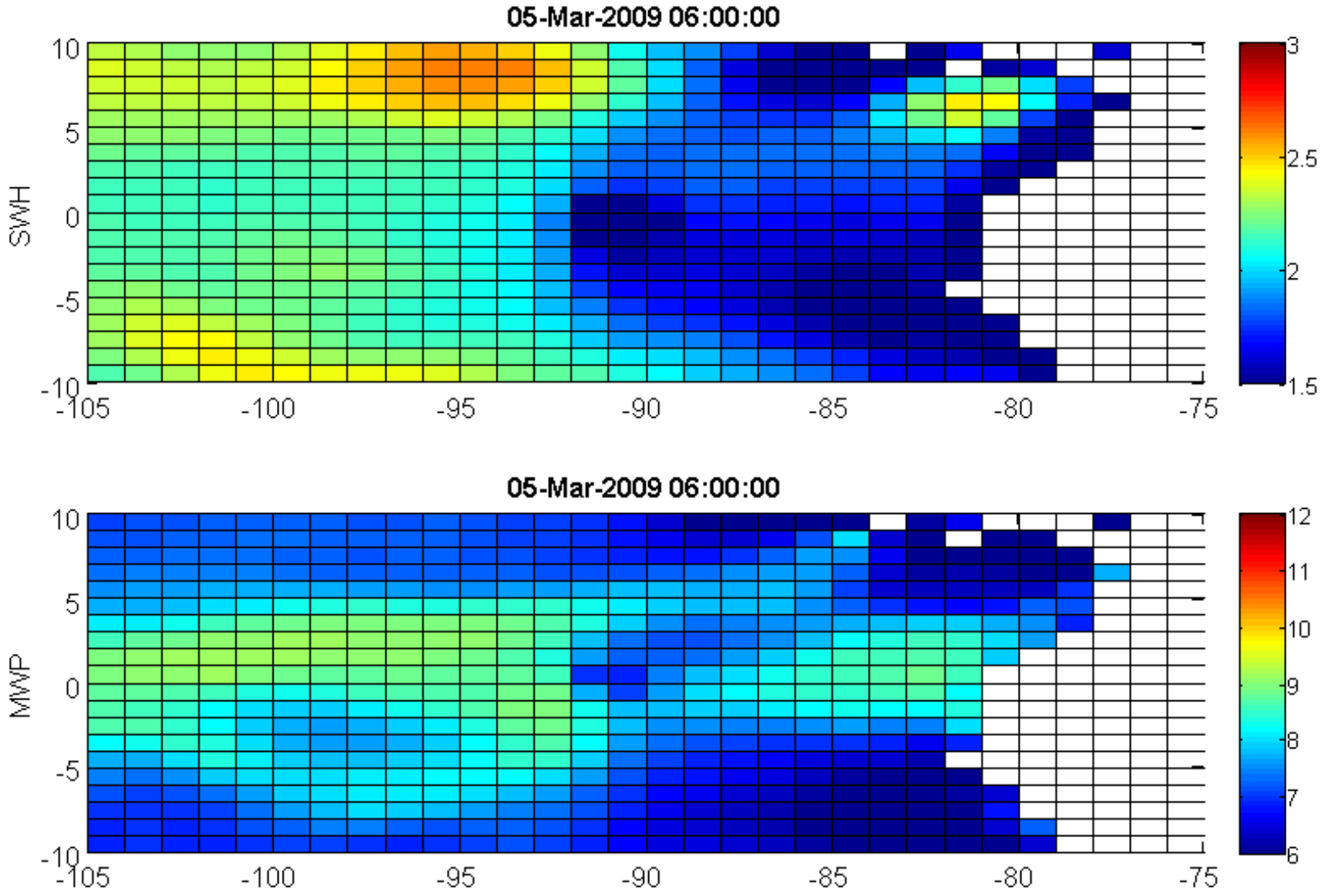

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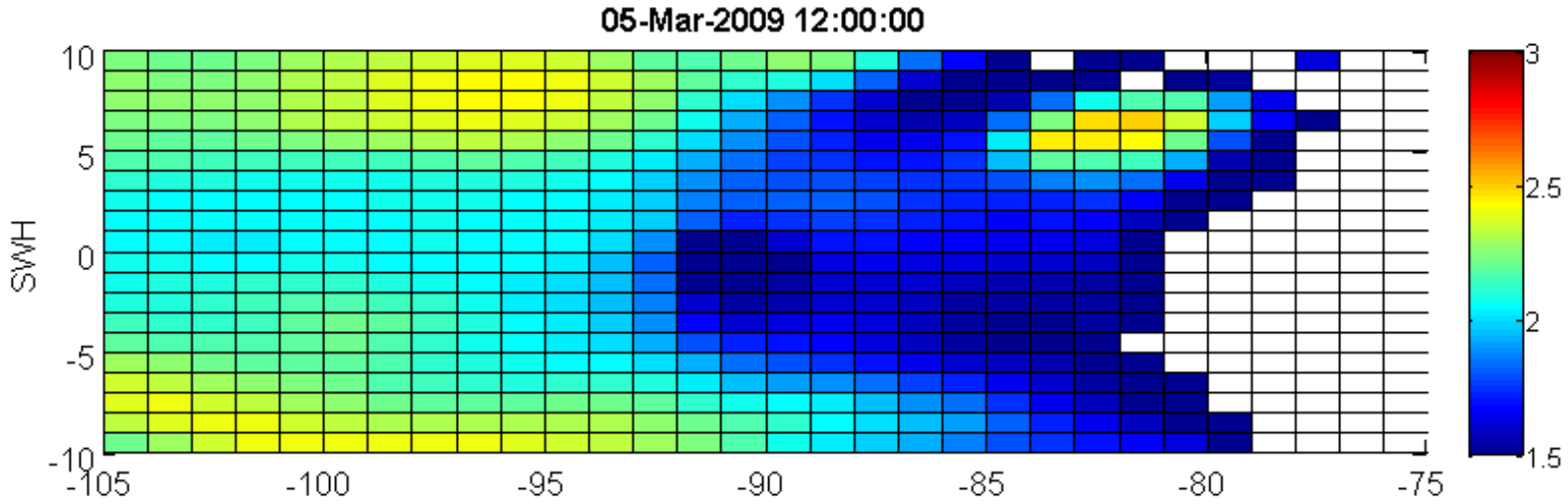

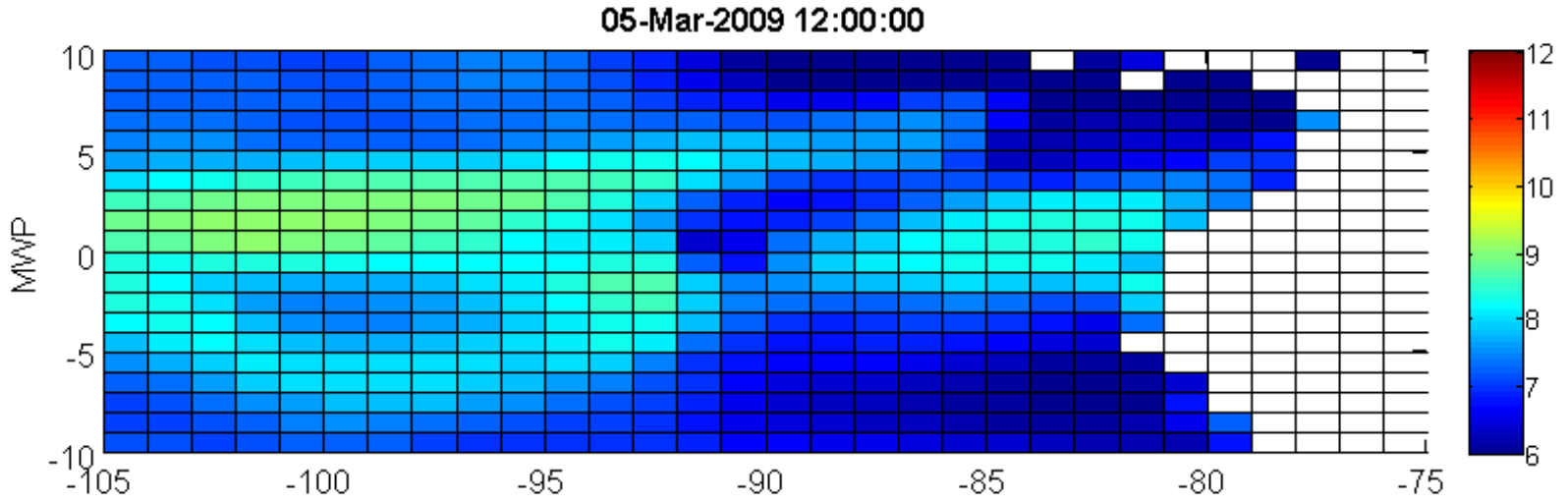

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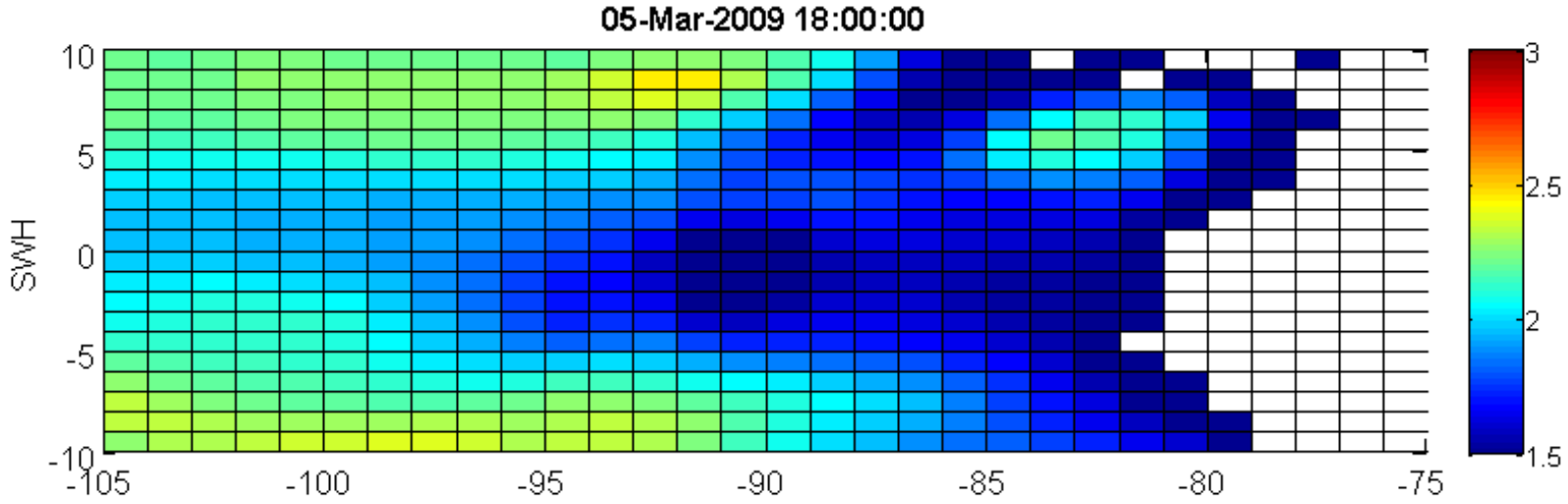
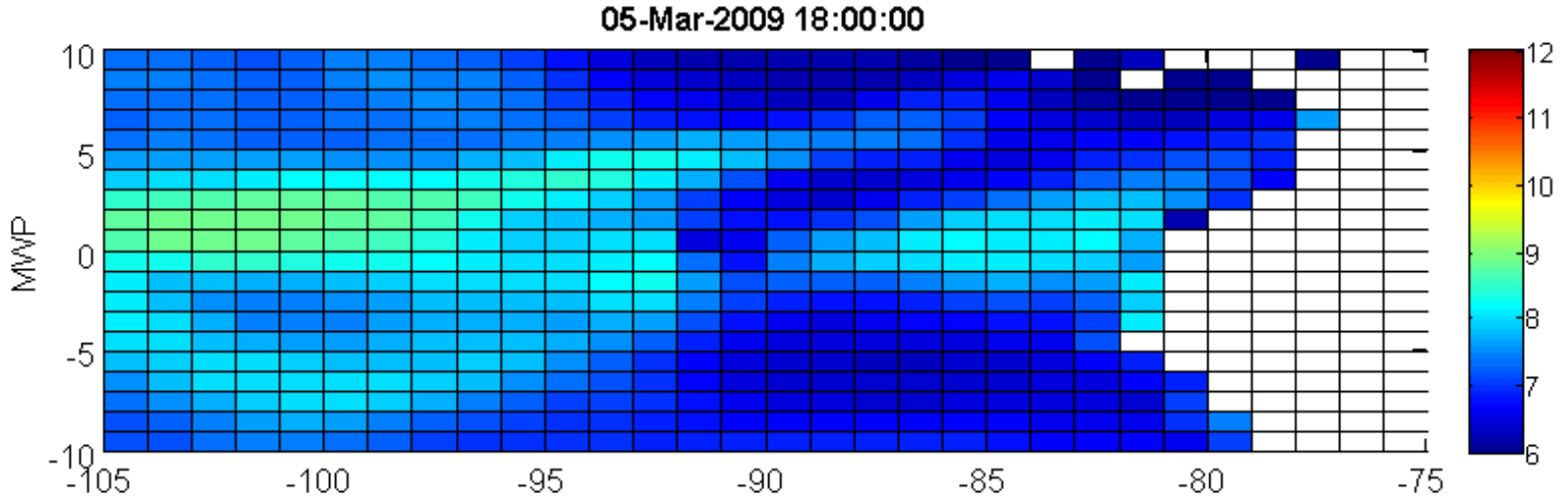
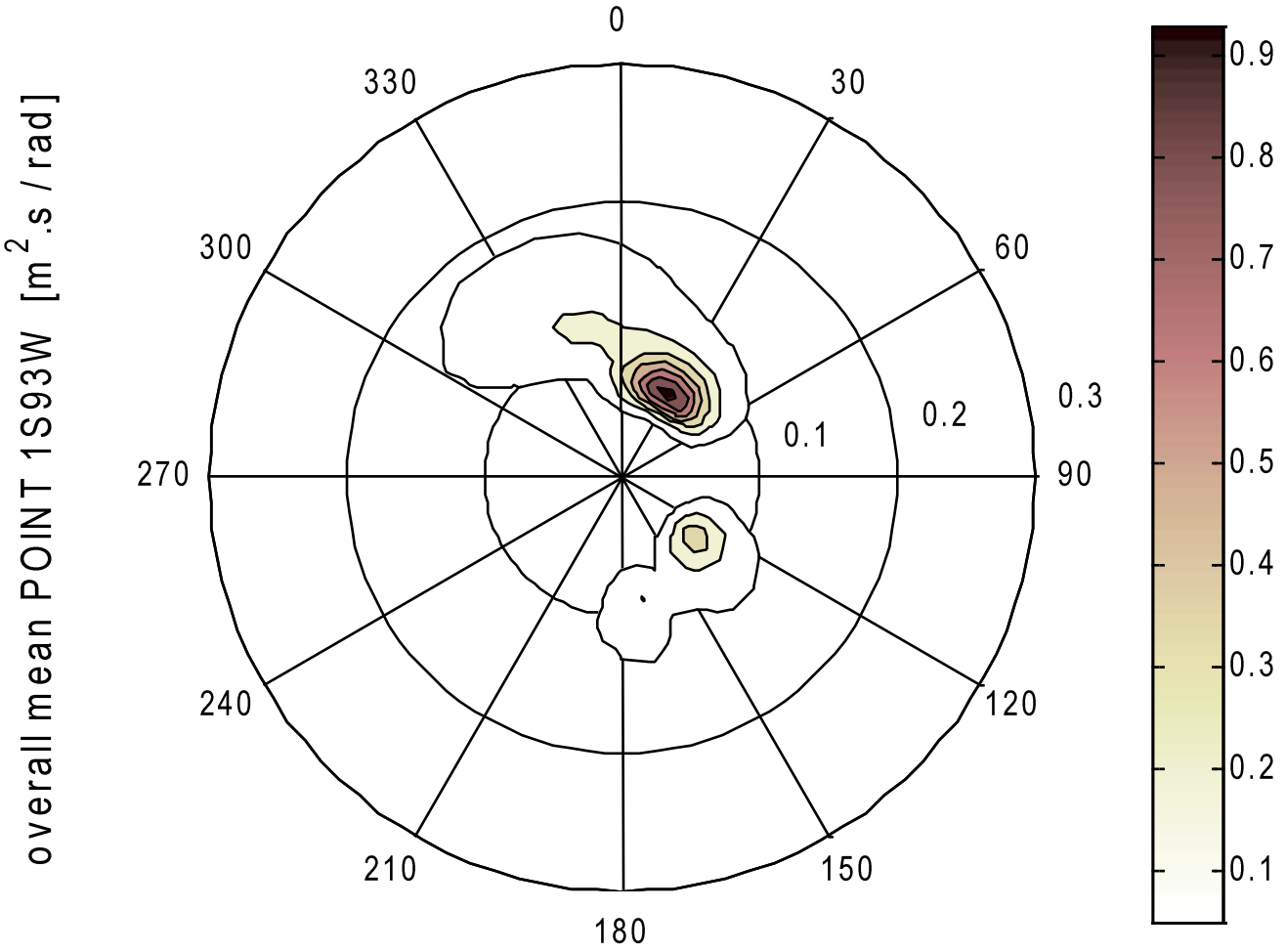




Verification data

ECMWF reanalysis data (ERA Interim)

Spectral statistics at Galapagos (21 years of data)



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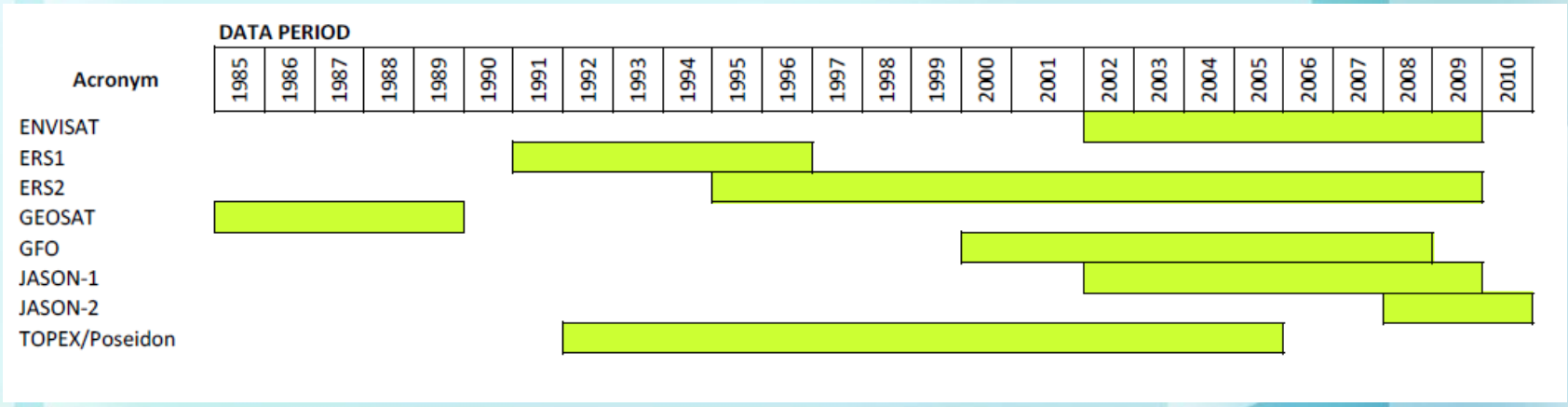
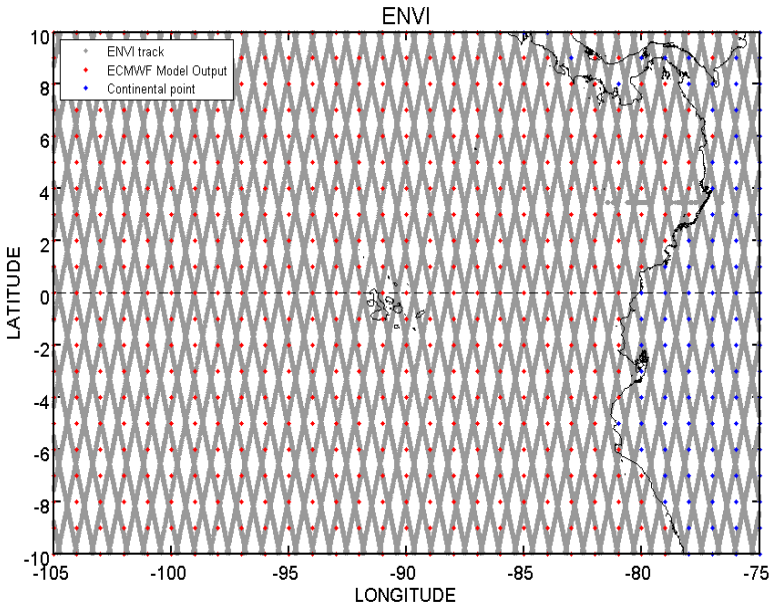
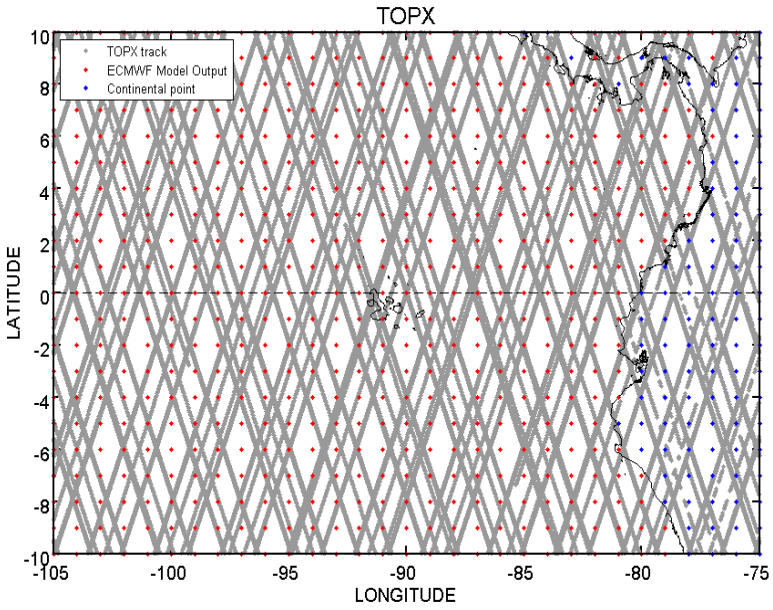
Verification data

Altimeter data (several missions)







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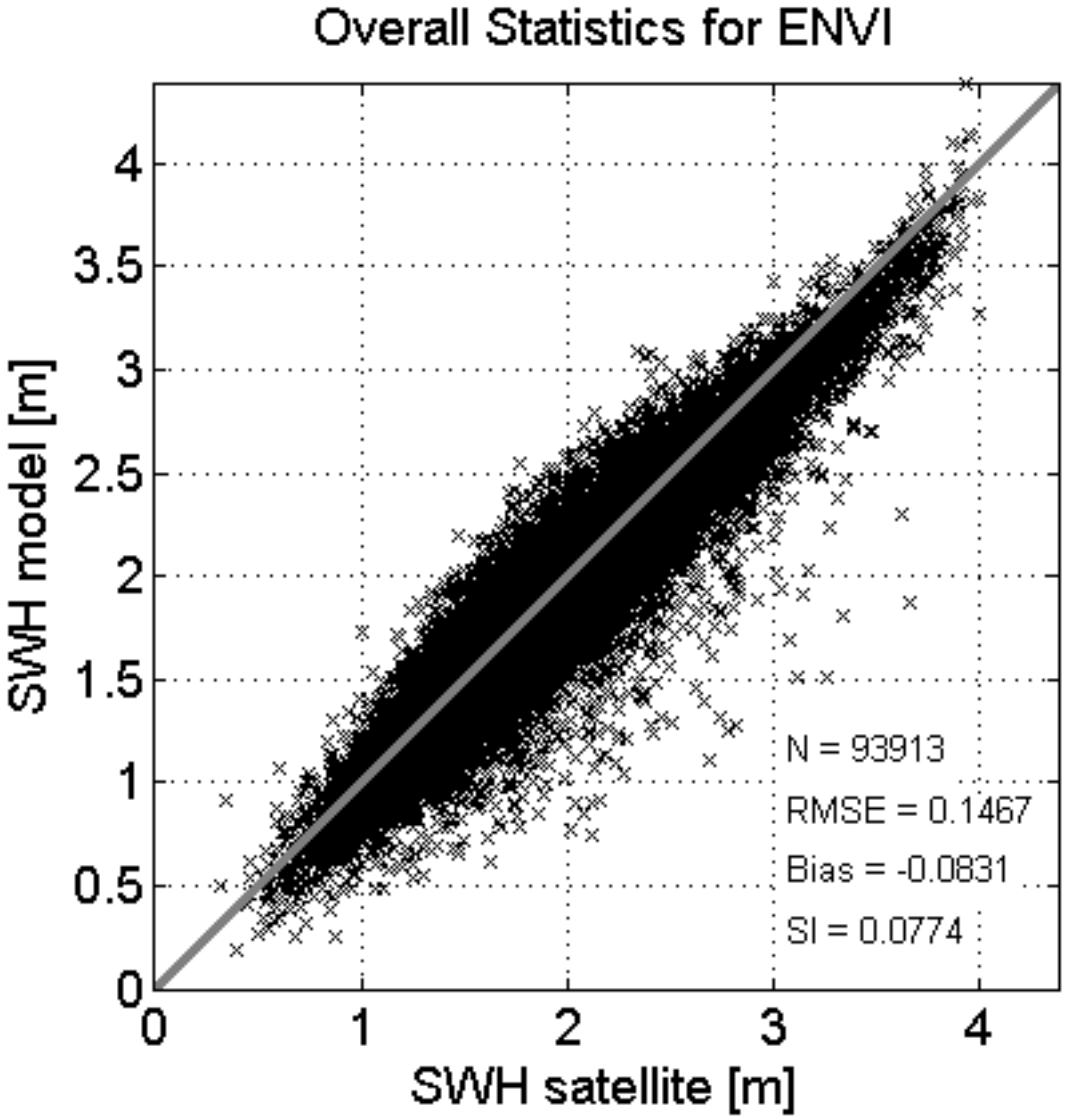

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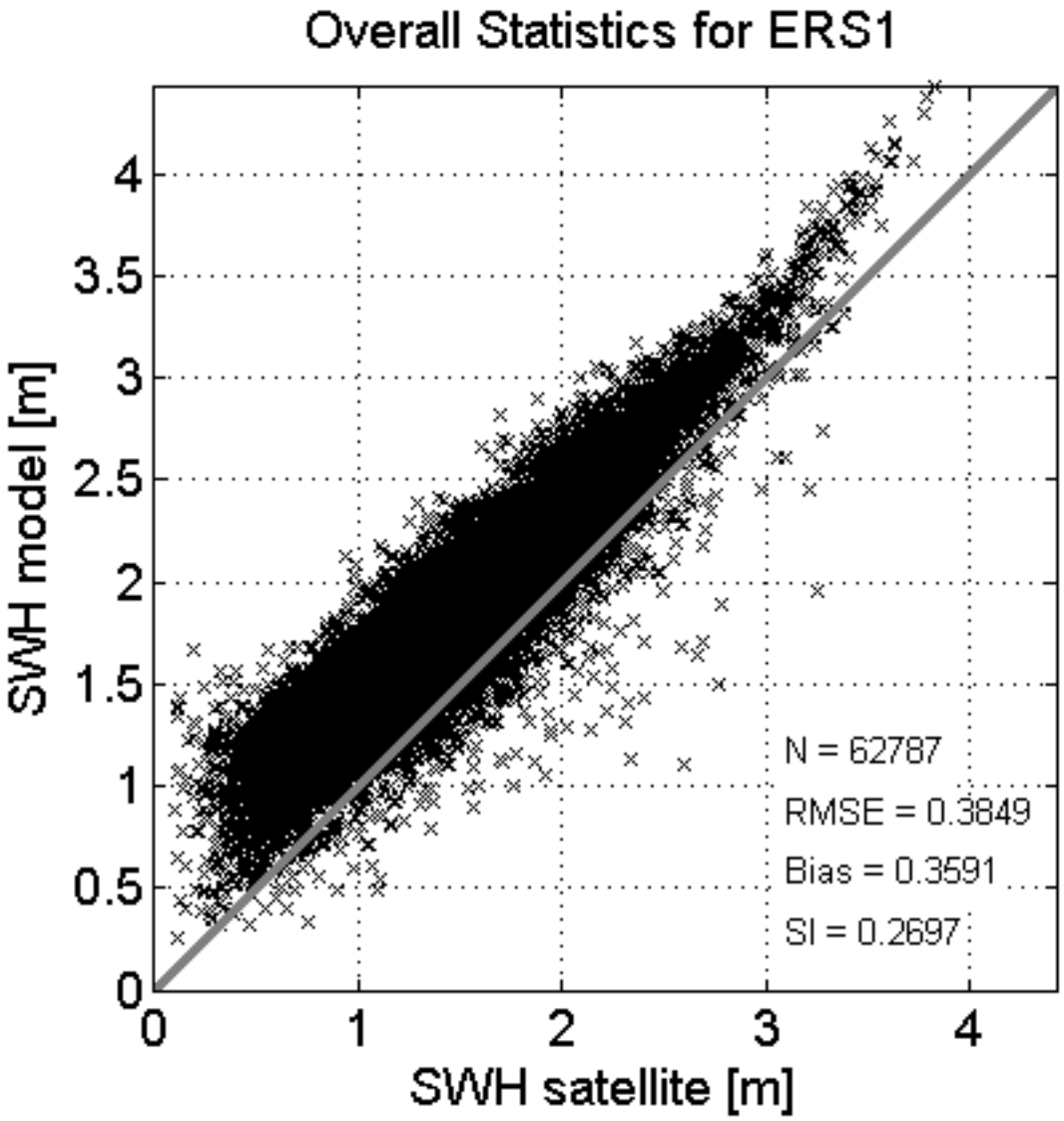
Altimeter data (several missions)



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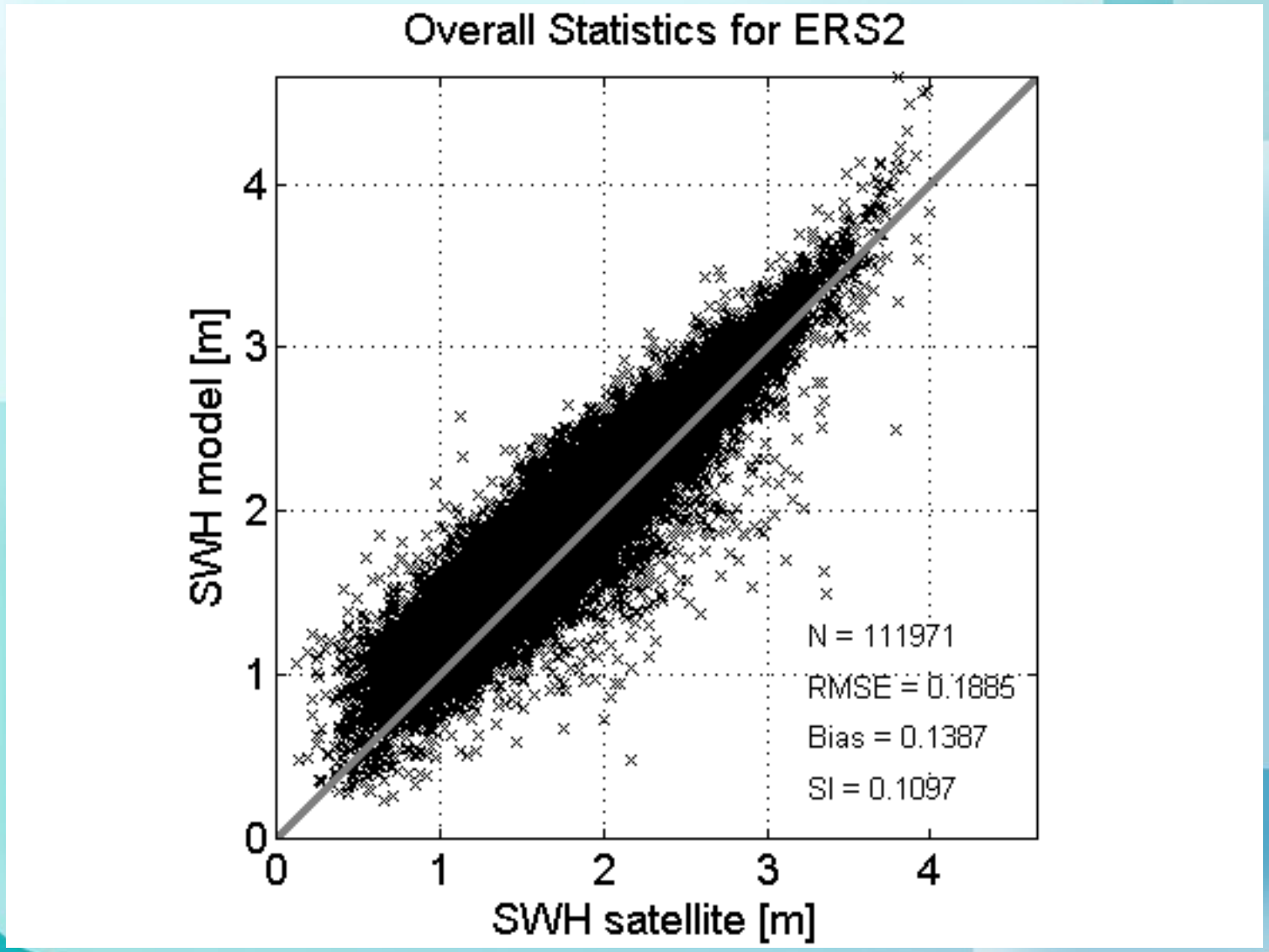
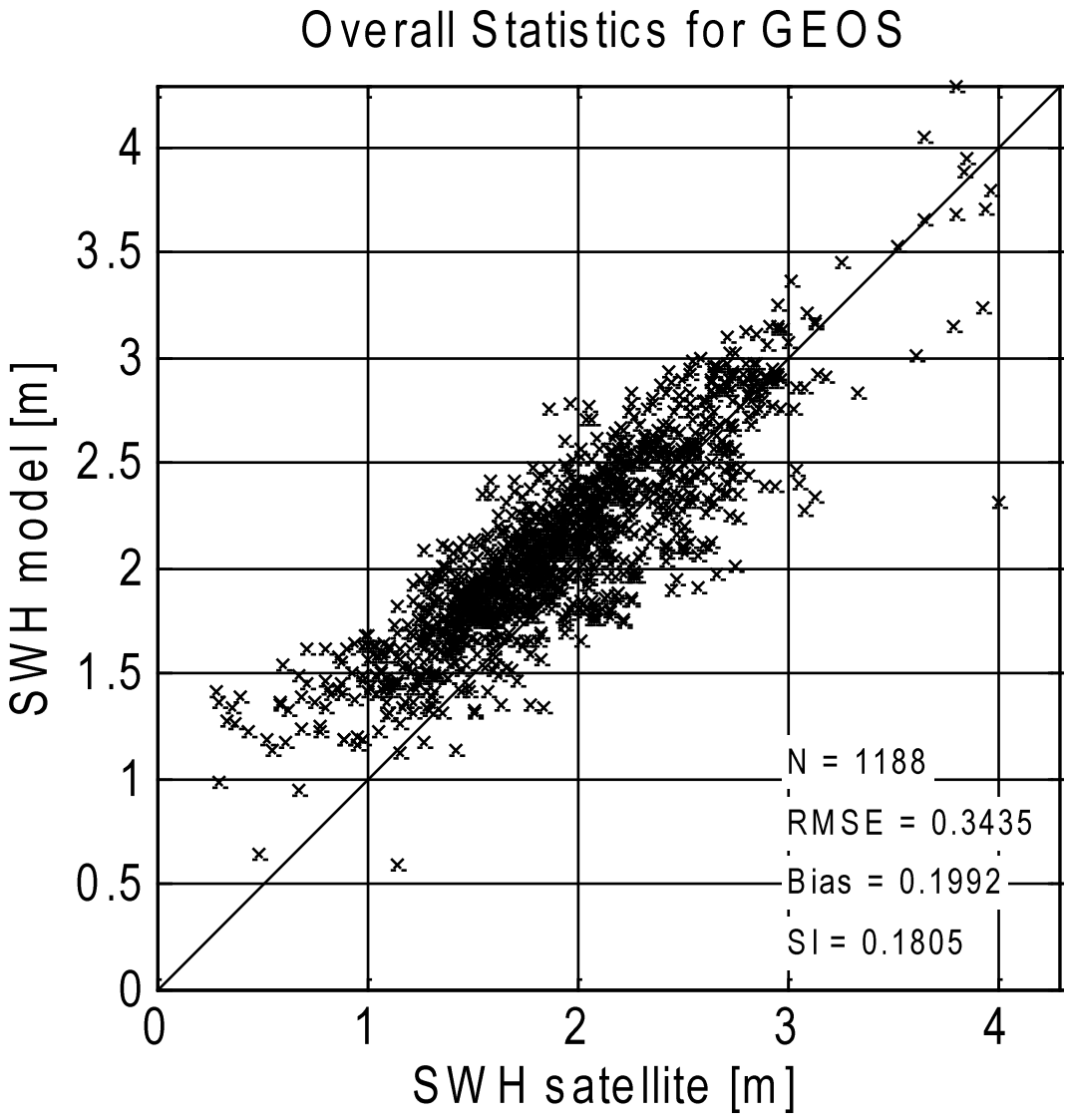
Altimeter data (several missions)



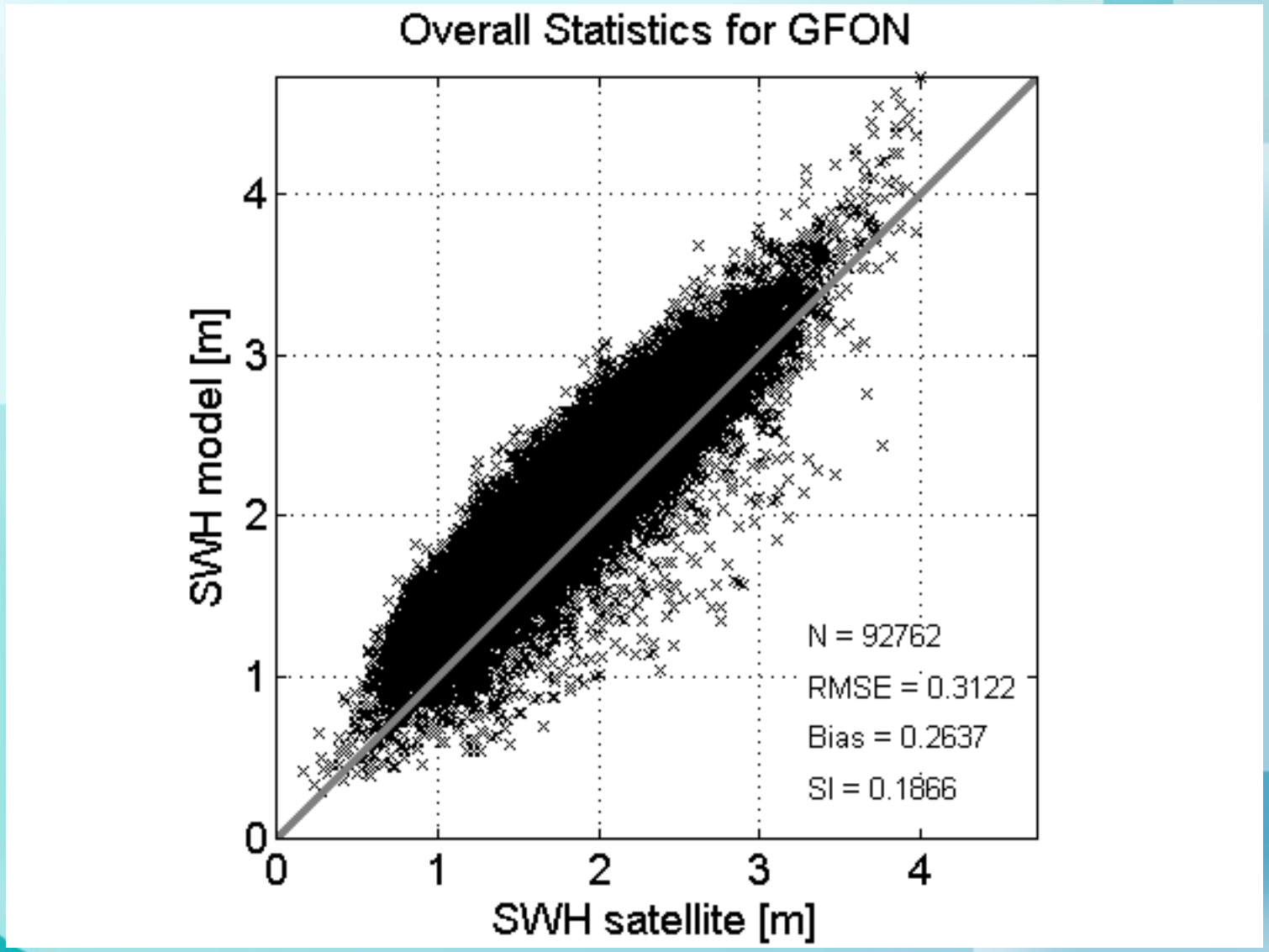
Verification data

Altimeter data (several missions)



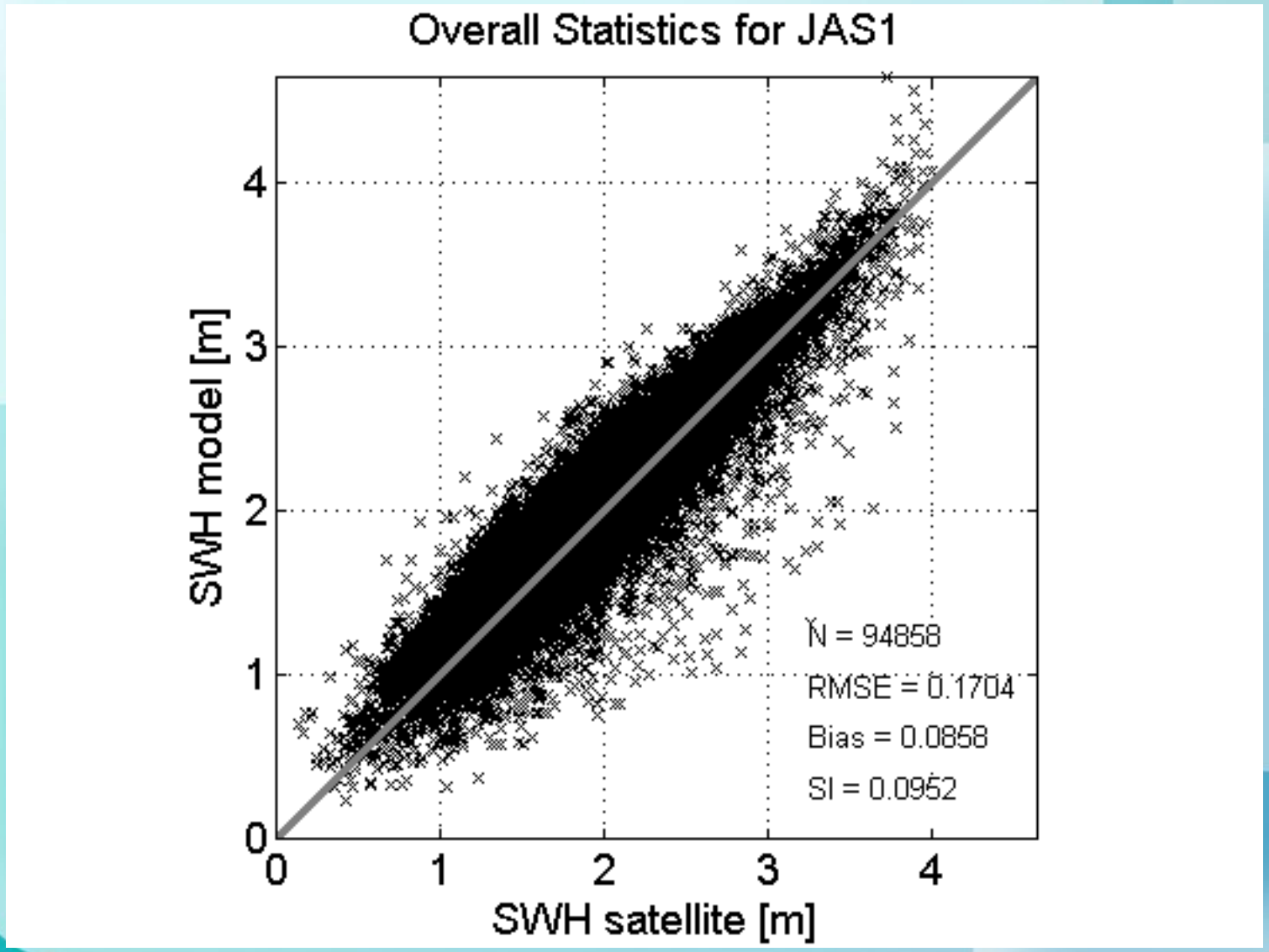
Verification data

Altimeter data (several missions)



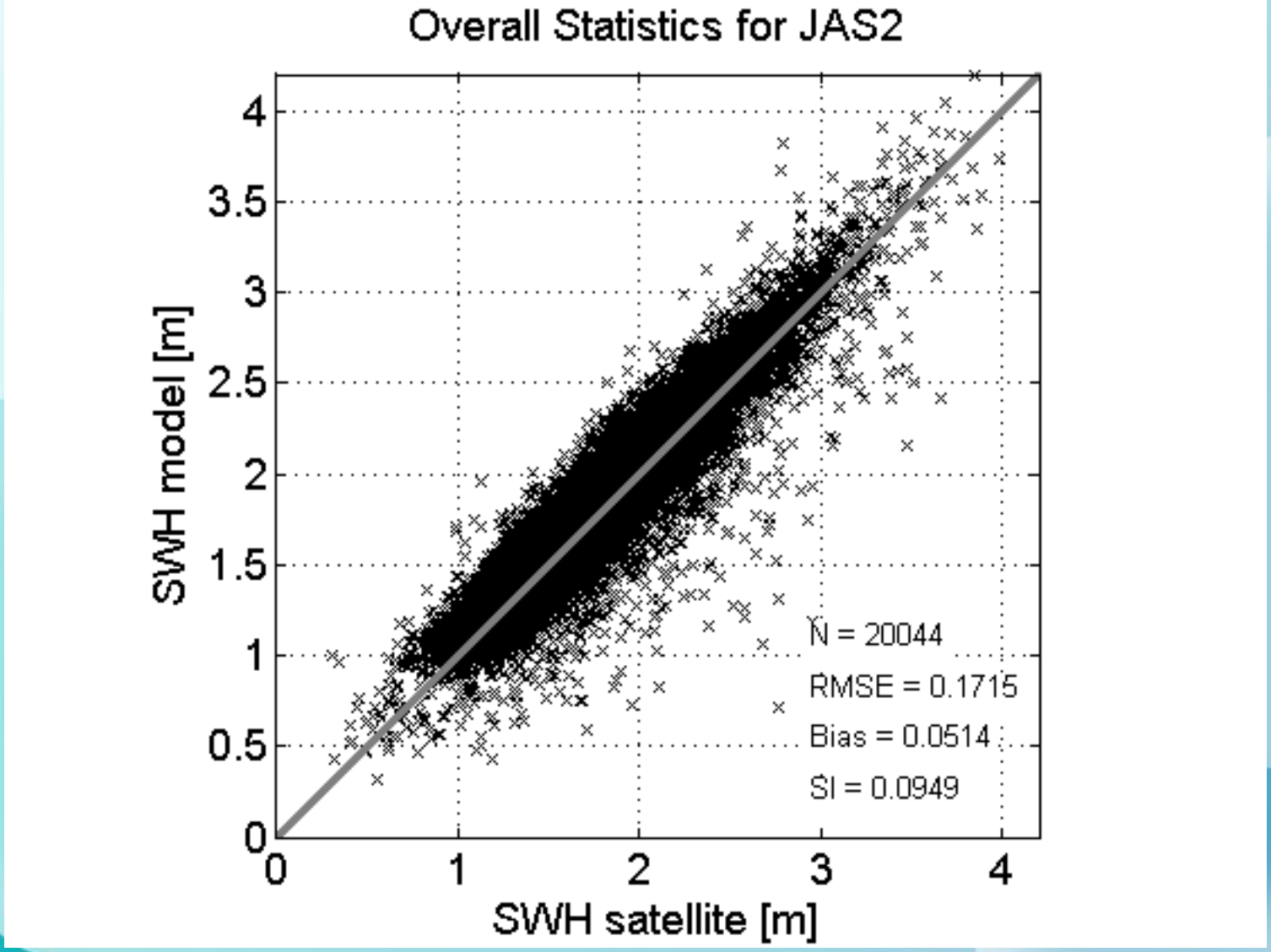
Verification data

Altimeter data (several missions)



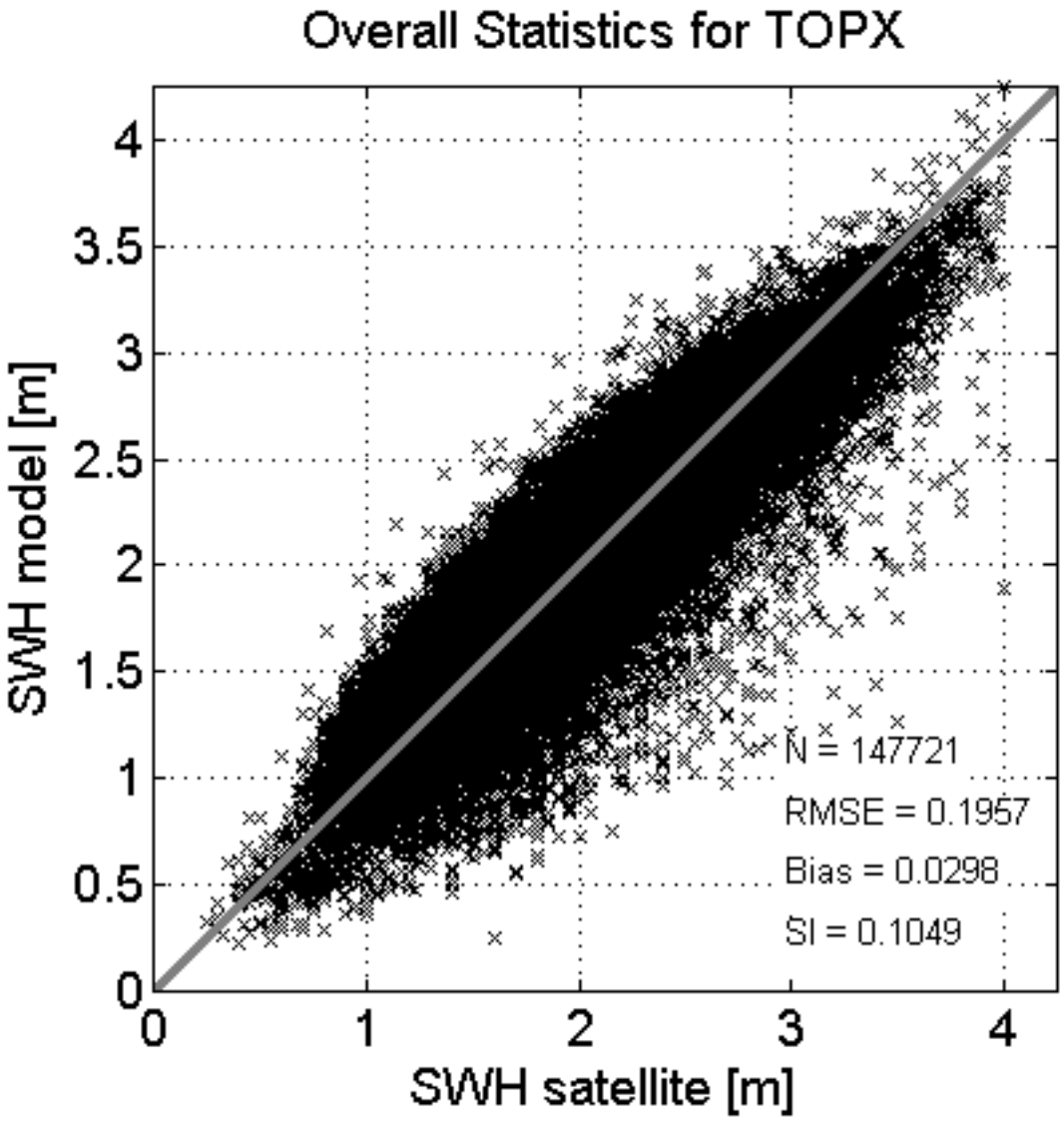
Verification data

Altimeter data (several missions)



Verification data

Altimeter data (several missions)



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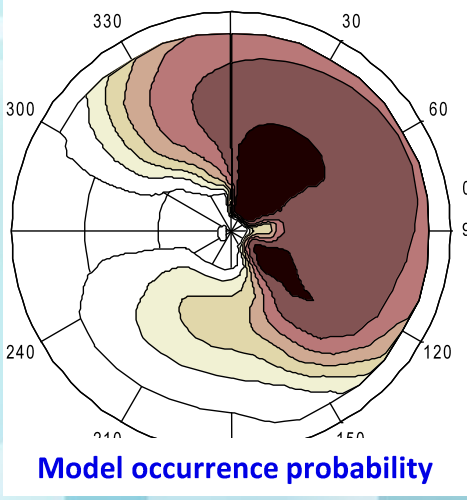
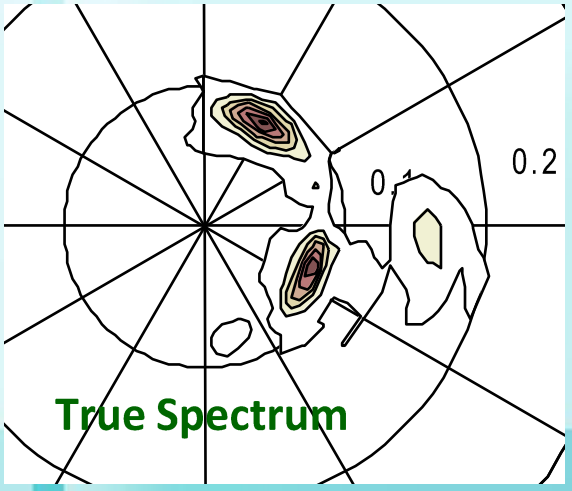
Verification data

SAR spectra (ENVISAT)

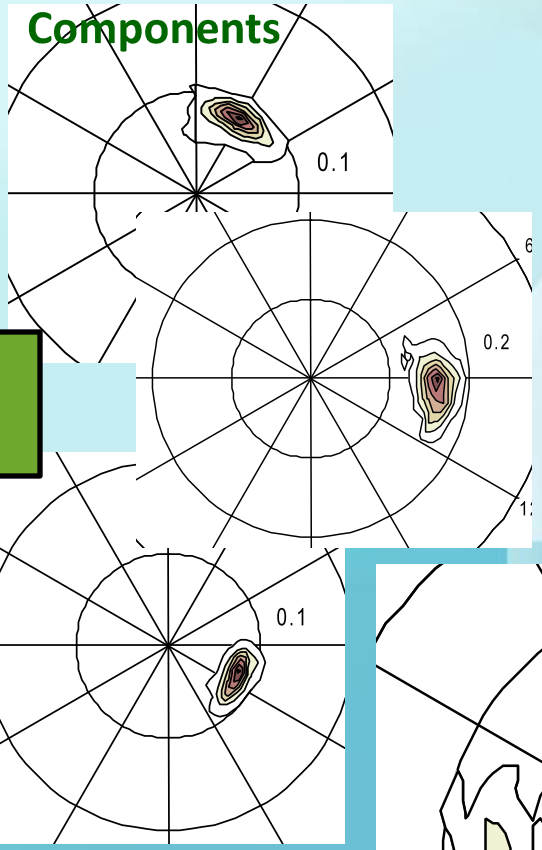


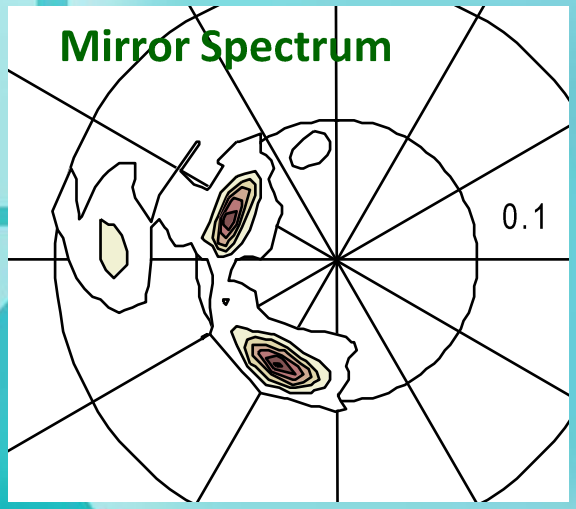
Model occurrence probability

Components

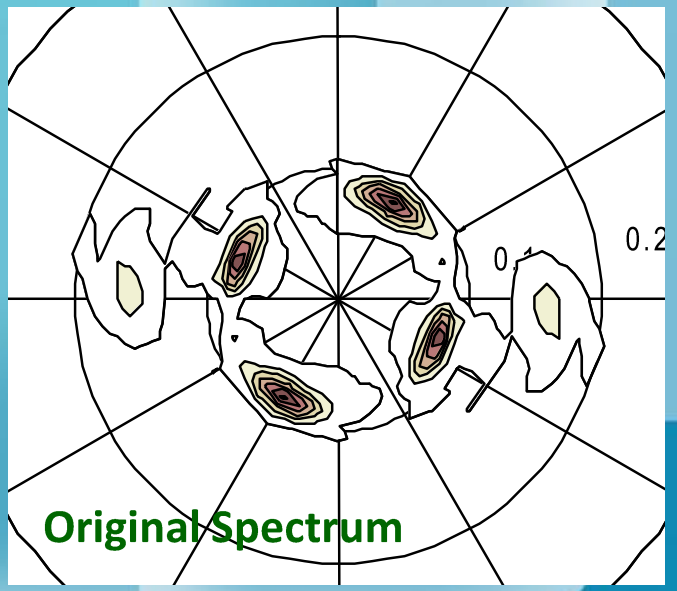


True Spectrum





Mirror Spectrum



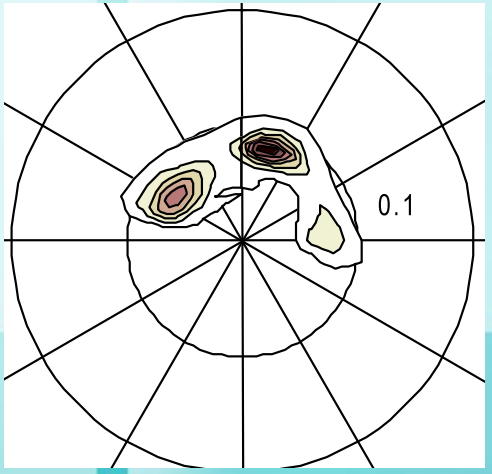
Original Spectrum

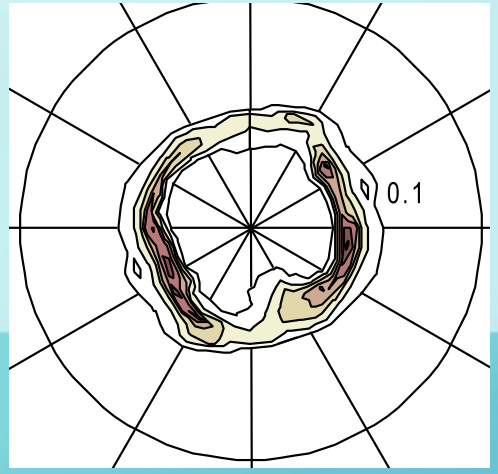
SAR Disambiguation algorithm

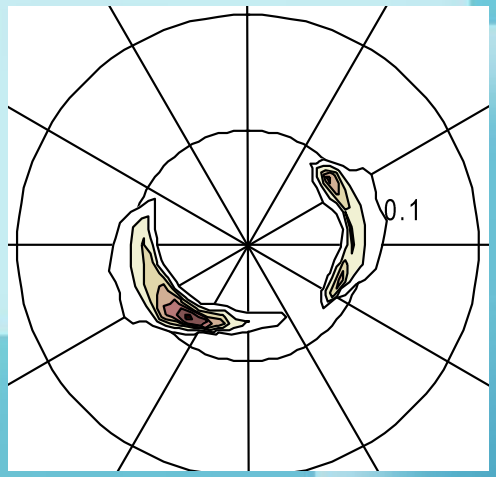
Verification data

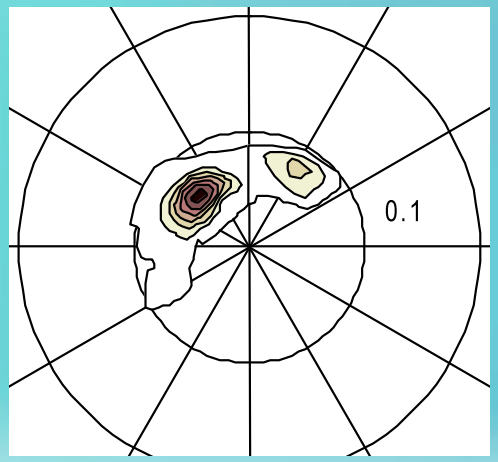
SAR spectra (ENVISAT)

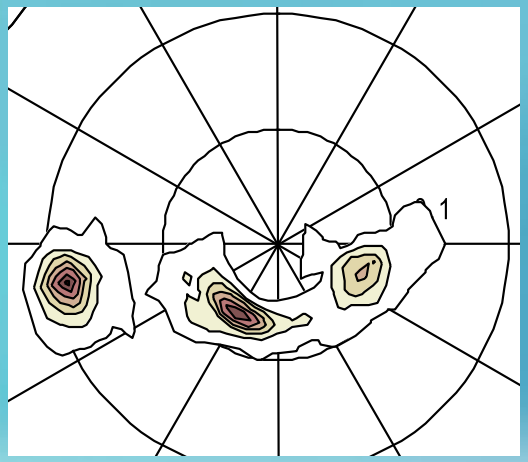
Issues with the L2P level products

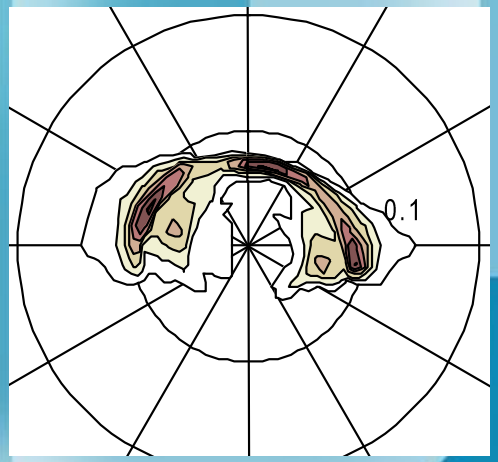












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Verification data

Seismic Noise

Ocean wave sources of seismic noise ***2011***
Ardhuin F., Stutzmann E., Schimmel M., Mangeney A.
Journal of Geophysical Research, V. 116, C09004, doi:10.1029/2011JC006952, 2011

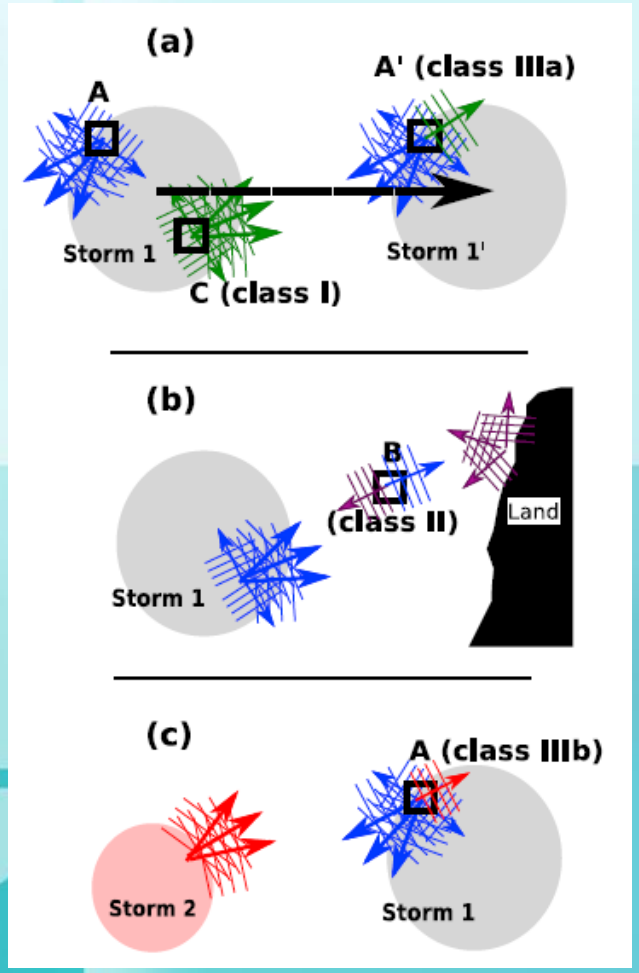
"Ocean waves are known to generate microseisms via at least two distinct generation mechanisms. [*Hasselmann, 1963].*
We consider microseisms, which are generated over large regions of the ocean. They appear when ocean wave trains with nearly opposite directions and frequency *are superimposed [Longuet-Higgins, 1950], which* makes noise at the double frequency*."*

STATIONS

- **Galapagos**
- **Otavalo**

Verification data

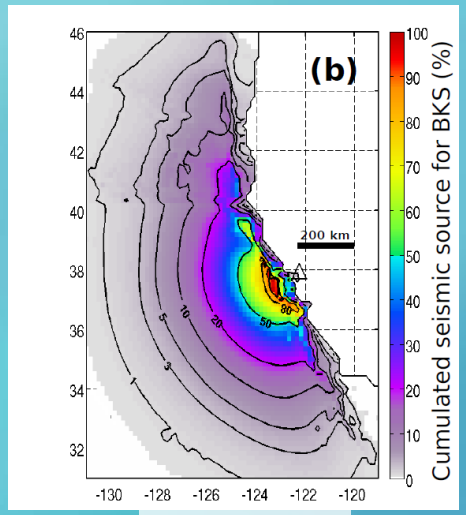
Seismic Noise



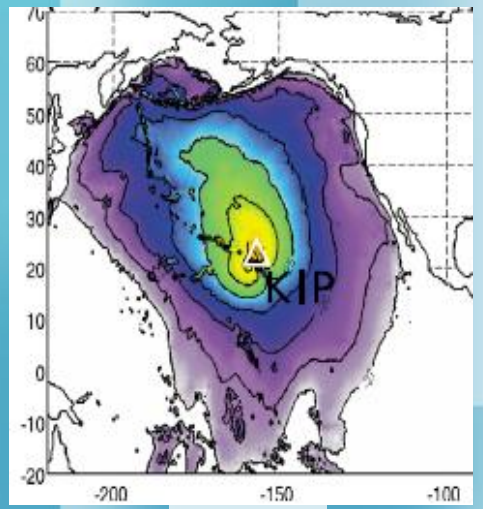
Noise generation conditions

- ❖ Moving storm
- ❖ Coastal reflexion
- ❖ Opposing wave systems

Seismic noise source



California



Hawaii

Ocean wave sources of seismic noise ***2011***
Ardhuin F., Stutzmann E., Schimmel M., Mangeney A.
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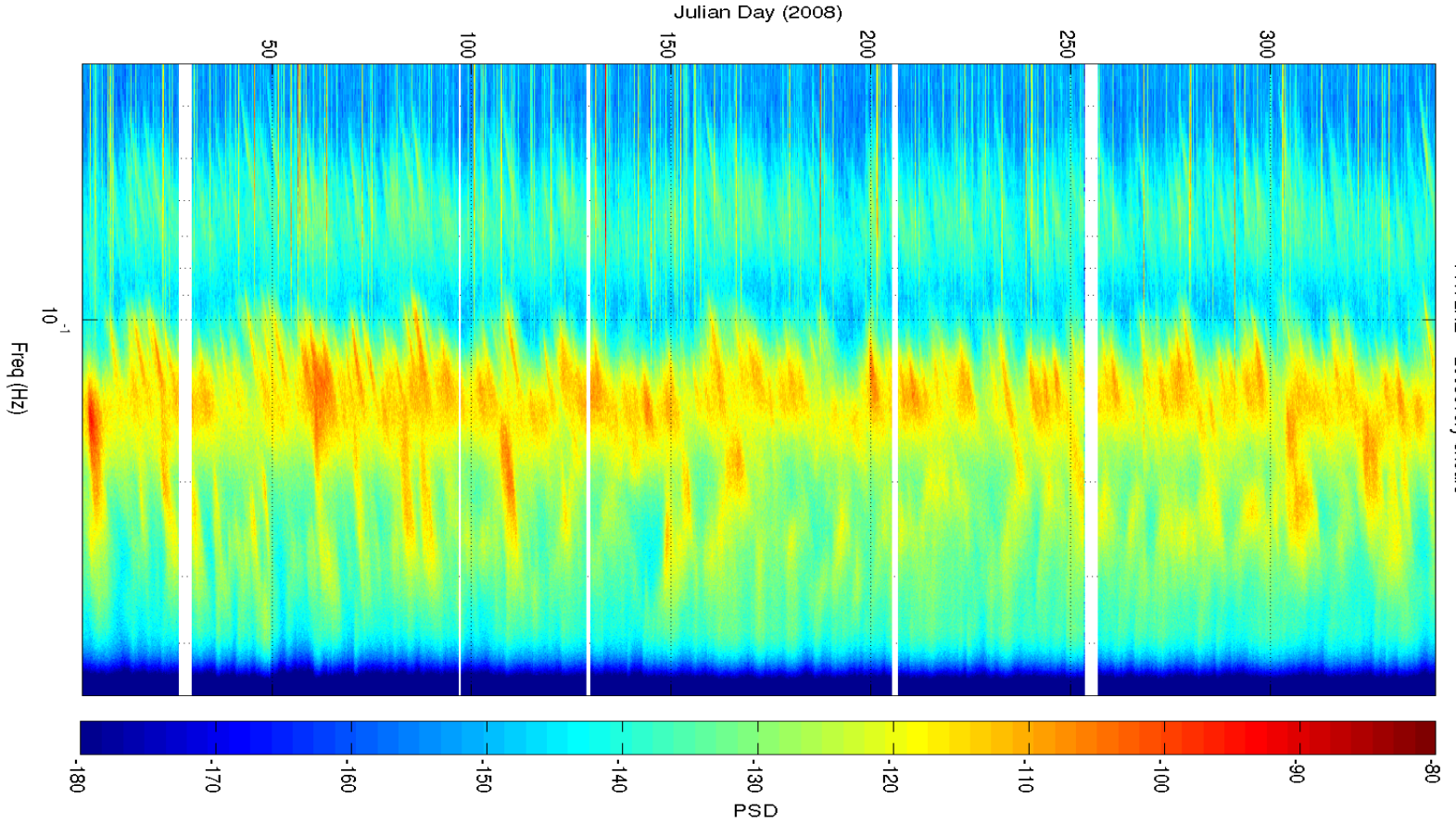
Verification data

Seismic Noise

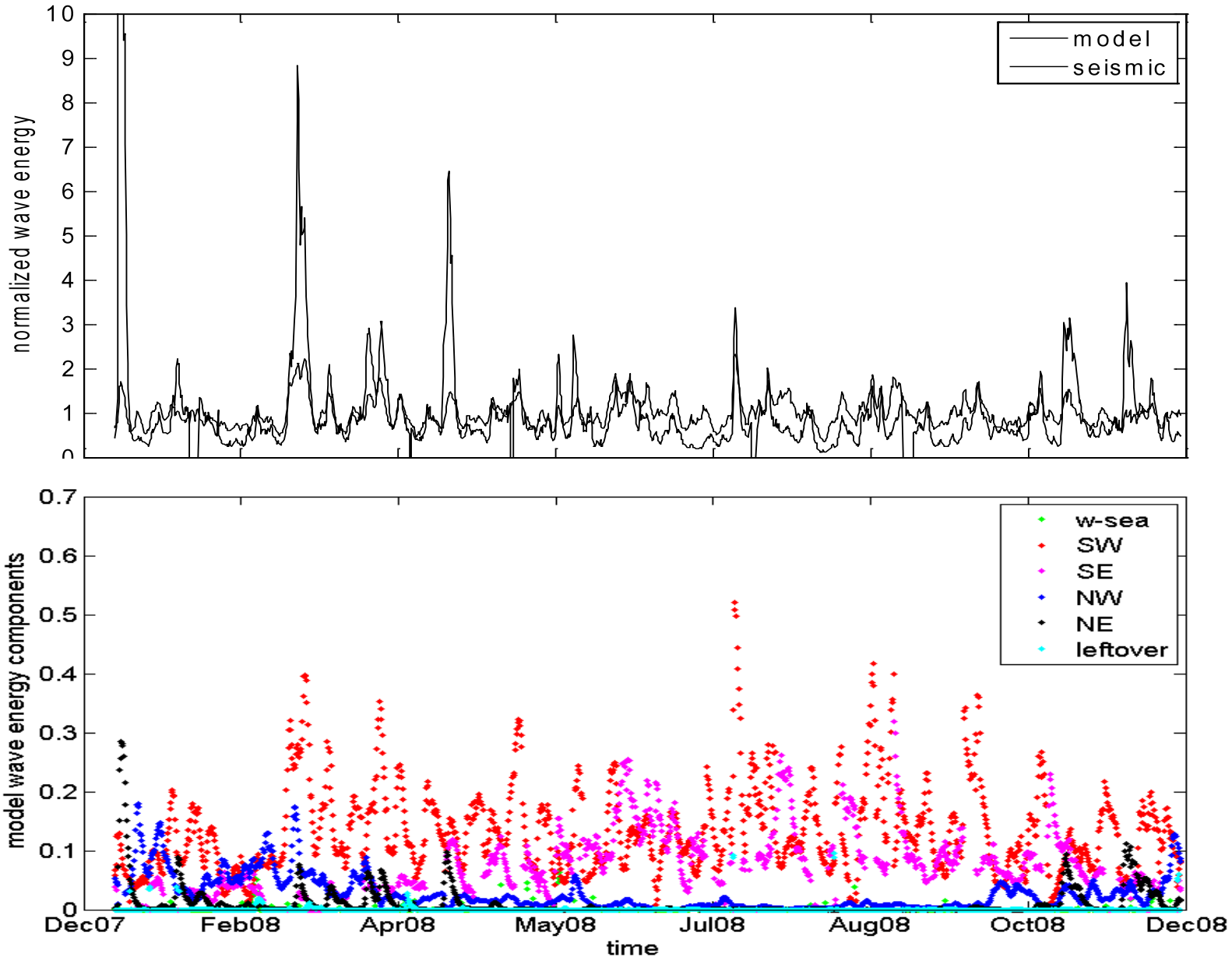
STATION: PAYG - Galapagos



Verification data

Seismic Noise

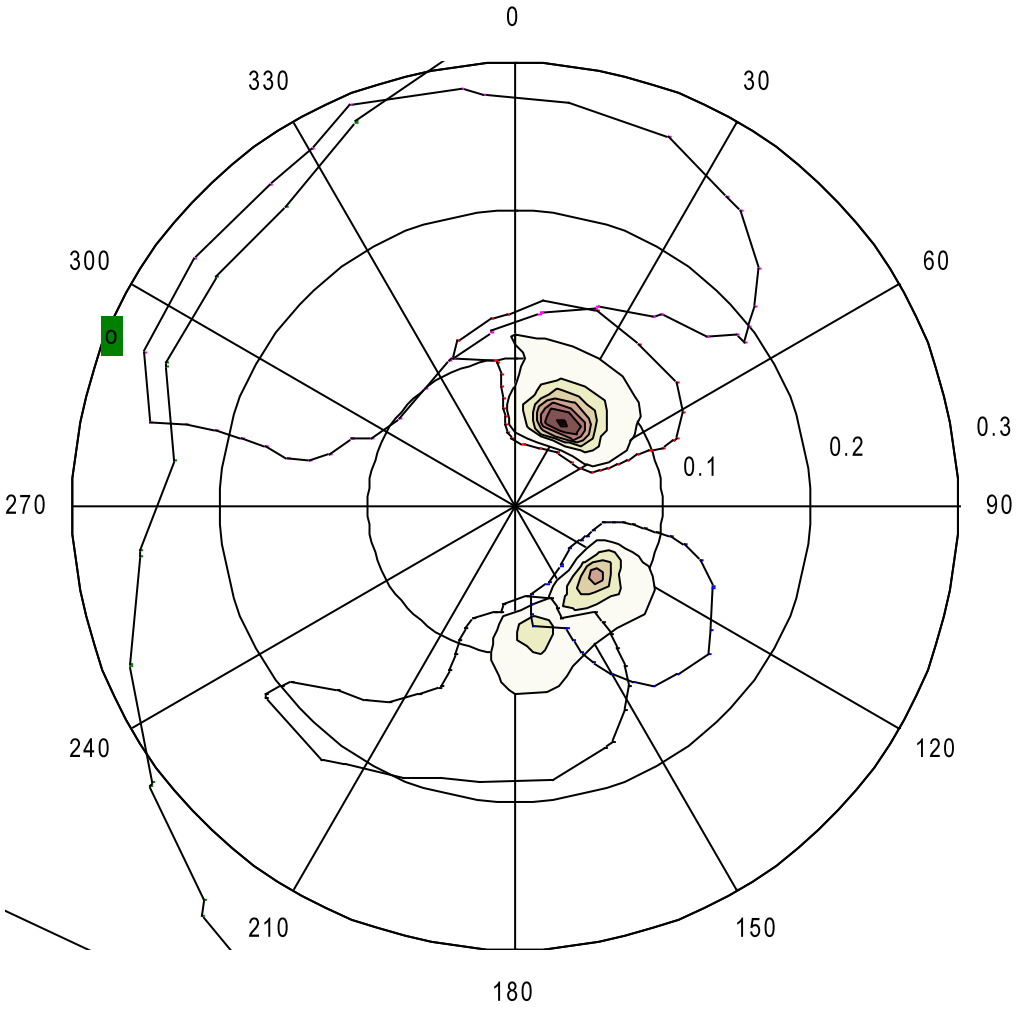
STATION: PAYG - Galapagos



Verification data

Seismic Noise

STATION: PAYG - Galapagos



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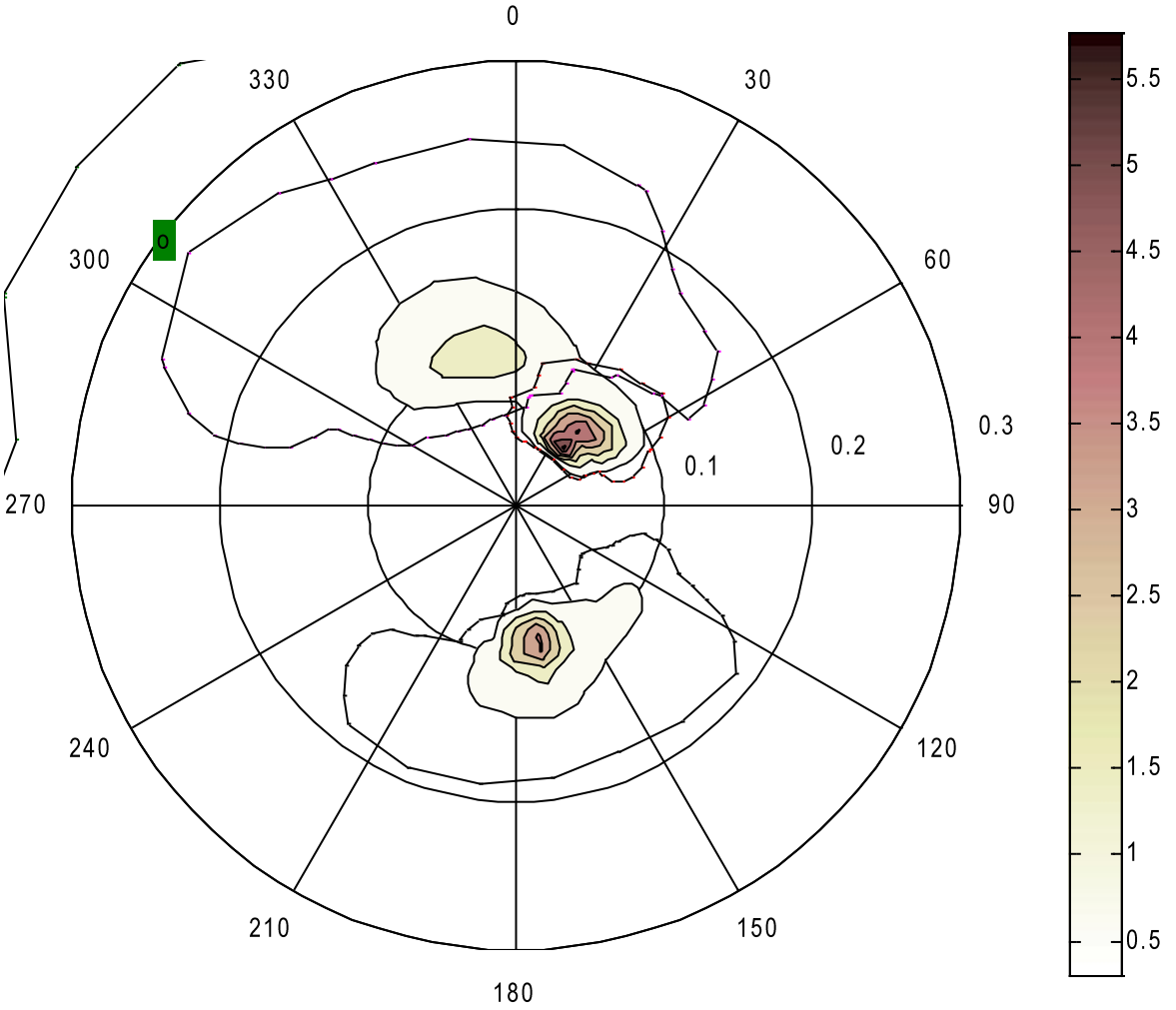
Verification data

Seismic Noise

STATION: PAYG - Galapagos



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Outline

- Applications
- The WaveWatchIII™ model
- Model setup
- Input data
  - Bathymetry
  - Wind fields
  - Ice coverage
- Verification data
  - ECMWF reanalysis data
  - Altimeter
  - SAR spectra
  - Seismic noise
- **Storm source detection algorithm**
- Preliminary results
- Summary, conclusions and further work

Storm source detection algorithm

Theoretical background

The dispersion relationship (linear wave theory), shows that ocean gravity waves are dispersive

$$\omega^2 = gk \tanh \; kd$$

In deep water the wave group velocity becomes:

$$c_g = \frac{g}{4\pi f}$$

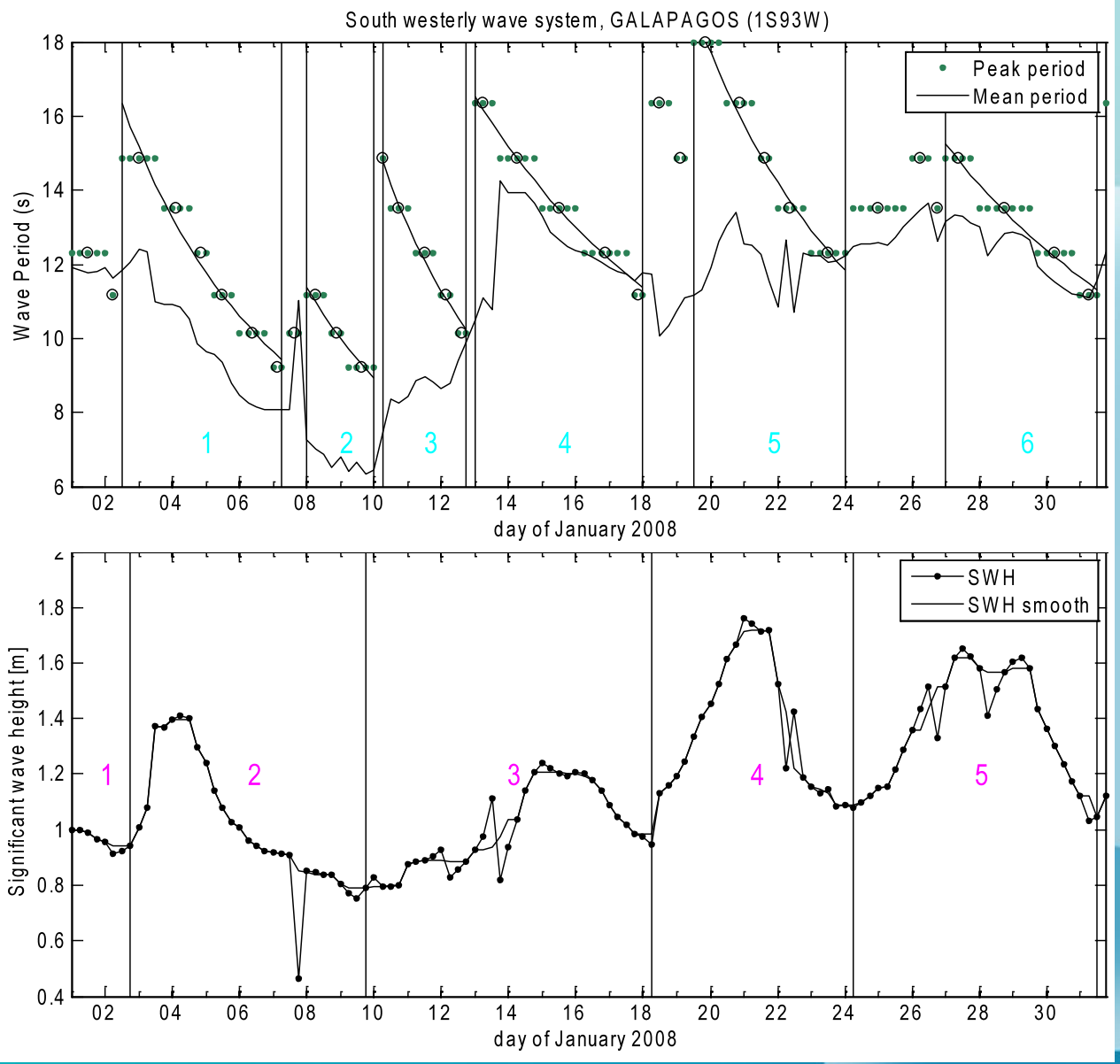
(is a function of frequency)

This property can be used in order to obtain information about the place and the time of origin of specific wave events (e.g., Munk, 1963, Snodgrass, 1966)

Storm source detection algorithm

Algorithm: Analysis of South-Westerly system

- Events are clustered by wave period
- Longer waves arrive first followed by shorter waves



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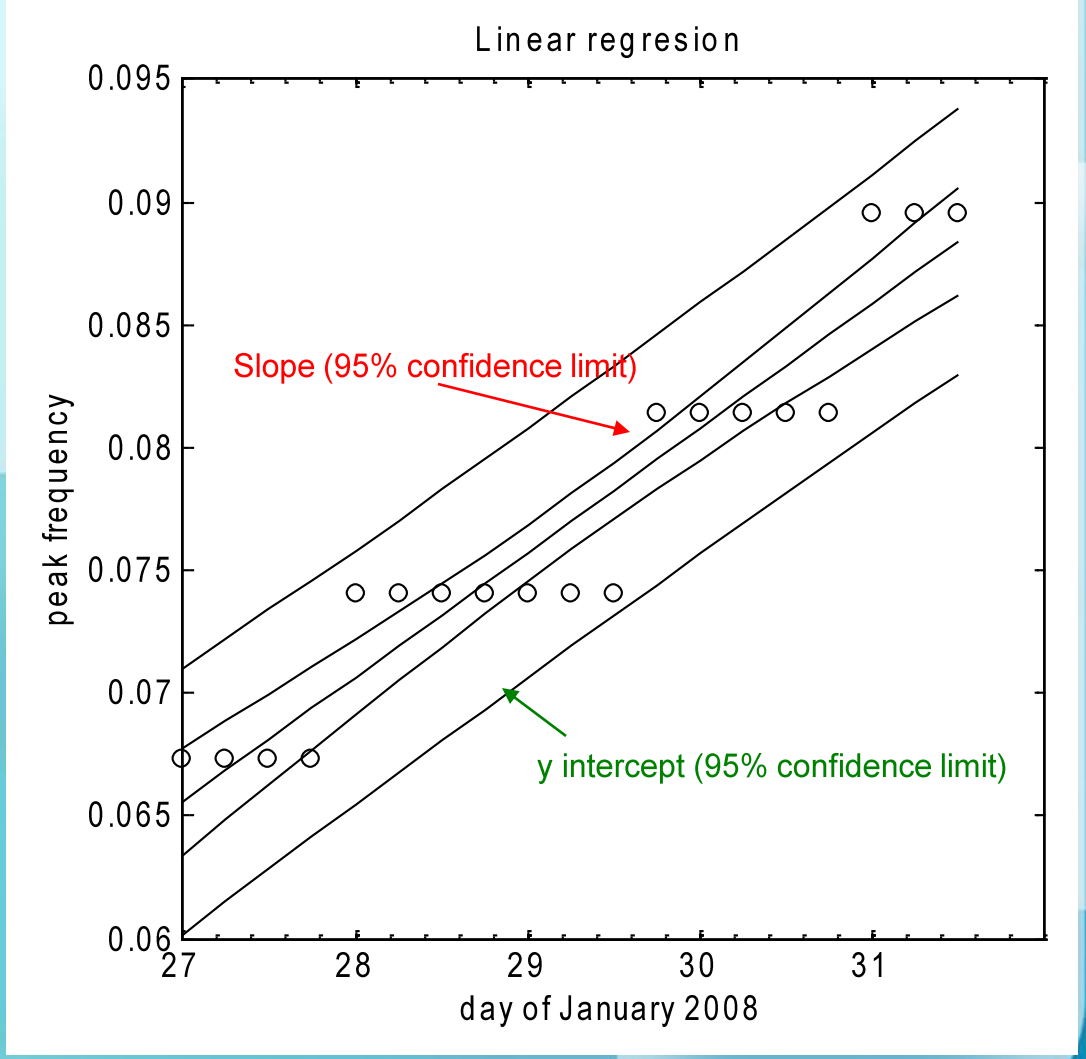
Storm source detection algorithm

Algorithm: Analysis of South-Westerly system

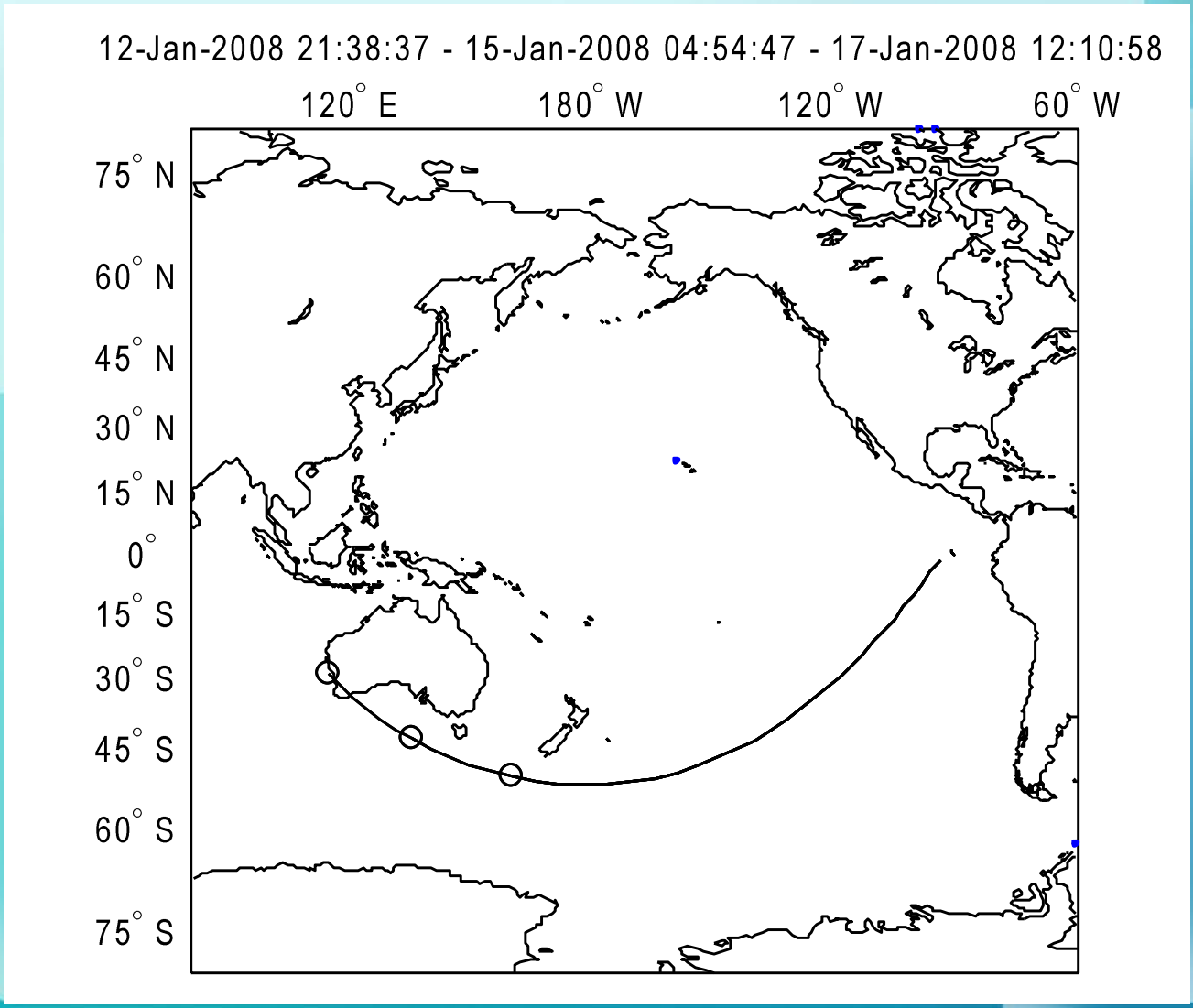
- Arrival time relates linearly with frequency, the slope correspond to the distance from origin.
- Uncertainties are associated to:
  - Model discretization
  - Storm displacement
- Confidence intervals provide space and time ranges for occurrence.



Storm source detection algorithm

Results: Analysis of South-Westerly system

Wave event of 29-Jan-2008



Storm source detection algorithm

Results: Analysis of South-Westerly system

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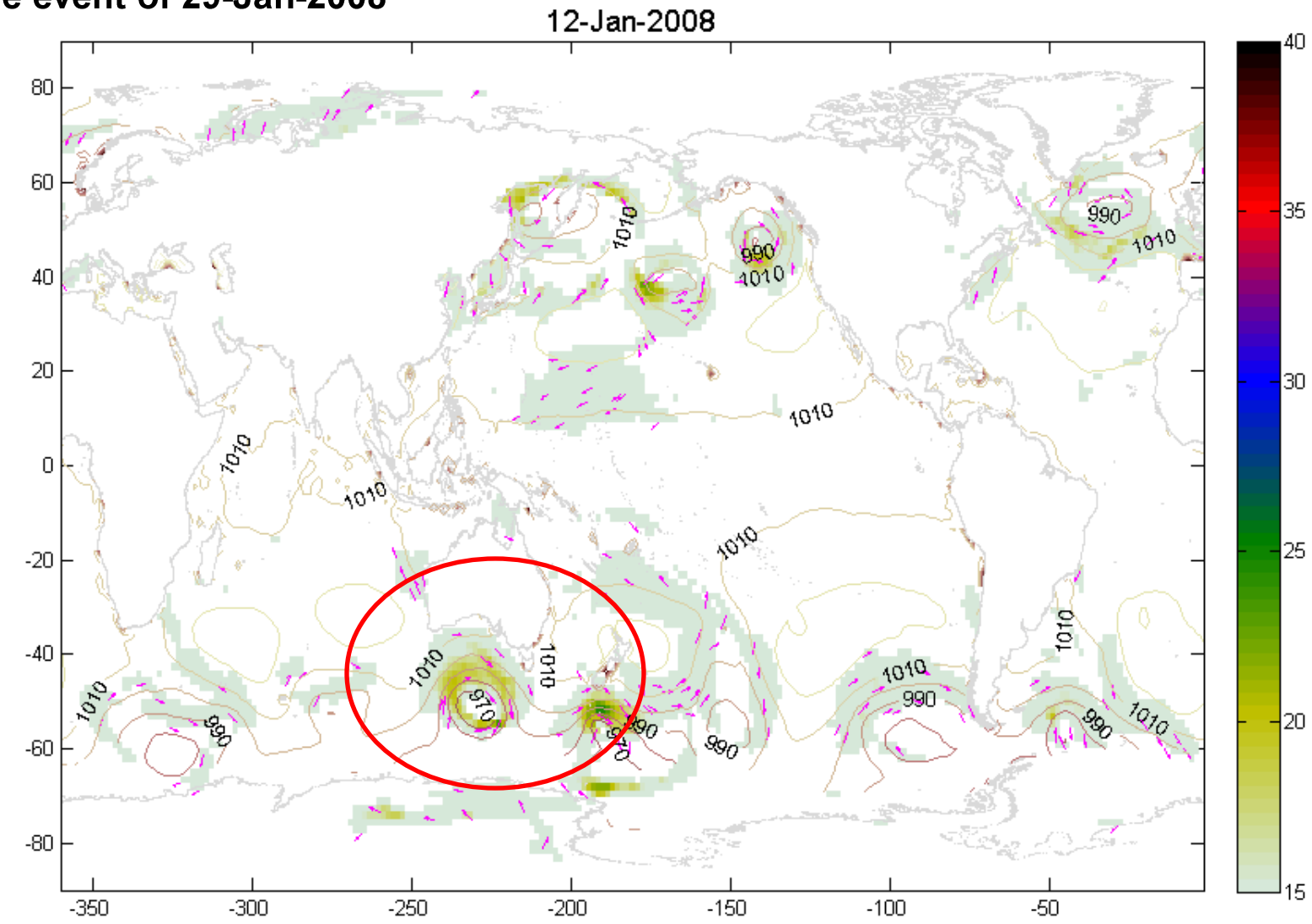
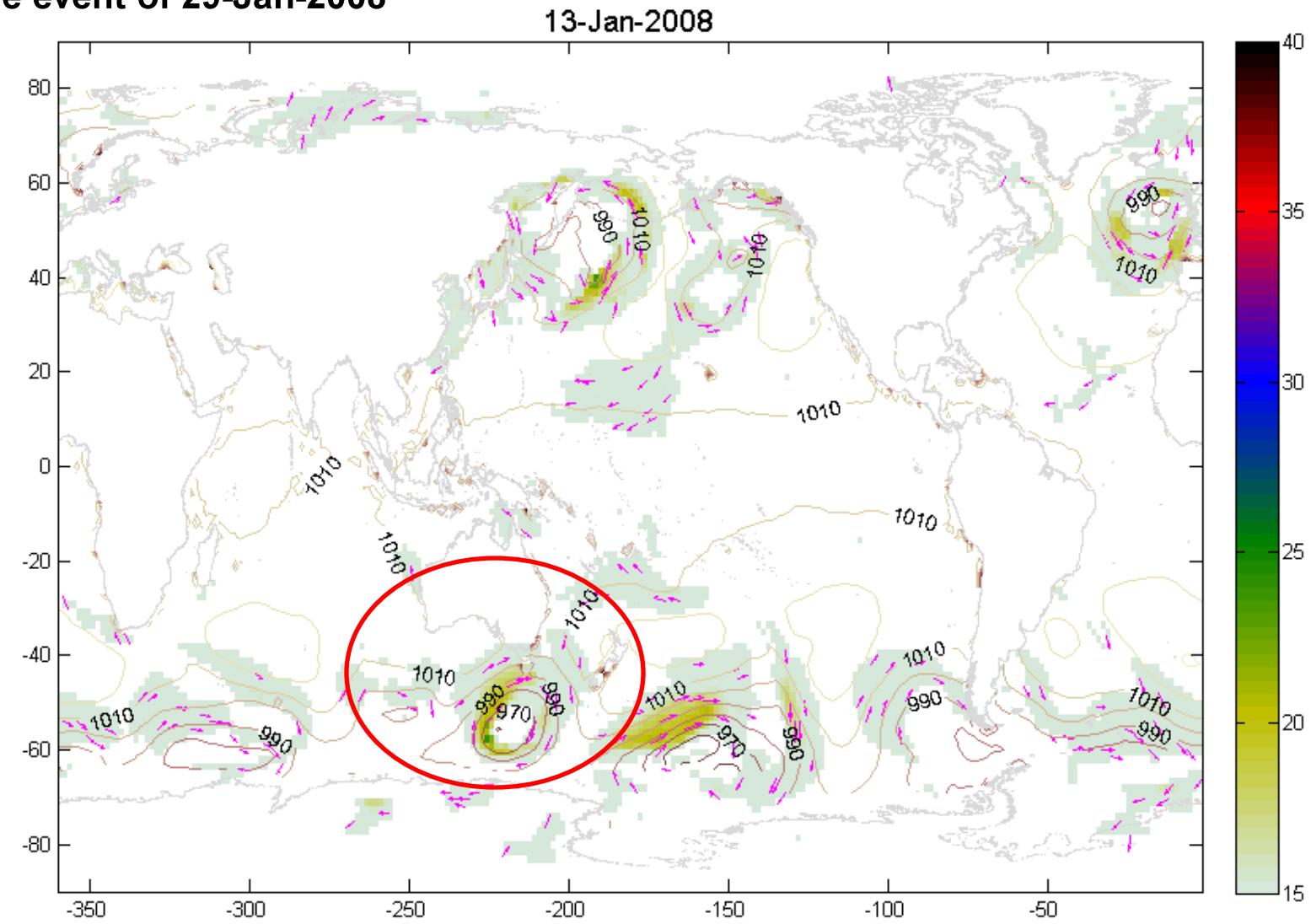


Storm source detection algorithm

Results: Analysis of South-Westerly system

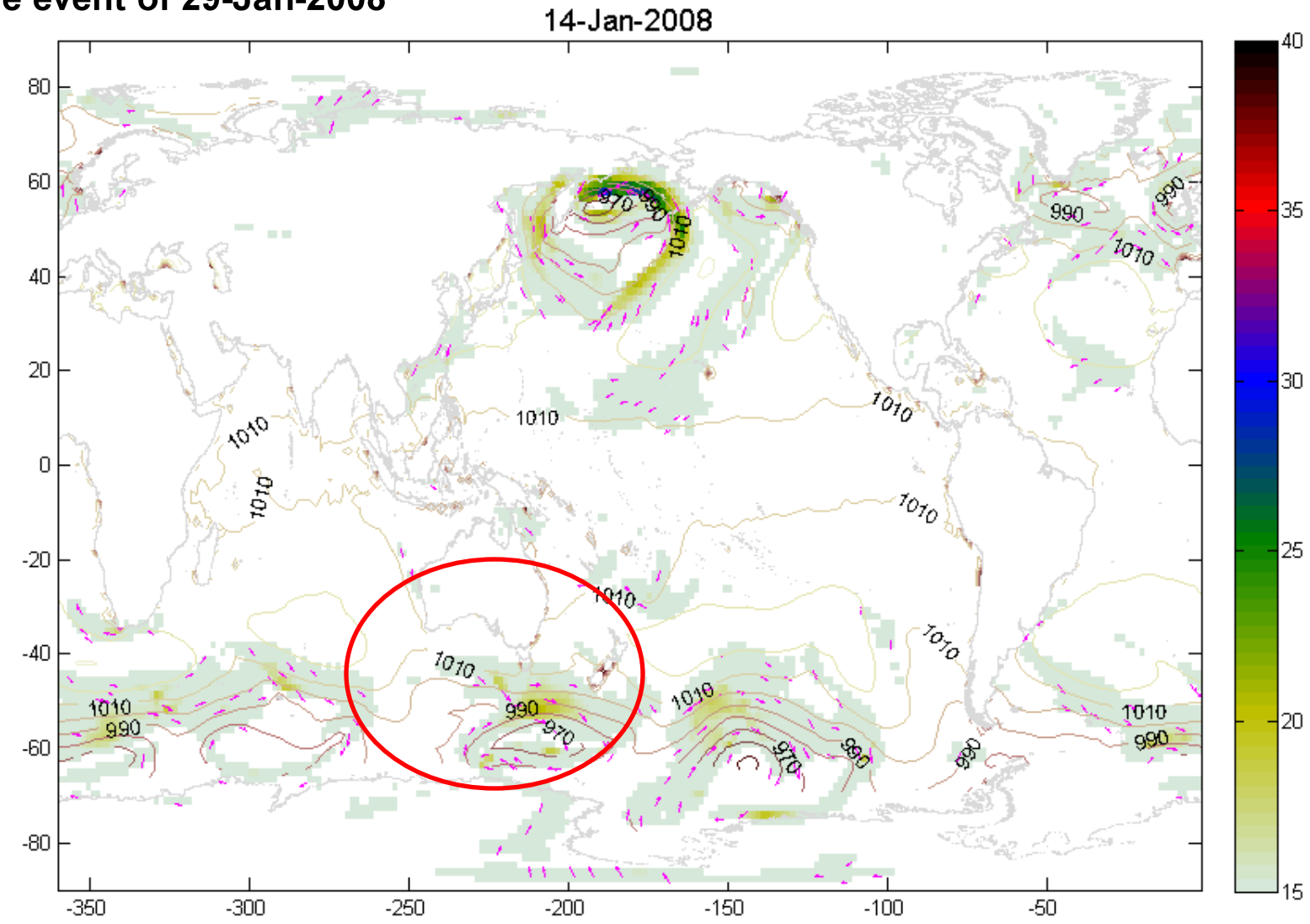
Wave event of 29-Jan-2008



Storm source detection algorithm

Results: Analysis of South-Westerly system

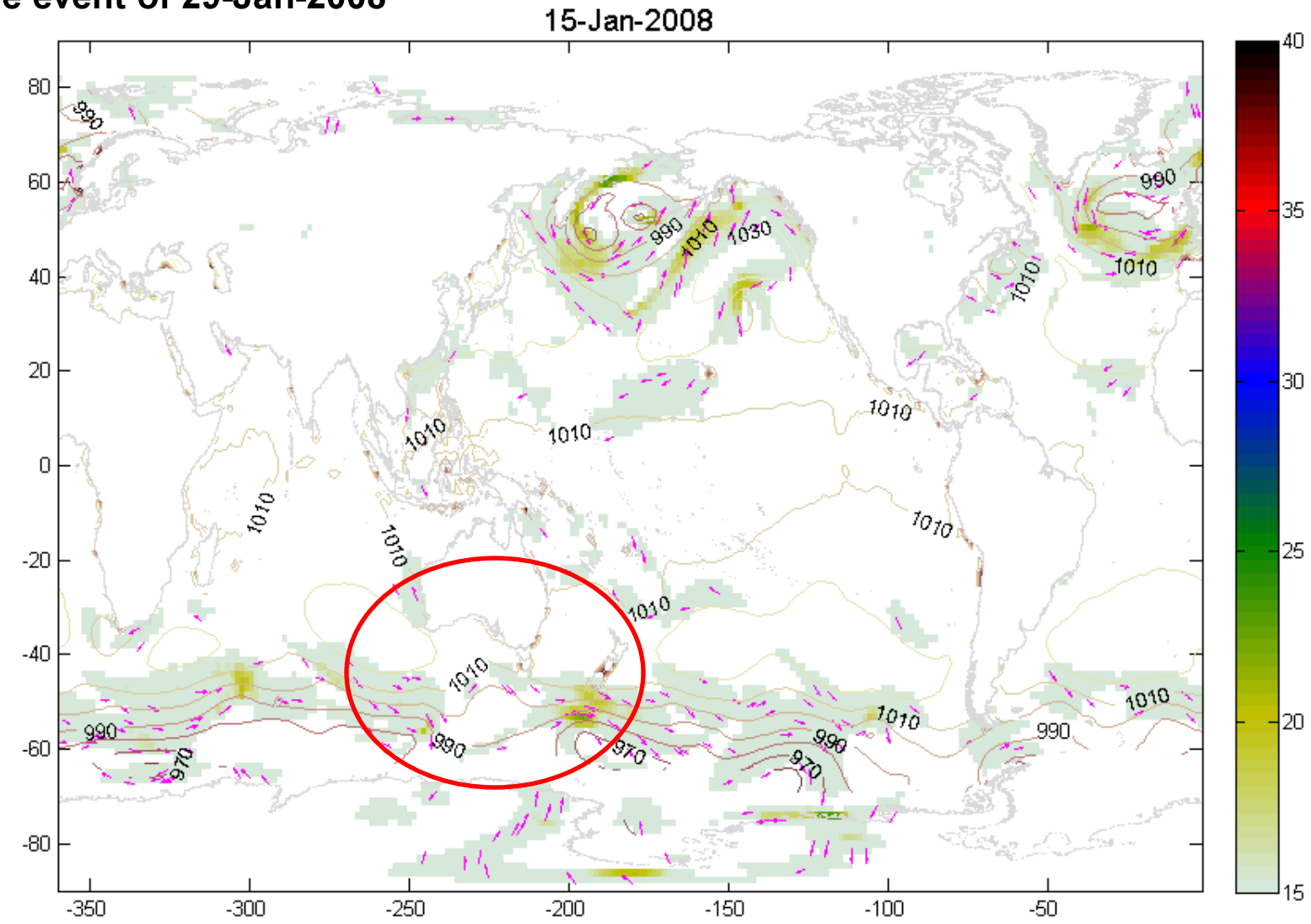
Wave event of 29-Jan-2008



Storm source detection algorithm

Results: Analysis of South-Westerly system

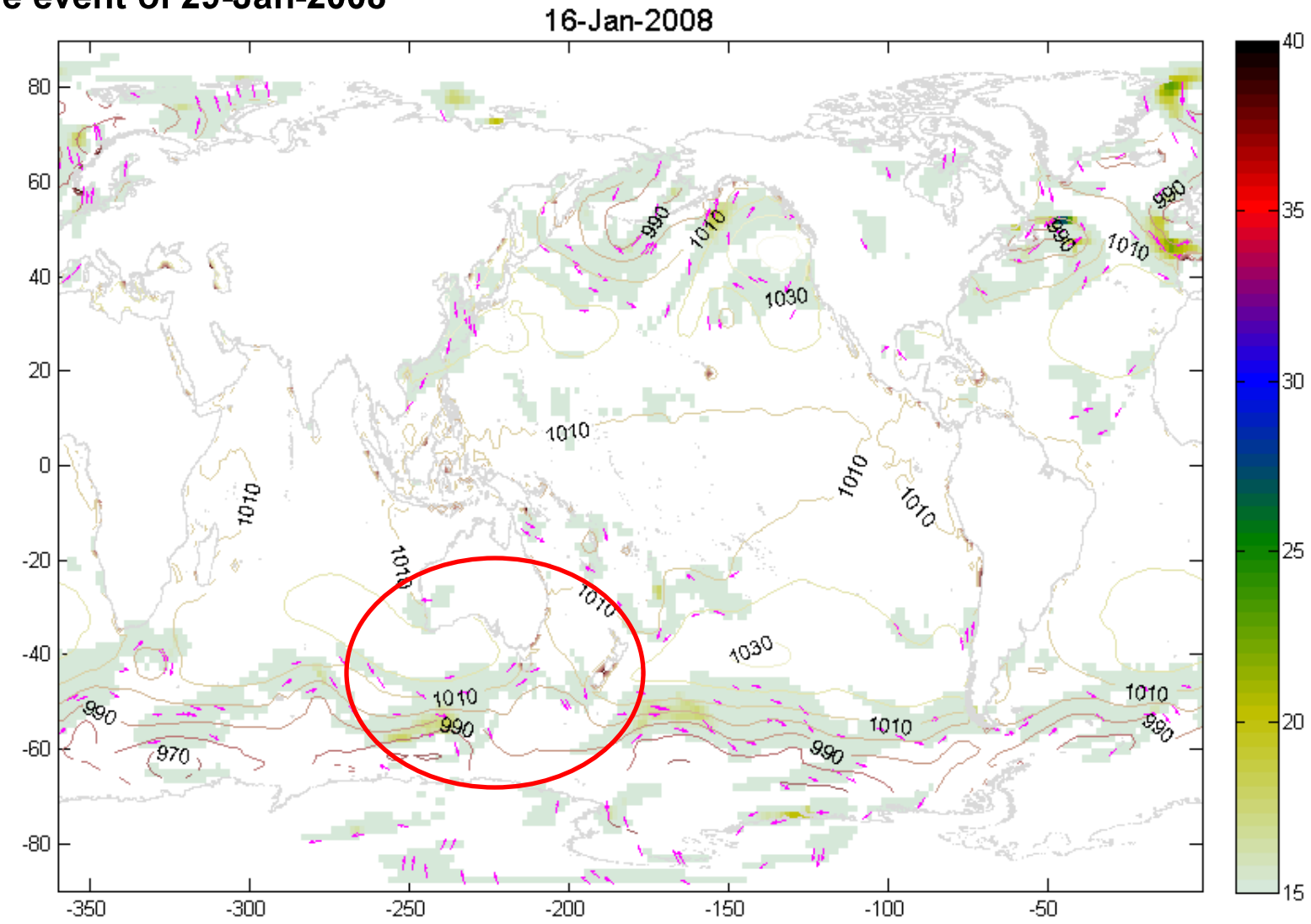
Wave event of 29-Jan-2008



Storm source detection algorithm

Results: Analysis of South-Westerly system

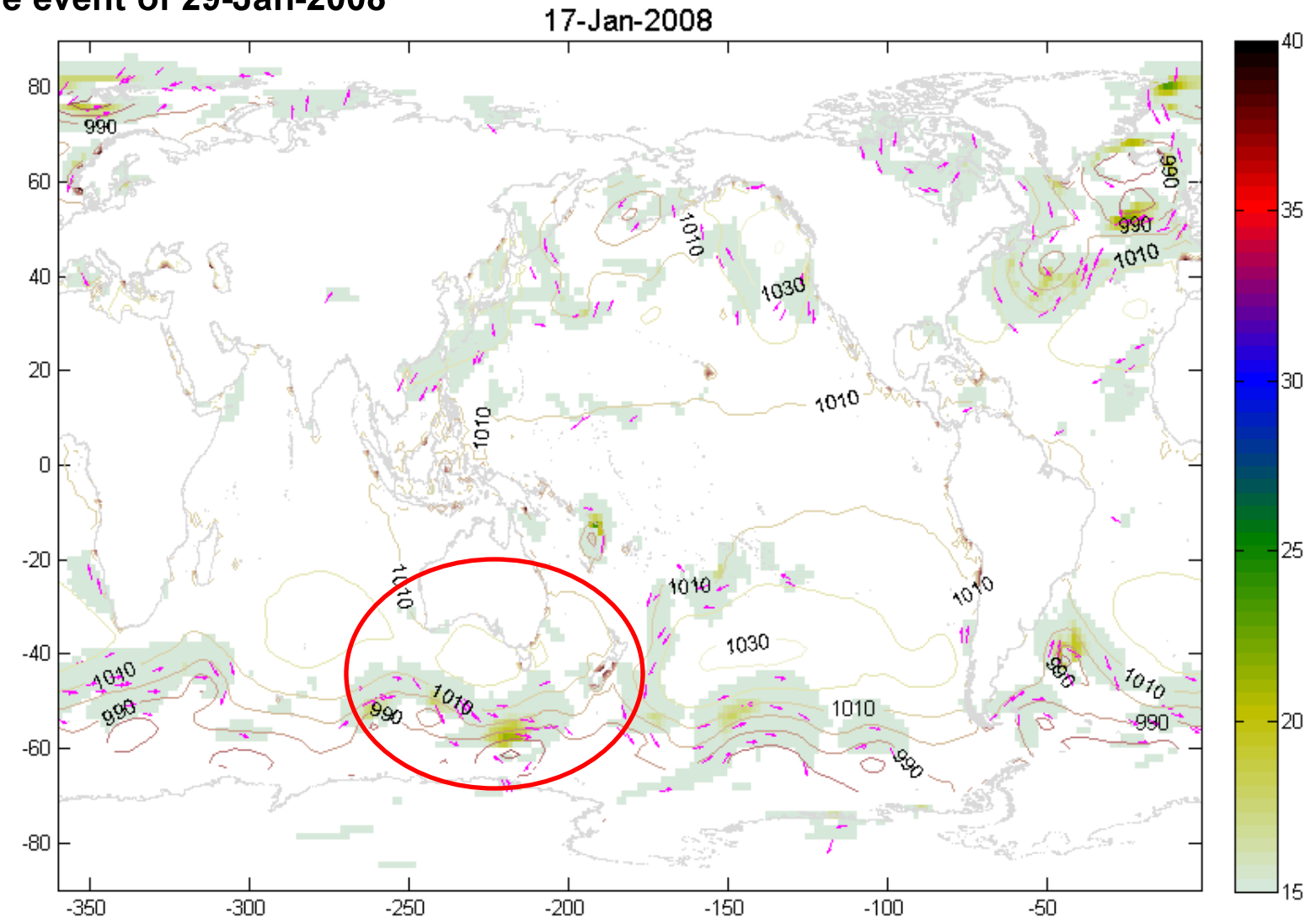
Wave event of 29-Jan-2008



Storm source detection algorithm

Results: Analysis of South-Westerly system

Wave event of 29-Jan-2008



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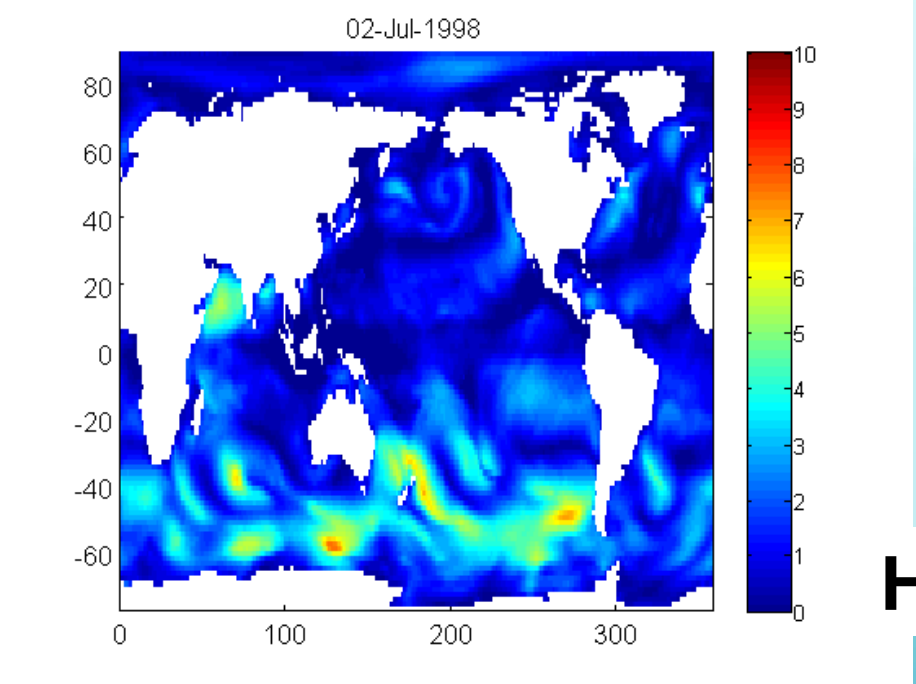
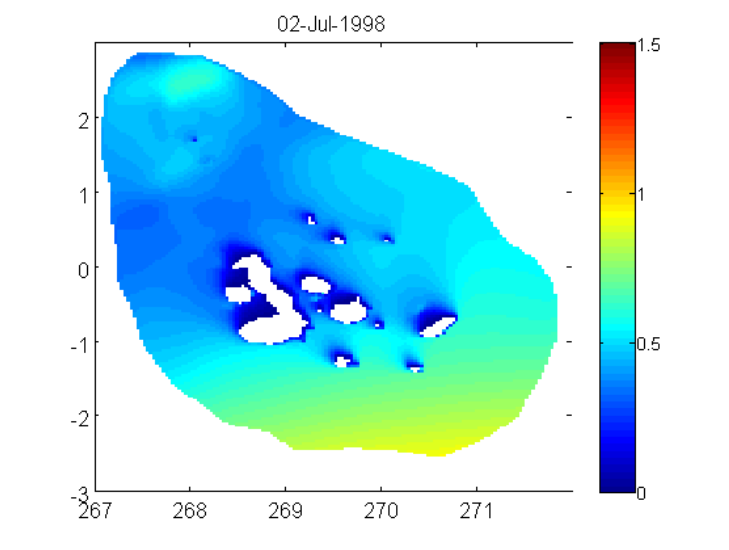
- Storm source detection algorithm
- **Preliminary results**
- Summary, conclusions and further work

Preliminary results





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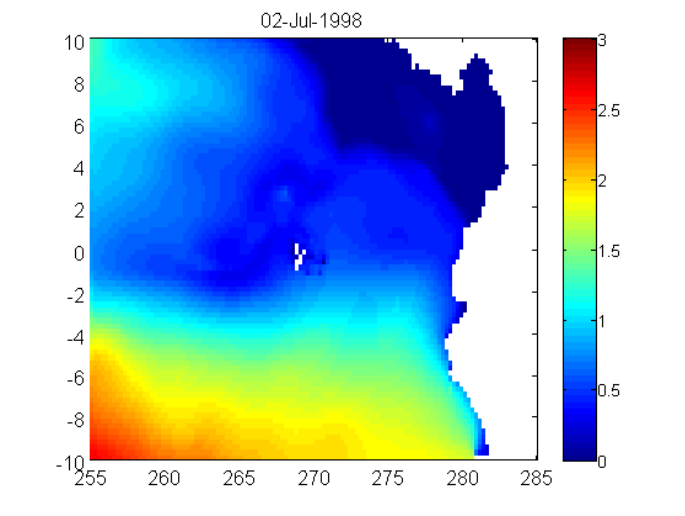
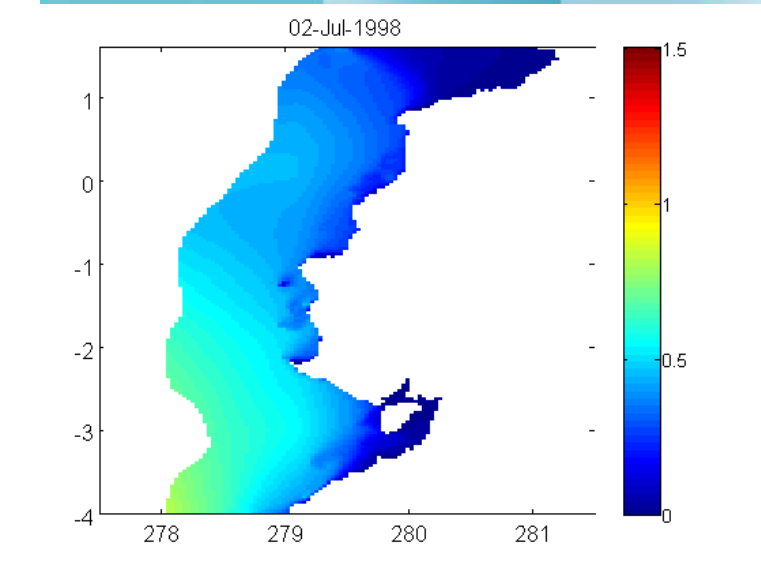
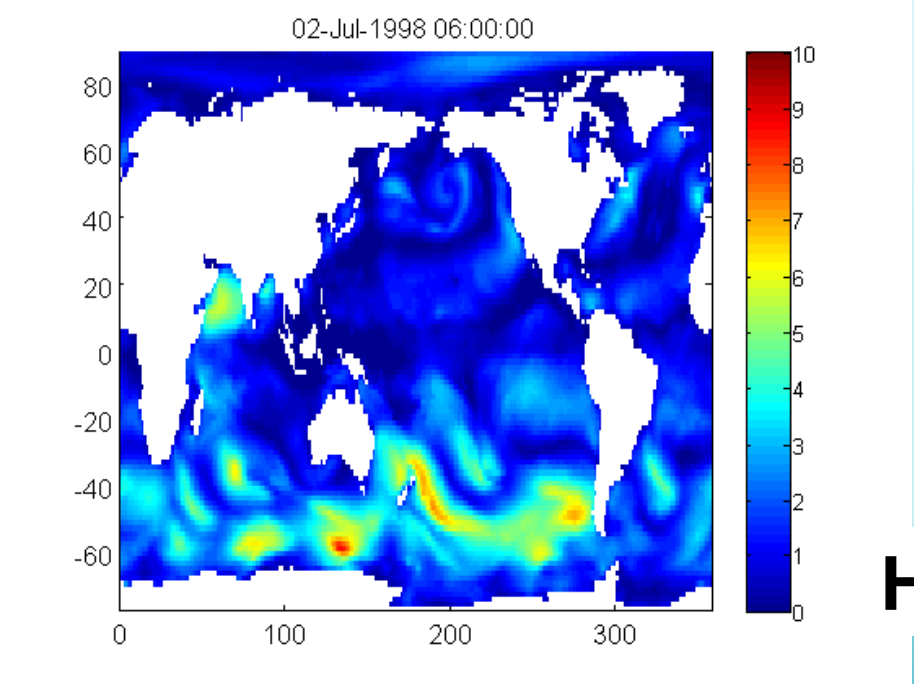
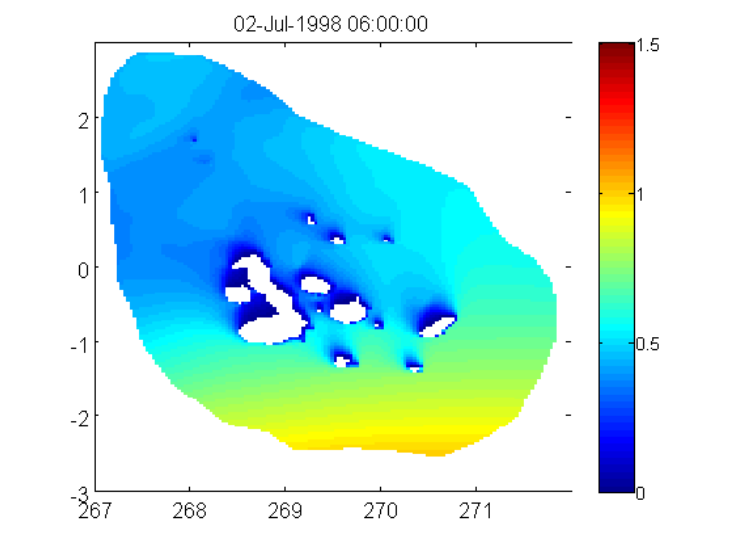




Preliminary results





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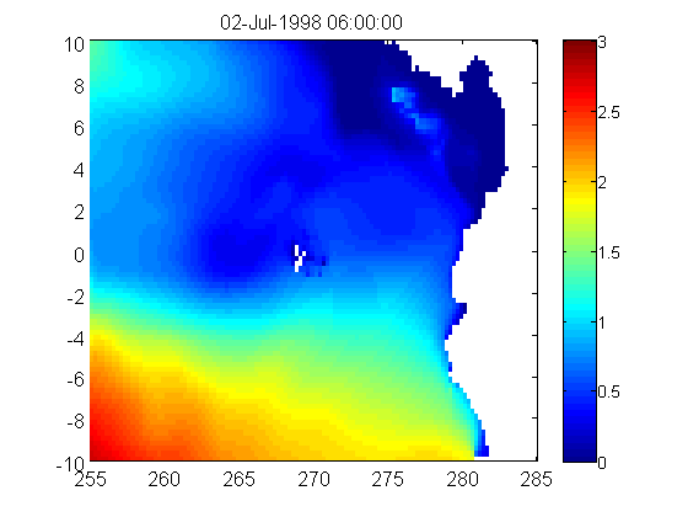

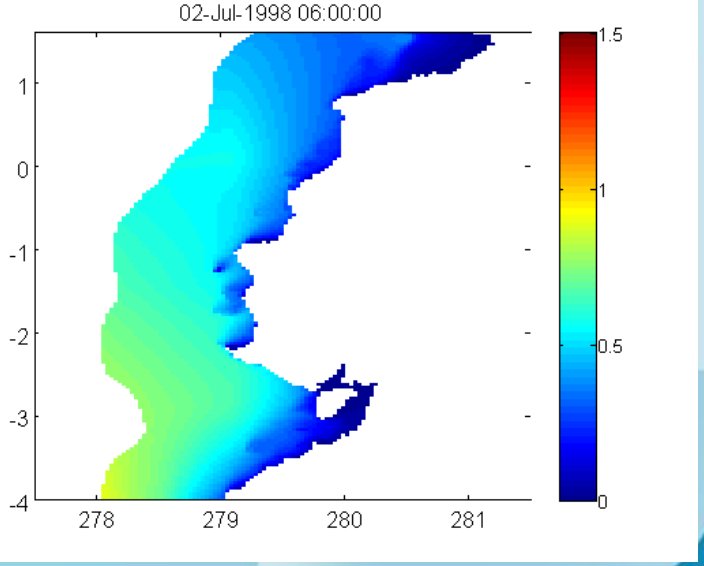

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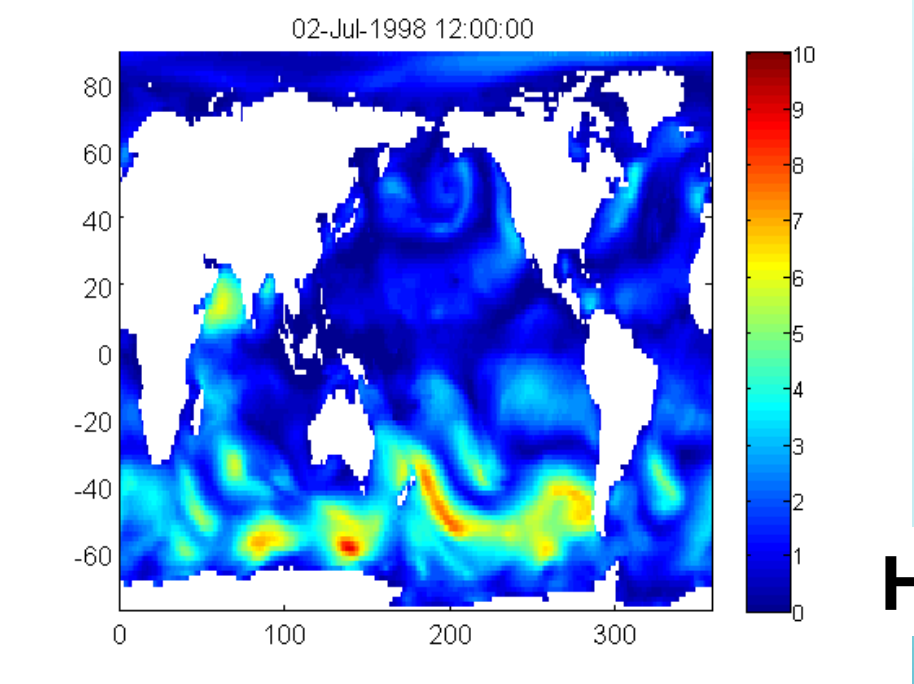

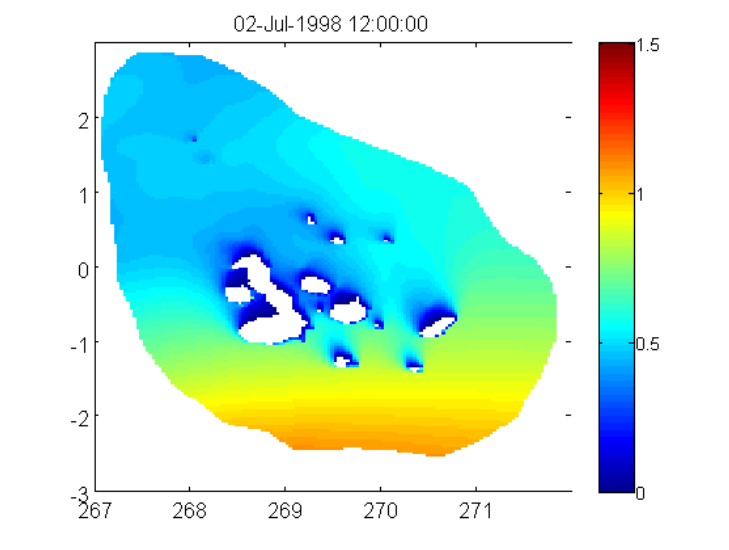

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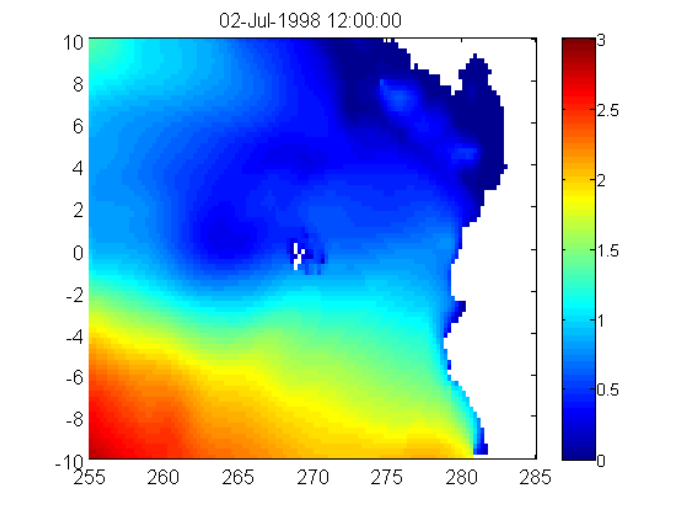

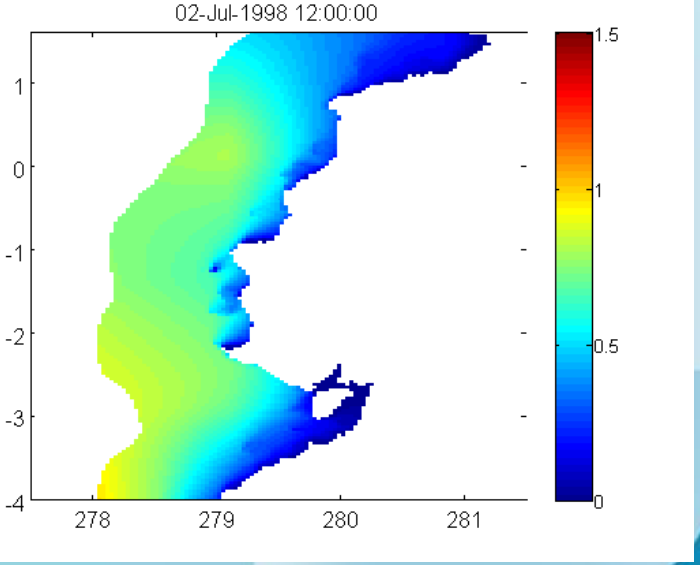

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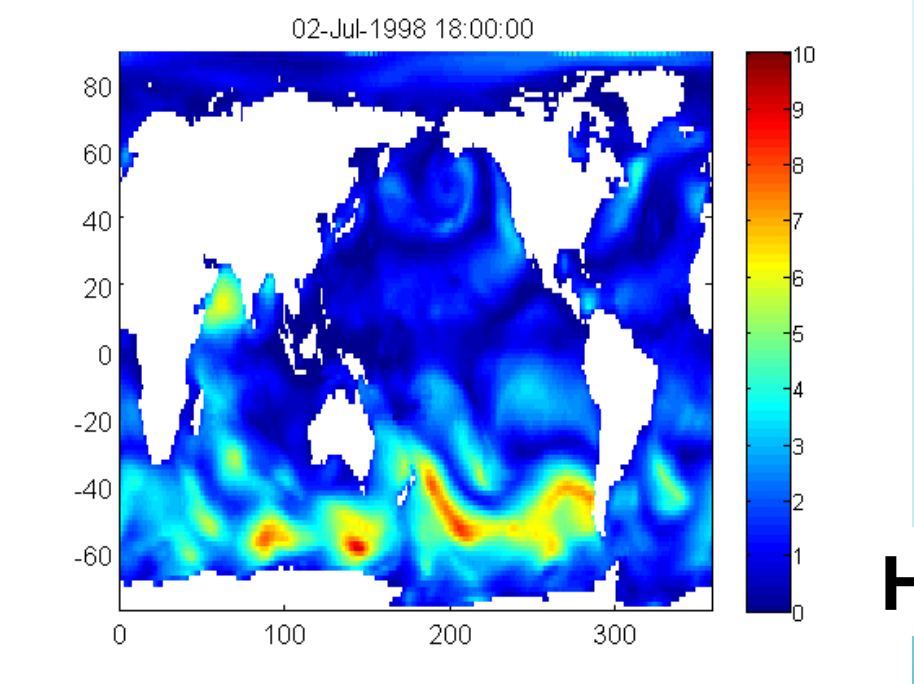

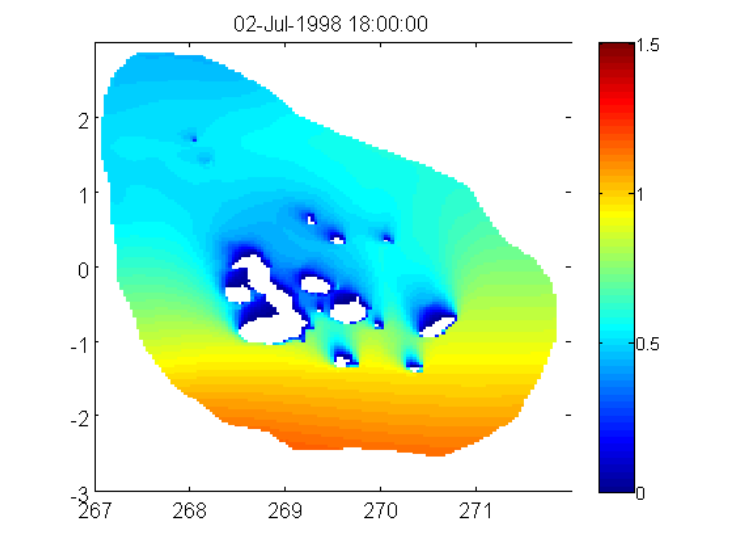

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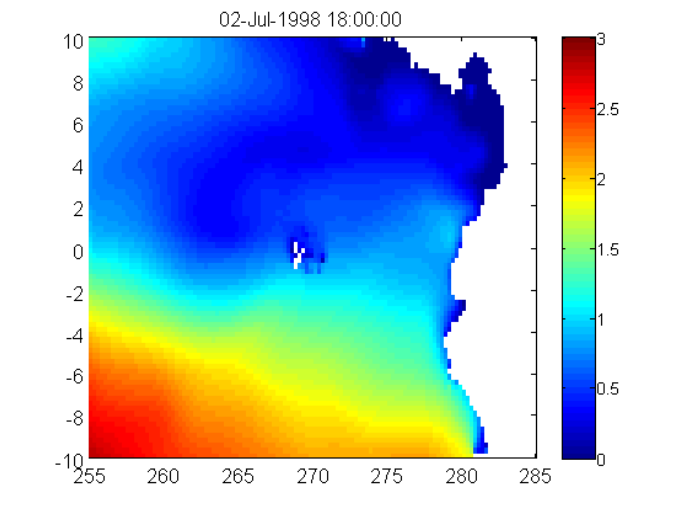

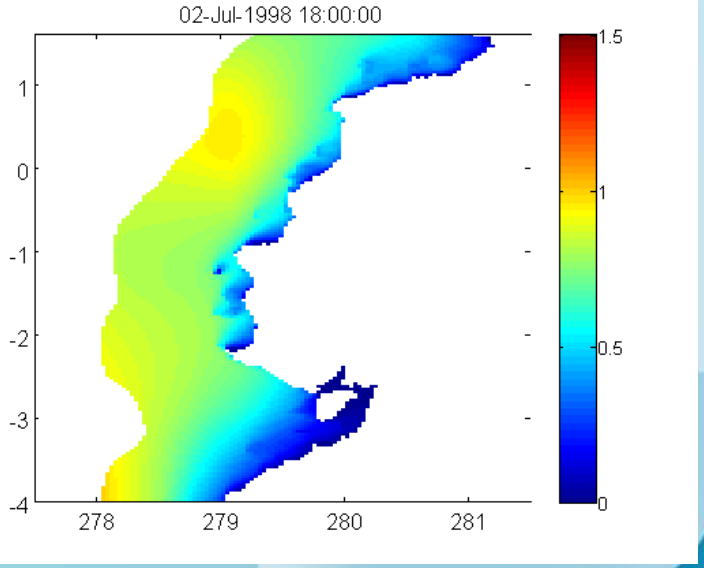

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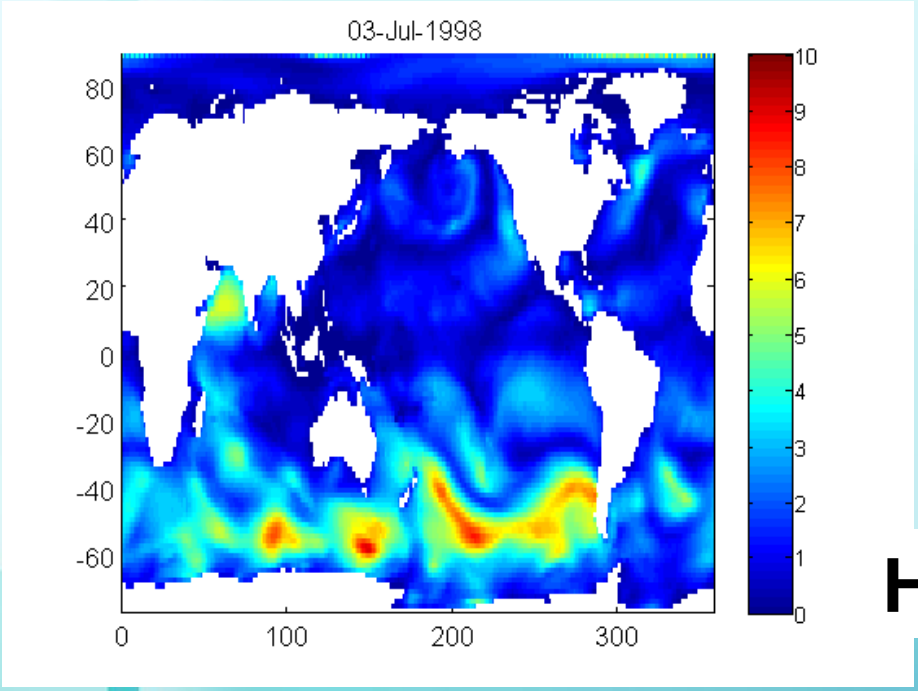

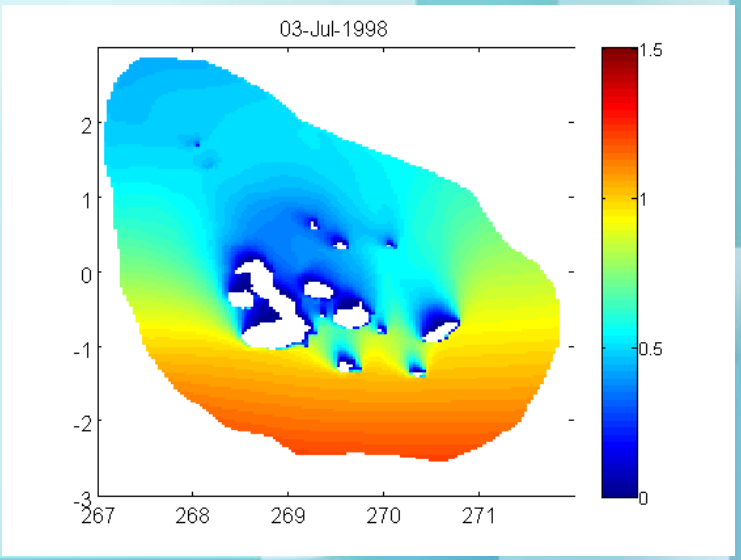

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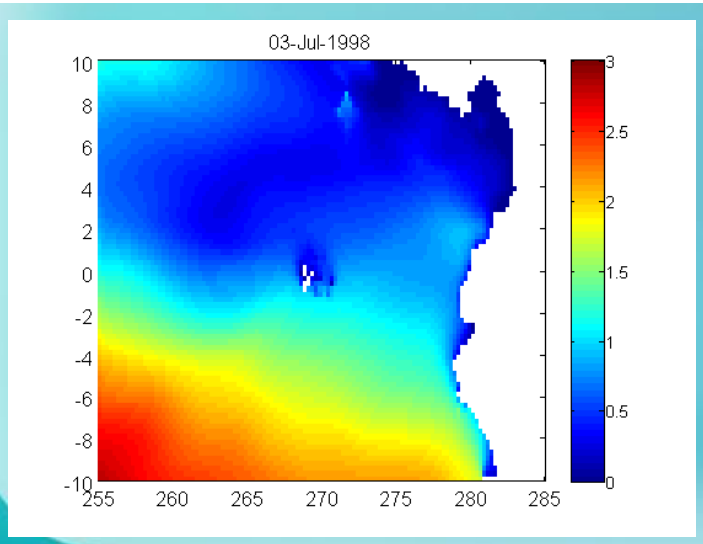

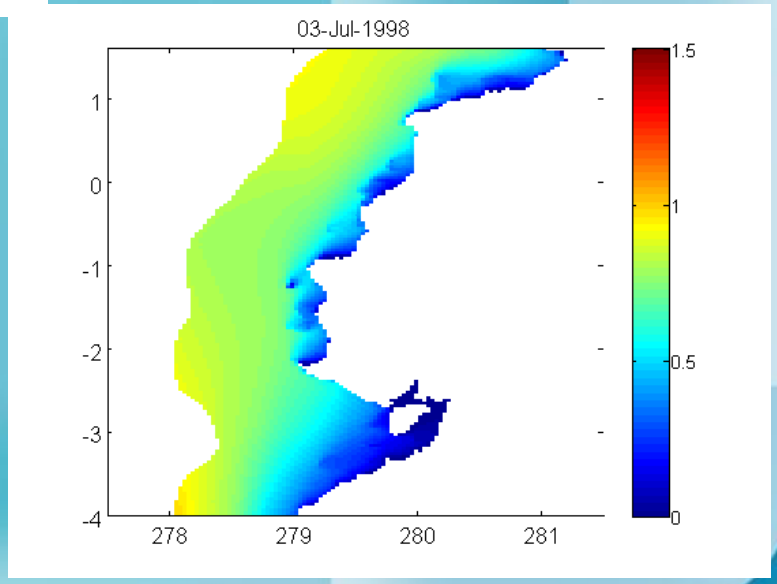

Preliminary results

Work in progress

- Influence of Antarctic Ice Coverage in Equatorial Wave conditions
  - Synthetic test case (maximum ice concentration)
  - Verification runs
- One year verification period
- Nesting SWAN for coastal related use

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Summary, conclusions and further work

- The WaveWatchIII™ model has been implemented in the Equatorial Pacific Zone, using 4 nested grids.
- Wave conditions in the EPZ are dominated by swells originated by remote storms in the southern and northern hemispheres. For proper representation of the wave conditions:
  - A large domain needs to be covered
  - Ice concentration in the poles needs to be taken into account
- Altimeter data is a precious source of information in the EPZ zone where in-situ observations are scarce.
- SAR spectral data constitutes a potential source of data for the EPZ.
  - Disambiguation issues need to be solved.
- Seismic noise data is another potential source information. It is specially attractive given to the length of the dataset.
  - Further work needed for calibration.
- Model verification is in progress in order to setup the system for practical use.


Thanks for your attention