PREDICTION OF EXTREME WAVE CONDITIONS IN THE BLACK SEA WITH NUMERICAL MODELS

Eugen Rusu

Liliana Rusu

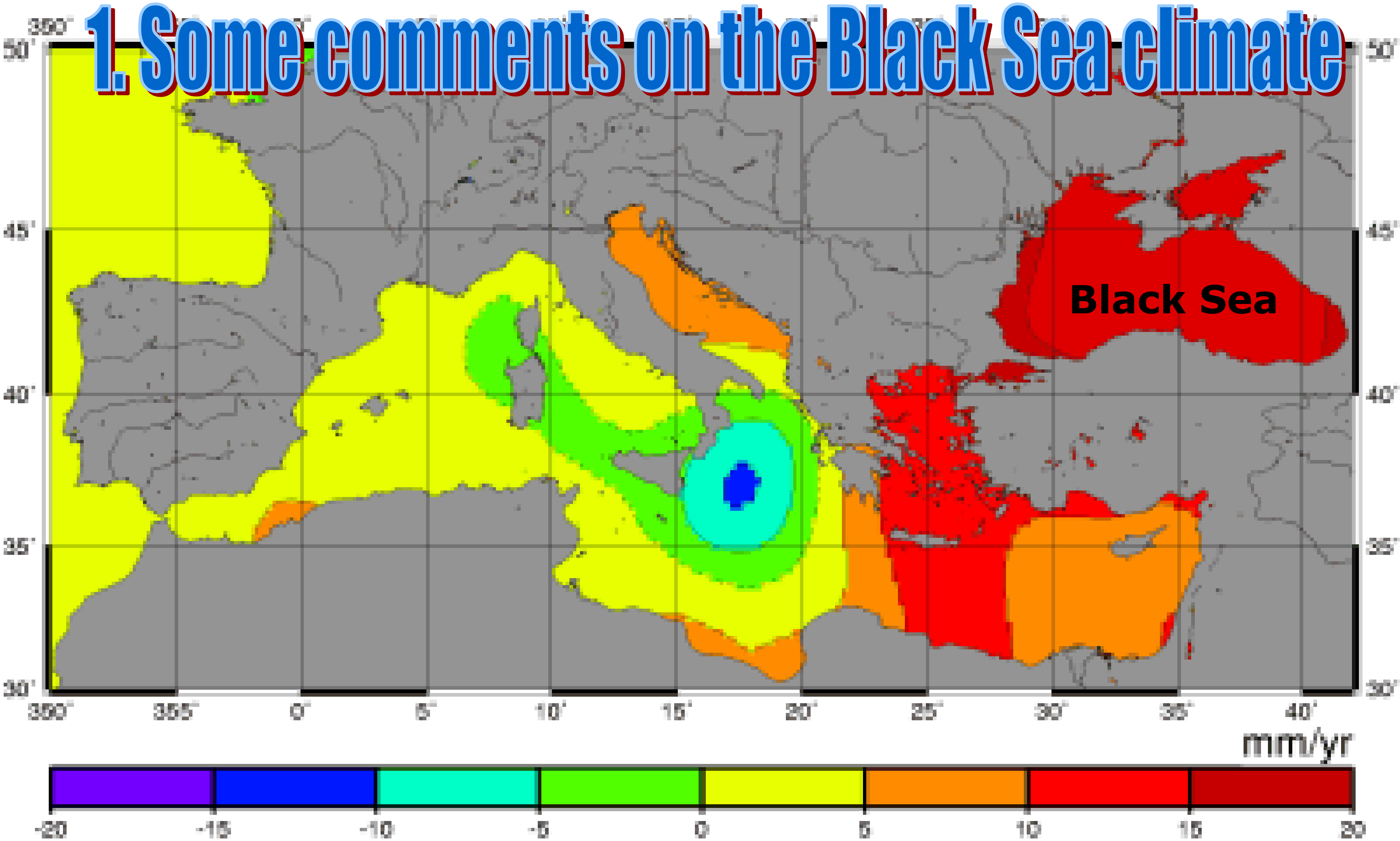
Carlos Guedes Soares

INSTITUTO SUPERIOR TÉCNICO
INSTITUTO SUPERIOR TÉCNICO
LISBON. PORTUGAL

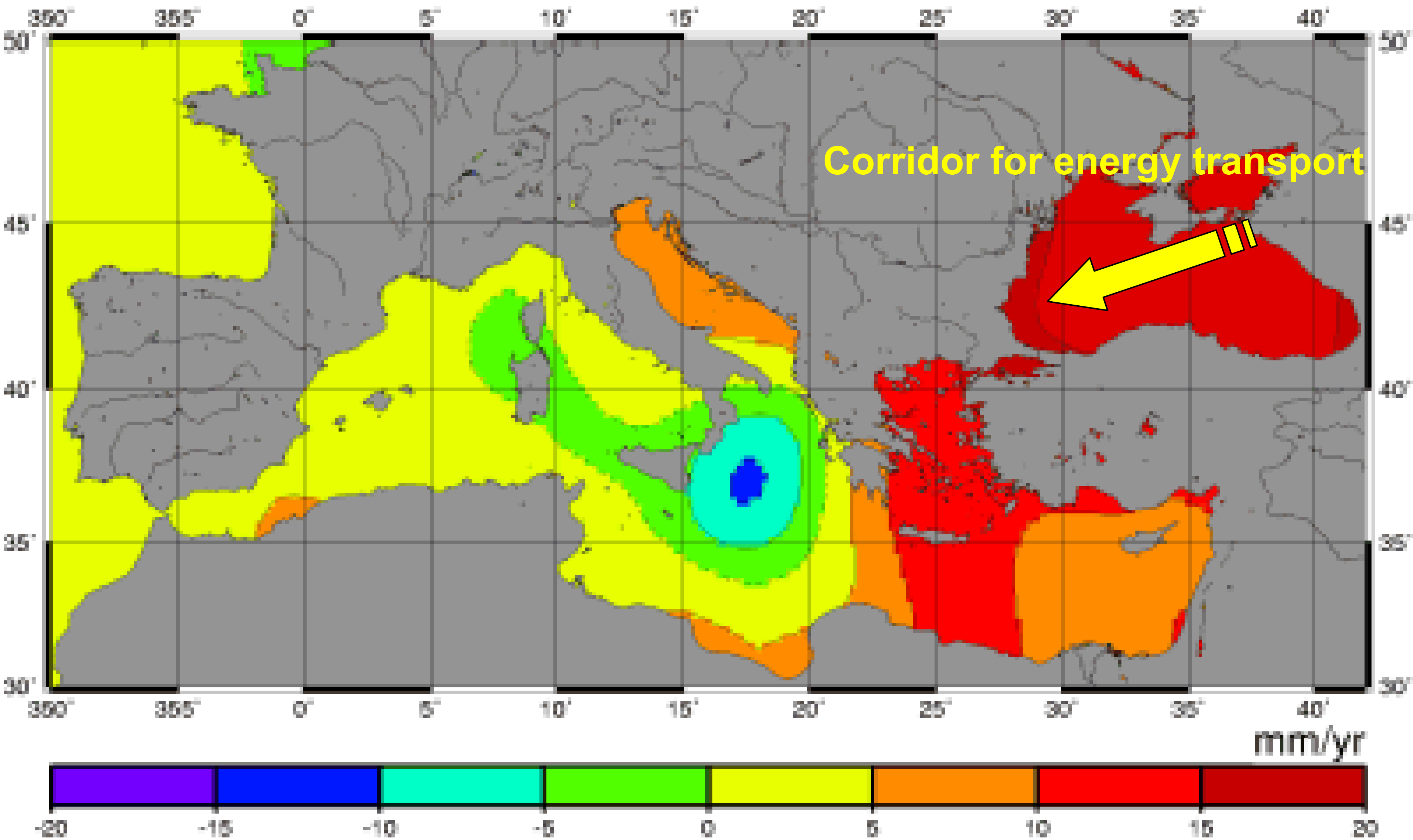
OBJECTIVES

- To evaluate SWAN as a generation model in the Black Sea
- To develop a flexible wave prediction system able to focus rapidly on local areas

1. Some comments on the Black Sea climate



Topex/Poseidon data – variation of the sea level in Mediteraneean and Black Seas 1993-2000



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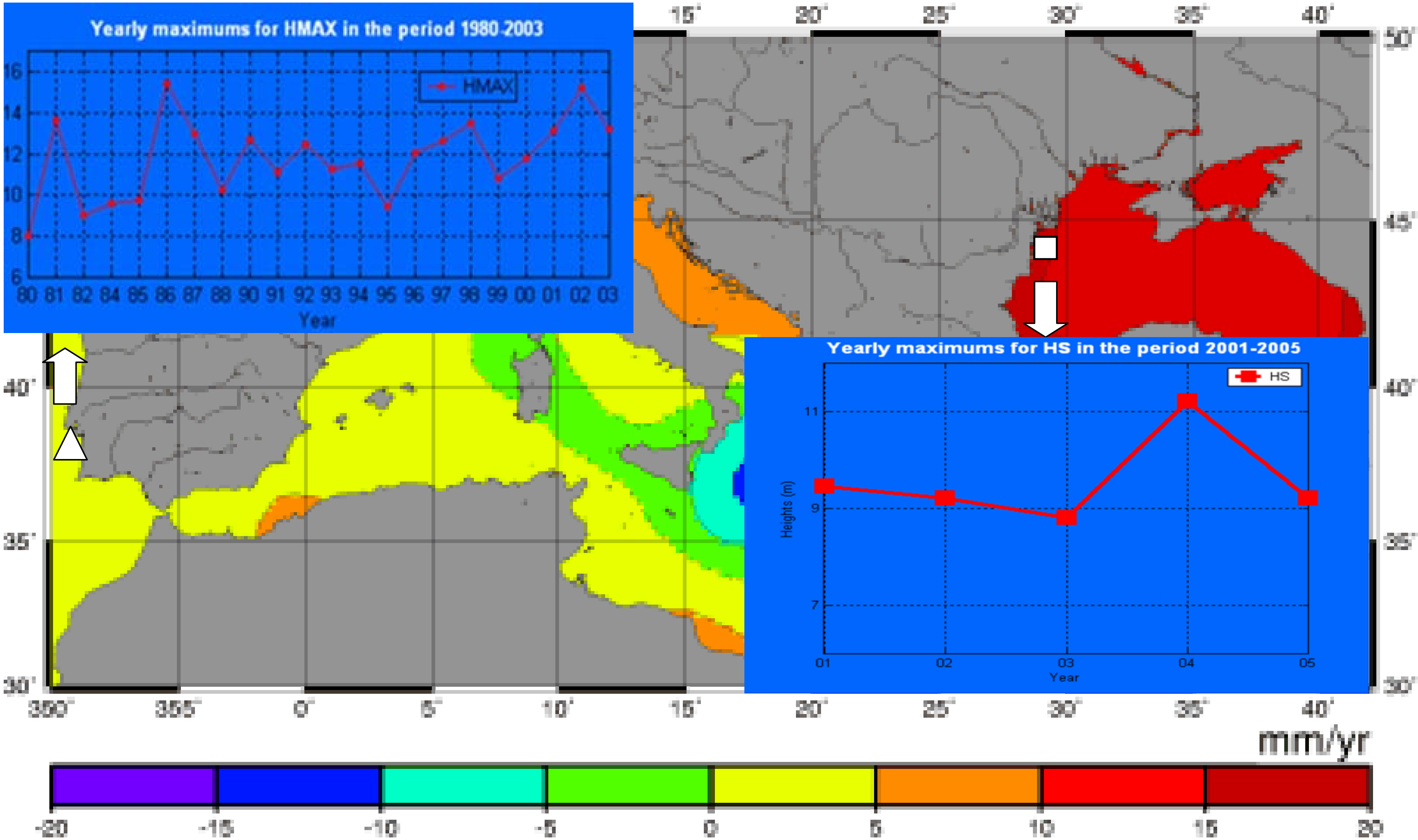


Topex/Poseidon data – variation of the sea level in Mediteraneean and Black Seas 1993-2000

2. Options for deep water wave modeling in SWAN

The main physical processes in deep water

$$S_{total} = S_{in} + S_{dis} + S_{nl}$$

Atmospheric input

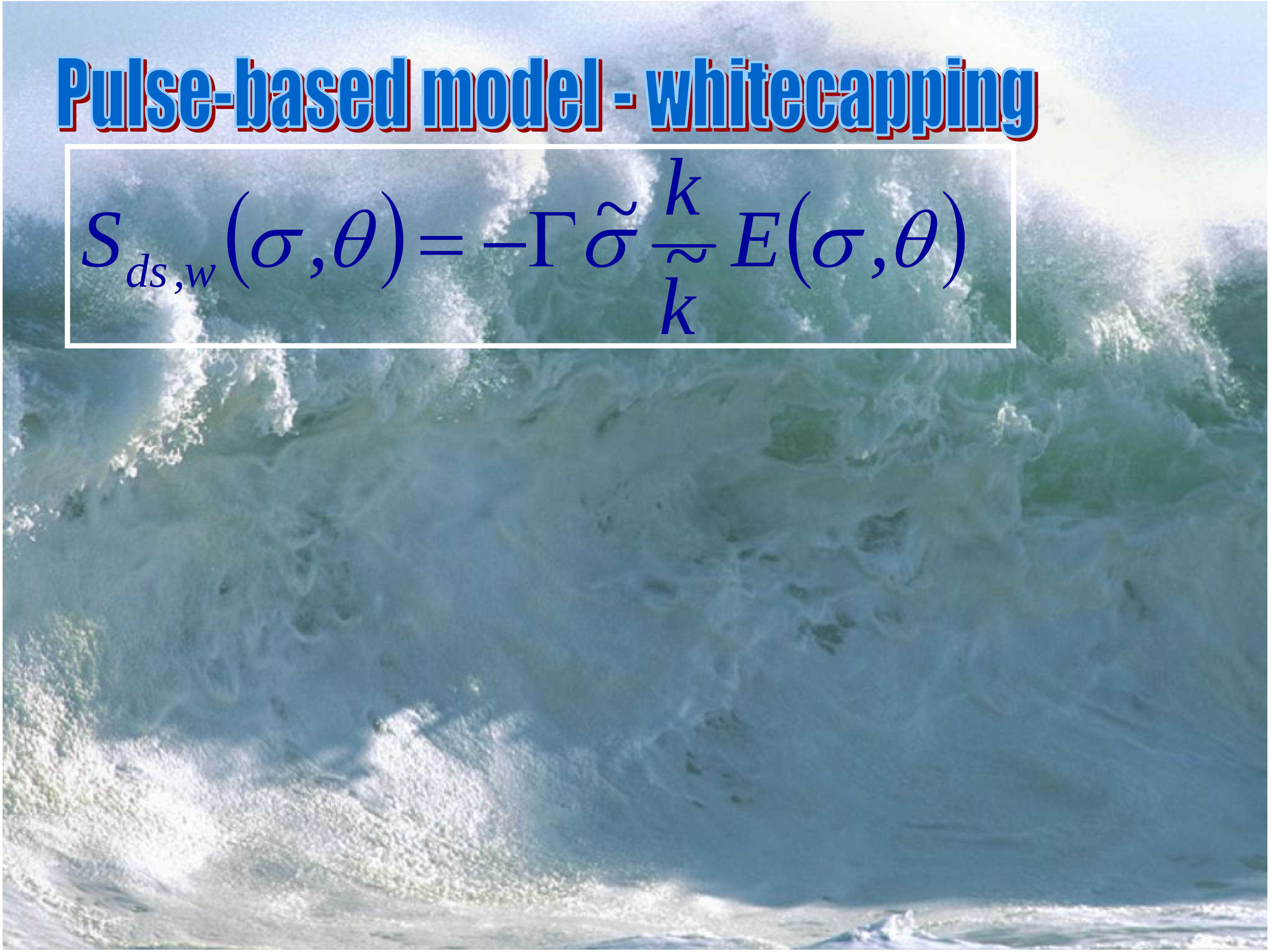
$$S_{in}(\sigma, \theta) = A + BE(\sigma, \theta)$$

***A* - linear growth; *BE* exponential growth**

A (default 0.0015)

2 expressions for the coefficient B:
Komen and Janssen

Pulse-based model - whitecapping



$$S_{ds,w}(\sigma,\theta) = -\Gamma\,\tilde{\sigma}\,\frac{k}{\tilde{k}}\,E(\sigma,\theta)$$

Pulse-based model - whitecapping

$$S_{ds,w}(\sigma,\theta) = -\Gamma\,\tilde{\sigma}\,\frac{k}{\tilde{k}}\,E(\sigma,\theta)$$

$$\Gamma = \Gamma_{KJ} = C_{ds}\left((1-\delta)+\delta\frac{k}{\tilde{k}}\right)\left(\frac{\tilde{S}}{\tilde{S}_{PM}}\right)^{p}$$

$\tilde{S}_{PM}$ overall wave steepness for Pierson-Moskowitz spectrum (= $(3.02\times10^{-3})^{1/2}$). exponent p=4

Komen - *Cds* (default 2.36 ×10-5). δ=0

Pulse-based model - whitecapping

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Komen - *Cds* (default 2.36 ×10-5). δ=0

Janssen $C_{ds1} = C_{ds}\left(\frac{1}{\tilde{S}_{PM}}\right)^{4}$ **(default 4.5)**

δ (default 0.5)

Cumulative Steepness Method (40.20)

$$S_{wc}^{st}(\sigma,\theta) = -C_{wc}^{st} S_{st}(\sigma,\theta) E(\sigma,\theta)$$

$$S_{st}(\sigma,\theta) = \int_0^{\sigma}\int_0^{2\pi} k^2 \left|\cos(\theta-\theta')\right|^m E(\sigma,\theta)\, d\sigma\, d\theta$$

C_{wc}^{st} (default 0.5 - 40.41) **m (default 2)**

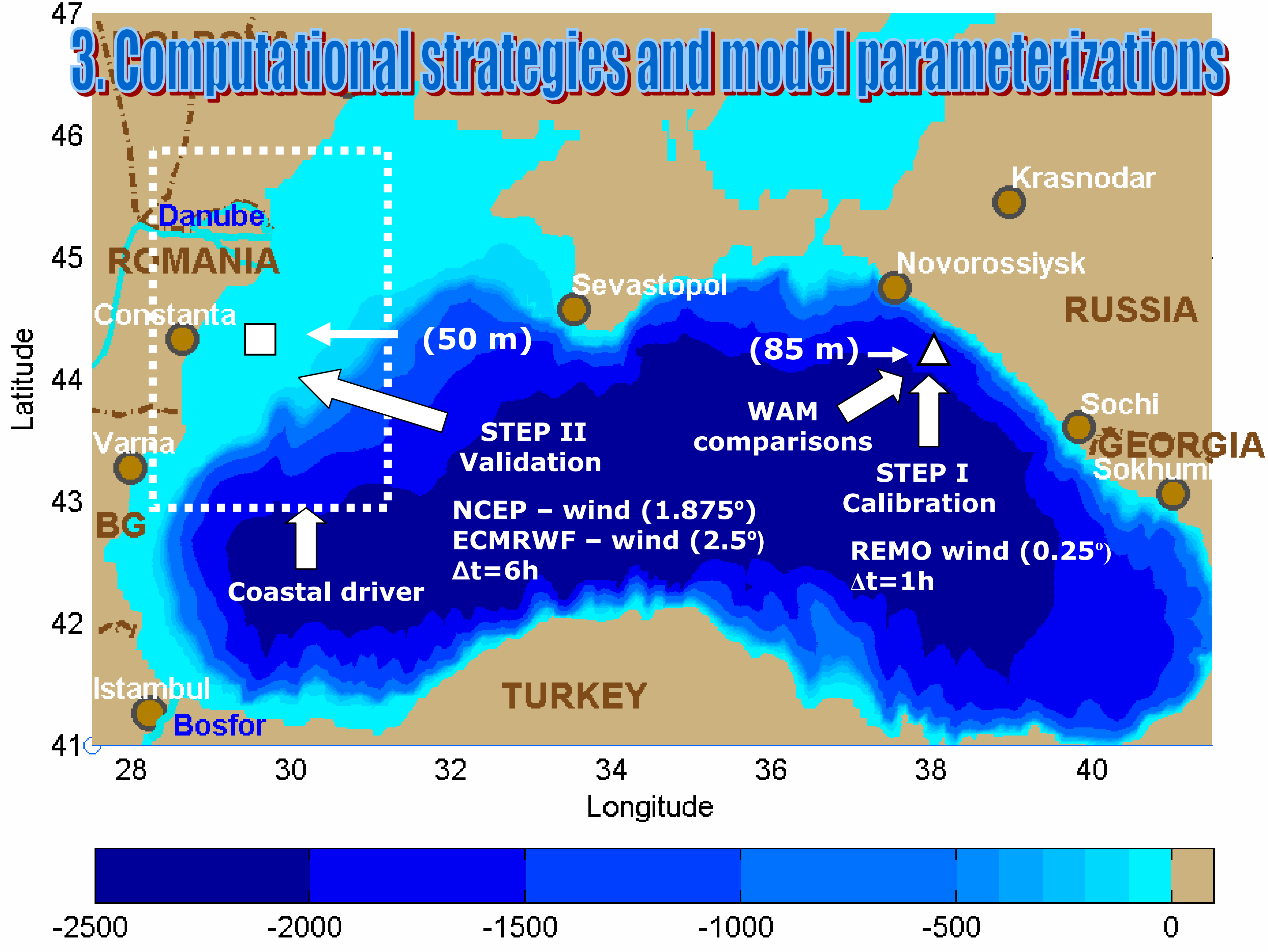
40.51 - Saturation-based model of Alves and Banner (2003). more appropriate for mixed sea-swell conditions and in shallow water.

Quadruplet interactions

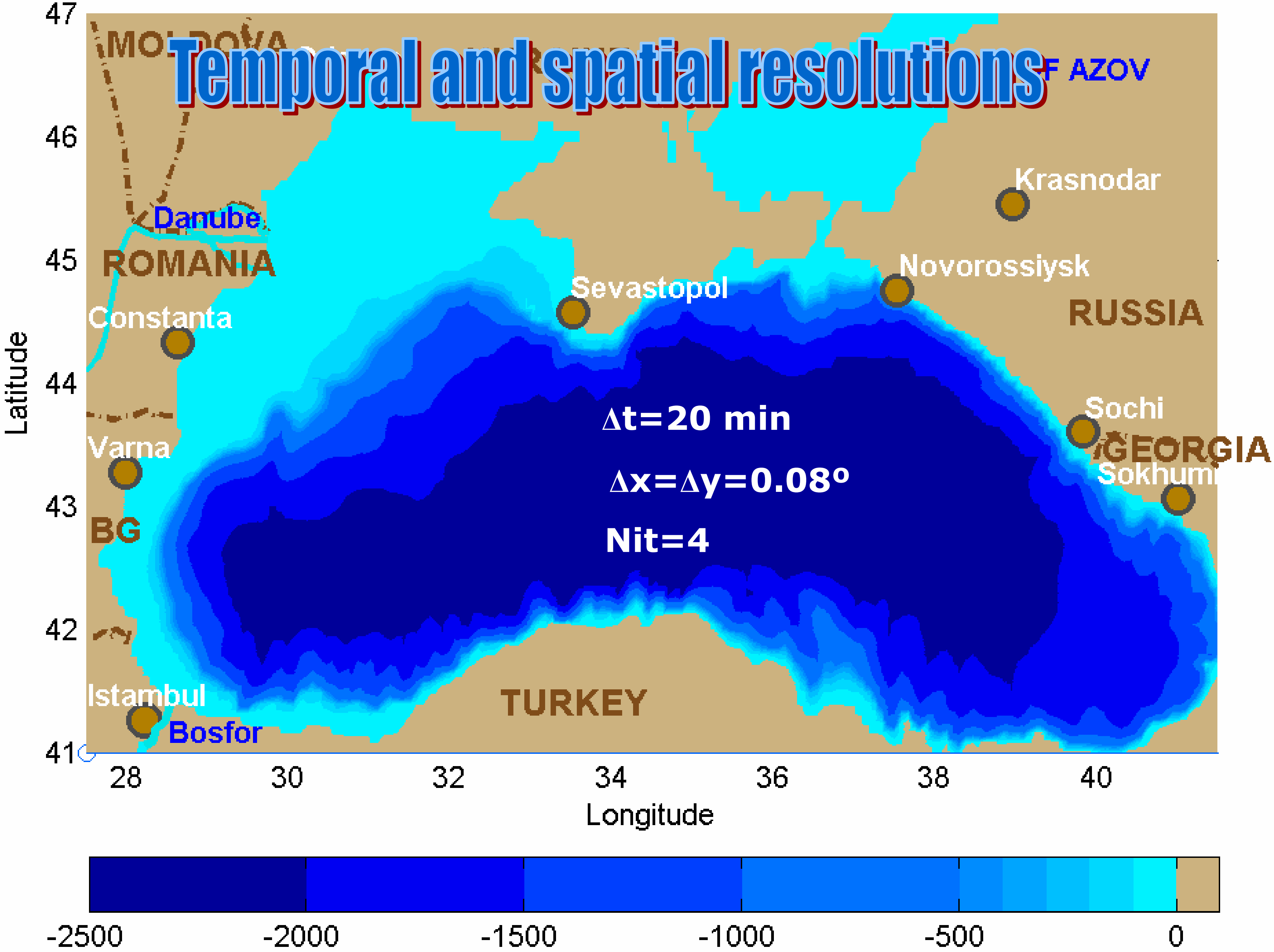
Transfer wave energy from the spectral peak both to lower and to higher frequencies

9 - parameterizations

3. Computational strategies and model parameterizations



Temporal and spatial resolutions



Δt=20 min

Δx=Δy=0.08º

Nit=4

4. East coast calibration (buoy data)

Default values:

Komen: $C_{ds} = 2.36 \cdot 10^{-5}$ $\tilde{S}^2_{PM} = 3.02 \cdot 10^{-3}$

Janssen: $C_{ds1} = 4.5$ $\delta = 0.5$

CSM: $C^{st}_{wc} = 0.5$ $m = 2$

New values:

Komen: $C_{ds} = 1.12 \cdot 10^{-5}$ $\tilde{S}^2_{PM} = 3.02 \cdot 10^{-3}$

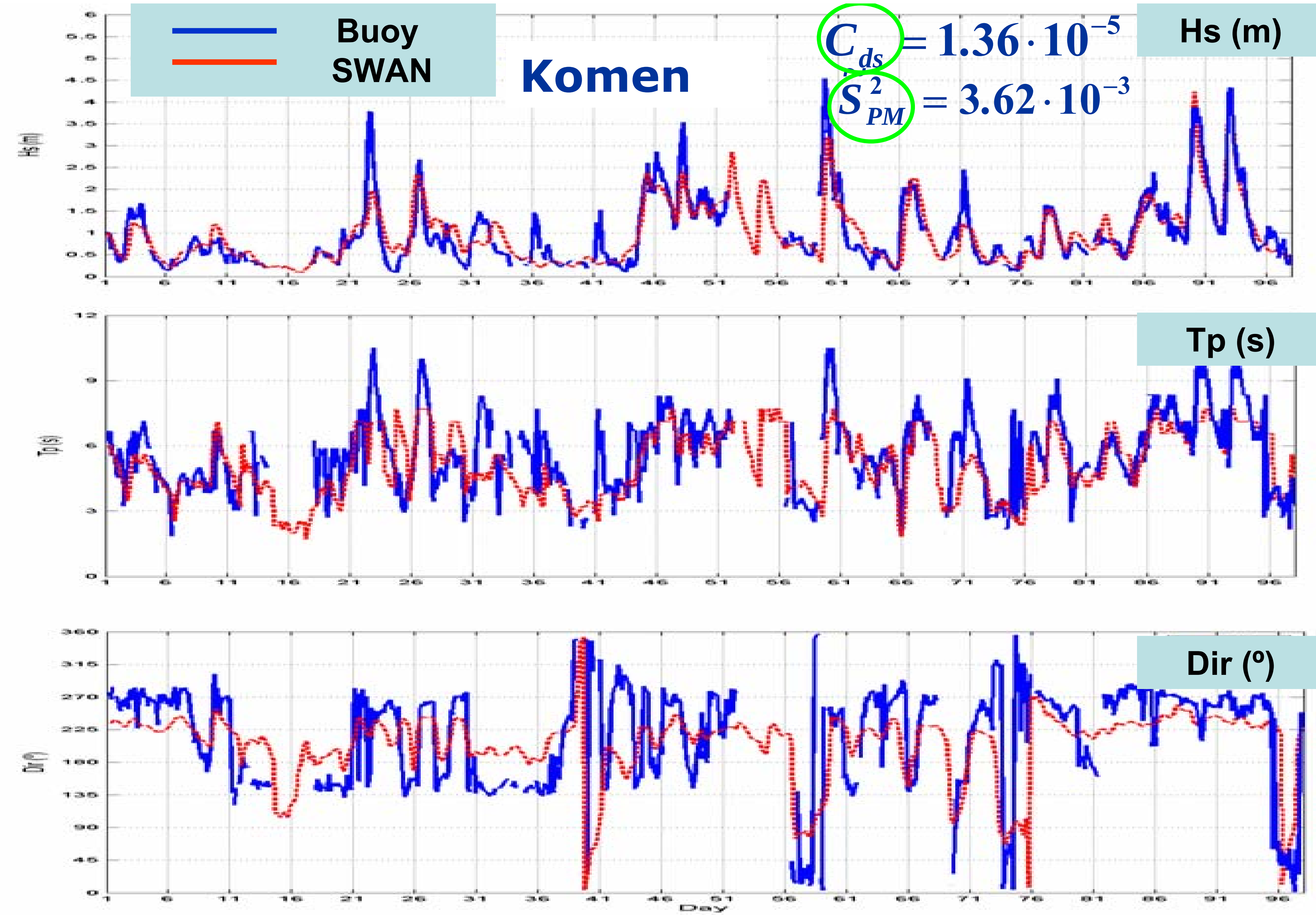
Janssen: $C_{ds1} = 1.1$ $\delta = 0.5$

CSM: $C^{st}_{wc} = 0.1$ $m = 2$

Wave statistics for SWAN (1996.11.01h00-1997.02.06h00)

Wave statistics for WAM (Valchev et al.. 2004)

n=660	X_{med}	Y_{med}	*Bias*	*RMSE*	*SI*	*r*	
Hs(m)	1.005	1.013	-0.008 0.270	0.386 0.530	0.384 0.680	0.871 0.730	KOM
Tp (s)	5.62	5.25	0.369 0.430	1.42 1.74	0.253 0.340	0.651 0.550	
Dir (°)	216.1	207.5	8.58 33.10	53.5 92.7	0.25 0.46	0.47 0.36	
Hs (m)	1.005	1.026	-0.022	0.432	0.430	0.837	JNS
Tp (s)	5.62	5.52	0.1	1.516	0.270	0.562	
Dir (°)	216.1	224.5	-8.4	68.1	0.315	0.33	
Hs (m)	1.005	1.104	-0.099	0.407	0.405	0.865	CSM
Tp (s)	5.62	5.82	-0.197	1.43	0.255	0.629	
Dir (°)	216.1	222.0	-5.83	66.65	0.308	0.403	



Day 1 - 1996.11.01. day 96- 1997.02.04

Study on the influence of DIA-based computations for the quadruplets
Period: 1997.01.01 (day 62) – 1997.02.06

PIV. 3.2 GHz. 1024 RAM

n=272	*Xmed*	*Ymed*	*Bias*	*RMSE*	*SI*	*r*	Case	Time
Hs (m)	1.089	1.081	0.008	0.316	0.290	0.921		
Tp (s)	5.87	5.40	0.467	1.375	0.234	0.72	Q1	21h09min
Dir (°)	229.9	209.6	20.36	51.657	0.225	0.58		1.53U
Hs (m)	1.089	1.117	-0.028	0.321	0.294	0.919		
Tp (s)	5.87	5.27	0.604	1.429	0.243	0.723	Q2	13h50min
Dir (°)	229.9	207.3	22.643	51.344	0.223	0.602		U
Hs (m)	1.089	1.118	-0.029	0.321	0.295	0.919		
Tp (s)	5.87	5.29	0.576	1.408	0.240	0.726	Q3	15h31min
Dir (°)	229.9	207.3	22.643	51.344	0.223	0.602		1.12U
Hs (m)	1.089	0.969	0.12	0.335	0.308	0.923		
Tp (s)	5.87	4.9	0.973	1.683	0.287	0.708	Q8	14h45min
Dir (°)	229.9	204.6	25.3	51.07	0.222	0.578		1.07U

DIA per sweep

- Q1- semi-implicit computation
- Q2- fully explicit computation (default)

DIA per iteration

- Q3- fully explicit computation
- Q8- as Q3 but neighbouring interactions are interpolated

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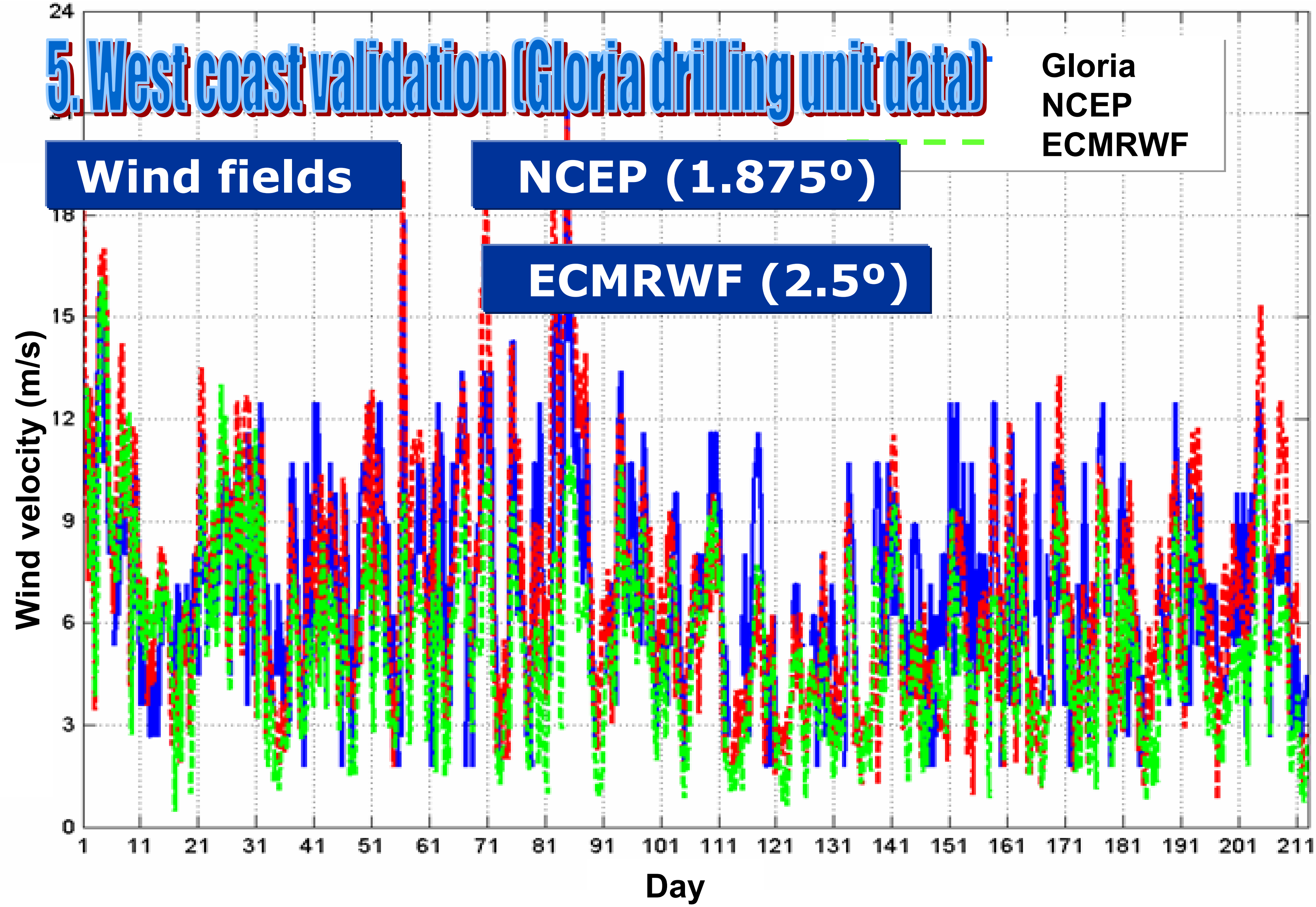
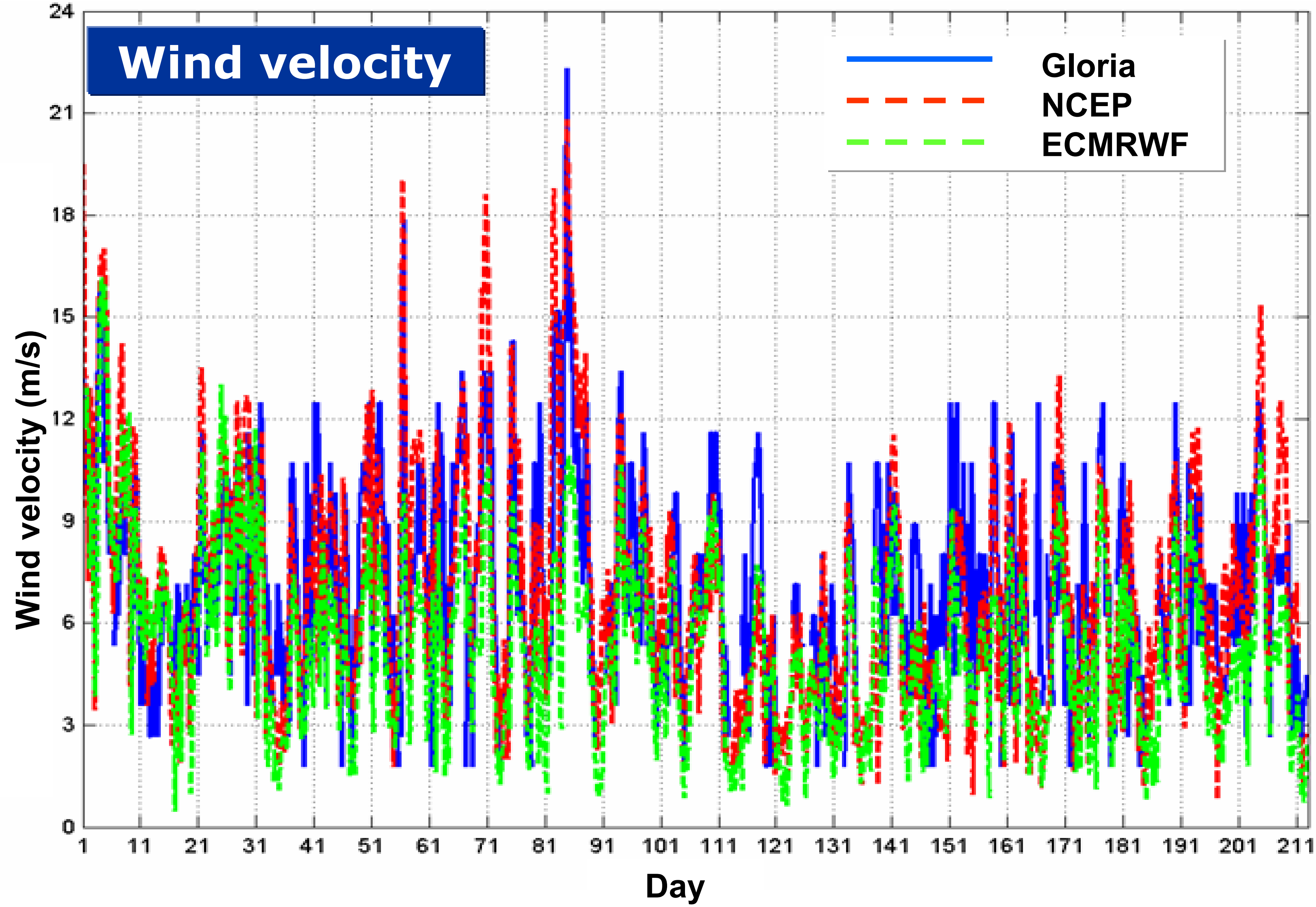
Hs (m)	1.089	1.118	-0.029	0.321	0.295	0.919		
Tp (s)	5.87	5.29	0.576	1.408	0.240	0.726	Q3	16h19min
Dir (°)	229.9	207.3	22.643	51.344	0.223	0.602		1.18U
Hs (m)	1.089	0.969	0.12	0.335	0.308	0.923		
Tp (s)	5.87	4.9	0.973	1.683	0.287	0.708	Q8	14h45min
Dir (°)	229.9	204.6	25.3	51.07	0.222	0.578		1.07U

Q4- multiple DIA – 38h12min = 2.76U

5. West coast validation (Gloria drilling unit data)



Direct comparison for wind velocity: GLORIA (measured) - NCEP – ECMRWF. day 1 – 2002/01/01. day 211 – 2002/07/31



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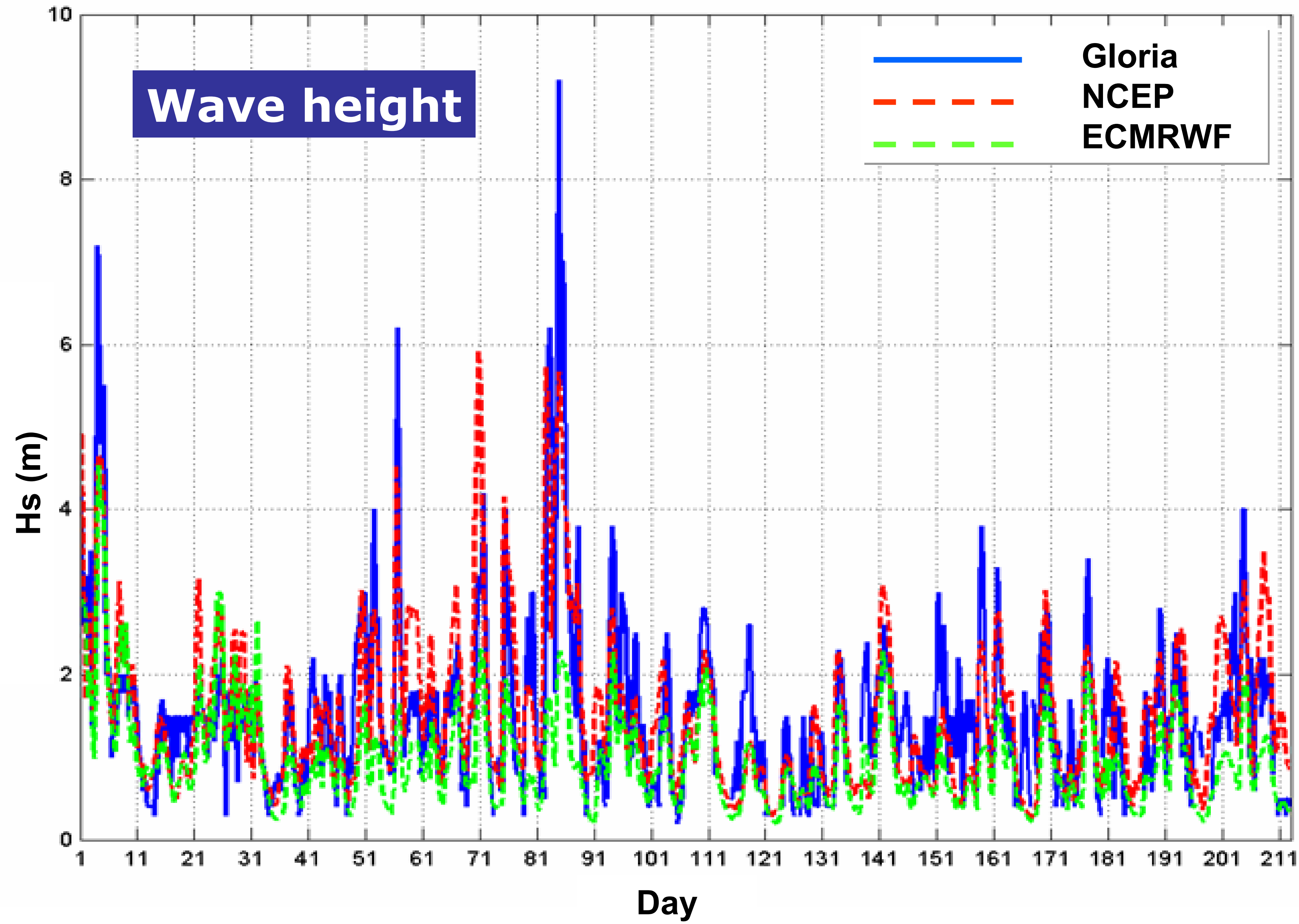


Direct comparison for Hs: GLORIA (measured) - NCEP – ECMRWF. day 1 – 2002/01/01. day 211 – 2002/07/31

Wave statistics (2002.01.01-2002.07.31)

n=781	X_{med}	Y_{med}	*Bias*	*RMSE*	*SI*	*r*	Wind field
Hs (m)	1.535	1.551	-0.016	0.762	0.496	0.709	NCEP
Tm (s)	5.08	2.738	2.342	2.664	0.524	0.218	
Dir (°)	215.03	140.978	74.05	81.08	0.377	0.401	
Hs (m)	1.535	0.937	0.539	0.937	0.610	0.683	ECMRWF
Tm (s)	5.08	2.349	2.731	2.972	0.585	0.300	
Dir (°)	215.03	133.62	81.407	87.133	0.405	0.341	

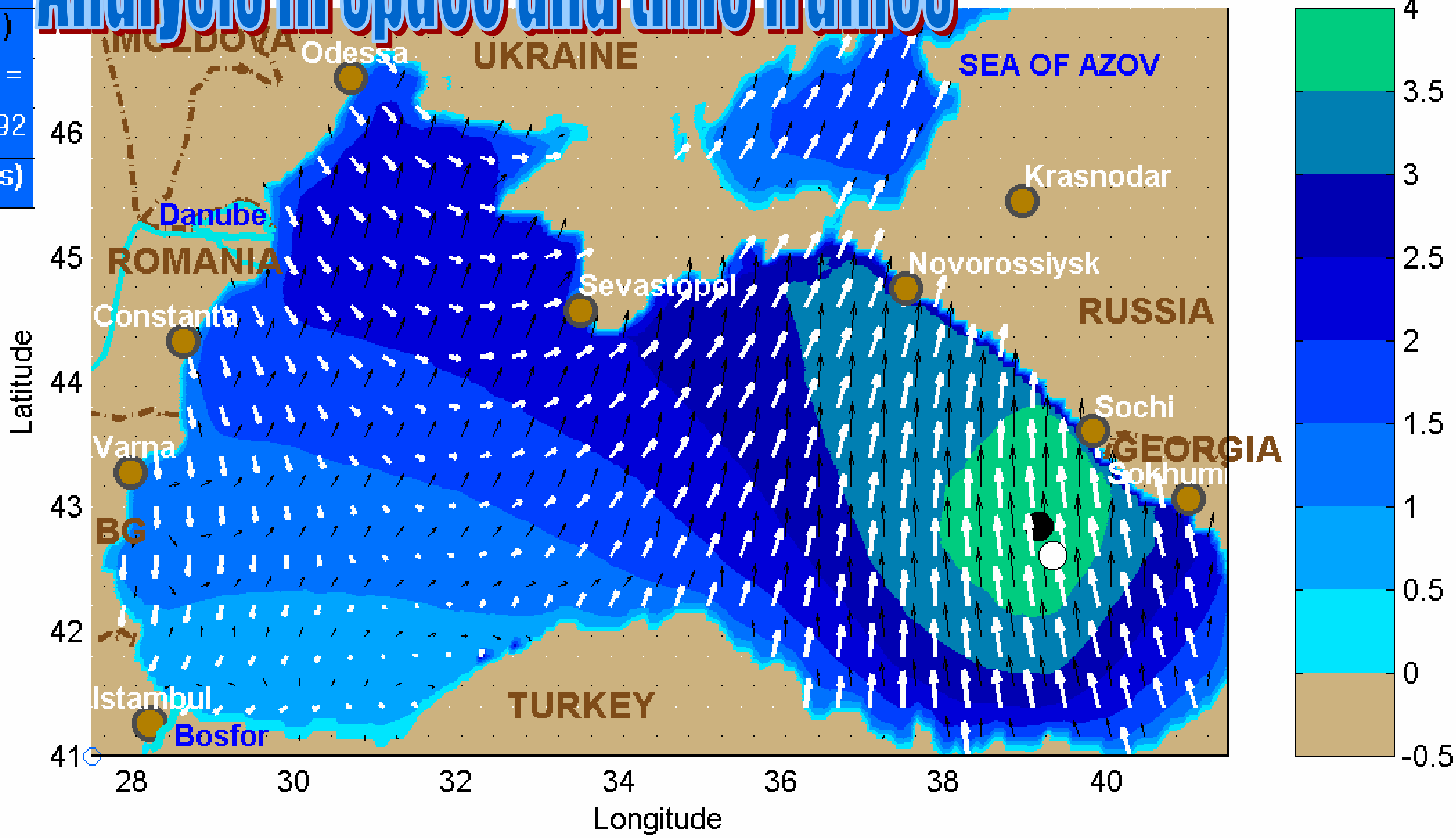
6. The BLACK SWAN wave prediction system

- A single model covers the full scale
- A MATLAB toolbox
- Data processing
- Comprehensive visualisations

Real time assesments
Analysis in space and time frames

2002/03/10_h18

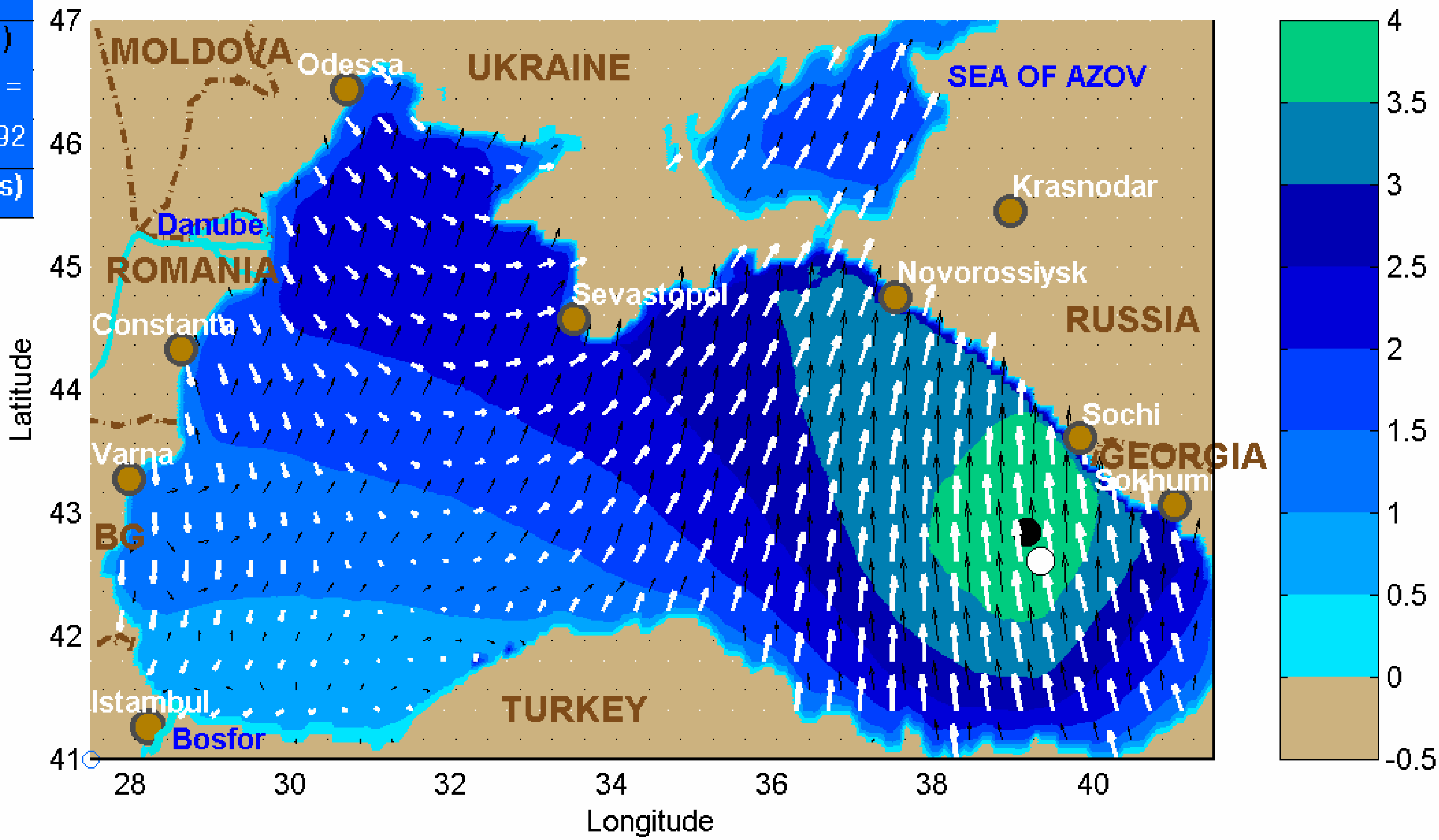
Hs =
4
(m)
Vw =
15.92
(m/s)



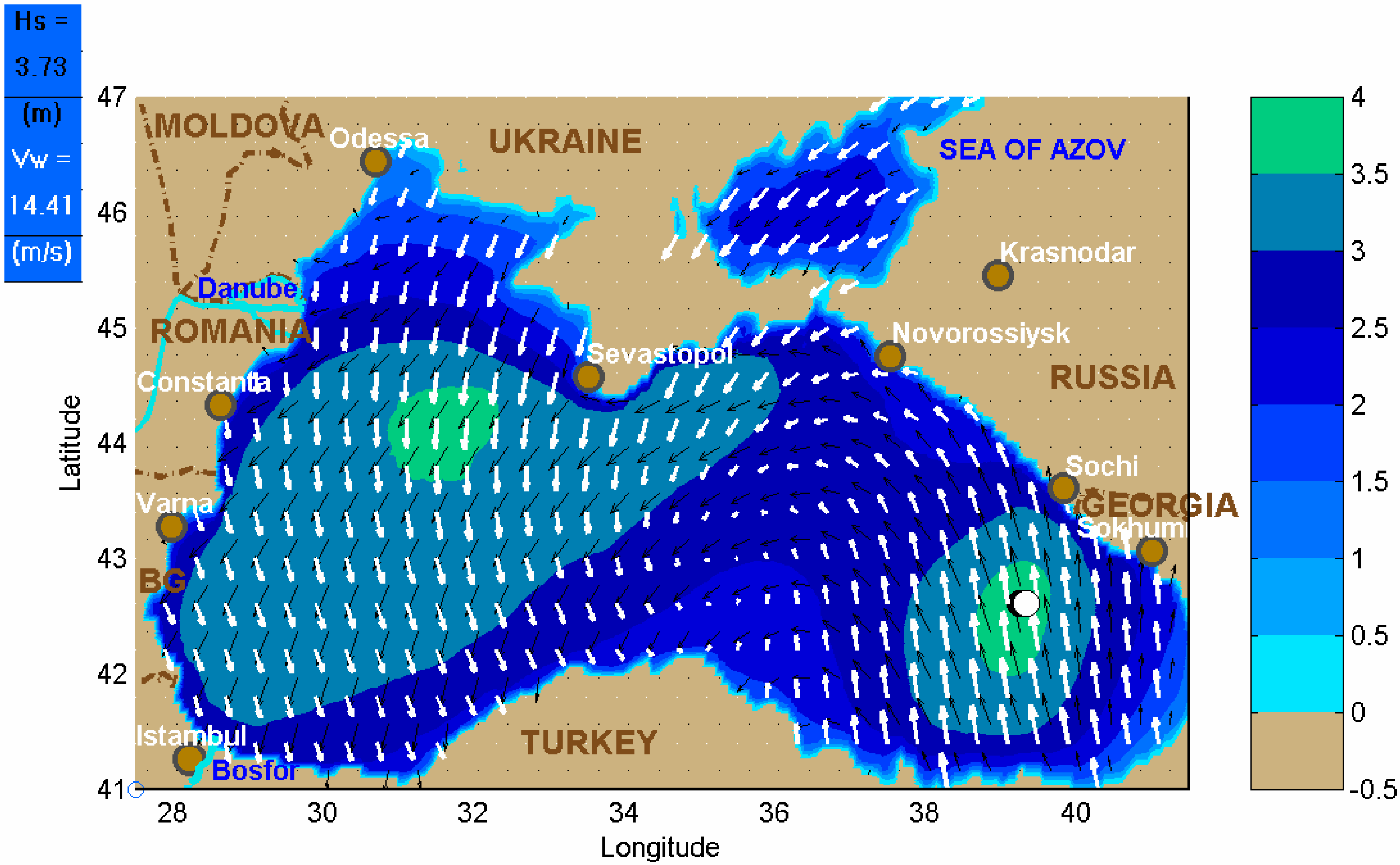
Typical storm

2002/03/10_h18

Hs = 4 (m)
Vw = 15.92 (m/s)



2002/03/12_h18



Nearshore focusing

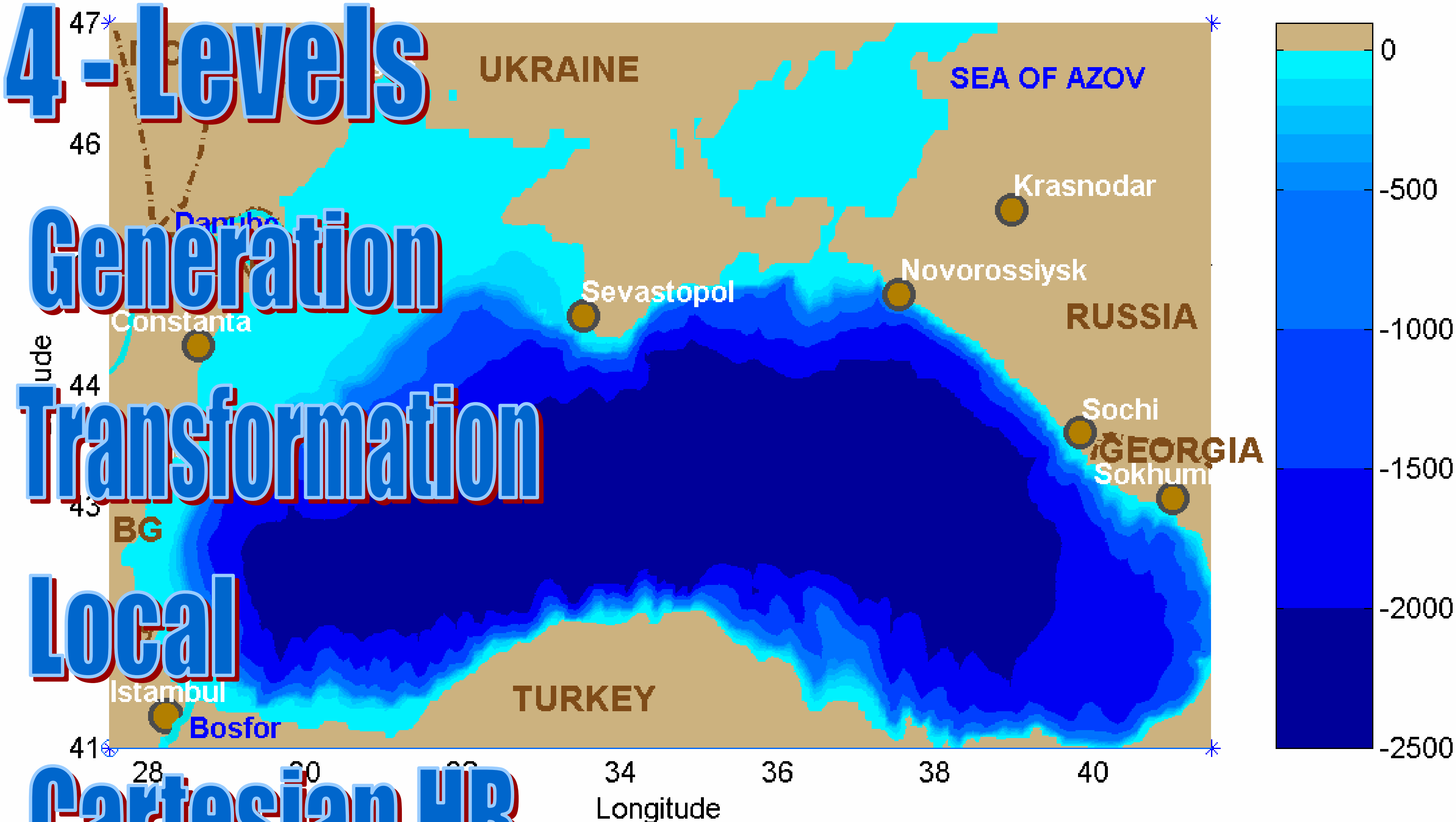
4 - Levels

Generation

Transformation

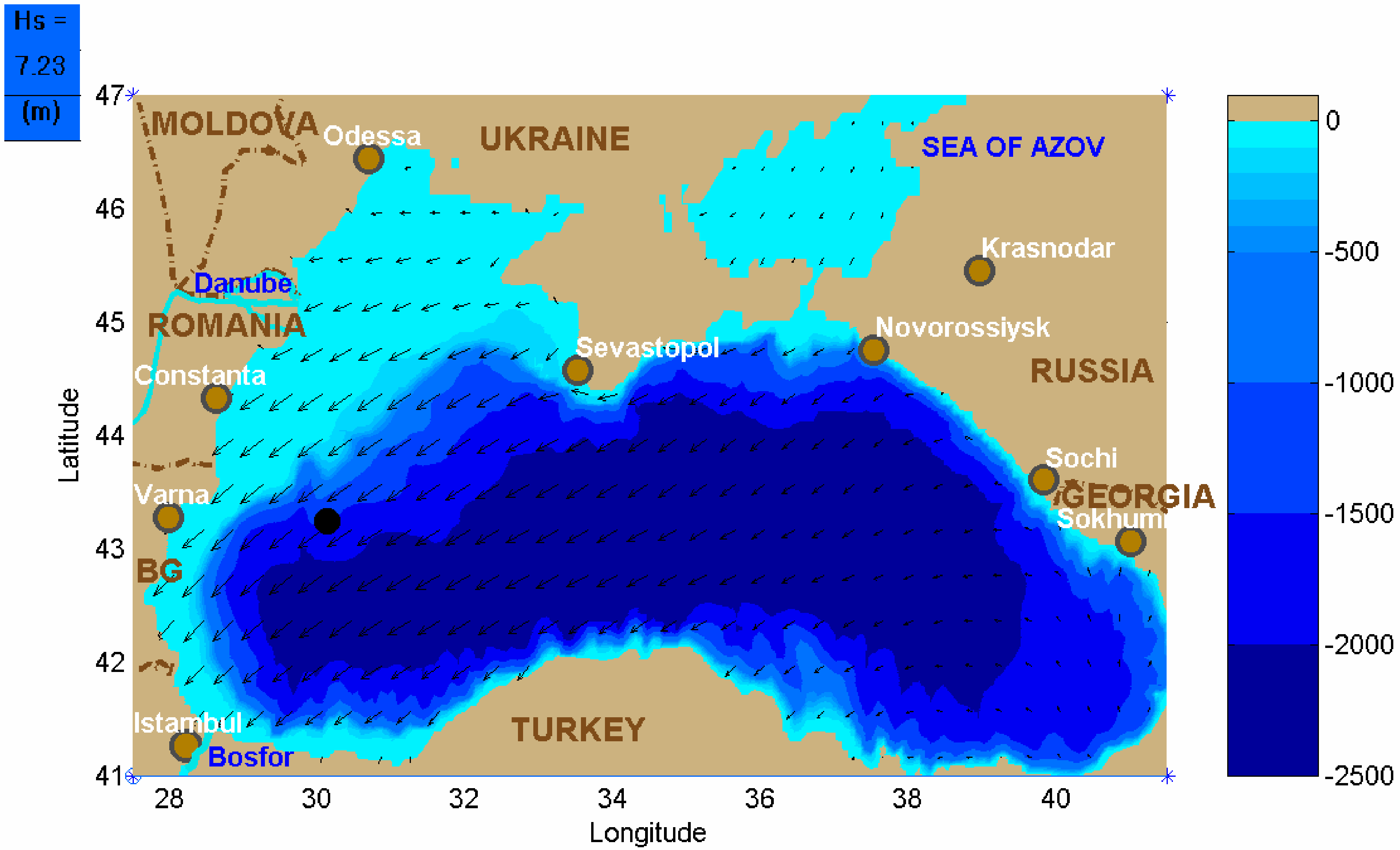
Local

Cartesian HR



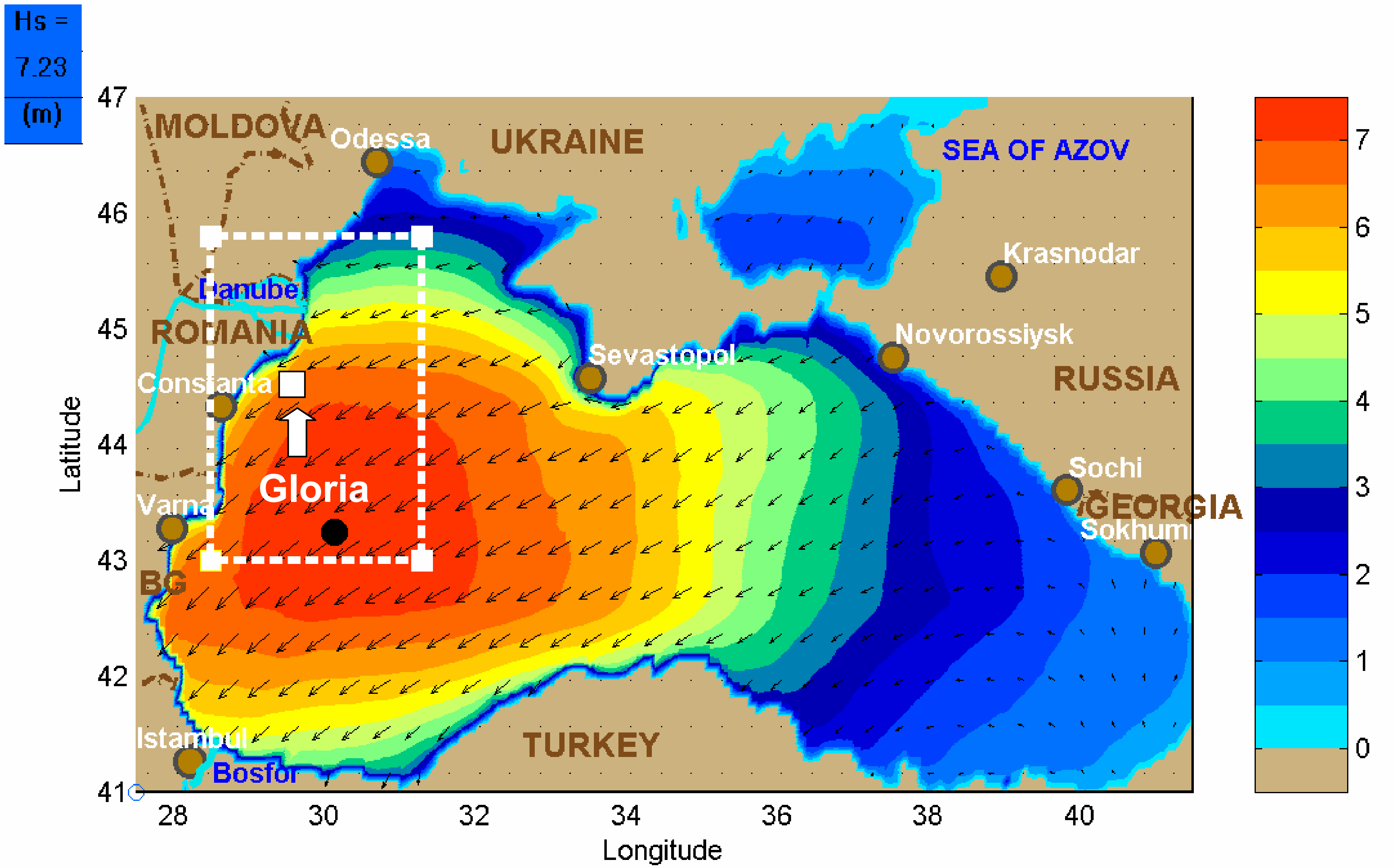
2002/03/11_h18

Level I – wave generation

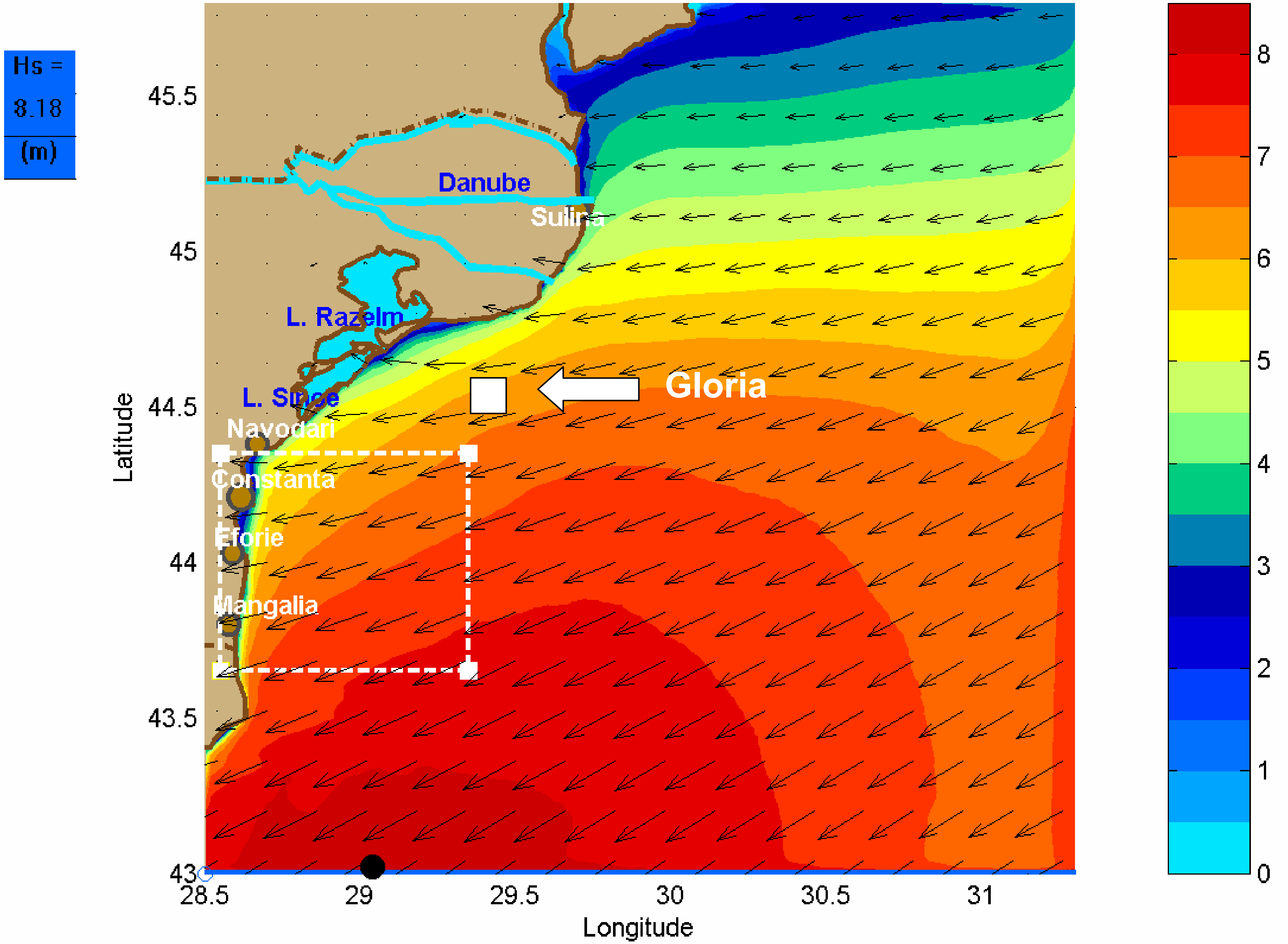


2002/03/11_h18

Level I – wave generation

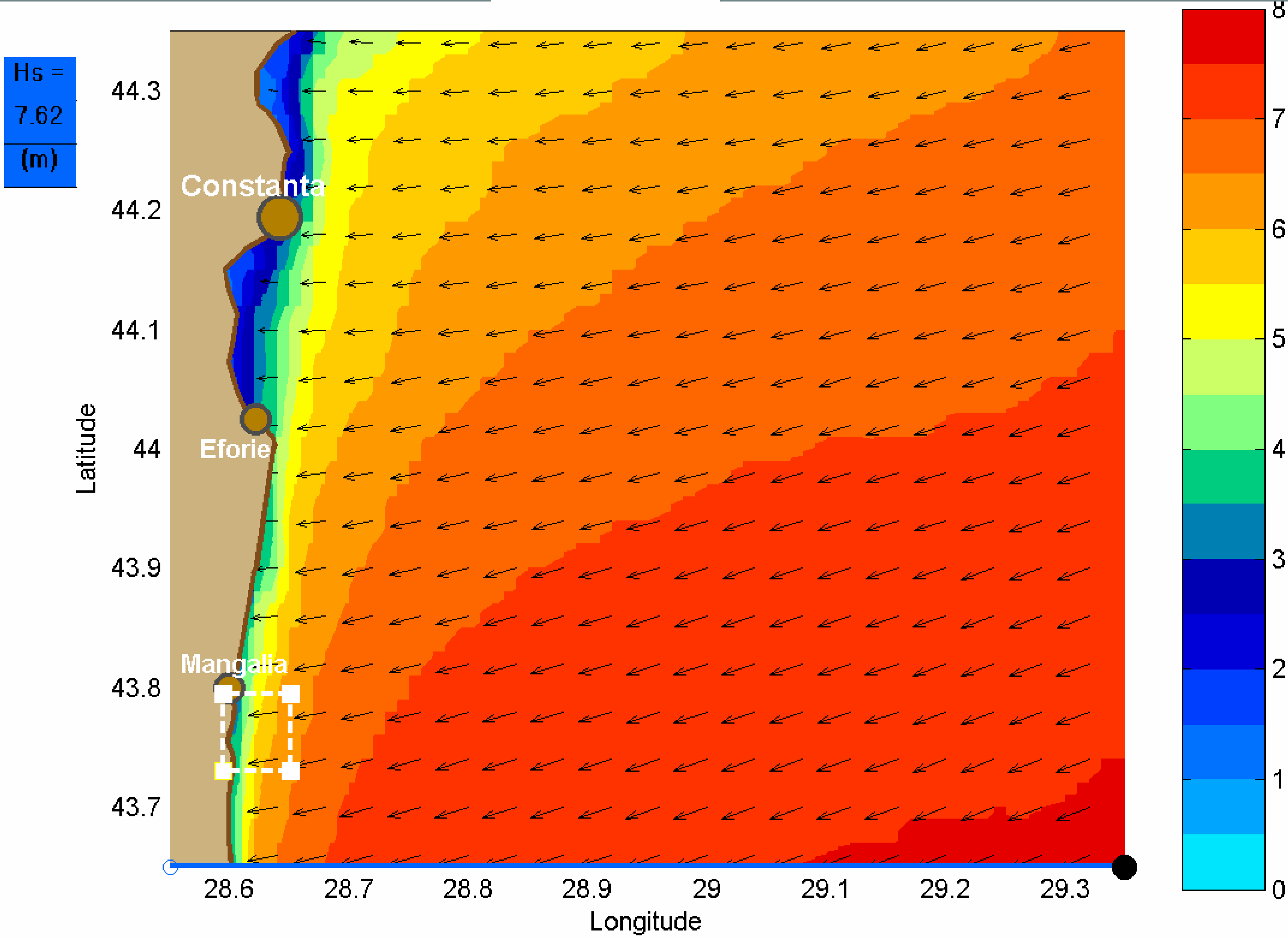


2002/03/11_h18 Level II – coastal transformation



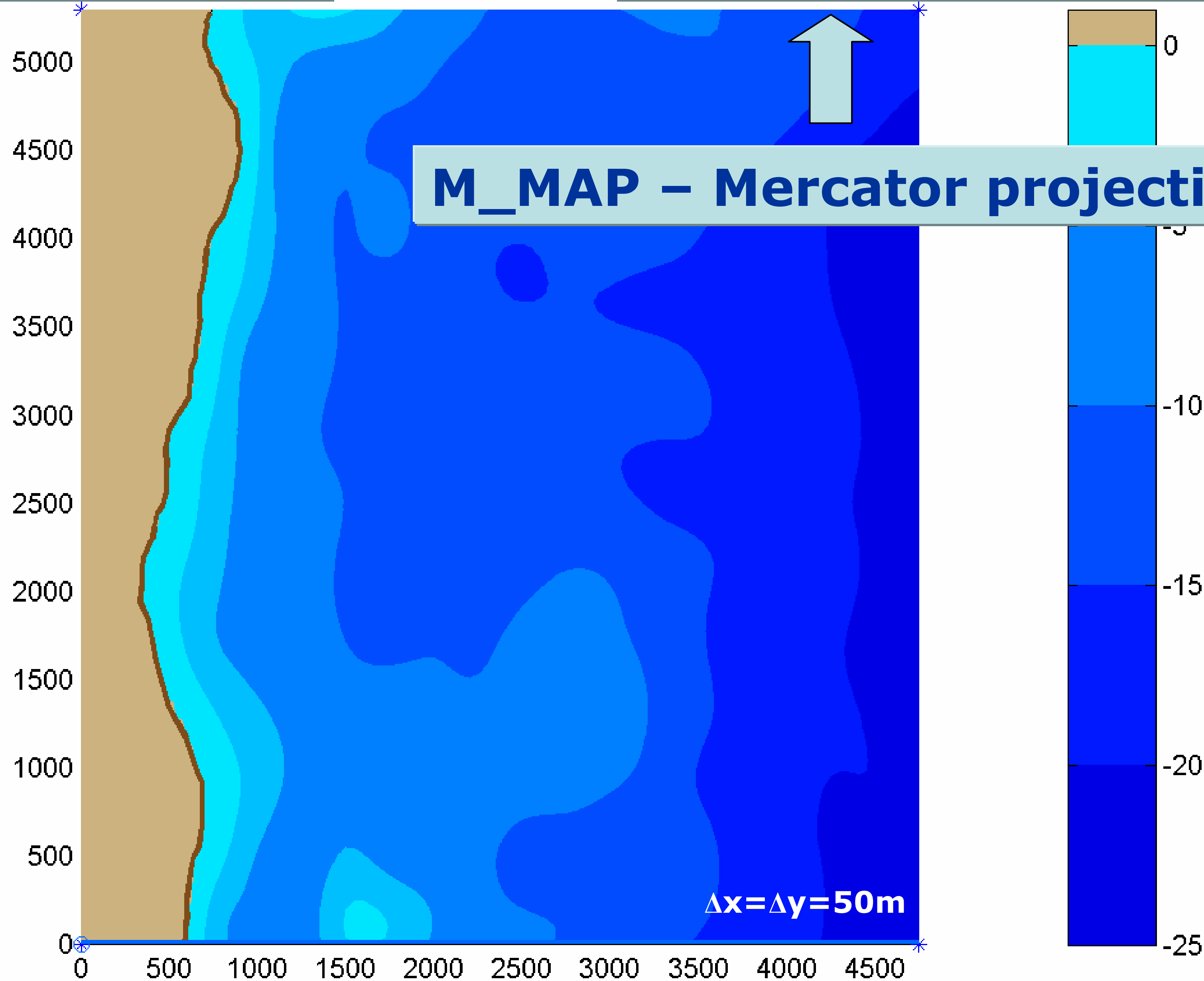
2002/03/11_h18

Level III – local focusing



2002/03/11_h18

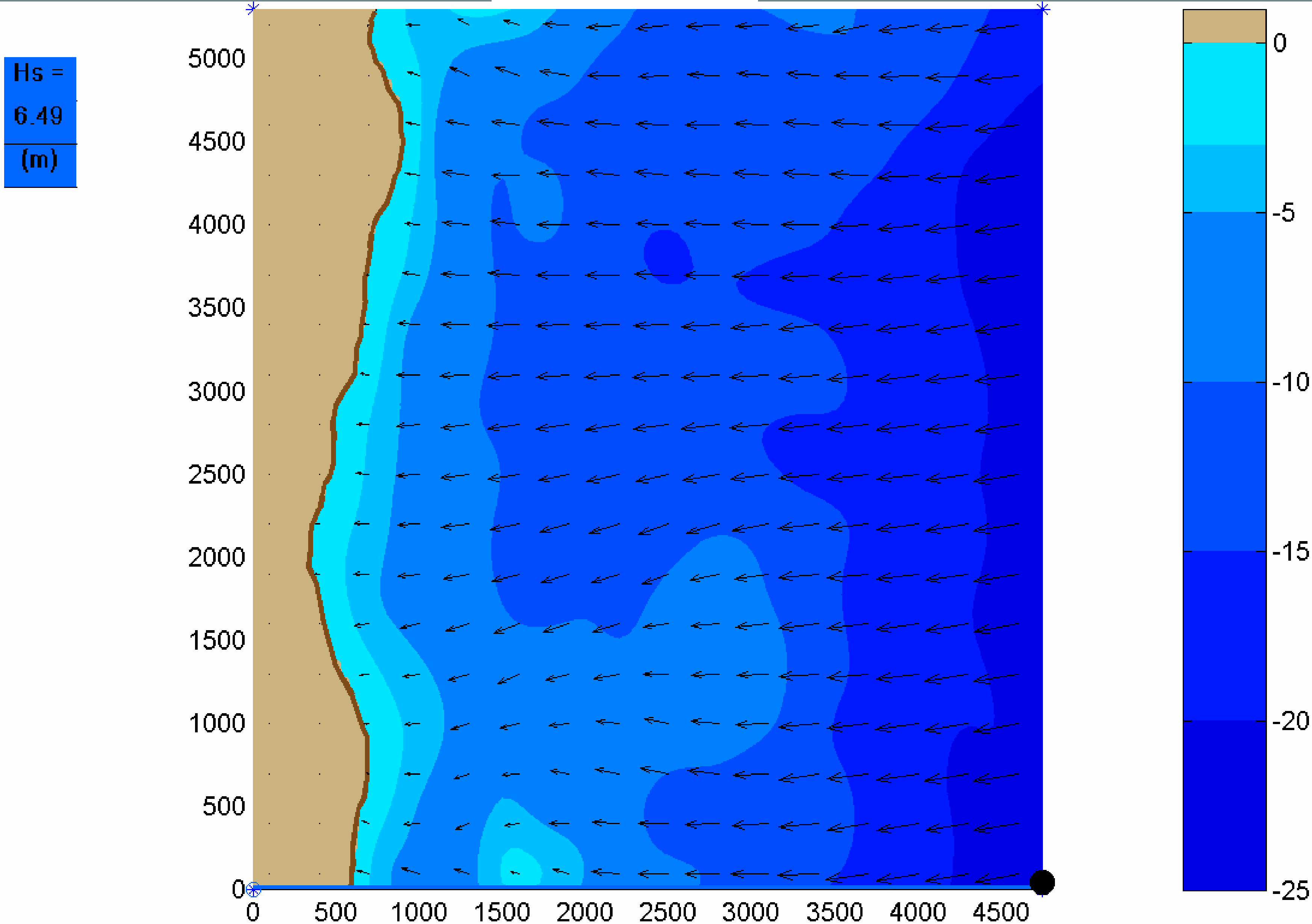
Level IV – Cartesian HR



M_MAP – Mercator projection

2002/03/11_h18

Level IV – Cartesian HR



2002/03/11_h18

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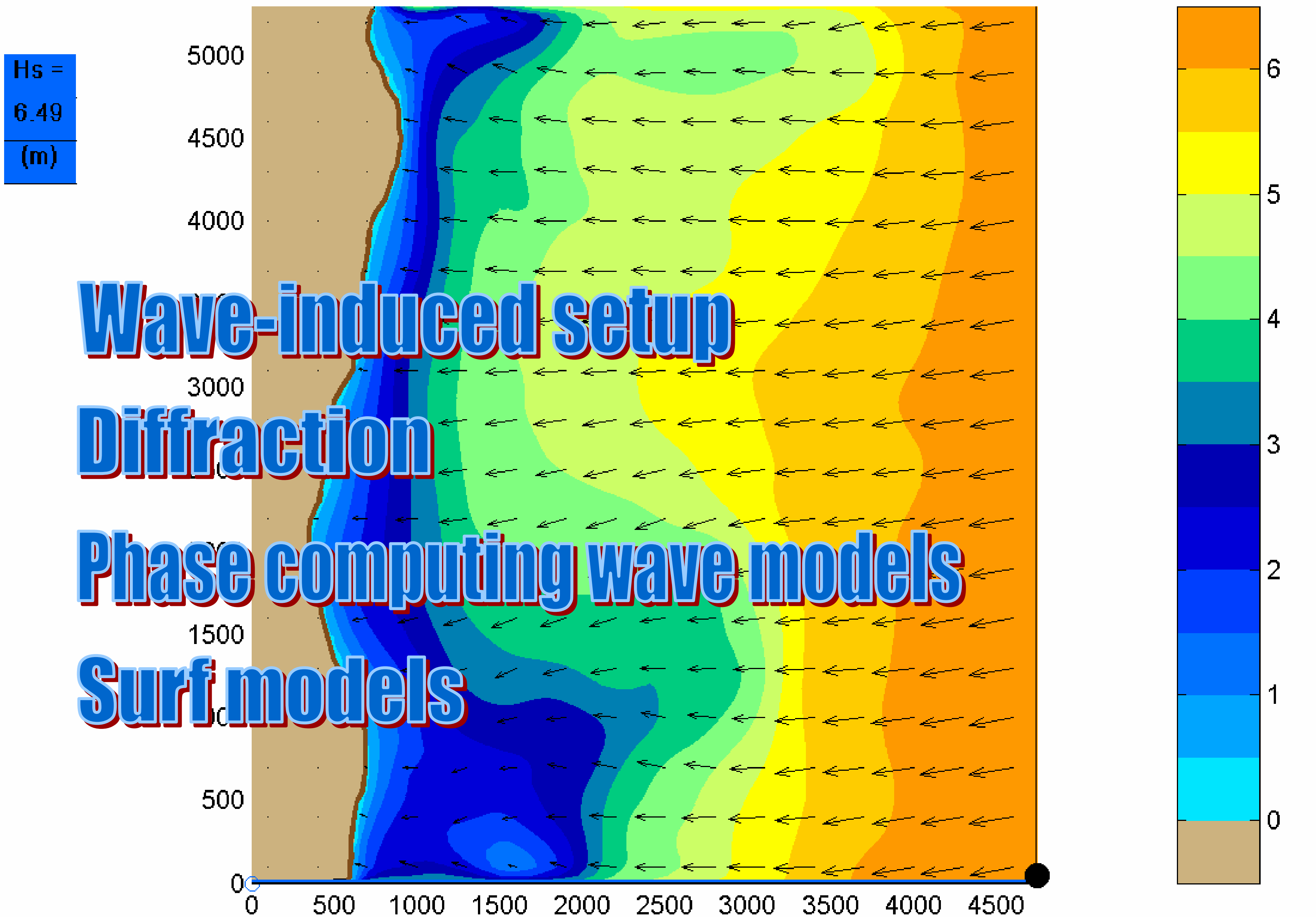


Wave-induced setup

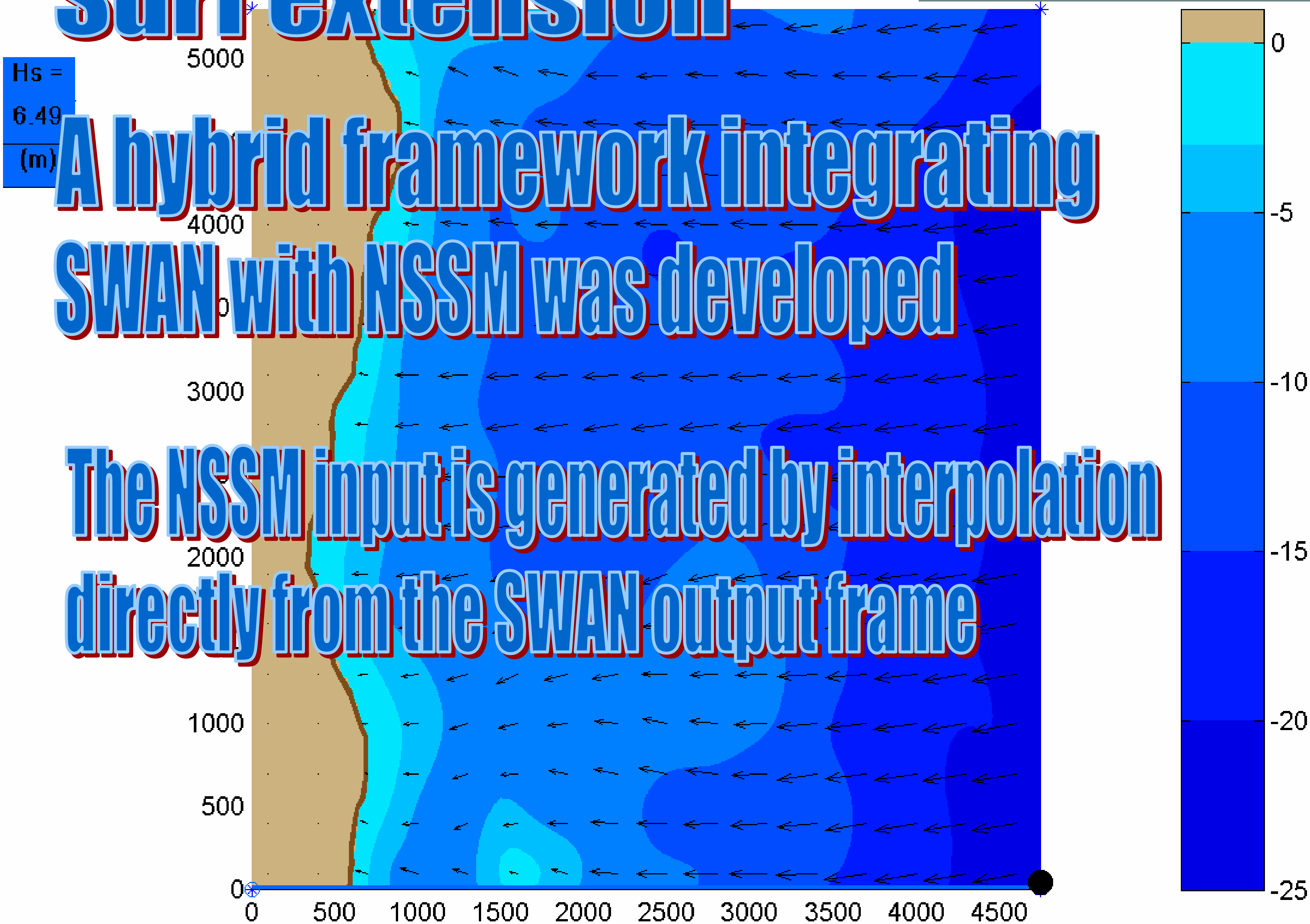
Diffraction

Phase computing wave models

Surf models

Surf extension

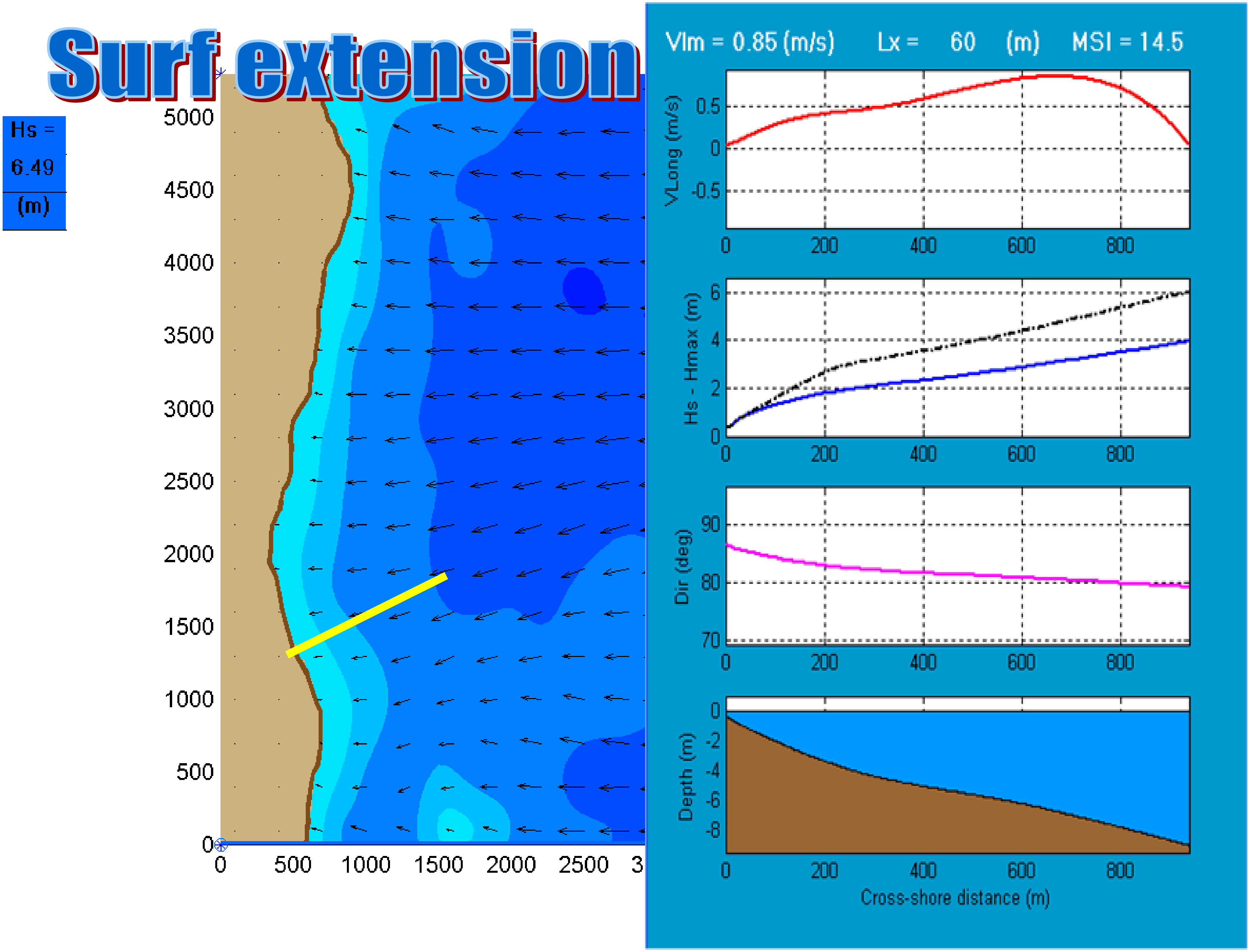
2002/03/11_h18



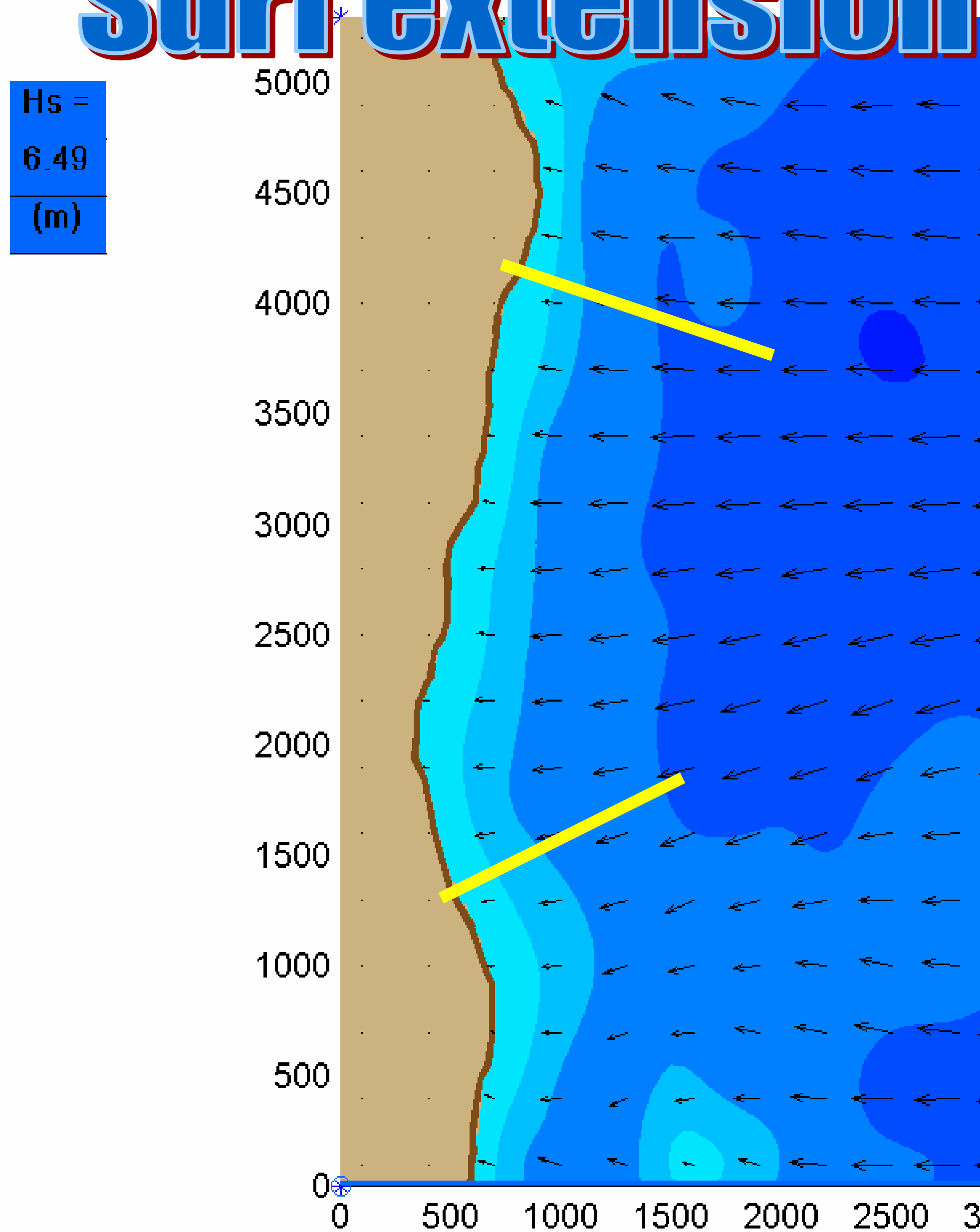
A hybrid framework integrating SWAN with NSSM was developed

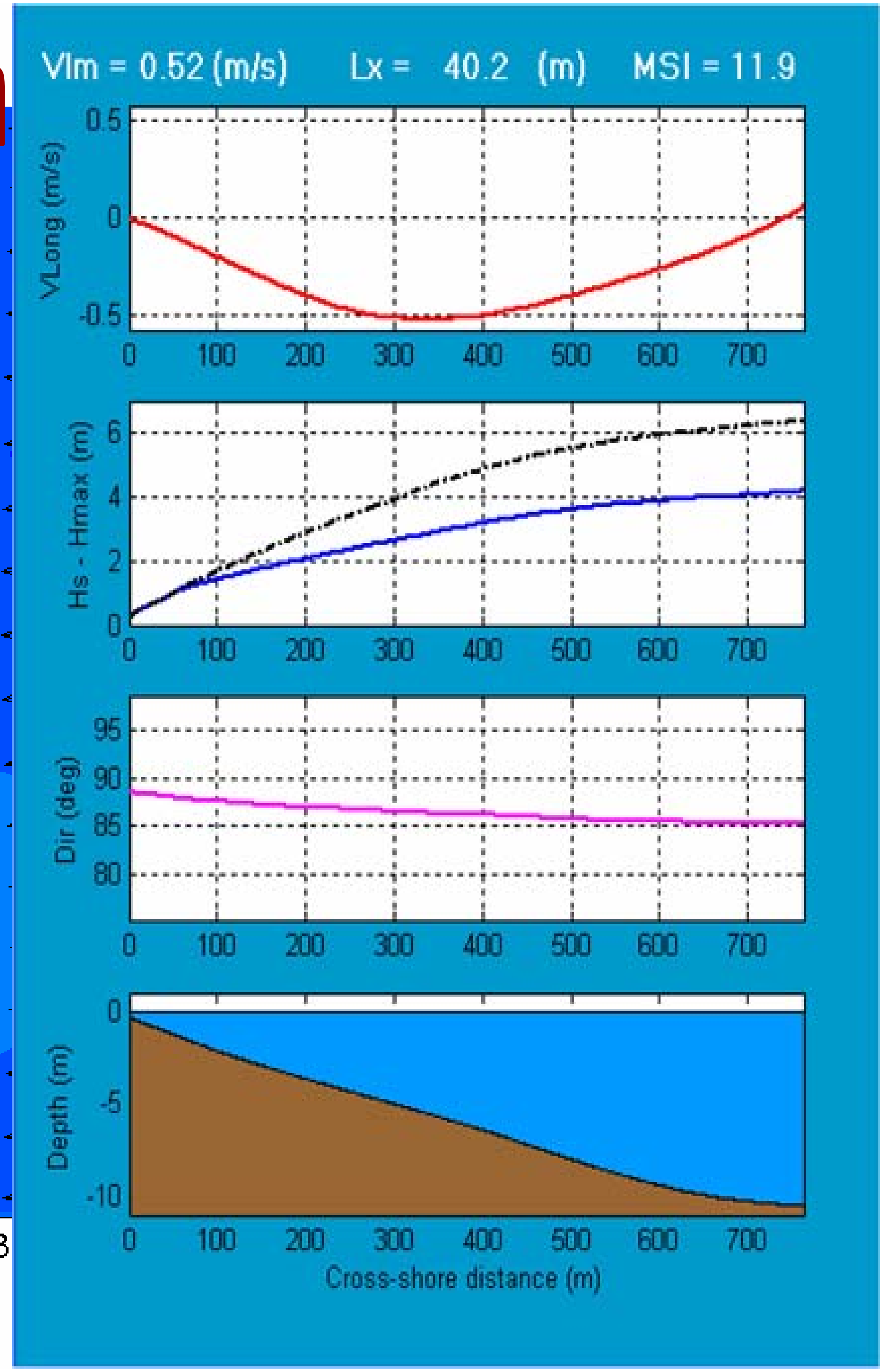
The NSSM input is generated by interpolation directly from the SWAN output frame

Surf extension



Surf extension





7. Final considerations

SWAN seems to be an adequate model for closed seas of medium size as Black Sea (or Caspian Sea)

One single model can cover the full scale of wave modeling

The validation of the Black SWAN wave prediction system will continue at various levels

Further studies will be focused more on storm events