# Investigation of Coastal Processes by HF Radars: Two Case Studies in Tidal and Micro-Tidal Sea

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Case 1: Surface circulation in the Iroise Sea from HFR observations (tidal)

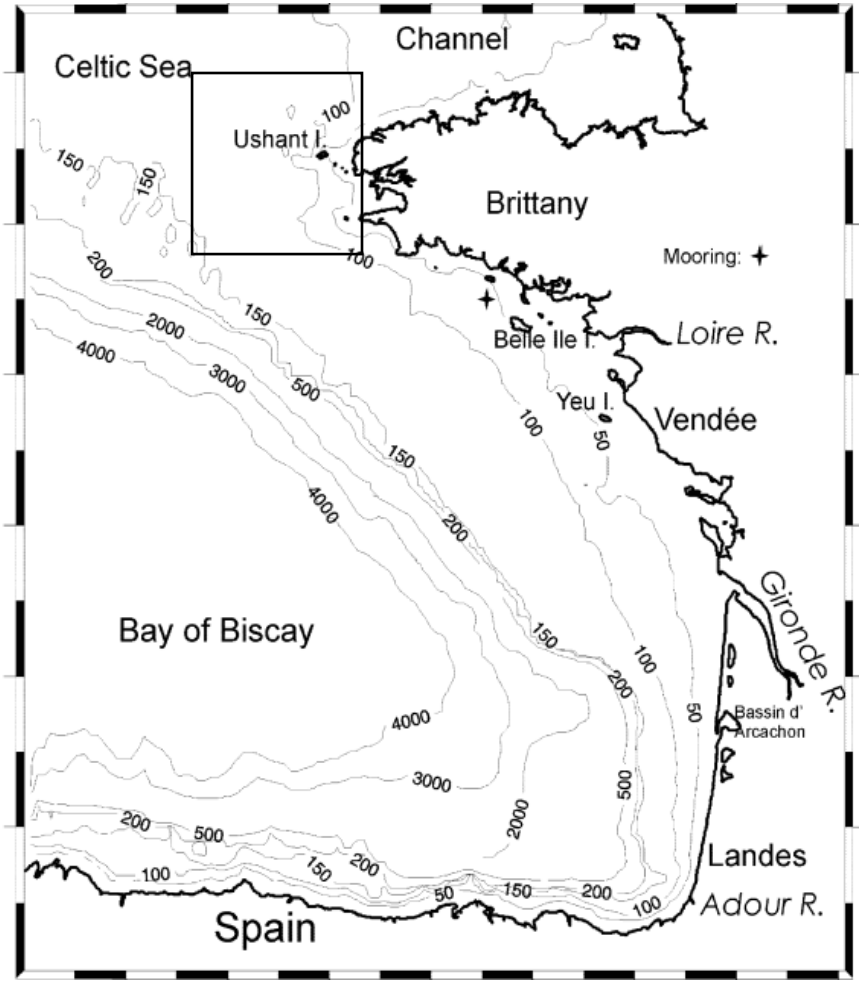
Case 2: thermocline destruction from HFR and in situ measurements (micro-tidal)

# Case 1: Surface circulation in the Iroise Sea from HFR observations (Tidal)

Frame of research program program EPIGRAM

"STUDY OF OCEANIC PHYSICAL PROCESSES IN THE BAY OF BISCAY AND THE CHANNEL"

funded by ANR 2009-2013



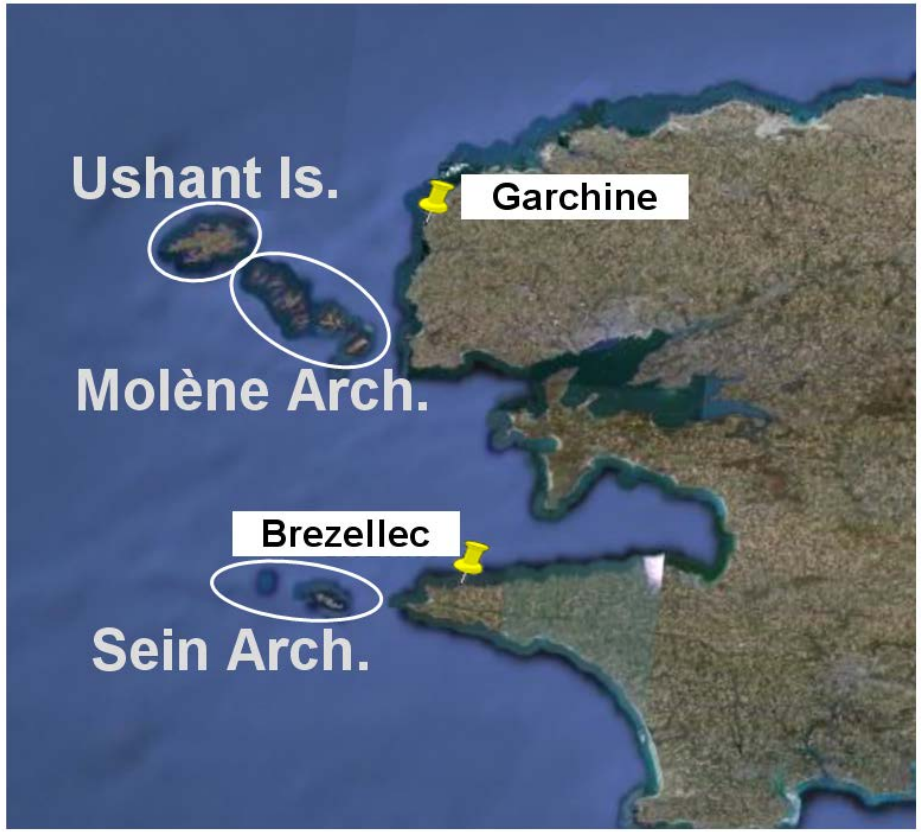

<u>Main goals</u>

☞ to improve our comprehension of the dynamical processes of the continental shelf and margins in Manche and Golfe de Gascogne

☞ to improve the ability of the numerical models to represent them

*Sentchev A., Forget P., Barbin Y., Yaremchuk M. 2011. Surface circulation in the Iroise Sea (W. Brittany) from high resolution HF radar mapping, J. Marine Systems, in revision*

# Site and radar implementation

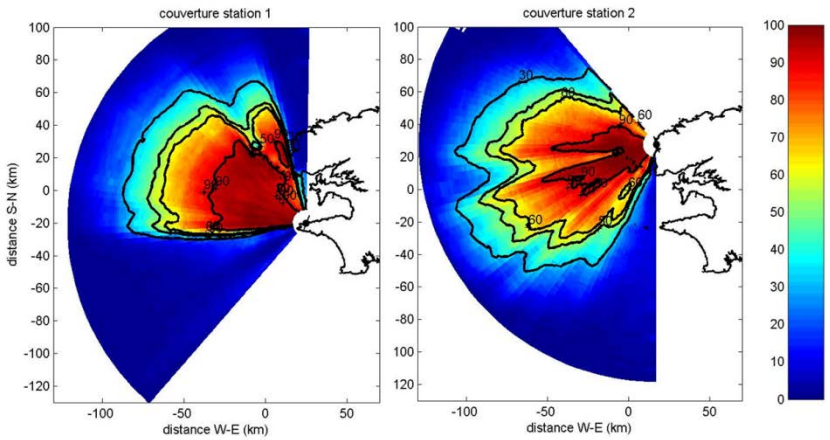



## Iroise radars

- 12 MHz
- long time series (from 2006 to date)
- time resolution: 1/3 h
- resolution: 1.5 km along beam

  2° in azimuth

coverage per range pixel %



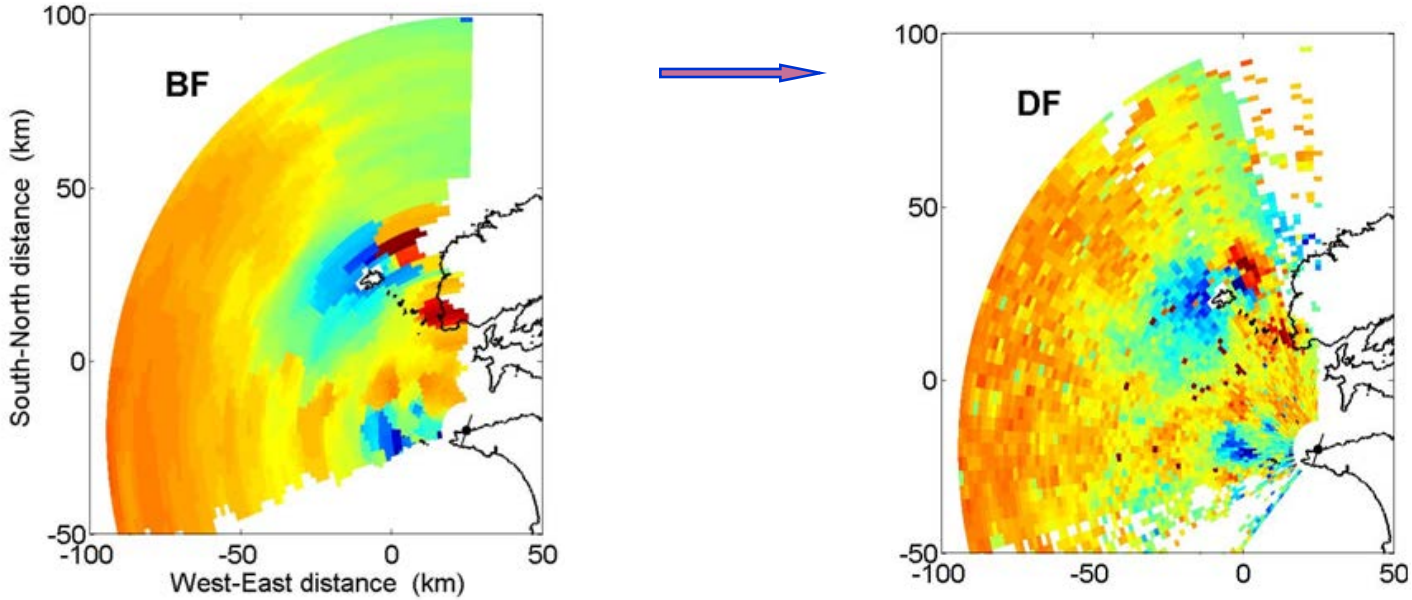
# Advanced radar current data

## I - MUSIC processing

MUSIC is a method of source direction finding: at a given distance, get azimuth corresponding to a given $V_{Doppler}$

<u>Main advantage</u> : to provides high resolution radial velocity maps, better than traditional beam forming

<u>Outcomes</u> : noise, holes in pixel fields



# II - 2dVar interpolation + EOF-based gap-filling method

## Step 1 : Gap-filling

iterate

**Filling the gaps $\Gamma^n$:**

- compute zeroth-approximation to C:

$$C_{ij} = \overline{(v_i - \bar{v}_i)(v_j - \bar{v}_j)}; \qquad \overline{\varphi_i \varphi_j} = \frac{1}{N_{ij}} \sum_{n=1}^{N} \varphi_i^n \varphi_j^n$$

- expand $v(\mathbf{x}_k \in \Omega \setminus \Gamma^n)$ in $K_s$ modes of C:

$$\text{find } \alpha_i : \sum_{\mathbf{x}_k \in \Omega \setminus \Gamma^n} \left[ v(\mathbf{x}_k) - \sum_{i=1}^{K_s} \alpha_i^n e_i(\mathbf{x}_k) \right]^2 \to \min_{\alpha_i^n}$$

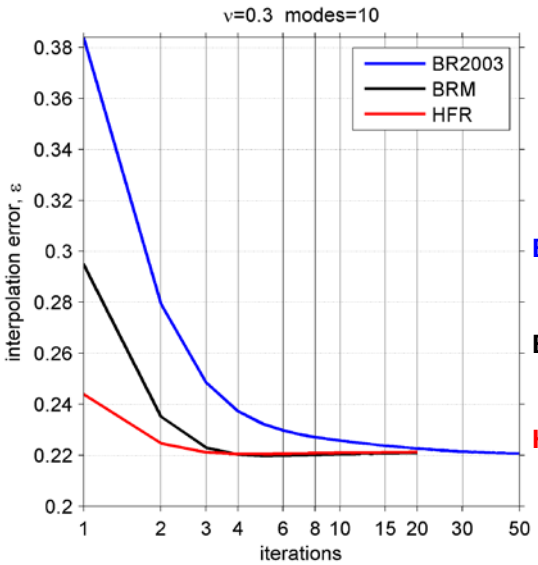
- fill the gaps $\Gamma^n$ using these expansions:

$$v^*(\mathbf{x}_k \in \Gamma^n) = \sum_{i=1}^{K_s} \alpha_i^n e_i(\mathbf{x}_k \in \Gamma^n)$$

- estimate the time-mean approximation error in $\omega$:

$$\varepsilon^2 = \frac{1}{N} \sum_{n=1}^{N} \frac{\sum_{\mathbf{x}_k \in \omega} \left[ v^*(\mathbf{x}_k) - v(\mathbf{x}_k) \right]^2}{\sum_{\mathbf{x}_k \in \omega} v^2(\mathbf{x}_k)}$$

- compute new C using the filled data set




**Approximation error decrease vs iteration**

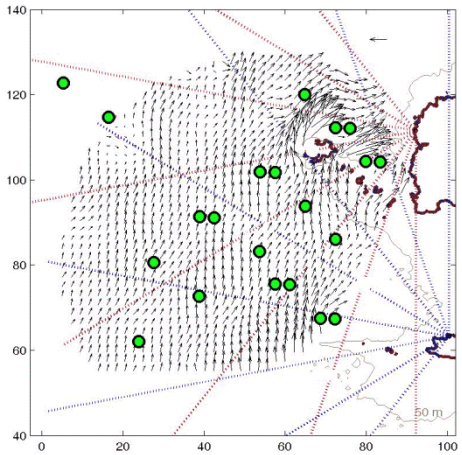
**BR03:** Beckers & Rixen (2003) – gaps filled with zeroes on 0th iteration

**BRM:** same as BR03, but with traditional covariance estimate on 0th iteration

**HFR:** BRM with EOF expansion

**HF radars Iroise sea**

**Check points for time-mean error estimation: update 3 times/hr**

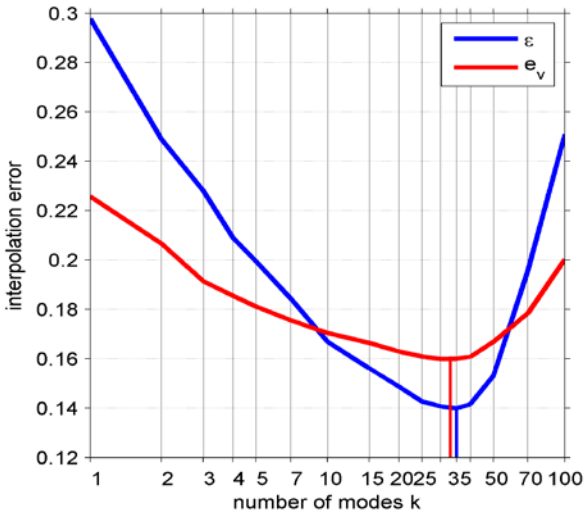



*Yaremchuk & Sentchev, CSR 2011*

## Step 2: S/N separation scheme

-Determine the noise level using EOF analysis for radial velocity covariance matrix, C

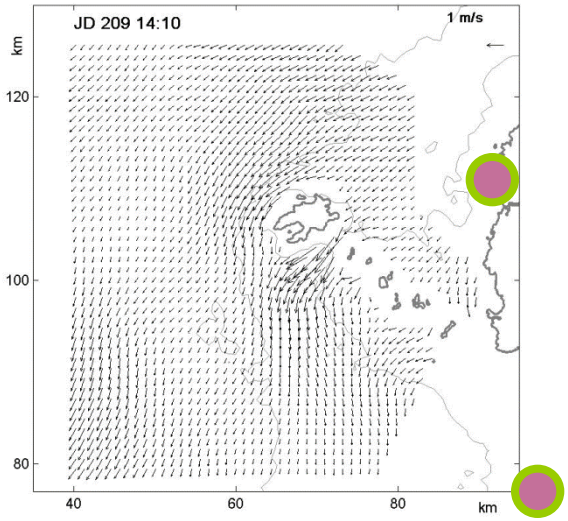
-Interpolation error is minimal for 33 modes (example). Corresponding velocity error variance is 5.2 cm/s

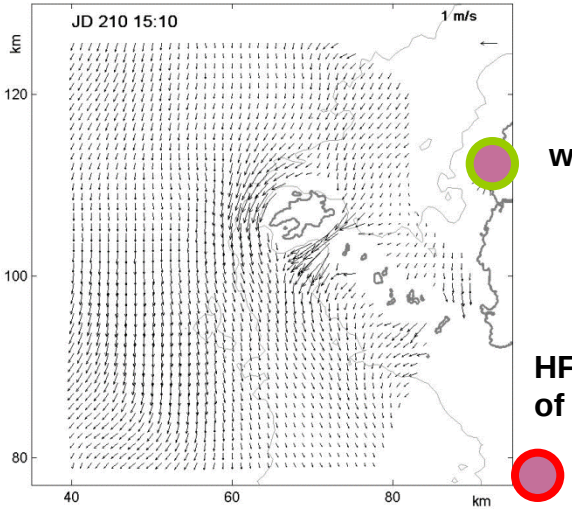



## Step 3 : Variational interpolation

**Example**

Currents over 1 tidal cycle: mapping by 2 radars (left) and 1 radar (right)



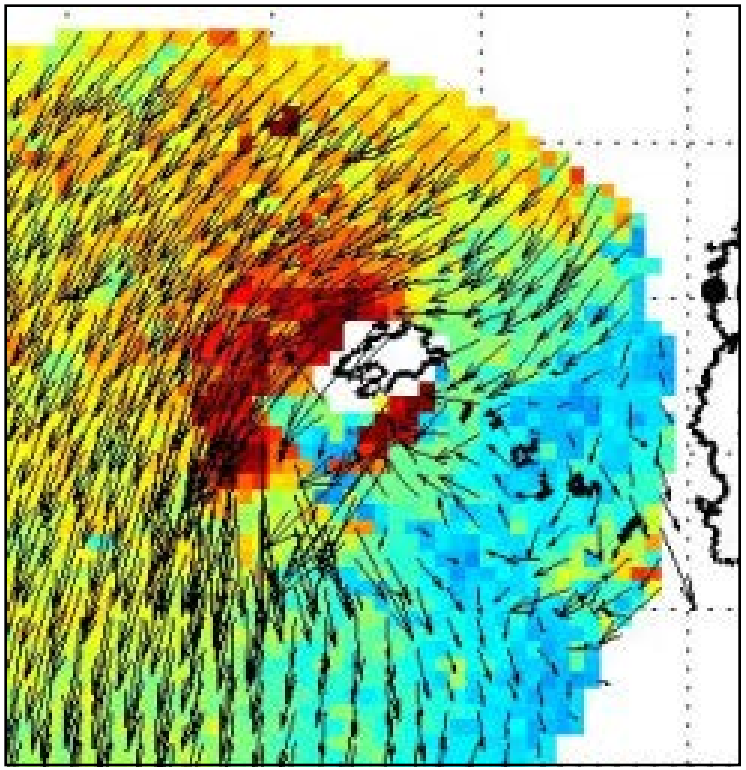



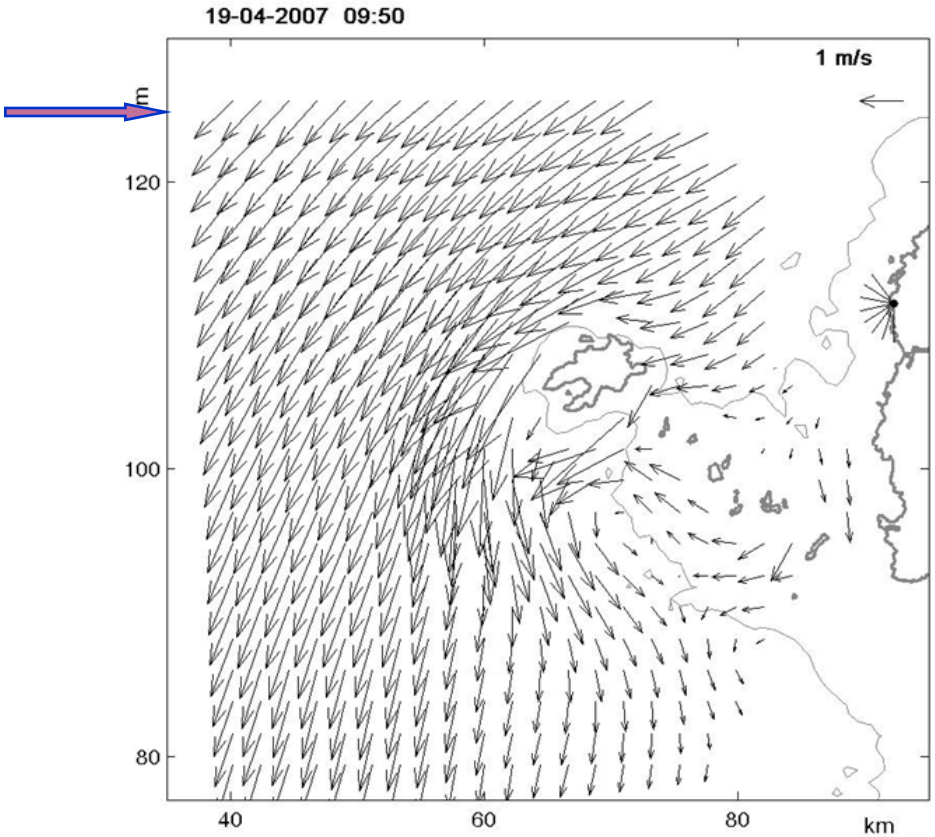

**working station**

**HFR station is out of order this day**

raw current map

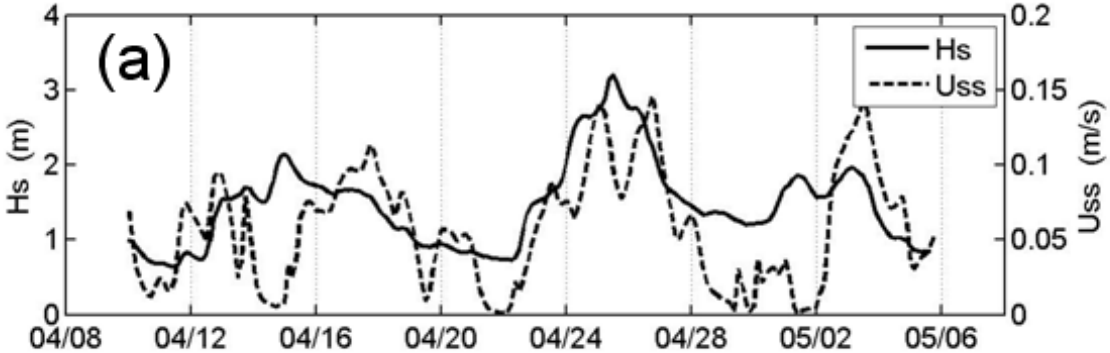
with 2DVar/gap filling

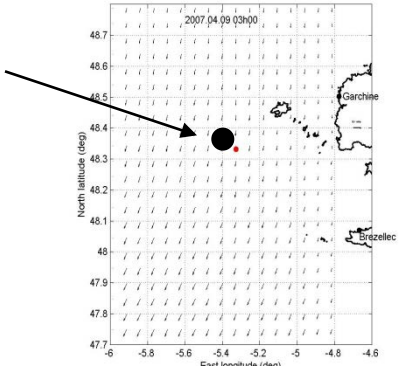


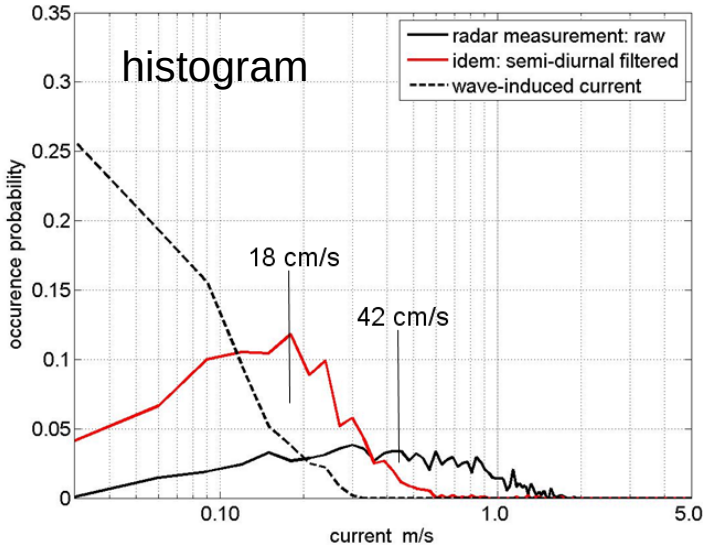


# III - Wave influence correction

Wave induced current ($U_{ss}$) and significant waveheight ($H_s$) at point



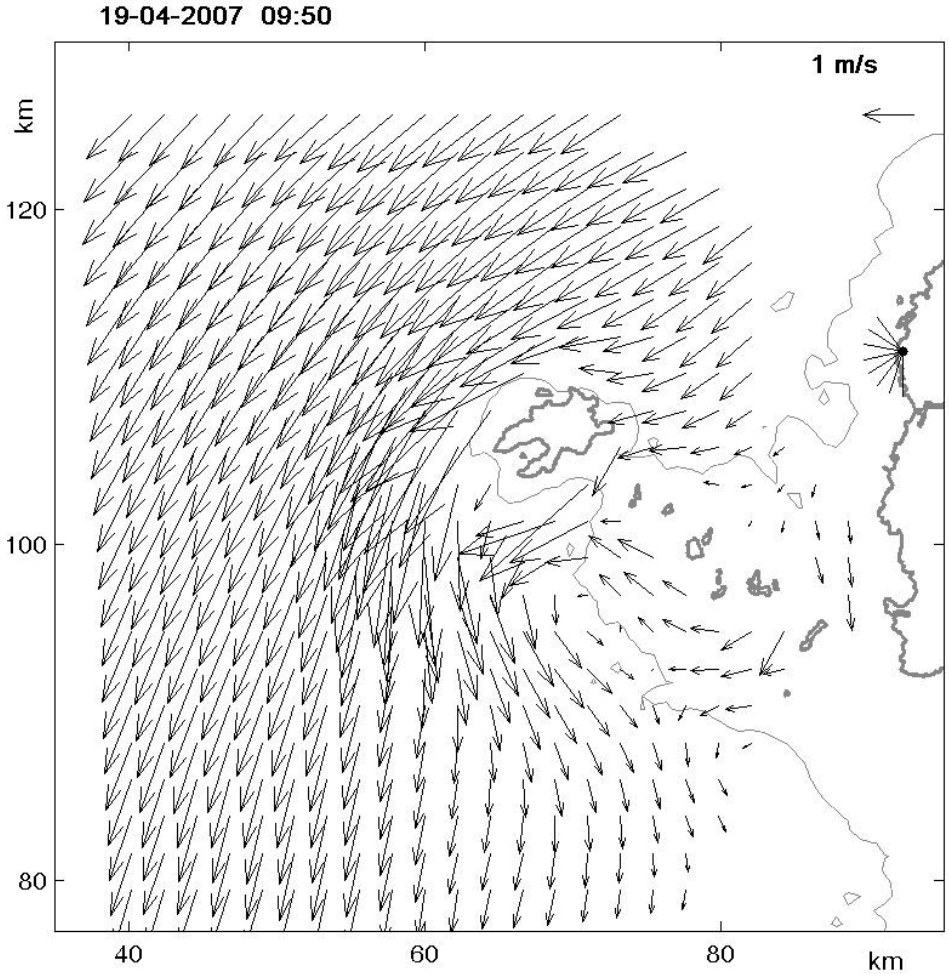




➔ weak but non-negligible contribution of wave-derived surface current for residuals

***Ardhuin F., Marié L., Rascle N., Forget P. and A. Roland (2009). Observation and estimation of Lagrangian, Stokes and Eulerian currents induced by wind and waves at the sea surface. J. Phys. Oceanogr. 39(11) pp. 2820–2838.***

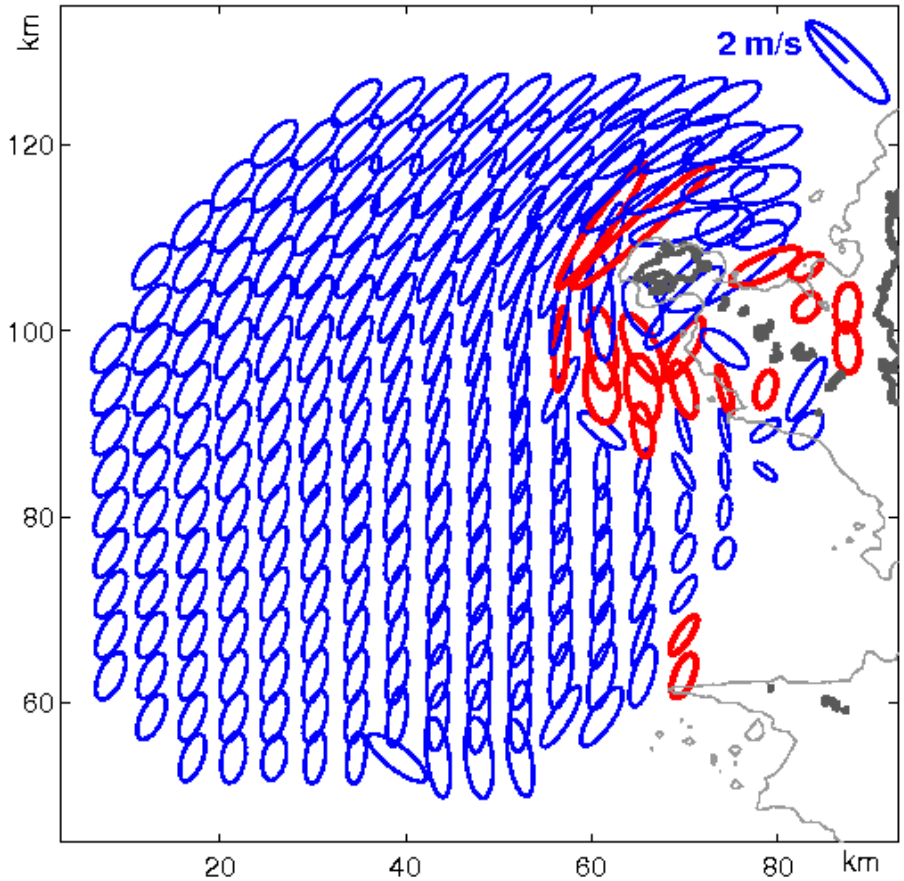
# Recent results of circulation in Iroise Sea

One tidal cycle from April 18, 2007: 21h10 to April 19: 09h50



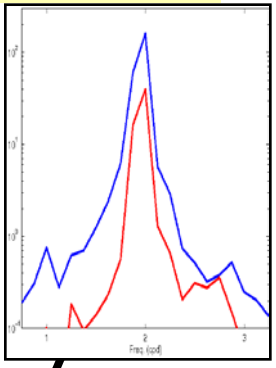
# Tidal currents

Derived synthetic ellipses during primary spring tide (7-d averaged )



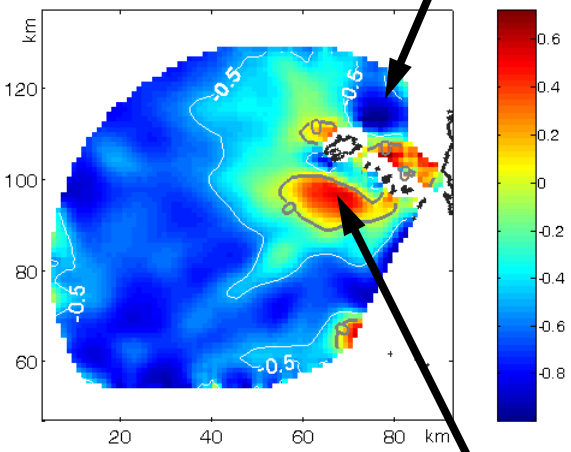

**red: ccw rotating current vectors**
**blue : cw rotating** (anticyclonic)

Rotary power spectra



rotary coefficient

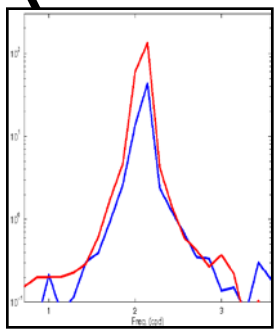
$$r = \frac{S^+ - S^-}{S^+ + S^-}$$



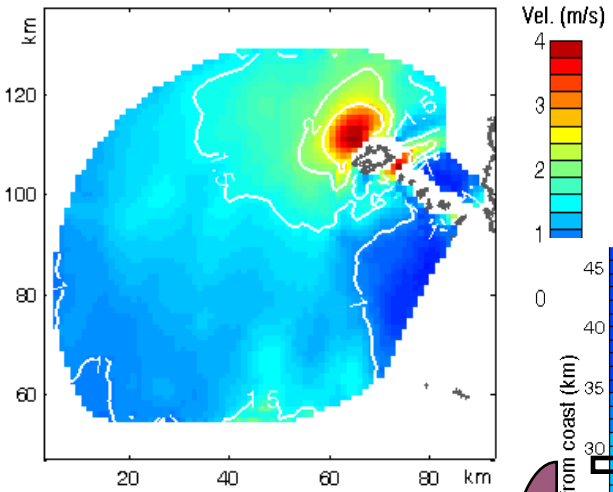

***r* < 0 for cw motion**

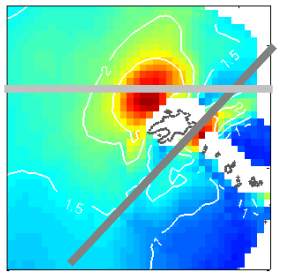
***r* > 0 for ccw motion**

***r* = 0 for unidirectional flow**

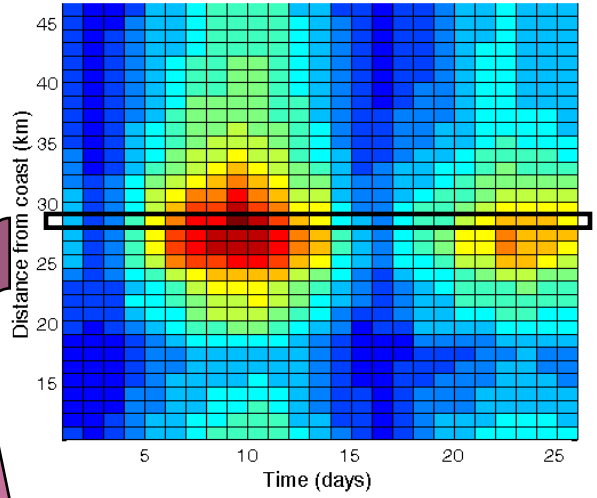


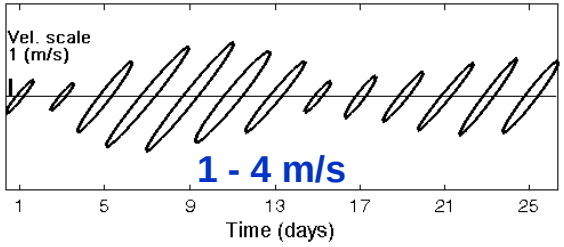
# Time/Space variations of the amplitude of tidal currents 10 Apr – 5 May 2007



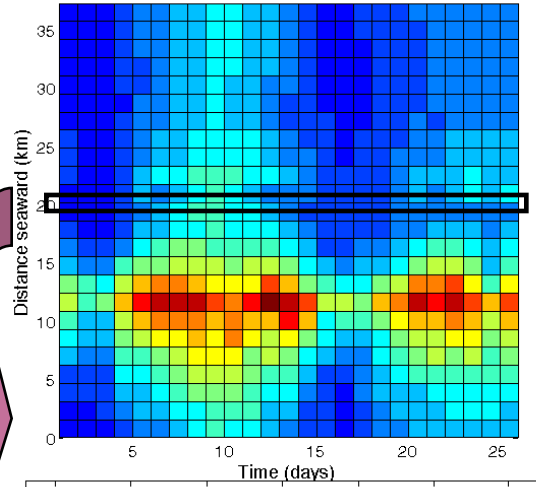



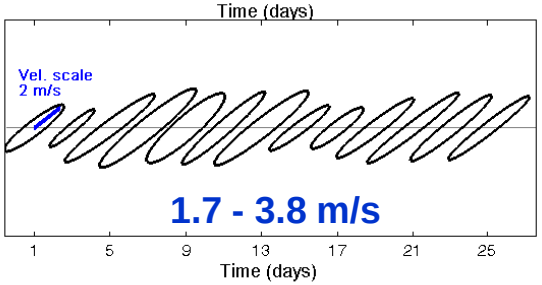
**W-E line**




**SW-NE line**




*Spatial variability*

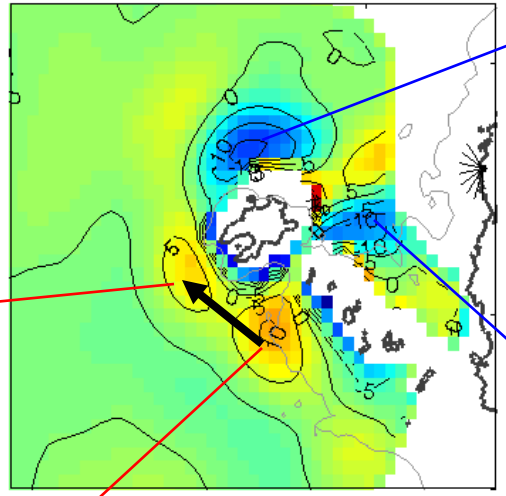
*Max* velocity 0.7 - 4 m/s
*Min* velocity 0.2 - 1.7 m/s

| Tidal constit. | M2 | S2 | N2 | M4 | MS4 | 2MN6 | M6 | 2MS6 |
|---|---|---|---|---|---|---|---|---|
| A: Ushant | 1.74 | 0.92 | 0.47 | 0.15 | 0.16 | 0.06 | 0.06 | 0.08 |
| B: Fromveur | 2.09 | 0.83 | 0.35 | 0.12 | 0.09 | 0.12 | 0.16 | 0.20 |

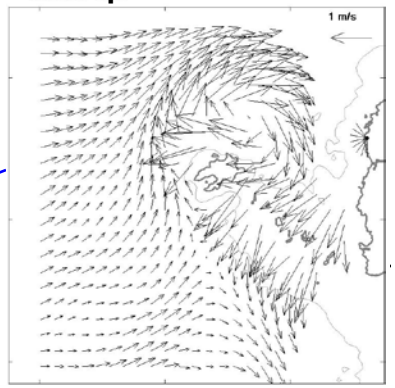
# Tidally generated eddies

***Flood***

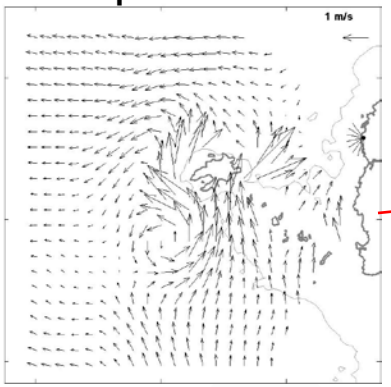
Average vorticity field (25 days)



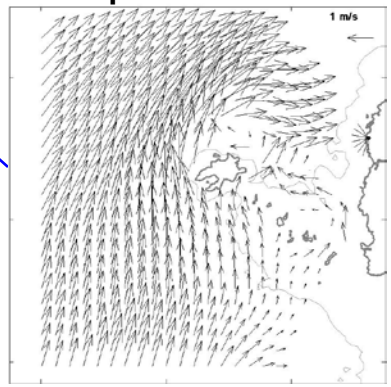
April 19 06:10



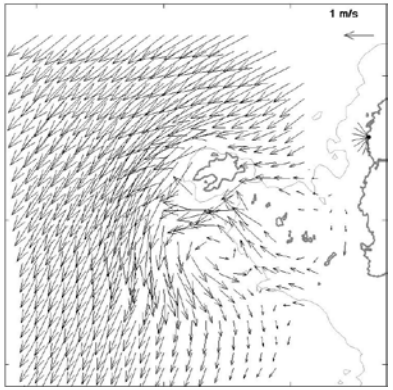

April 19 00:10

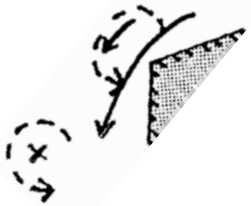



April 19 04:10




April 18 22:10



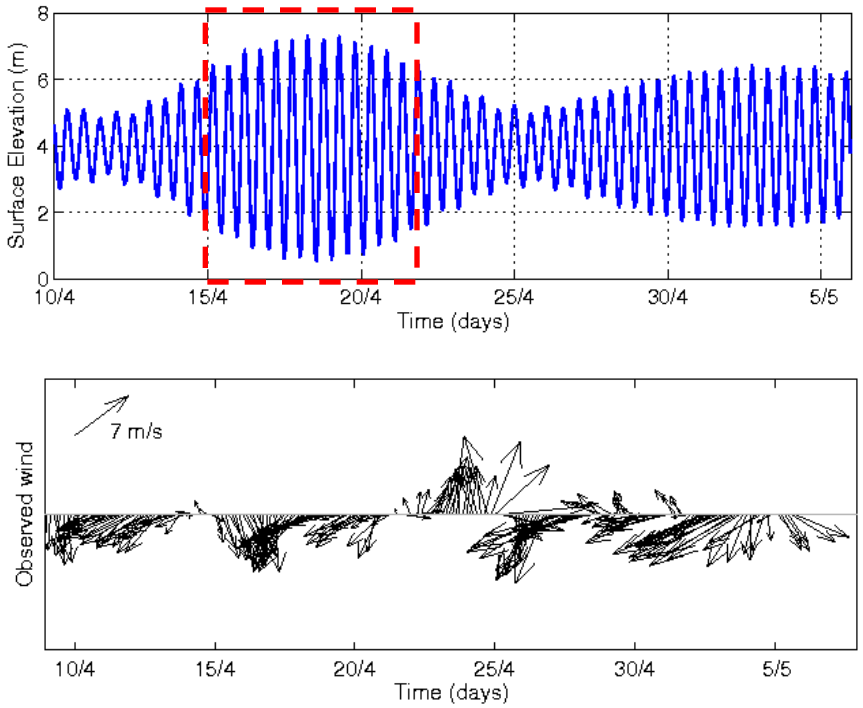



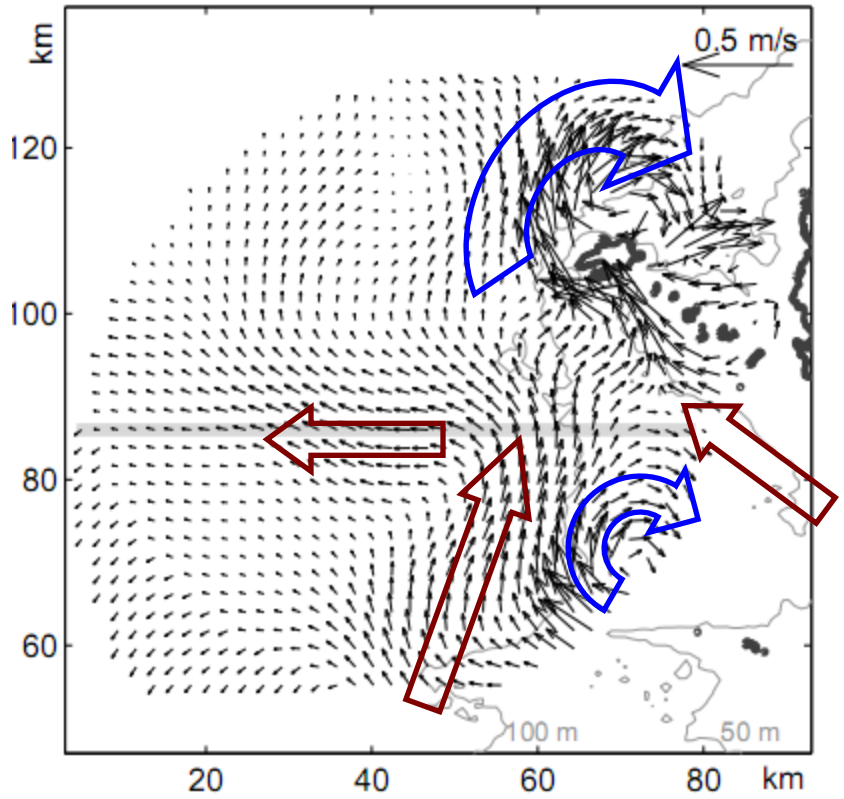
***Ebb***

- generation by bottom friction
- advection by tidal currents
- time-averaged vorticity of opposite sign appears on both sides of a cape or island

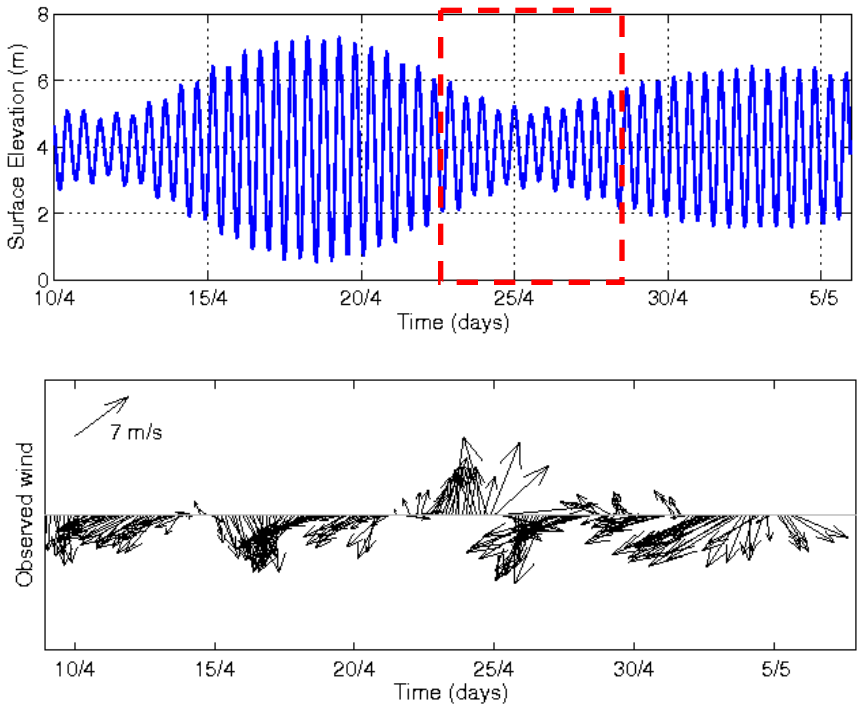
# Residual currents

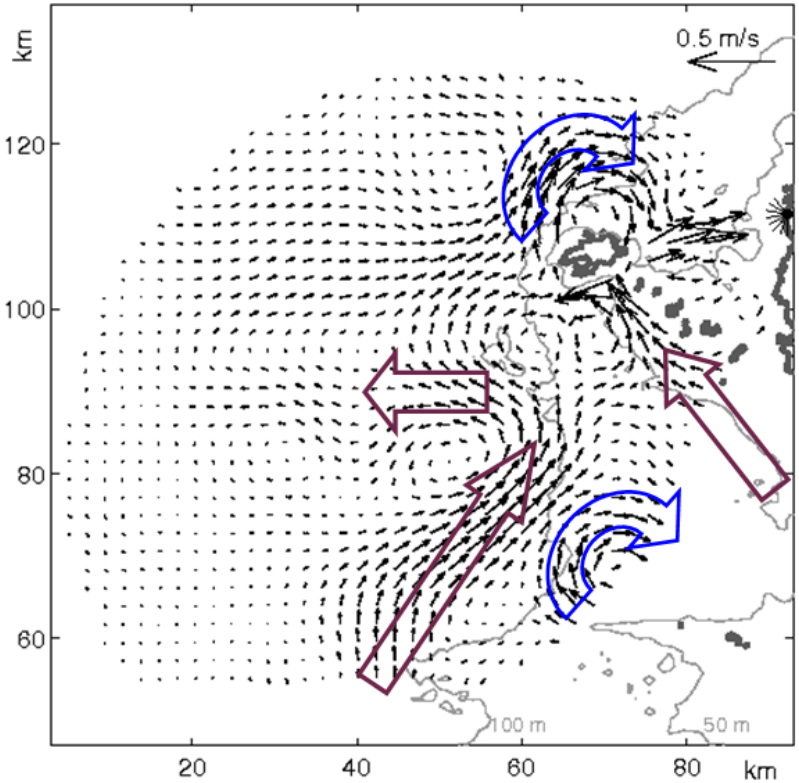
Spring



# Neap

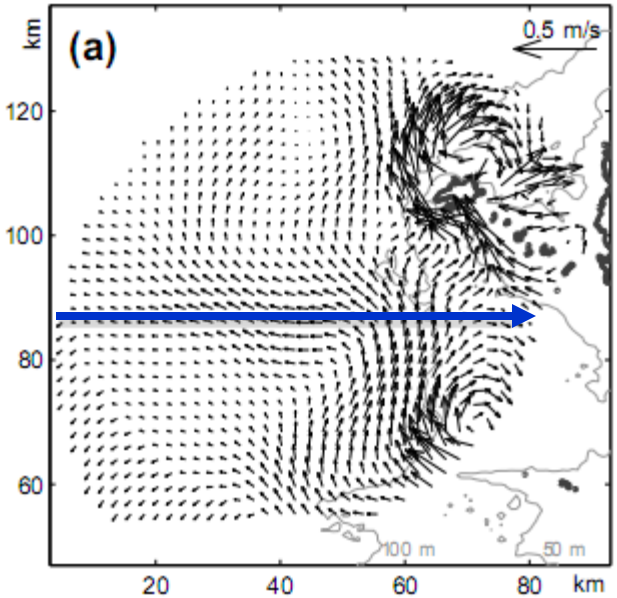


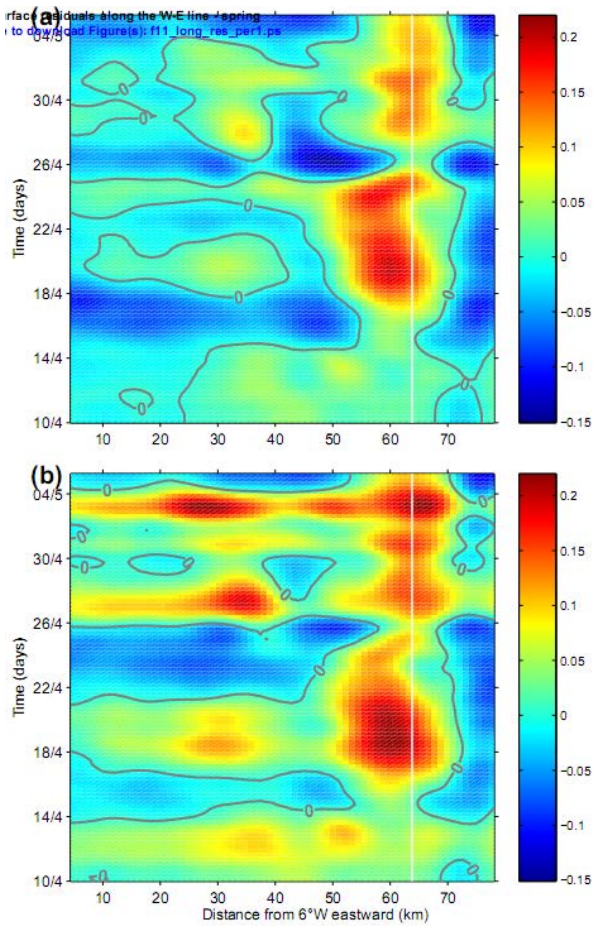




Features:
- high velocity values (up to 0.5 m/s)
- rotational field (permanent eddies)
- control of the RC by bathymetry
- off-shore and near-shore jets
- pronounced fortnightly variability

# mid-spring : 10 Apr – 5 May 2007

de-tided current



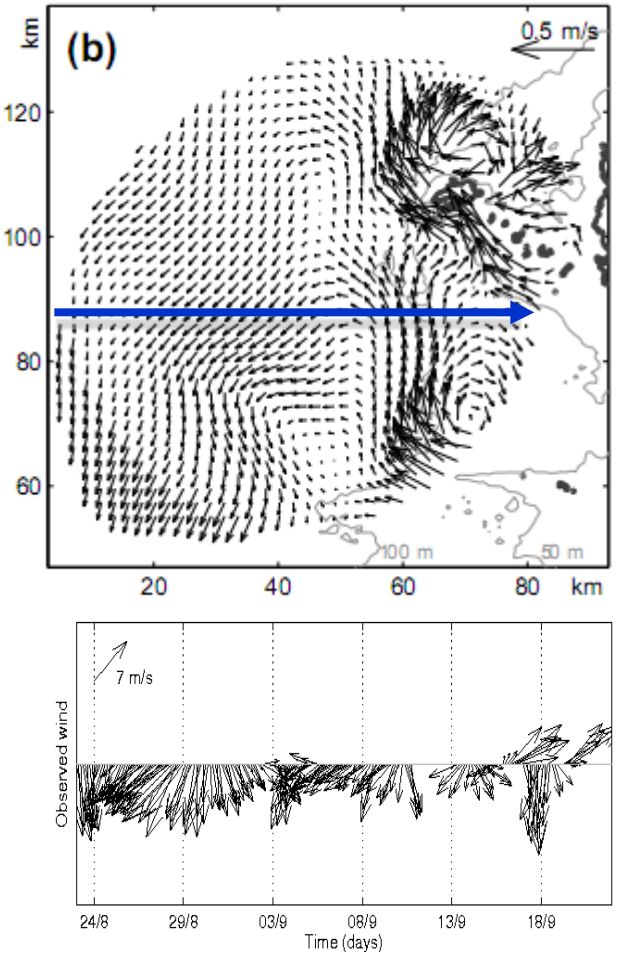

de-tiding: diurnal, semidiurnal, inertial filtering => 1% variability left

wind influence: Prandle-Matthews method 1990

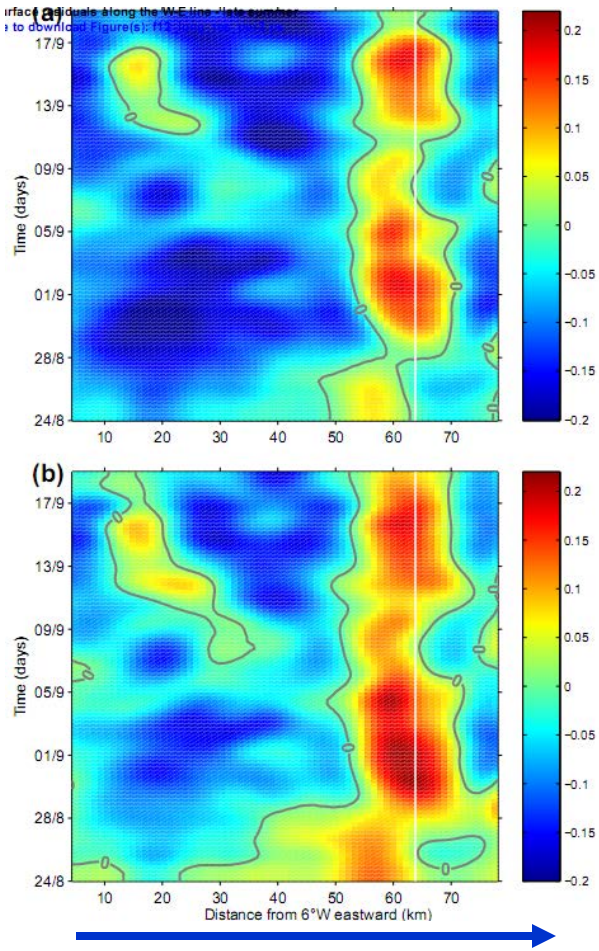
de-tided current minus wave & wind influence

# late summer : 24 Aug – 19 Sep 2007

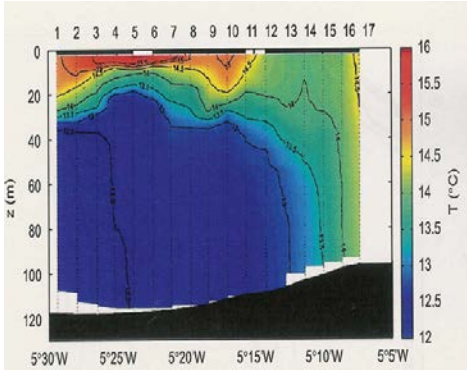
## Ushant thermal front



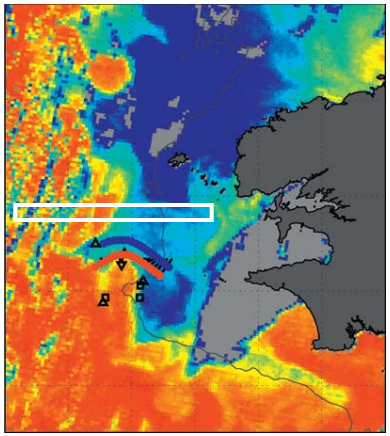

de-tided current




**Temp. 48°N section on 14 Sep, 2007**
**(*Le Boyer et al., CSR 2009*)**




**SST on 14 Sep 2007 from MODIS**



de-tided current minus wave & wind influence

➔ **Signature of the Ushant thermal front**

# CONCLUSION

● sophisticated radar signal processing : DF, gap-filling, 2DVar, wave contribution

● radar data analysis provides a significant contribution to understanding the dynamics of the Iroise Sea

● quantitative estimates

- dipole structure of the currents
- polarization of tidal ellipses
- RC patterns
- fortnightly modulation of tidal currents NW of Ushant Island

● next research issues

- model validation/initialization
- interpretation of satellite images
- eddy & thermal tidal front dynamics
- high resolution Lagrangian circulation
- passive tracer dynamics

# Case 2: thermocline destruction from HFR and in situ measurements (Micro-tidal)

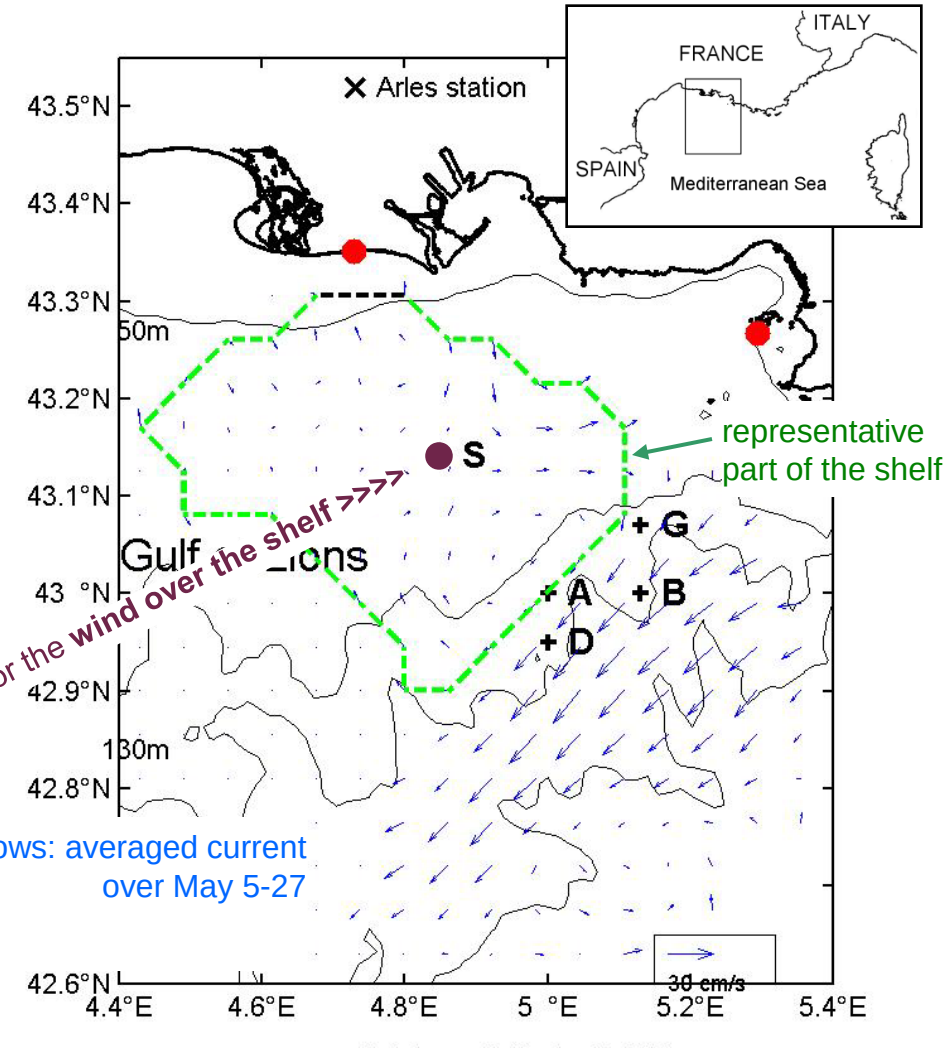
Radar data: 1.5 year experiment in 2005-2007)
2 WERA radar systems, frequency≈16MHz
MUSIC data processing

In situ data:

- ADCP's (stations A-B-G)
- RCM7 currentmeters (station D)
- MICREL thermistors (station D)
- met-stations

MM5 surface winds (3h)

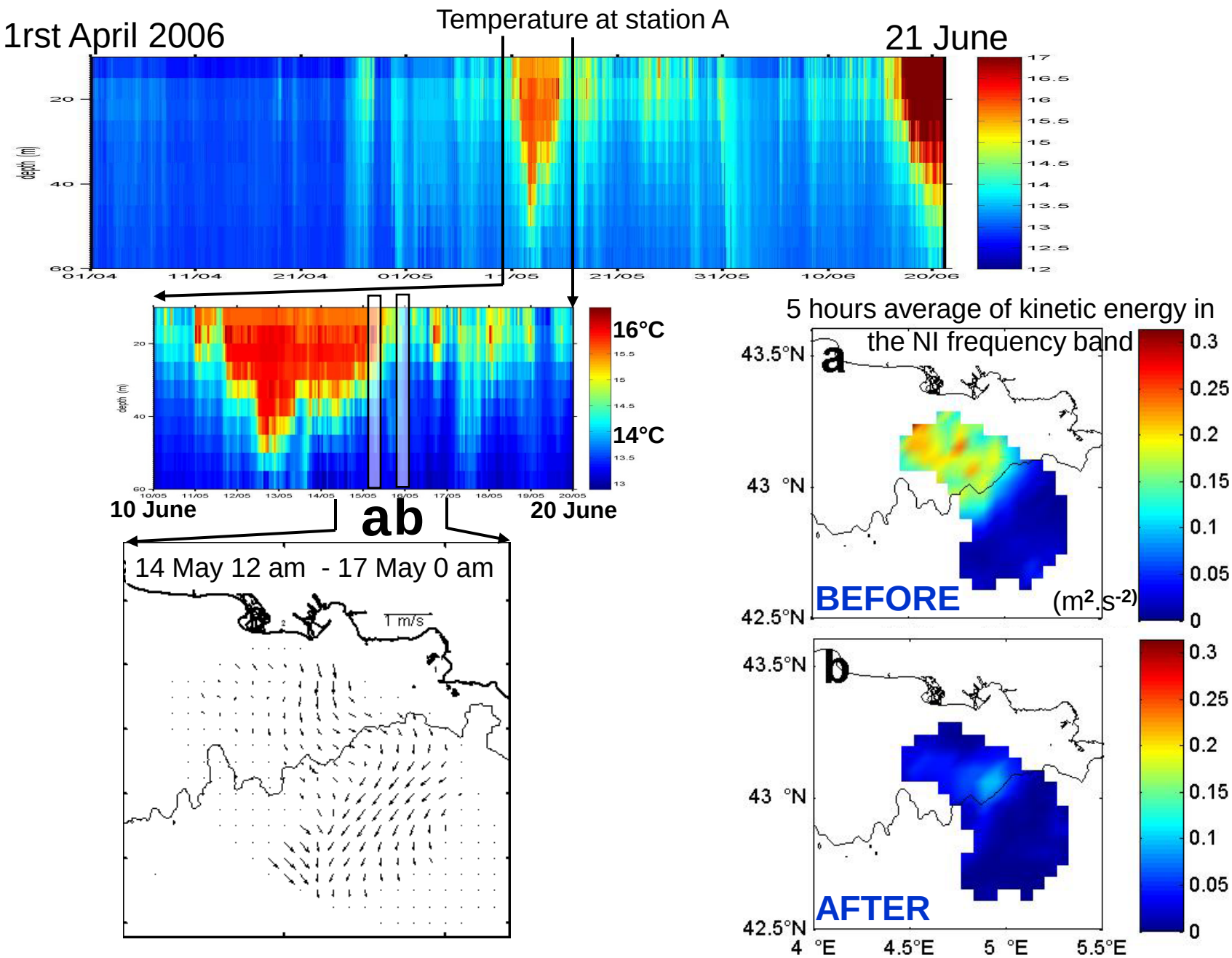
S=reference grid point for the **wind over the shelf >>>>**




blue arrows: averaged current over May 5-27

*Forget P., Shrira V., 2011. HF radar probing of seasonal stratification in the upper ocean, J. Phys. Oceanogr., submitted*

# OBSERVATIONS

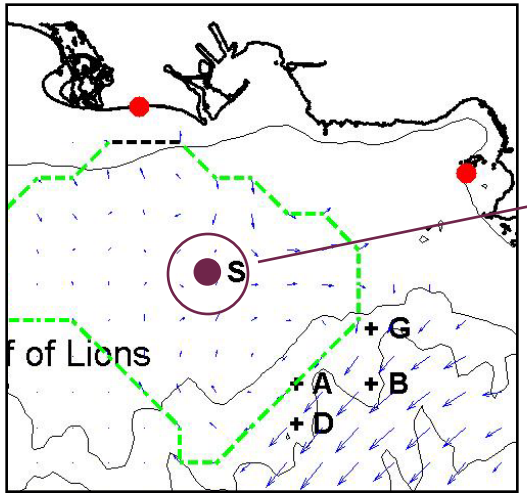


onset of inertial motions 14 May 8-9 pm

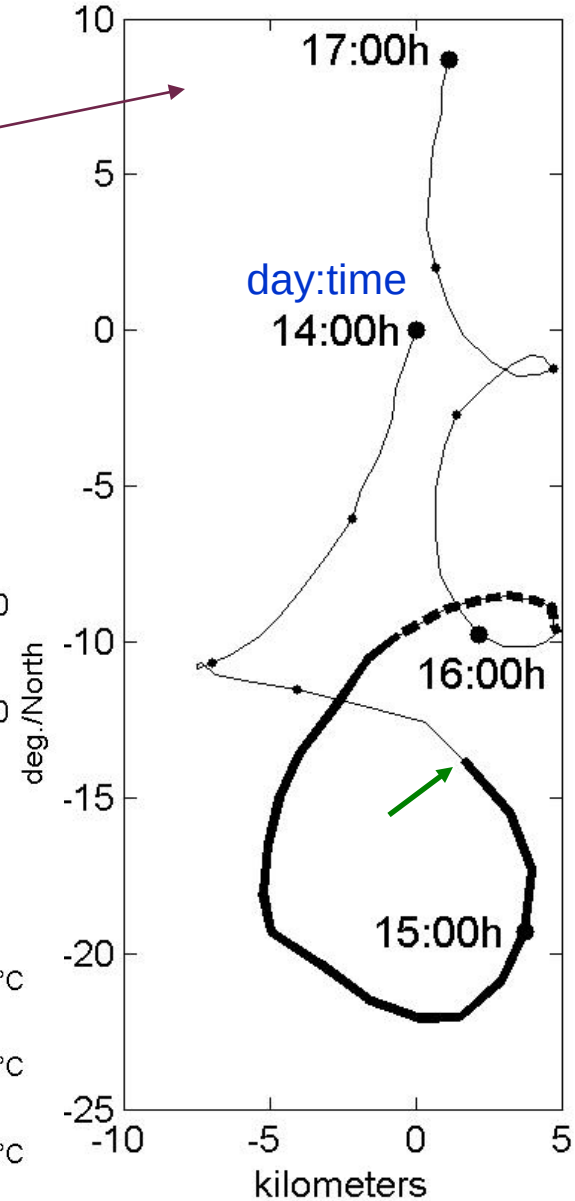
- wind veering
- wind relaxation
- non local generation

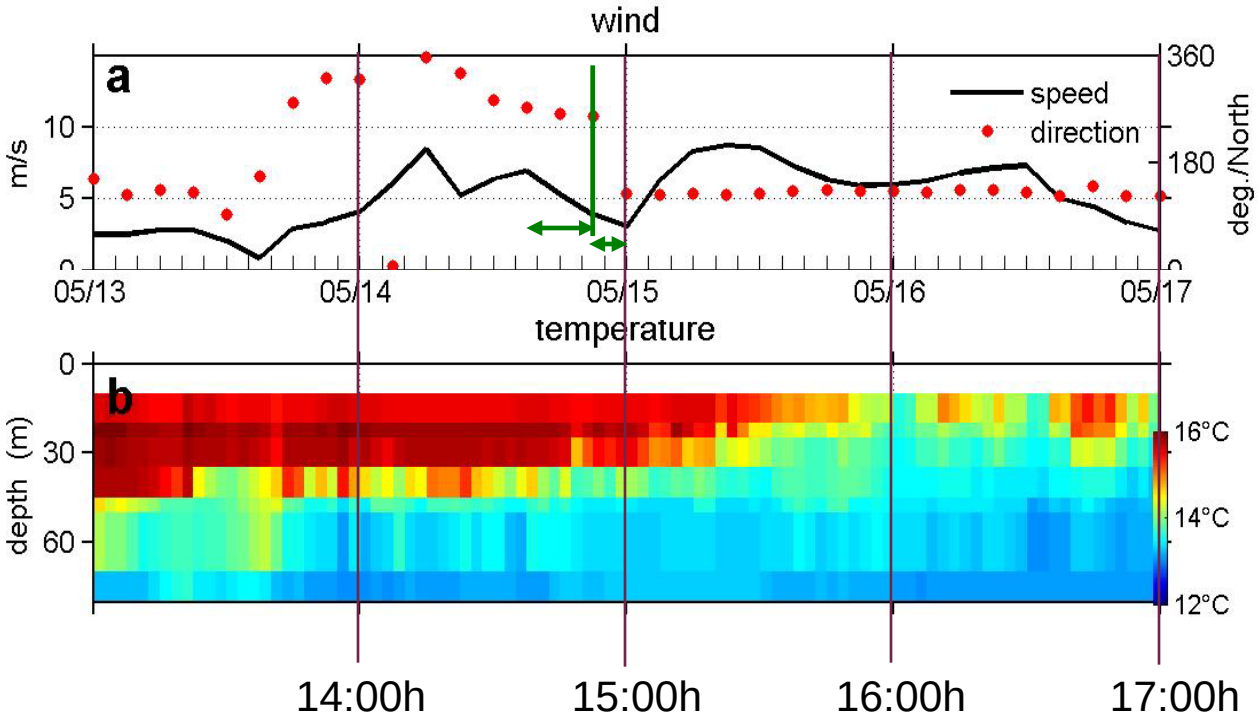
5 cycles of NIO's (until 18 May 2 pm)

Mean period = 17.8h (theoretical:17.5h)



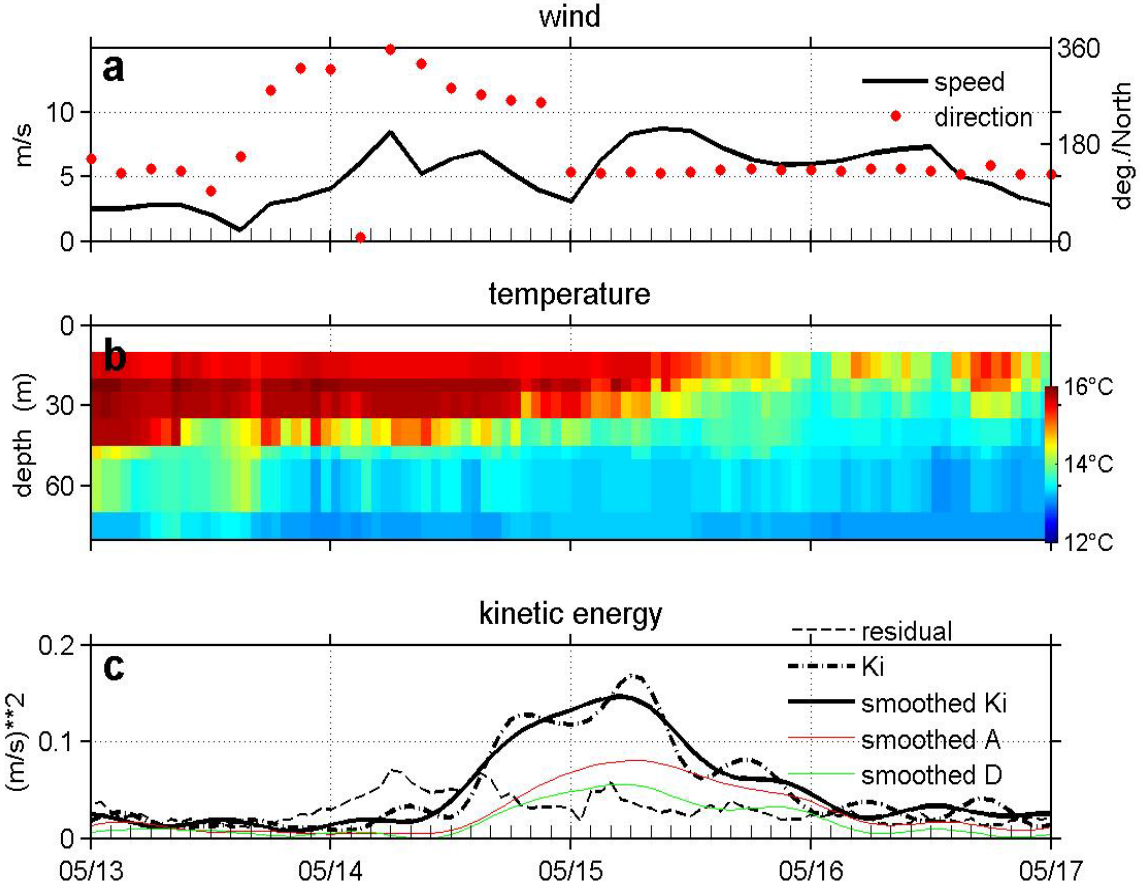

hodograph on the shelf



Variation of kinetic energy density in the NI fequency band from radar data

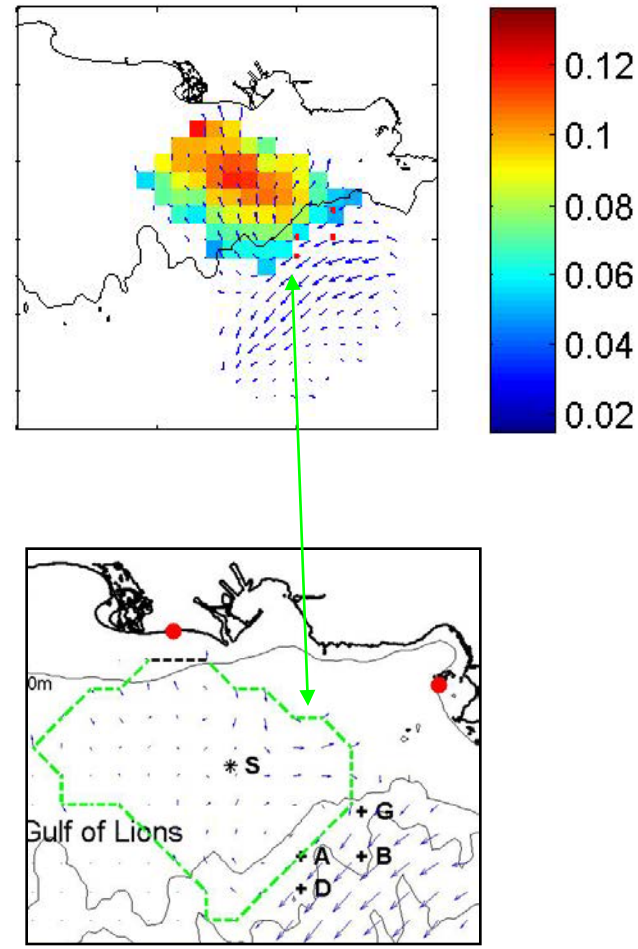
- at stations A and D – smoothed
- averaged over the shelf ( $K_i$ )
- residual: raw $K_i$ minus filtered $K_i$ at NIO's frequency



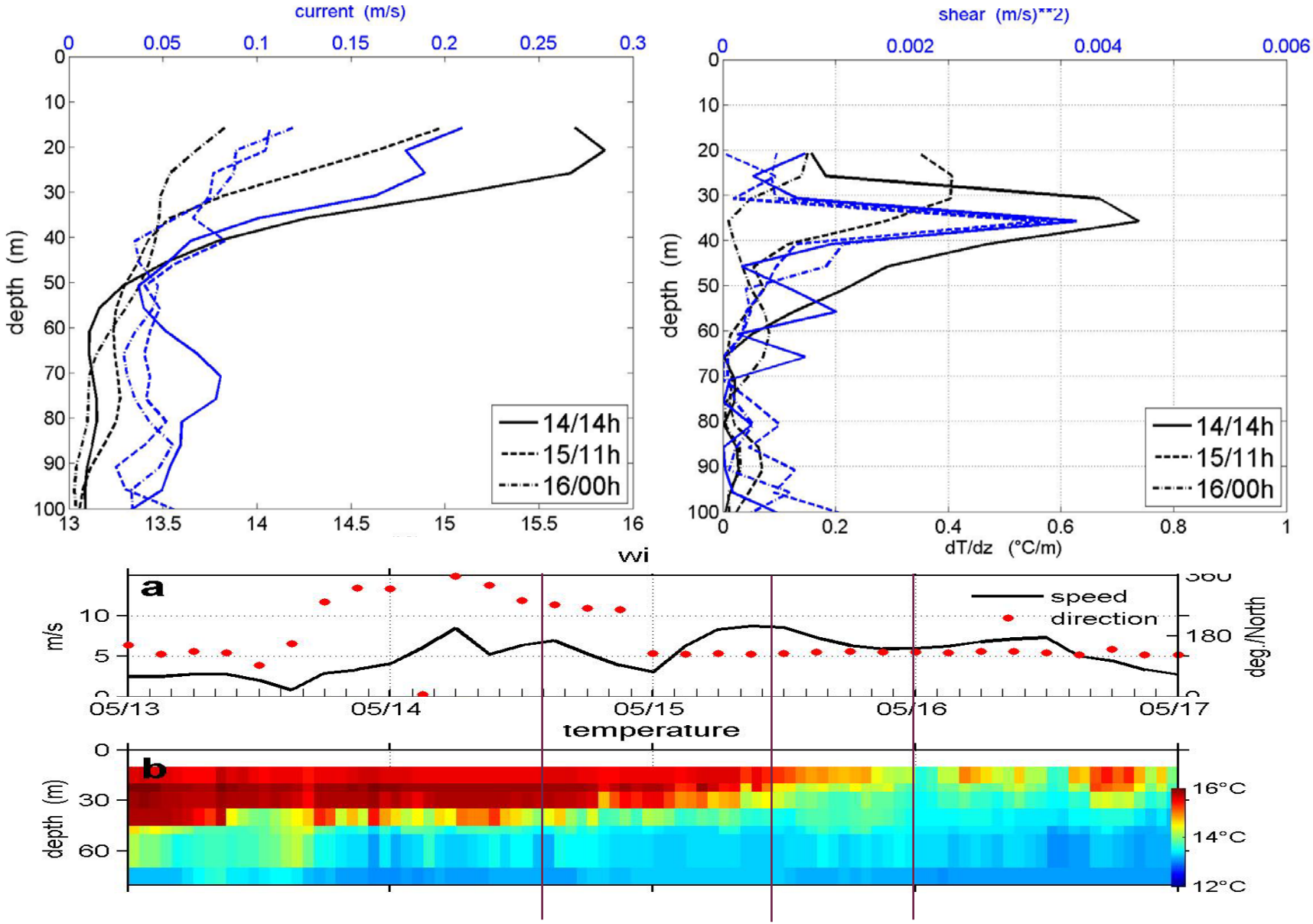

oscillations 0 1 2 3

thresholded variance (0.048 m²/s²)

period : 14 May 7 pm – 19 May 2 am

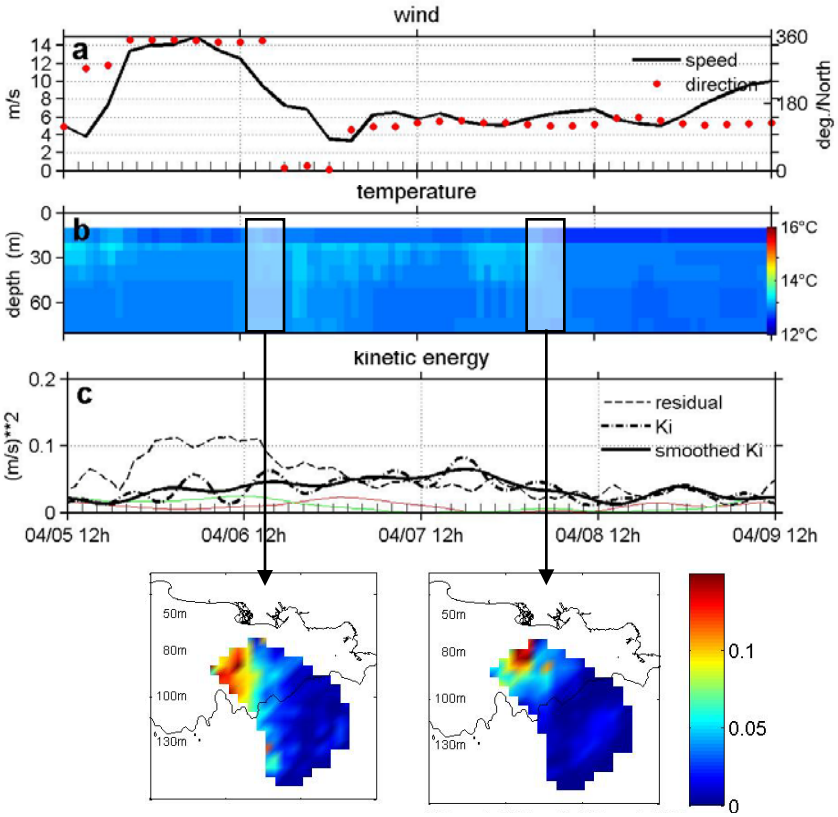


# Vertical profiles of current, temperature and gradients

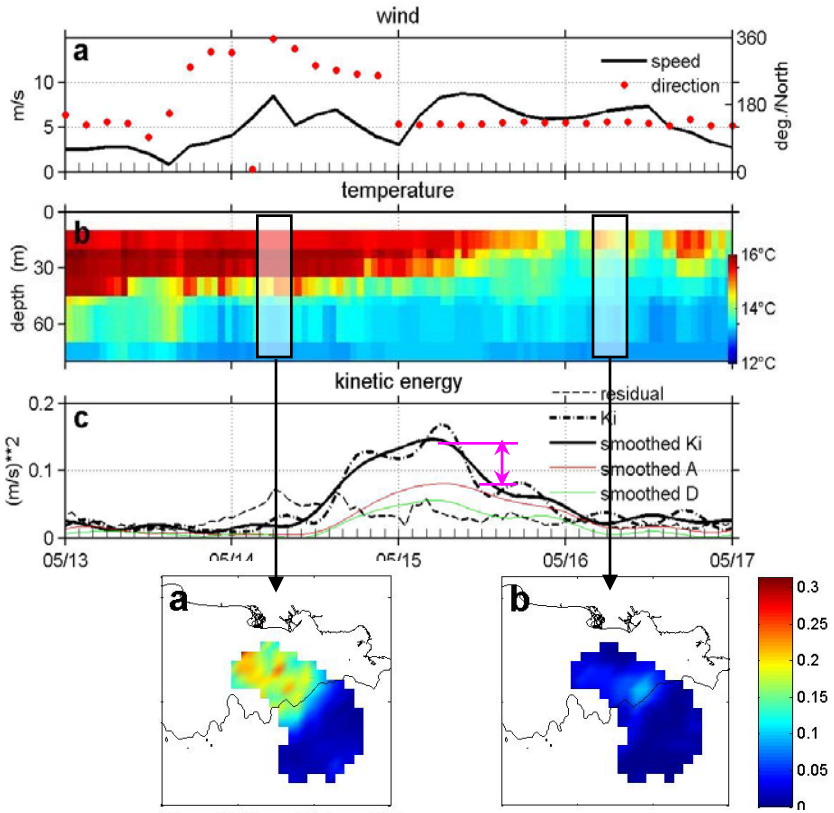


# Comparison without & with stratification

**WITHOUT:** April 05 - 09




**WITH :** May 13 - 17




- normalized kinetic energy in the NI band* $NK_i = 4.10^{-4}$
- spatial distribution: intensification in the shallow part of the shelf
- decay rate : low

- $NK_i = 2.10^{-3}$
- intensification over the whole shelf
- high

* $NK_i = \langle u^2 + v^2 \rangle \div W^2$

# CONCLUSION

● We suggest simple processing of surface velocity fields retrieved by HF radars to infer the presence/absence of seasonal pycnocline

● Basic idea: the dependence of the upper ocean response in the inertial band to sharp changes of wind on the mixed layer thickness or, in case of unstratified shallow waters, depth

● This opens a way for spotting mixing events important for vertical heat and mass exchange and biological activity

Remark : the approach was tested in non-tidal environment. Tidal and inertial frequencies must be separated, i.e. everywhere except for a vicinity of the critical latitudes