Improving Storm surge modeling along the French (Atlantic and English Channel) coast

Idier D., Muller H., Dumas F., Pineau-Guillou L., Paradis D., Pedreros R., Créach R.

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Géosciences pour une Terre durable

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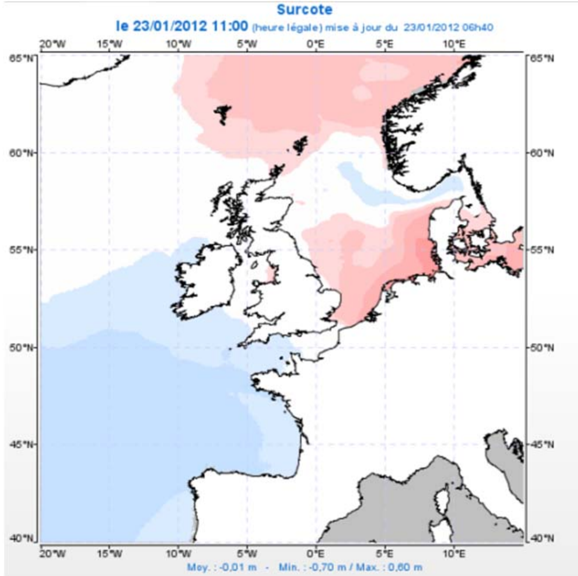
METEO FRANCE

Toujours un temps d'avance

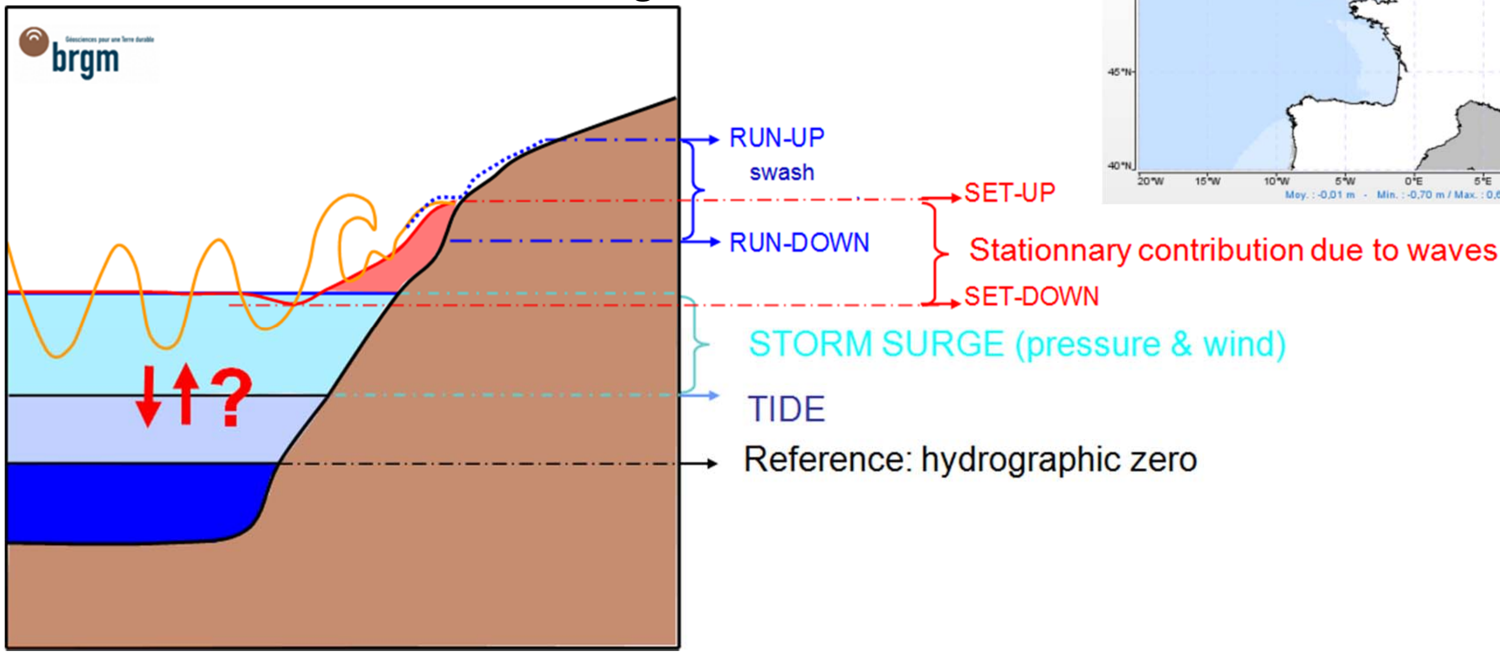
SH OM

Framework

- Previmer system (www.previmer.org)
  - Forecasts of water levels and surges



- Phenomena contributing to water level



Issue 1: Storm surge generation and propagation processes along the French coastlines bordering the English Channel & the Atlantic Ocean

→Tide and surge interaction

Framework

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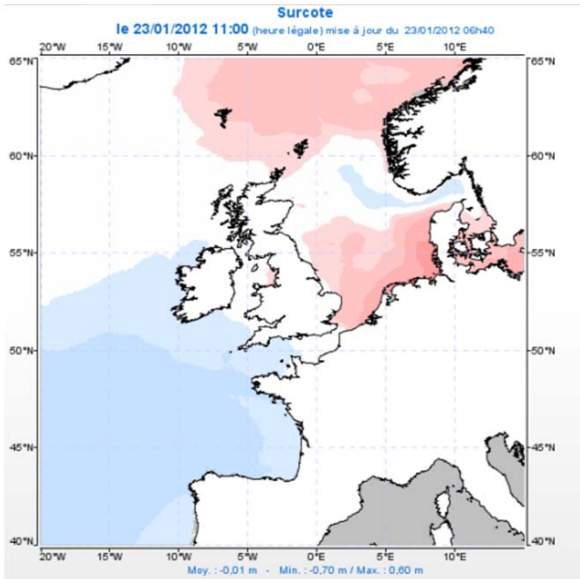
  - Forecasts of water levels and surges



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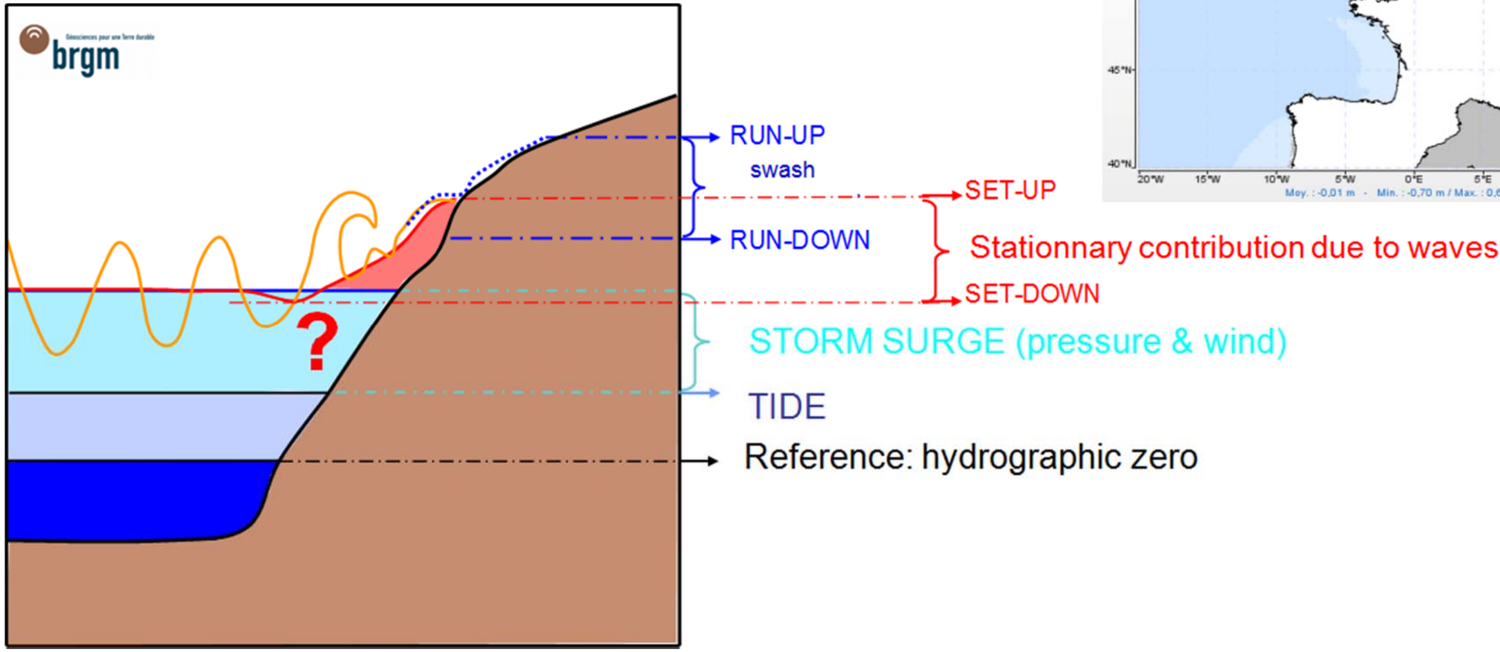


Issue 2: Storm surge modeling

→ Sensitivity study on sea surface drag parameterization and meteorological input data

The approach

> **Storm surge modeling: Shallow water equations**

$$\frac{\partial \xi}{\partial t} + \nabla.(D\vec{U}) = 0$$

$$\frac{\partial \vec{U}}{\partial t} + \vec{U}.\nabla\vec{U} - f\vec{k} \times \vec{U} = -g\nabla\left(\xi - \bar{\xi}\right) - \frac{1}{\rho}\nabla p_a + \frac{1}{\rho D}\left(\vec{\tau}_s - \vec{\tau}_b\right) + A\nabla^2\vec{U}$$

Water height (tide + storm surge)

$$\left|\vec{\tau}_b\right| = k\rho_e\left|\vec{U}_s + \vec{U}_t\right|^2$$

Tidal current

Storm induced current

→ Tide and surge interactions not negligible while high tidal range or strong tidal currents (Flather, 2001; Zhang et al, 2010), with 3 terms :

- **Friction**
- **Continuity equation**
- **Advection**

→ Wind contribution linked to the sea surface drag parameterization (Cd) (eg Mastenbroek et al. 1993)

The approach

> **Storm surge modeling: Shallow water equations**

$$\frac{\partial \xi}{\partial t} + \nabla.(D\vec{U}) = 0$$

$$\frac{\partial \vec{U}}{\partial t} + \vec{U}.\nabla\vec{U} - f\vec{k} \times \vec{U} = -g\nabla\left(\xi - \bar{\xi}\right) - \frac{1}{\rho}\nabla p_a + \frac{1}{\rho D}\left(\vec{\tau}_s - \vec{\tau}_b\right) + A\nabla^2\vec{U}$$

$$\vec{\tau}_s = \rho_a C_D U_{10}^2$$

10-m wind

Drag coefficient

Atmospheric pressure

Water height

$$\left|\vec{\tau}_b\right| = k\rho_e\left|\vec{U}_s + \vec{U}_t\right|^2$$

k **cst : no wave effect**

→ Tide and surge interactions not negligible while high tidal range or strong tidal currents (Flather, 2001; Zhang et al, 2010)

→ Wind contribution linked to the sea surface drag parameterization (Cd) (eg Mastenbroek et al. 1993)

The approach

> **Reference configuration**

> 2DH hydrodynamic model (MARS)

> dx=2 km

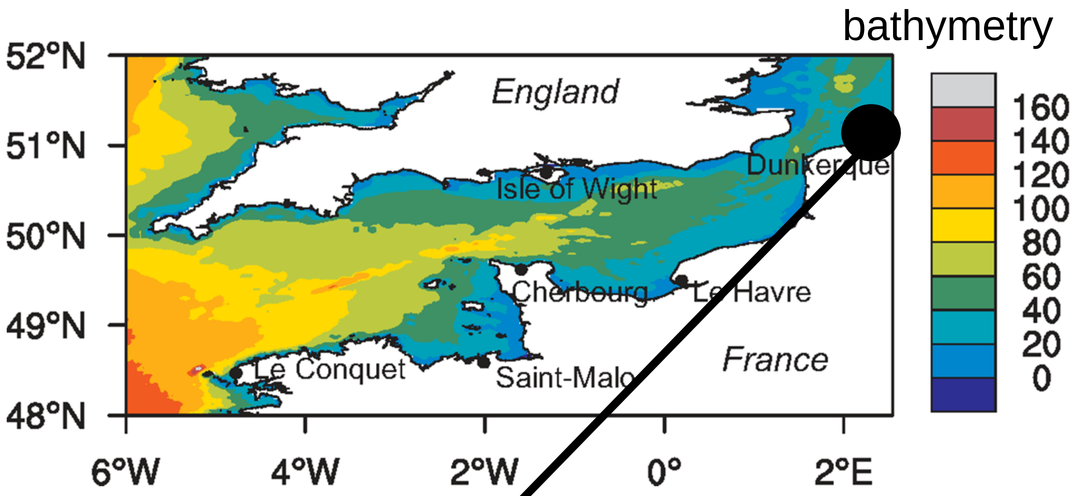
> Constant drag coefficient (Cd = 0,0016)

> Input data:
>> Tides: FES 2004
>> Meteo: ARPEGE analysis (dt=6h, dx=0.5°)

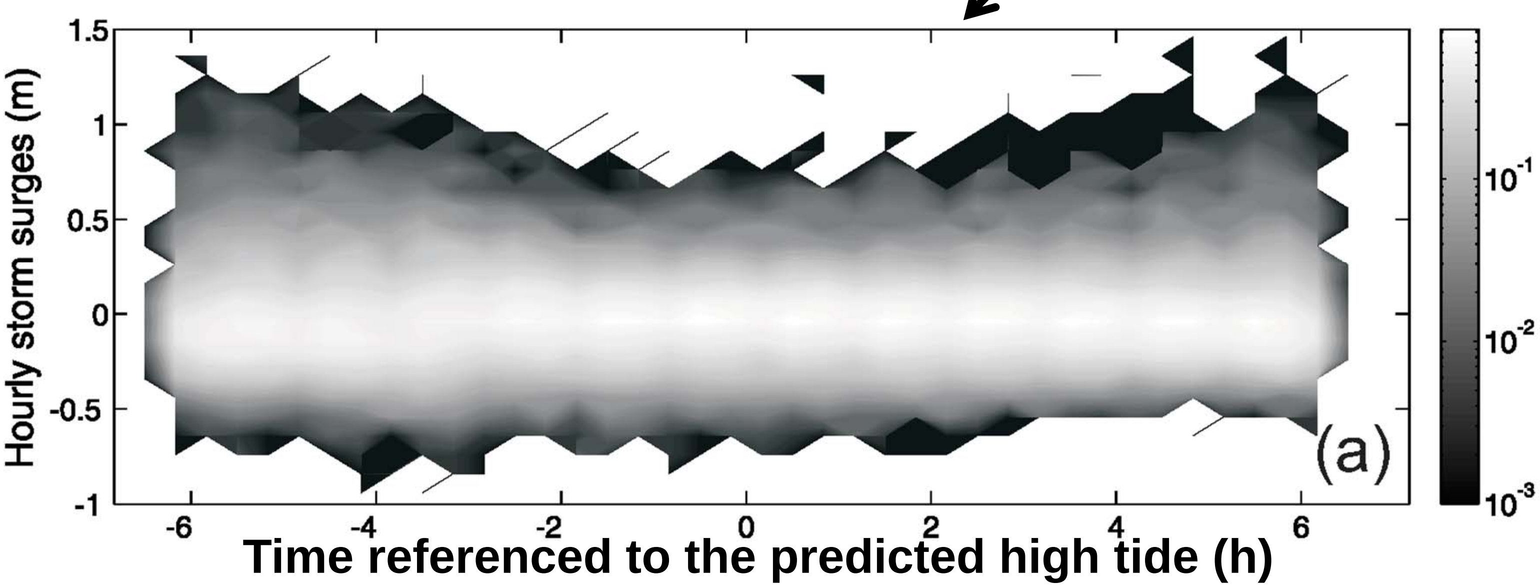
> 4 locations of interest

Tide and surge interactions (1/3)

> **Preliminary indications : data**



Data analysed over 2003-2010



Tide and surge interactions (2/3)

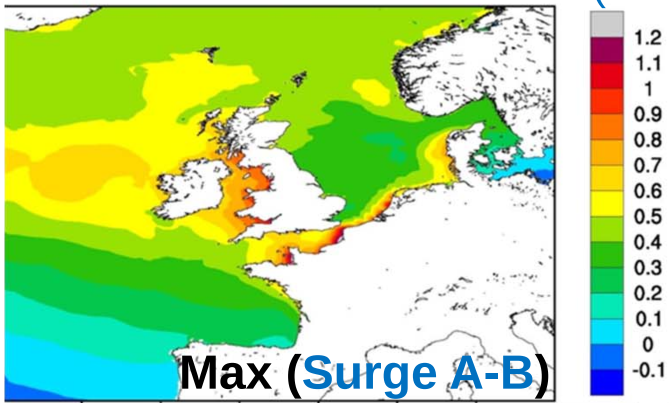
Simulations

3 complementary storm events

Nov 2007, Mar 2008 (Johanna), Feb 2009 (Quentin)

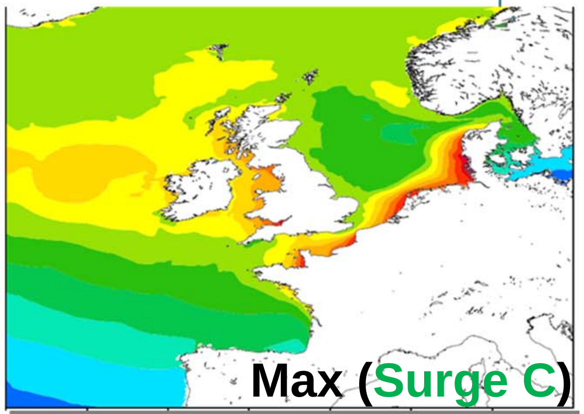
3 types of simulation

(A: Tide + Meteo), (B: Tide), (C: Meteo)

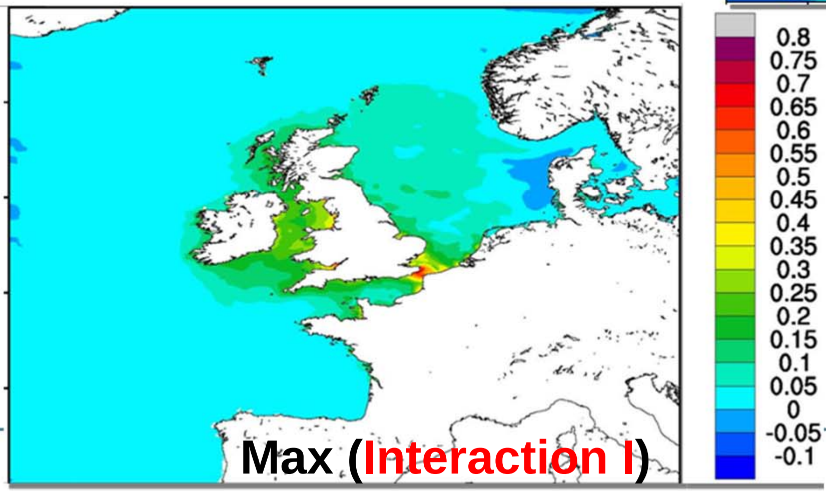


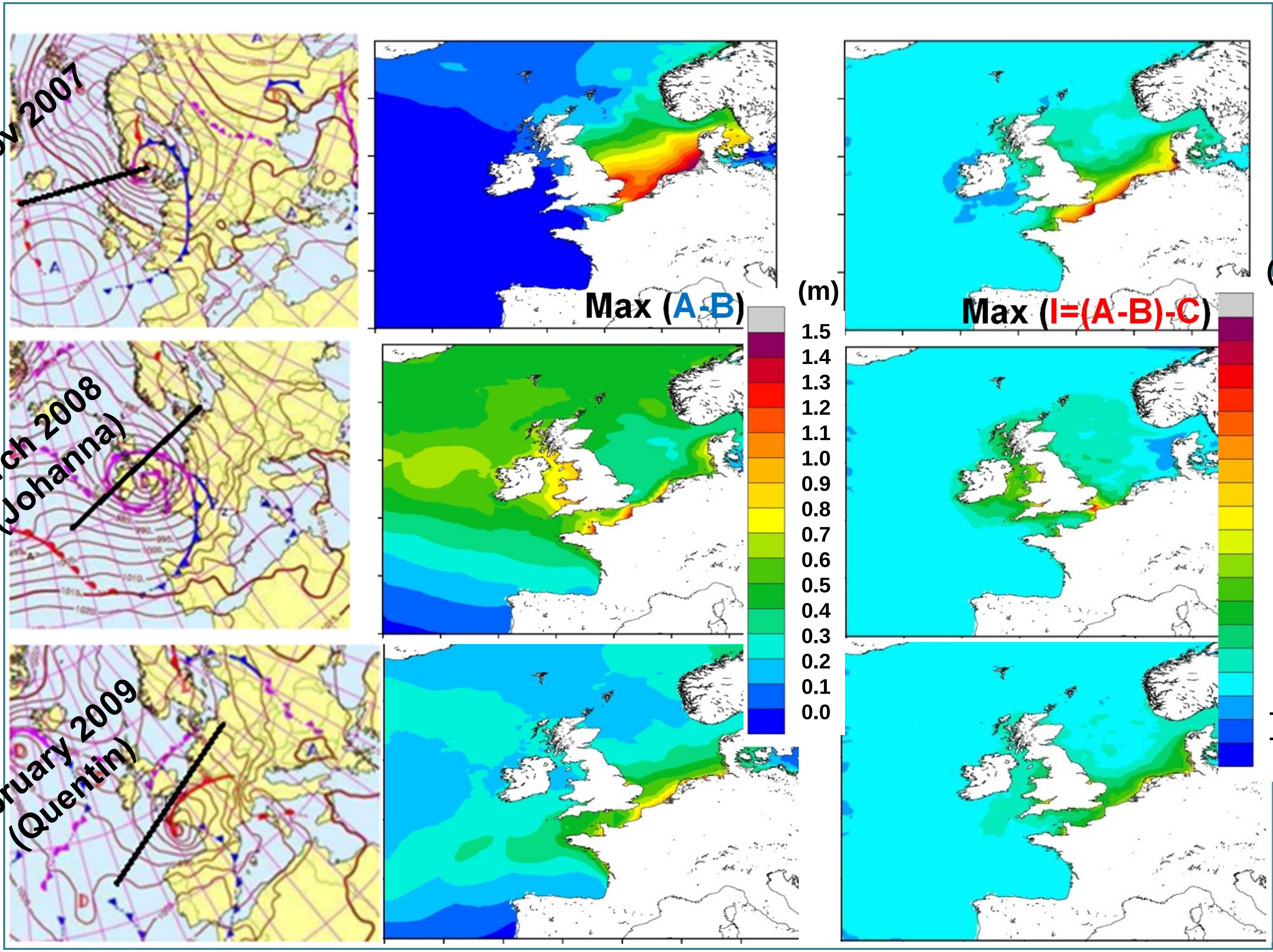
A – B = Surge **with** tide/surge interactions

C = Surge **without** tide/surge interaction

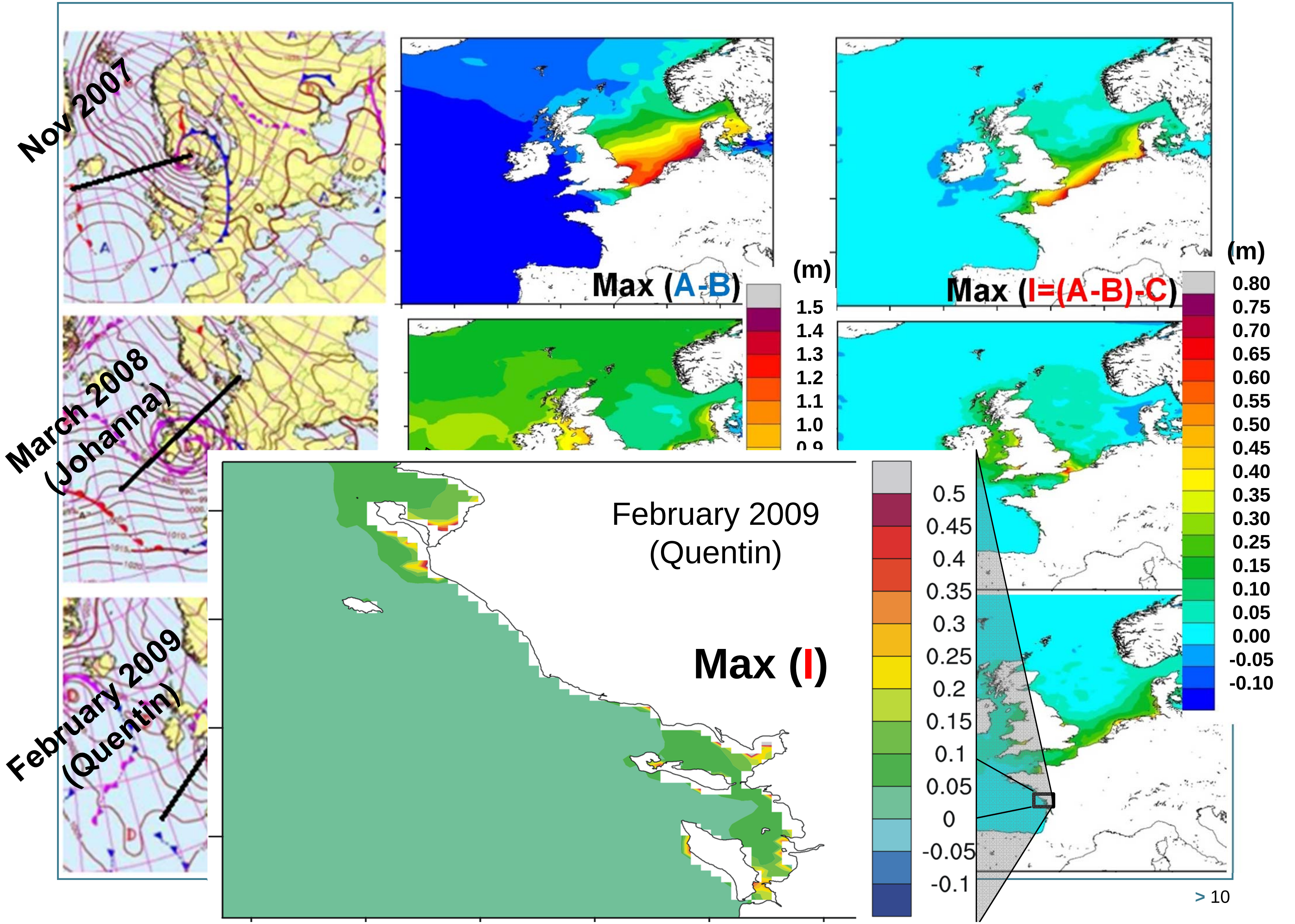


Interaction I=(A-B)-C





Nov 2007
March 2008 (Johanna)
February 2009 (Quentin)
Max (A-B)
(m)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Max (I=(A-B)-C)
(m)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.15
0.10
0.05
0.00
-0.05
-0.10

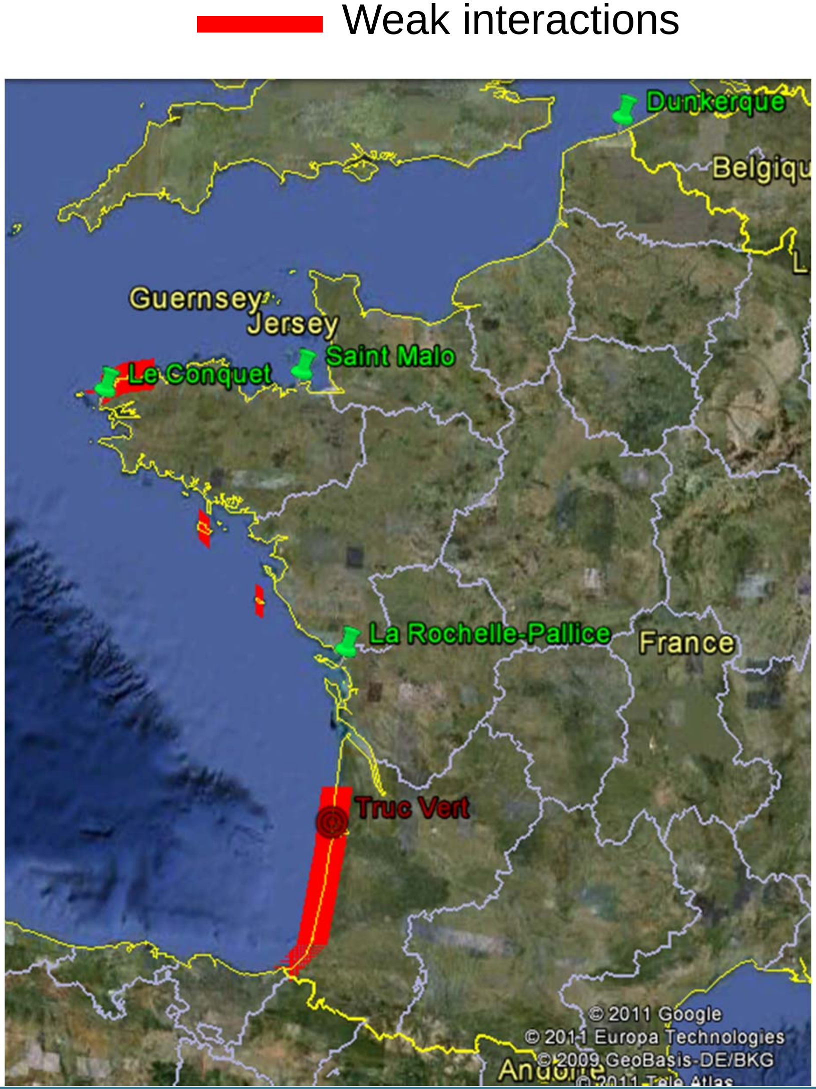

Nov 2007
March 2008 (Johanna)
February 2009 (Quentin)
Max (A-B)
(m)
1.5
1.4
1.3
1.2
1.1
1.0
Max (I=(A-B)-C)
(m)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.15
0.10
0.05
0.00
-0.05
-0.10
February 2009 (Quentin)
Max (I)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1

Tide and surge interactions (3/3)

- **Conclusions : Interaction between tide and instantaneous surge**
  - Only weak at some locations
  - > 60 cm in Dunkerque during the North Sea storm (nov 2007)

- **Consequences**
  - Necessity to take into account tides for instantaneous surges forcecasts on the most part of English Channel and Atlantic French coast

For more details and further investigation: Idier and Dumas (submit)



Sensitivity study to Cd formulation and met data (1/7)

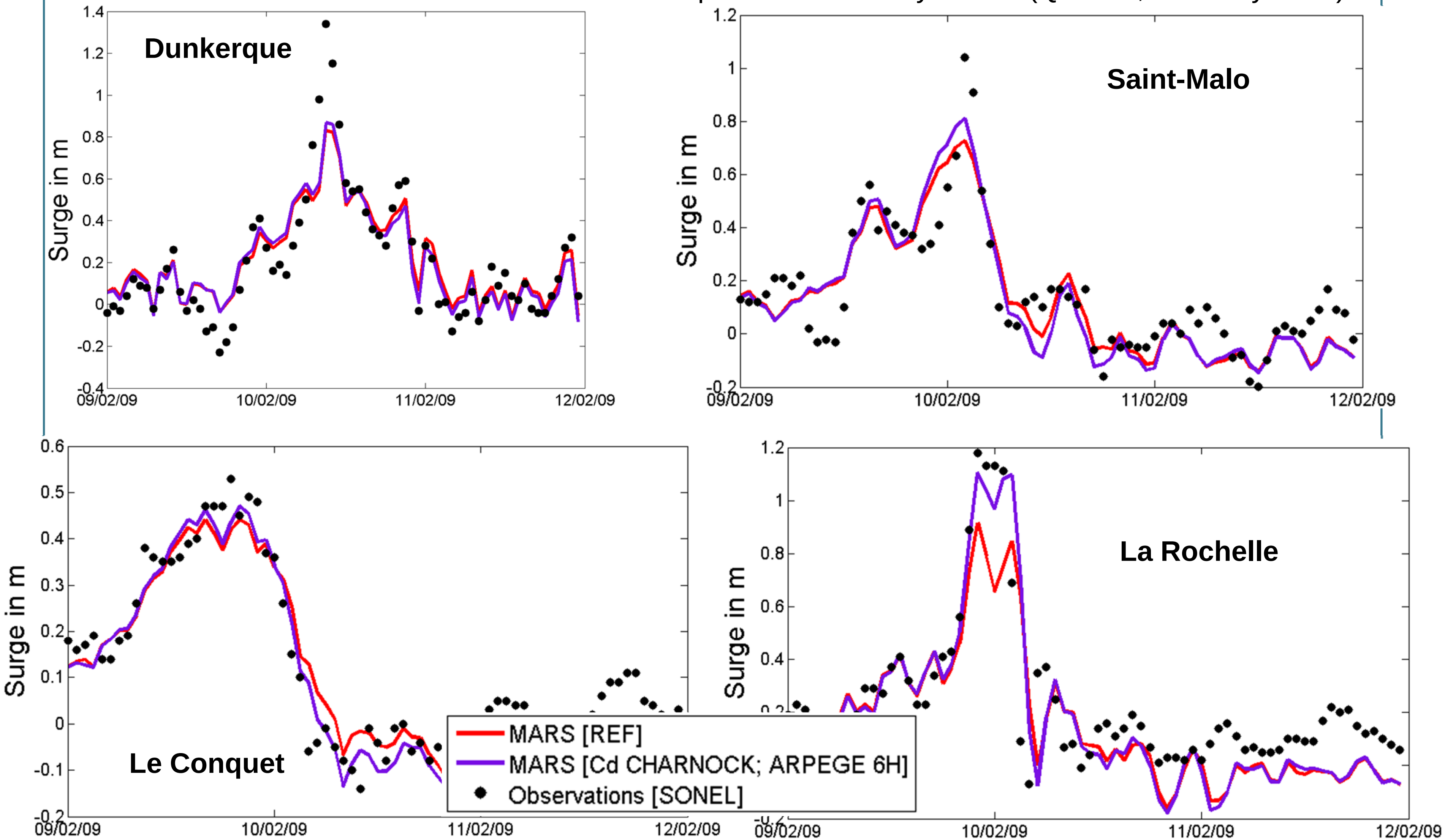
> **Reference configuration**
>> dx=2 km
>> Meteo : **6H ARPEGE analysis** (dx=0.5°)
>> Constant drag coefficient: **Cd=0,0016**

> **Methodology**
>> Pre-treatment: intantaneous surges issued from model and observations following the same protocol (harmonic analysis → tide)
>> Analysis
>>> during specific storm events (Nov 2007, March 2008, February 2009)
>>> over 7,5 ans
>> Sensitivity study
>>> On drag coefficient→ **Charnock's Cd** using wave data from WW3
>>> On meteorological input data (6H and 3H ARPEGE)

Sensitivity study to Cd formulation and met data (2/7)

> **Charnock's Cd and constant Cd + 6H ARPEGE : storm events results**

The best reproduced event by MARS (Quentin, February 2009)



Sensitivity study to Cd formulation and met data (3/7)

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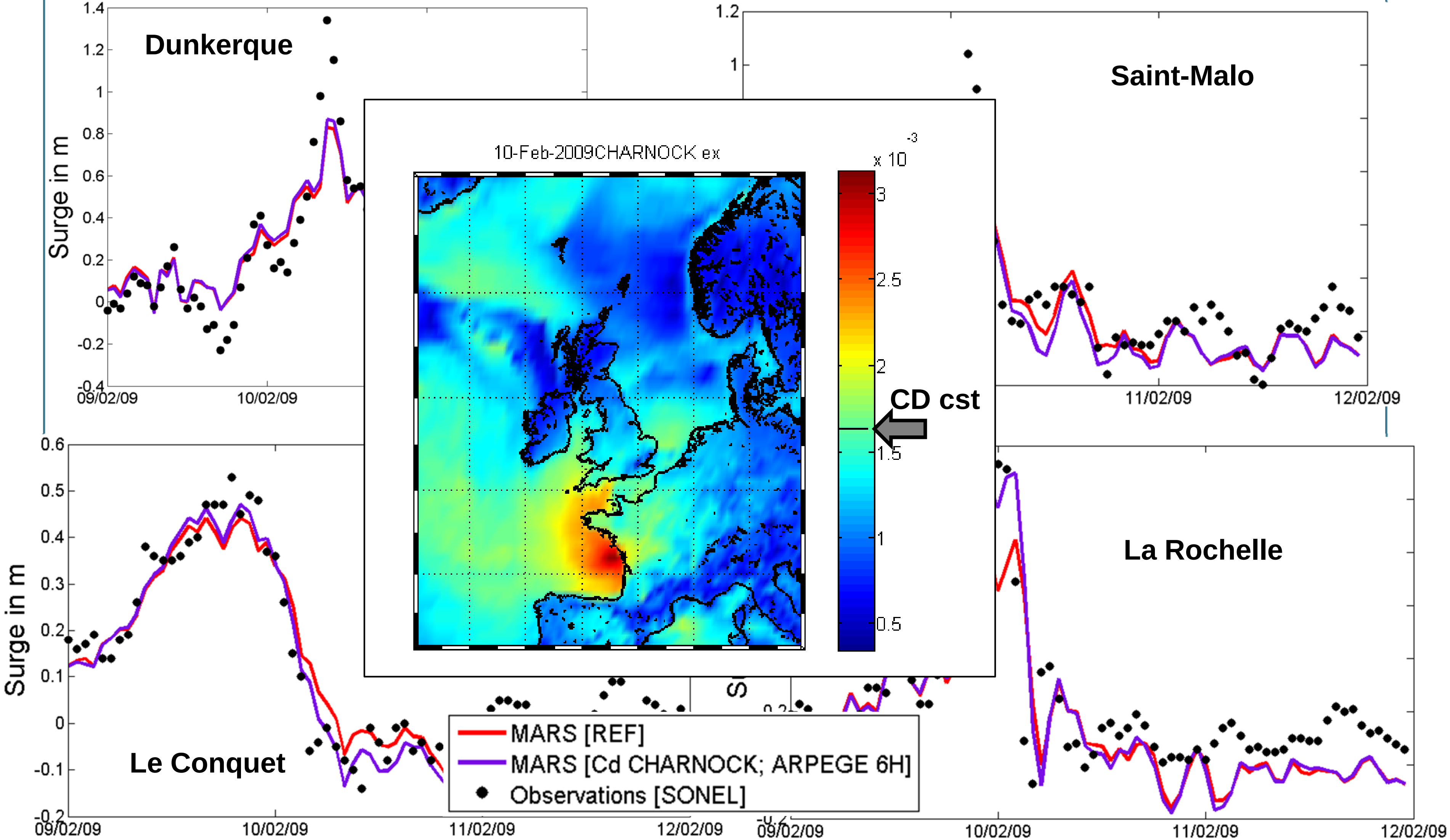
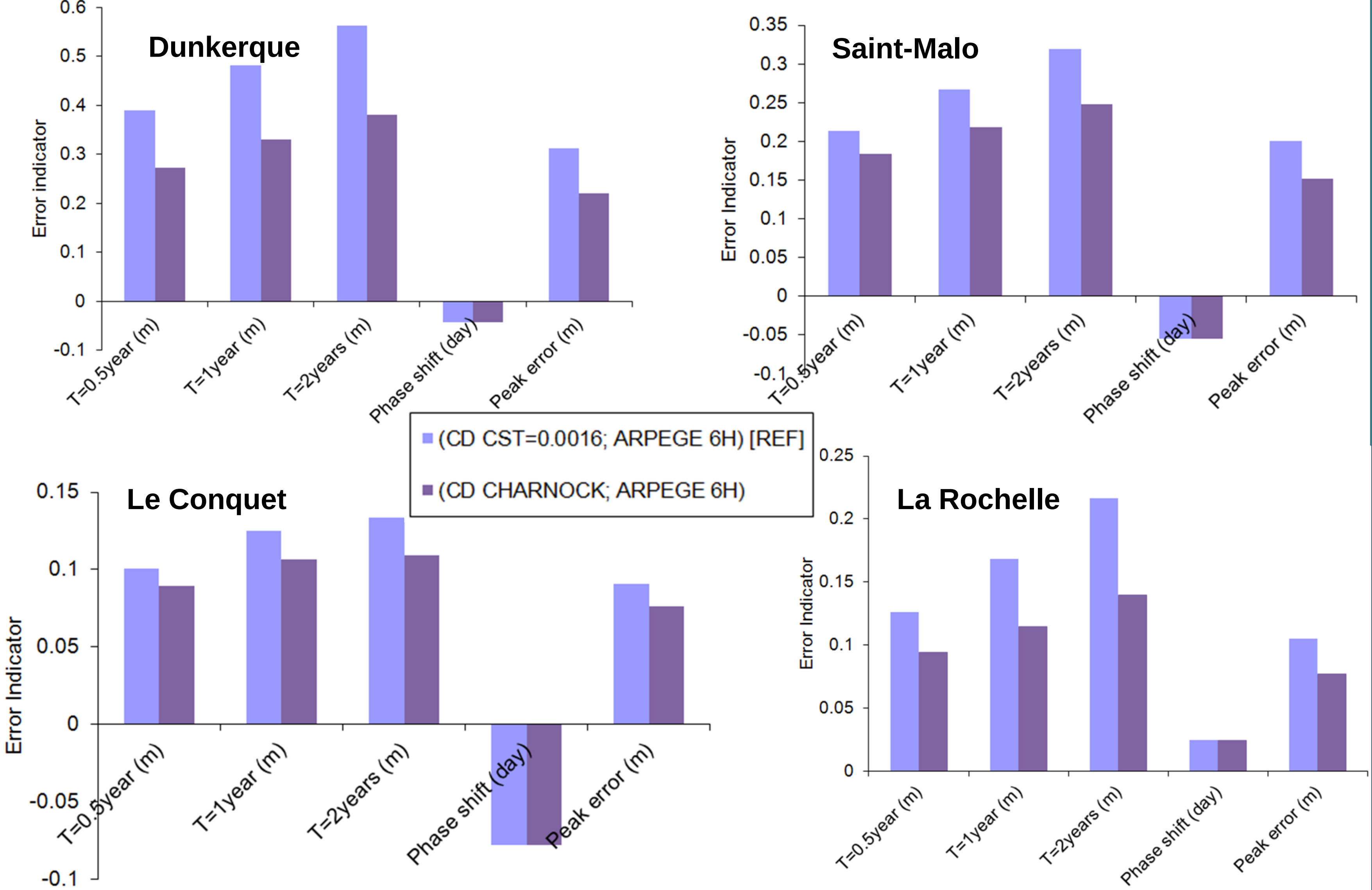


Sensitivity study to Cd formulation and met data (4/7)

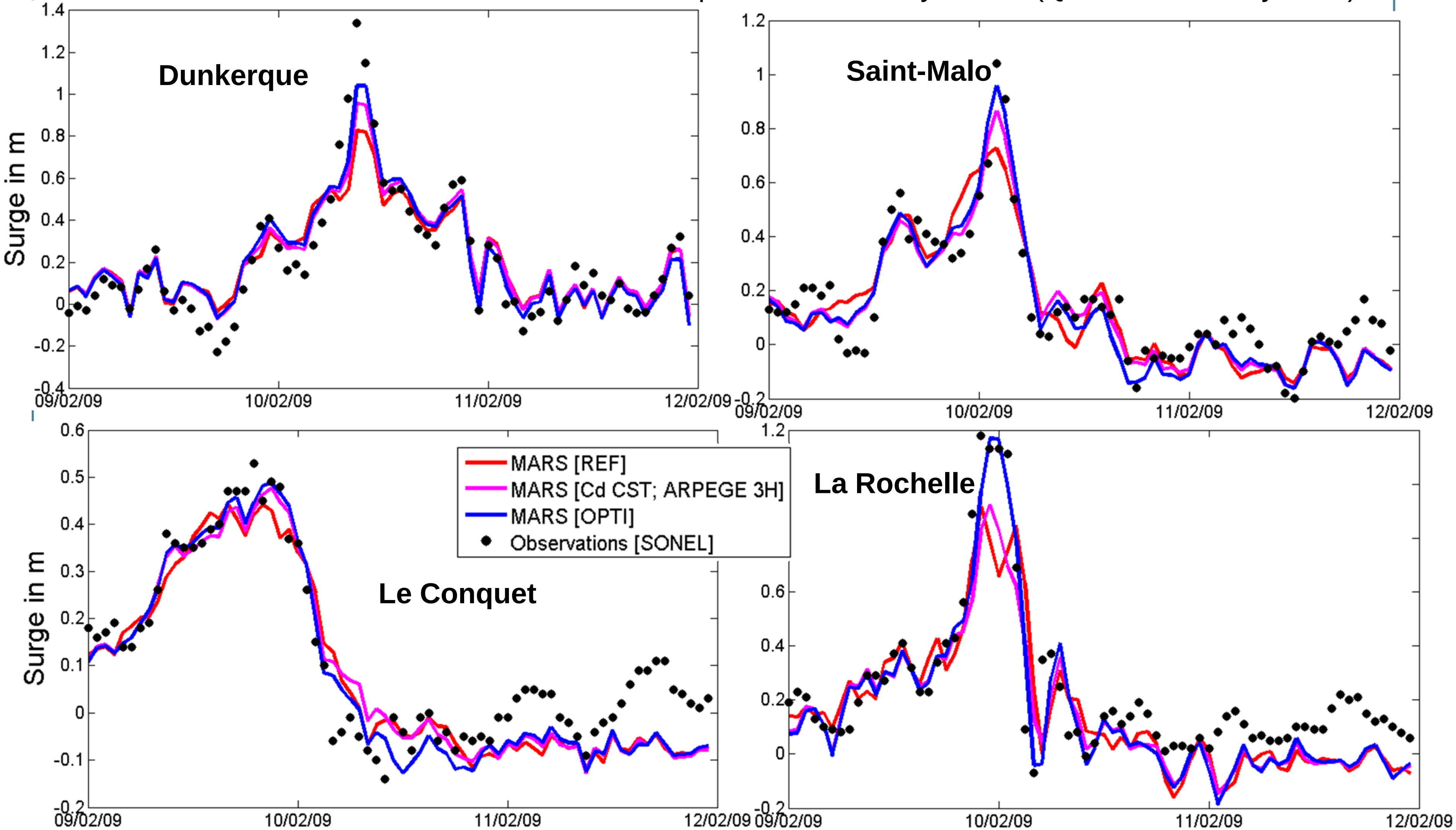
> **Charnock's Cd and constant Cd + 6H ARPEGE : Pluriannual results**



Sensitivity study to Cd formulation and met data (5/7)

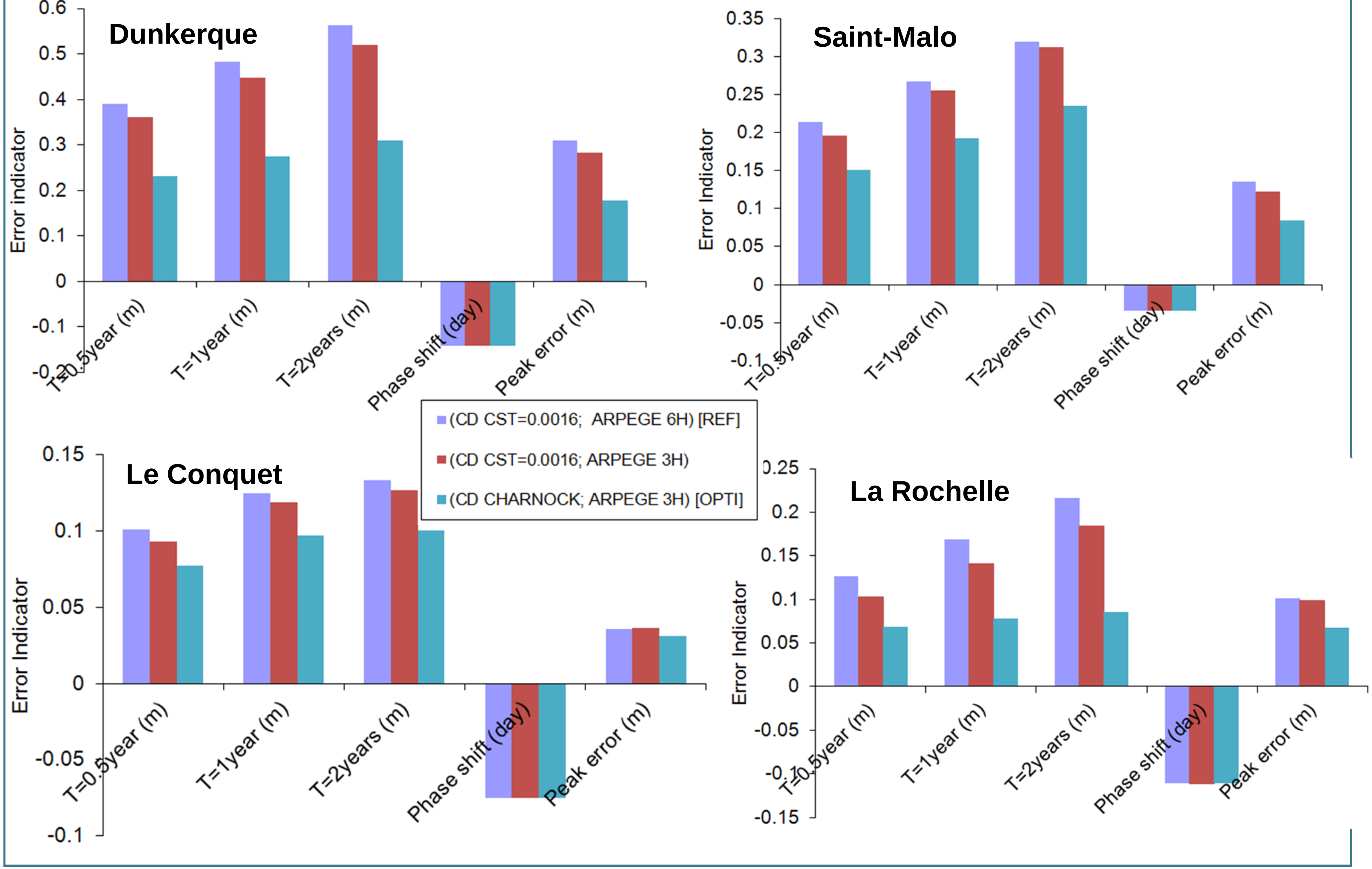
> **6H and 3H ARPEGE, constant and Charnock's Cd : storm events results**

The best reproduced event by MARS (Quentin, February 2009)



Sensitivity study to Cd formulation and met data (6/7)

> **6H and 3H ARPEGE, constant and Charnock's Cd: Pluriannual results**



Sensitivity study to Cd formulation and met data (7/7)

- **Conclusions** / reference configuration
  - Charnock's Cd + 3H ARPEGE → Improve clearly the results :
    - **Tens of centimeters higher** instantaneous surges, up to **50%** of the initial surges estimated with (constant Cd + 6H ARPEGE)
  - For the events analysis
    - Well reproduced surges for February 2009 (Met data are closest to the observations)
    - Underestimated surges for Nov 2007, March 2008 & February 2010
  - Possible improvments thanks to :
    - Met data, directly (→ surge)
    - Met data, indirectly (→ waves → Charnock's Cd → surge)

Conclusion and perspectives

- **Instantaneous atmospheric surges**
  - Tide-surge interactions
    - about **tens of cm**
      - → Necessity to take into account tide in surge modeling
  - Modeling
    - Cd(waves) and met data (3H ARPEGE) → better reproduction of surge peaks (improvement up to **tens of cm)** / constant Cd & 6H ARPEGE
    - Prospects for the area modeling: high resolution met forcing(1H AROME ?)

- **Perspectives**
  - **set-up contribution (open ocean beach):** reaches 50 (obs) to 70% (model) of the full surge
  - Wave influence on bottom drag coefficient

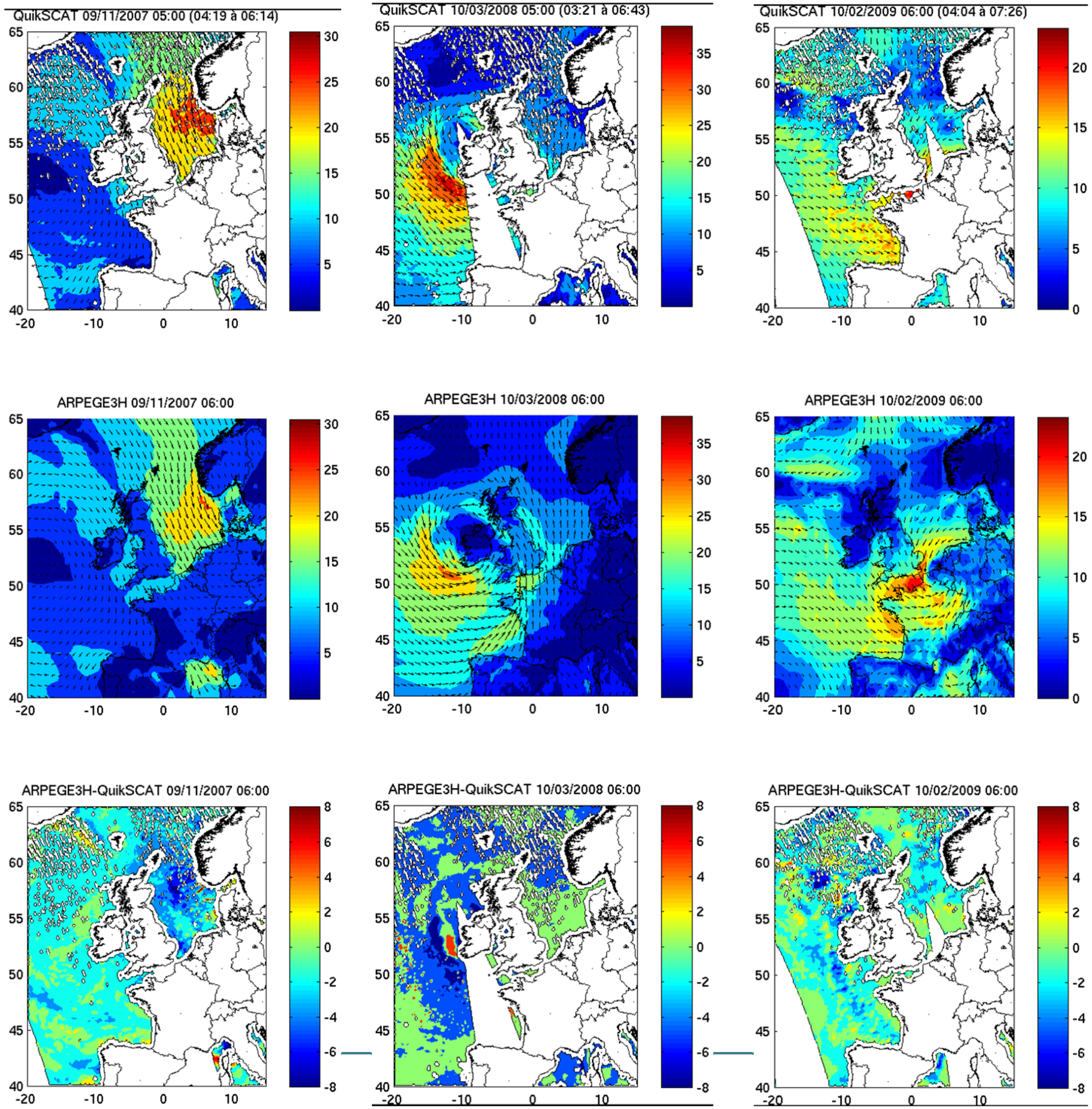
For questions…..

Meteorological data quality

Events	Location of interest	ARPEGE	
		Pressure	Wind
Event 1	Dunkerque	~	~
Event 2 : JOHANNA	Saint-Malo	~	~
	Le Conquet	+ overestimation about 4hPa max	~
	La Rochelle	~	+ overestimation about 10 to 20%
Event 3 : QUENTIN	Dunkerque	~	~
	Saint-Malo	~	~
	Le Conquet	~	~
	La Rochelle	~	+ overestimation about 2 to 4 m/s
Event 4 : XYNTHIA	Dunkerque	~	~
	Saint-Malo	~	- slightly underestimation
	Le Conquet	~	~
	La Rochelle	~	+ overestimation about 5 m/s max

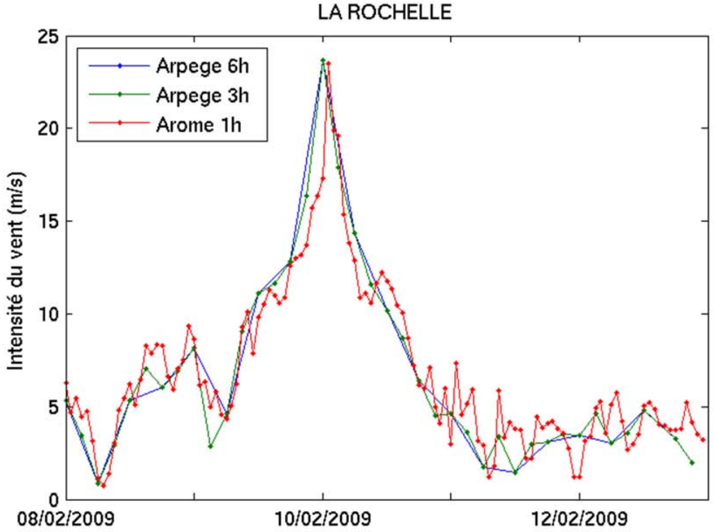
Summary of the comparaison between (6H and 3H) ARPEGE meterological forcing and observations (semaphores) for wind and pressure min and max

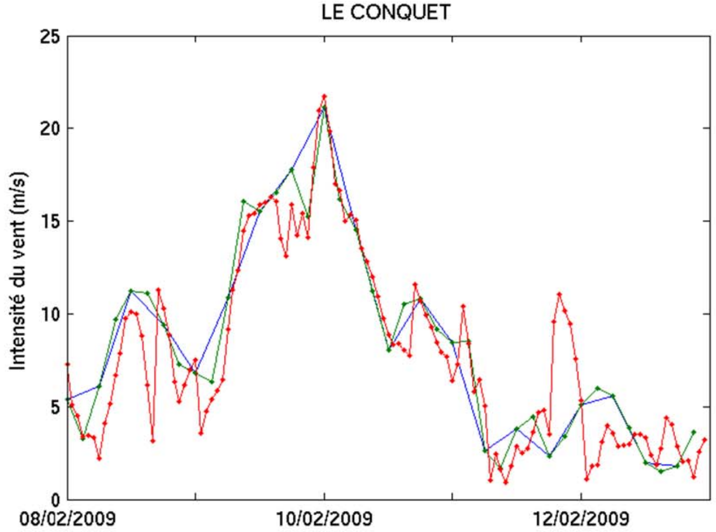
Meteorological data quality



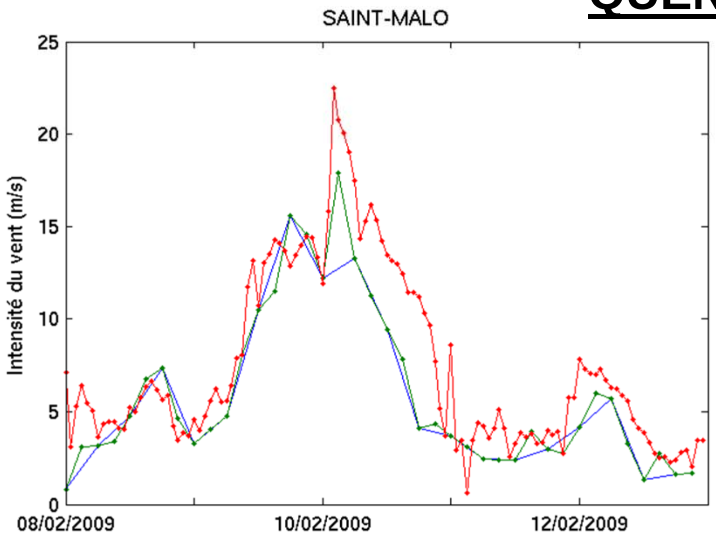
<u>Comparison between Quikscat and 3H ARPEGE winds</u>

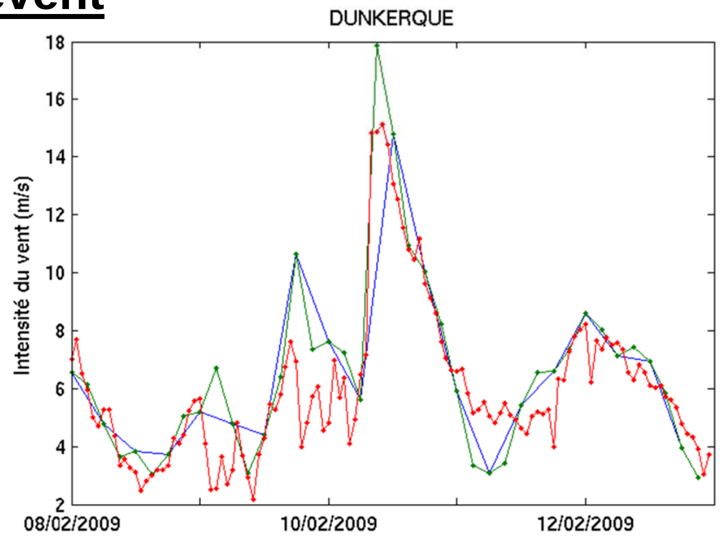
Meteorological data quality



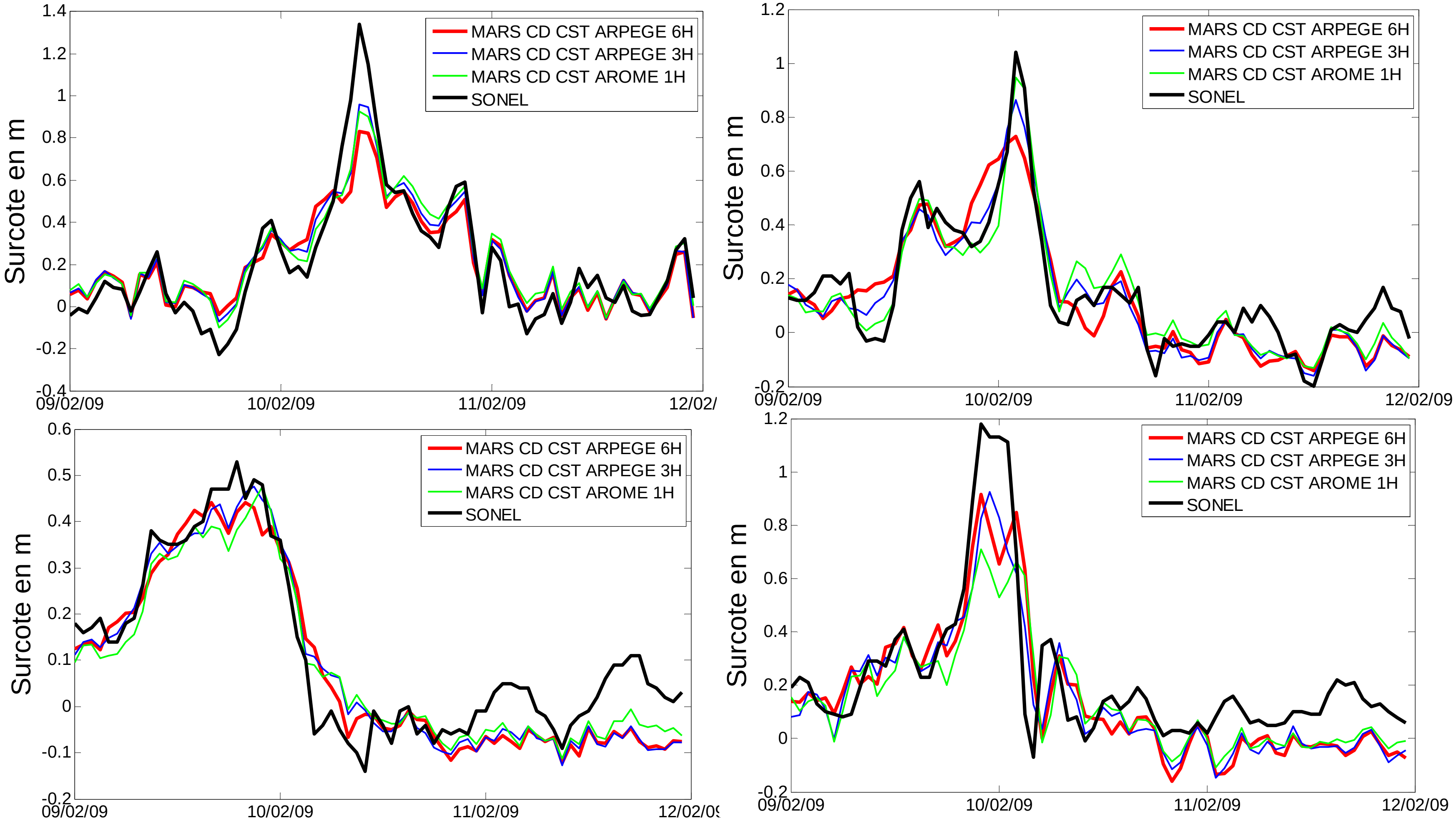


Comparisons between 3H & 6H ARPEGE and AROME wind intensity over QUENTIN event





Some results with 1H meteorological forcing (AROME data)



<u>Surges time series issued from MARS with different meteorological forcing and from SONEL (data in black) for QUENTIN event at : (a) Dunkerque, (b) Saint-Malo, (c) Le Conquet, (d) La Rochelle.</u>

From Bertin et al. 2011

“In the central part of the Bay of Biscay: 6h oscillations with amplitudes of up to 0.2 m (10–20% of the surge peak) in observed and predicted water level.

the period of the observed oscillations corresponds to the resonant mode of the continental shelf in the central part of the Bay of Biscay.

=>these oscillations originate from the interactions between the water level perturbation and the continental shelf

=> this phenomenon is expected to be relevant at other places along the world’s coastlines.”

Charnock's formulation at z=10m

$$c_D = [(1/\kappa)\ln\{gz/(\alpha c_D W^2)\}]^{-2}$$

c_D **Surface drag coefficient**

κ **Von Karman's constant**

z **Height above the surface**

α **Charnock constant**

W **wind velocity at a height of 10m above the surface**