Analysis of the atmospheric influence in water level modelling along the Iberian Atlantic coast

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Summary

- Objectives of the study
  - Determination of the importance of the atmospheric processes in forecasting sea water levels
  - Improve the model results and forecasts through various techniques i.e. implementing the inverted barometer technique and wind effects, improving tidal conditions and bathymetry.
- Objectives of the model
  - A comprehensive calibration and validation of the Portuguese Coastal Operational model system (PCOMS) using the available data.

Meteorological Effects on Tides

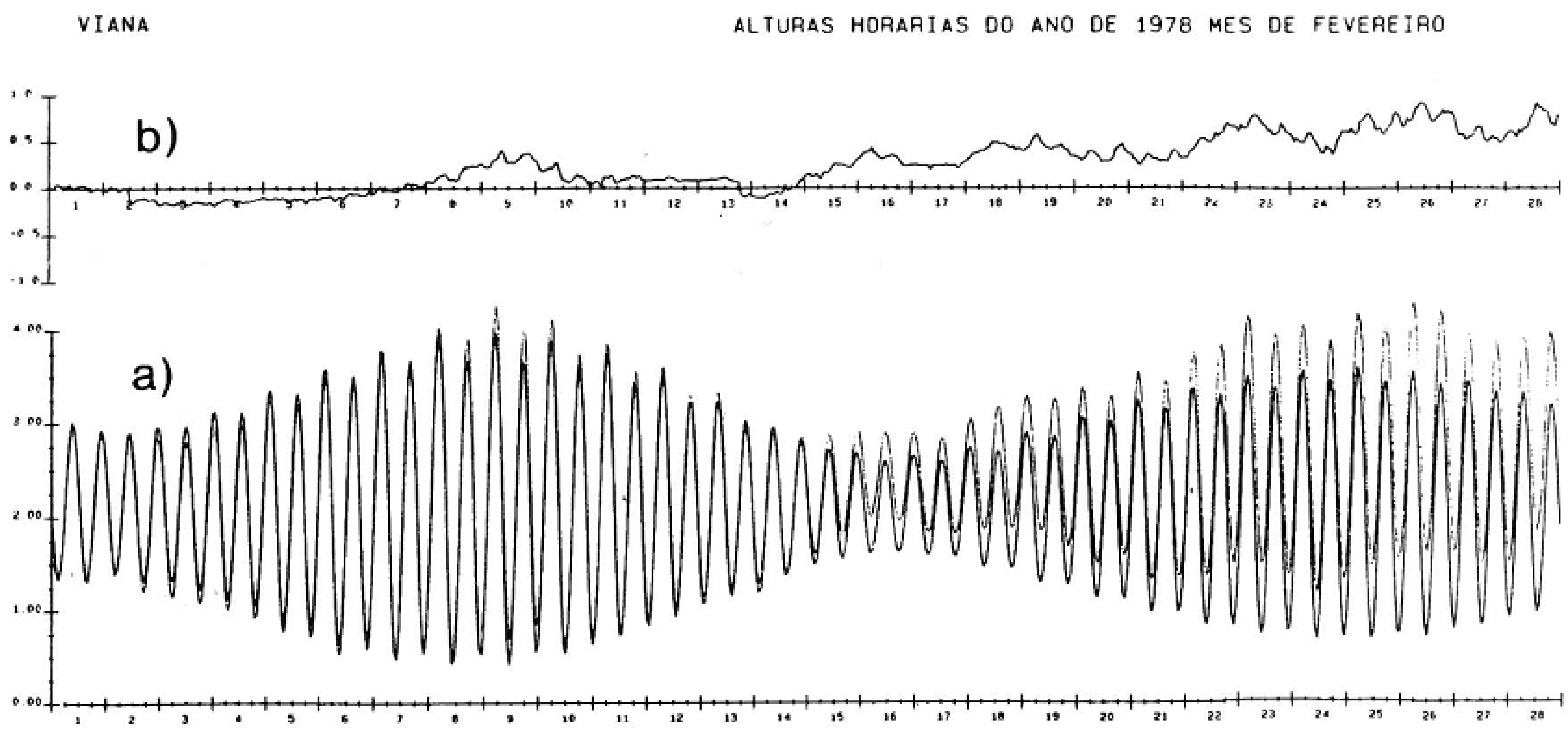
- **Barometric pressure** (inverted barometer effect). Changes in sea level due to barometric pressure alone seldom exceed 30 centimetres but, as such circumstances are usually associated with adverse weather conditions, the actual change in sea level is often much greater.

- **Wind setup**: A strong wind blowing onshore will pile up the water and cause the sea level to be higher than predicted, while winds blowing off the land will have the reverse effect.

- **Storm surges**: A long surface wave travelling with the storm depression can further exaggerate this sea level increase. A negative storm surge is the opposite effect, generally associated with high pressure systems and offshore winds, and can create unusually shallow water. When it reaches the scale of meters it can be included in the catastrophe type of events.

- Source: Land Information New Zealand (LINZ) http://www.linz.govt.nz/hydro/tidal-info/tidal-intro/meteorological-effects

Historical Extreme Events



Taborda, Rui; Dias, J.M. Alveirinho (1992) - Análise da Sobreelevação do Mar de Origem Meteorológica durante os Temporais de Fevereiro/Março de 1978 e Dezembro de 1981. *Geonovas,* Nº Especial 1 "*A Geologia e o Ambiente*", p.89-97, Lisboa, Portugal. ISSN: 0870-7375.

Historical Extreme Events

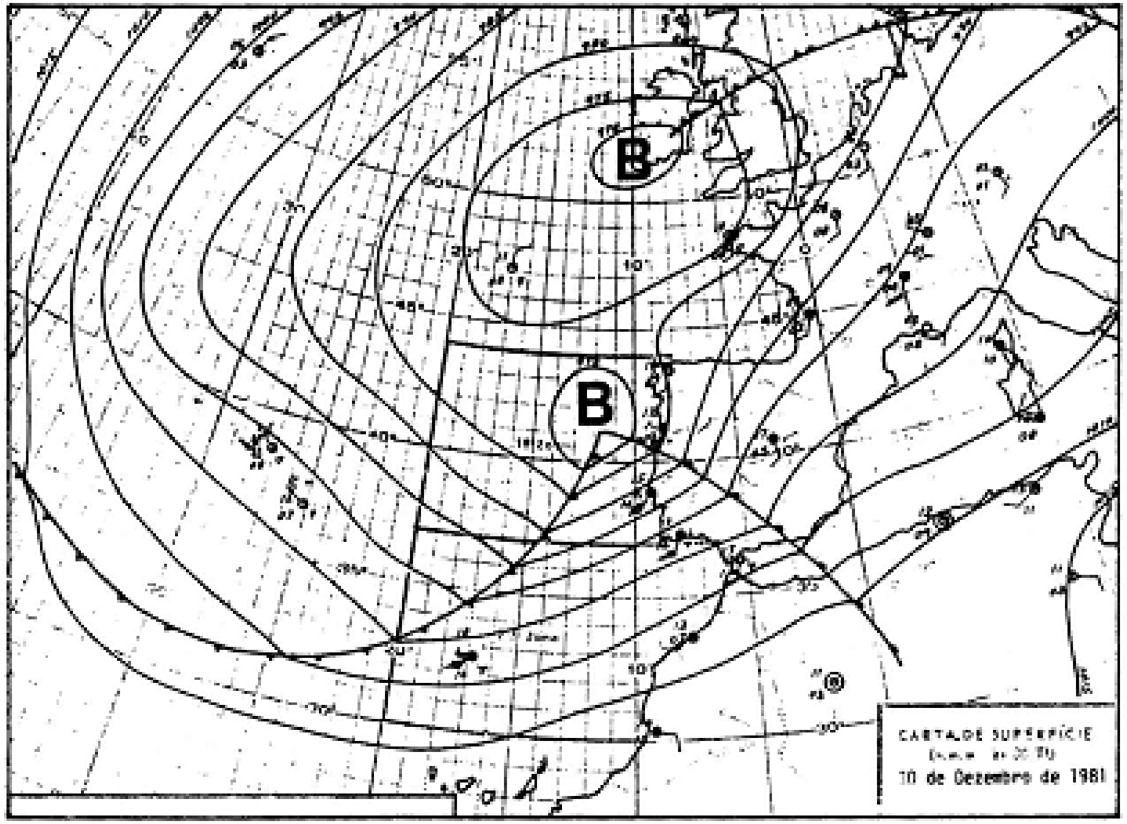


Fig. 2 - Carta de superfície às 0h TMG do dia 30 de Dezembro de 1981 (Segundo o Boletim Metereológico Diário nº 13301)

Maximum difference registered between astronomical and observed water level between **0.4 and 1.2 m**

Taborda, Rui; Dias, J.M. Alveirinho (1992) - Análise da Sobreelevação do Mar de Origem Meteorológica durante os Temporais de Fevereiro/Março de 1978 e Dezembro de 1981. *Geonovas,* Nº Especial 1 "*A Geologia e o Ambiente*", p.89-97, Lisboa, Portugal. ISSN: 0870-7375.

Atmosphere and ocean stations

🟥 **Uncomplete no Atm Press**

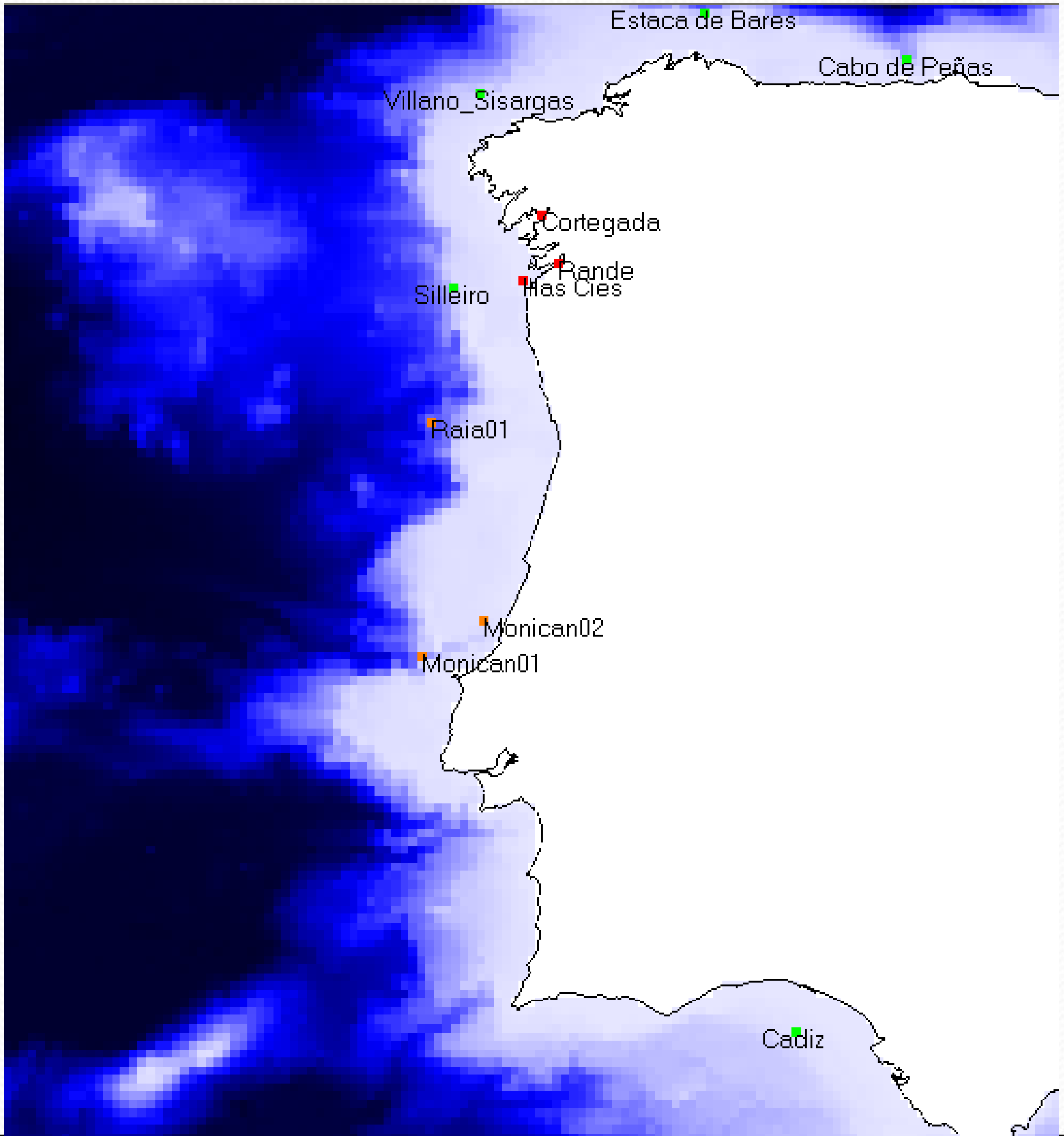
🟧 **Uncomplete with Atm Press**

🟩 **Complete**

Data Availability:

Atmosphere
- **Temperature**
- **Atm. Pressure**
- **Wind**

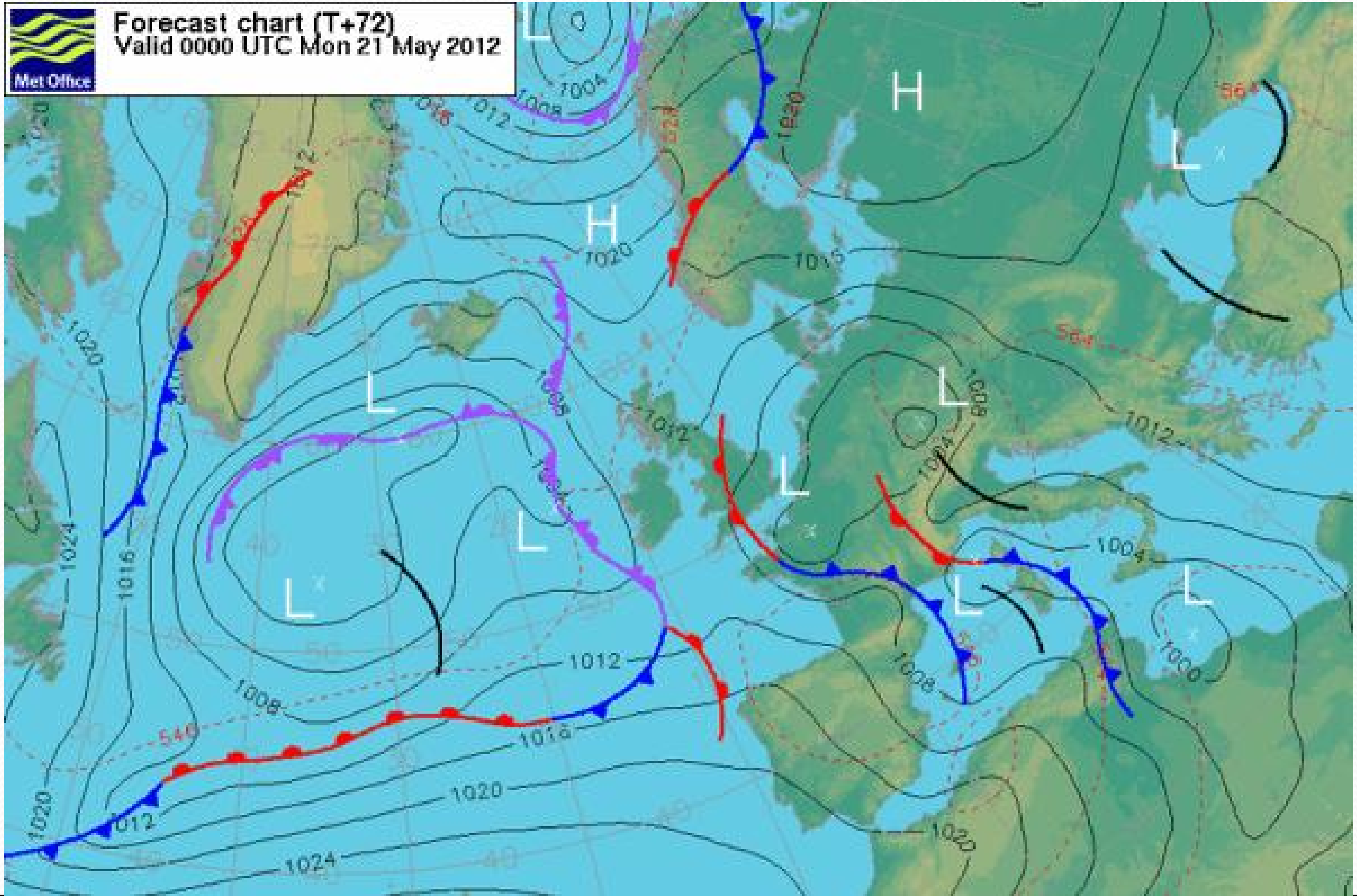
Ocean
- **Temperature**
- **Salinity**
- **Currents**
- **Waves**



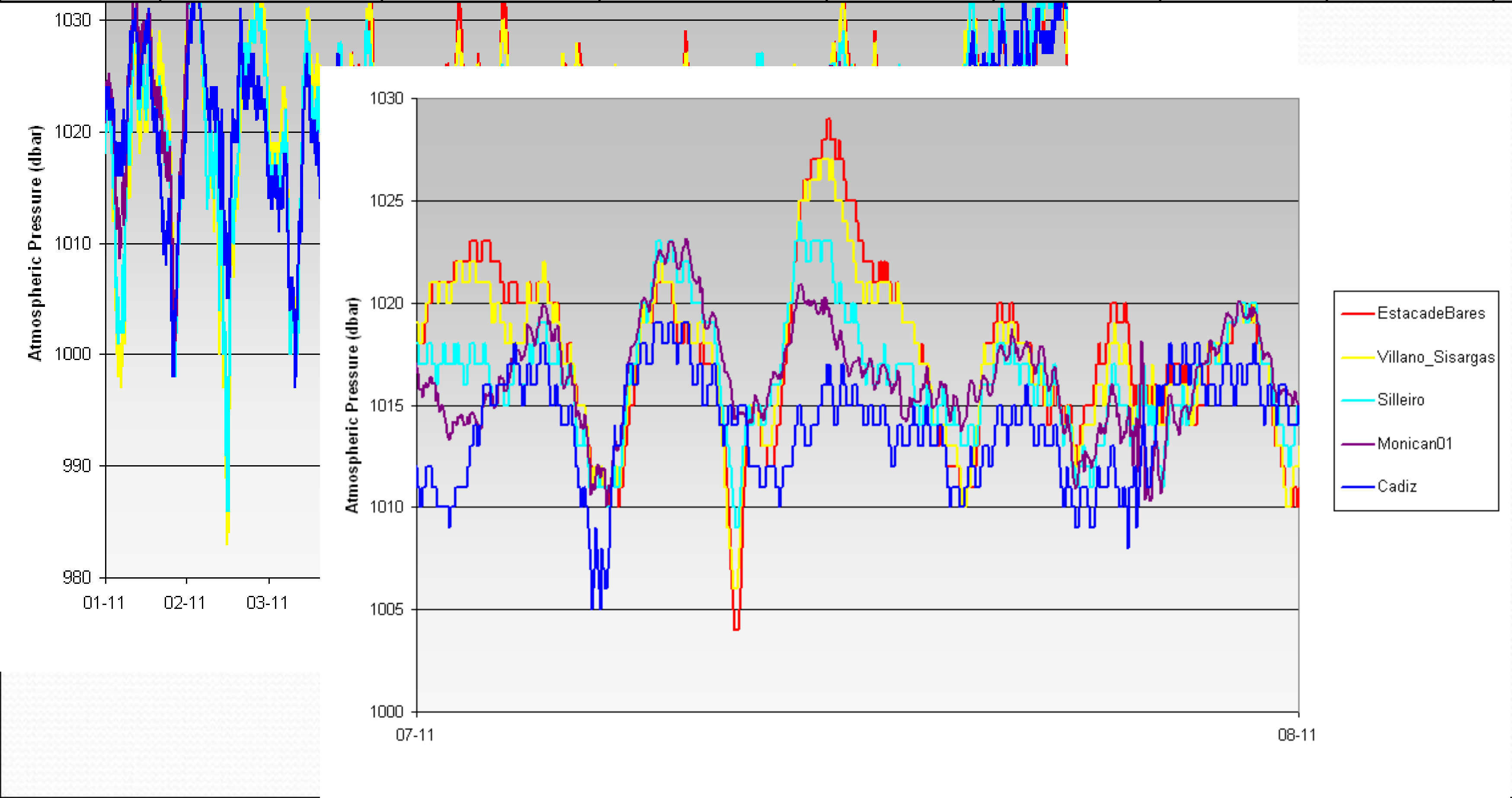
Data Availability

Station	Atmosphere			Ocean		
	Temp	Atm Press	Wind	Temp	Salinity	Currents
Cabo de Penhas	✓	✓	✓	✓	✓	✓
Estaca de Bares	✓	✓	✓	✓	✓	✓
Villano_Sisargas	✓	✓	✓	✓	✓	✓
Cortegada	✓	✗	✓	✓	✓	✗
Rande	✓	✗	✗	✓	✓	✗
Illhas Cies	✓	✗	✓	✓	✓	✗
Silleiro	✓	✓	✓	✓	✓	✓
Raia01	✓	✓	✓	✓	✗	✗
Monican02	✓	✓	✓	✓	✗	✗
Monican01	✓	✓	✓	✓	✗	✗
Cadiz	✓	✓	✓	✓	✓	✓

Atmospheric Pressure along the Iberian Peninsula

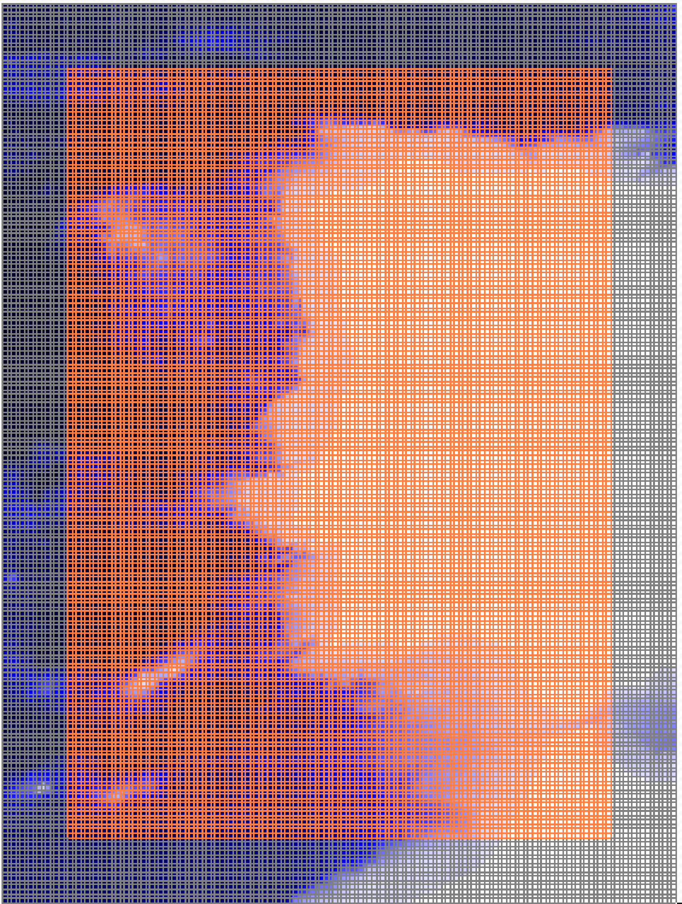


	Cabo de Penhas	Estaca de Bares	Villano_Sisargas	Silleiro	Raia01	Monican02	Monican01	Cadiz
Average	1019.23	1019.12	1018.92	1018.58	1016.97	1019.34	1018.24	1017.72
Maximum	1041.00	1041.00	1041.00	1039.00	1031.64	1038.28	1034.91	1036.00
Minimum	985.00	989.00	983.00	986.00	997.12	993.80	993.07	997.00
SD	8.11	7.68	8.33	7.81	7.53	6.61	6.10	6.23
Median	1020.00	1020.00	1020.00	1019.00	1018.36	1018.90	1018.65	1017.00
N	**8051**	**6716**	**8678**	**8578**	**1606**	**4633**	**3501**	**7994**



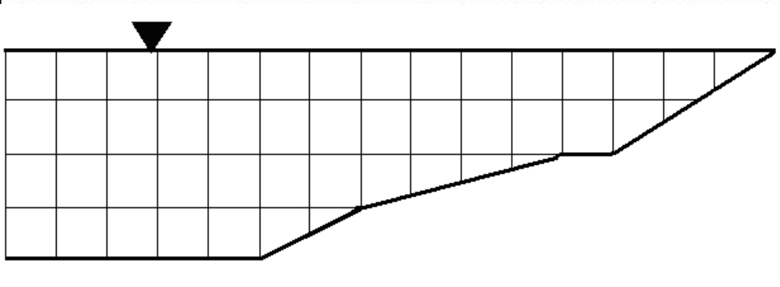
PCOMS Settings

- 2D West Iberia: 208x155 (0.06 degrees ≈ 5.6 km)
- 3D Portugal: 177x125 (0.06 degrees ≈ 5.6 km)



Vertical Discretisation

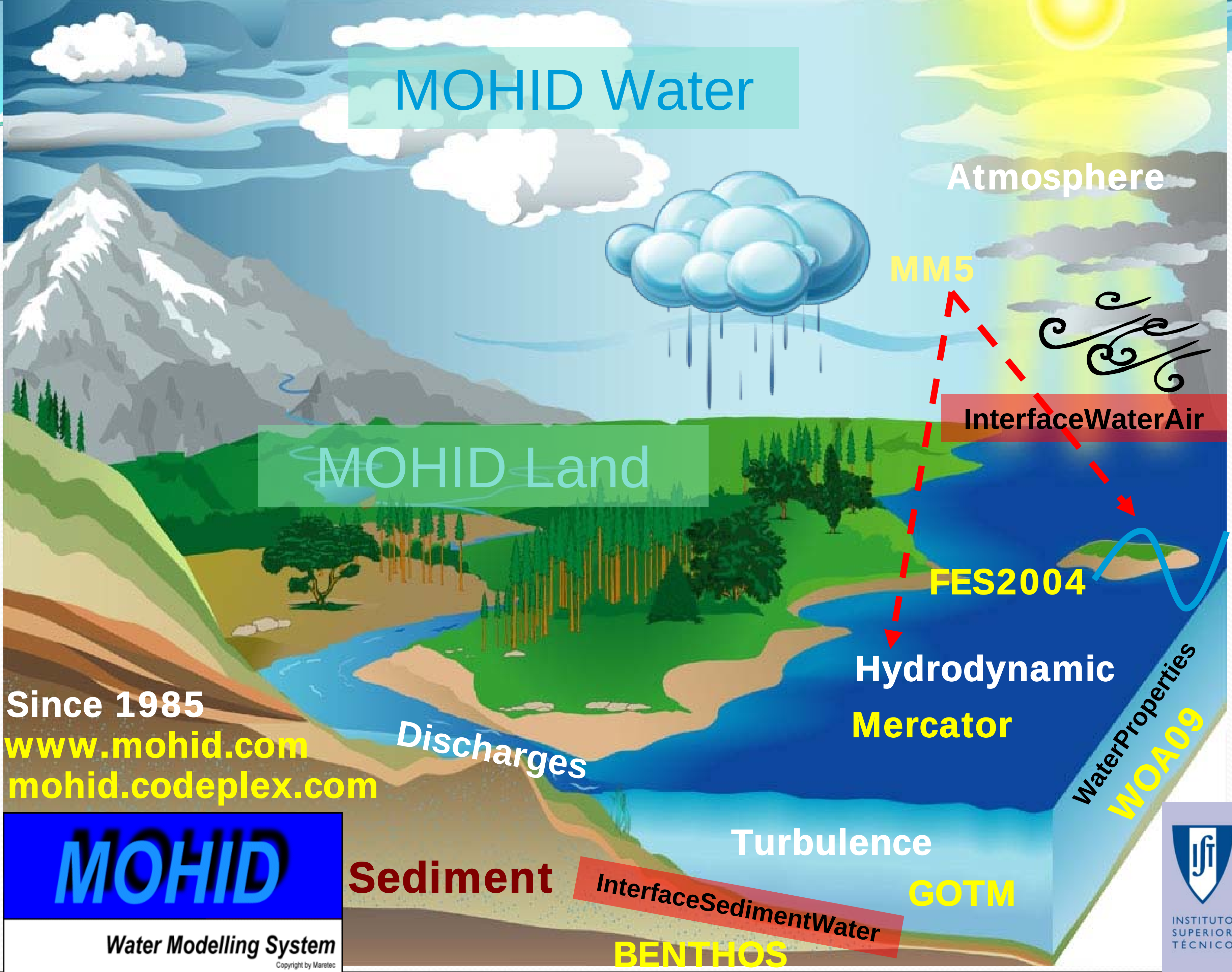
50 vertical layers corresponding to the layers defined in the model Mercator Ocean mercator Psy2v4



L	W (m)	C	W (m)	C	W (m)	C	W (m)	C	W (m)
1	0.98	**11**	2.44	**21**	13.06	**31**	79.87	**41**	295.81
2	1.12	**12**	2.93	**22**	15.89	**32**	94.43	**42**	320.71
3	1.09	**13**	3.27	**23**	18.91	**33**	110.53	**43**	344.02
4	1.25	**14**	3.96	**24**	22.97	**34**	129.00	**44**	366.22
5	1.27	**15**	4.50	**25**	27.40	**35**	149.01	**45**	386.20
6	1.46	**16**	5.48	**26**	33.15	**36**	171.19	**46**	404.70
7	1.51	**17**	6.34	**27**	39.55	**37**	194.52	**47**	420.78
8	1.78	**18**	7.72	**28**	47.58	**38**	219.40	**48**	435.36
9	1.88	**19**	9.06	**29**	56.59	**39**	244.66	**49**	447.62
10	2.25	**20**	11.03	**30**	67.58	**40**	270.56	**50**	458.65

L = Layer W = Width

MOHID Water



Atmosphere

MM5

InterfaceWaterAir

MOHID Land

FES2004

Hydrodynamic

Mercator

WaterProperties

WOA09

Since 1985

www.mohid.com

mohid.codeplex.com

Discharges

Turbulence

GOTM

Sediment

InterfaceSedimentWater

BENTHOS

MOHID

Water Modelling System

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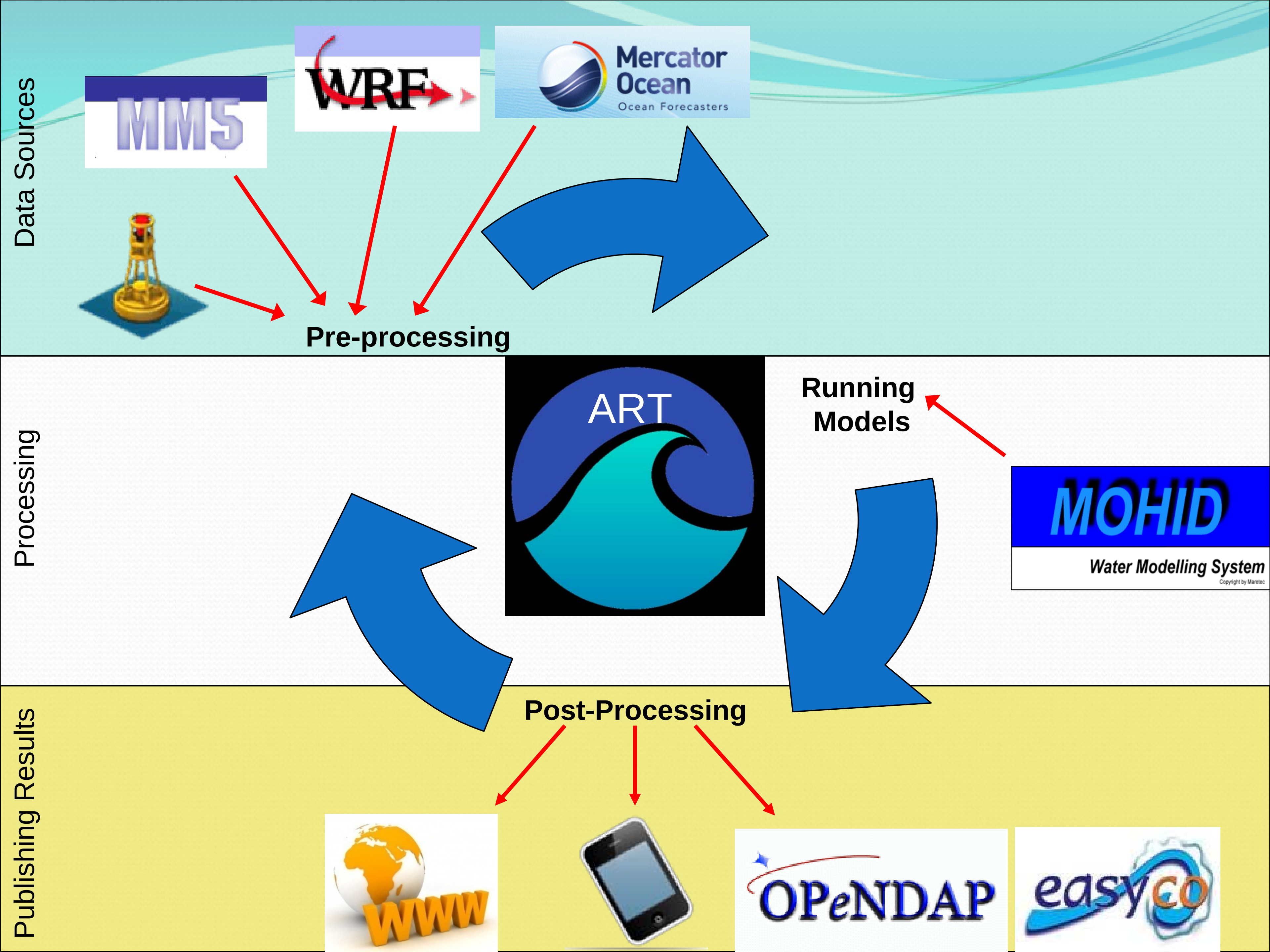


Data Sources

Pre-processing

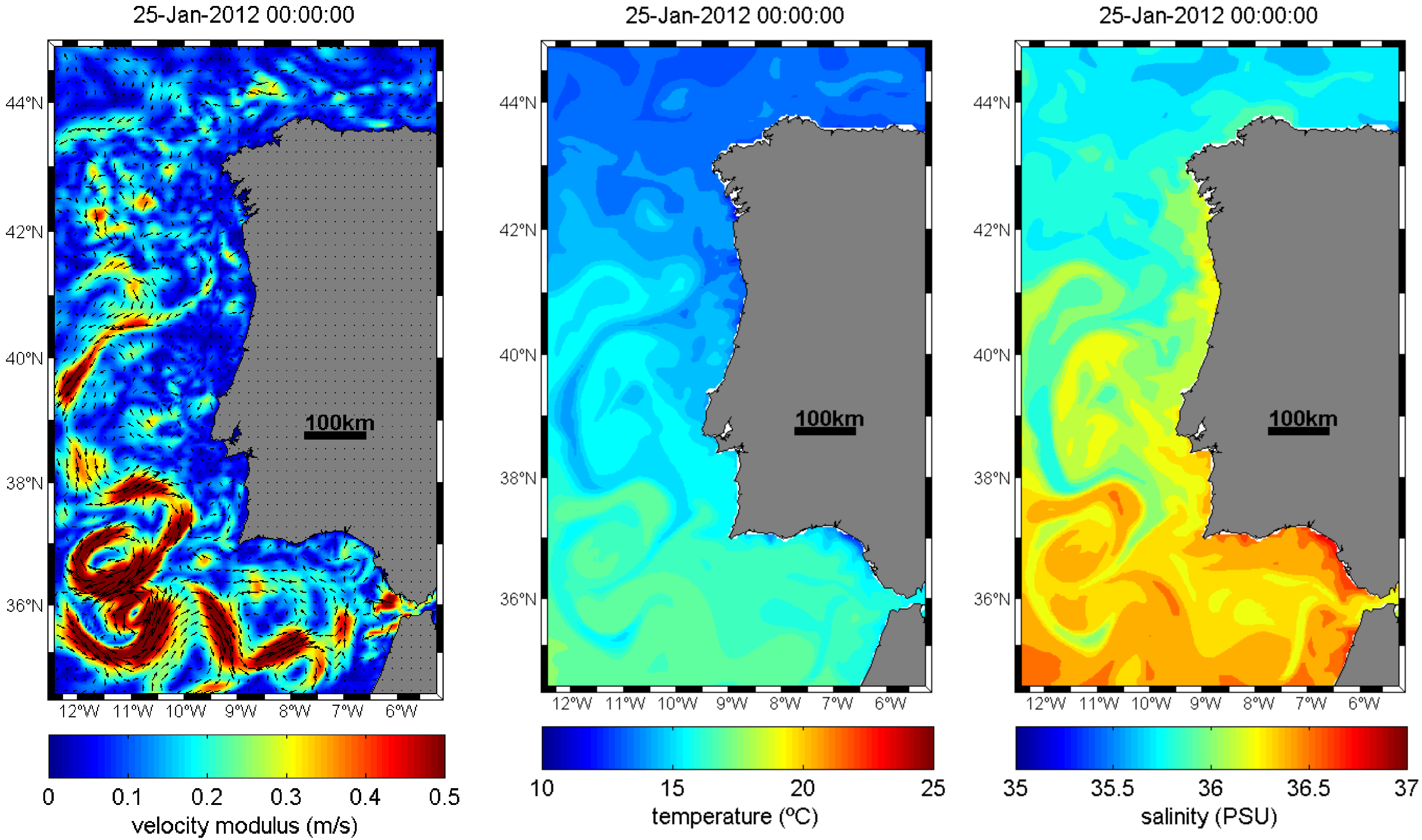
Processing

Running Models

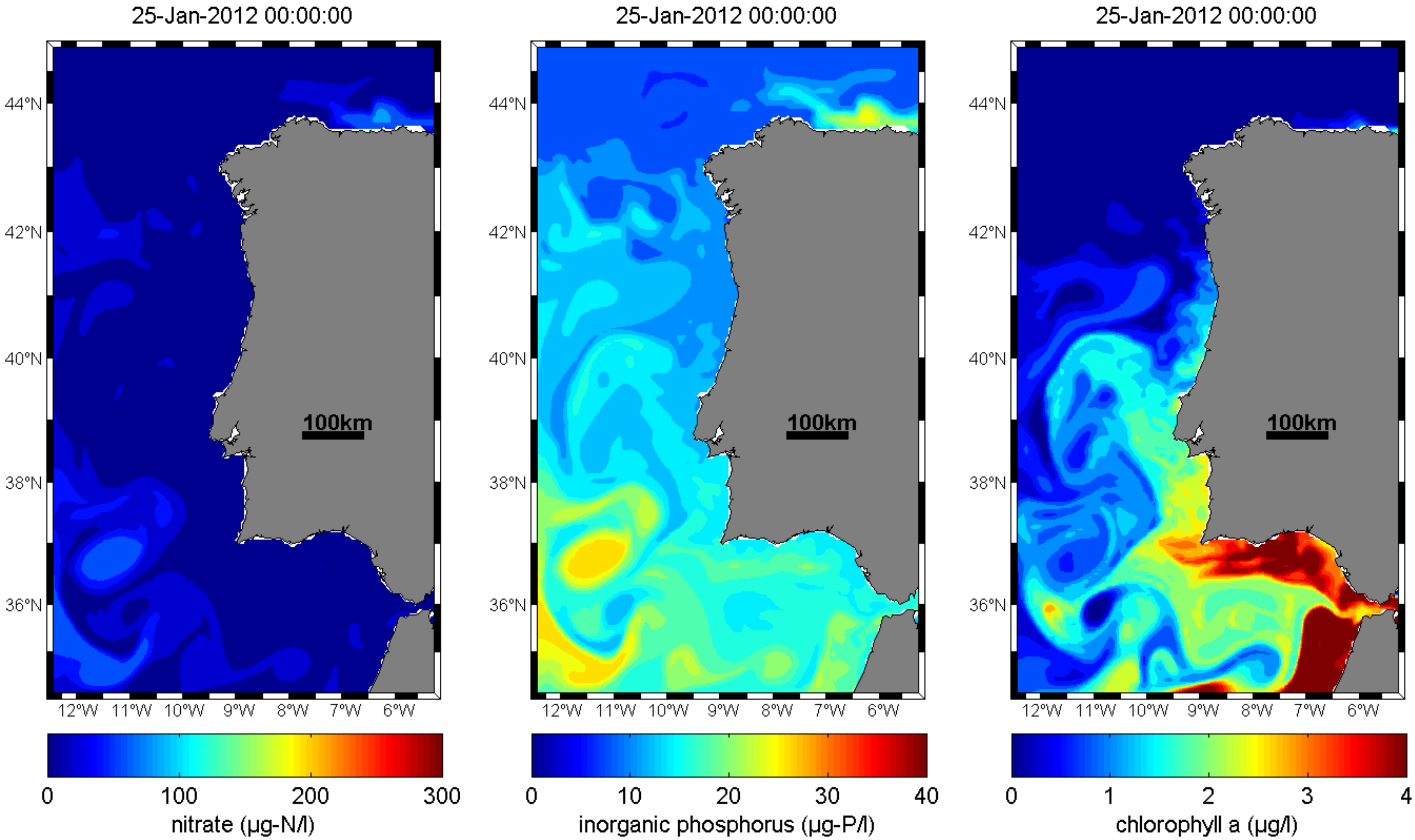
Post-Processing

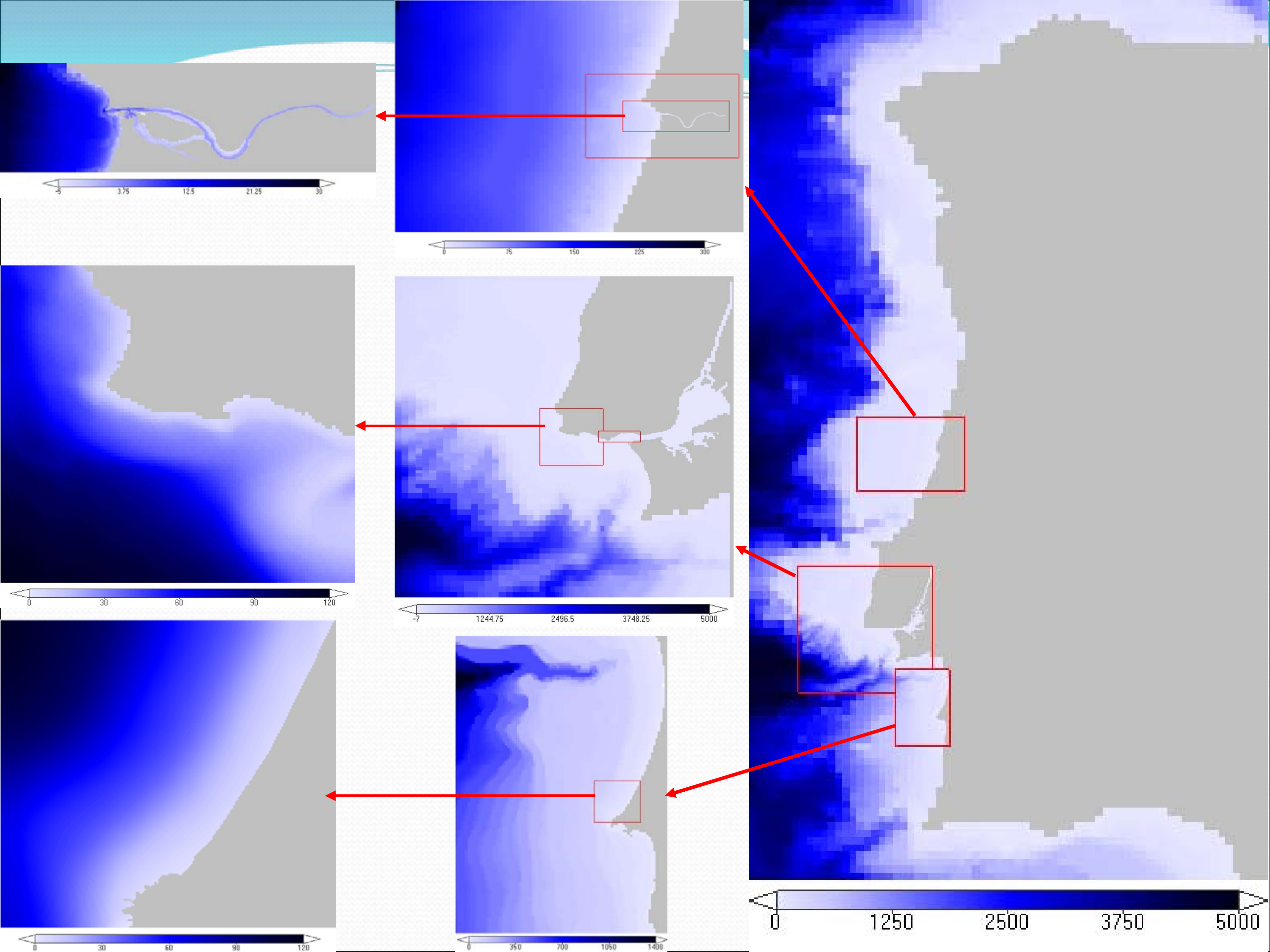
Publishing Results

Surface plots



Surface plots

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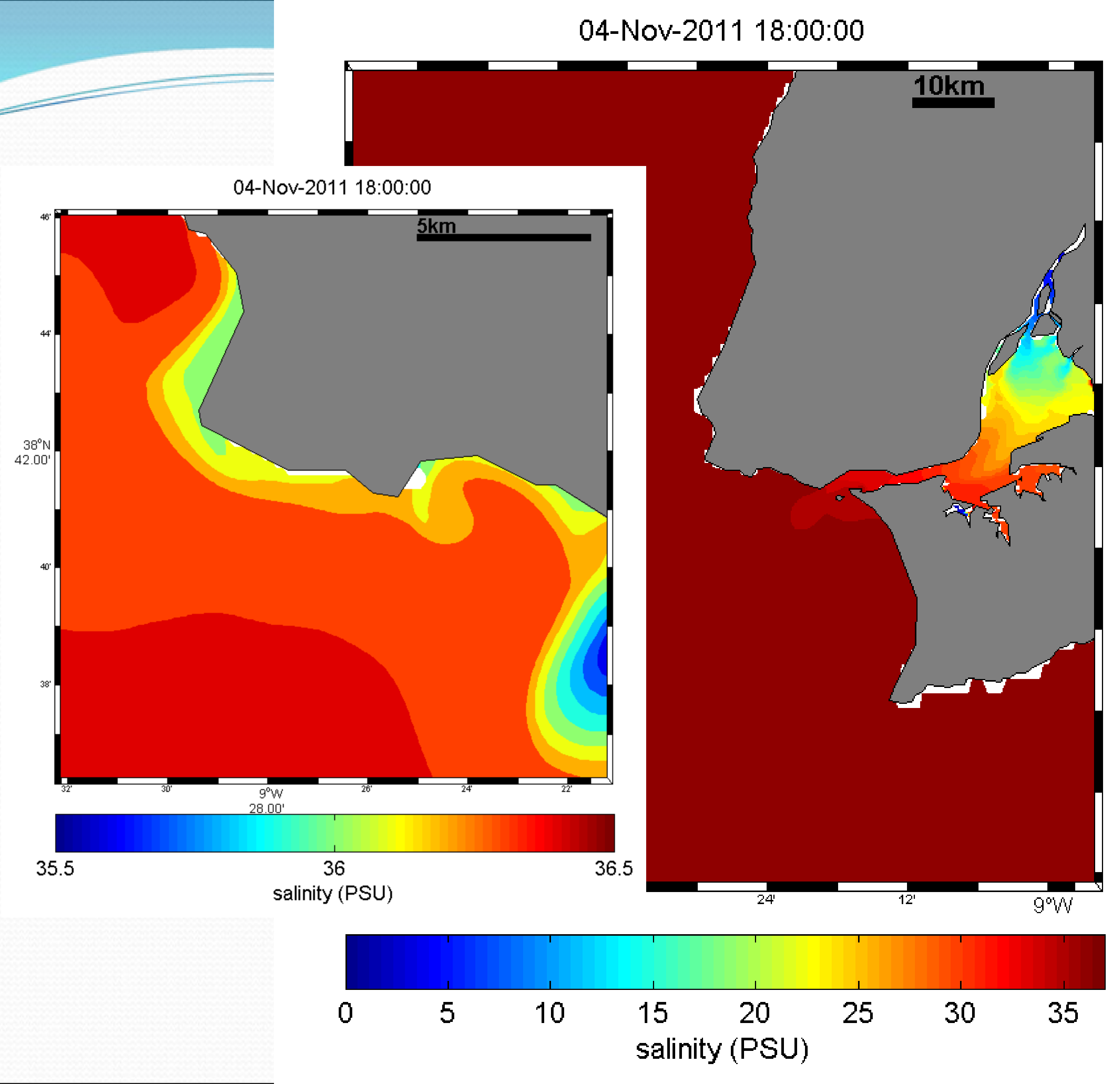
3.75
12.5
21.25
30
0
75
150
225
300
0
30
60
90
120
-7
1244.75
2496.5
3748.25
5000
0
30
60
90
120
0
350
700
1050
1400
0
1250
2500
3750
5000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5km
46'
44'
38°N
42.00'
40'
38'
32'
30'
9°W
28.00'
26'
24'
22'
35.5
36
36.5
salinity (PSU)
04-Nov-2011 18:00:00
10km
24'
12'
9°W
0
5
10
15
20
25
30
35
salinity (PSU)

Tidal Gauges Network

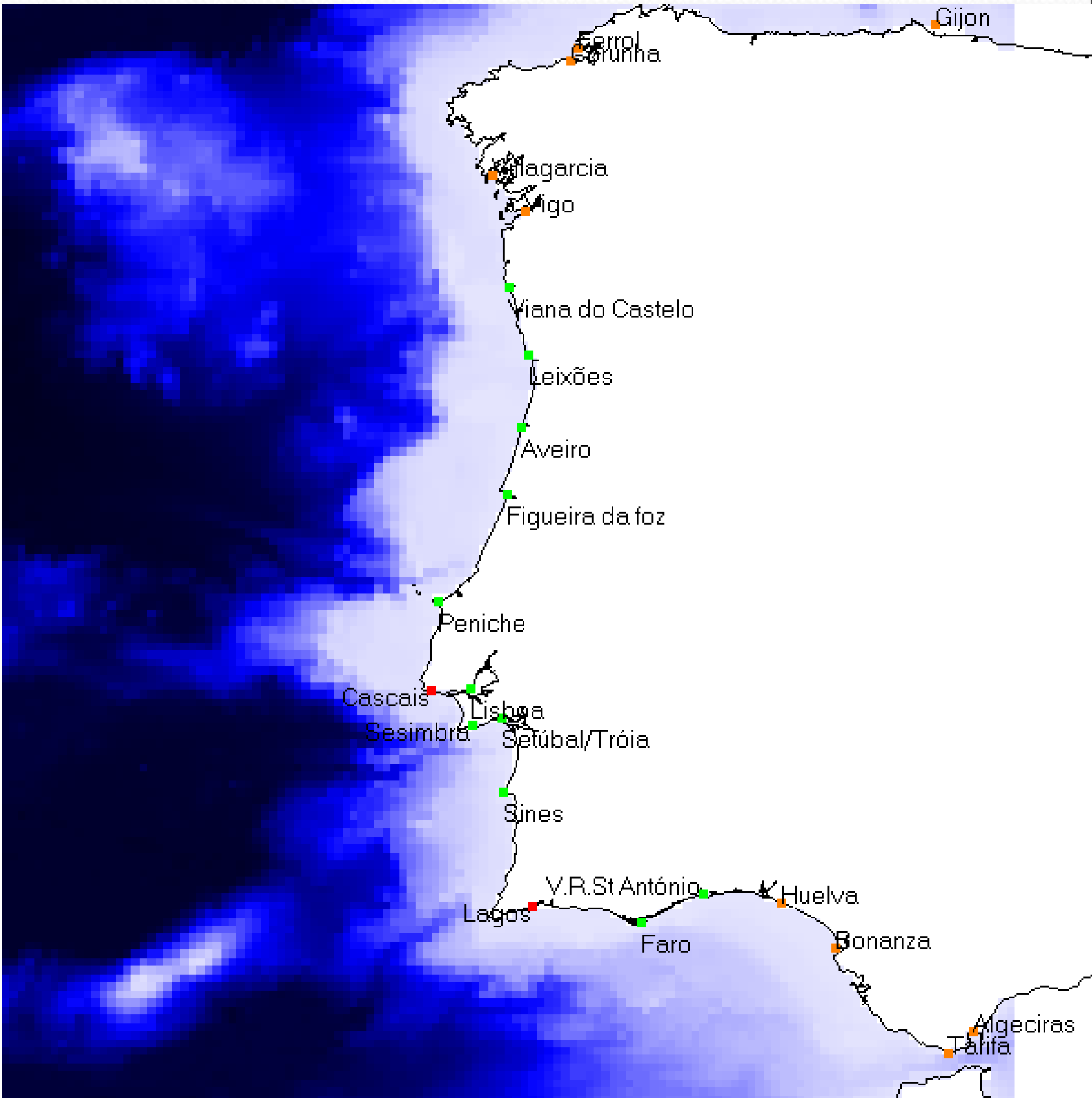
- 🟥 **Instituto Geográfico (IGeo)**
- 🟧 **Puertos Del Estado (PdE)**
- 🟩 **Instituto Hidrográfico (IH)**

Data Availability:

IGeo – Freely distributed through ftp

PdE – Made available through the myocean project

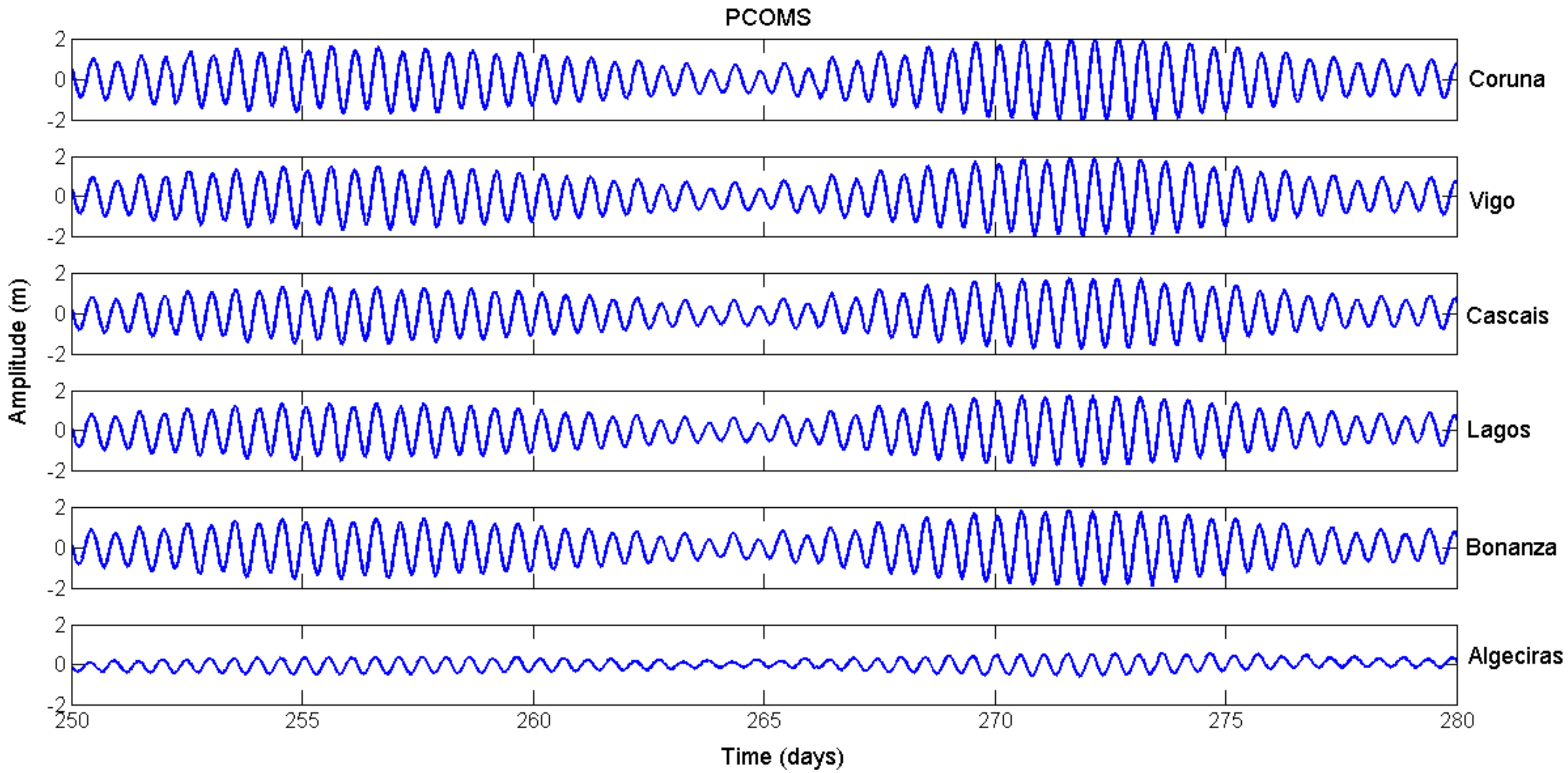
IH – Not yet available



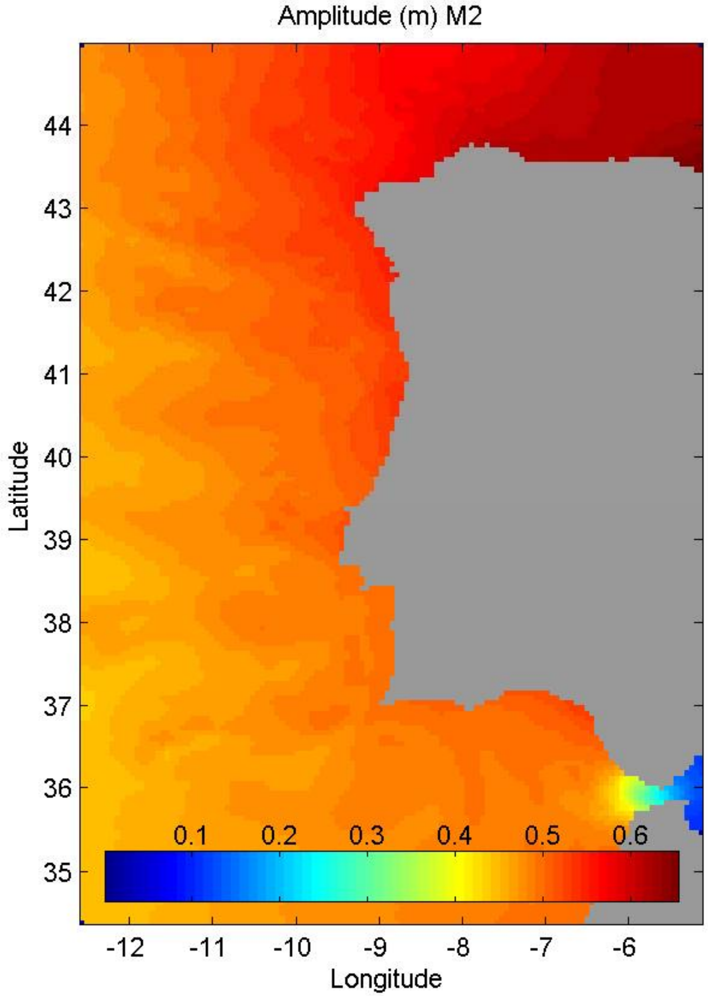
Tidal Components Evolution

	Amplitude			
	M2	**S2**	**K1**	**O1**
Algeciras	0.3311	0.1225	0.0247	0.0088
Tarifa	0.4191	0.1550	0.0276	0.0028
Bonanza	0.9055	0.3111	0.0606	0.0631
Huelva	1.0436	0.3755	0.0620	0.0579
Lagos	1.1430	0.4373	0.1135	0.0698
Sines	0.9886	0.3477	0.0674	0.0643
Cascais	0.9935	0.3523	0.0689	0.0598
Vigo	1.1041	0.3872	0.0725	0.0642
Coruna	1.1880	0.4136	0.0725	0.0645
Ferrol	1.1863	0.4124	0.0711	0.0625

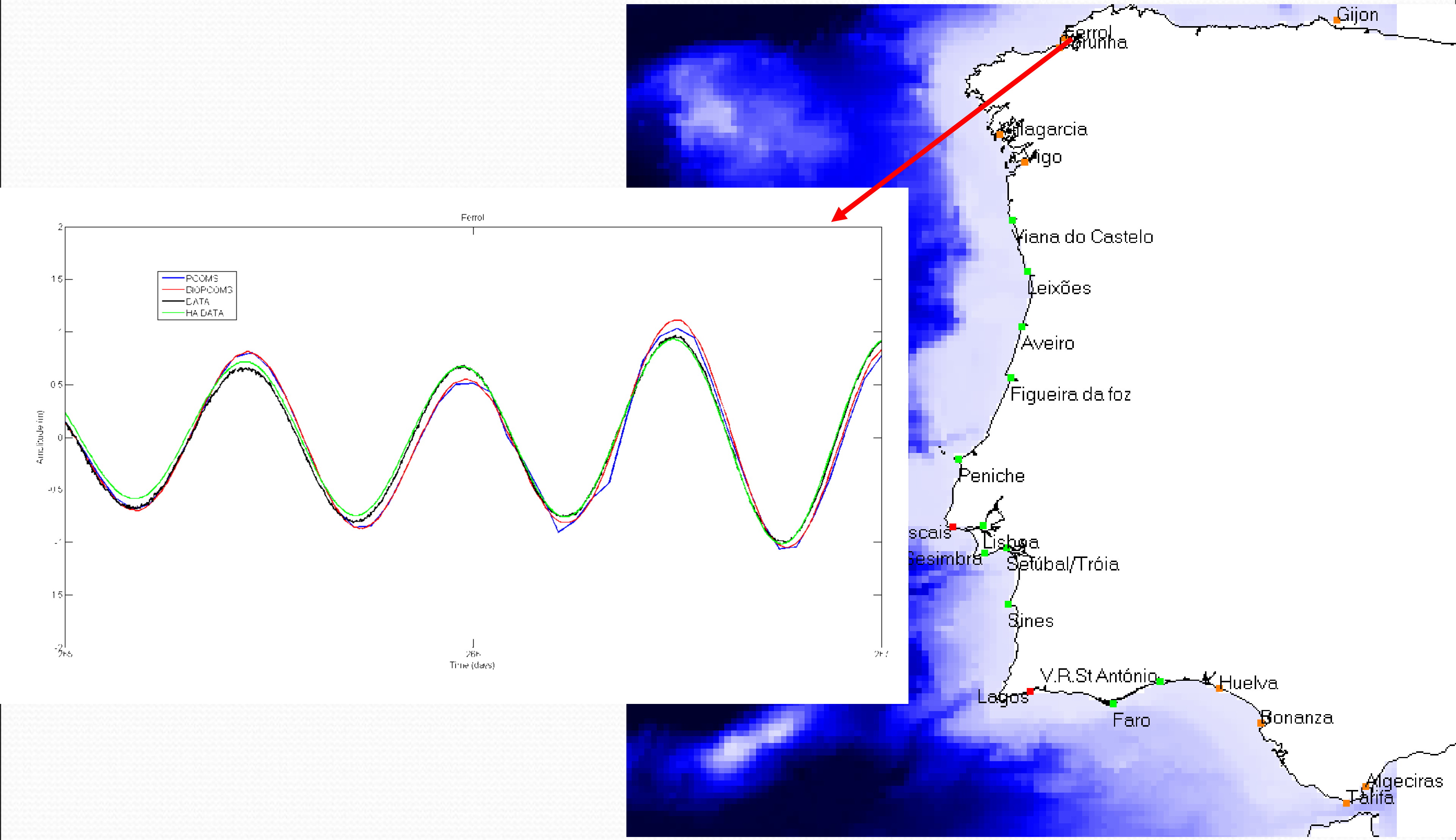
Tide Evolution



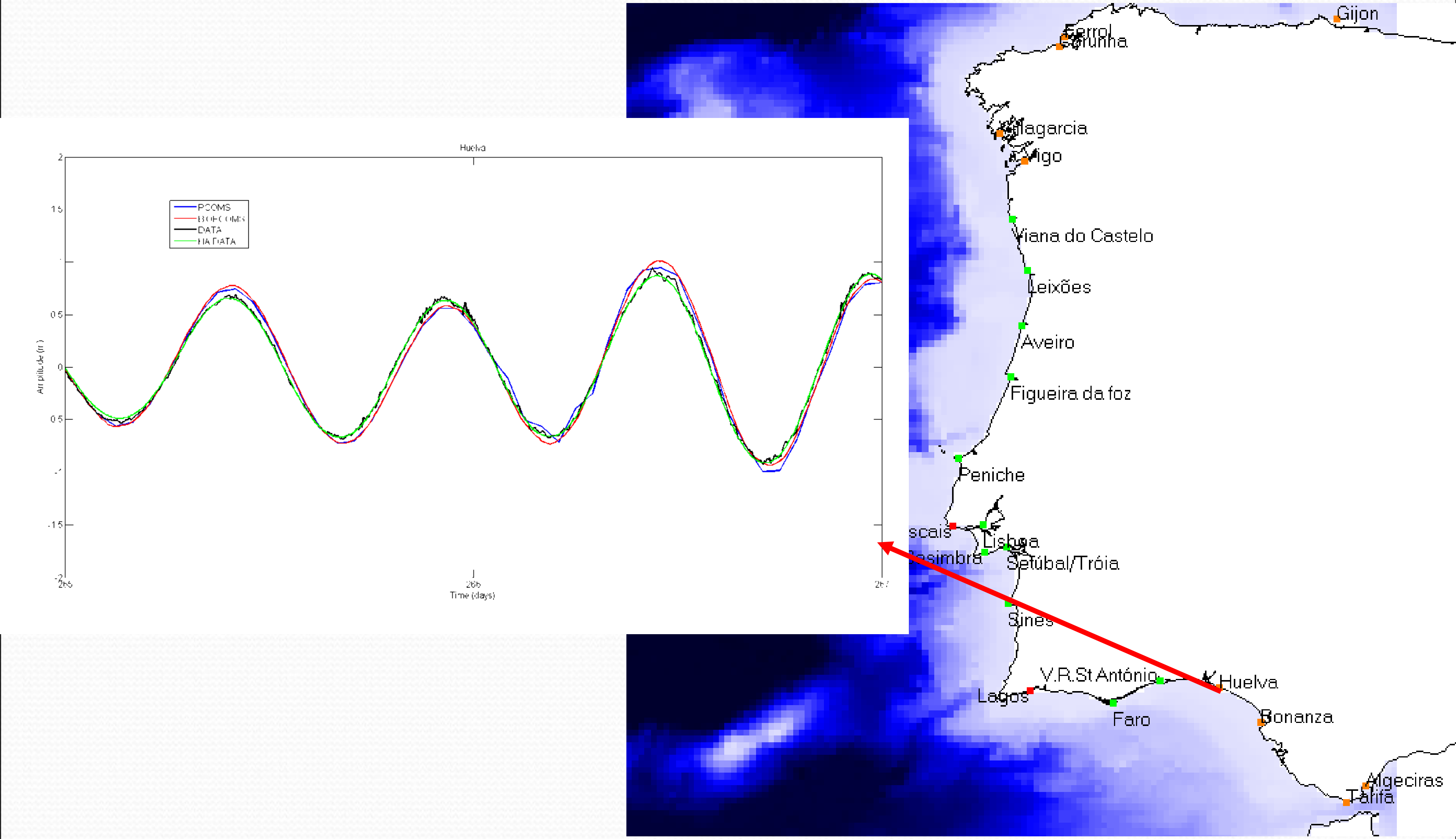
Tide Evolution



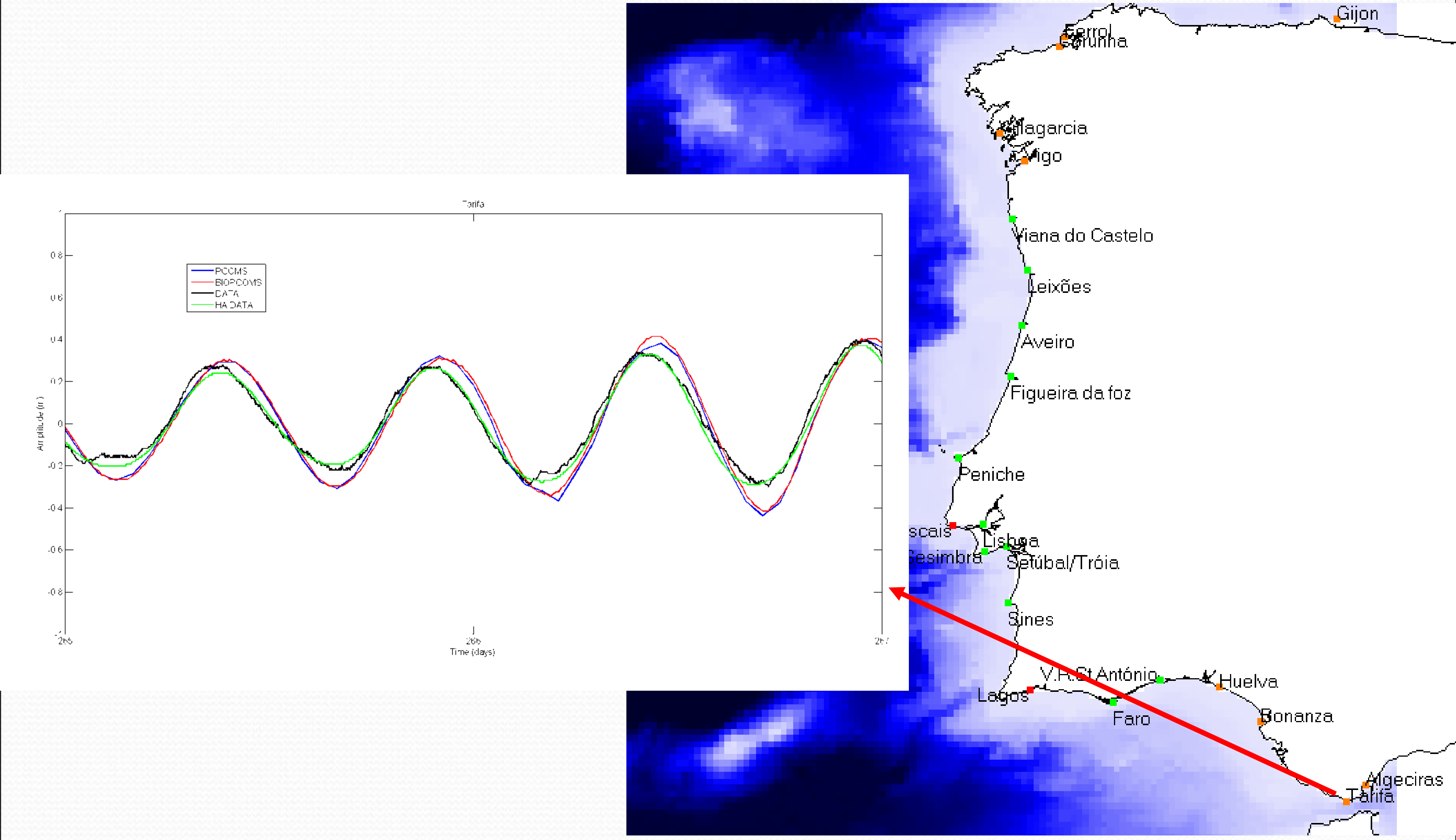
Ferrol Tidal Gauge



Huelva Tidal Gauge



Tarifa Tidal Gauge

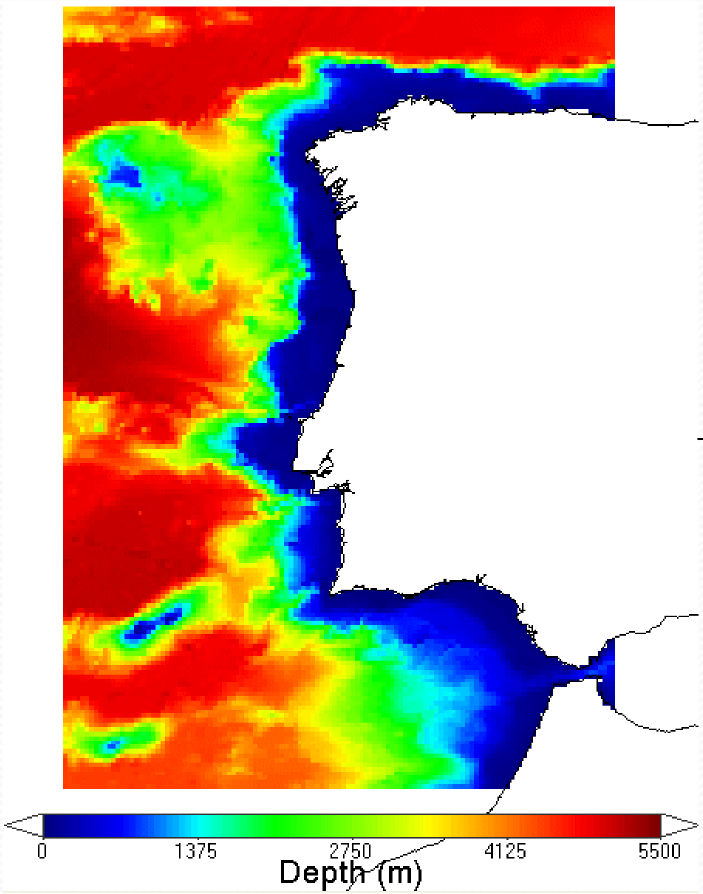


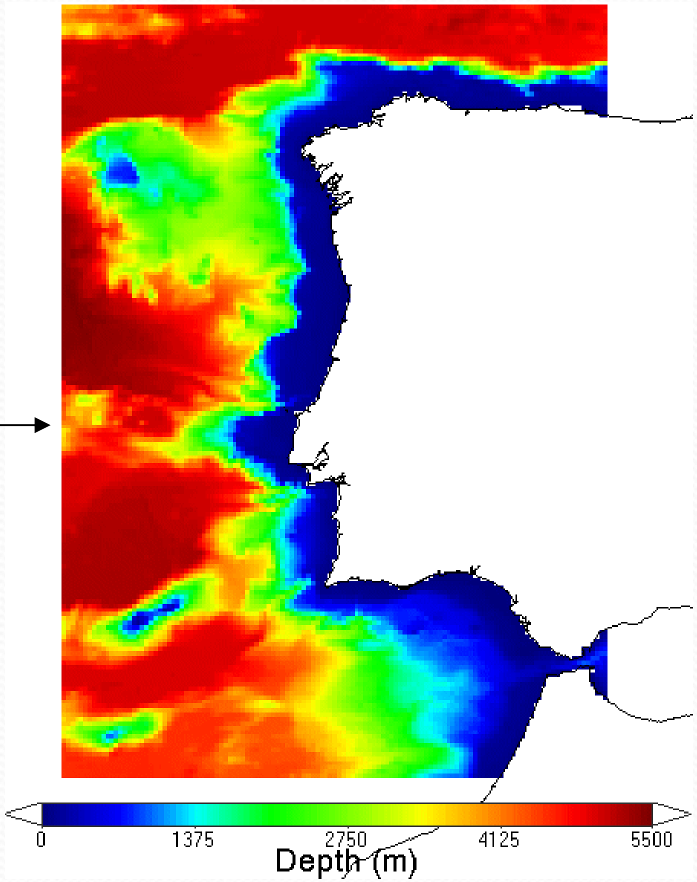
PCOMS Simulations

- PCOMS_NOATM: No atmosphere at all
- PCOMS_WIND: Only wind effects
- PCOMS_ATM_PRES: Only atmospheric pressure
- PCOMS: wind and atmospheric pressure effects included
- PCOMSUP: Same grid, bathymetry updated
- PCOMS_ADM: PCOMS with FES2004 with admittance
- PCOMS_AS_TOT: Assimilating all Mercator properties.

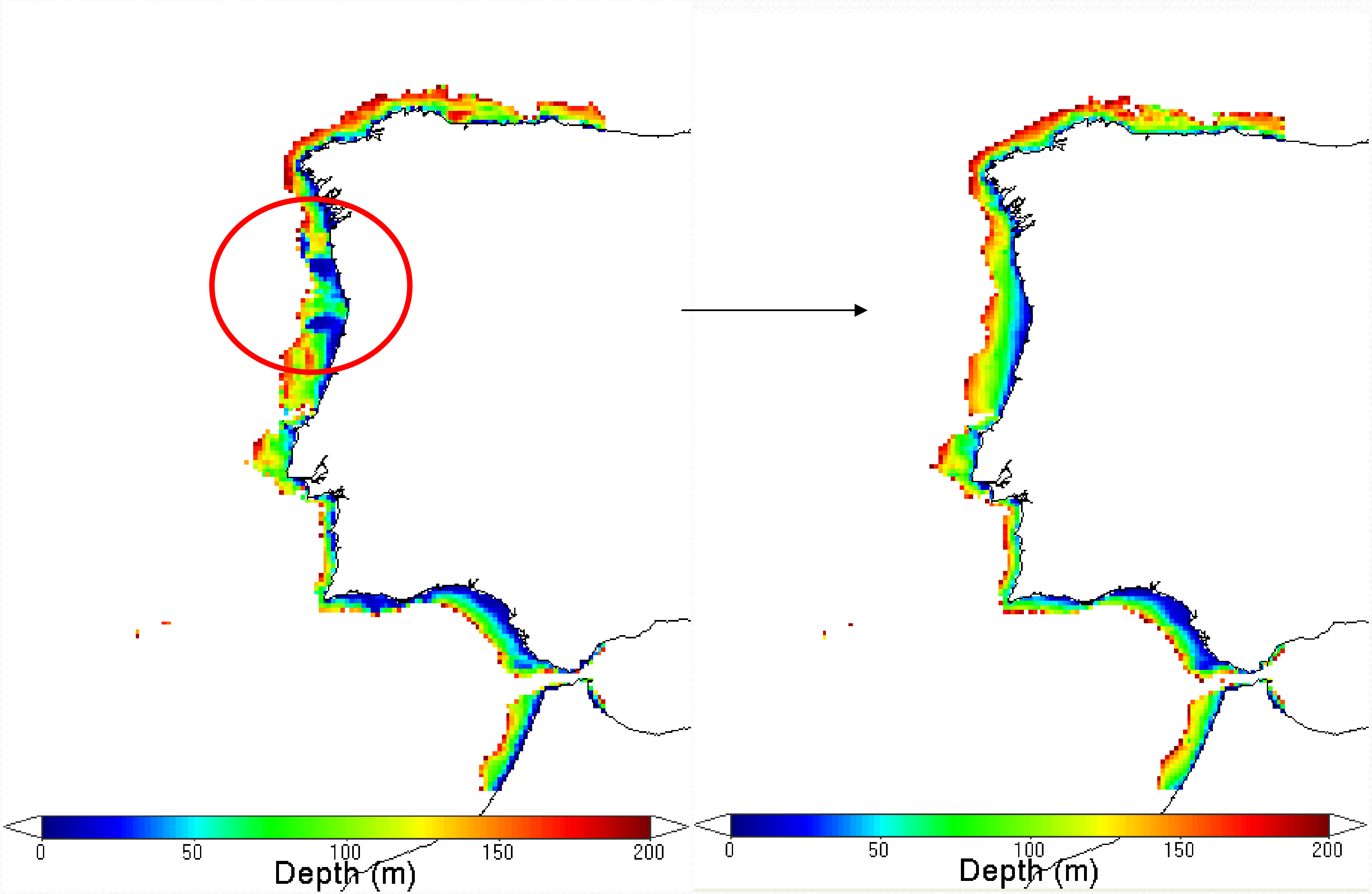
PCOMS Updated (PCOMSUP)

Same domain and water cells than BIOPCOMS, only updated bathymetry, continue running from previous version





PCOMS Updated (PCOMSUP)



Admittance technique

- FES2004 provides the following tidal components: M2, S2, K1, K2, N2, 2N2, O1, Q1, P1, M4, Mf, Mm, Mtm, MSqm.
- With the admittance technique new constituents can be calculated based on the originals:
- i.e.

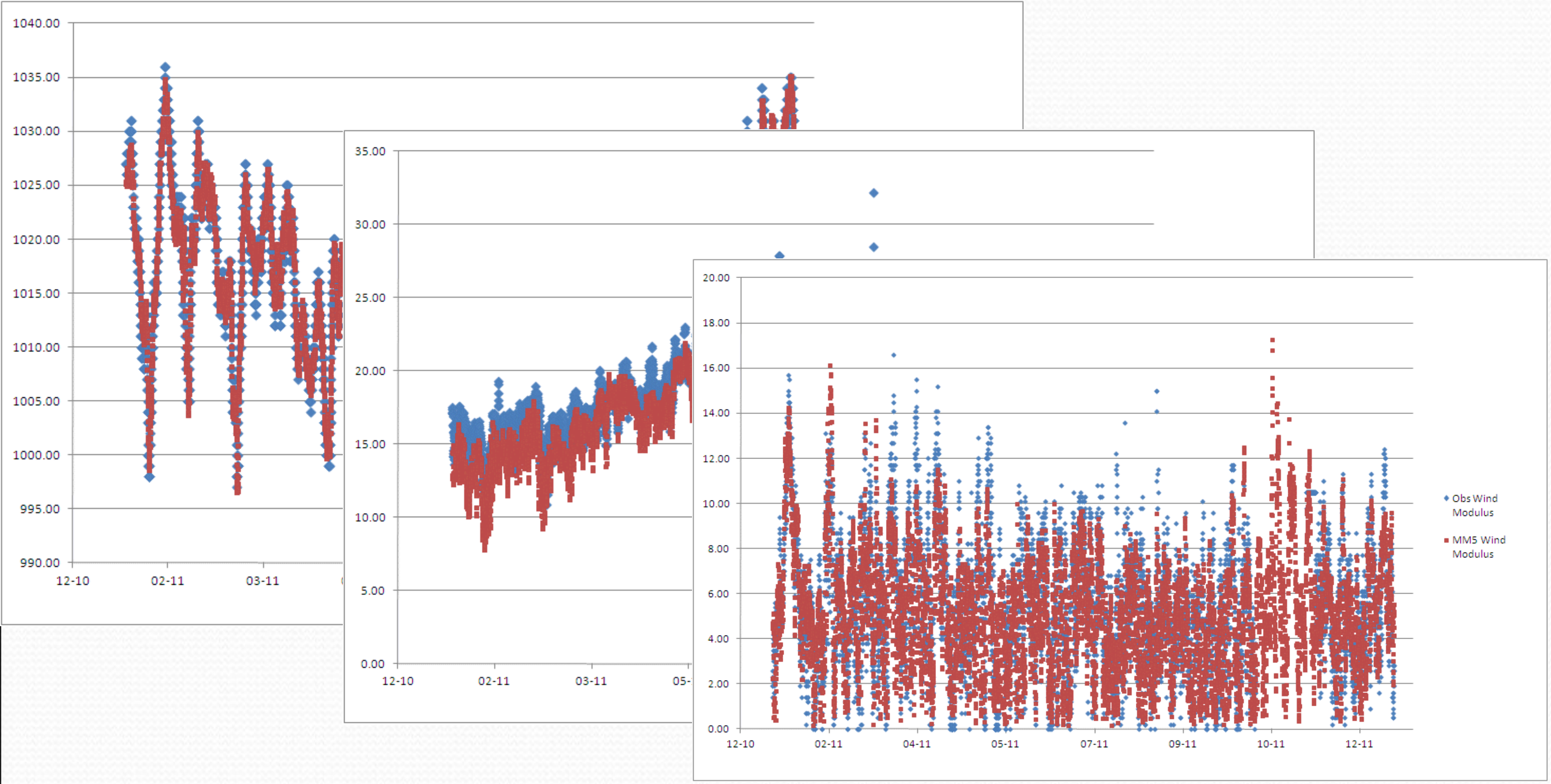
Q1 and O1 → 2Q1, SIG1, RHO1
O1 and K1 → CHI1, PI1, PHI1, THE1, J1, OO1, M12
2N2 andN2 → EPS2
M2 and K2 → ETA2,
Q1 and O1 and K1 → P1
K2 and N2 and M2 → MU2, NU2, LDA2, L2, T2

Mercator Boundary Conditions

Property	**Units**
Barotropic Velocity U	m/s
Barotropic Velocity V	m/s
Water Level	m
Velocity U	m/s
Velocity V	m/s
Temperature	ºC
Salinity	PSU

PCOMS_AS_TOT

Atmospheric Model Validation



Statistics employed for analysis

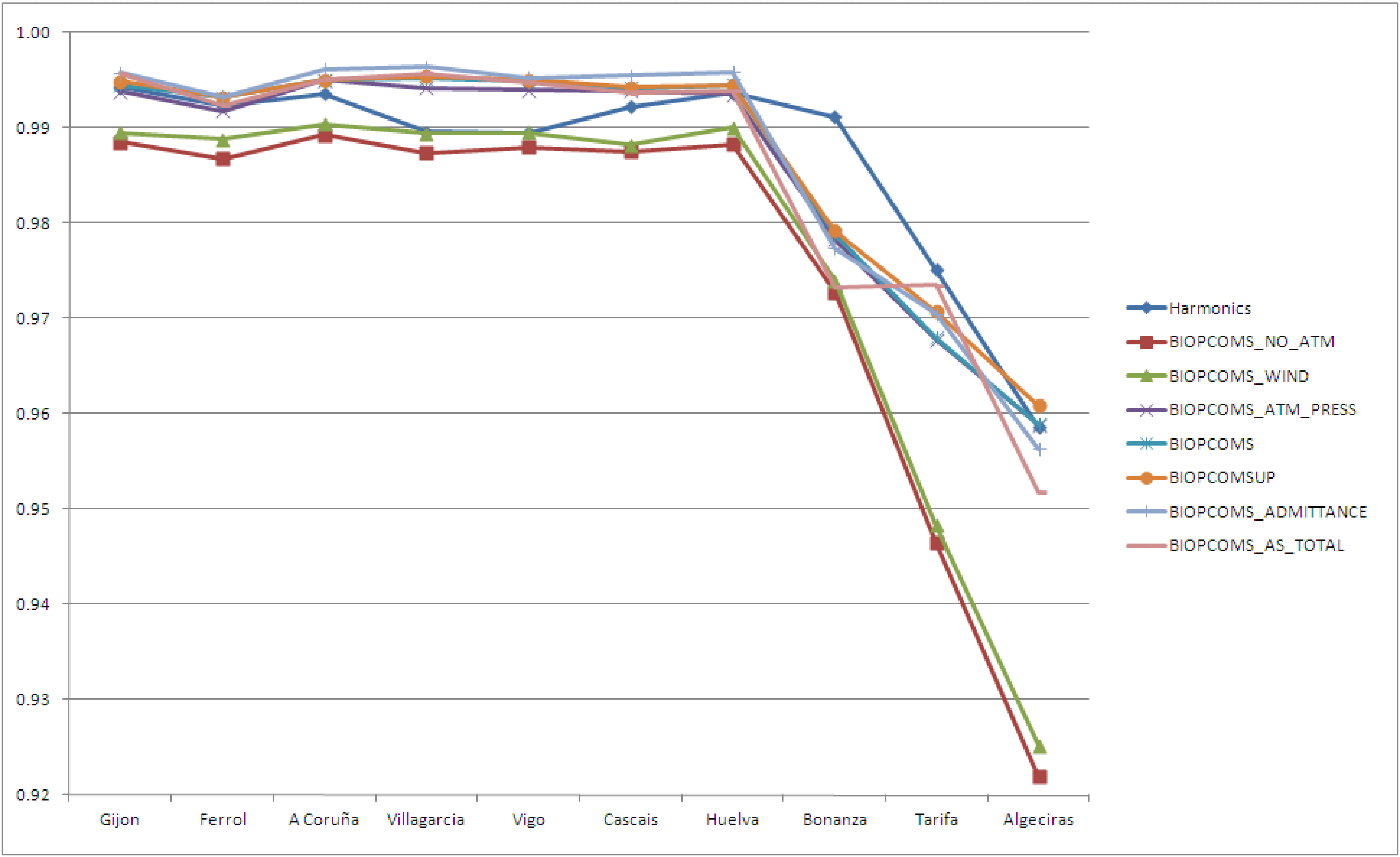
- Correlation
- RSME
- RSR

Correlation Coefficient (r)

- Describes the degree of collinearity between simulated and observed data. Correlation Coefficient ranges from -1 to 1 and is a index of the degree of linear relationship between observed and simulated data. If r=0 no linear relationship exists. If r=1 or r=-1, a perfect positive or negative relationship exist.

$$r = \frac{Covariance_{OP}}{STDEV_o STDEV_p} = \frac{\frac{1}{N-1}\sum_{i=1}^{N}(O_i - \overline{O})(P_i - \overline{P})}{STDEV_{obs} STDEV_p}$$

Correlation

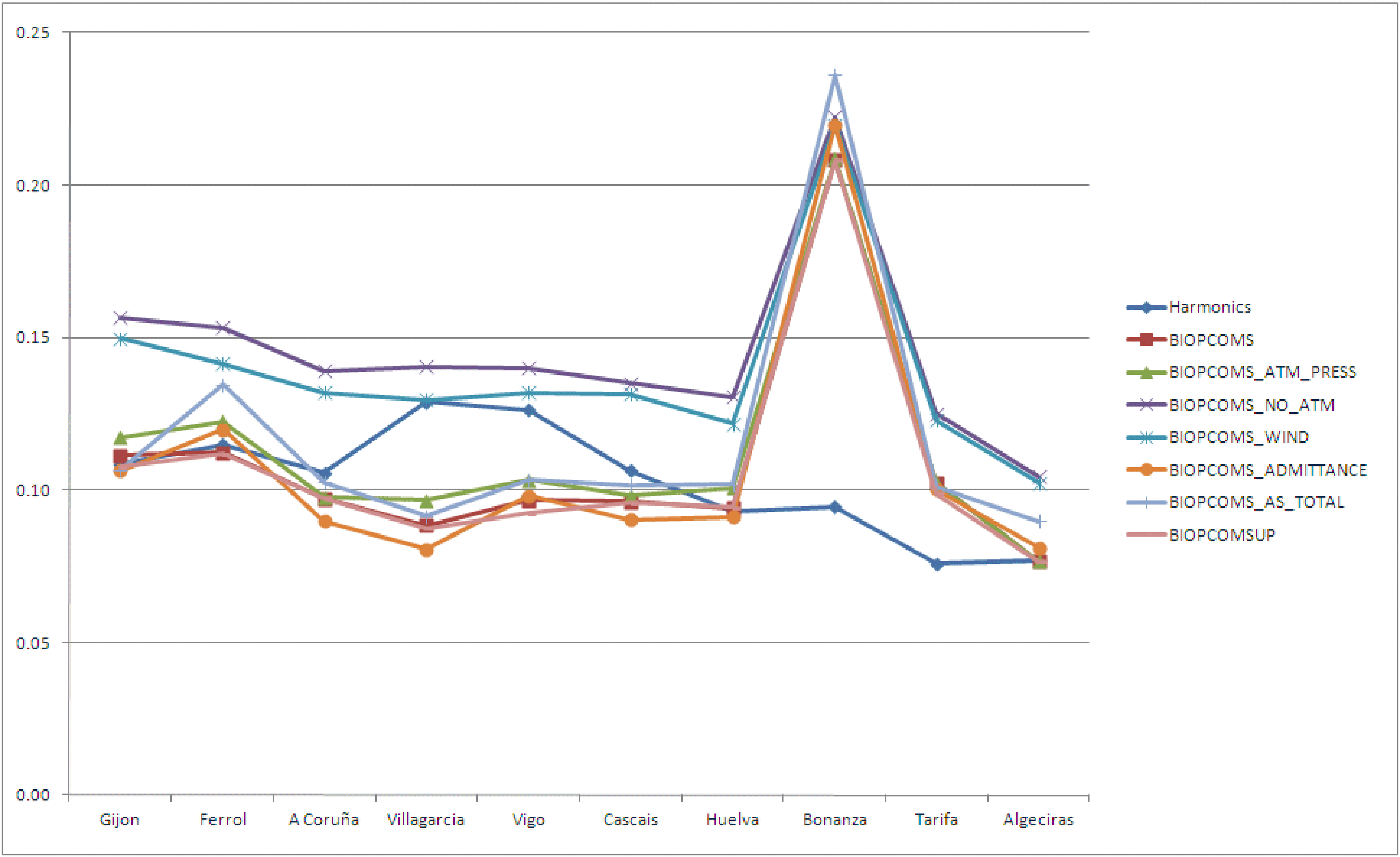


Root Mean Square Error (RMSE)

- Values of 0 indicate a perfect fit. the RMSE gives a relatively high weight to large errors. Since the errors are squared before they are averaged, the RMSE is most useful when large errors are particularly undesirable.

$$RMSE = \left[N^{-1} \sum_{i=1}^{N} (O - P)^2 \right]^{0.5}$$

RSME

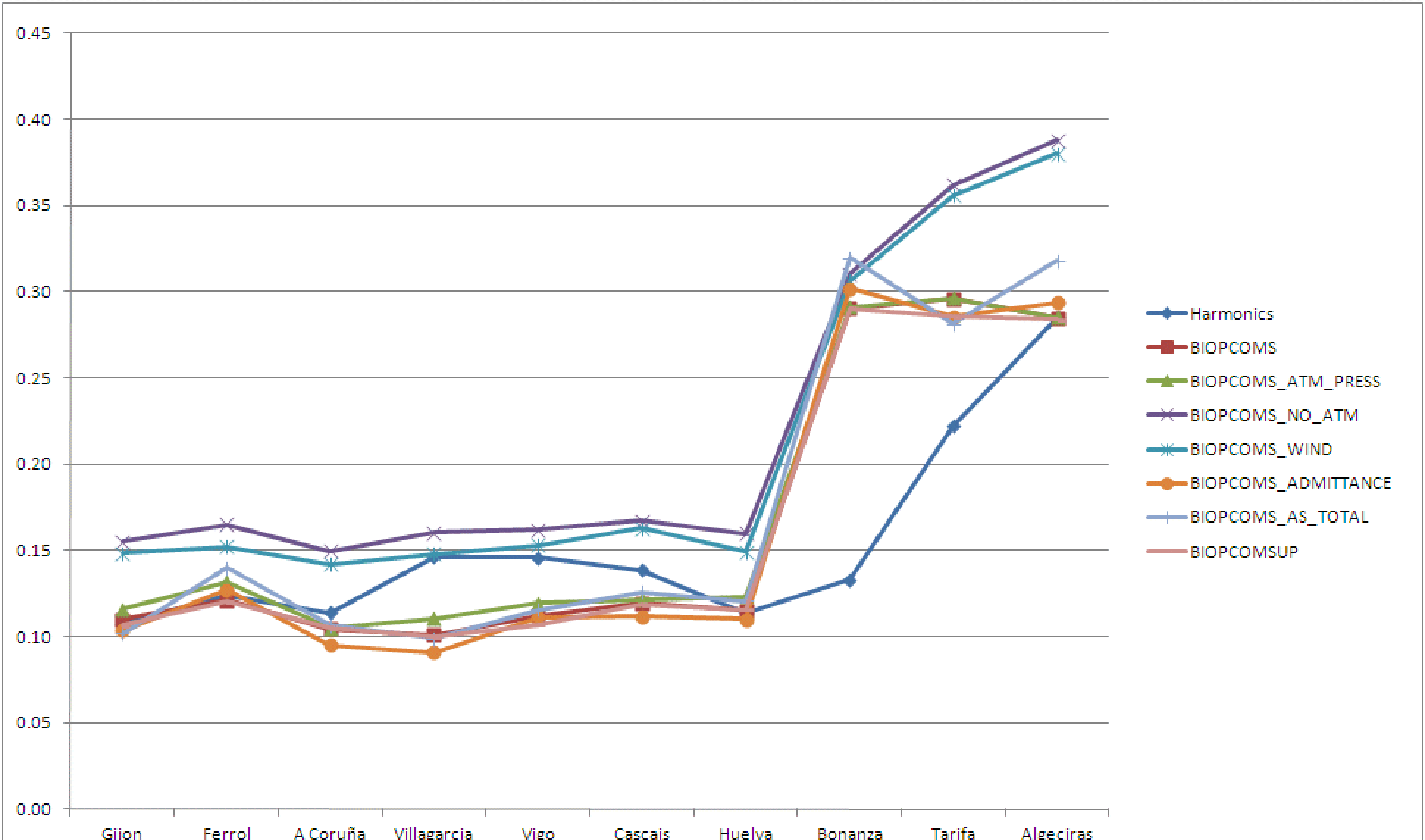

0.25
0.20
0.15
0.10
0.05
0.00
Gijon
Ferrol
A Coruña
Villagarcia
Vigo
Cascais
Huelva
Bonanza
Tarifa
Algeciras
Harmonics
BIOPCOMS
BIOPCOMS_ATM_PRESS
BIOPCOMS_NO_ATM
BIOPCOMS_WIND
BIOPCOMS_ADMITTANCE
BIOPCOMS_AS_TOTAL
BIOPCOMSUP

RMSE-observation standard deviation ratio (RSR)

- RSR standardizes RMSE using the observations standard deviation, and it combines both an error index and the additional information. RSR is calculated as the ratio of the RMSE and standard deviation of measured data. RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR varies from the optimal value 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value.

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV}_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2}\right]}$$

RSR


0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Gijon
Ferrol
A Coruña
Villagarcia
Vigo
Cascais
Huelva
Bonanza
Tarifa
Algeciras
Harmonics
BIOPCOMS
BIOPCOMS_ATM_PRESS
BIOPCOMS_NO_ATM
BIOPCOMS_WIND
BIOPCOMS_ADMITTANCE
BIOPCOMS_AS_TOTAL
BIOPCOMSUP

Discussion

- Tidal constituents alone are able to explain more than 90 % of the total variability in all the stations.

Station	Gijon	Ferrol	A Coruña	Villagarcia	Vigo	Cascais	Huelva	Bonanza	Tarifa	Algeciras
Harmonics	0.994	0.992	0.994	0.990	0.990	0.992	0.994	0.991	0.975	0.959

- However, when the wind and the atmospheric pressure are included the variability explained by modelling is generally higher.

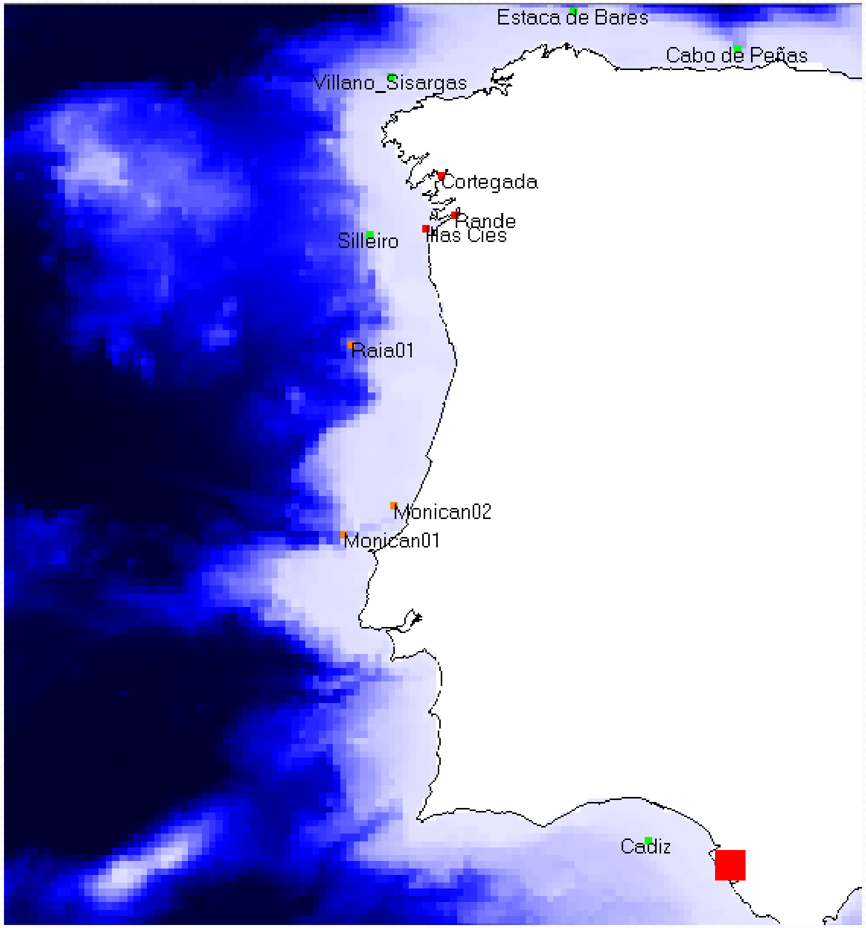
Station	Gijon	Ferrol	A Coruña	Villagarcia	Vigo	Cascais	Huelva	Bonanza	Tarifa	Algeciras
Harmonics	0.995	0.993	0.995	0.995	0.995	0.994	0.995	0.979	0.968	0.959

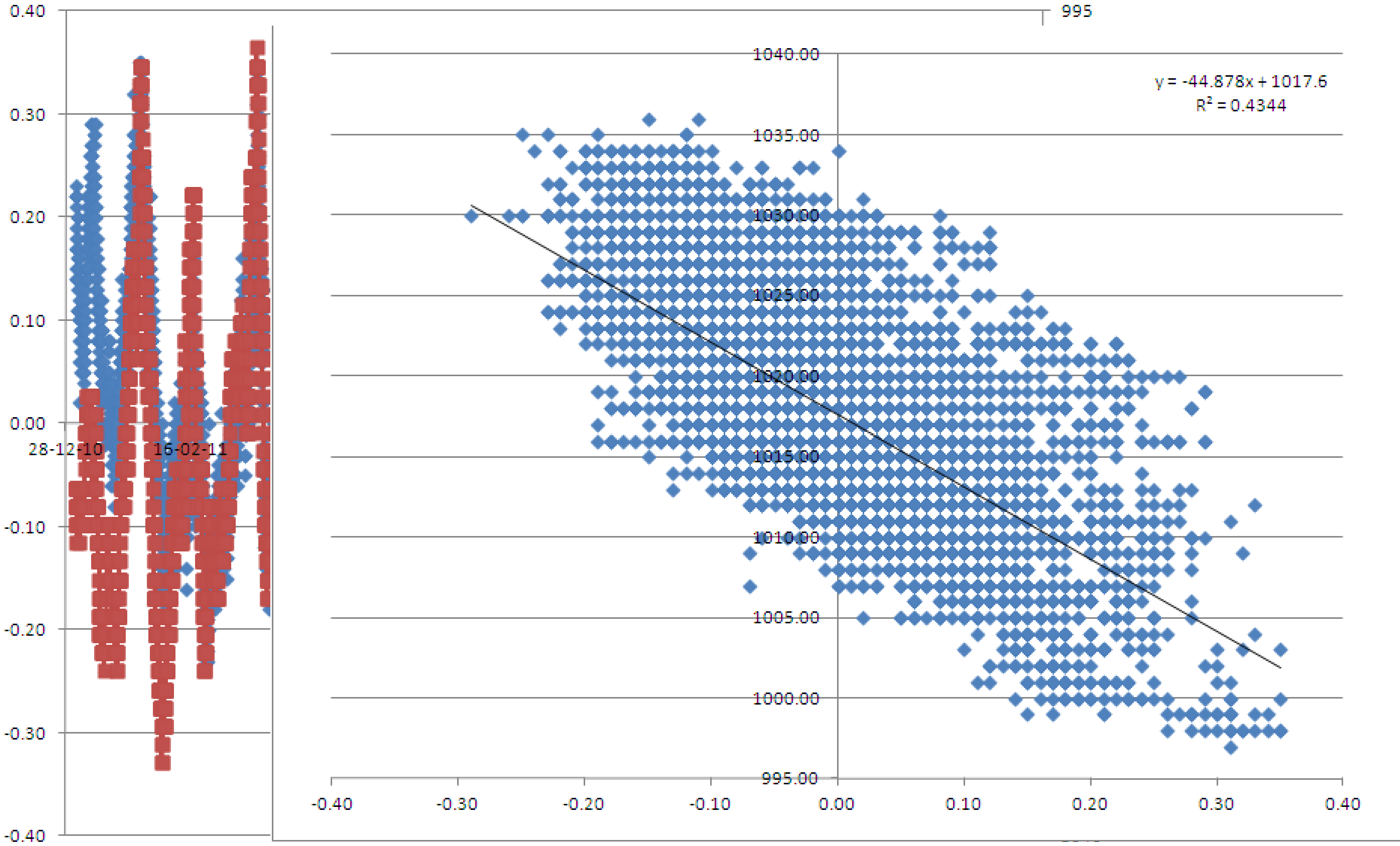
Discussion

- In order to improve water levels forecast, the harmonic constituents are not useful to predict extreme events. In the year 2011 for the analysed stations, the residuals found are summarised in the table below.

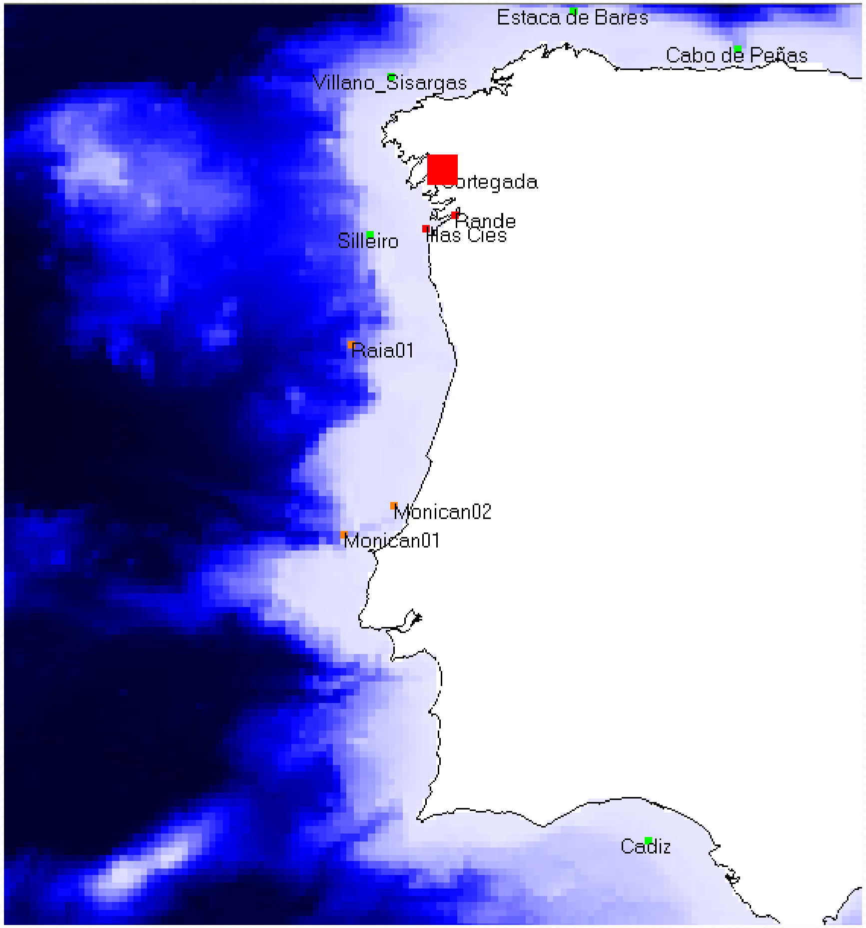
	Algeciras	Tarifa	Bonanza	Huelva	Vigo	Villagarcia	Coruña	Ferrol	Gijon
Average	0.00	0.00	0.00	0.00	-0.04	-0.07	0.00	0.00	0.00
SD	0.07	0.07	0.09	0.09	0.13	0.13	0.10	0.11	0.11
Maximum	0.39	**0.43**	**0.58**	0.39	**0.53**	0.38	**0.52**	**0.83**	**0.46**
Minimum	-0.26	-0.25	-0.31	-0.29	**-0.44**	**-0.50**	-0.31	-0.35	-0.31
Median	0.00	0.00	-0.01	-0.01	-0.03	-0.07	0.00	0.00	-0.01
N	8760	8760	8760	8760	7512	7586	8760	8760	8760

Cadiz-Bonanza

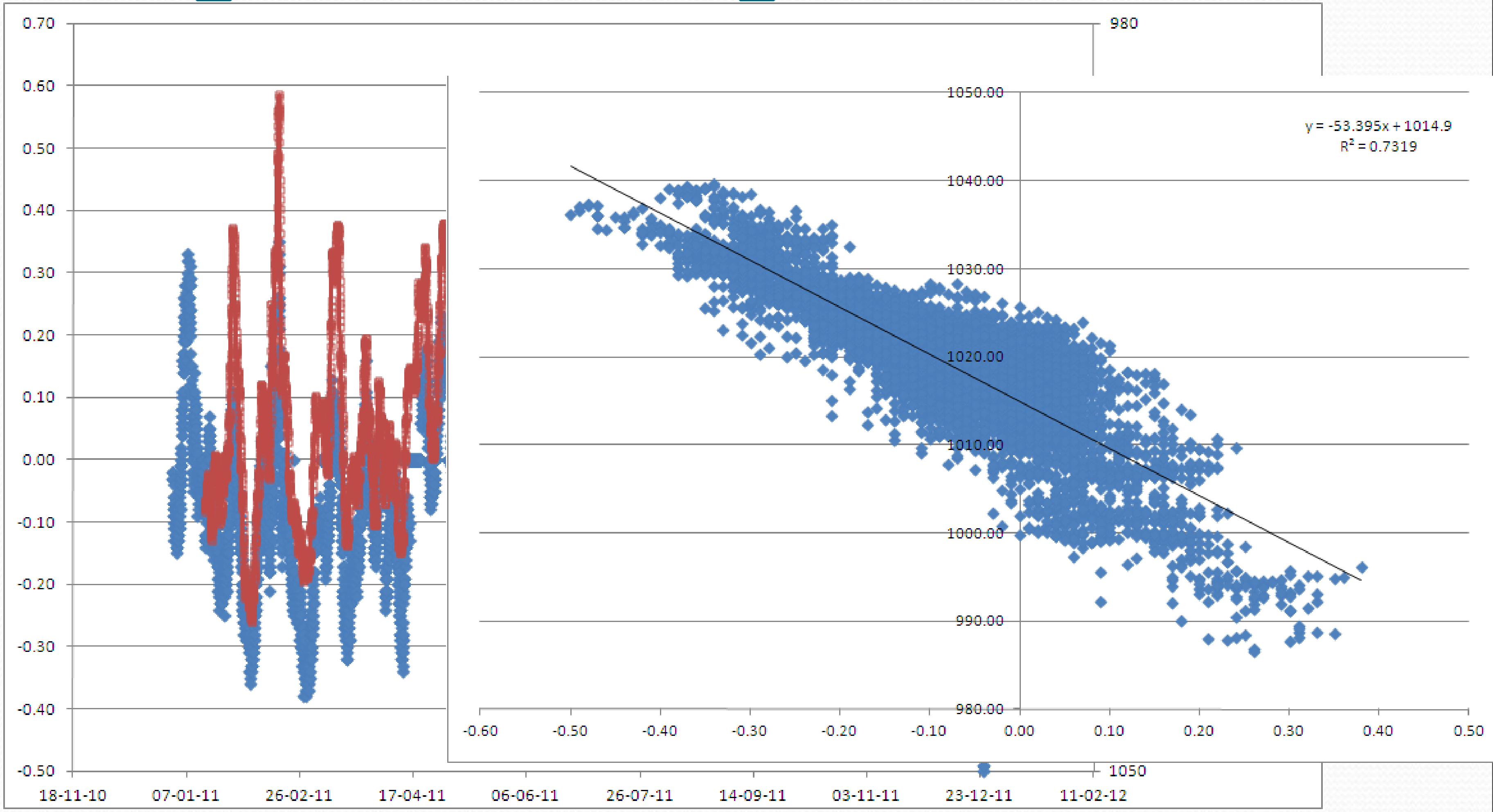



0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
28-12-10
16-02-11
995
y = -44.878x + 1017.6
R² = 0.4344
1040.00
1035.00
1030.00
1025.00
1020.00
1015.00
1010.00
1005.00
1000.00
995.00
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40

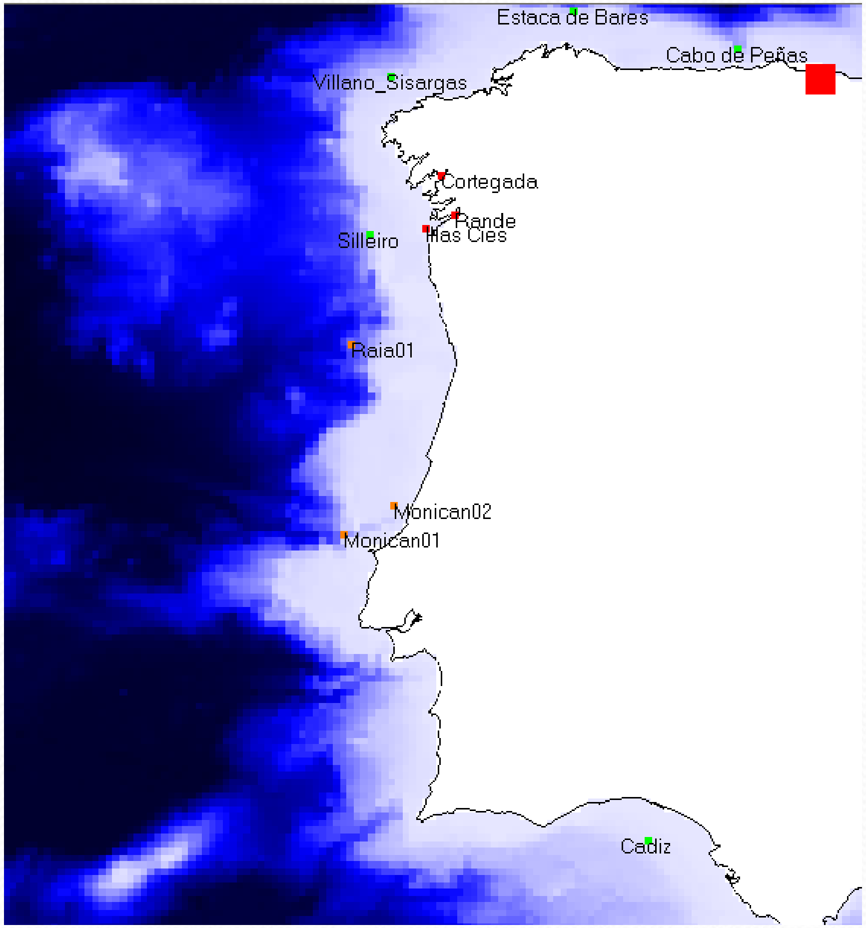
Villagarcia-Cortegada



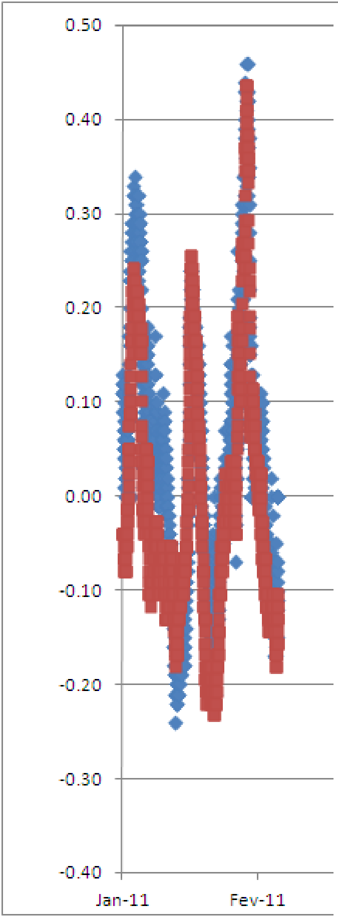
Villagarcia-Cortegada

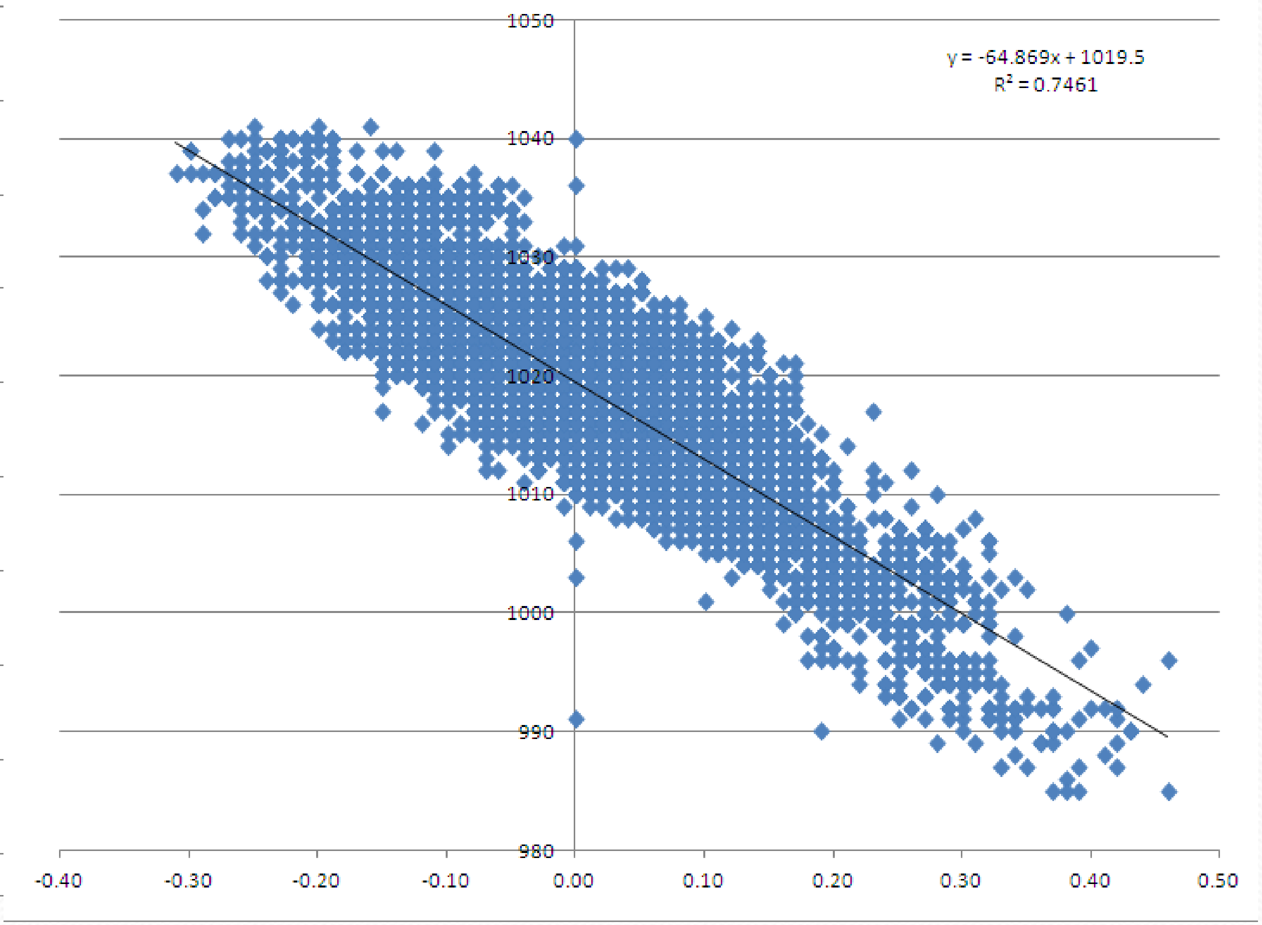


Gijon-Cabo de Peñas

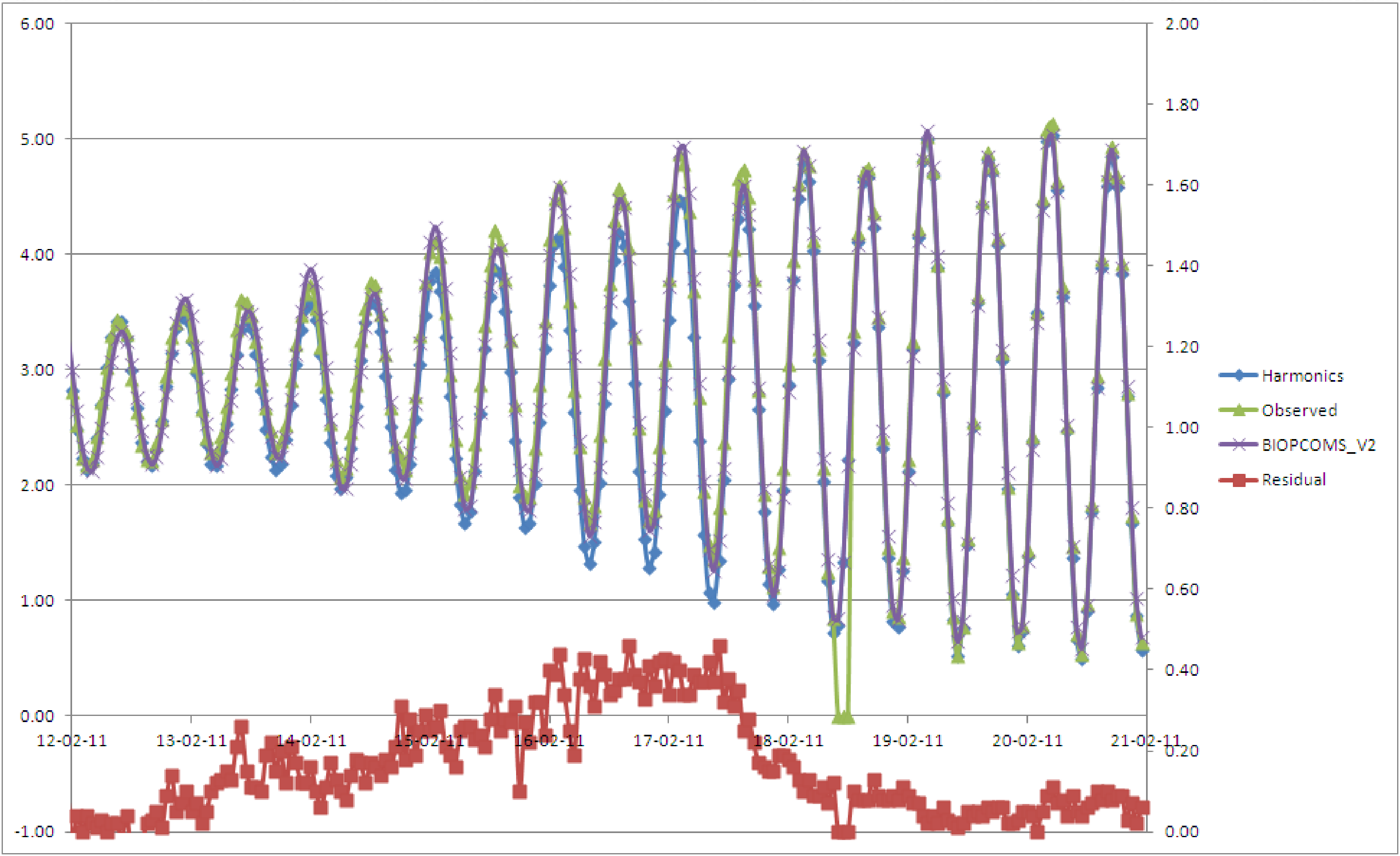


Relation Residual-Atm Press





Low Pressure Event Gijon



Conclusions

- Bathymetry, bathymetry, bathymetry….
- Admittance improves water level predictions
- A latitudinal tidal and atmospheric pressure pattern can be described
- Adding the atmospheric processes to numerical models allow to gain a level of prediction higher than with the local tidal harmonics.
- Integrated metocean studies help to understand better the variability of the ocean observed processes

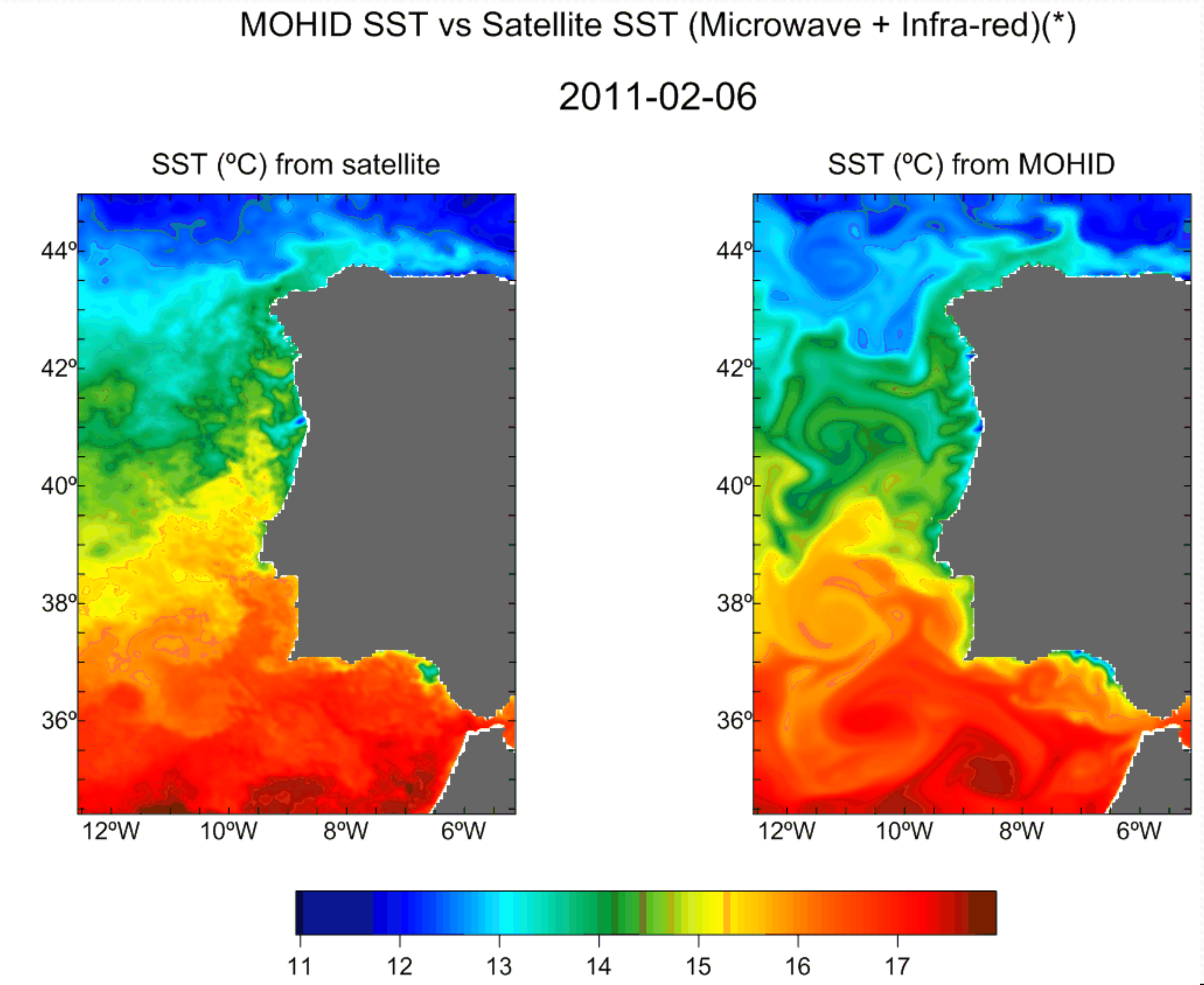
Conclusions

- Numerical models are able to simulate and predict extreme levels.
- Atmospheric models are able to obtain satisfactory atmospheric pressure values for ocean models.
- The chosen statistics help to identify the areas where models can be improved.

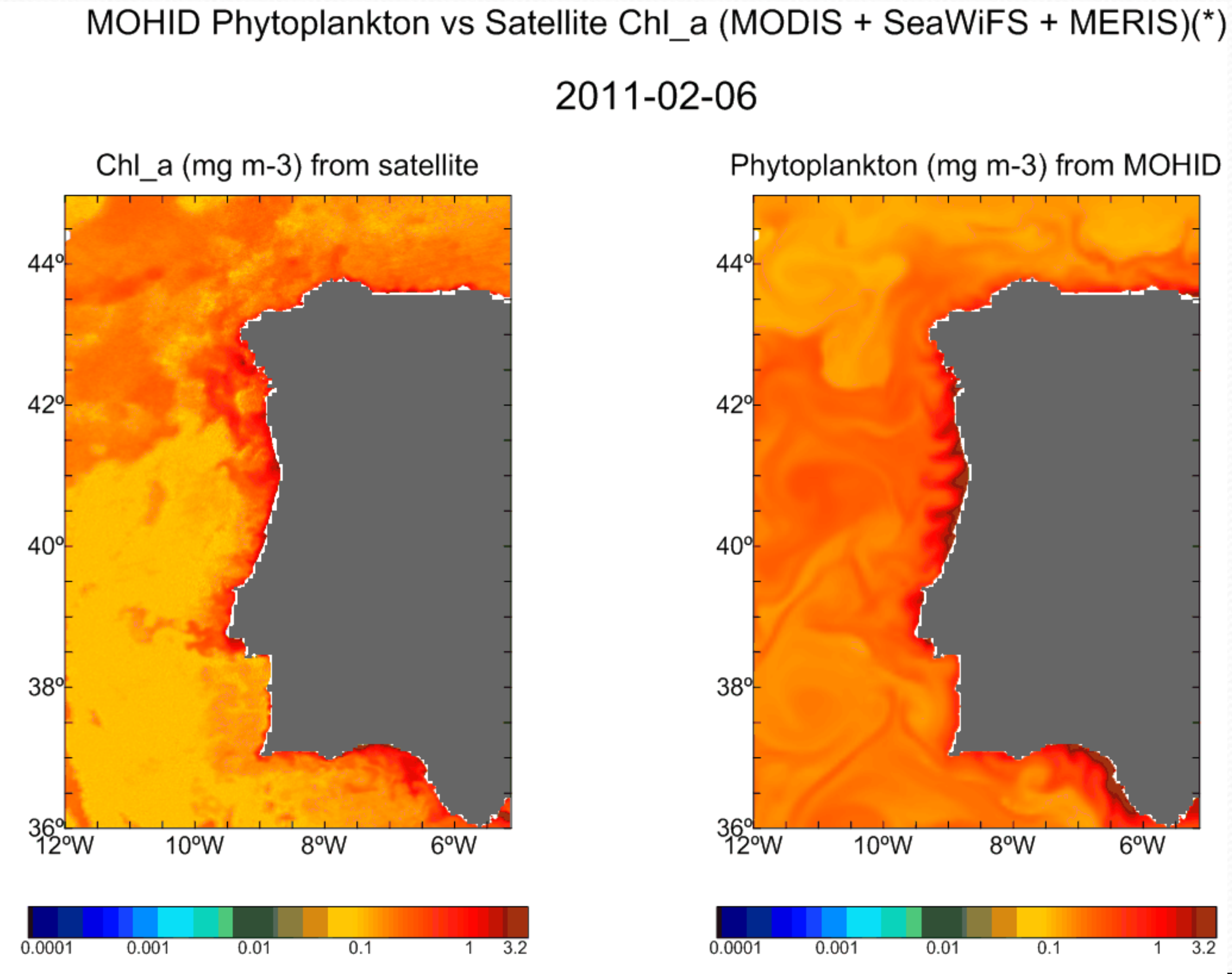
Future Work

- Simulate the best combination of results
- Include the IH gauges in the analysis and validation
- Perform this analysis for a longer period of time
- Identify and analyse extreme events
- Analysis of the role played by the Gibraltar Strait in the hydrodynamics of the southern part of the domain.
- Implement the described validation methods in operational mode.

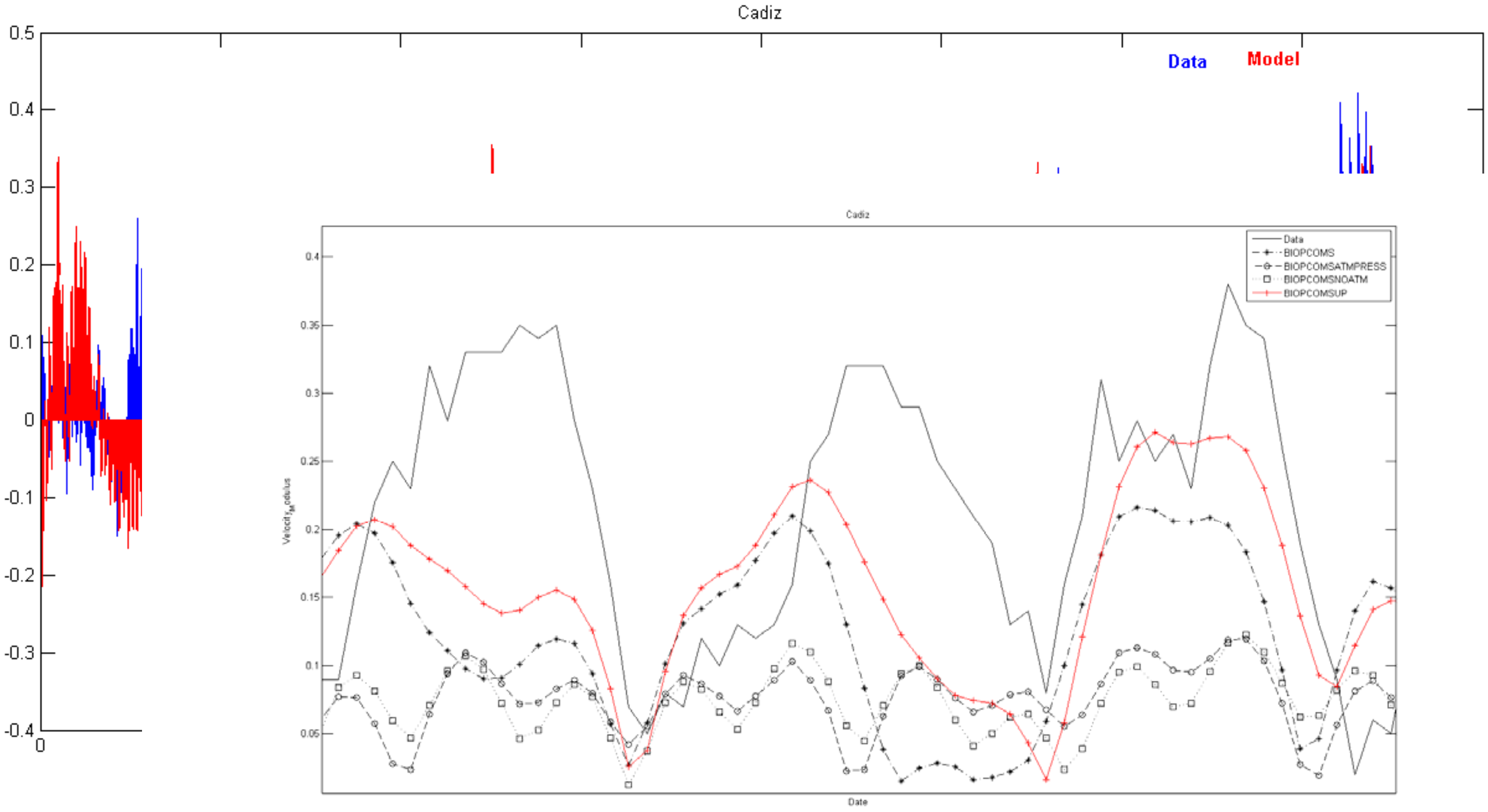
Model Validation



Model Validation



And a question…



- Trugarez deoc'h evit bezañ bet o selaou ac'hanon !!
- Merci de votre attention !!
- Thank you very much for your attention!!