Coastal Altimetry

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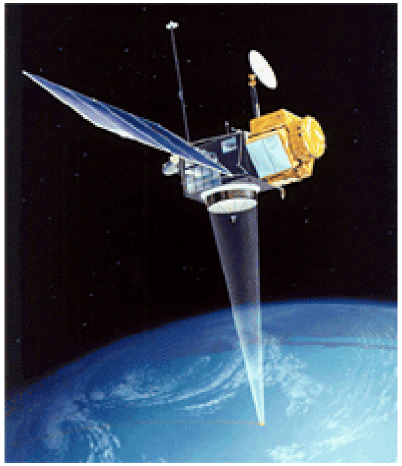

- Coastal sea level
- Coastal wave conditions and extreme events
- Coastal currents

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Coastal Dynamics

50% of the world's population live less than 100 km from the coast

=> Understanding coastal dynamics important for **society** : **economics** (fishing, shipping, oil platforms, …), **environment** (pollution control, algal blooms, marine management.

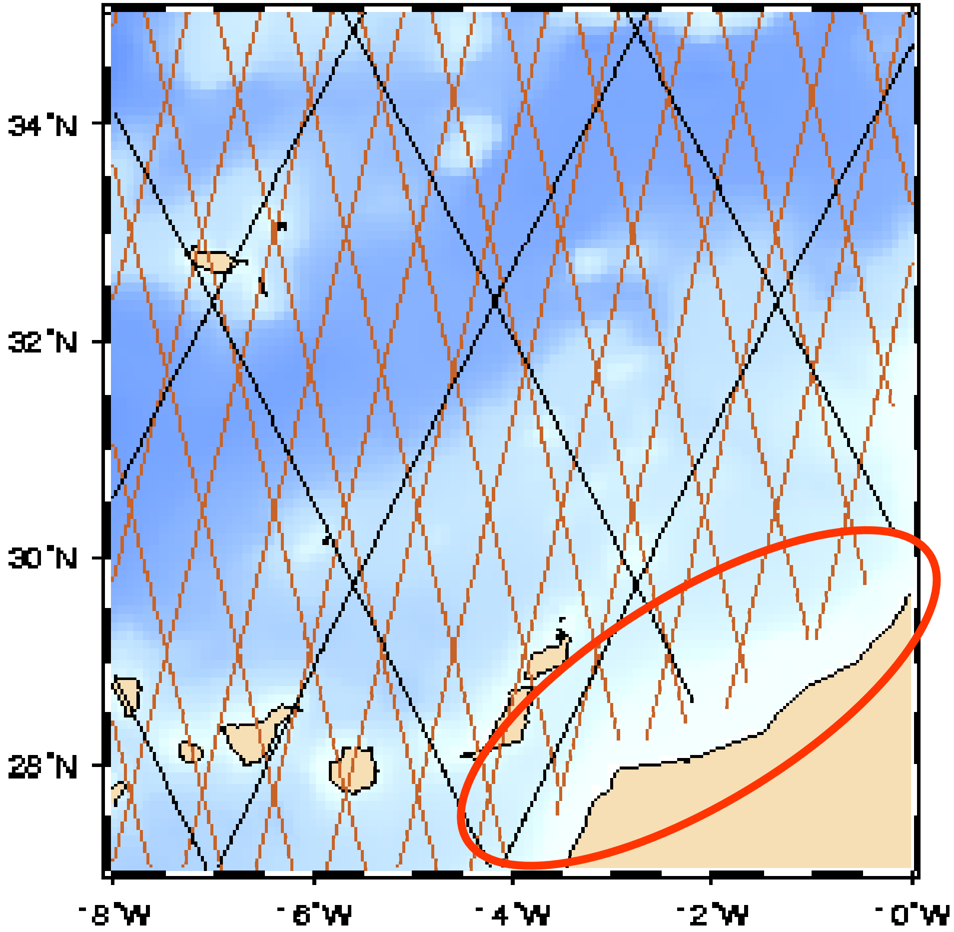
Yet monitoring coastal processes is difficult :

- rapid time scales,
- small cross-shore space scales,
- shallow-water amplifications and non-linearities
- atmospheric attenuation changes (coastal cloud, fog)

1. Coastal Sea Level

Satellite altimetry sea level observations are not well-adapted to the coastal domain :

- 30-50 km from the coasts, the radiometer and altimetric footprint is « blinded » by the presence of the coast,
- certain corrections (tides, inverse barometer effect) adapted for the open ocean, are underestimated in the coastal zone.



Specific problems with altimeter data in coastal zones

1. Standard altimeter waveforms are deformed by the presence of the land (10-15 km from coast),

2. Radiometer signal (wet troposphere correction) is contaminated by land (30-50 km from coast).

3. Tides and atmospheric responses are amplified. Specific « shallow water » tidal constituents are needed.

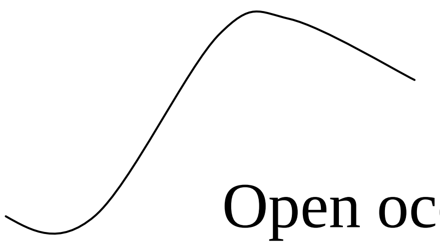
4. Altimetric mean sea surfaces do not exist for the coastal zone

Specific processing of coastal altimetric data … 1

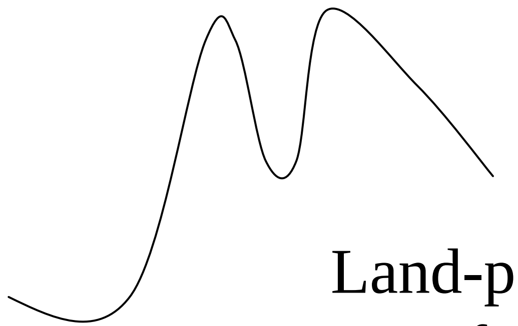
1. **Retracking** of altimeter waveforms

Standard waveforms are deformed by the presence of the land in the nearshore zone (10-15 km from coast),

Special retracking algorithms can recover « good » geophysical parameters (sea level, wave height, etc) in the nearshore zone.



Open ocean waveform

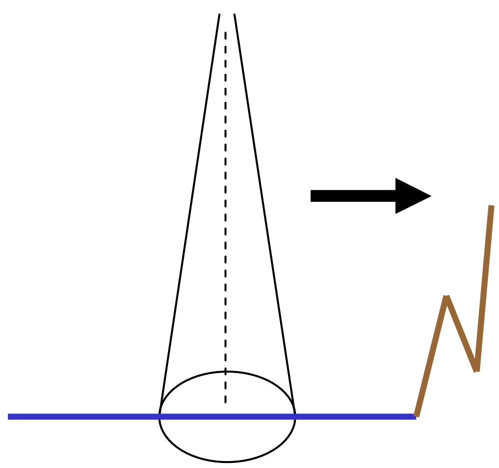


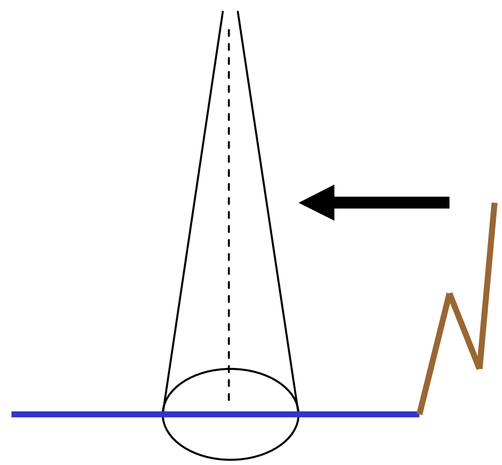
Land-perturbed waveform

Approaching or leaving the coast

Altimeter approaching the coast –altimetric signal up to 10 km from coast

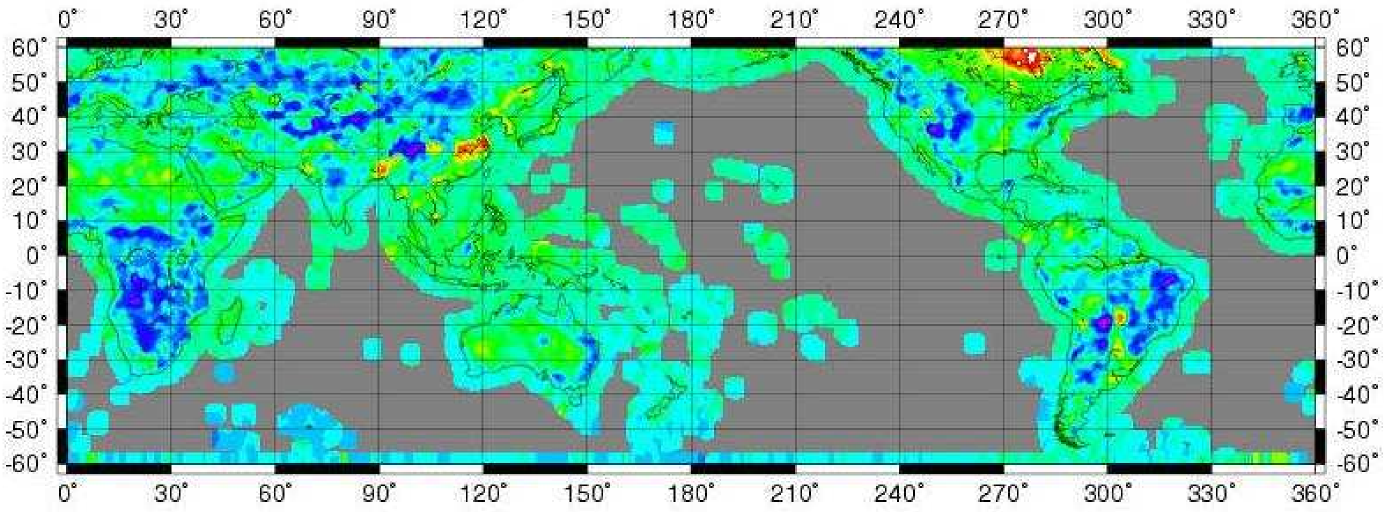
Altimeter leaving the coast – may take 2-3 secs to « lock in » on ocean obs : 14-21 km!





Retracking of altimeter wave forms in the coastal zone

The CTOH/LEGOS has a project of « retracking » the altimeter wave forms in the coastal domain and over continental surfaces



• ERS 1/2 waveforms have been « retracked » in the coastal zone, the same algorithm is now used on ENVISAT (ICE2) … retracked data exist from 1991 – 2004+

• Retracking the T/P+Jason waveforms is underway at JPL and AVISO

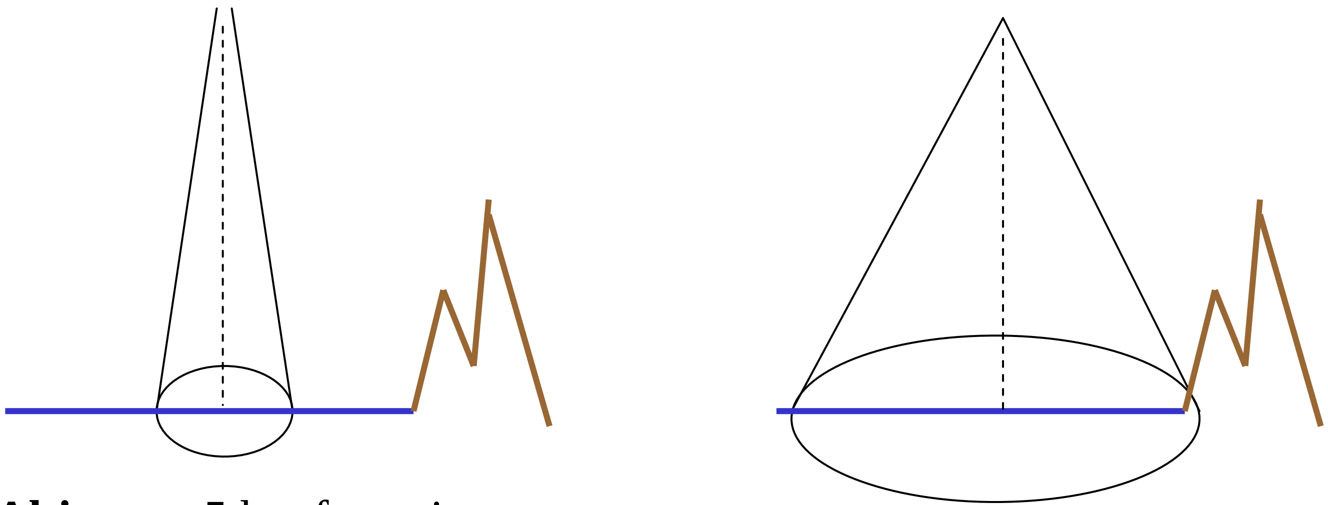
Specific processing of coastal altimetric data … 2

2. **Wet tropospheric correction** (radiometer decontamination)

-uses microwave radiometer measurements of **brightness temperature**. Due to their frequency, the footprint for these channels is larger than the altimeter footprint, and the wet troposphere correction is contaminated by land up to 30-50 km from the coast.

Radiometer measurements **can be replaced by model estimates**, but the errors are large, especially in coastal zone.

<u>Result :</u> with standard corrections – no corrected altimetry data is available in the band 30-50 km from coast.



Altimeter 5 km footprint

Radiometer 50 km footprint

Radiometer solutions

1) Radiometer decontamination techniques are being developed (JPL, CLS)

2) At CTOH/LEGOS, we have an interpolation algorithm which **fills the gaps in the radiometer, sea state bias, and ionospheric corrections**, and **extrapolates** these corrections by 3 points (21 km) into the coastal zone.

- These corrections have been **validated in the different coastal regions**.

Specific processing of coastal altimetric data … 3

3. Improved **high frequency corrections** (tides, response to atmospheric forcing)

Problem : In shallow coastal zones, tides and atmospheric responses are amplified. More tidal constituents « shallow water tides » are needed.

Tides

a) **new global tidal models** can be implemented (**FES2004**) with improved performance in the coastal zones.

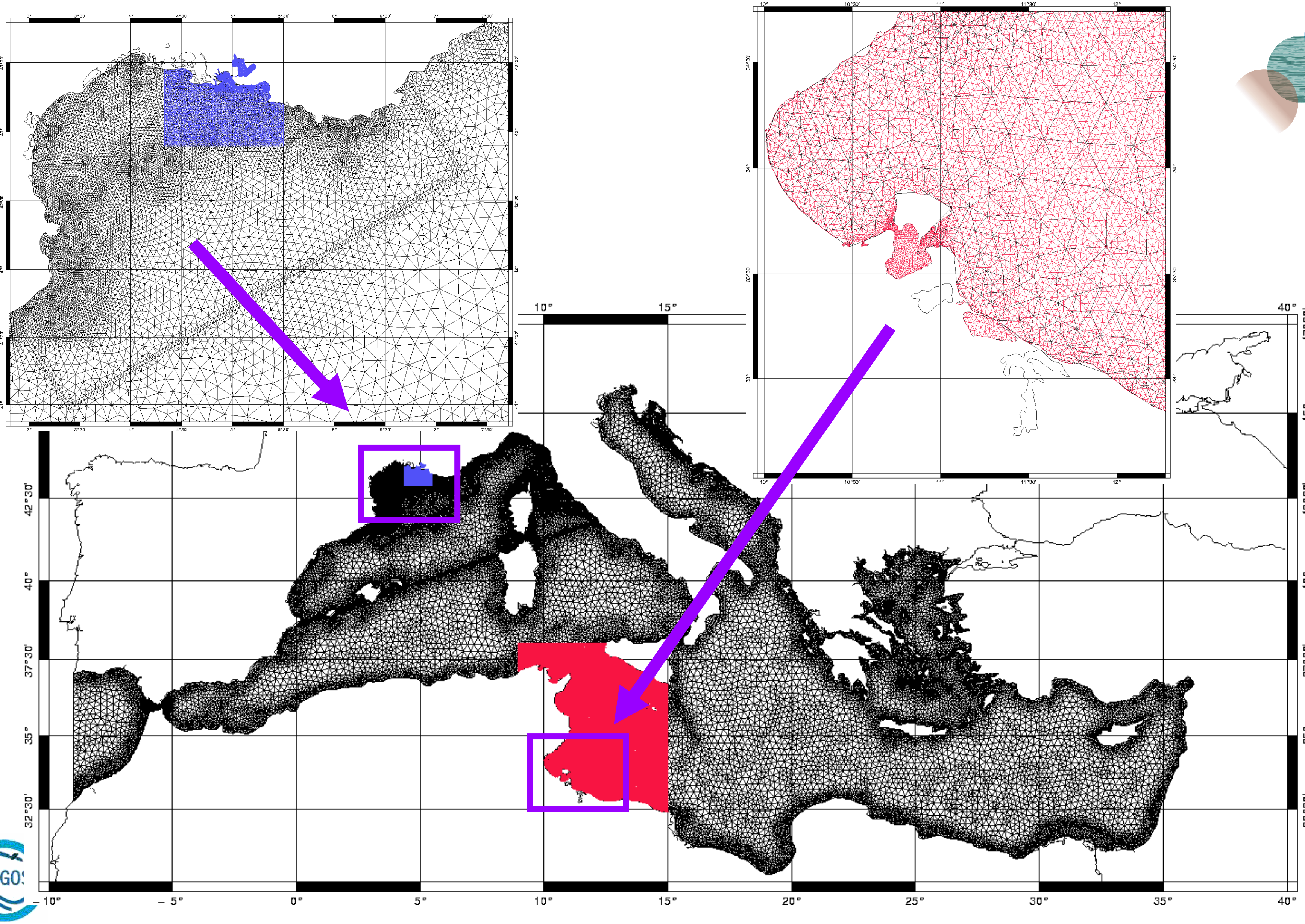
b) Regional tidal models are also used for high space-time resolution.

Response to atmospheric forcing

a) **new global barotropic model** correction can be implemented (**MOG2D**) which corrects for the high-frequency barotropic response.

b) Regional, high-resolution versions of MOG2D are also used

For specific sites, higher-resolution models are developed to improve tides and response to atmospheric forcing : eg, Mediterranean Sea



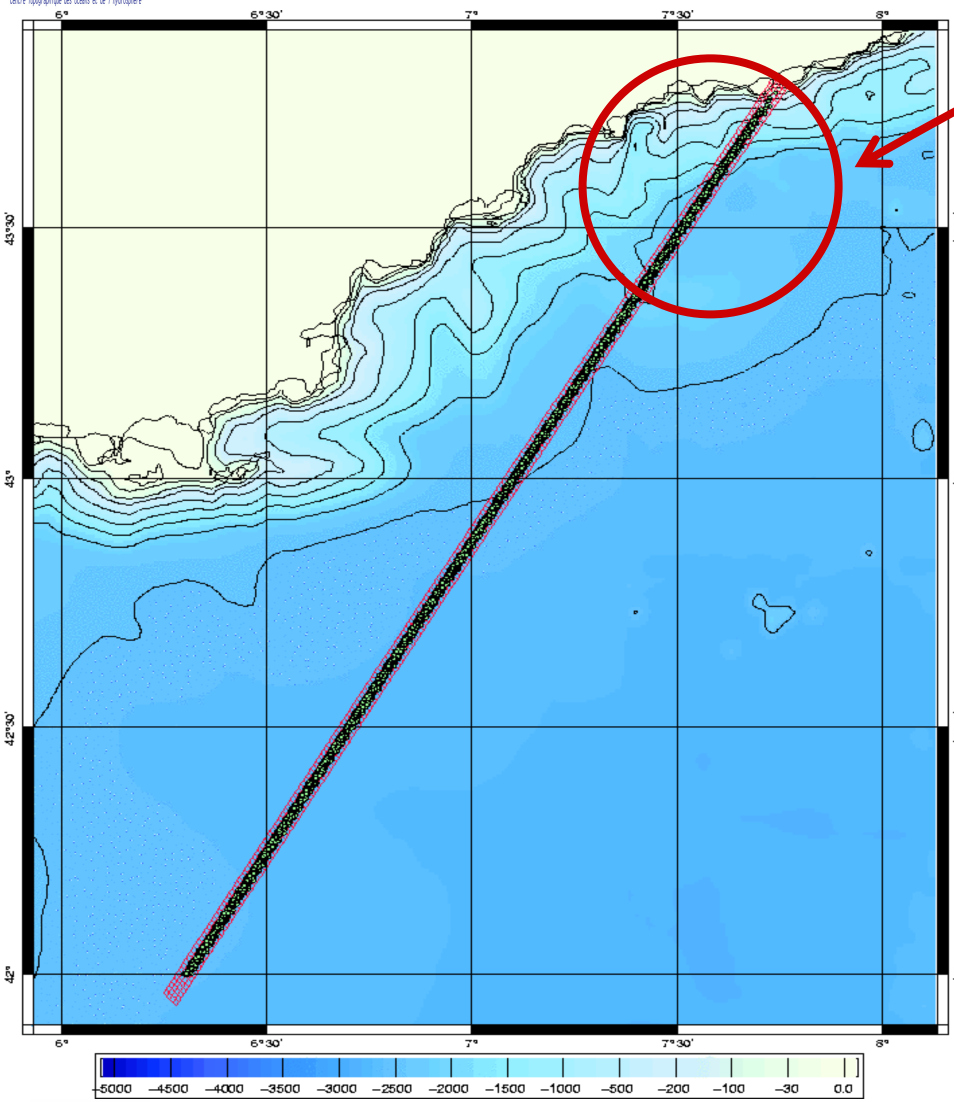
Influence on the mean sea surface

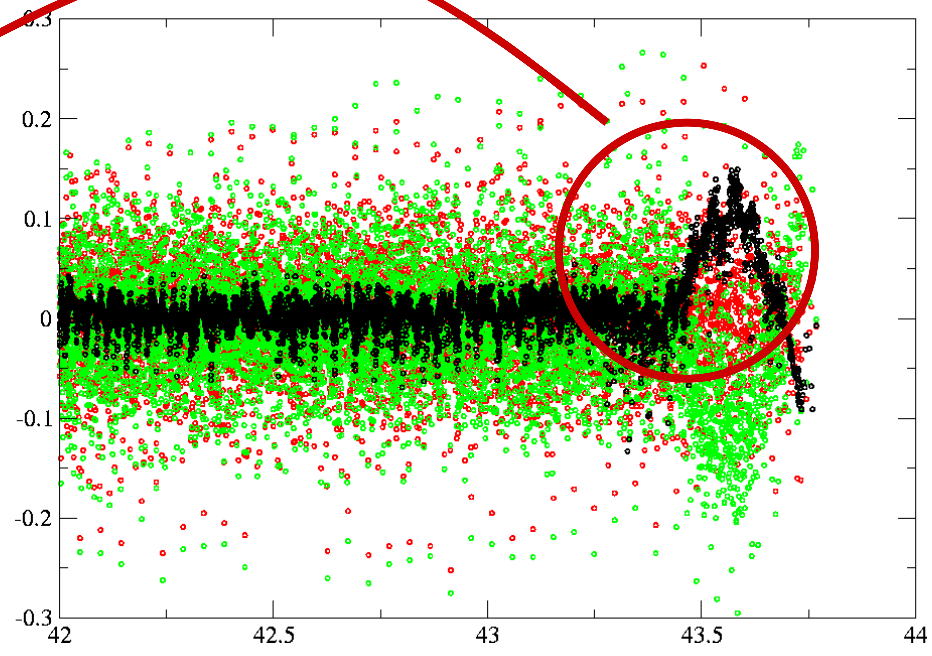
Problem :

- Altimetric sea level anomalies are normally referenced to a mean profile or mean sea surface.
- Historical mean sea surfaces do not exist in the coastal zone, since there was no corrected SL data available to construct the mean.
- Accurate offshore mean sea surface cannot be extrapolated into the coastal zone towards a terrestrial geoid at low resolution = > this leads to large errors in the mean sea surface in the coastal zone.

Solution : reconstruct a new mean sea surface (reference surface) in the coastal domain from improved altimetry data

Reconstruction of the mean sea surface using the improved data close to the coast





Topex SSHA obtained from :

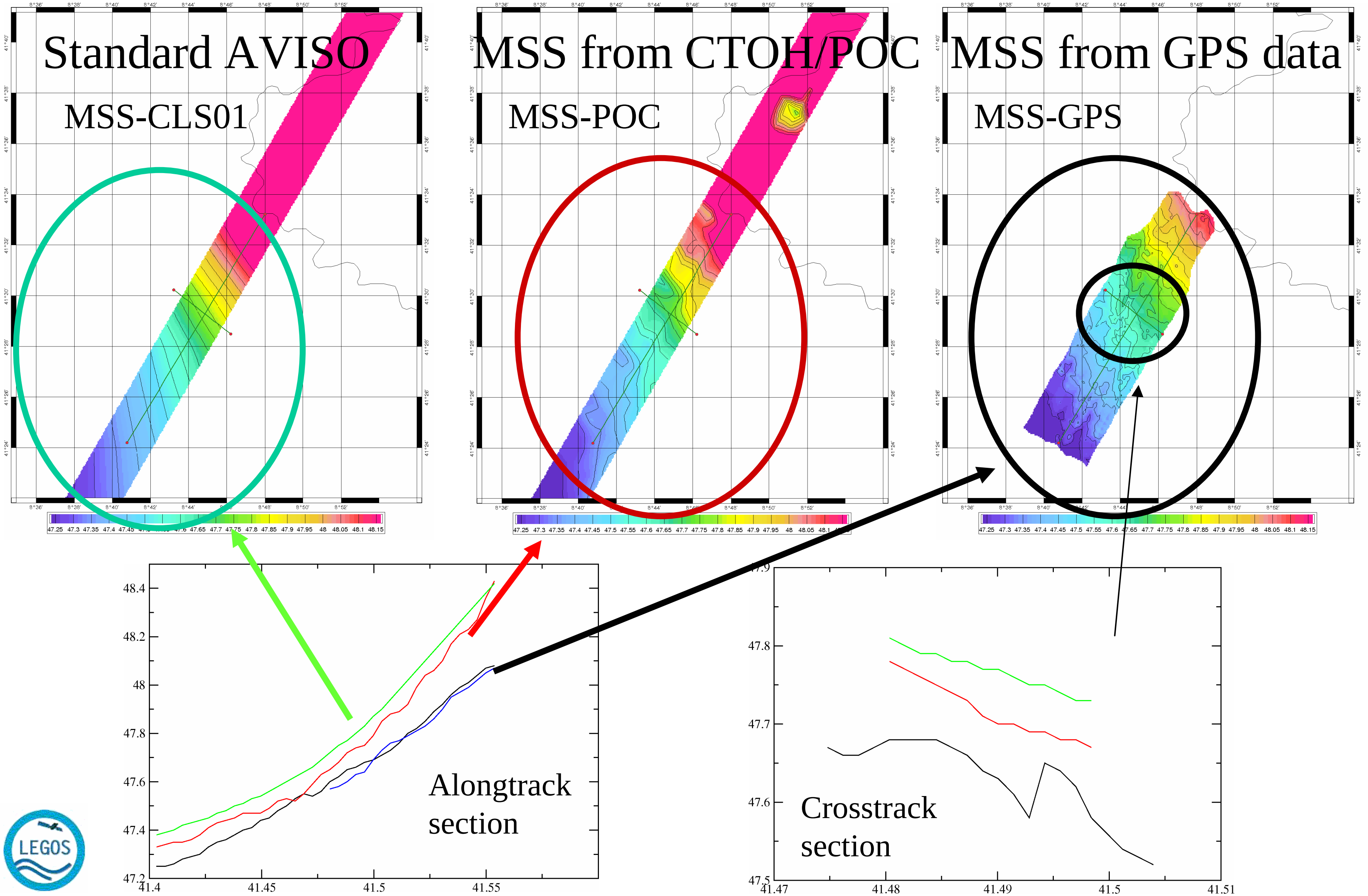
#reconstructed MSS (red)

#standard CLSO1-MSS (green)

#MSS differences (black).

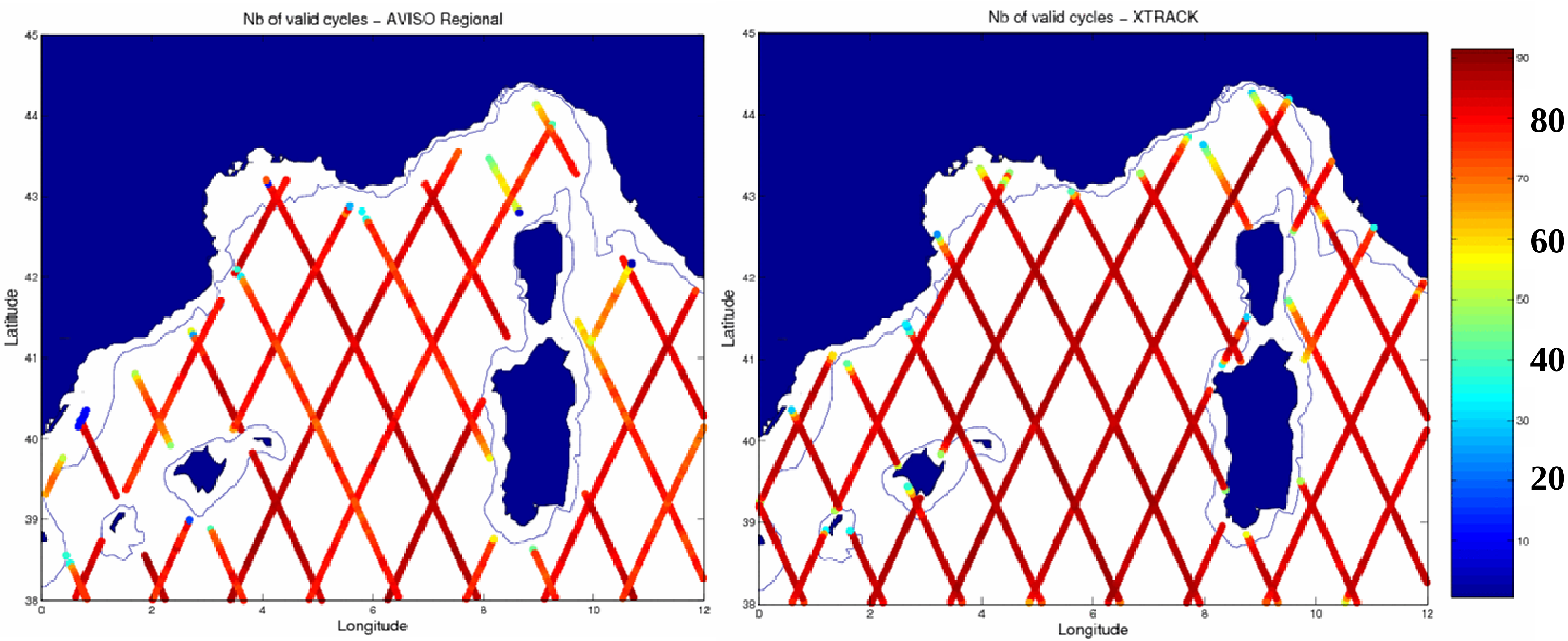
Unit in meters

Difference between the standard and improved mean sea surfaces



Specific Processing : Coastal altimetry data

Topex/Poseidon et Jason-1: Nb valid data
(common period : 20/09/2002 – 20/03/2005)



AVISO: Regional along-track product

CTOH: alongtrack produit

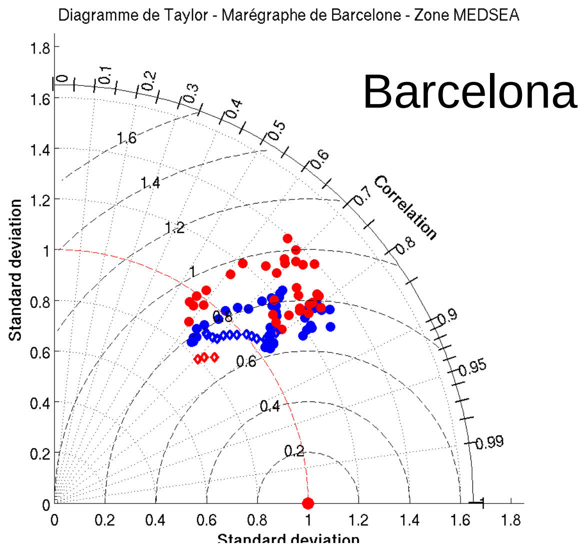
→ **Better space-time coverage**

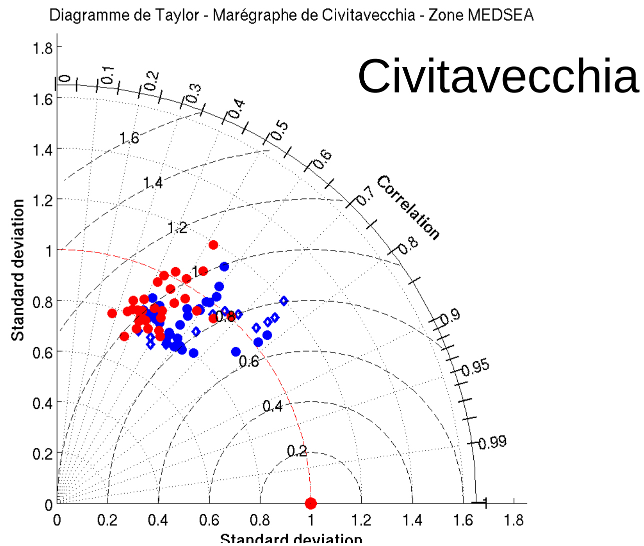
Tide gauge comparisons – NW Mediterranean Sea

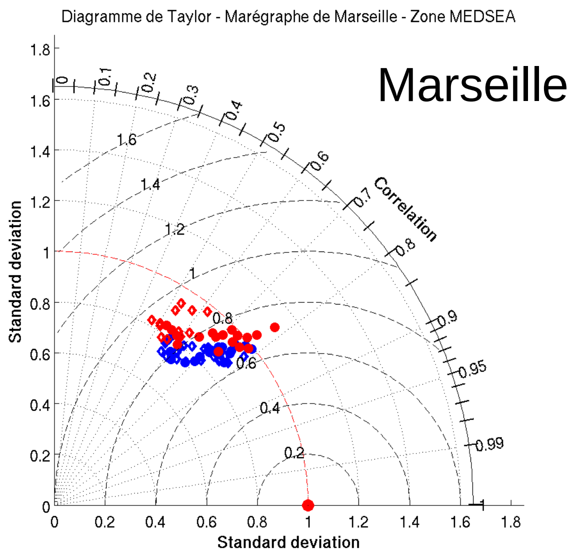
Topex/Poseidon et Jason-1: tide gauge comparisons (Taylor Diagrams) (common period : 20/09/2002 – 20/03/2005)

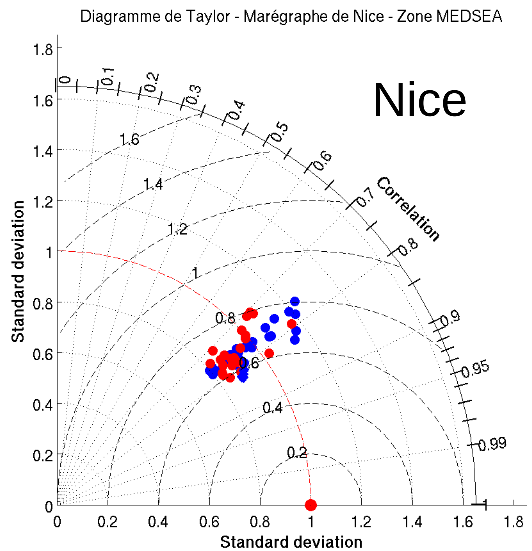
AVISO: along track regional product

CTOH: alongtrack product





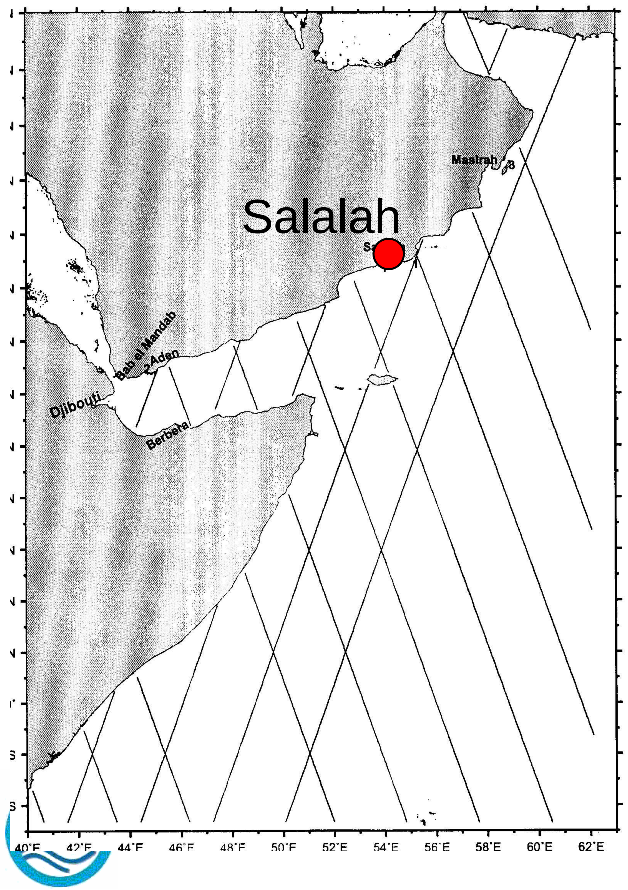




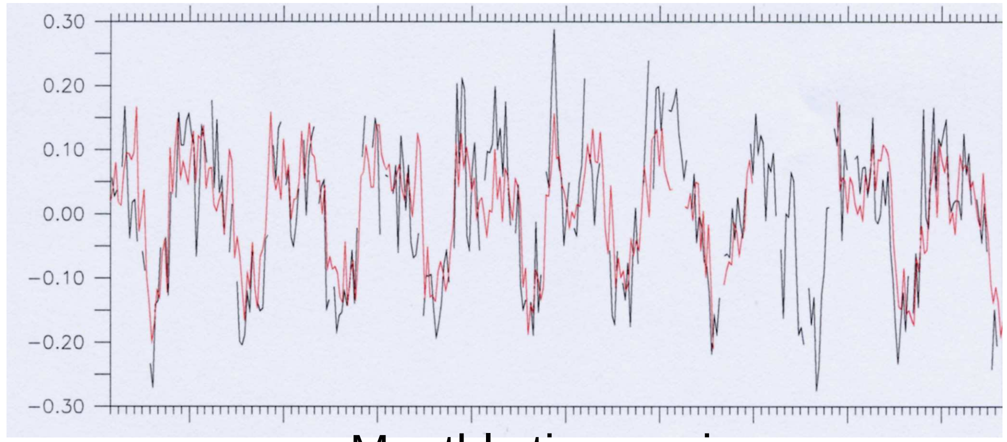
Validation with coastal tide gauges

Comparison between sea level anomalies (SLA) & tide gauge data at Salalah and T/P (trace 157) in Gulf of Aden

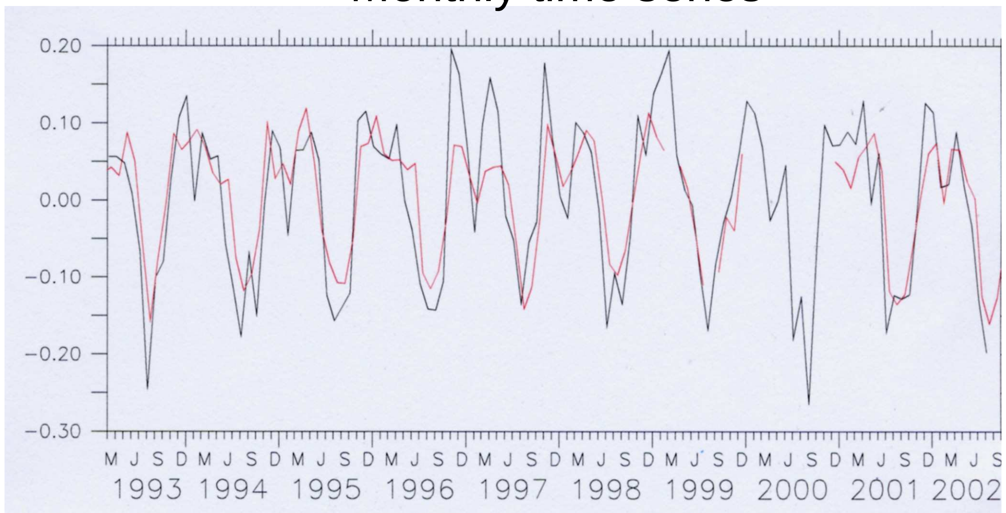
Traces T/P



10 day time series



Monthly time series

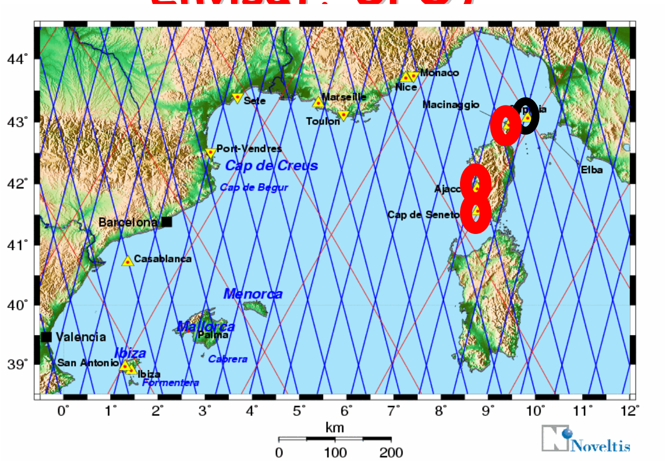


___ Tide Gauge

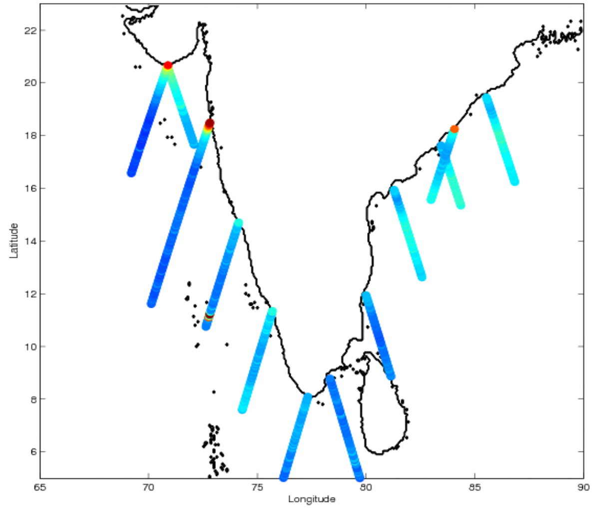
___ Altimetry

Scientific Applications

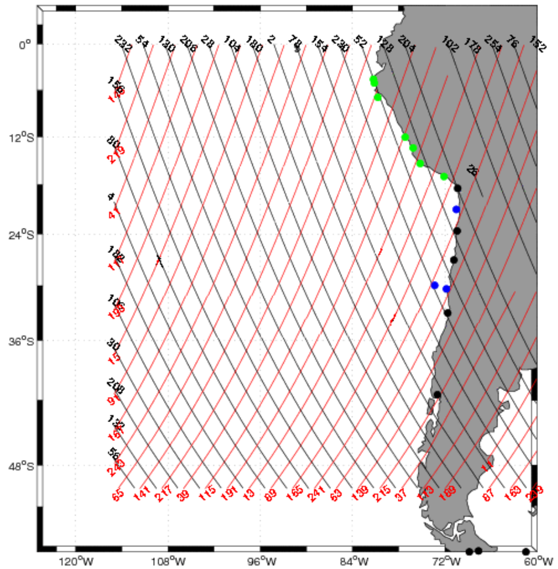
NW Méditterranée (T/P, Jason, Envisat, GFO)



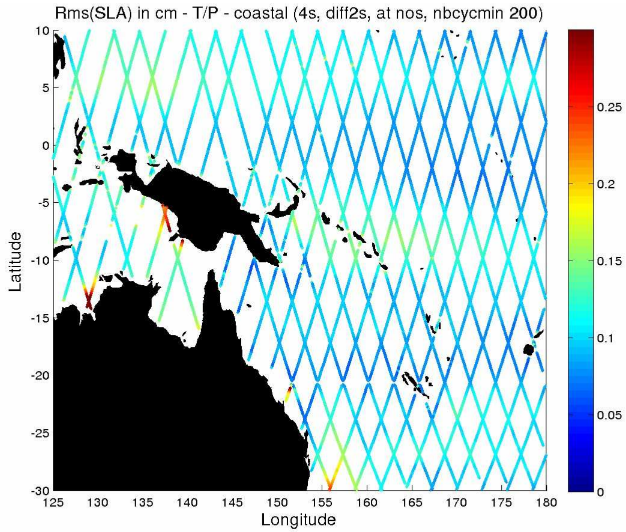
Côtes Indienne (T/P)



Perou-Chili (T/P)

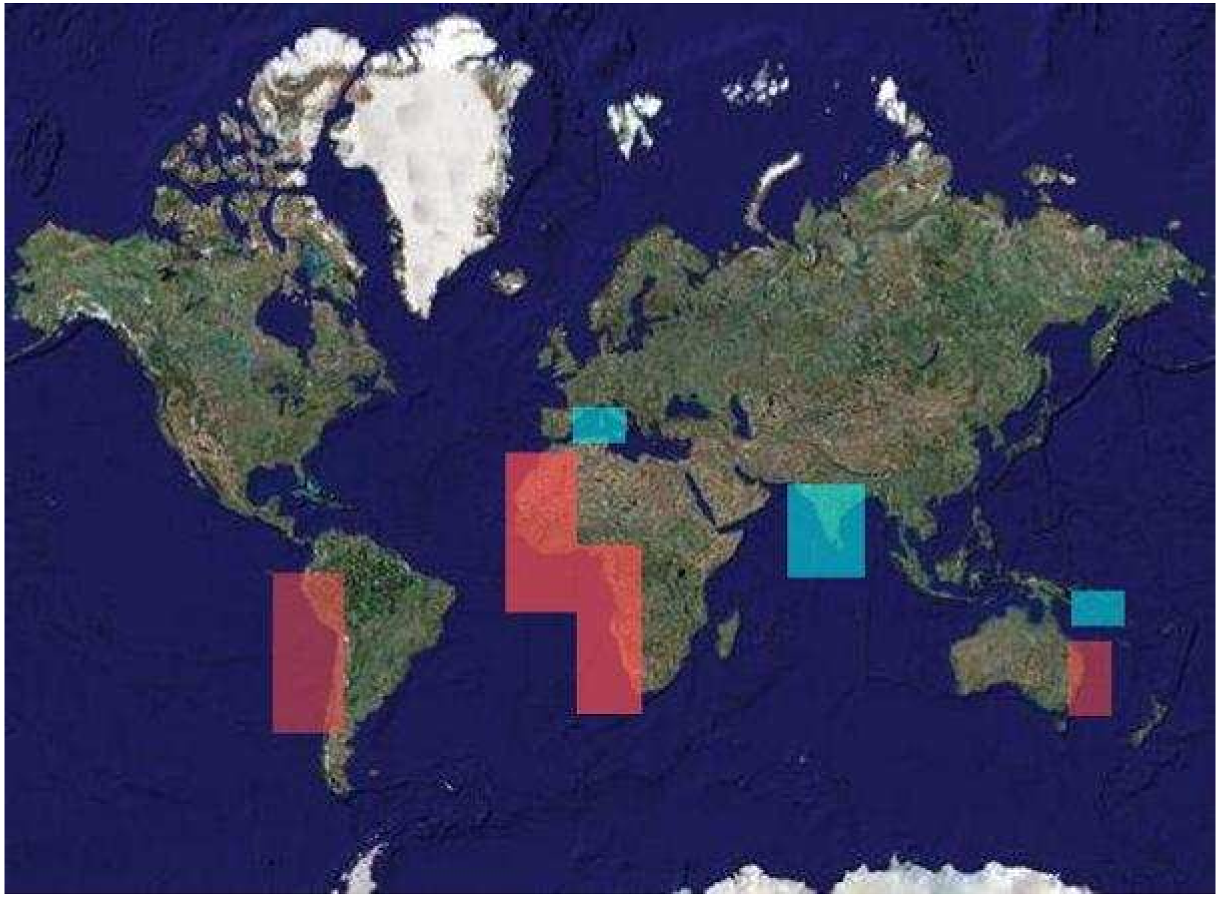


Iles Salomon (T/P)



Available coastal altimetry products :

www.legos.obs-mip.fr/fr/observations/ctoh



2. Coastal Waves

Storm : 9 December 2007

http://www.nantes.maville.com/

Four Lighthouse

Photo Sunday 09 Decembre 2007 C. Bernard LE BRAS

Lesconil, Sunday 17h00 http://www.nantes.maville.com/
Photo Sunday 09 décembre 2007 Dominique Corbel

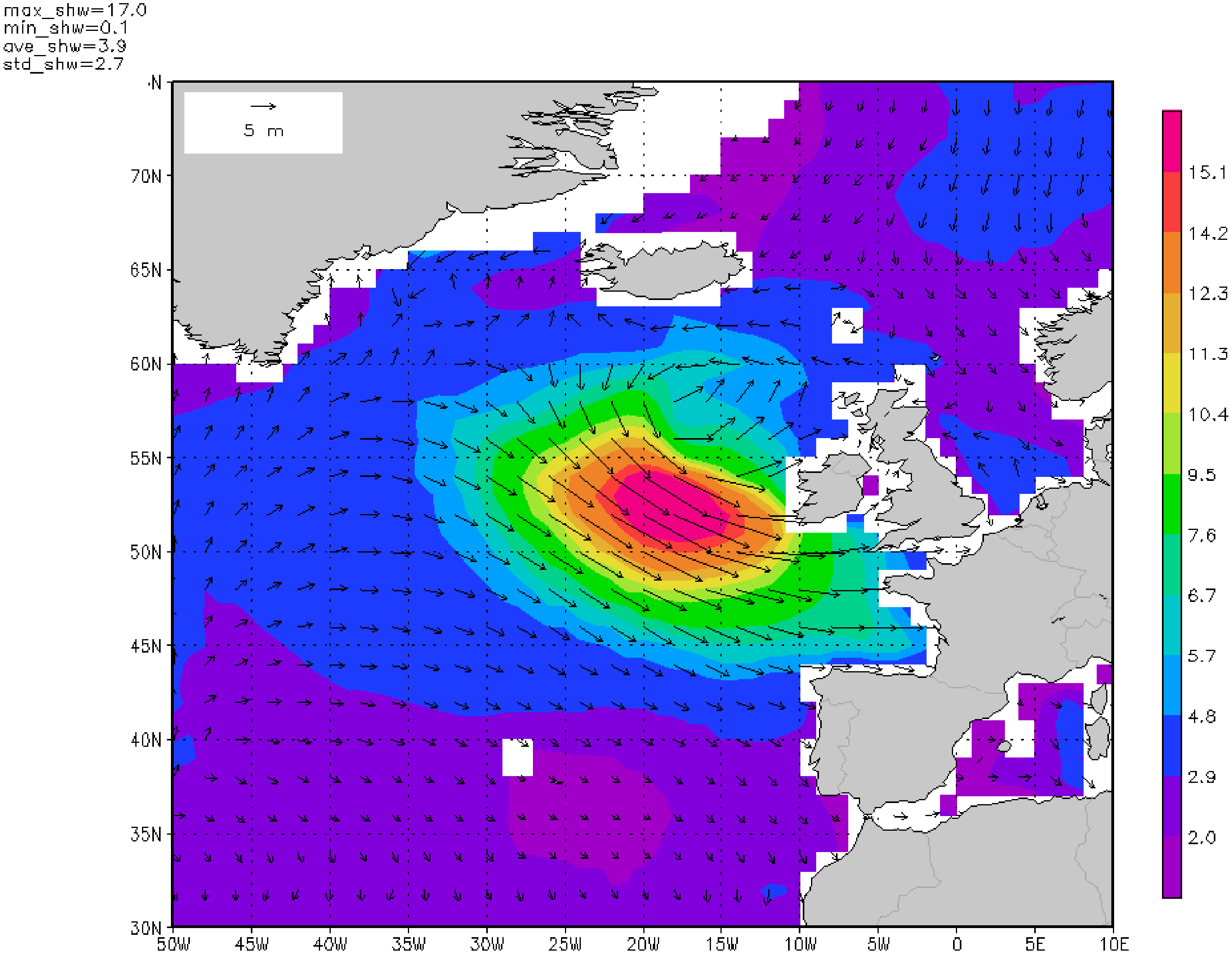
Lesconil, Sunday 17h00 http://www.nantes.maville.com/
Photo Sunday 09 Decembre 2007 C. Dominique Corbel

Storm 9 Decembre 2007

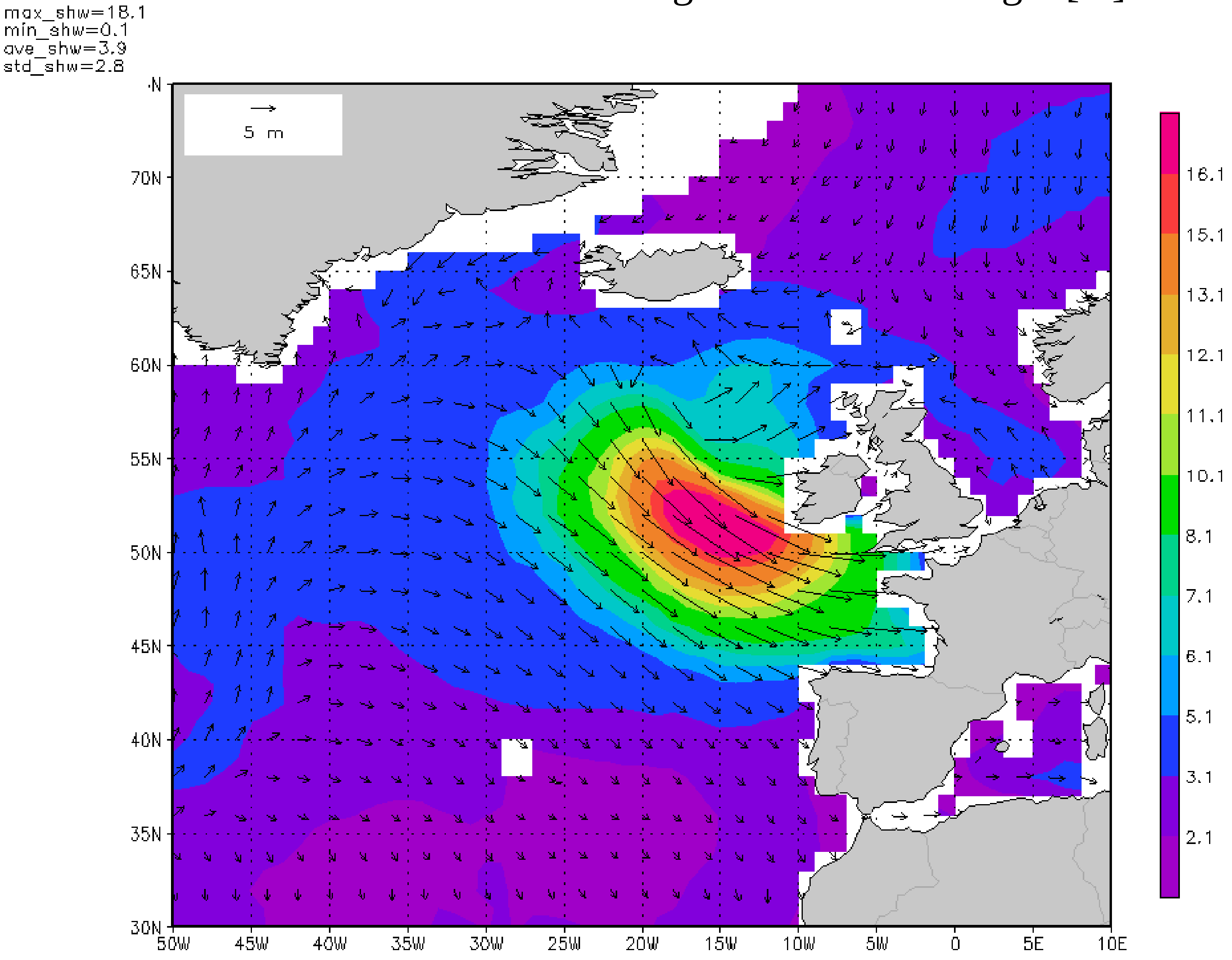
http://www.nantes.maville.com/

Photo Sunday 09 December 2007 C. Christian Patey

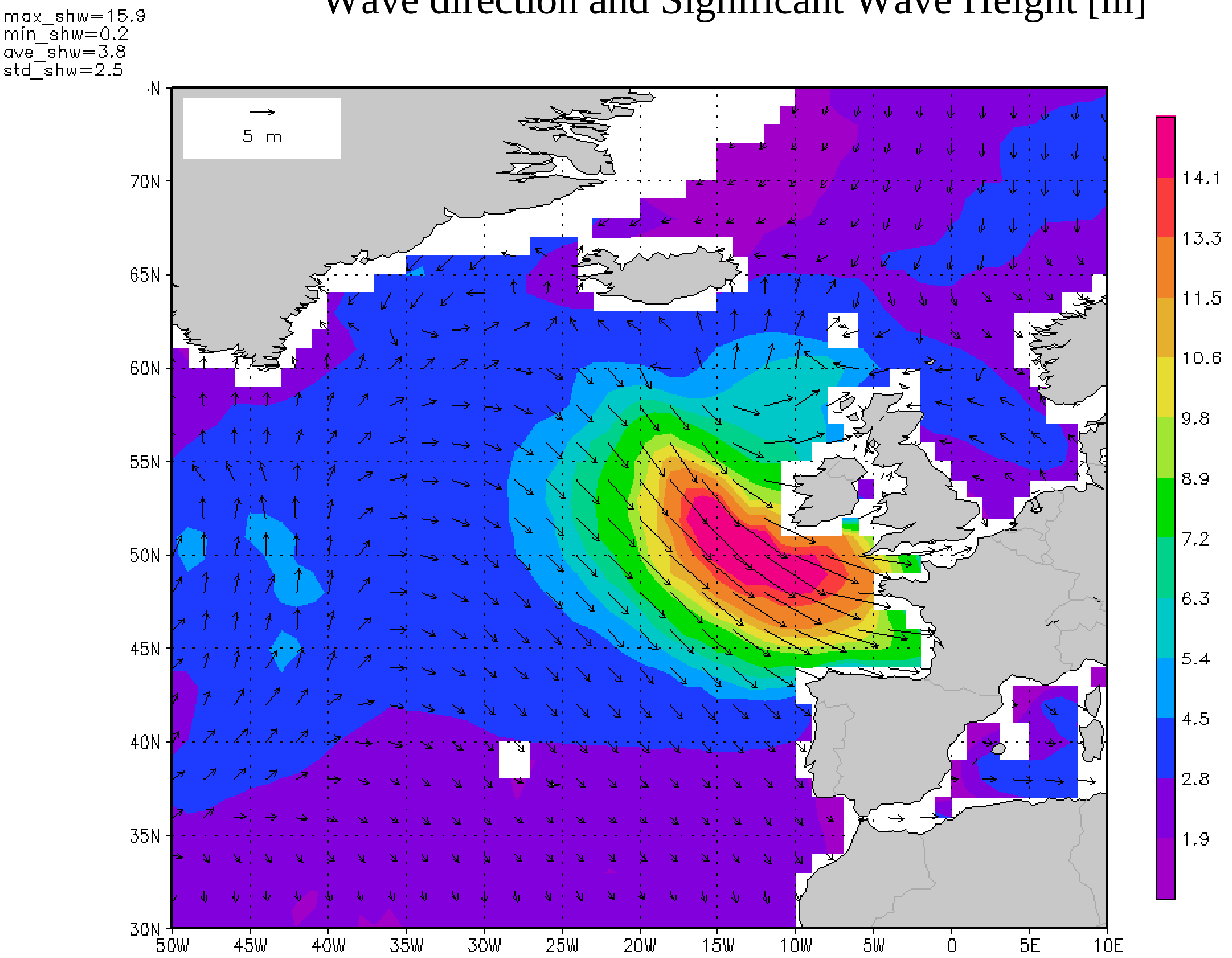
Meteo-France global wave model forecast +72H for 09 Dec 2007 00:00 UTC;
Wave direction and Significant Wave Height [m]



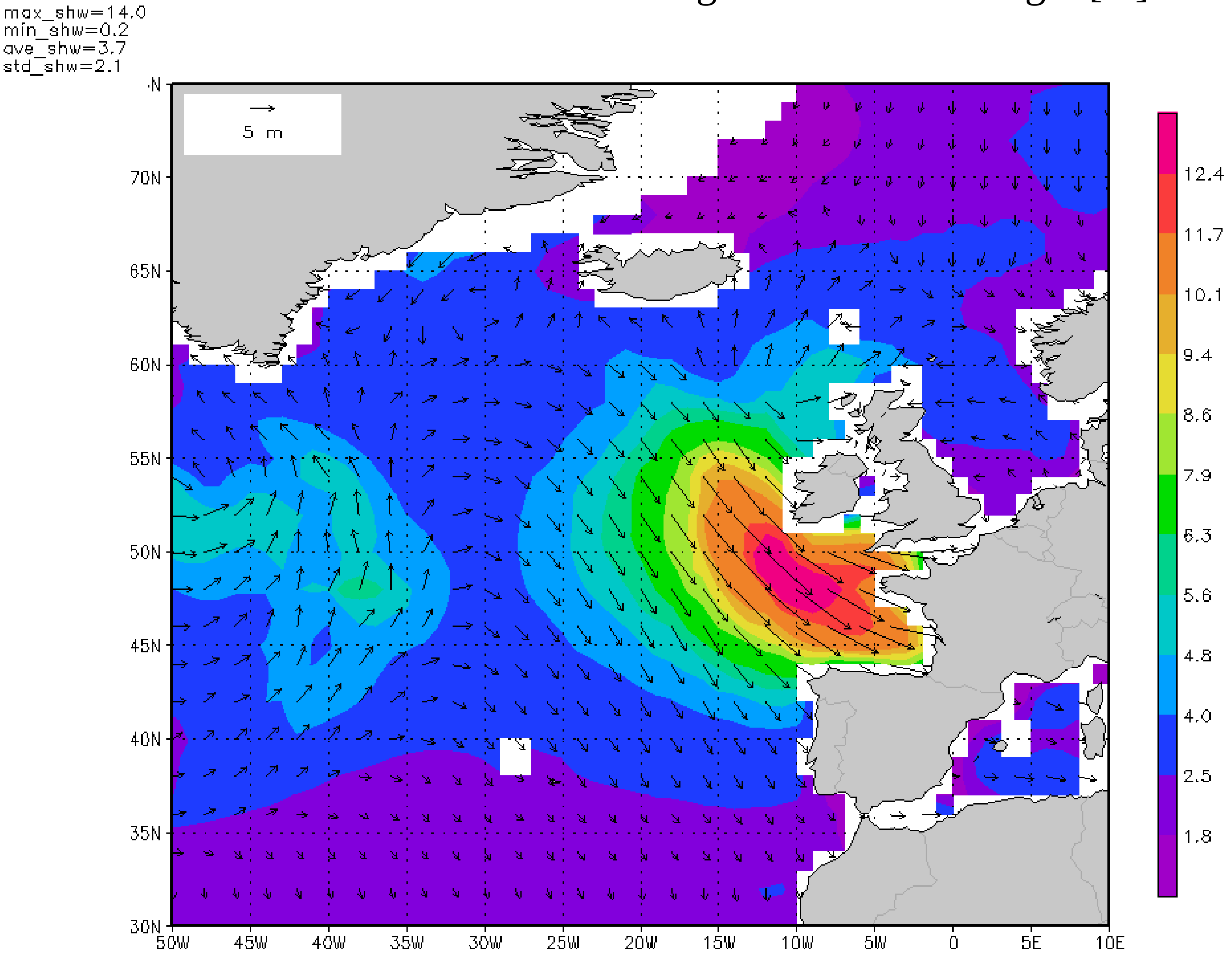
Meteo-France global wave model forecast +78H for 09 Dec 2007 06:00 UTC; Wave direction and Significant Wave Height [m]



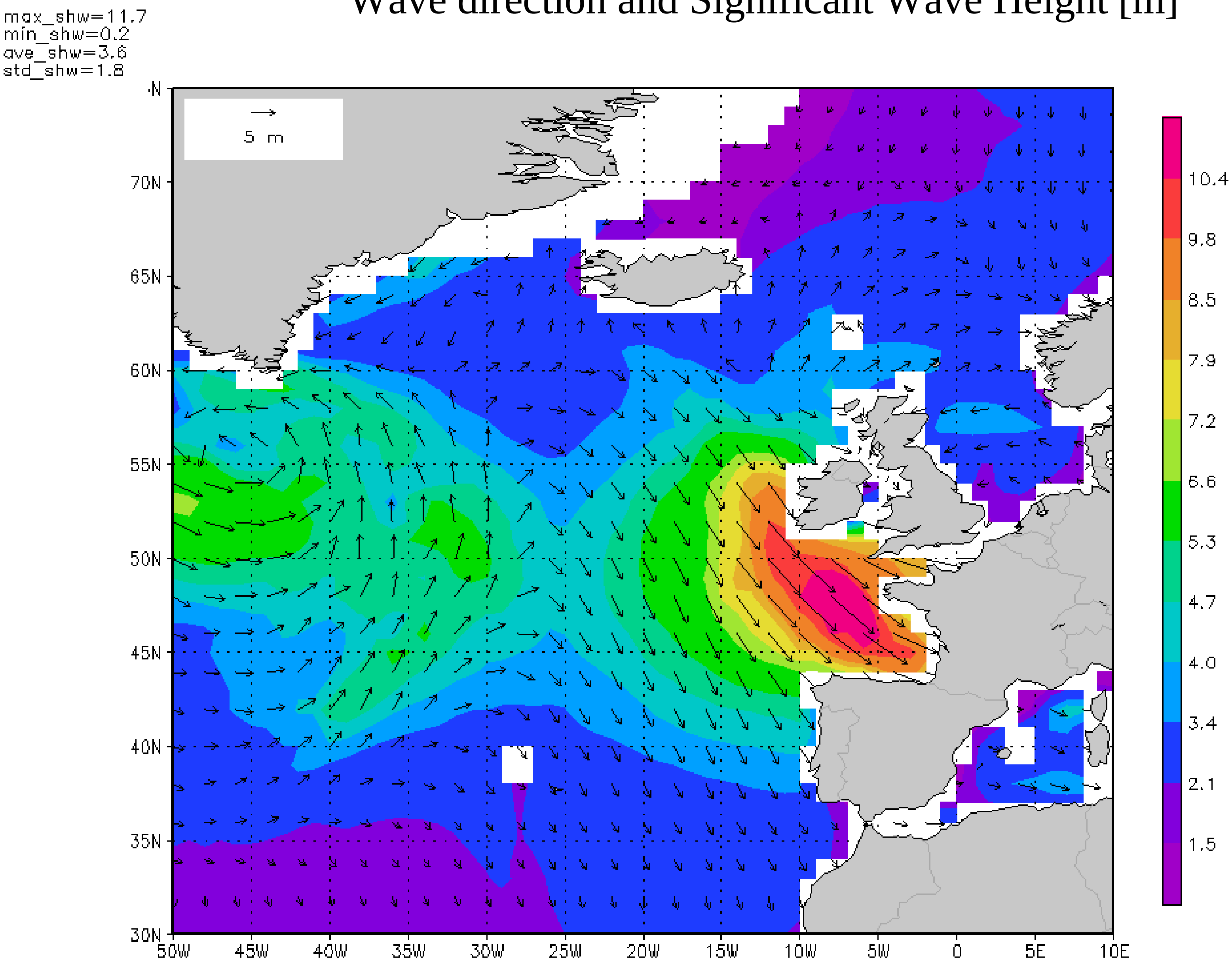
Meteo-France global wave model forecast +84H for 09 Dec 2007 12:00 UTC;
Wave direction and Significant Wave Height [m]



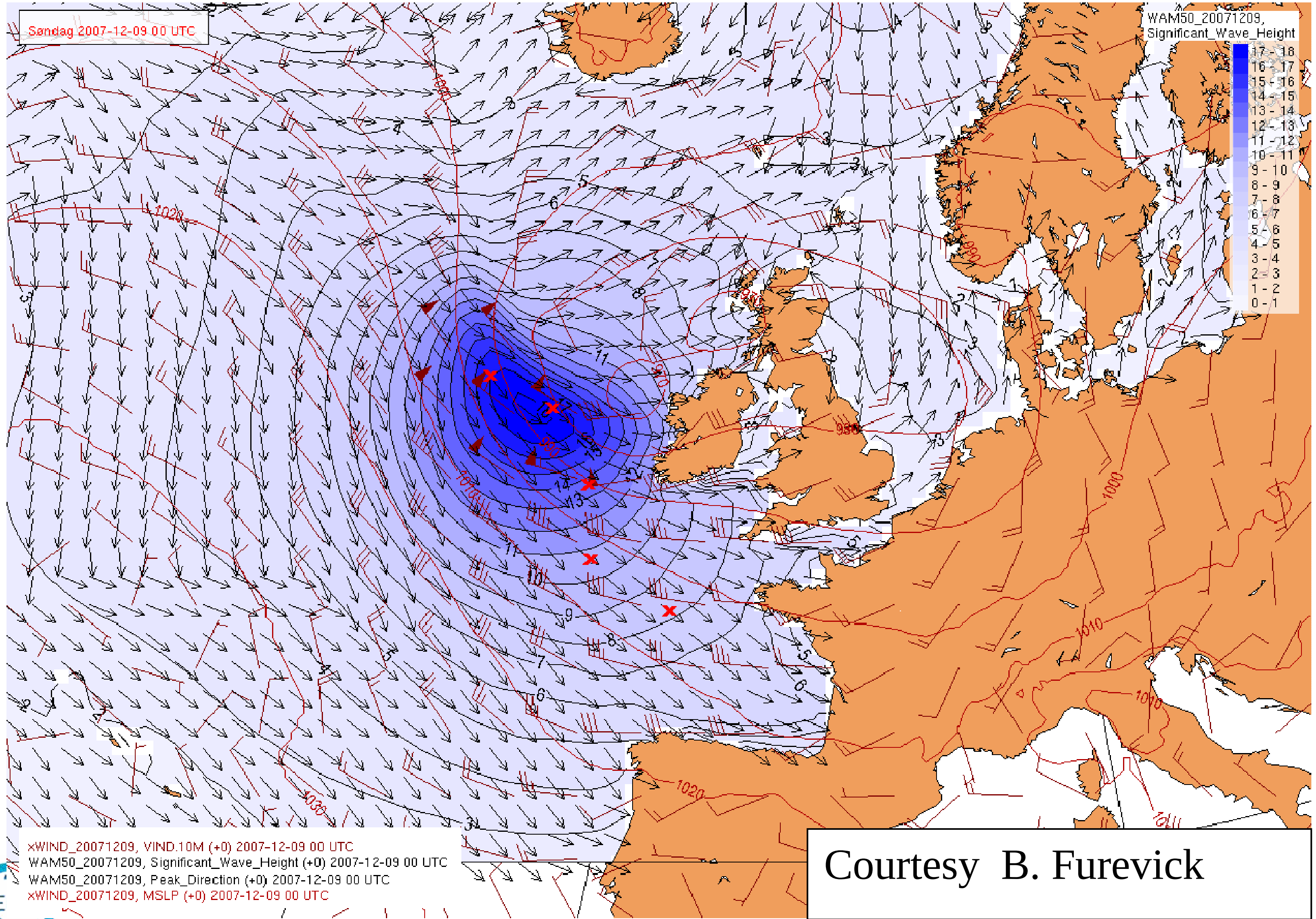
Meteo-France global wave model forecast +90H for 09 Dec 2007 18:00 UTC;
Wave direction and Significant Wave Height [m]



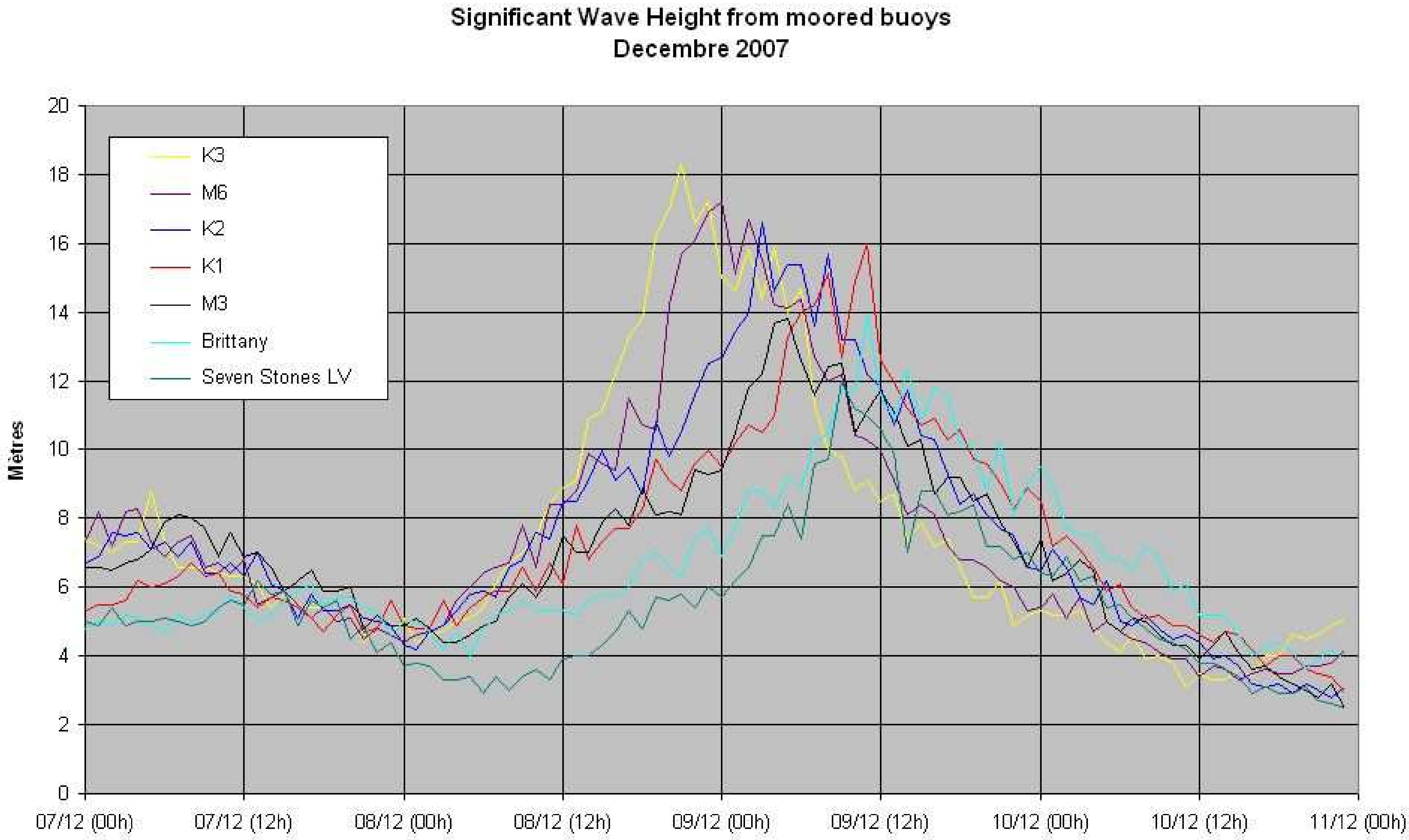
Meteo-France global wave model forecast +96H for 10 Dec 2007 00:00 UTC;
Wave direction and Significant Wave Height [m]



Big waves west of Ireland, December 9, 2007 from WAM/NORWAY With location of buoys K3,M6,K2,K1,Brittany, From West to East

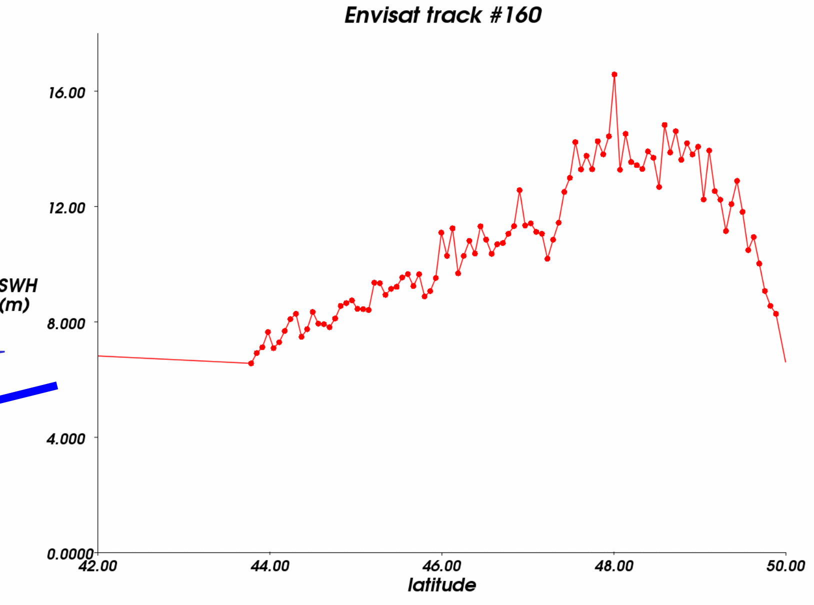


Courtesy B. Furevick

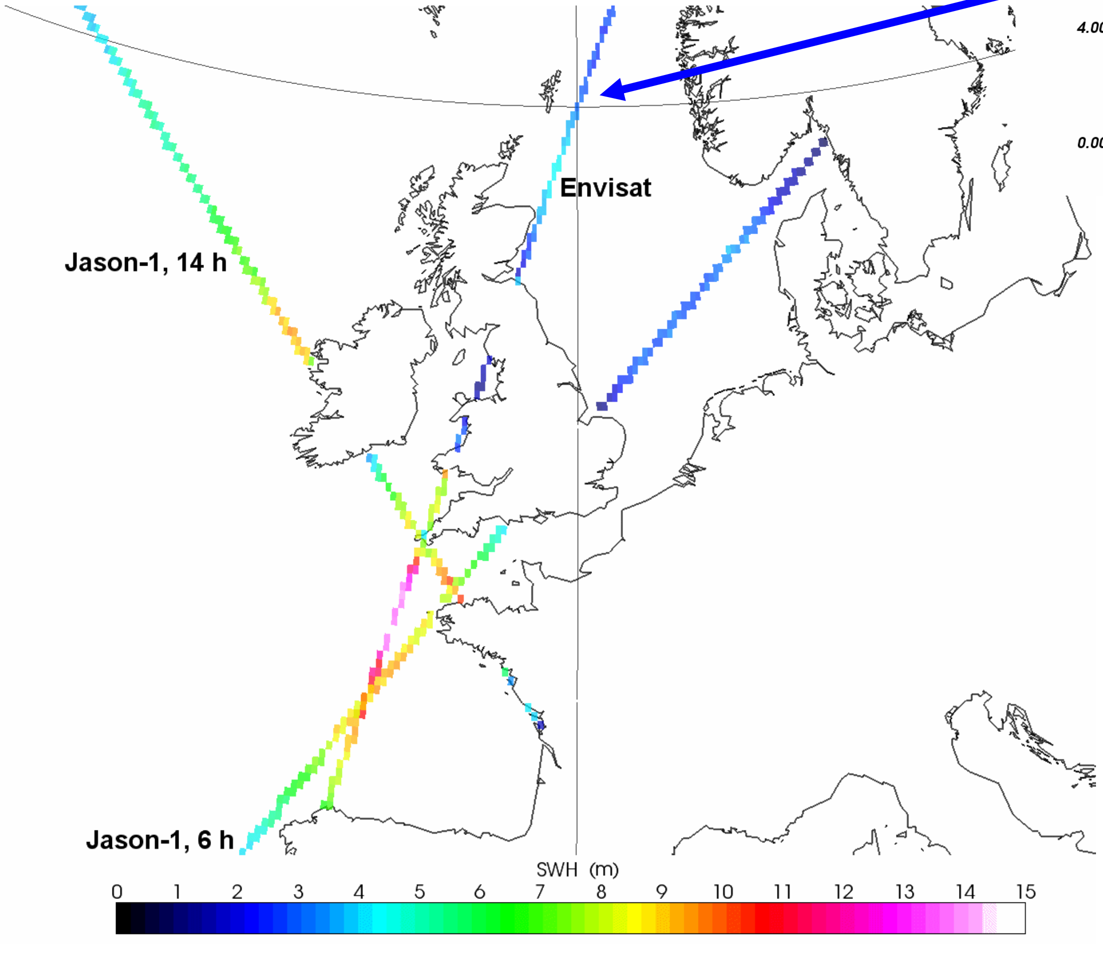


Significant Wave Height from moored buoys
Decembre 2007
Mètres
20
18
16
14
12
10
8
6
4
2
0
K3
M6
K2
K1
M3
Brittany
Seven Stones LV
07/12 (00h)
07/12 (12h)
08/12 (00h)
08/12 (12h)
09/12 (00h)
09/12 (12h)
10/12 (00h)
10/12 (12h)
11/12 (00h)

Altimetric observations (H1/3)

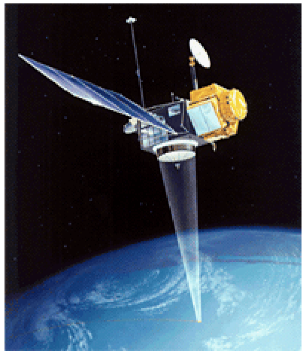


09/12 vers 12hTU



http://www.jason.oceanobs

Credits CNES/CLS



Altimetry for Coastal wave applications

- Altimetric SWH and wind speed available in near real time (~3h delay) and over large alongtrack areas
- Better spatial coverage than buoys, worse temporal coverage
- Altimetric wave heights can be assimilated into operational wave models

Biggest observed Significant Wave Height (H1/3)

- Halloween Storm (1991): 17.3 m
- Storm of the century (1993) :16.9m
- Luis (1995):17.5 m
- Ivan (2004) :17.9 m (Hmax 27.7m)
- Katrina (2005): 16.9 m
- RSS Discovery vessel (2006): 18.5m (Hmax of 29.1 m)
- 09-12-2007 18.3m buoy K3
- 09-03-2008 17.8 m buoy

LEGOS

2 juin 2003, Pays Basque

Page 40 Daily Mail, Tuesday, September 16, 2003

Daily Mail, Tuesday, September 16, 2003 Page 41

The world's biggest waves (no, not Australia, just across the Channel!)

by **Michael Hanlon**

THEY called it Le Belhara — Basque for 'The Gigantic One' — a series of three gigantic waves which appeared out of nowhere, three miles off the Atlantic coast on the French-Spanish border. Such monsters are seldom found, even at the world's most extreme surfing spots off the coasts of Mexico and Hawaii, where the Pacific allows true giants to form.

But in the Bay of Biscay, breaking rollers off St-Jean-de-Luz normally average 8-12ft. This time they were nearly ten times that.

On June 2, locals noticed a larger-than-normal swell building up about two miles offshore. The waves had been getting larger all day, drawing surfers to the beach, and now the offshore swell was so huge it was visible from the bars that line the spectacular coastline between Hossegor, Biarritz and St Jean. Yet the weather was clear and there had not been the type of tropical storm in the Atlantic that could generate such water mountains.

Soon, local surfers led by professional Fred Basse, seen in these extraordinary pictures by photographer Eric Chauche, were scampering out to tackle the incoming giants. To catch the wave, Fred and his fellow surfers had to hitch a ride on jetskis — using arm-power alone, they could not move fast enough.

It is impossible to overstate how dramatic — or dangerous — a wave 70-100ft high can be. It contains enough kinetic energy to power a small town. Should one break on your body, you would be subjected to a force of 120 tons — similar to being run over by a tank. And should a surfer get it wrong, he would be crushed and hauled along the seabed for four minutes. But if he gets it right, it is a once-in-a-lifetime thrill.

When the surfer reaches a high point in the face of the wave, he will pull away from the jetski — which continues safely over the top. Only the very best can hope to surf a wave as big as a ten-storey office block and live. The trick is to stay ahead of the surf, and avoid being 'dumped' as the crest topples over. So how was this extraordinary series of waves created? The seabed on this part of the French coast is is fairly shallow — but offshore from Hossegor, a surfing town 20 miles north of Biarritz, is an underwater channel, two miles deep, leading from the Atlantic floor. This acts as a funnel, forcing the water over huge sand dunes on the seabed, where the waves build and break.

Until recently, 70ft waves were thought impossible. It was believed that only an under-sea earthquake or volcanic eruption could create a truly giant breaker — a tsunami.

But the cause here was something that has been recognised only recently: the rogue wave. Yet while rogue waves may be a mariner's nightmare, they are a dream come true to surfers. But only for the most brave.

Pictures: ERIC CHAUCHE/DIGITAGENT

What a high: Professional surfer Fred Basse displays his skill — and his bravery

Thrill of the chase: The massive waves can be as big as a ten-storey office block

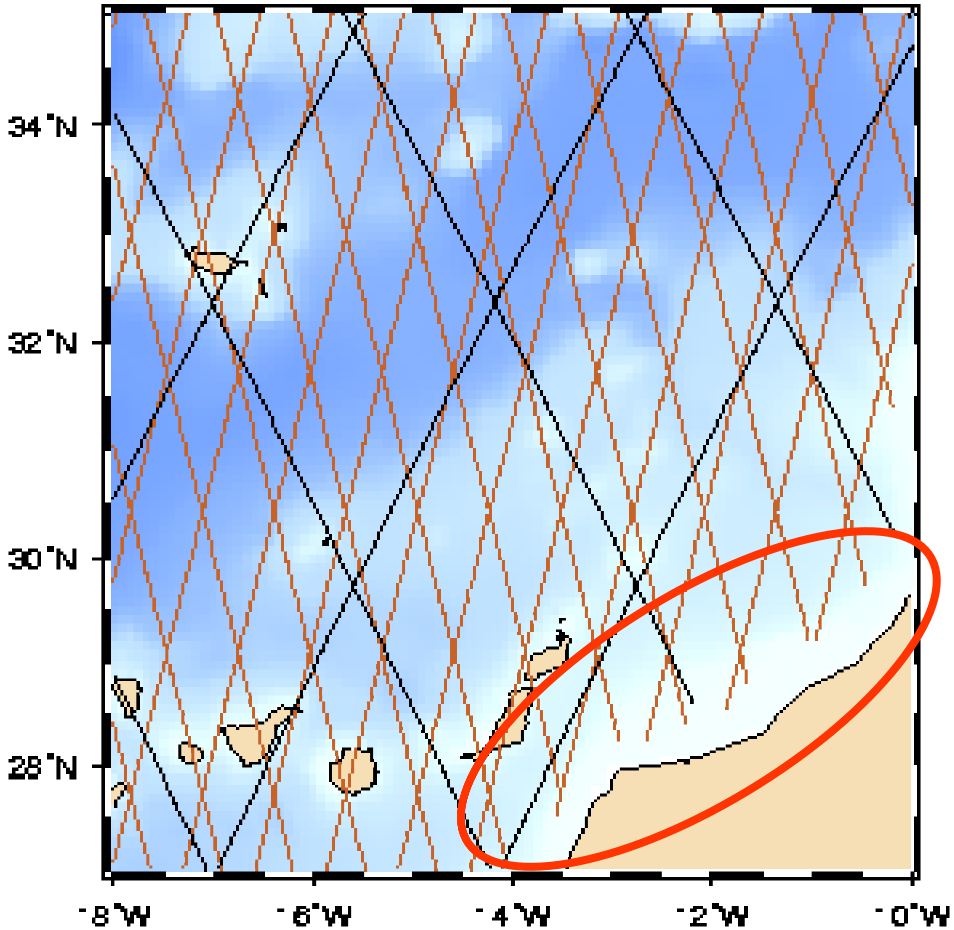
3. Coastal Currents

Observing coastal currents

Missing data from 25-50 km from coast means most coastal currents are unobserved

Big problem for global and regional data assimilation projects – unconstrained coastal regions have largest model errors

Improved CTOH / LEGOS data coverage up to 15 km – but can do more!



Solution 1) Combining altimetry and tide gauges

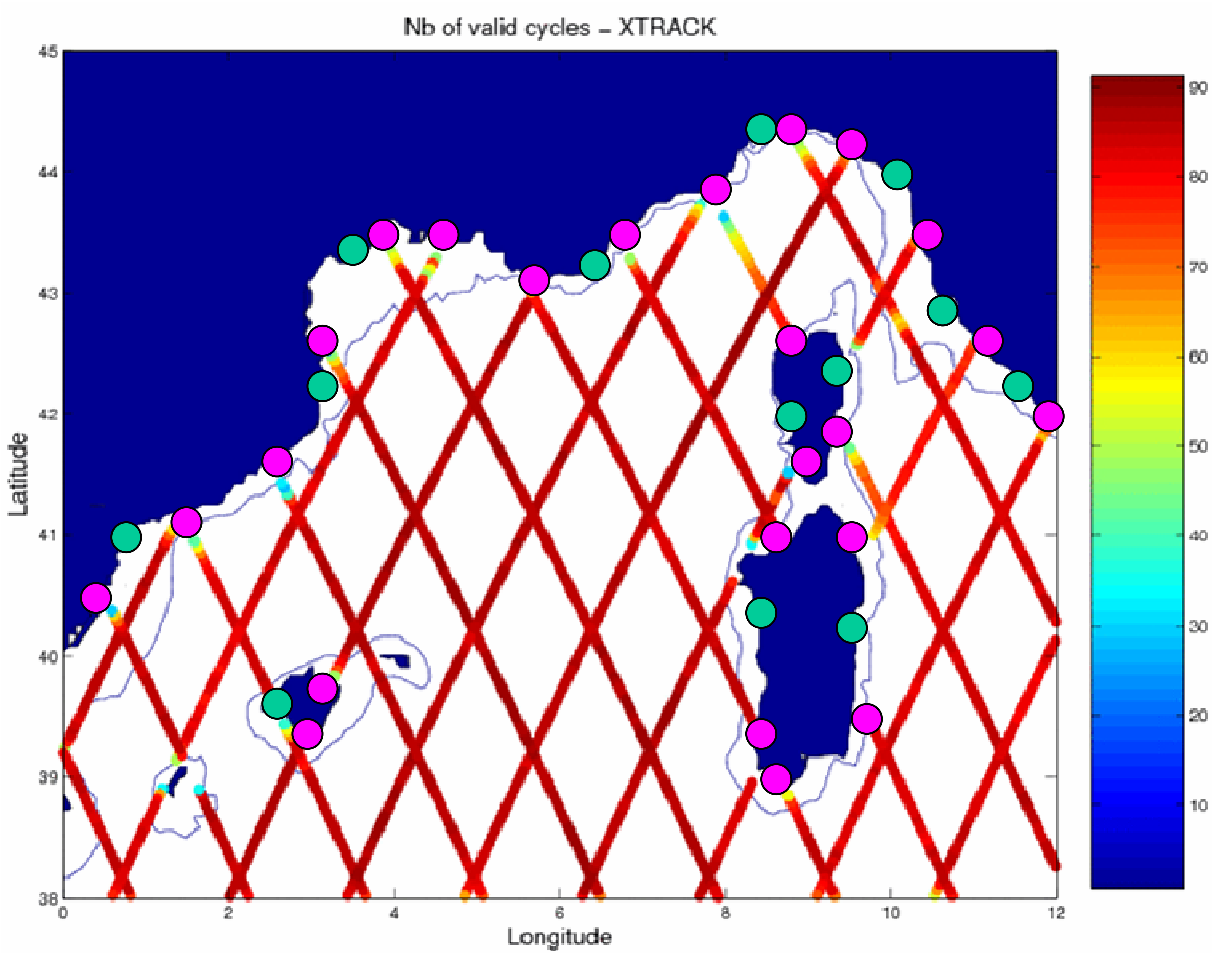
Reconstruct coastal sea level : then calculate coastal currents

- Observed tide gauge SL time series

- Interpolated « pseudo » SL time series

Strub et al., California Current

Griffin et al., Australian coast.



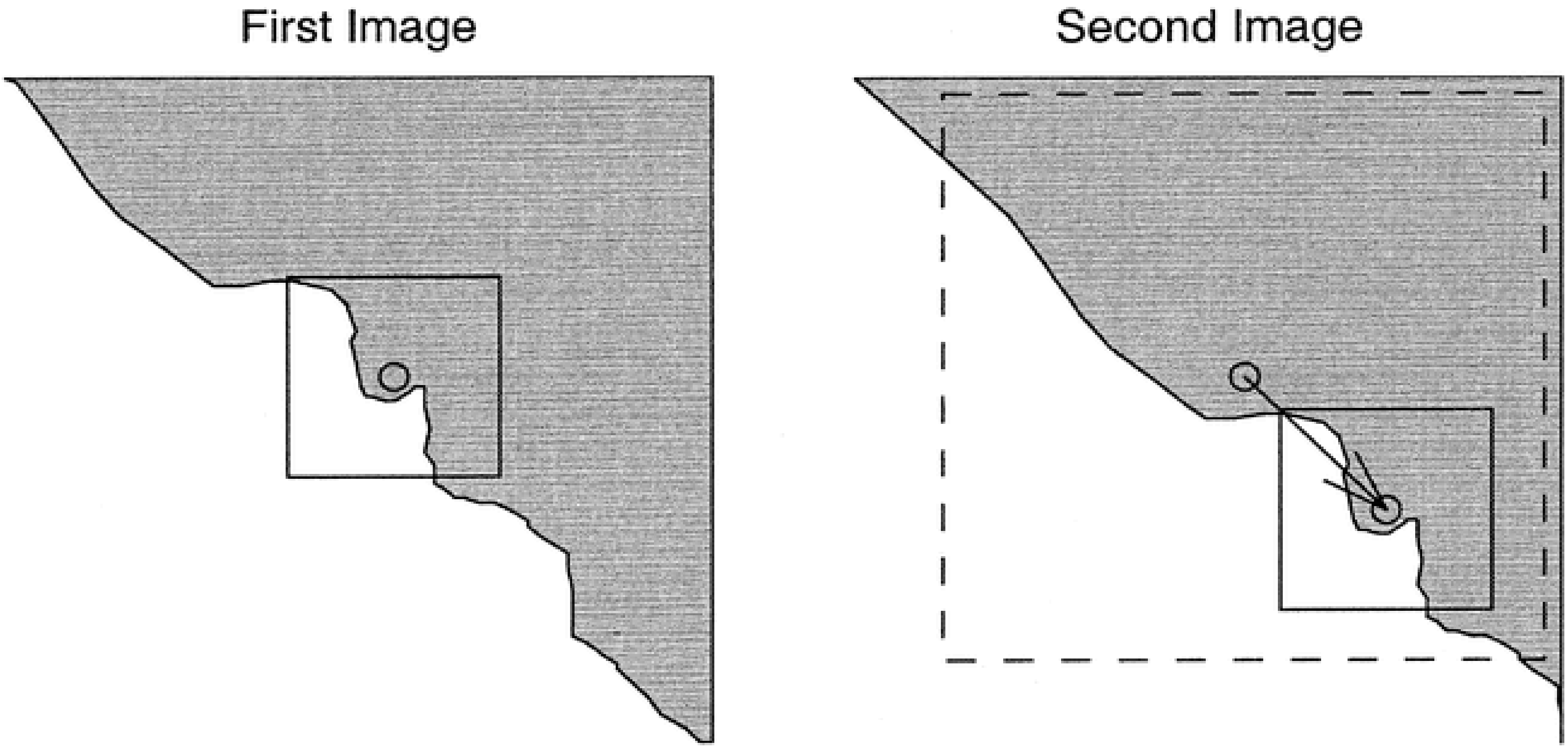
Solution 2) Combining satellite SST and altimetry : High resolution coastal currents

- Sequential thermal infrared images are used to compute surface currents with the Maximum Cross Correlation (MCC) method (e.g., Emery et al.)

- First filtered for cloud contamination

- Successive images are used to retrieve vector currents of feature movements with a 1 km spatial resolution, that are then composited over 3 and 10-day periods

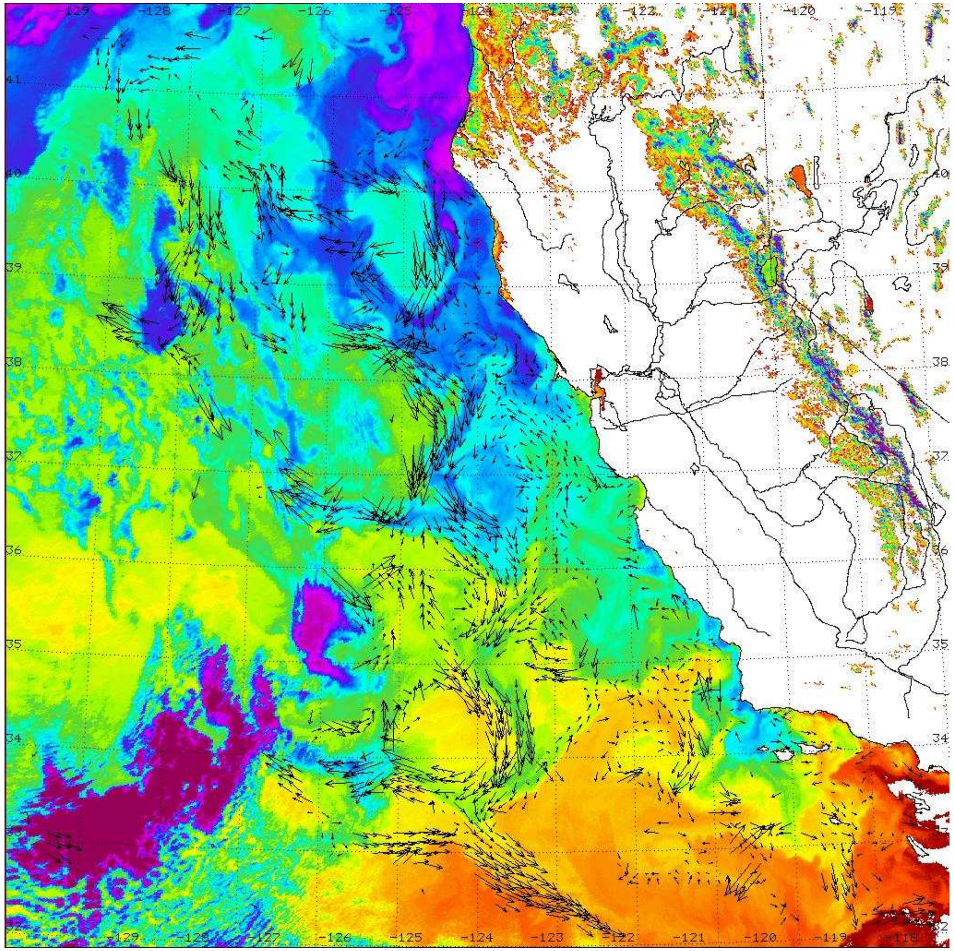
Maximum Cross Correlation



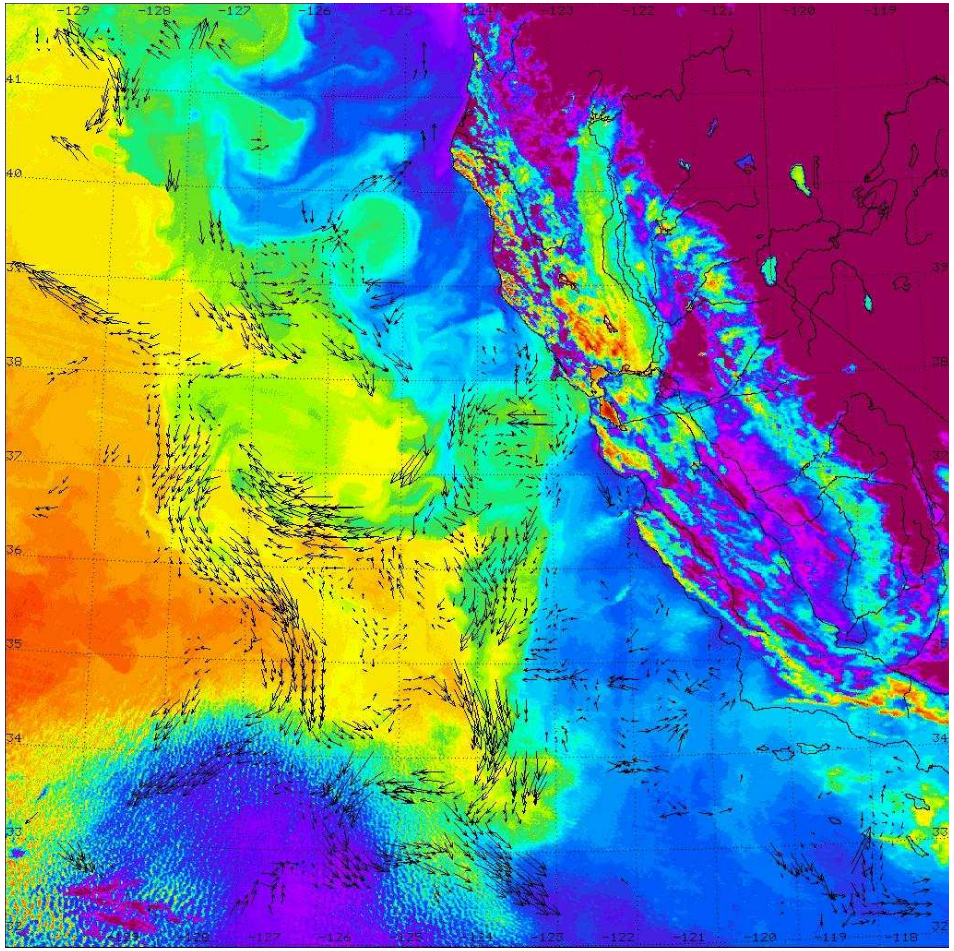
LEGOS : We use the MEDICIS algorithm (Chanie, CNES, 2001)

Fine-scale MCC currents derived from successive SST images

30 Sep – 10 Oct 1999



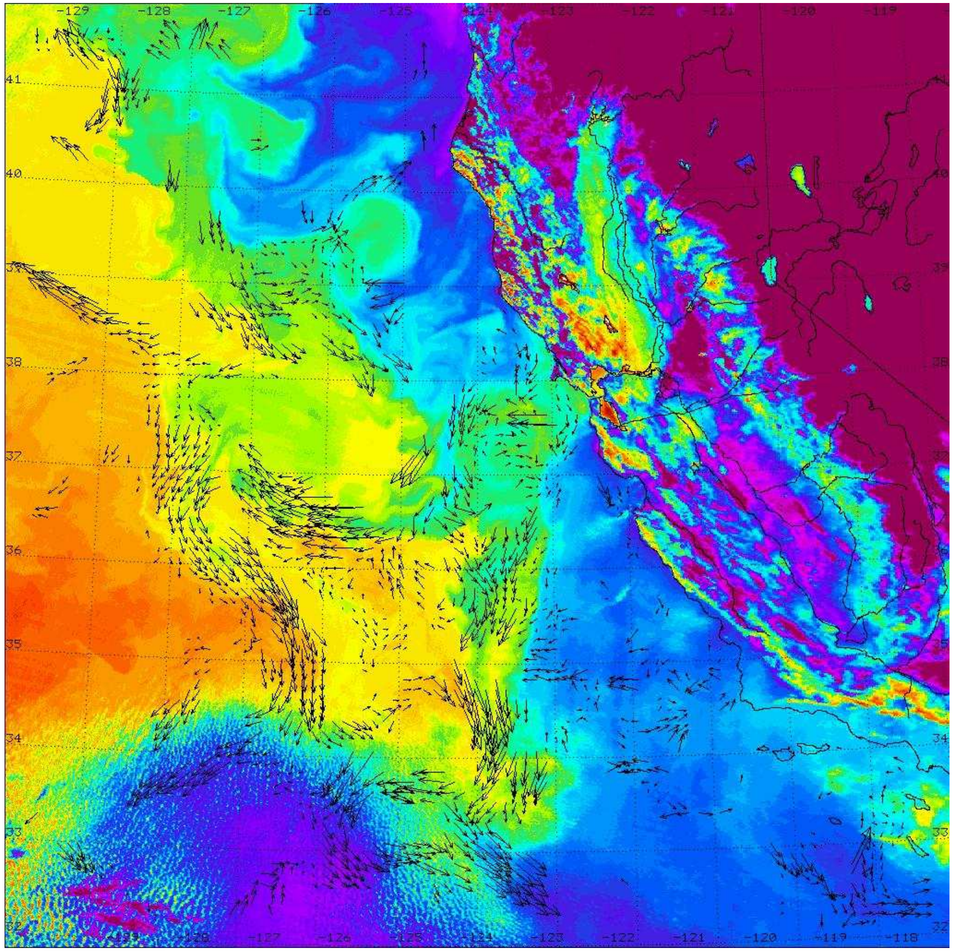
10 Oct – 20 Oct 1999



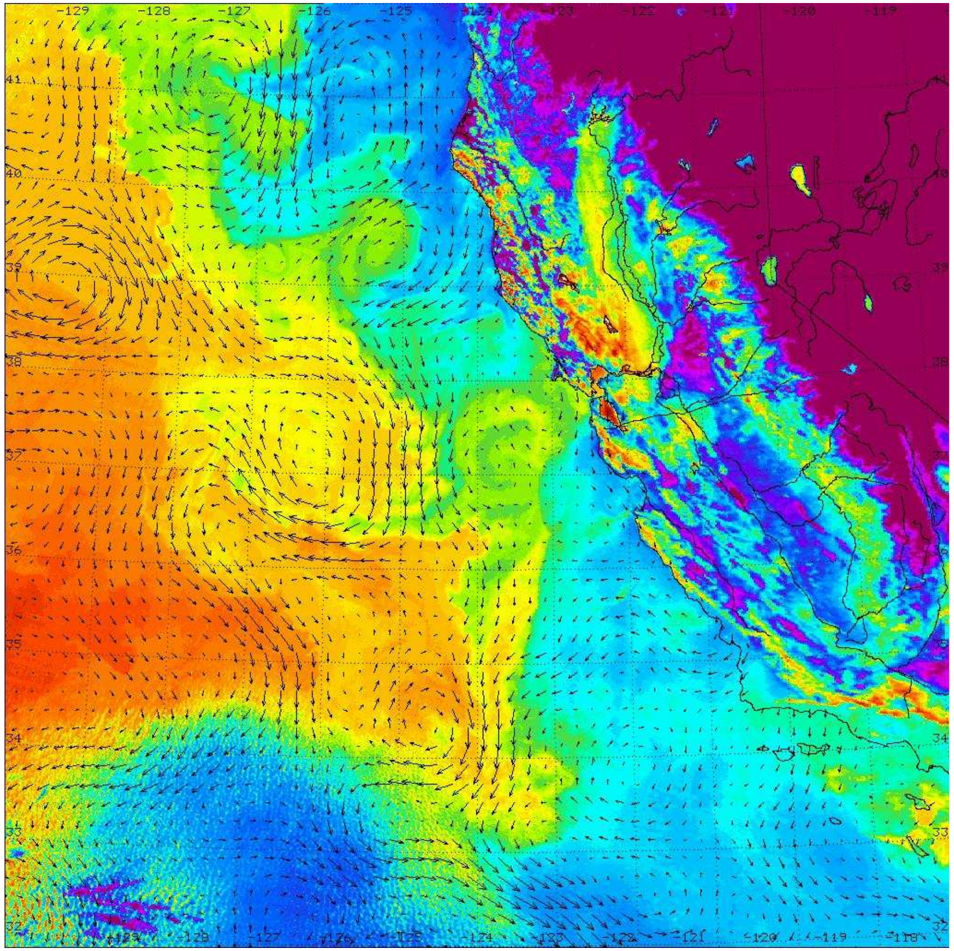
Eg : Californian coast between San Francisco and Los Angeles

Optimal interpolation of altimetric geostrophic currents and MCC (SST) currents

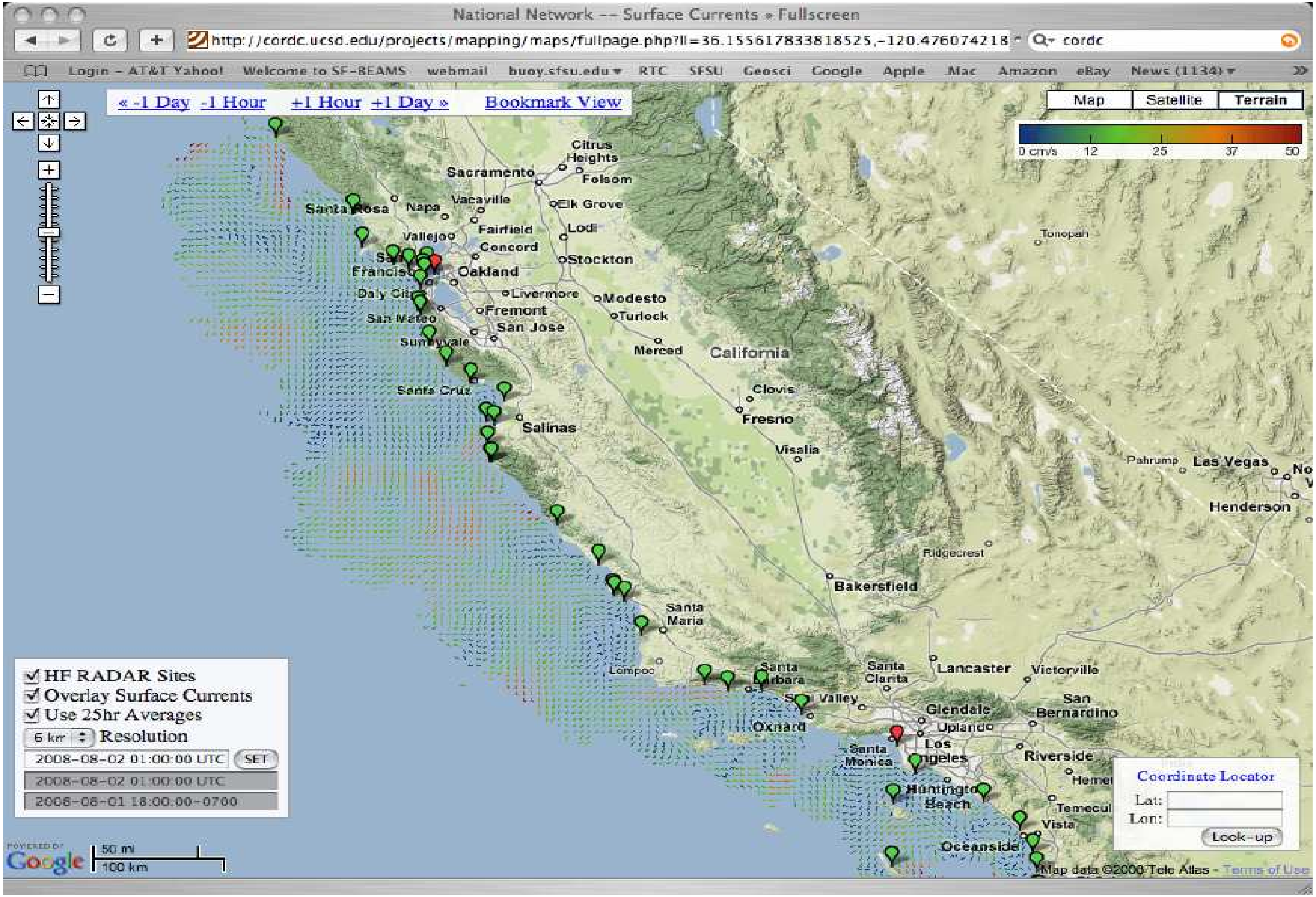
SST only : 10 Oct – 20 Oct 1999



OI (SST+altimetry) : 15 Oct 1999



Solution 3) Combining altimetry and HF radar



Solution 4) Calculating filament positions from mesoscale altimetry : FSLE

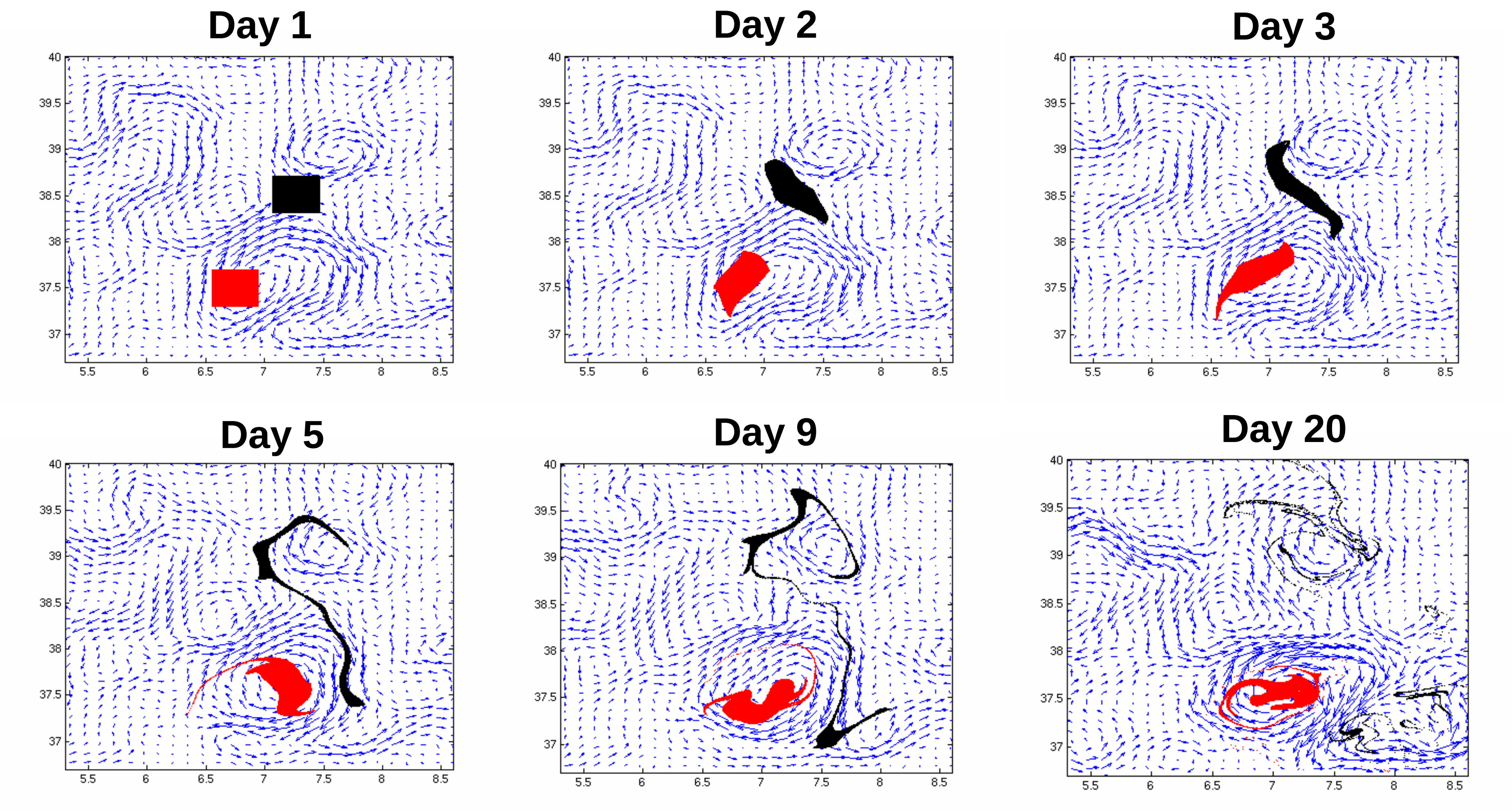
Can use the horizontal advection field from gridded altimetry to derive the lagrangian flow evolution

Can derive the dispersion characteristics of the flow, and eddy diffusion co-efficients (eg Sallée et al., 2008)

Can also derive **Finite Size Lyapunov Elements (FSLE)** – positions regions of strong flow convergence, divergence, and mixing

- Called « transport barriers »

SMALL-SCALE STRUCTURES FROM MESOSCALE EDDIES: CHAOTIC ADVECTION



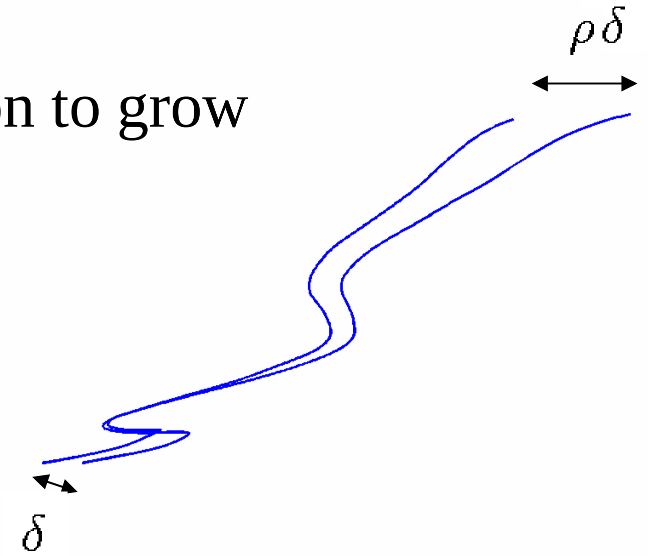
Finite Size Lyapunov Exponents (FSLEs)

δ =Initial separation

ρ =amplification factor

τ = time needed for the perturbation to grow

$$\lambda = \frac{\ln \rho}{\tau(\delta)}$$



Aurell et al., Phys. Rev. Lett. ***77****, 1262 (1996)*
Boffetta et al., J. of Phys. A, ***30****, 1 (1997) chao-dyn/9904049*

EULERIAN FIELD

Simple, instantaneous description

Mesoscale structures only

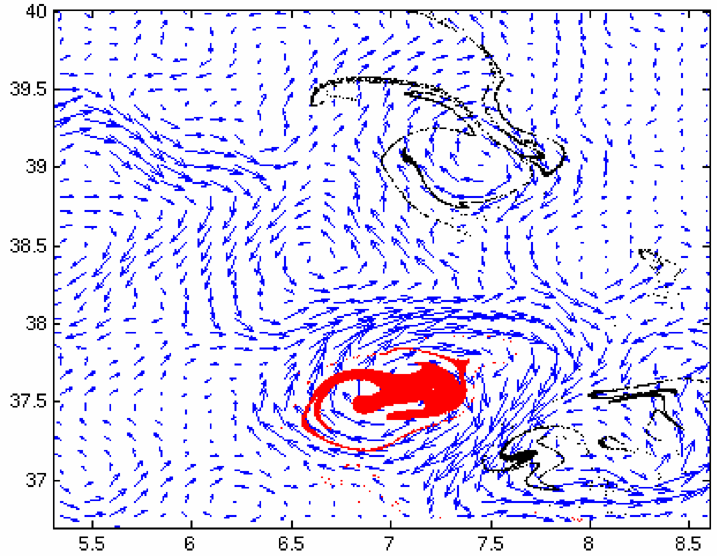
Approximate tracer distribution

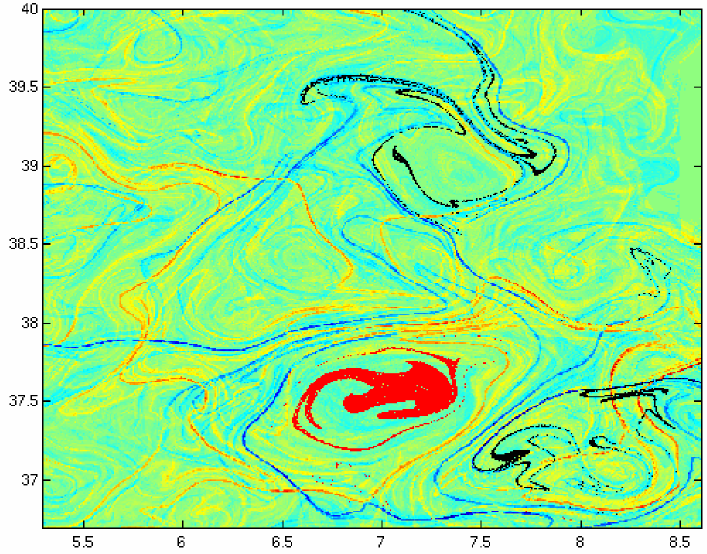
FSLE MANIFOLDS

Time-integrated tangle of structures

Precise localization of transport barriers

Mesoscale and submesoscale structures



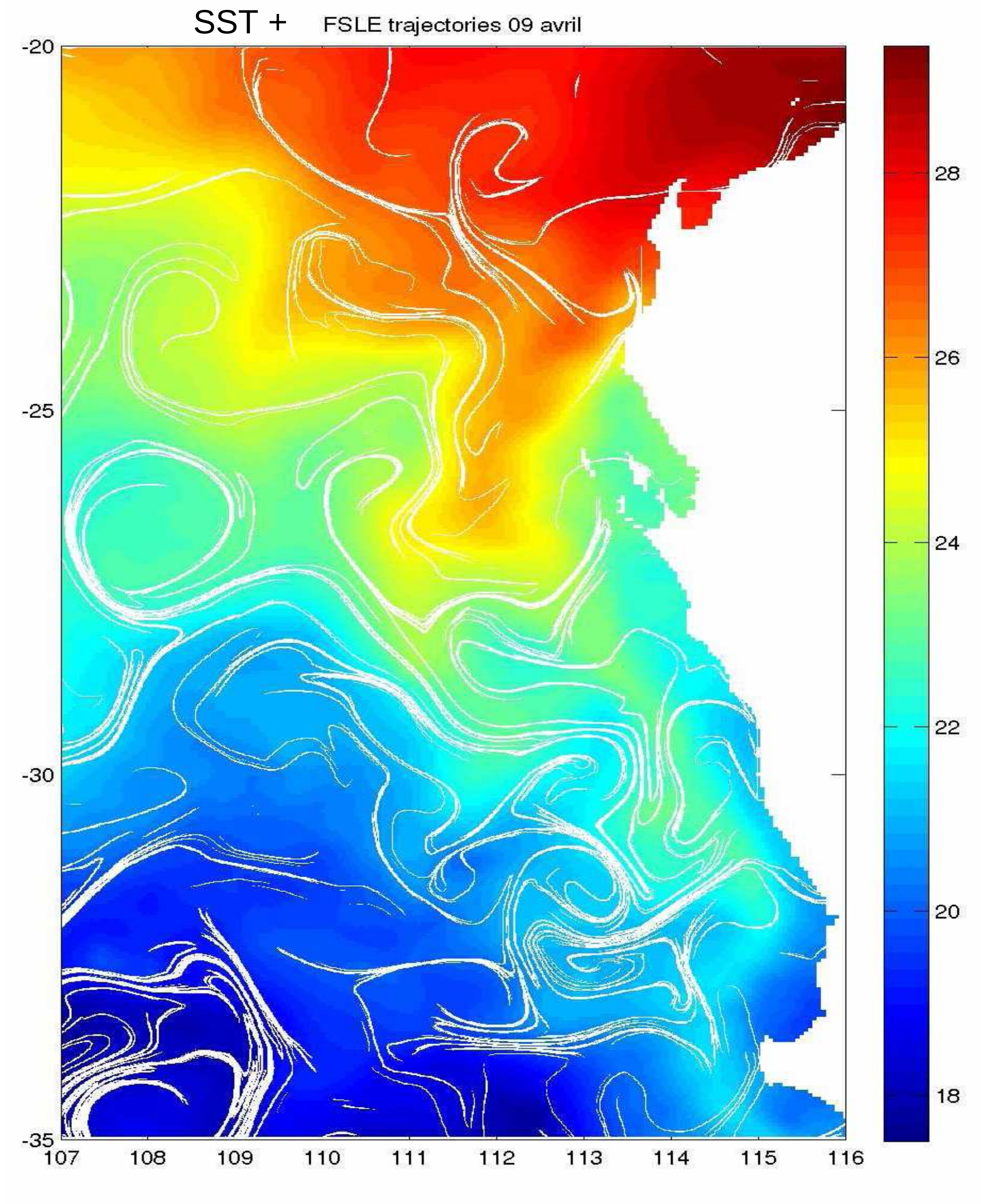


FSLE transport barriers

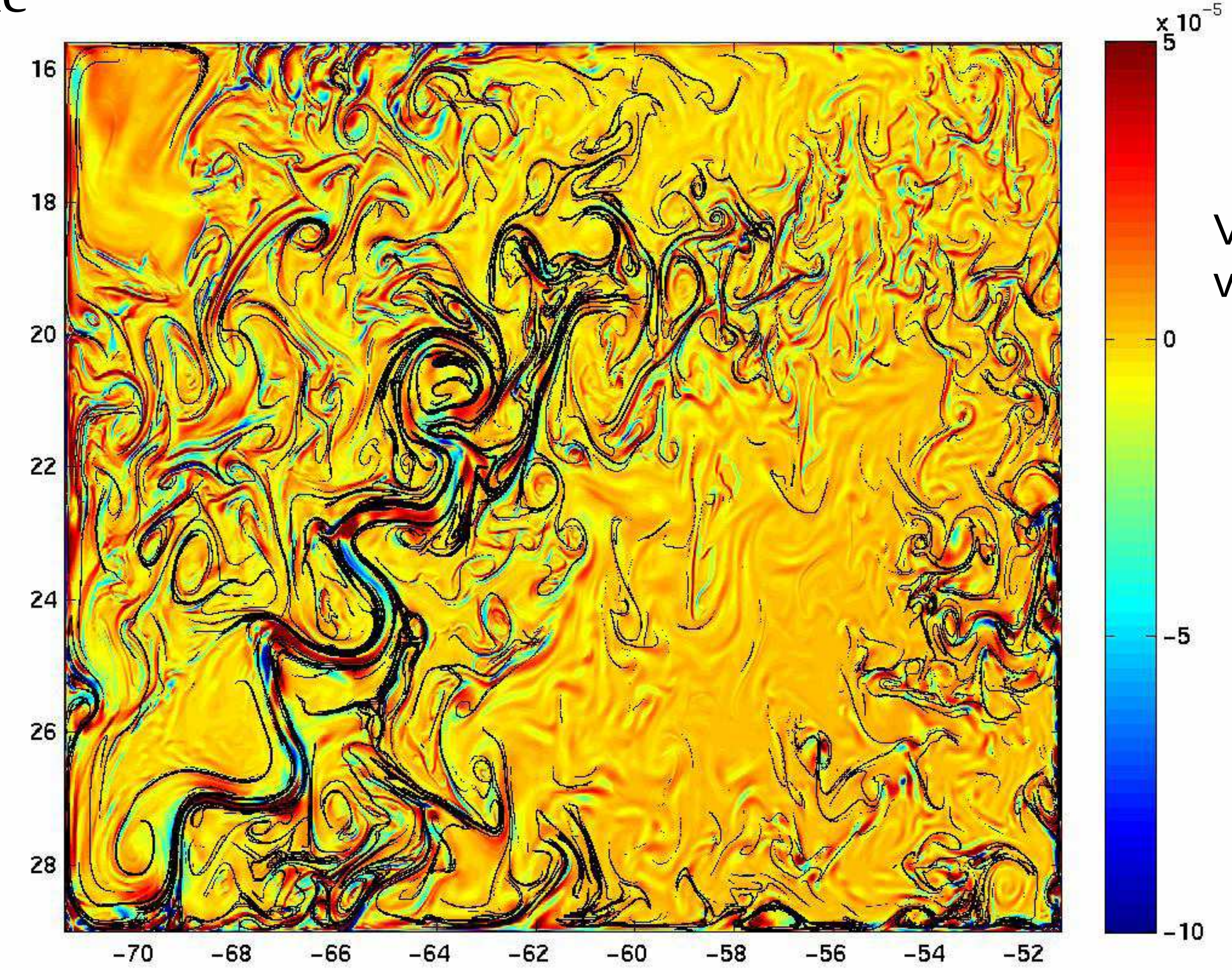
These FSLEs calculated from gridded 1/3° AVISO altimetric geostrophic velocities

good spatial correlation with surface tracer fields,

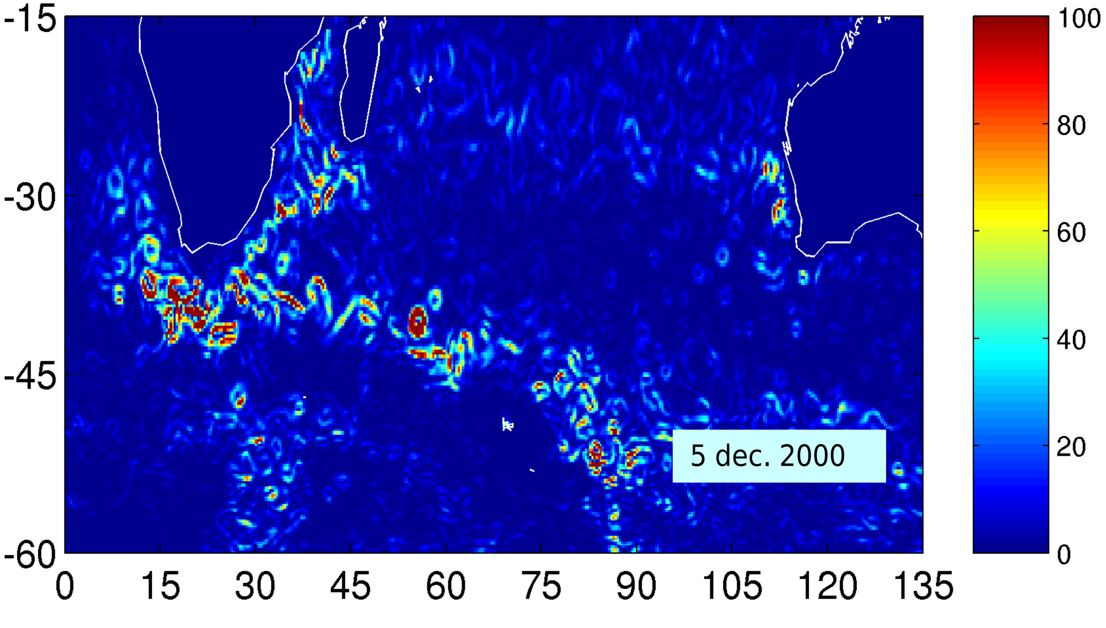
eg SST or ocean colour



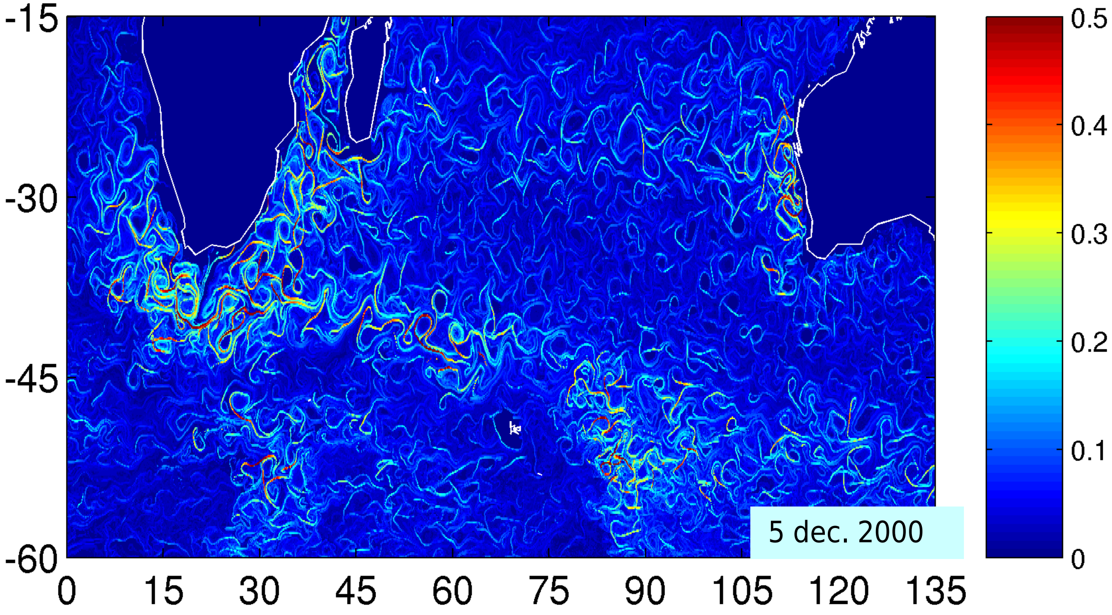
OPA 1/54 resolution (F. D'Ovidio, M. Lévy and M. Jouini)
N Atlantic



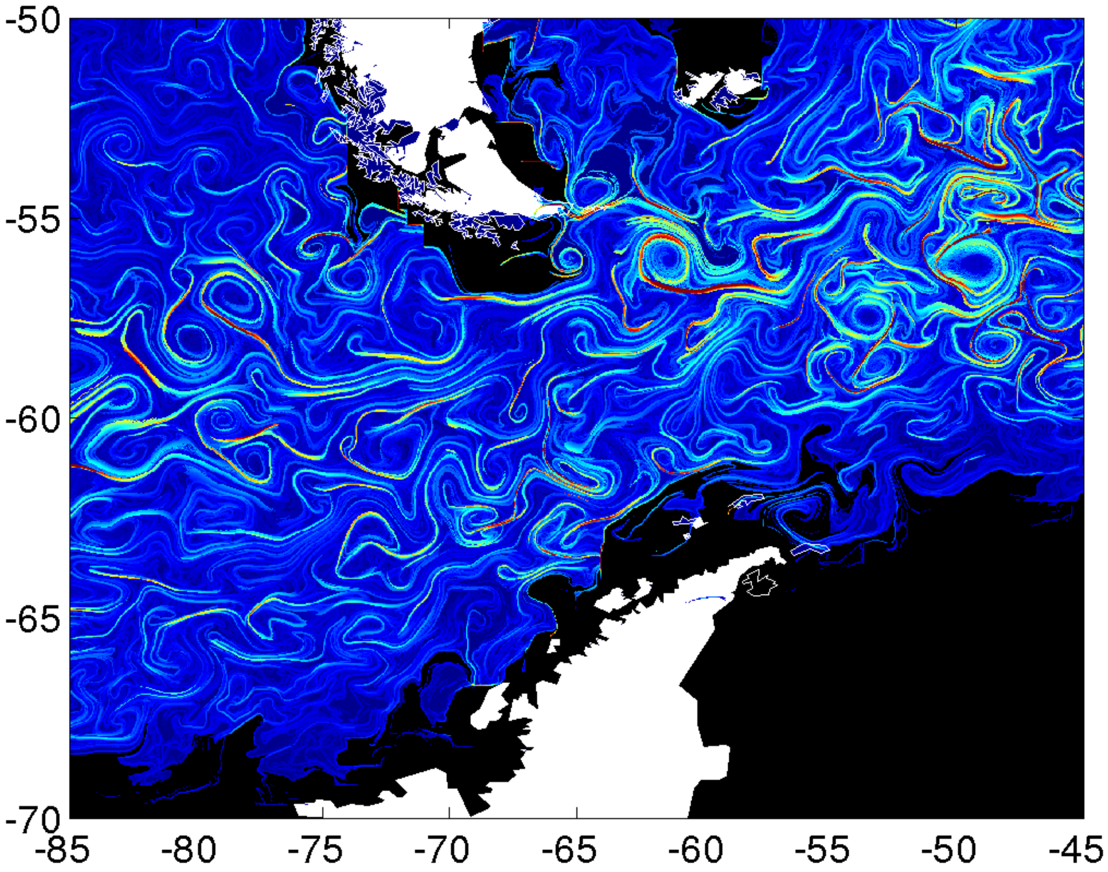
Vertical cells and Lyapunov lines are colocalized
Regions of vertical exchange of heat, salt, nutrients, …



Traditional analysis : altimetric EKE
Mesoscale eddies
Resolution 30 km



Lagrangian analysis (Lyap. Exp)
Sub-mesoscale Filaments
Resolution 1-10 km



Qualitative :

FSLEs indicate the **position** of filaments or transport barriers

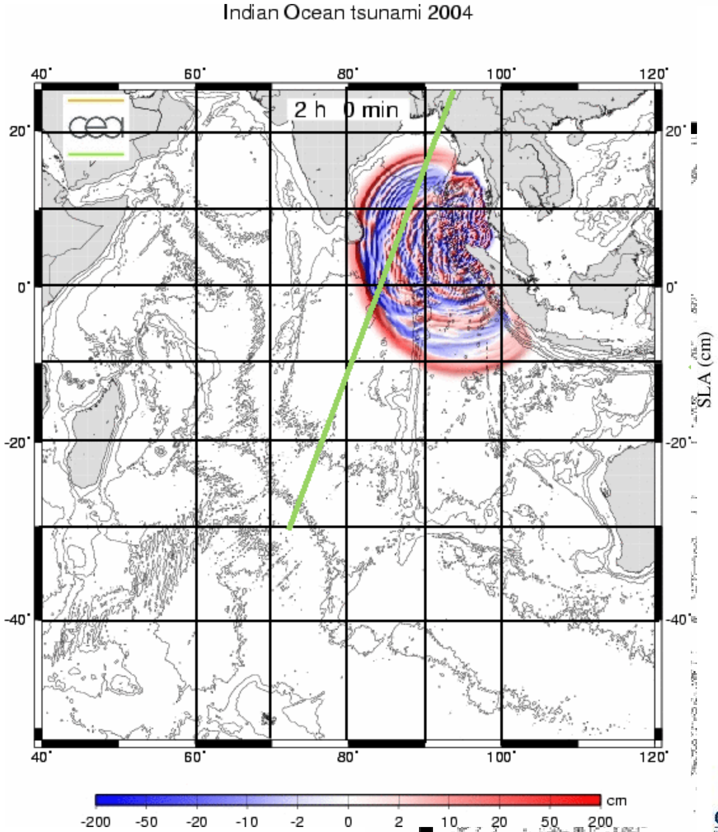
Quantitative :

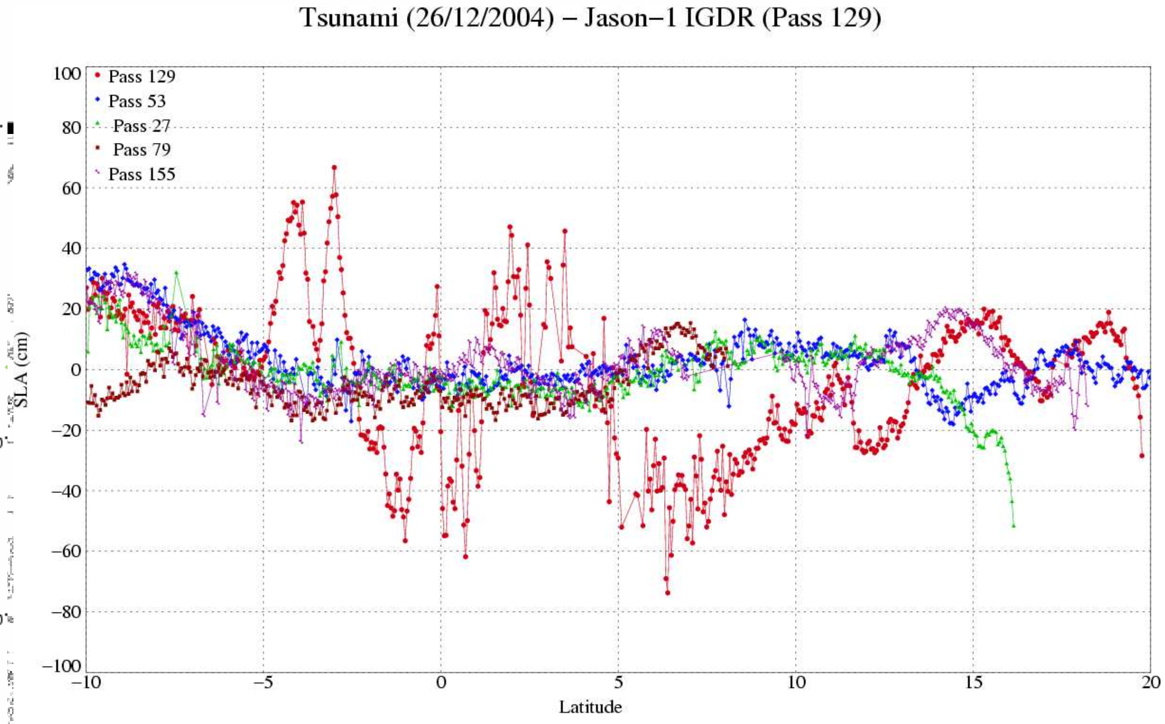
The length of the unstable manifold can be related to **eddy diffusion**, within the formalism of the effective diffusivity.

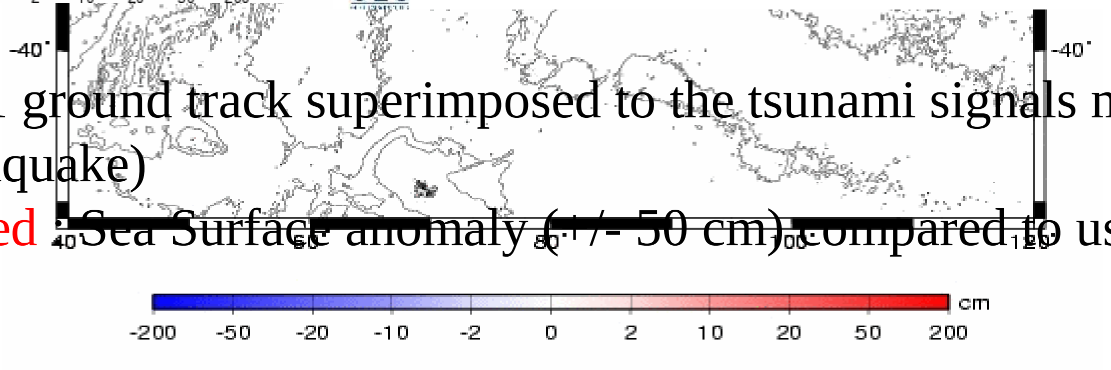
Emily Shuckburg (BAS), Francesco d'Ovidio (LMD)

4) Tsunamis

OBSERVATION DU TSUNAMI DU 26 décembre 2004







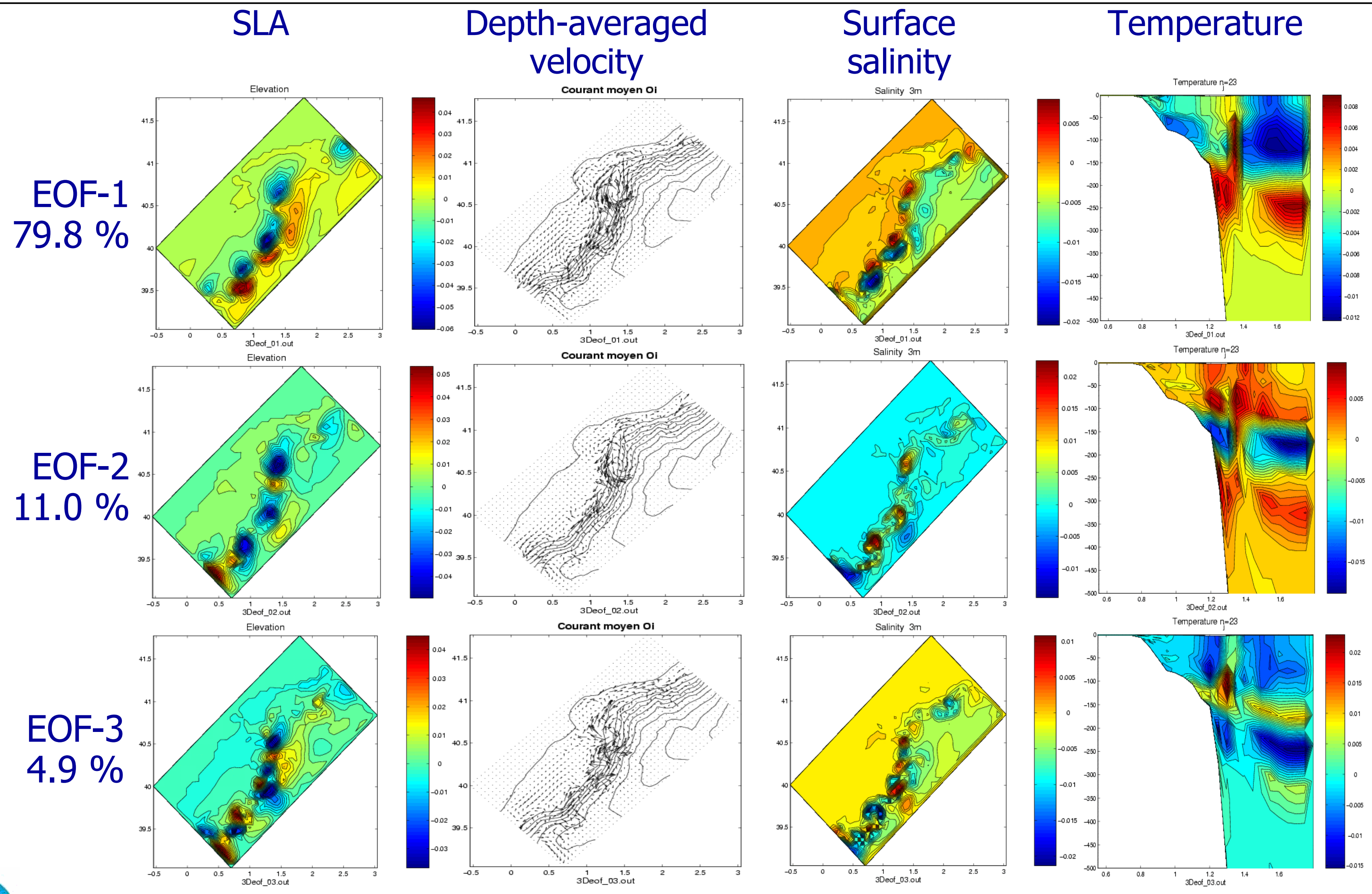
Left part Jason-1 ground track superimposed to the tsunami signals modeled by CEA (1h53 after earthquake)

Right part – in red : Sea Surface anomaly (+/- 50 cm) compared to usual signals

Constraining coastal ocean models with altimetry

Pierre De Mey, LEGOS/POC

Perturbation errors introduced into coastal current
– highlights space and time scales that we need to observe



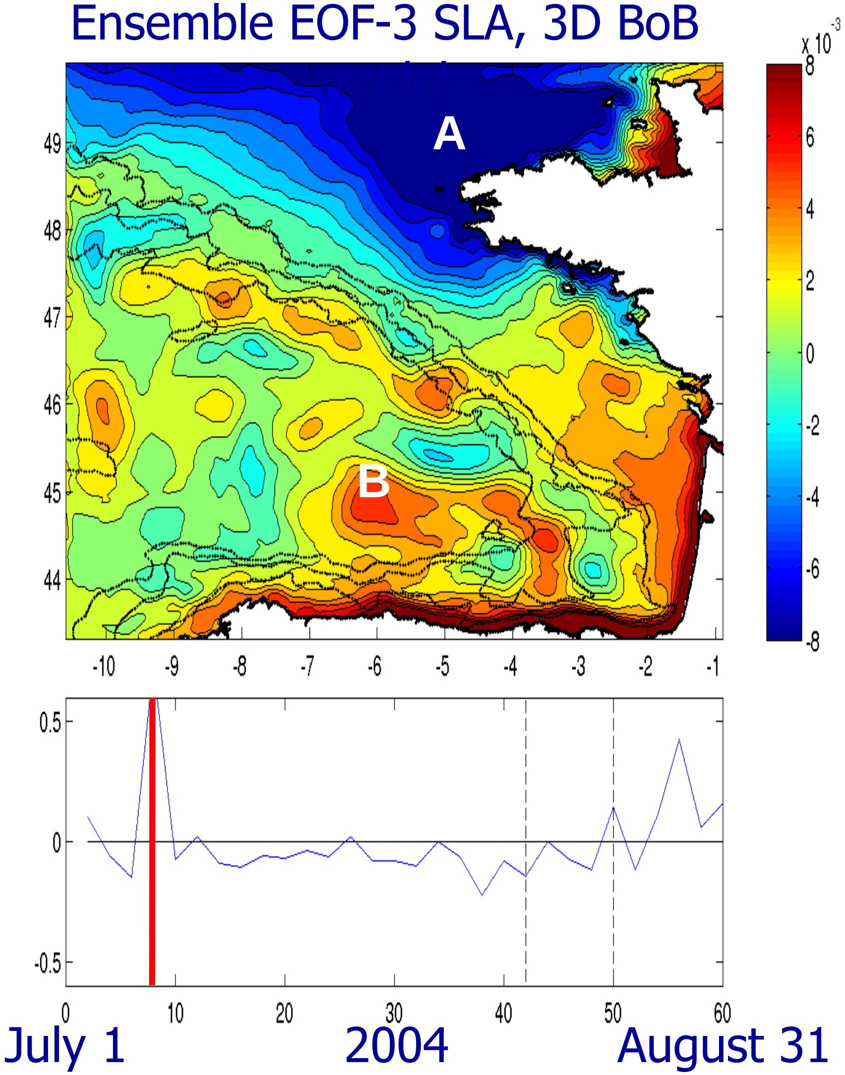
O(10-20 km) 2-5 km 2-5 km

(Jordà et al., 2006)

Activation of coherent error features by storms

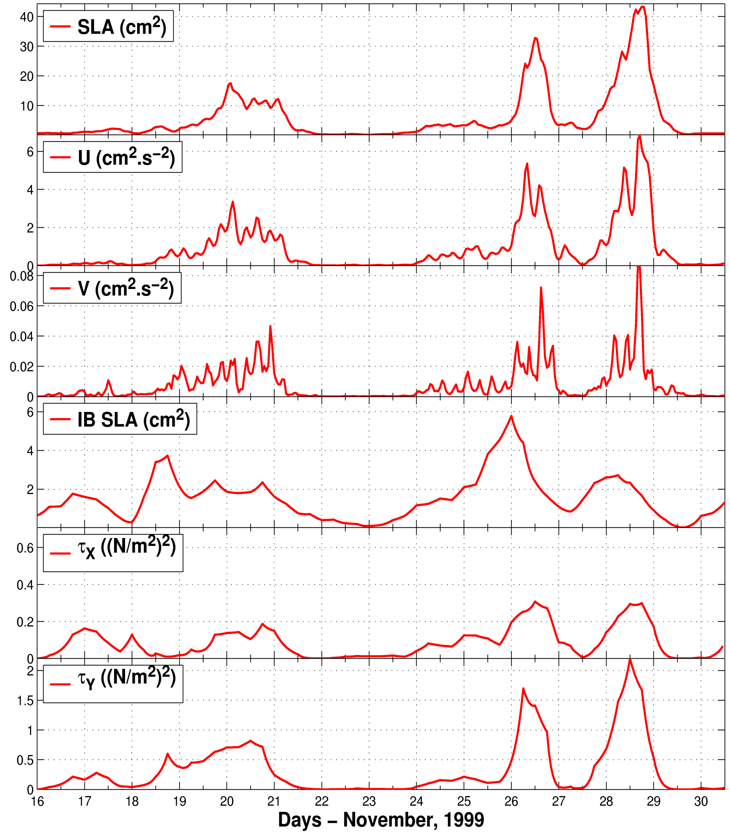
What is this? The SLA component of a particular ensemble EOF in response to atmospheric forcing errors. It is a proxy of the actual model errors. As the time series shows, it is activated during the July 7-8 storm and is characterized by a shelf-wide response, a surge response, and a mesoscale response with O(1day) time scale.

Ensemble EOF-3 SLA, 3D BoB

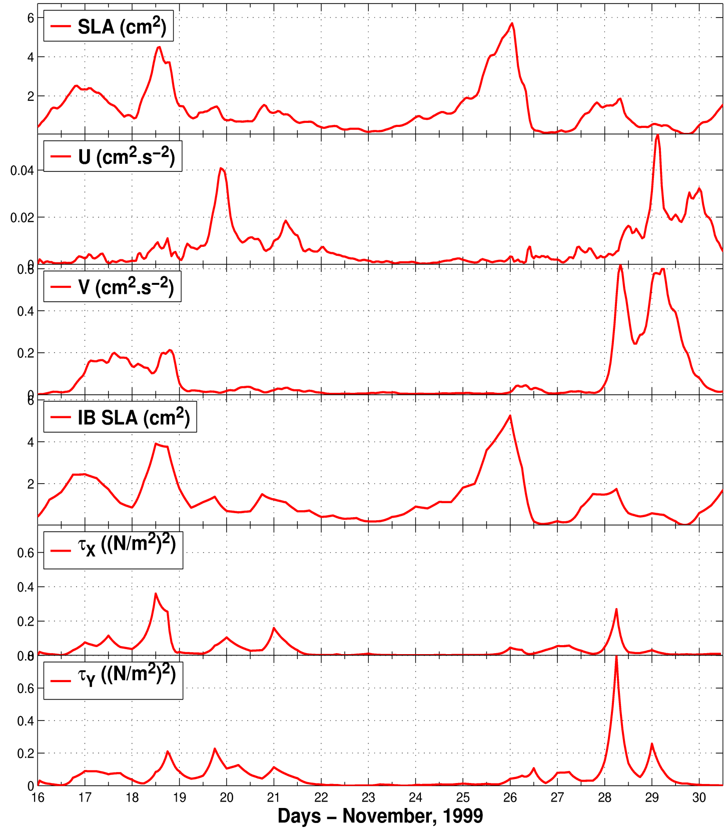


Time variations of ensemble variance

Point A: EC



Point B: BoB



SLA, $\mathbf{U}_b$ errors linked to local wind errors

Kelvin waves propagation in error subspace

SLA errors attributable to pressure errors

Summary : altimetry as a constraint for coastal models

Problems with traditional altimetric data :

⇒ **missing altimetric data 25 km from coast** leads to large unconstrained model errors in nearshore zones

⇒ Need to **constrain model SL at the Rossby radius** (10-50 km resolution) at mid – high latitudes – multi-mission altimetry data resolves 70-100 km only

⇒ Need to **constrain the high frequency** « storm surges » < 1 day – multi-mission altimetry data resolves 15 days!

⇒ **Higher spatial and temporal sampling of SL is necessary for coastal studies**

Future for altimetry in the coastal zone

→ improve the radiometer decontamination in the nearshore zone

⇒ perform T/P + Jason altimetric waveform retracking

⇒ Multi-mission altimeter data

⇒ Higher resolution altimetry (SWOT)

⇒ Multi-captor applications

(altimetry, SST, ocean colour, …)

} to resolve fine space and time scales

⇒ Combine altimetry with in-situ data (coastal tide gauges, current meters, surface currents from radar)

⇒ Use improved coastal altimetric data for studying offshore exchange (squirts and jets) and vertical exchange in the filaments (FSLEs)