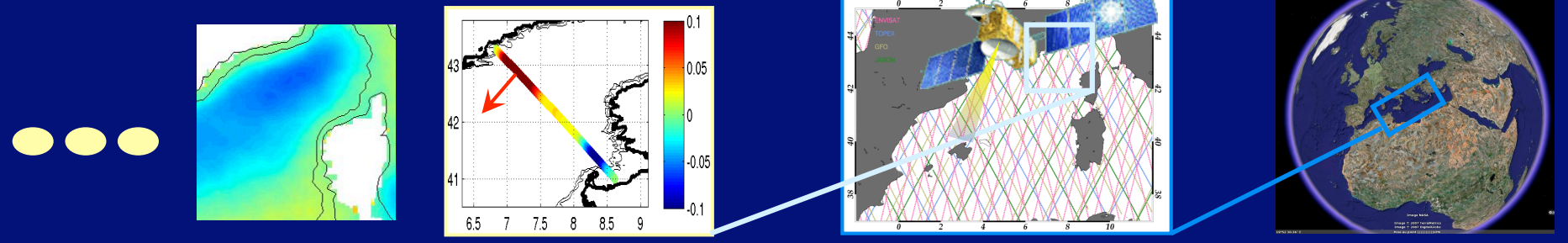

Altimetry applications over European coasts

by *J. Bouffard (LEGOS)* and *A. Pascual (IMEDEA)*

With contributions from:

F. Birol, S. Vignudelli, L. Roblou, L. Fenoglio-Marc, M. Cancet, M. Le Henaff, K. Madsen, P. Garreau, J.J. Benjamin Martinez & P. Bonnefond

Problematics risen:

Are altimetric data good enougth to monitor coastal processes ?

Is there a potential synergy between coastal altimetry with other kind of sensors ?

What about the use altimetry in combination with models ?

Outlines

- **Zone of studies**
- **Coastal altimetry data processing**
  - **Absolute long-term sea surface Height**
  - **Multi-mission approach and validation with tide gauges**
- **Multi sensor approach to monitor coastal dynamics**
  - **Information from Sea Level Anomaly (SLA)**
    - Combination of altimetry and tide gauge data
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    - Altimetric SLA vs SST data
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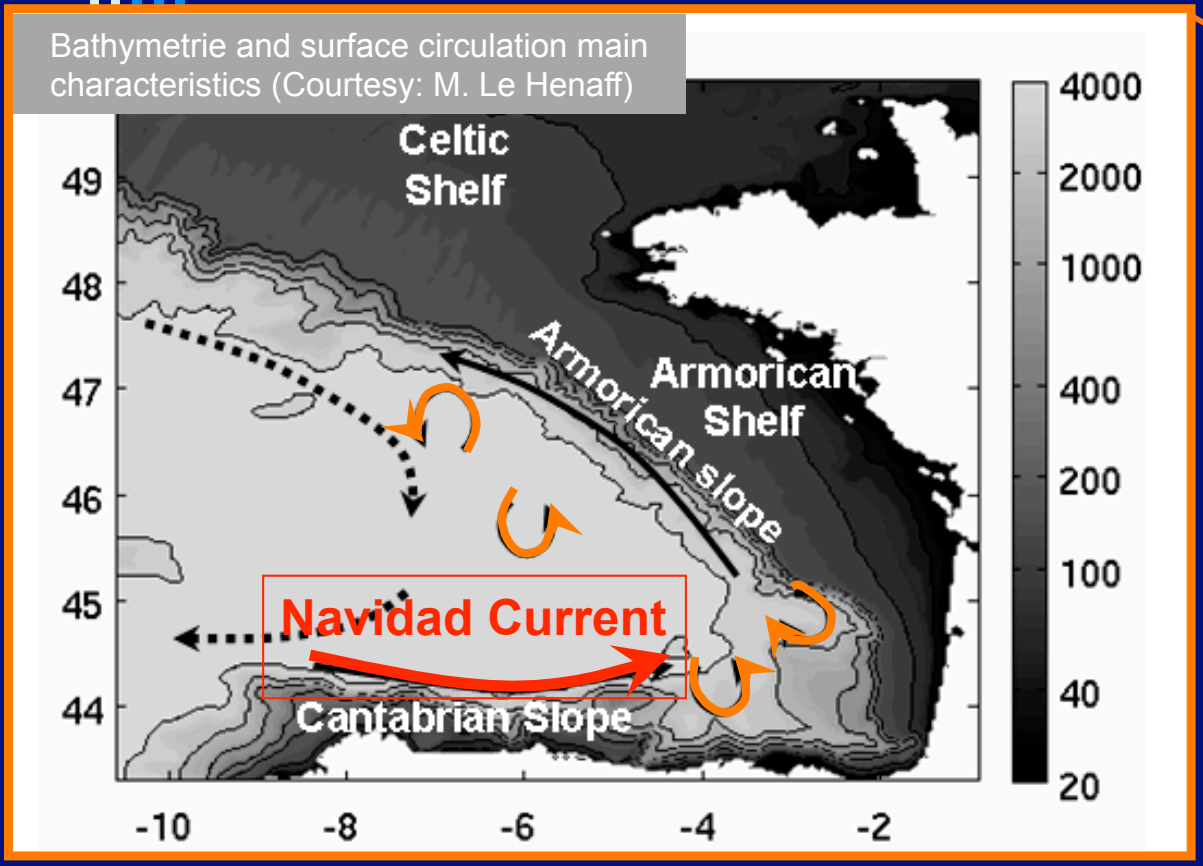
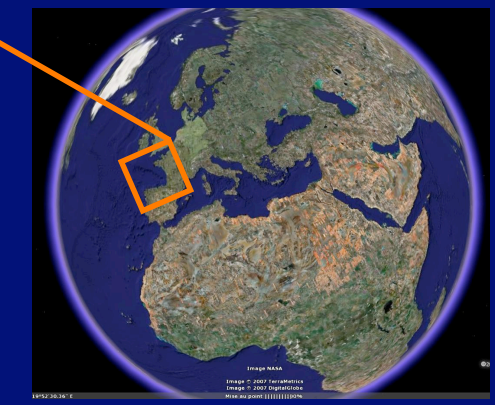
    - Crossover GVA VS currentmeter data
- **Validation of coastal models over two areas**

Zone of studies

North East Atlantic and Bay of Biscay

Bathymetrie and surface circulation main characteristics (Courtesy: M. Le Henaff)





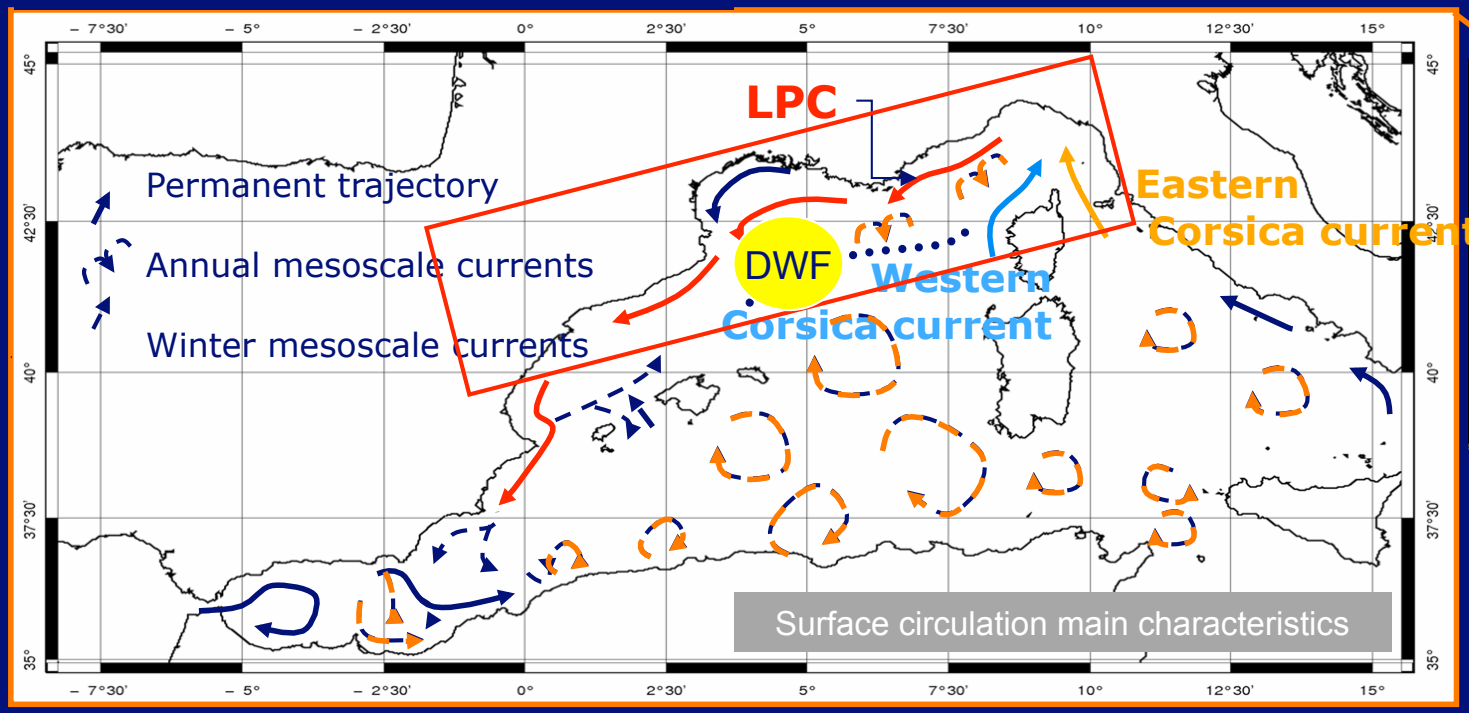
At south: The Navidad Current

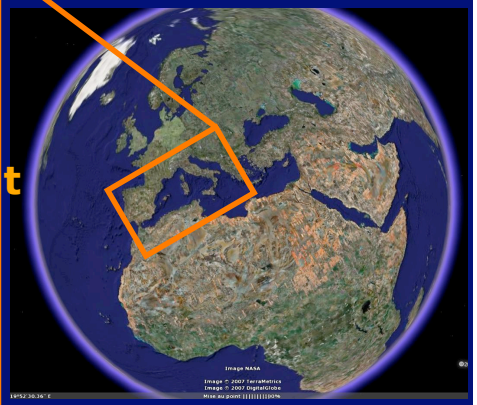
Marked seasonal and interannual variabilities (*Pingree et Le Cann, 1990*)

Intense mesoscale (eddies, meanders)

Zone of studies
The Mediterranean Sea

Adapted from *Millot et Taupier-Letage*, 2004



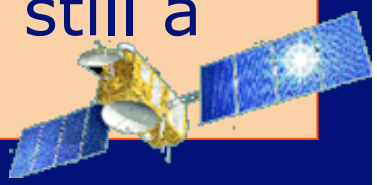


Complex dynamics characterized by a **wide spectrum** of spatial and temporal scales of **variability** (*Send et al.*, 1999).

At north: the Liguro Provençal Catalan Current (LPC)

Marked seasonal variability (*Gostan*, 1967)	**Intense mesoscale** (eddies, meanders) (*Millot*, 1991)	**Interannual variability** (*Mertens and schott*, 1998)

Monitor **coastal dynamics** with altimetry is still a **challenging issue**



Why?

- **Increased space/time sub-sampling of the coastal circulation**
- **Proximity of land :**

- No measurements at all (if the satellite approach from land)
- Land contamination of footprints (if close to shoreline)

- **Inadequacy of global geophysical corrections**

- Shorter time/spatial scales
- Non linearities over the continental shelves

Several efforts have been made (e.g. ALBICOCCA, ALTICORE, …) and **others are on going** (e.g. PISTACH COASTALT, RECOSETTO, MARINA,…) to improve the **quality and availability** of coastal altimetry ranging from improving one specific correction to the overall improvement of the data processing chain.

In which consist those efforts ? Which are their major outcomes ?

Outlines

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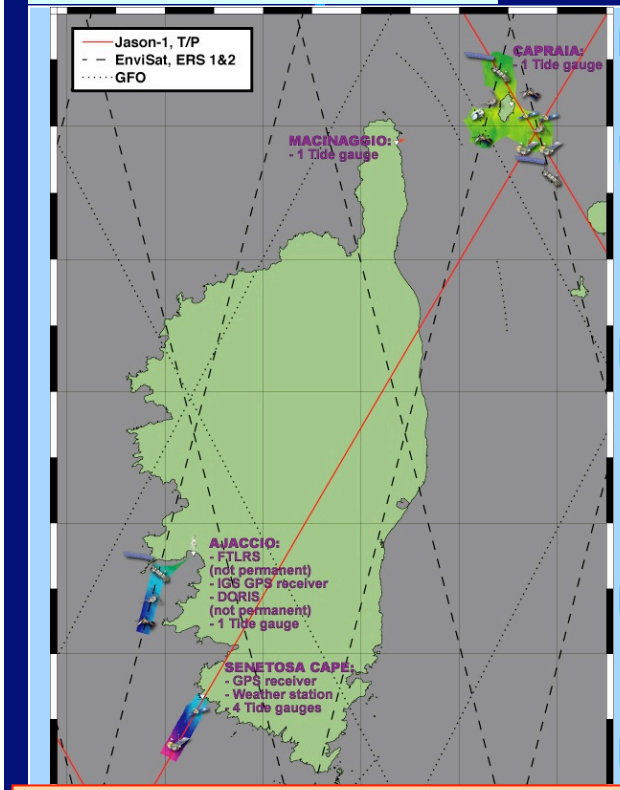
Coastal altimetry data processing

Absolute long term Sea Surface heigth

The Corsica and Spain sites

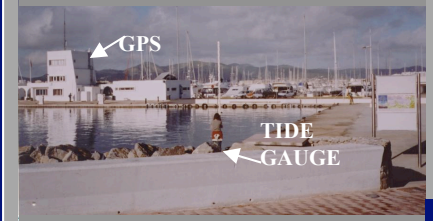
From Bonnefond et al

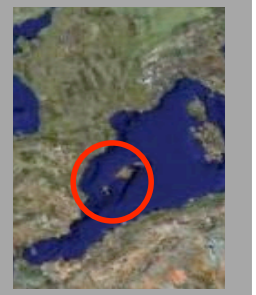


- CNES calibration site established in 1998
- Supports continuous monitoring of Jason-1 (and formerly T/P) and EnviSat, ERS, GFO
- Employs distributed configuration (Tide gauge measurements, GPS/FTLRS/ DORIS, GPS buoy deployments)
- Open-ocean altimeter readings connected to tide gauges via detailed local geoid model
- Extension to Ajaccio (2005)

From Martinez-Martinez et al.

CGPS IBIZA Harbour at Marina de Botafoch

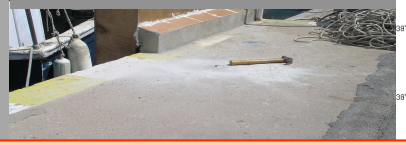


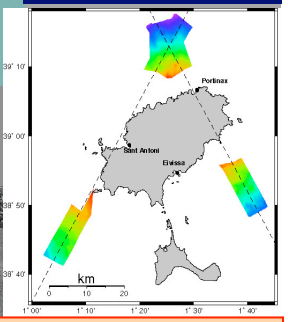


CGPS BARCELONA Harbour

RADAR ALTIMETER CALIBRATION CAMPAIGNS

CGPS L'ESTARTIT Harbour





World-wide distributed calibration sites help to solve geographically correlated errors…
<u>But</u> in-situ calibration also provide **details on the various corrections** and parameters:
- Wet tropospheric correction by comparison with the one derived from GPS,
- Significant Wave Height using the GPS buoy, …

Outlines

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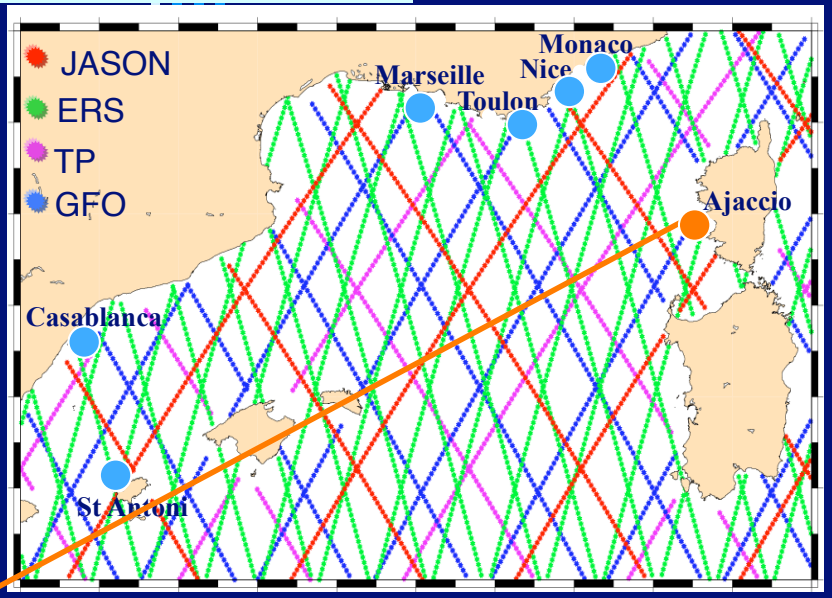
Coastal altimetry data processing

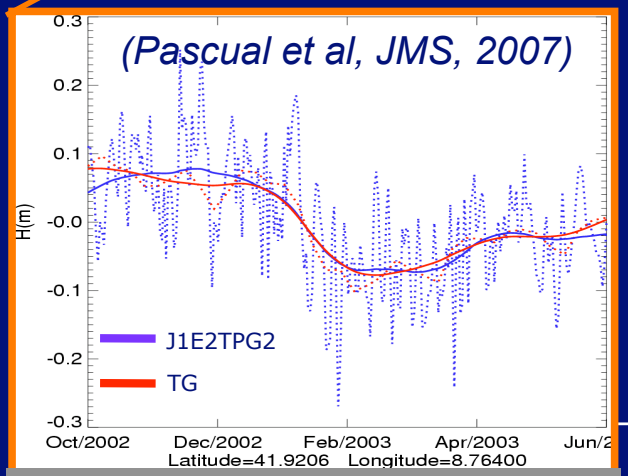
Multi-mission approach

From Pascual et al

Gridded data: Regional AVISO product vs tide gauges



- Altimeter data:
  - Delayed time gridded fields combining 2 or 4 altimeters (AVISO).
  - Specific product for Med Sea (1/8º)
- Tide gauge:
  - Filtering of tides: Demerliac filter (Lefevre, CLS, 2003)
  - Inverse barometer correction
- Altimeter data are interpolated onto the position and time of TG observations.



Dotted line: unfiltered data.
Continuous lines: 30-day low-pass filter

Rms diff between SLA and TG

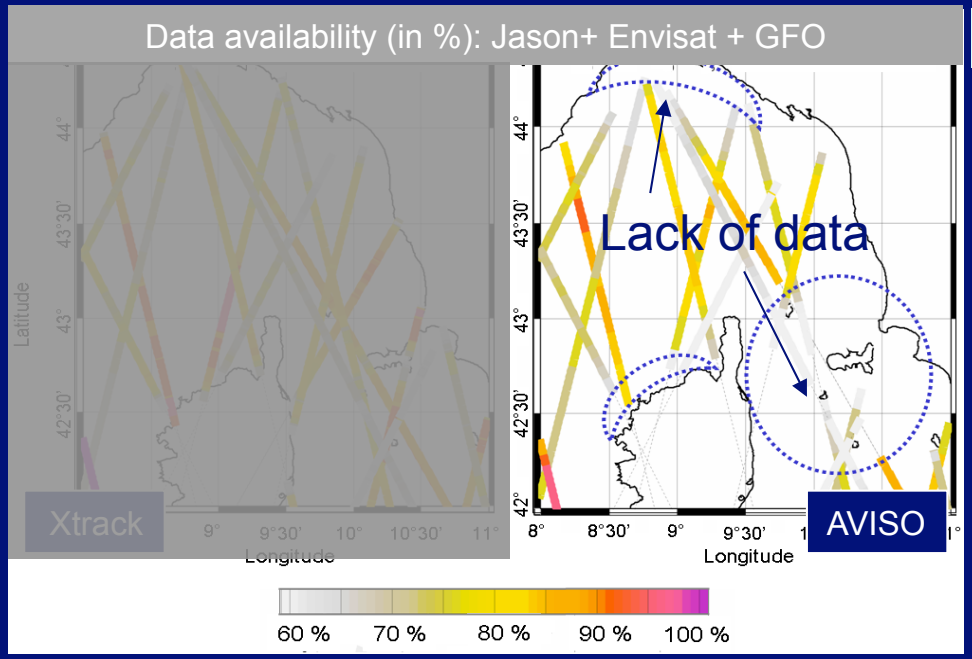
STATION	J1E2	J1E2TPG2
Ajaccio	5.2%	3.9%
Casablanca	6.4%	2.2%
Monaco	10.5%	9.3%
Nice	10.9%	9.7%
Portomaso	1.7%	0.6%
Toulon	7.1%	4.4%

Units: (% var TG)

Multi-mission altimetry allows to **improve the consistency** with in-situ SLA measurements

Comparisons with tide gauges show that the regional gridded **multi-mission** product are of good quality in general…

… but may be **inadapted to study small scale dynamics** (<30 km) over the **coastal ocean.**



Bouffard et al., 2008 b (GRL)

So, what solution ?

Reprocess multi-mission along track data with a coastal oriented strategy

Coastal altimetry data processing

Multi-mission approach

Data post-processing: X-track vs tide gauges

- **Features:**

❑ **Redefining the data editing strategy**
- *More altimeter data near coasts and even offshore*
- *Time series are longer (+10%), less noisy (-7%)*

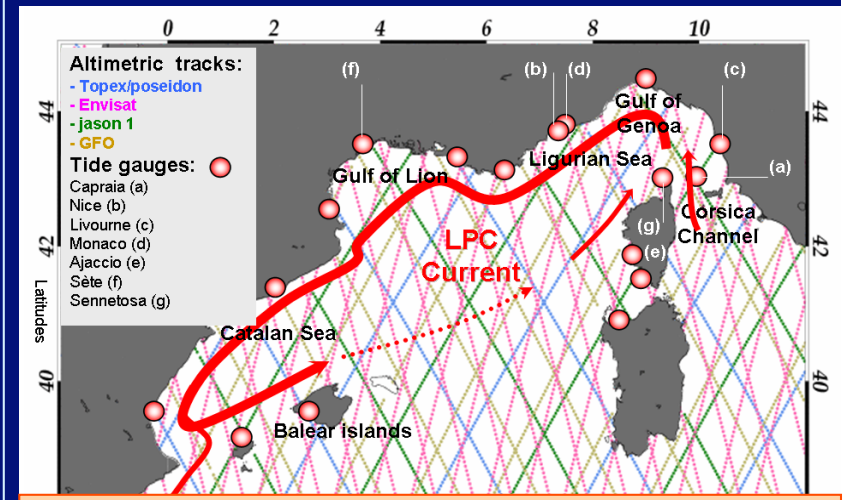
❑ **Using improved local modelling of tidal and short-period atmospheric forcing (T-UGO)**
- *Gain vs IB: 46%*
- *Gain vs Mog2D-G correction: 5%*

❑ **Using a multi-satellite and high frequency along track sampling (10-20 Hz data).**
- *Better sampling in space and time of a narrow coastal current such as LPC*
- *Allows to obtain more data close to the coast*

- **Xtrack data VS standard AVISO product**

❑ **Distance to the coast:** 33% closer
❑ **Time series length:** 24% longer
❑ **Agreement with tide gauges mesureamments:** improvment of 22 %

More details in: *Bouffard* , 2007 (PhD thesis); *Vignudelli et al*. 2005 (GRL).



Validation with Tide gauges

Dedicated post processing strategy improves the quality and quantity of coastal data

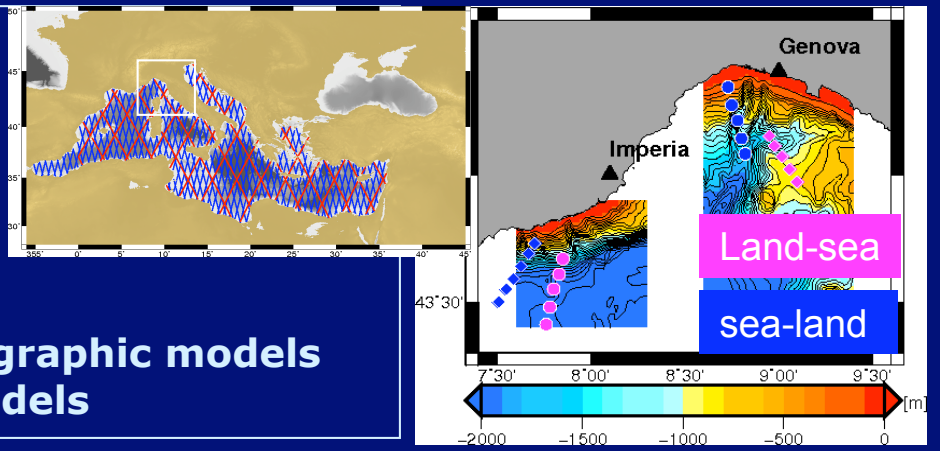
Coastal altimetry data processing

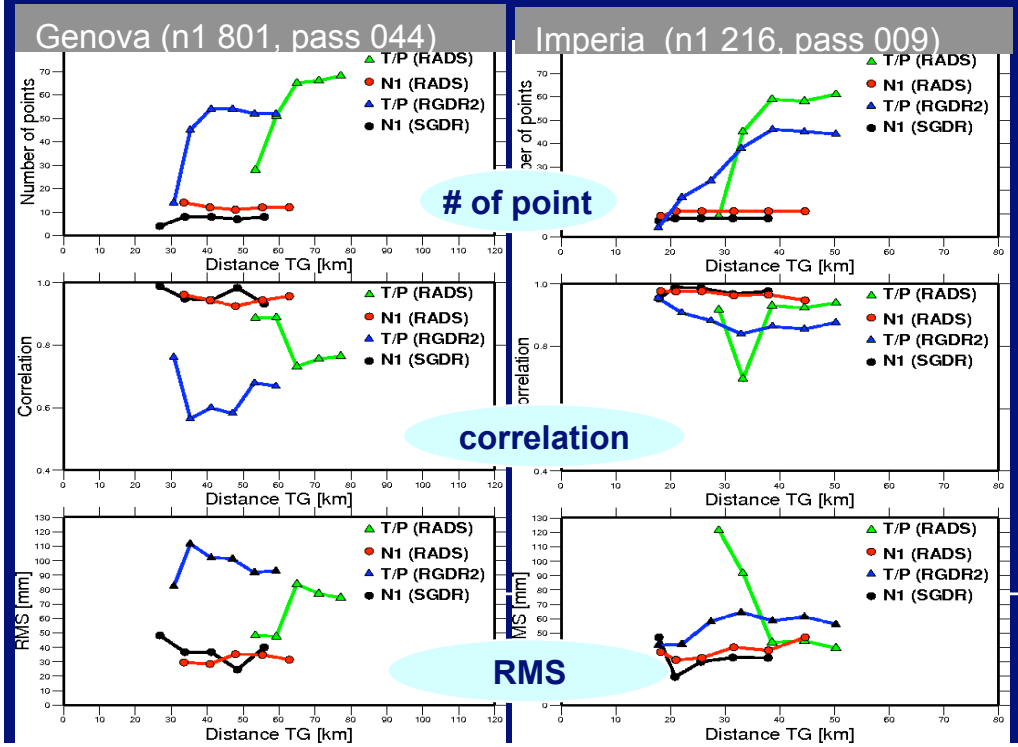
Multi-mission approach

From Fenoglio et al

Data pre-processing: RECOSETTO data vs tide gauge

- **Altimetric Data (Envisat and T/P):**
  - ❑ Multi-mission data (regional unification)
  - ❑ Standard 1-Hz data
  - ❑ Higher frequency data, data are re-tracked
- **Tide gauge station data:**
  - ❑ Correction from local barotropic and oceanographic models and of residual tidal effects from local tidal models





N1 RADS & GDR very similar.

Correlation with TG minimum 30-40 km from TG

N1 versus TP (same n)
- higher correlation
- lower RMS

Improved re-tracking allows to go closer to the coast with a better agreement wrt in-situ data

Coastal altimetry data processing
First synthesis

- Tide gauge data are useful to precisely asses coastal altimetric processing.
- Thought intercomparison experiments it has been showed that:
  - A multi-satellite strategy allow to improve the time/space sampling and the quality of altimetry in coastal and shelf zones.
  - It is possible to improve coastal altimetry (with existing data), tide gauges can used to evaluate the improvments of new post and pre-processing approachs

However, are those improvments sufficient to monitor dynamics over the coastal ocean ?

Can we combine coastal altimetry with other kind of sensors (in situ and spatial)?

Outlines

- Zone of studies
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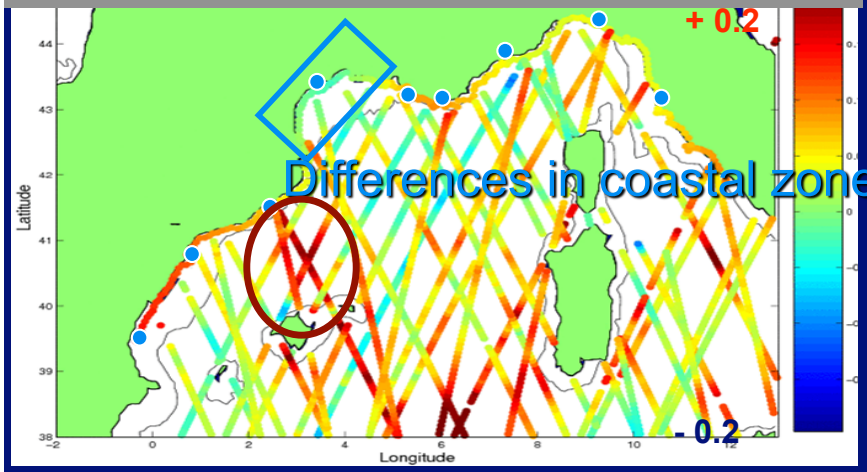
Multi-sensor approach to monitor

Information from SLA

Combination of altimetry and tide gauge data

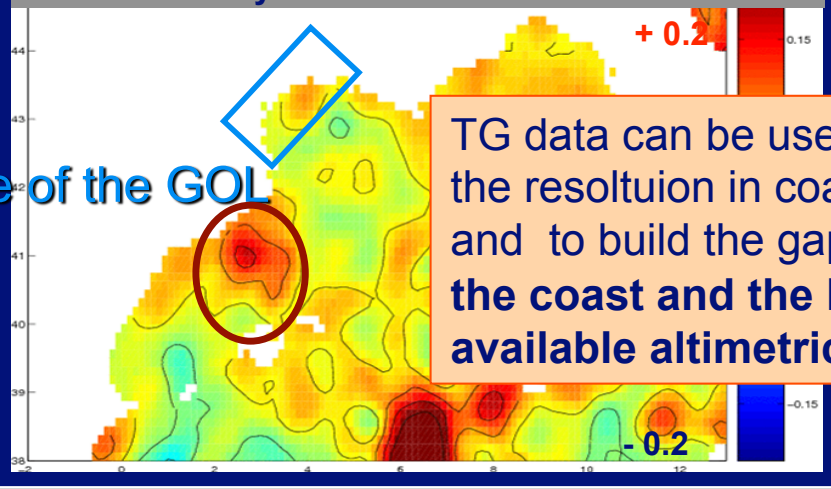
SLA from altimetry (time window: 5 days) and TG



SLA map from AVISO (in meters)

SLA Analysis: Nov. 17th 2004

From Birol et al

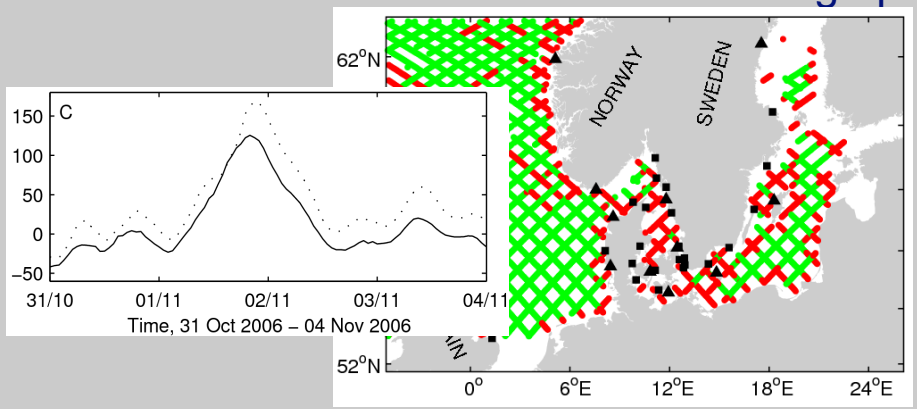


TG data can be use to increase the resoltuion in coastal zone and to build the gap **between the coast and the last available altimetric point**

***DMI plan 2009**

From Madsen et al

- Statistical model for real time storm surge prediction



**See talk at OSTST meeting Tuesday + poster. Also check ocean.dmi.dk*

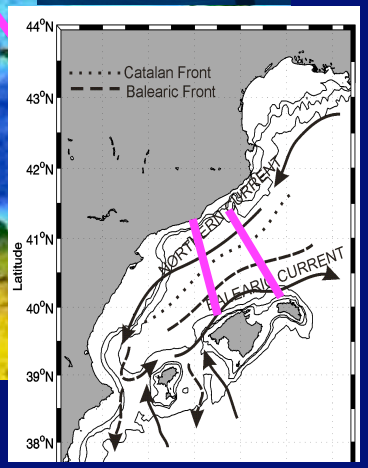
Multi-sensor approach

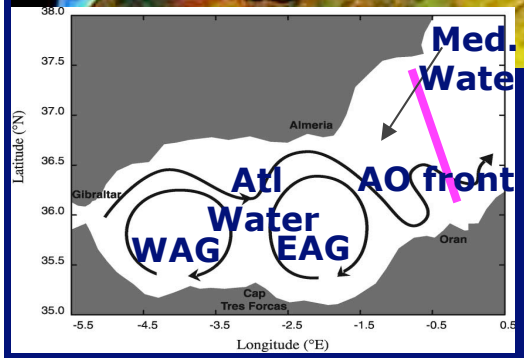
Information from SLA

Gliders vs Altimetry: what can we learn ?

From Pascual et al

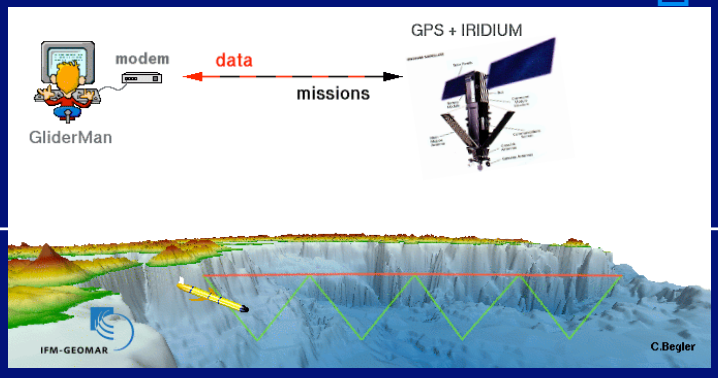
8 glider missions (July07 - August08) following altimeter tracks





- **ENVISAT**:**
  - **Balearic Sea**: T-773. Sustained glider observations (every 70 days): 6 missions up to now.
- **JASON-1/2**:**
  - **Balearic Sea**: T-70 (August 2008). Cycles Jason-2: 4 & 5
  - **Alboran Sea**: T-172 (July 2008).Cycles Jason-2: 0 & 1

** Along track SLA (AVISO/CLS) + MDT (Rio et al.).
Delayed time product (calval) / real-time (duacs, interim).
Horizontal resolution: 7 km



- **Glider data**
  - **Variables:** P, T, S, oxig., chl., turb.
  - **Vertical extension:**10-180 m
  - **Horizontal resolution:** 400 m

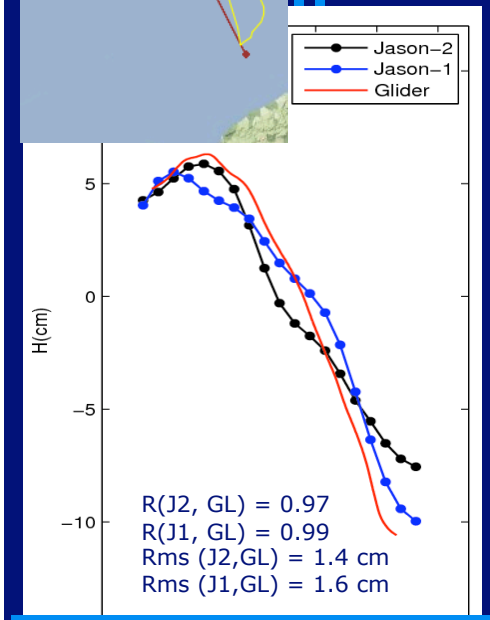
Is there a good agreement ?

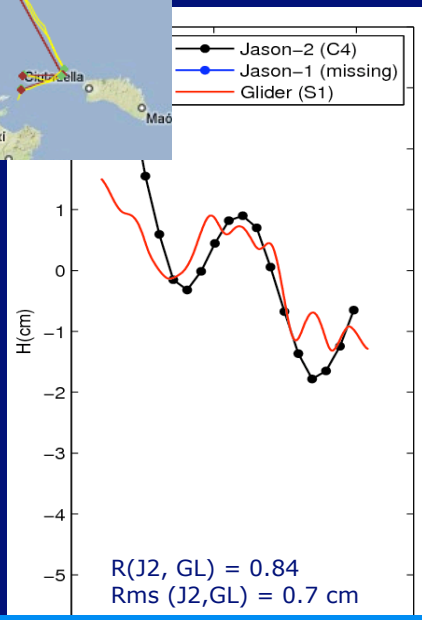
Multi-sensor approach

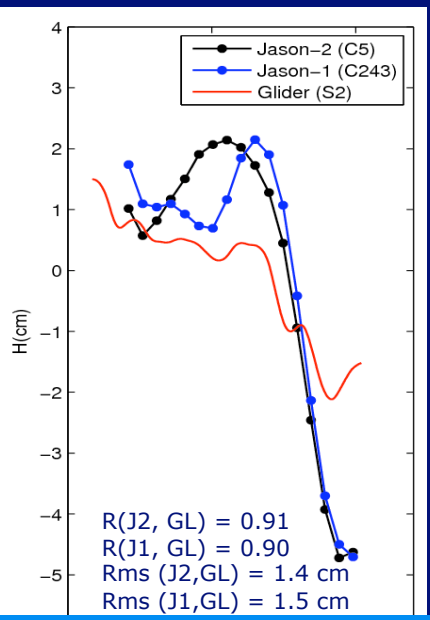
Information from SLA

Gliders vs Altimetry: what can we learn ?

From Pascual et al







Against Envisat

Good agreement despite high noise to signal ratio in coastal area.

Ongoing and future work: To apply specific altimetric algorithms (retracking, corrections, editing, etc) for coastal areas.

Alboran Sea (J1 & J2)

- Intense gradients.
- Very good correlation between altimetry and glider
- Jason-1 (IGDR) and Jason-2 (DUACS) ADT profiles correlate well (0.96).

Balearic Sea: (J1 & J2)

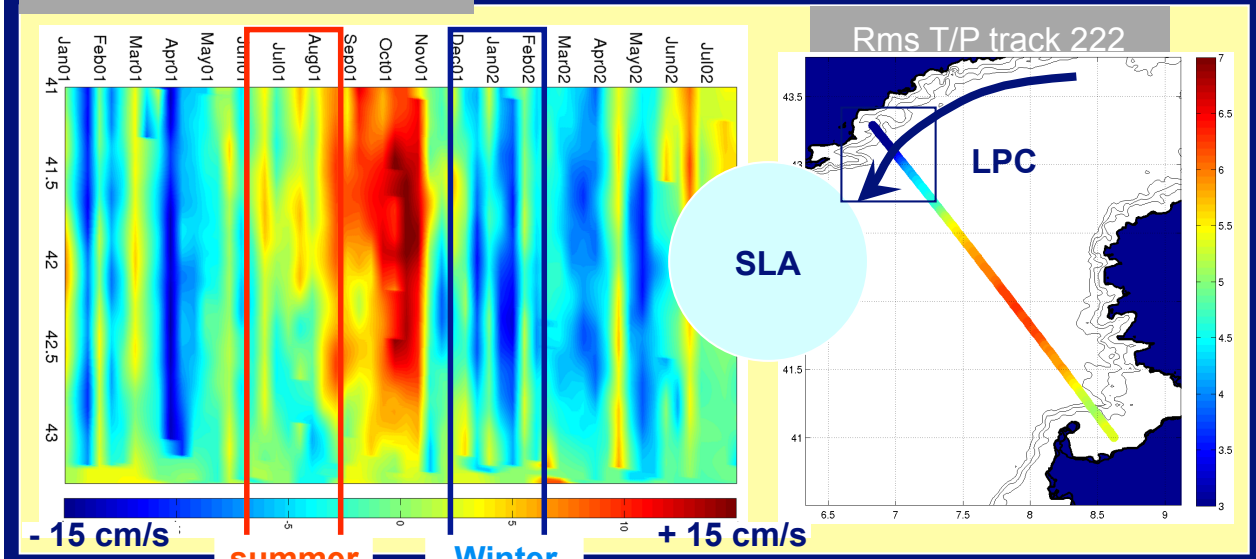
- Weak gradients (large noise to signal ratio).
- Agreement between altimetry and glider data is lower
- Reference level of 180 m might not be appropriate.
- Sensititivity to the ref. level in DH computation and mean dynamic topography.

Multi-sensor approach

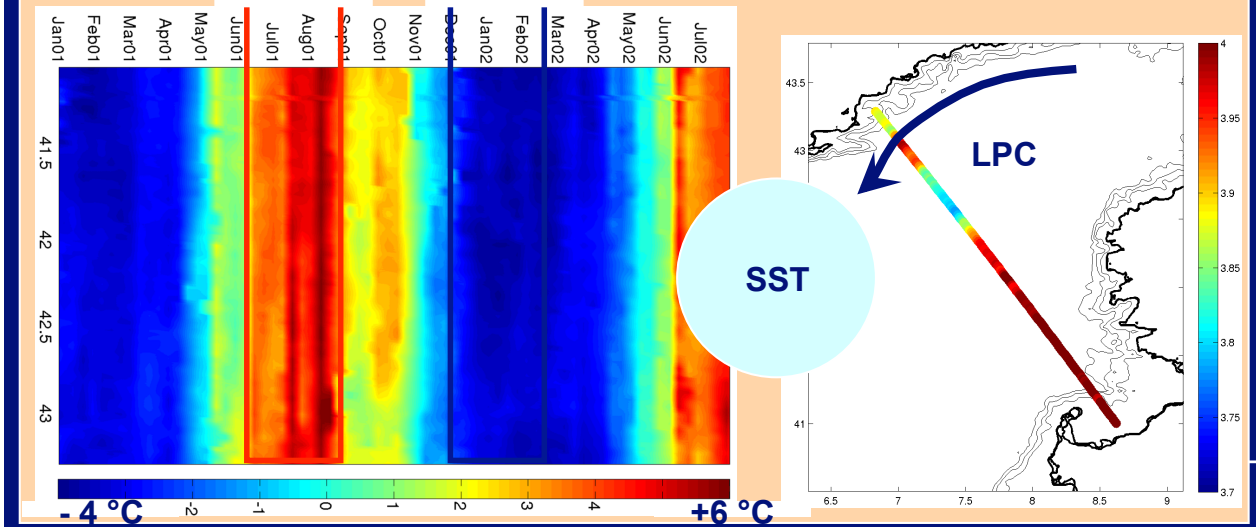
Information from SLA

Altimetry vs SST data

Hovmuller T/P track 222



Rms T/P track 222



From Bouffard et al

- **Agreement between SST and SLA signals at the seasonal scales**
  - SST (SLA) maximum in summer (automn)
  - SST minimum in winter
- **Minimum (max) of RMS SLA (SST) inside the LPC**
  - **Very surprizing:** How to explain it ? Is it Related to the LPC dynamics ?
- **Various spatial and temporal scales which interact**

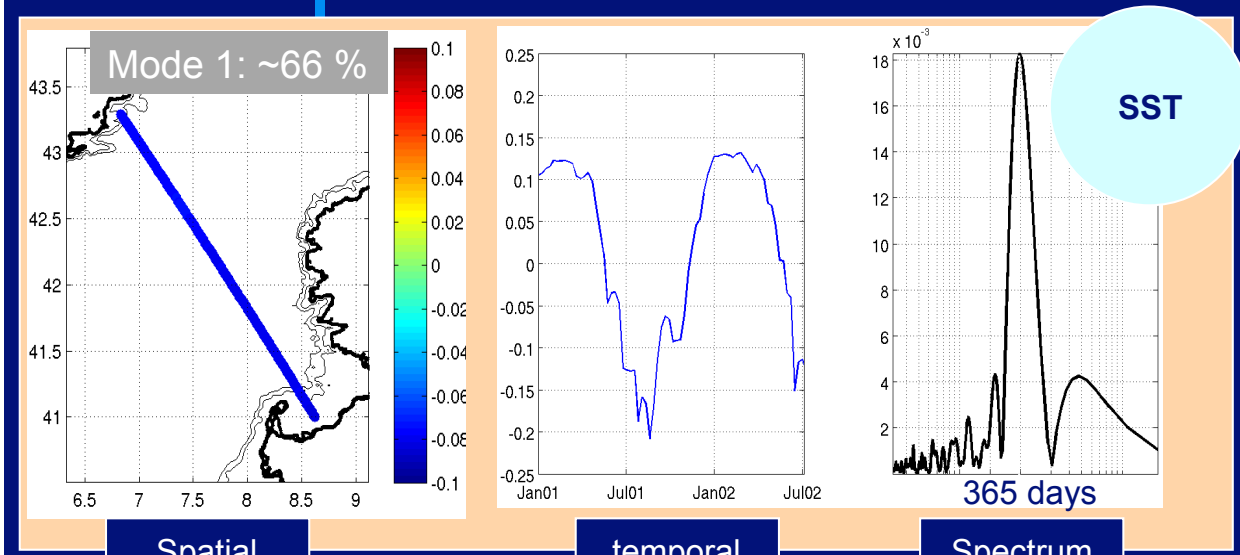
Need to separate the different dynamical contributions

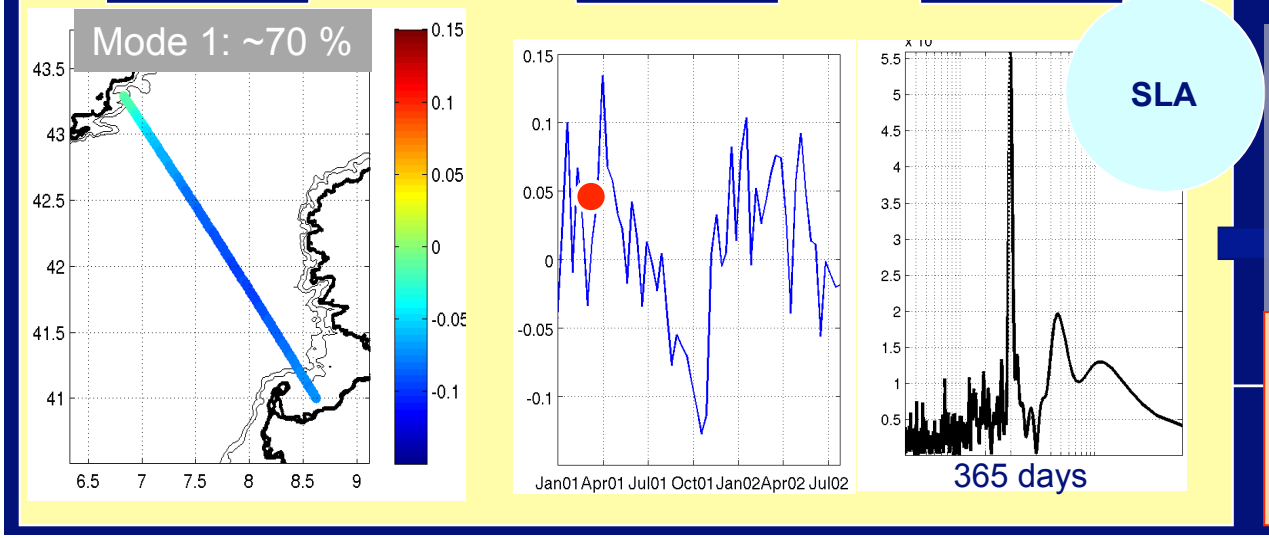
Multi-sensor approach

Information from SLA

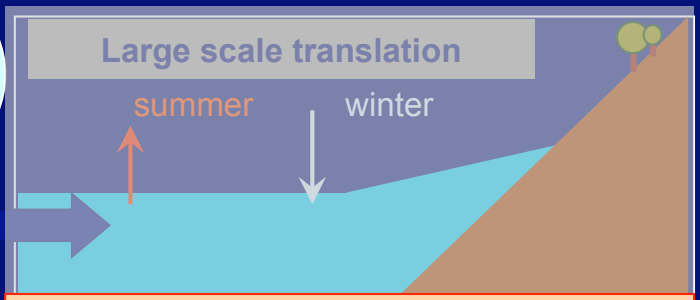
Altimetry vs SST data

From Bouffard et al





- **Mode1:**
  - 60-70 % of the variance explained
  - Good agreement between SST and SLA
  - Large scale annual signals



Not dynamically significant:

Steric signals ?

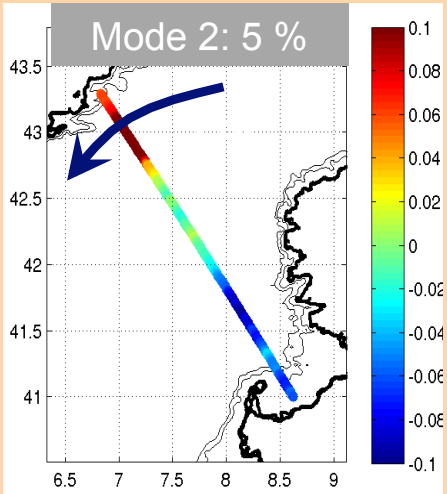
Multi-sensor approach

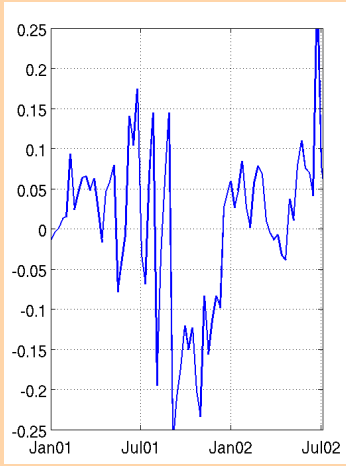
Information from SLA

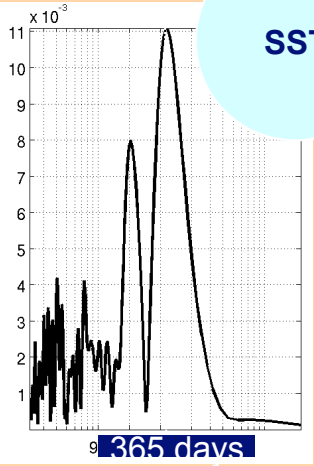
Altimetry VS SST data

From Bouffard et al

SST

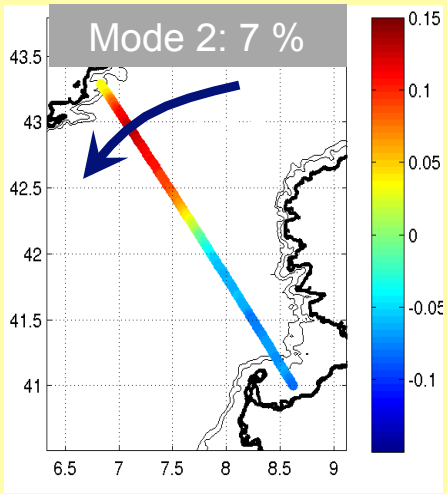


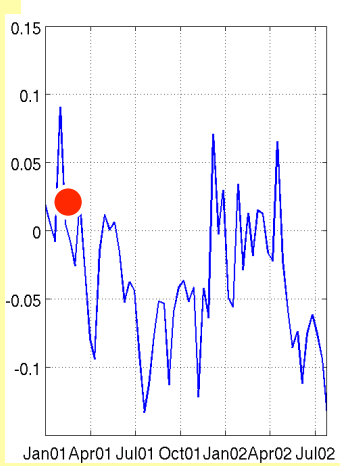


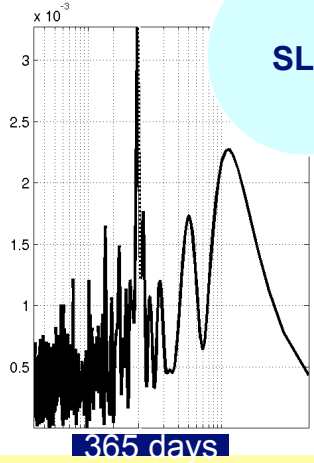


Spatial | temporal | Spectrum

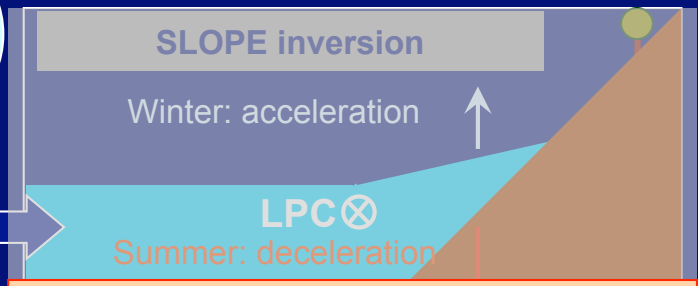
SLA







- **Mode 2 (1+n):**
  - <7% of the variance explained
  - High gradient inside the LPC both in SST and SLA
  - Significant annual component



Dynamically significant:

LPC variability?

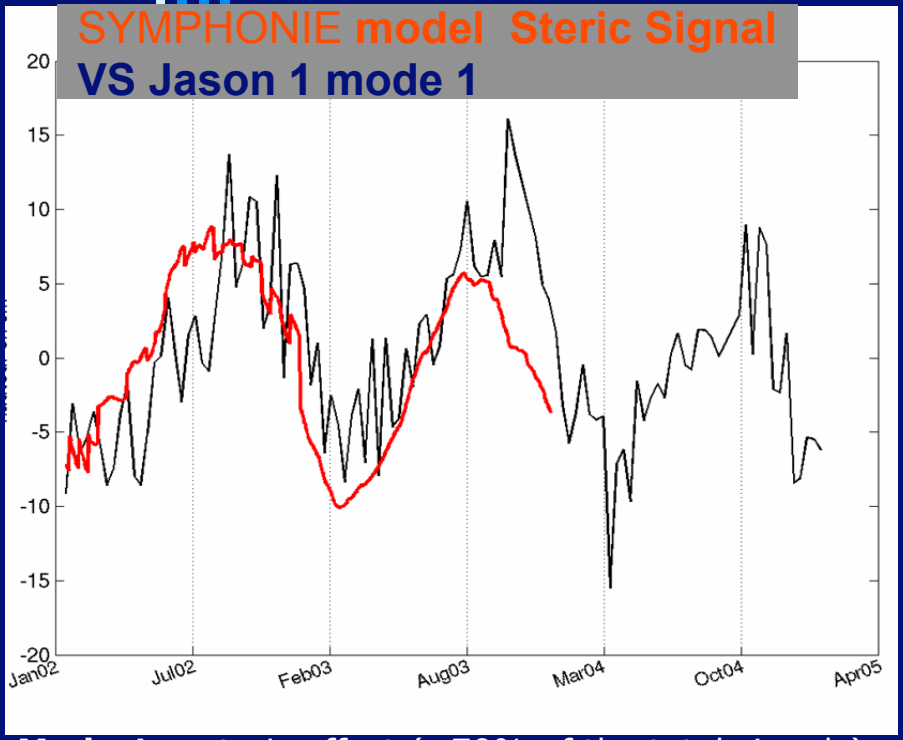
Multi-sensor approach

Information from SLA

Model VS SST altimetry

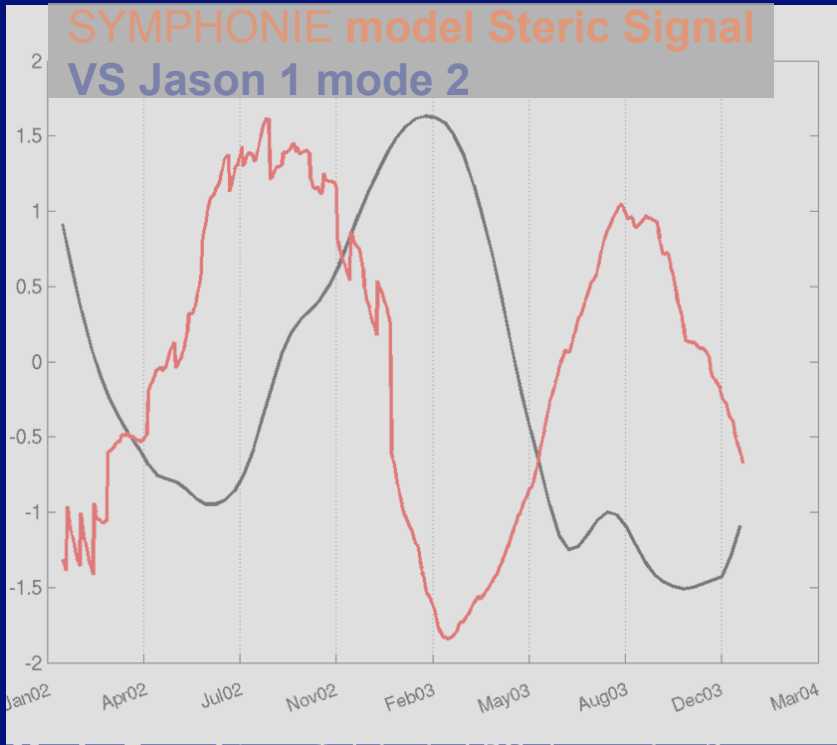
From Bouffard et al

SYMPHONIE model Steric Signal
VS Jason 1 mode 1



Mode 1 ~ steric effect (~70% of the total signals)

SYMPHONIE model Steric Signal
VS Jason 1 mode 2



Mode 2 and > ~ Intrinsic LPC dynamics ?
Opposite phase toward the steric effect

- **Mode 1:** Good agreement with the modelled steric signals
- **Mode 2:** Temporal dephazing with the steric signals which explained the minimum of RMS observed inside the LPC current

What is mode 2 (and mode n+1) ?
Need to investigate the **velocity anomaly**

Outlines

- Zone of studies
- Coastal altimetry data processing
  - Absolute long-term sea surface Height
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  - Information from Sea Level Anomaly (SLA)
    - Combination of altimetry and tide gauge data
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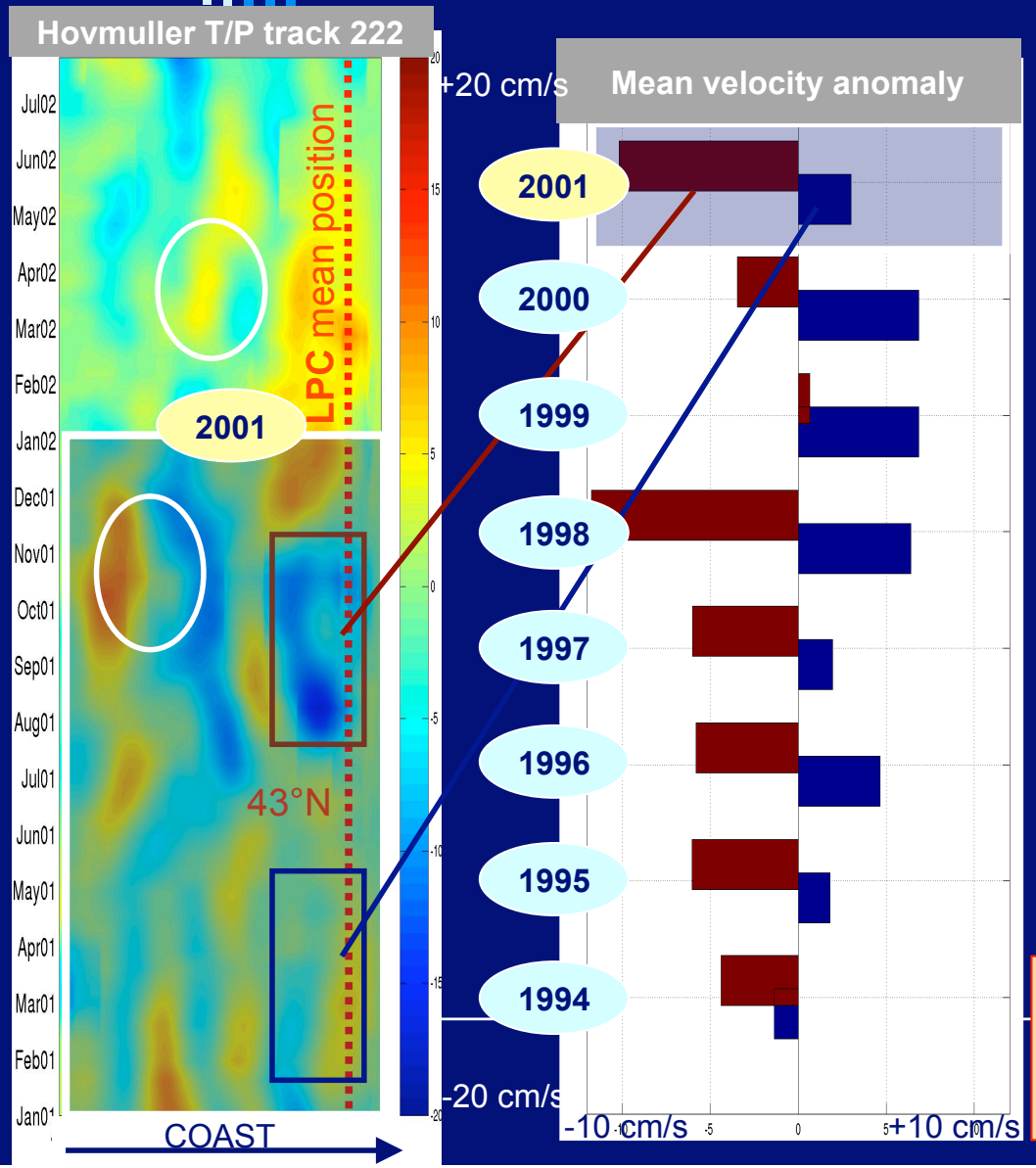
    - Crossover GVA VS currentmeter data
- Validation of coastal models over two areas

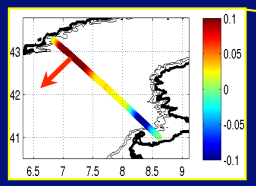
Multi-sensor approach

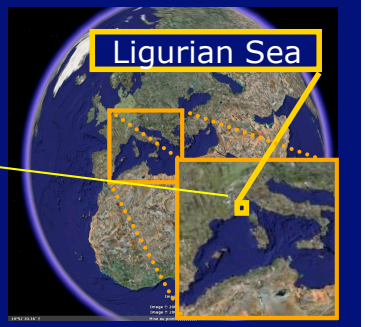
Information from velocity

Accross track geostrophic velocity anomaly (AGVA) from altimetry



From Bouffard et al





- **Seasonal variability**
- RMS: 5cm/s
- Winter : mean acceleration of 4 cm/s
- Summer : mean deceleration of -6 cm/s

- **Interannual variability**
- Summer 1998 et 2001 (<-12cm/s)
- Winter 1998->2000 (>5cm/s)

- **Small scale structures (Eddy? meander?)**
- **Need to intercompare with SST, other data and models and focus on some specific events(on going work)**

Improved coastal altimetry allows to precisely **monitor the LPC seasonnal and interannual processes**

Multi-sensor approach

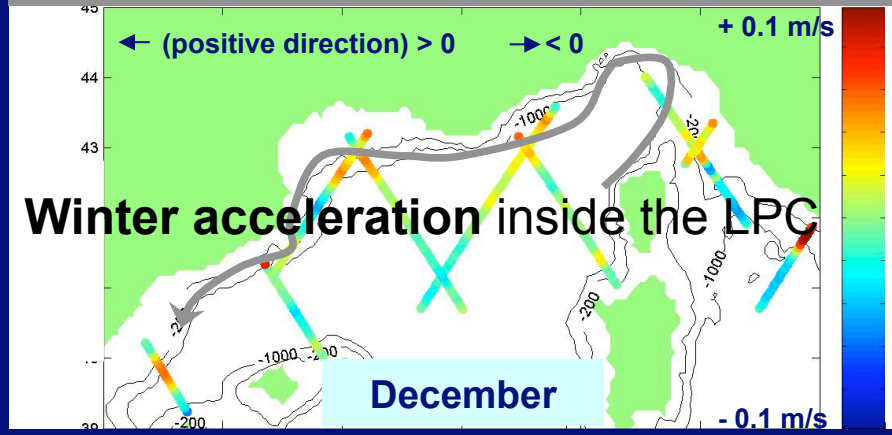
Information from velocity

Synergy between altimetry, SST and drifter

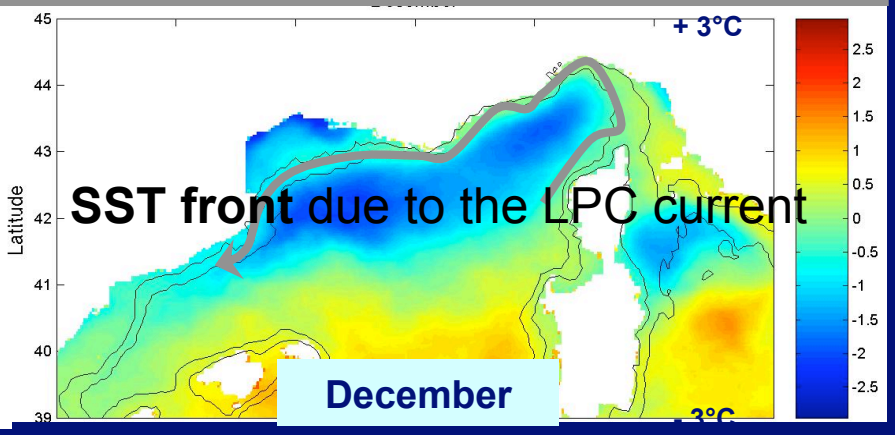
At bassin scale: LPC signature

From Birol et al

Monthly maps of Geostrophic Velocity Anomalies and of SST anomalies (Medspiration product)



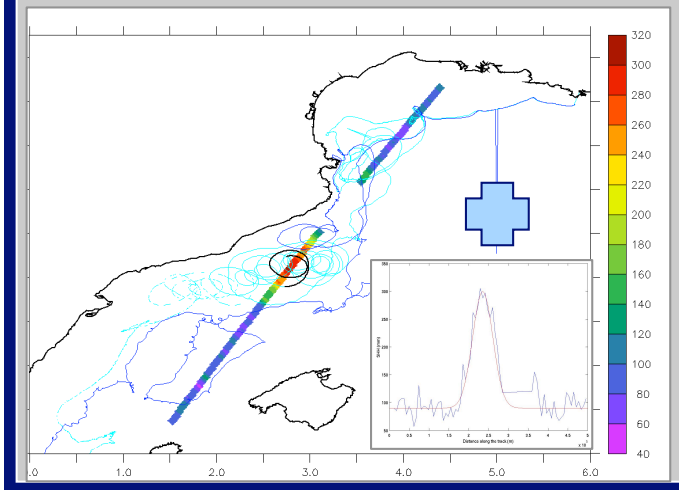
Winter acceleration inside the LPC



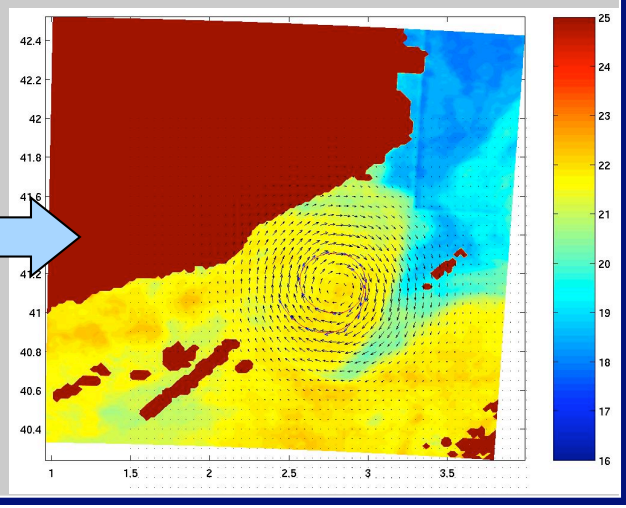
SST front due to the LPC current

Specific processes: Eddies monitoring in Catalan Sea

From Garreau et al., IFREMER



Altimetry track crosses drifter track catched by an eddy
+
Gaussian approximation of ssh
+
Geostrophy or cyclo-geostrophy
+
Sea surface temperature

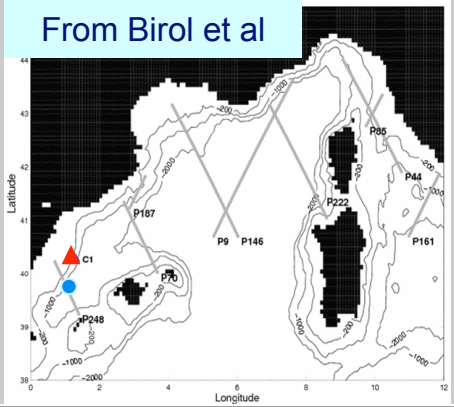


Multi-sensor approach

Information from velocity

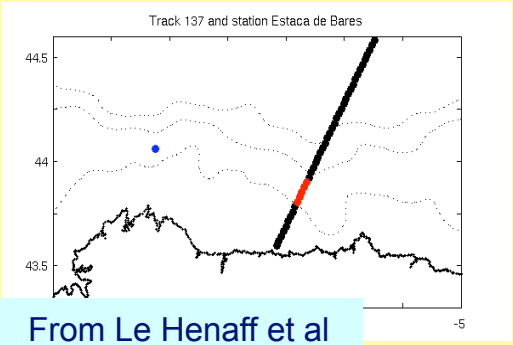
Altimetric AGVA VS currentmeter data over two areas

From Birol et al



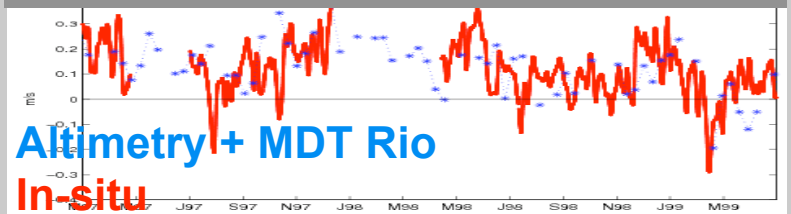
LPC current

Cantabrian current

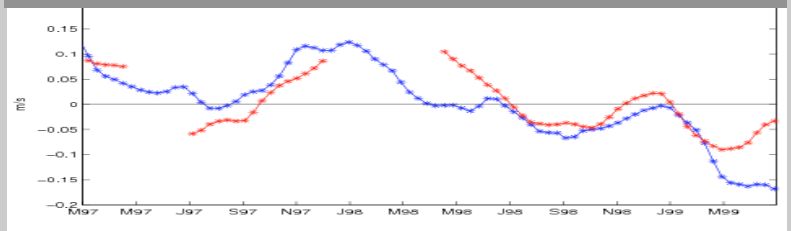


From Le Henaff et al

Raw time series (absolute values)



Filtered current anomalies (cut of 60 *days*)

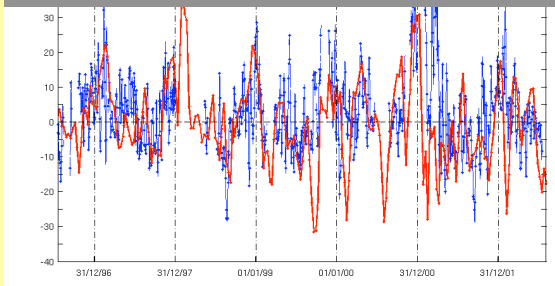


→ **Seasonal variations are in good agreement**

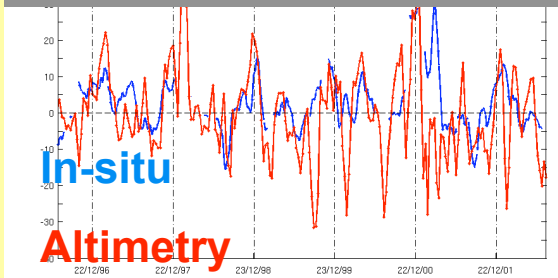
→ **Same scales of variability**

In-situ data from the YOYO and FANS project (refer to *Jordà*, 2005)

Raw current time series



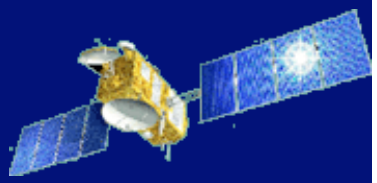
Filtered current (cut of 20 *days*)



→ **Seasonal variations are in good agreement …**

… but more amplitude and noise for altimetry

In-situ data, courtesy: Puerto del Estado



Accross track GVA from altimetry often allows to intercept the most part of the velocity anomaly

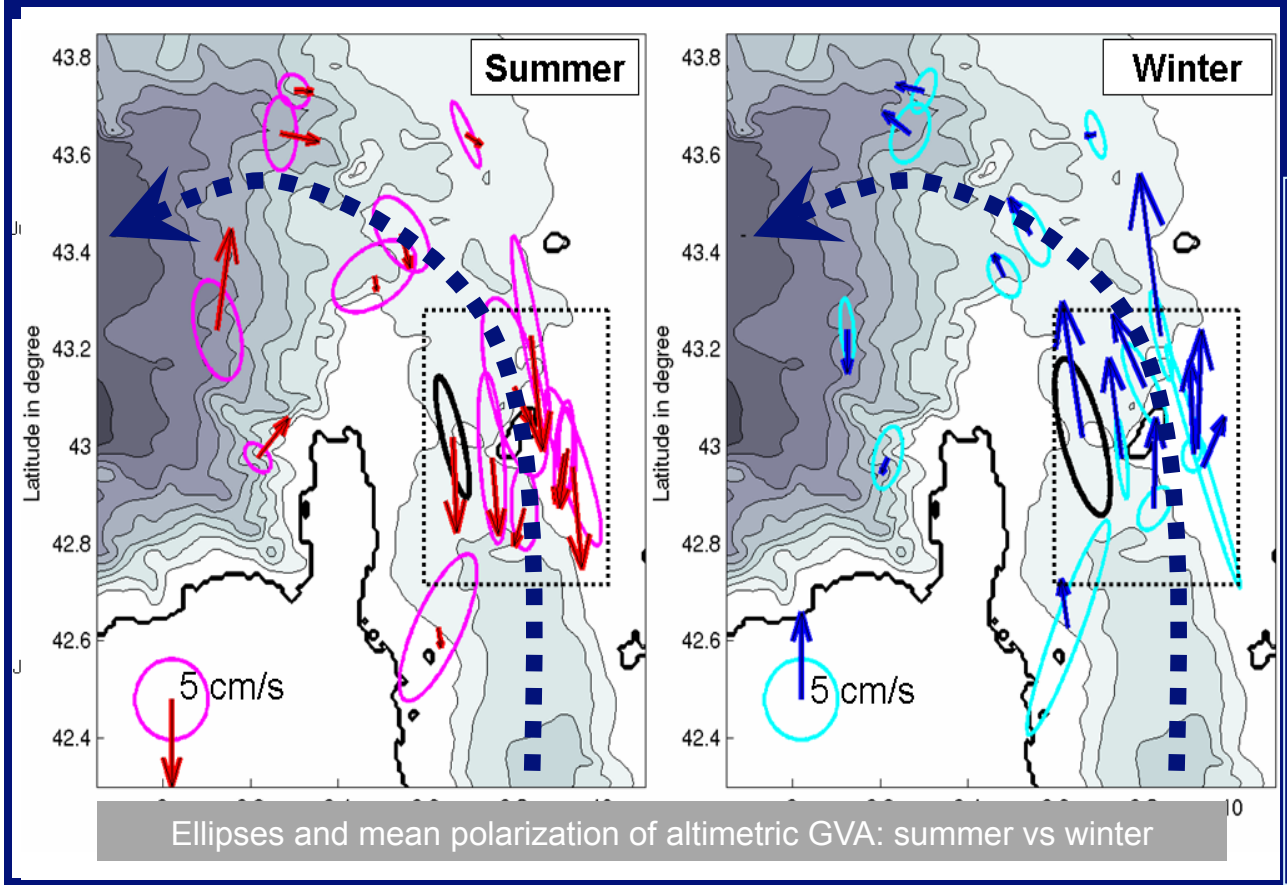
How to compute the velocity variability directions with a good resolution ?

Multi-sensor approach

Information from velocity

crossover GVA VS currentmeter data

From *Bouffard et al.*, 2008 b (GRL)



Ellipses and mean polarization of altimetric GVA: summer vs winter

❑ Method:

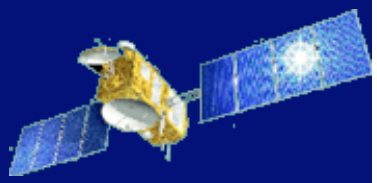
Based on Morrow et al., (1994) and generalized at a multi-satellite configuration

❑ Results:

Good agreement / in situ:
- Total signal: R=0.70
- Seasonal signals: R=0,80
- Mesoscale signals: R=0.5

Seasonal cyclonic EC current
- Summer: slowing down
- Winter : accelerating

Altimetric crossover can be used as **virtual current meter**



The use of coastal altimetry with other sensor allows to:

- Cross-calibrate the observation data
- Assess and better understand the physical contents
- Increase the space/time sampling of the processes

A important step should consist in **adopting an integrate approach** by combining model and observations in order to better understand the phenomenoly of the processes.

But are regional model sufficiently realistic ?
On which space/time scales ?

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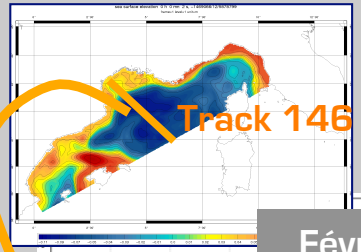
Altimetry and coastal models

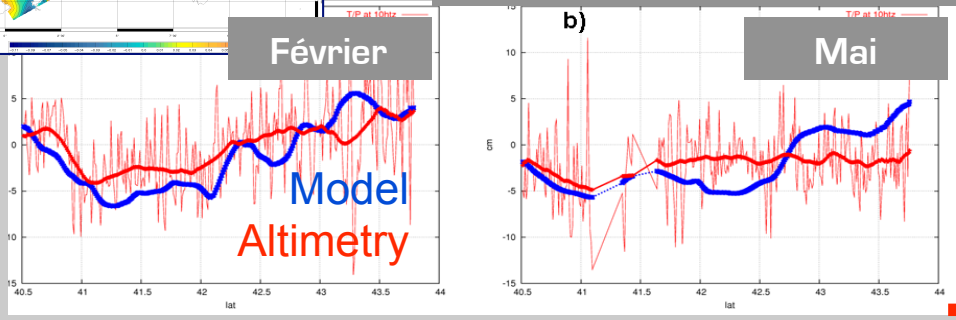
Validation of the Symphonie Model

Comparaison of spatial patterns

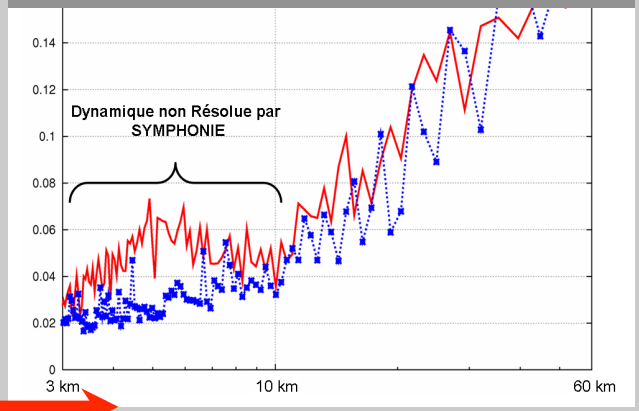


From *Bouffard et al.*, 2008 a (TAO)

Along-track comparisons

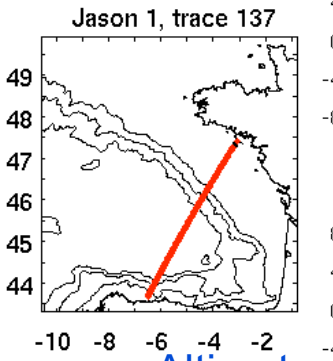


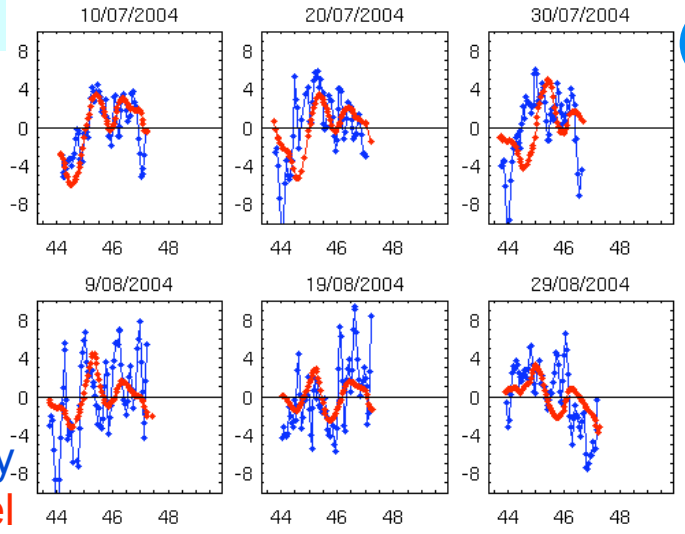
Spatial along track Spectrum



Med

From *Le Henaff et al.*





NEA

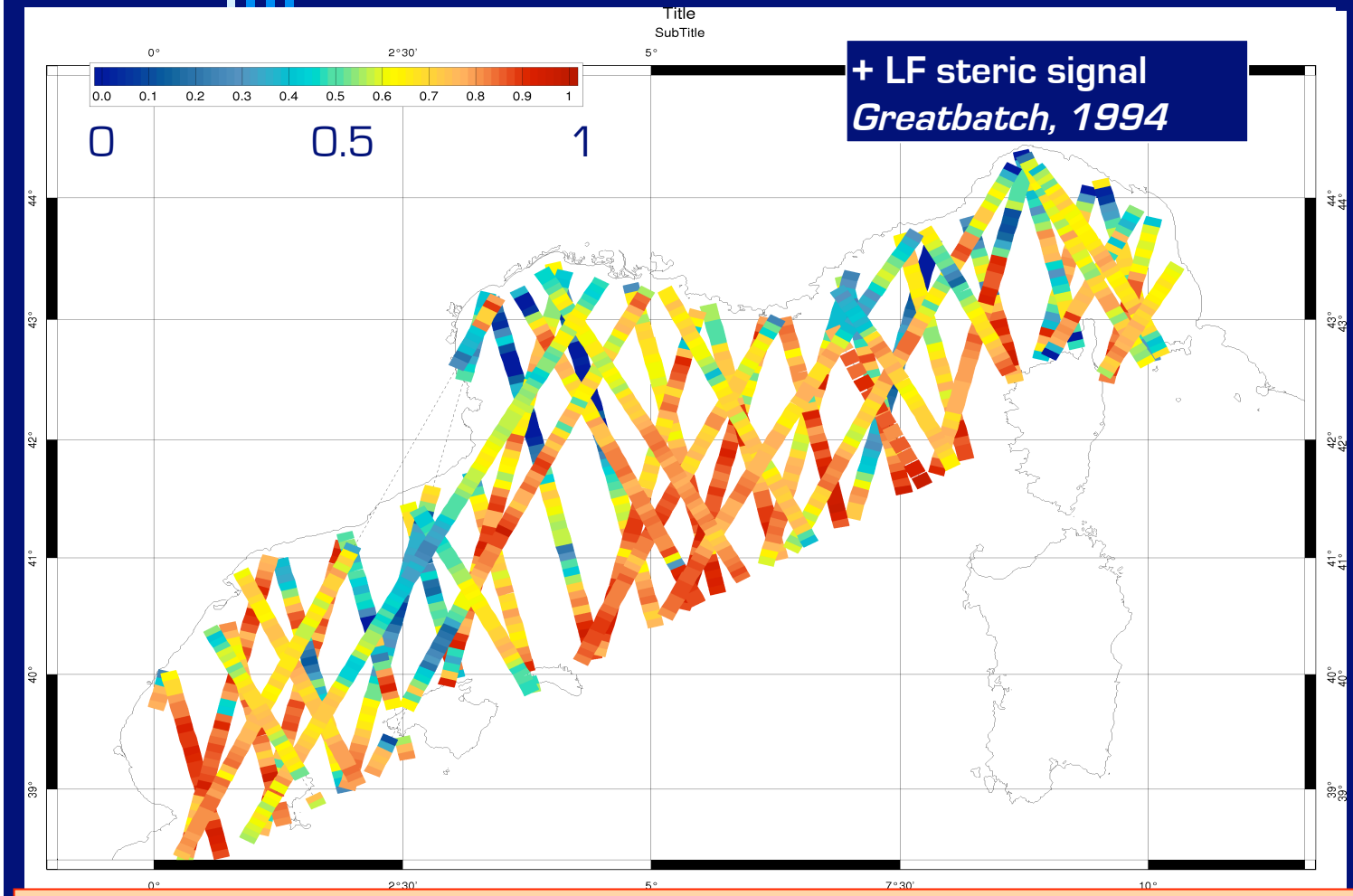
- Good **agreement** with the Symphonie model on spatial **scale greater than 50 km**.
- Very **small spatial scales** (<13 km) are **not reproduced by the model**
- Dynamics **between 13 km and 60 km** is only **reproduced statisticaly**

Altimetry and coastal models

Validation of the Symphonie Model

comparison of time series

From *Bouffard et al.*, 2008 a (TAO)



Correlation - 2001
SYMPHONIE model elevations – **altimetry SLA**: **TOPEX + GFO**

Correlation - 2002
SYMPHONIE model elevations – **altimetry SLA**: **Jason + GFO**

Correlation - 2003
SYMPHONIE model elevations – **altimetry SLA**: **Jason + GFO + Envisat**

Importance of the steric signals when compared sea level Obs./ Boussinesq model
Good agreements on instantaneous sea levels (at seasonal scales)
Some disagreemments close to the coast due to probleme at BC

Conclusion and Perspectives

- In-situ and remote-sensing data can be used as references to evaluate and thus improve coastal altimetric products.
- Cross-comparisons also allow to assess the dynamic content of altimetry and then better analyze coastal processes.
- The merge of data can be perform to study some specific coastal dynamics but models are key tools that have to be used in order to really understand the phenomenology of processes
- Coastal models are good for seasonnal and interannual signals but efforts should be done to improve meso-scale and sub-mesoscale representativity (only satisfying statistical agreement).
- Integrate approach combining models and multi-sensors data is the key to study coastal dynamics (*ie* through assimilation experiments). It is however a crucial issue to evaluate the potential synergy between data and models (in terms of physical contents & spatial and temporal scales of variability) before merging and/or constraint models

Many thanks to Ananda and…

…F. Birol, S. Vignudelli, L. Roblou, L. Fenoglio-Marc, M. Cancet, M. Le Henaff, K. Madsen, P. Garreau, J.J. Benjamin Martinez & P. Bonnefond …

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