“Variability of surface transport in the Northern Adriatic Sea from Finite-Size Lyapunov Exponents"

ISTITUTO NAZIONALE
DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE

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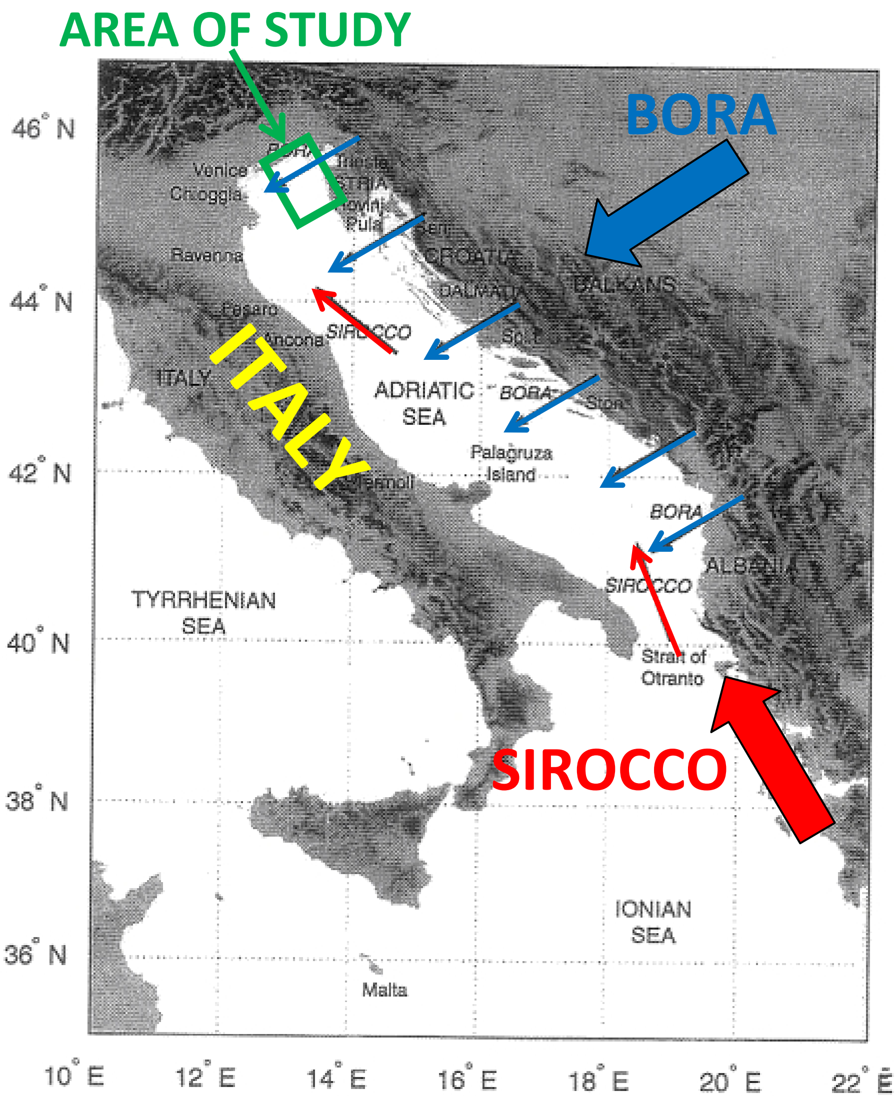
Marseille, 29 November 2011

Outline

- Geographical setting (winds and circulation of Adriatic Sea)
- Application of Finite-Size Lyapunov Exponent (FSLE) technique
- Transport from High Frequency (HF) radar currents
- Preliminary results for modeled currents
- Conclusions

Typical Wind events



(after Poulain and Raicich 2001)

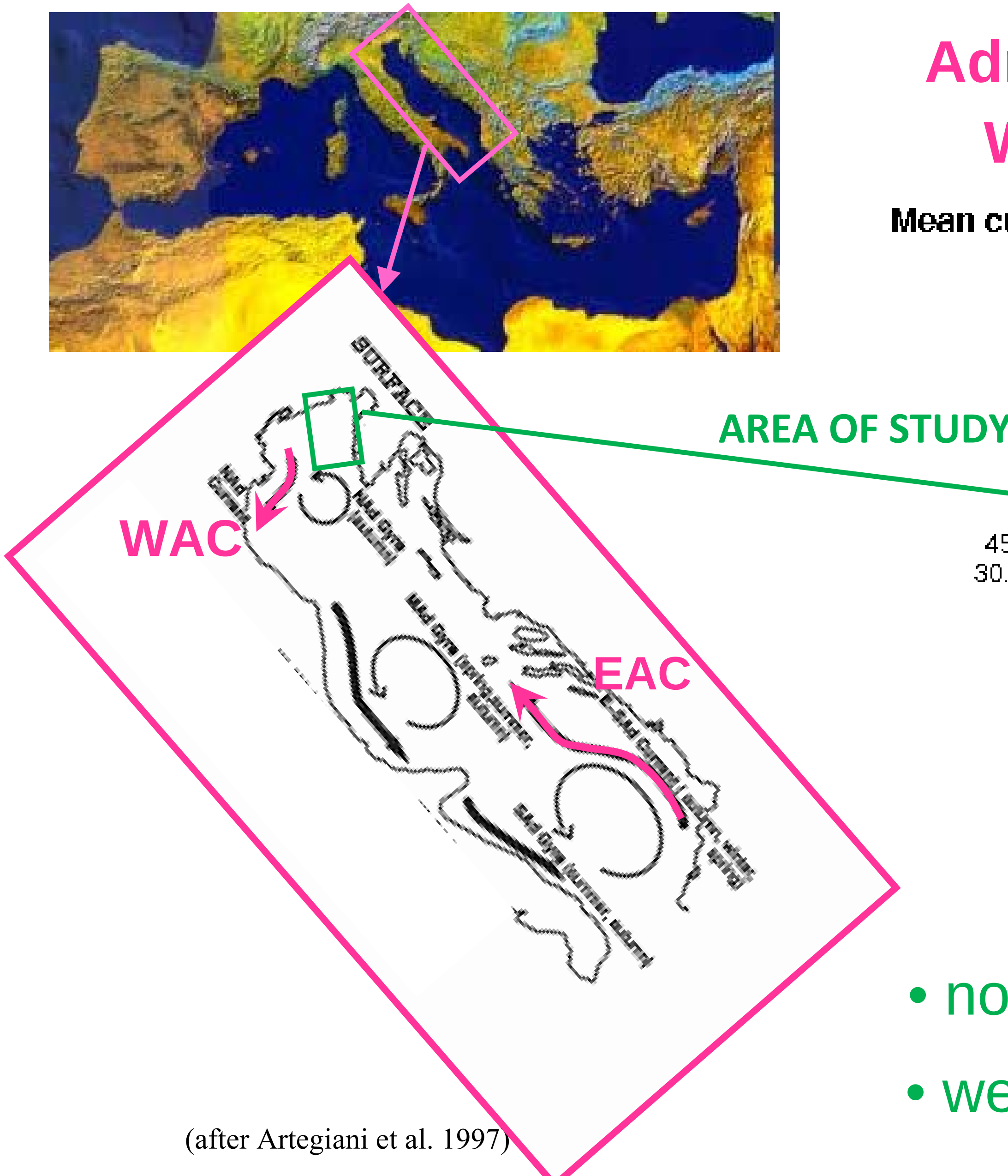
BORA

- Siberian katabatic wind (analogous mechanism of Mistral in GoL)
- blows from E-NE
- cold, dry and gusty
- 5 preferential entrances over the Adriatic

SIROCCO

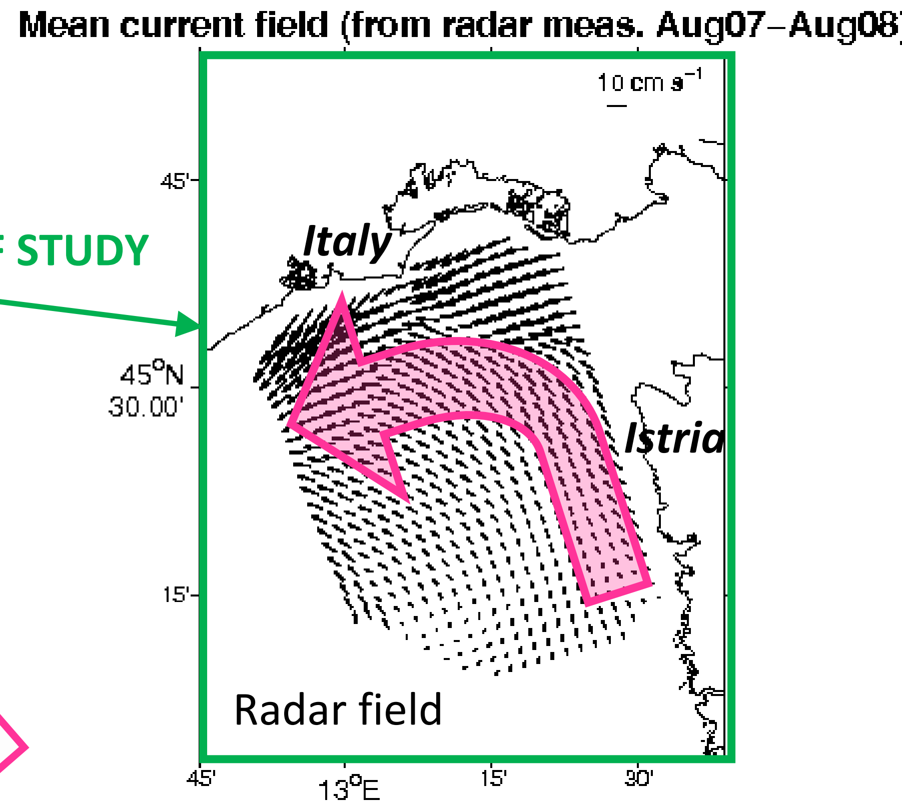
- Saharian wind pulled northward by low-pressure cell over Mediterranean Sea
- blows from S-SE
- warm, wet and steady

Adriatic Sea mean surface circulation



(after Artegiani et al. 1997)

Adriatic cyclonic pattern:
WAC / EAC system



- northward flow along Istria
- westward jet along Italy

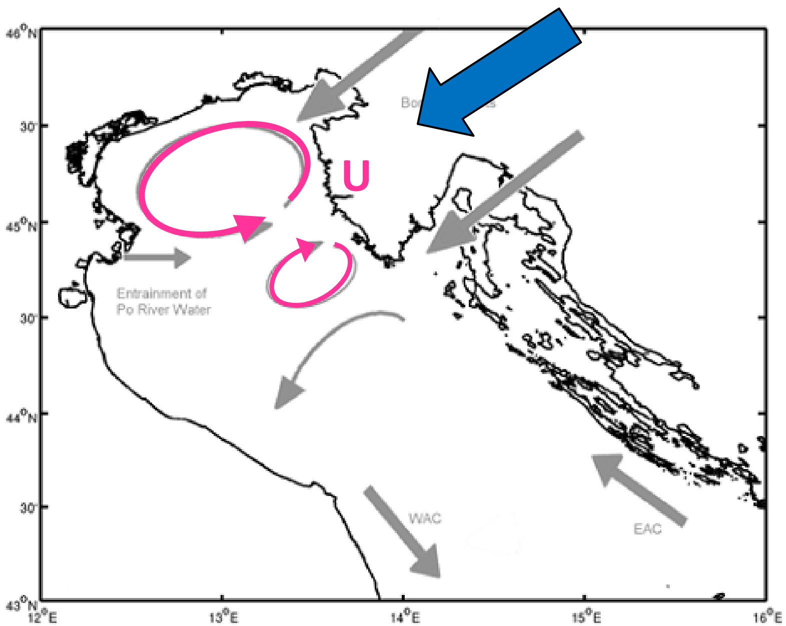
Effects of wind on circulation

BORA DRIVES

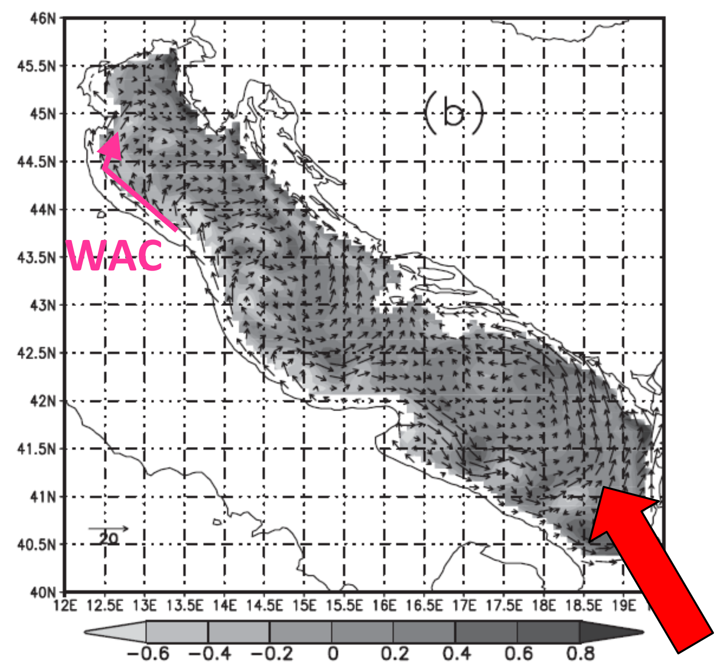
- upwelling along eastern coast (**U**)
- double gyre surface circulation
- as wind ceases, rapid return mean circulation

SIROCCO DRIVES

- sea level rise along northern coast
- possible WAC reversal (North Adr)
- as wind ceases, basin-wide barotropic seiches



(after Jeffries and Lee 2007)



(after Ferrarese et al. 2009)

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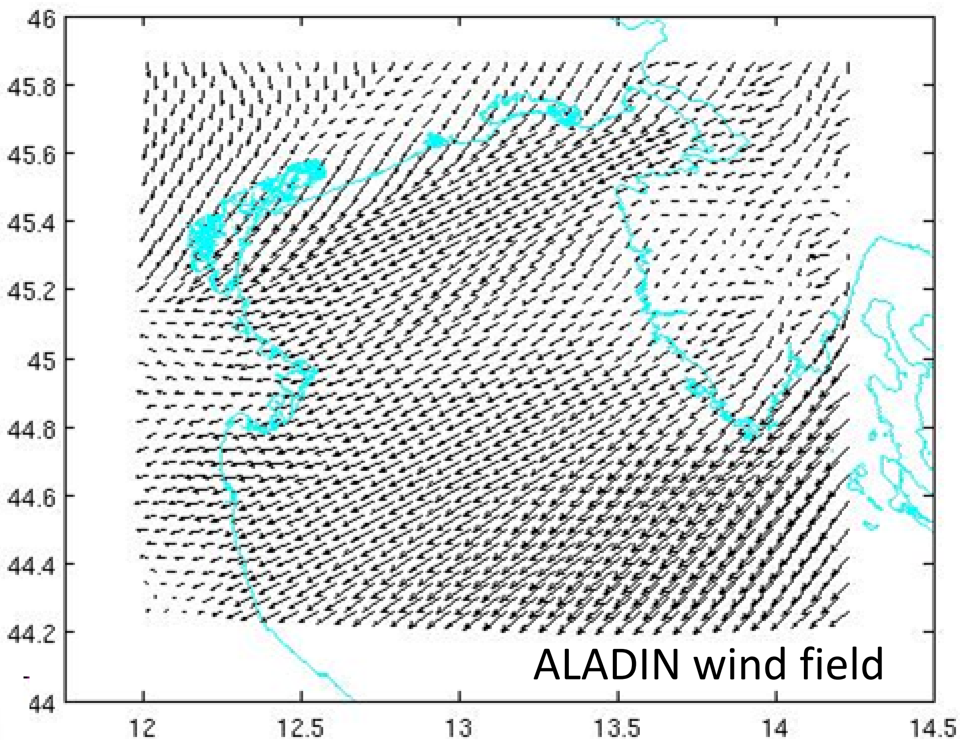
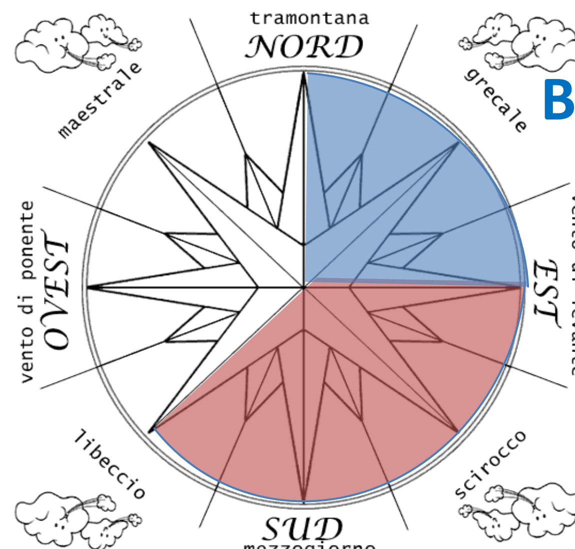
Surface current patterns in the northern Adriatic extracted from high-frequency radar data using self-organizing map analysis

Hrvoje Mihanović,[1] Simone Cosoli,[2] Ivica Vilibić,[3] Damir Ivanković,[3] Vlado Dadić,[3] and Miroslav Gačić[2]

- **WIND EVENTS SELECTION CRITERIA**



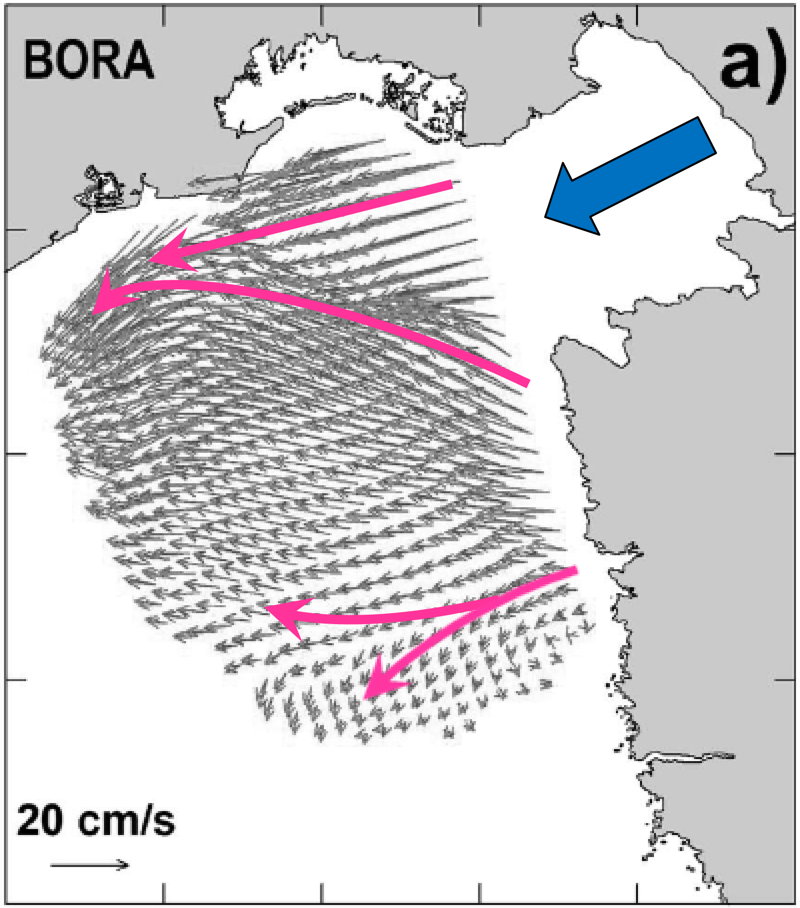


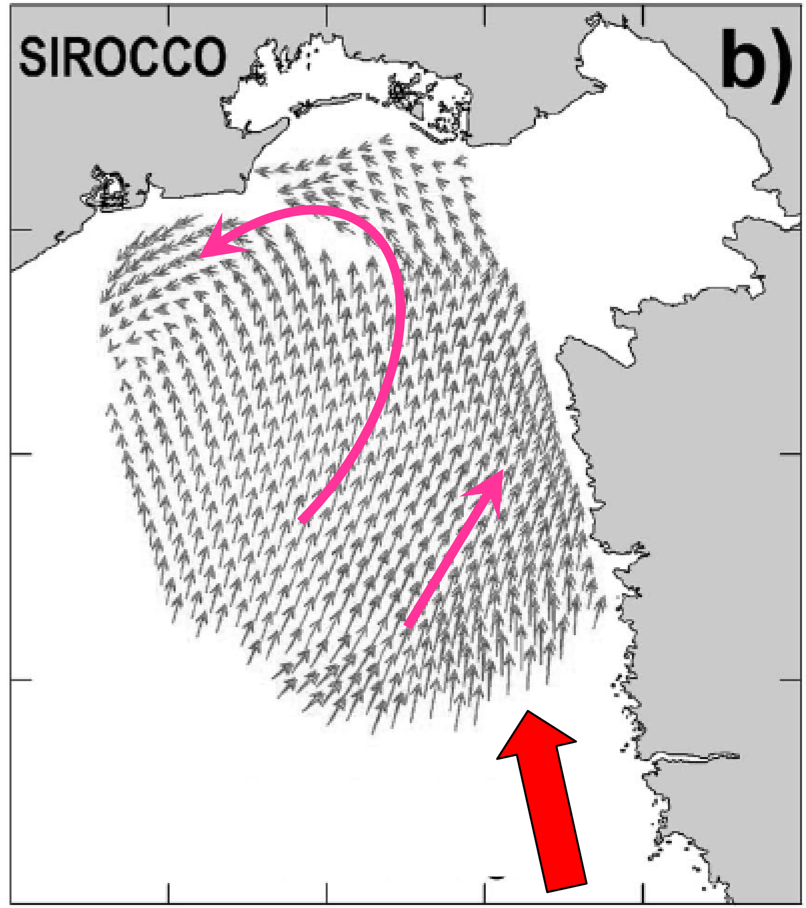
BORA

SIROCCO

http://prognoza.hr/karte_e.php?id=aladin&param=&it=

- **TYPICAL SURFACE CURRENT PATTERNS**





BORA drives

- intensification of westward jet along Italy (northern Bora corridor)
- downwind currents and divergence in front of the Istrian peninsula

SIROCCO drives

- intensification of northward flow along Istria
- westward veering along Italian coast

AIM AND STRATEGY OVERVIEW

Identification of **surface transport patterns** in the North Adriatic with Bora and Sirocco winds.

combining

DATA: High Frequency radar currents measurements

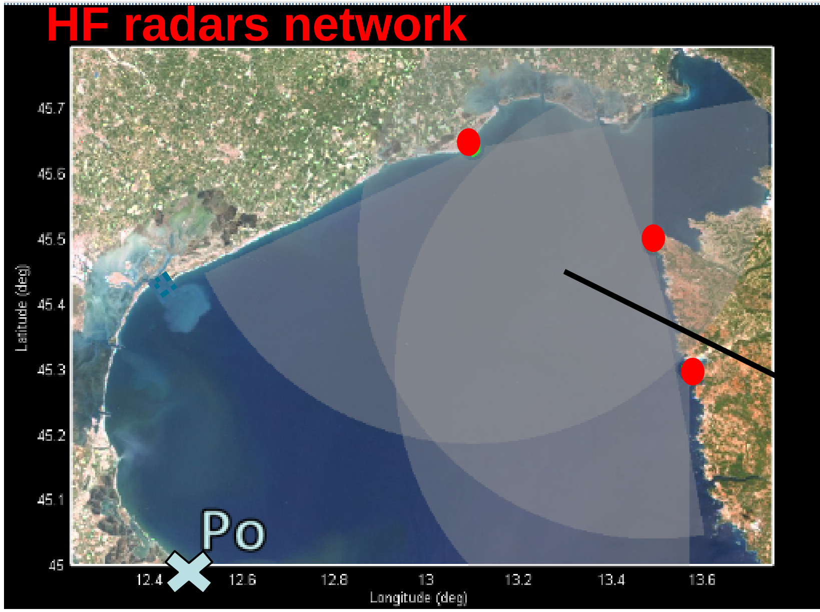
METHOD: Finize-Size Lyapunov Exponent (FSLE) technique

high resolution information + tracking sub-mesoscale dynamics

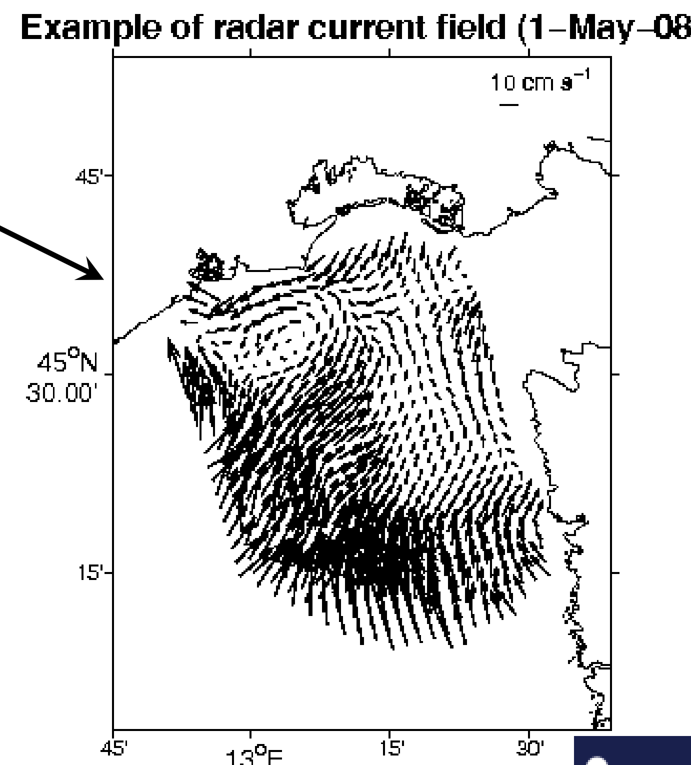
Investigation:

- Applicability of FSLE on highly variable current field, with small domain
- Transport structures development under specific wind conditions
- Implication of spatial organization of transport observed

Area of study and dataset



- deeply urbanized coasts
- natural resources exploitation
- riverine outputs (mainly Po)



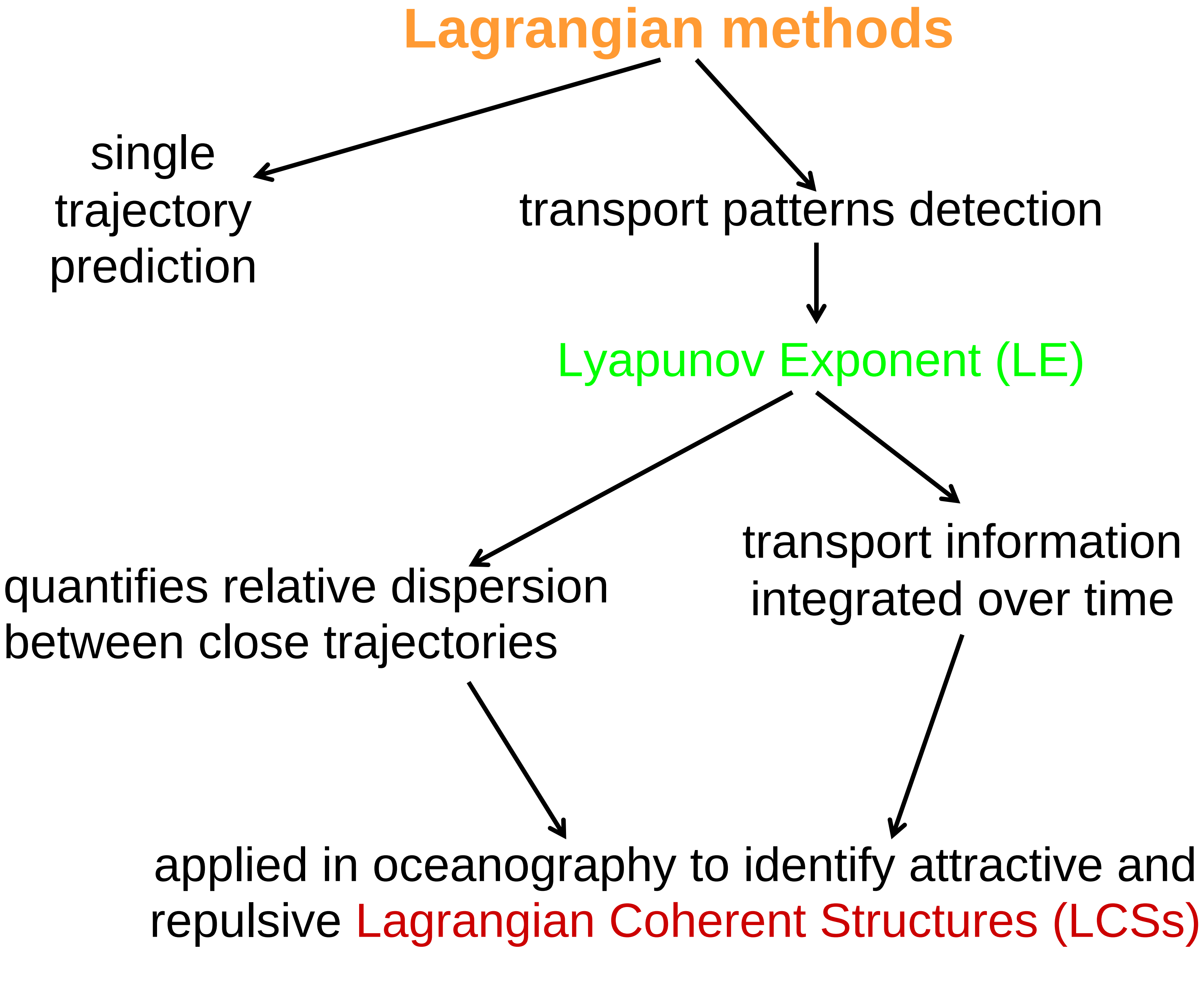
Radar dataset:

North Adriatic Surface CUrrent Mapping

- period: August 2007-August 2008
- maximum coverage: ~50x50 km^2
- resolution: spatial 2km x 2km; temporal 1 h.

http://poseidon.ogs.trieste.it/cgi-bin/jungo/nascum

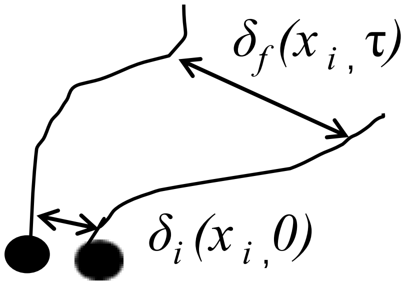
nascum


Lagrangian methods
single trajectory prediction
transport patterns detection
Lyapunov Exponent (LE)
quantifies relative dispersion between close trajectories
transport information integrated over time
applied in oceanography to identify attractive and repulsive Lagrangian Coherent Structures (LCSs)

Finite Size LE (FSLE)

- Definition: $\lambda\left(\boldsymbol{x}_i, \delta_i, t, \delta_f\right) = \frac{1}{\tau} \ln \frac{\delta_f}{\delta_i}$

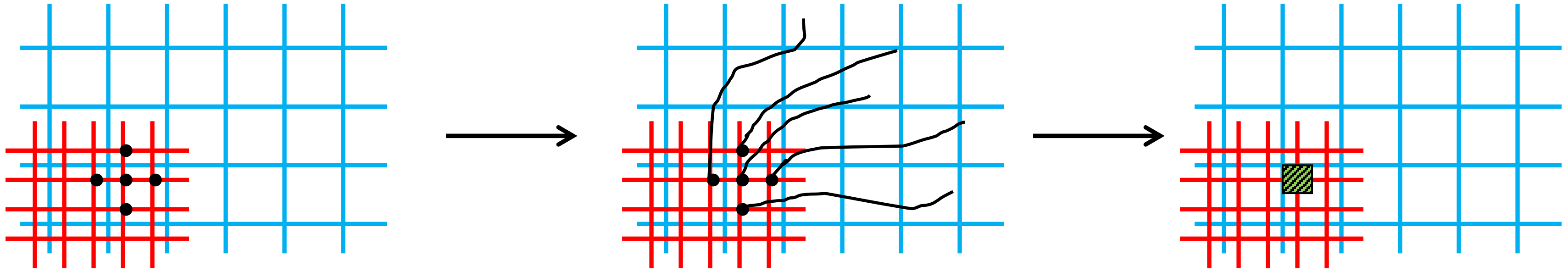
  small τ → fast separation → large λ



$\boxed{\delta_i} = \delta(0)$

$\boxed{\delta_f} = \delta(t)$

- Application: particles move with ***u*** *(t,**x**)*



VELOCITY GRID

FSLE GRID (resolution = initial distance of particles)

Num part = *f* (current field area / FSLE pixel resolution)

For each FSLE grid node → maximum λ of the 4 nearest couples

From FSLE to LCS

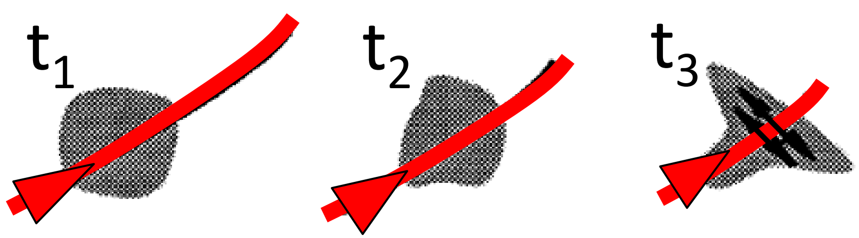
- LCS time scale evolution is very different from temporal variability of the flow field

Integration of particles **forward** in time
look for **divergence** of particles

positive FSLE : $\lambda_+ = \frac{1}{\tau} \ln \frac{\delta_f}{\delta_i}$

maximum FSLEs
identify **repulsive LCS**
or **barriers to transport**

Patch fate…

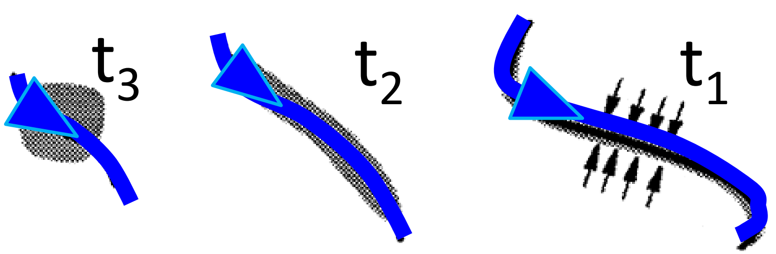


Integration of particles **backward** in time
look for **convergence** of particles

negative FSLE : $\lambda_- = -\frac{1}{\tau} \ln \frac{\delta_f}{\delta_i}$

minimum FSLEs
identify **attractive LCS**
or **direction of transport**

Patch fate…



(after Hall and Yuan 2000)

Algorithm and settings

- Trajectories evolution $\longrightarrow \dfrac{d\boldsymbol{x}}{dt} = \boldsymbol{u}(t, \boldsymbol{x})$
  - → Integration in time: 4th order Runge–Kutta
  - → Interpolation in space: bilinear (4 points)

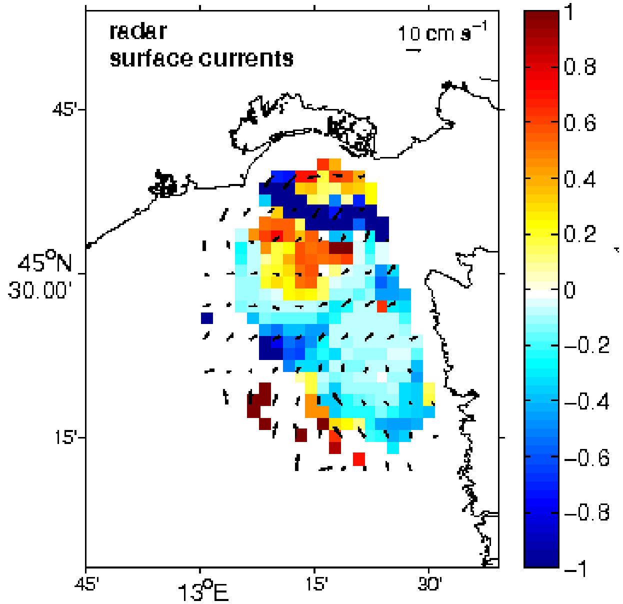
- Choice of δ_i and δ_f $\longrightarrow$ Depends on currents features, length scale of structures and details requirements in stuctures identification.

- Independent runs
  - → Forward FSLE (looking for divergence)
  - → Backward FSLE (looking for convergence)

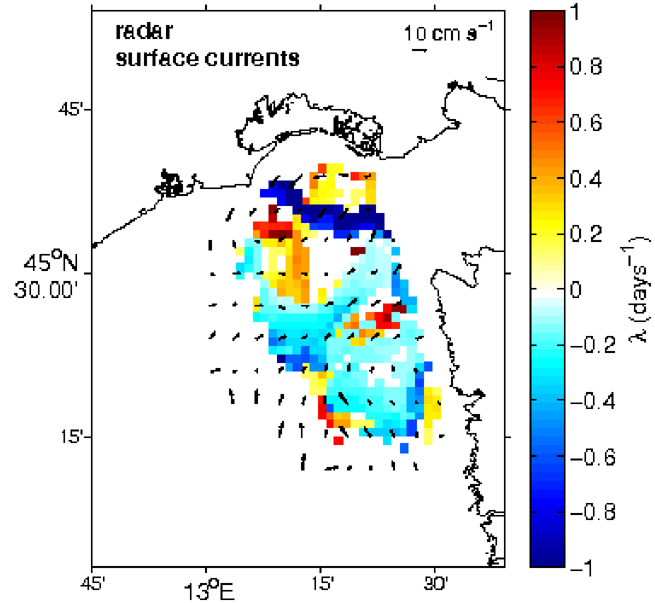
- Graphical superposition of forward and backward FSLEs

Comparison between different runs for $\delta_f = 3$ km

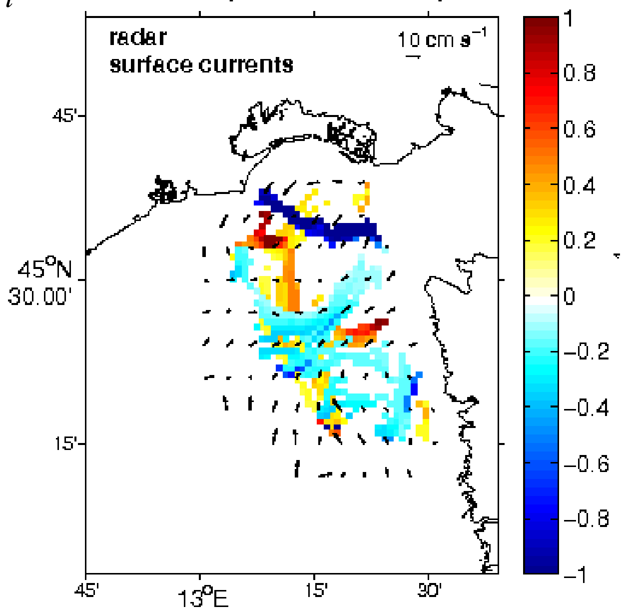
$\delta_i = 2$ km $\rightarrow$ nr. particles couples=1088



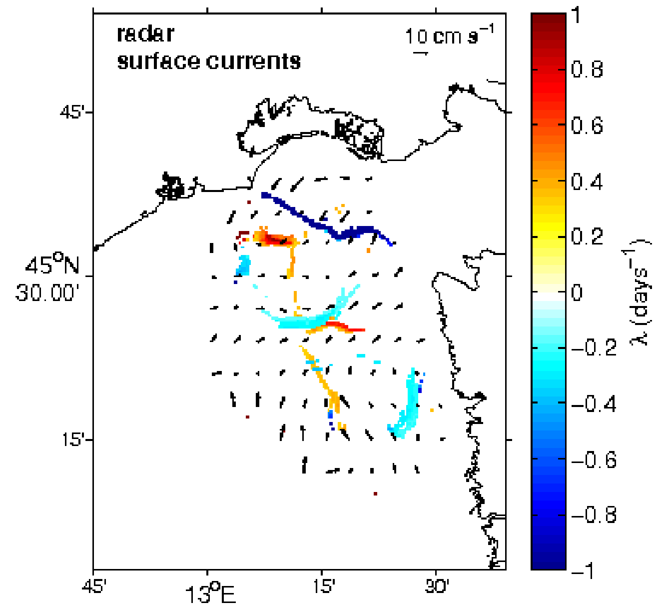
$\delta_i = 1.4$ km $\rightarrow$ nr. particles couples=2208



$\delta_i = 1$ km $\rightarrow$ nr. particles couples=4352

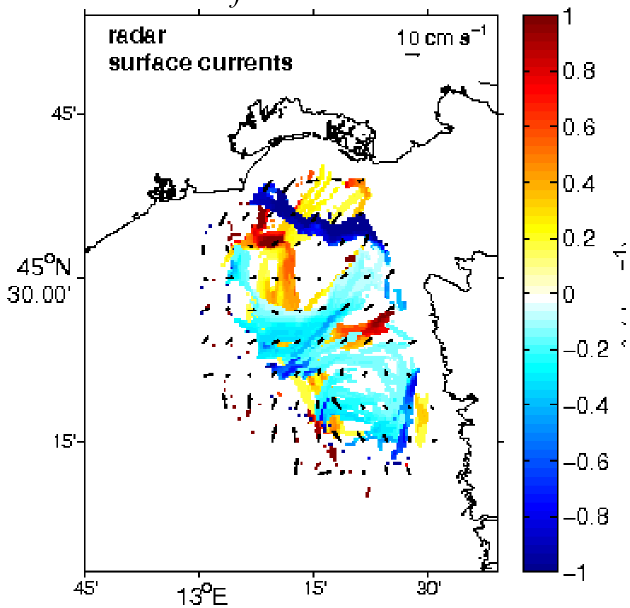


$\delta_i = 0.4$ km $\rightarrow$ nr. particles couples=26544

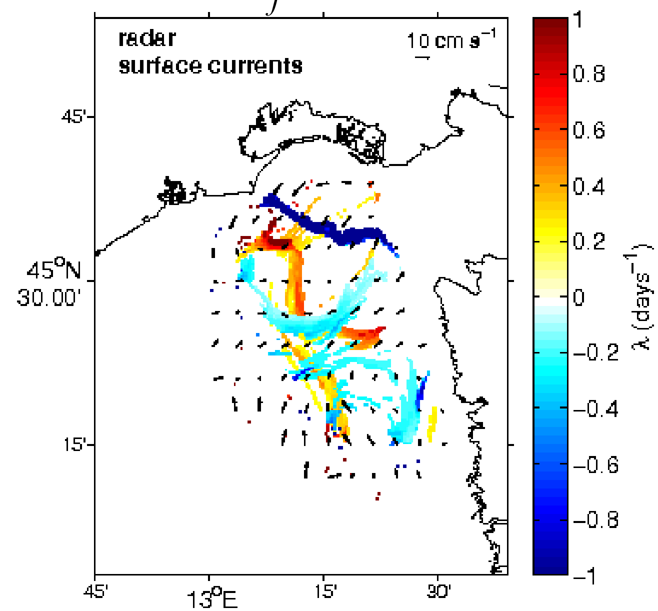


Comparison between different runs for $\delta_i = 0.4$ km

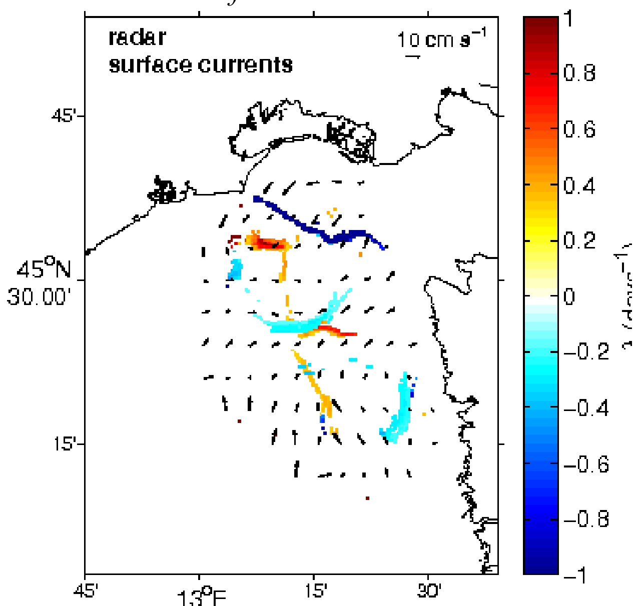
$\delta_f = 1$ km



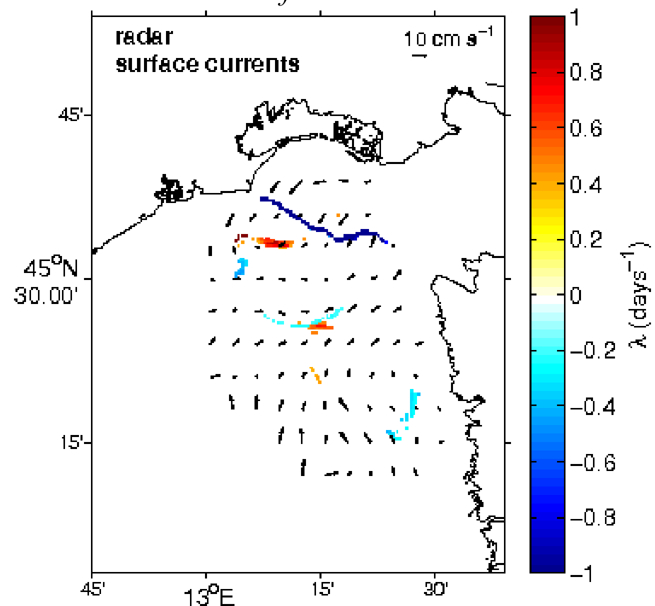
$\delta_f = 1.6$ km



$\delta_f = 3$ km



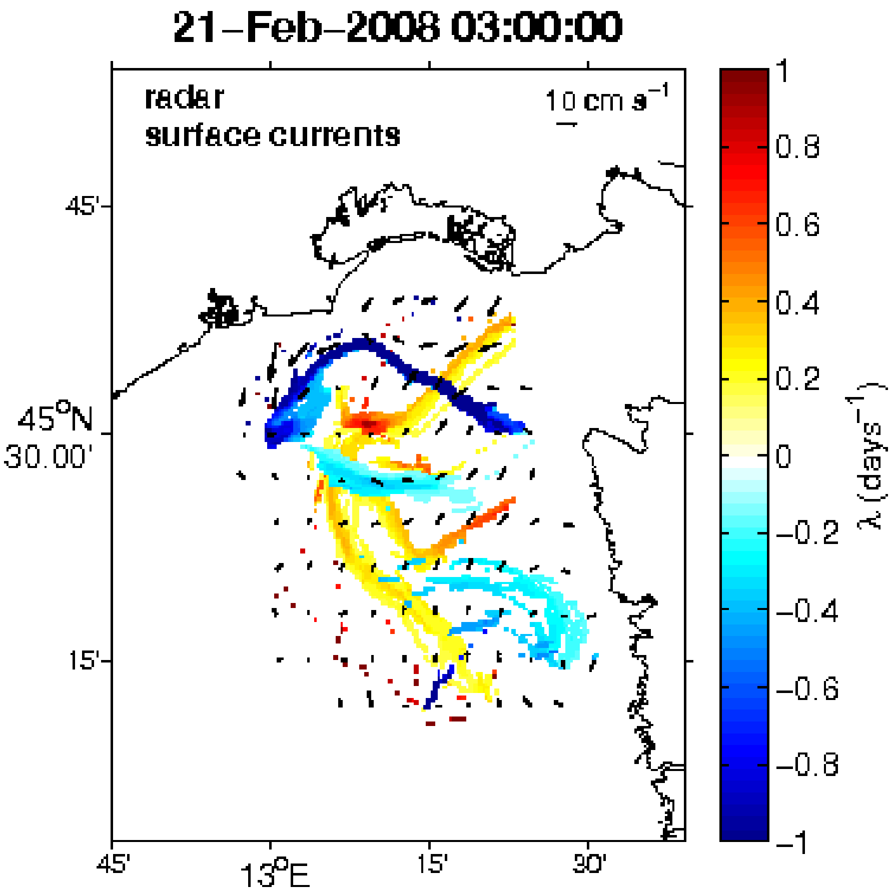
$\delta_f = 5$ km



FSLE during calm wind

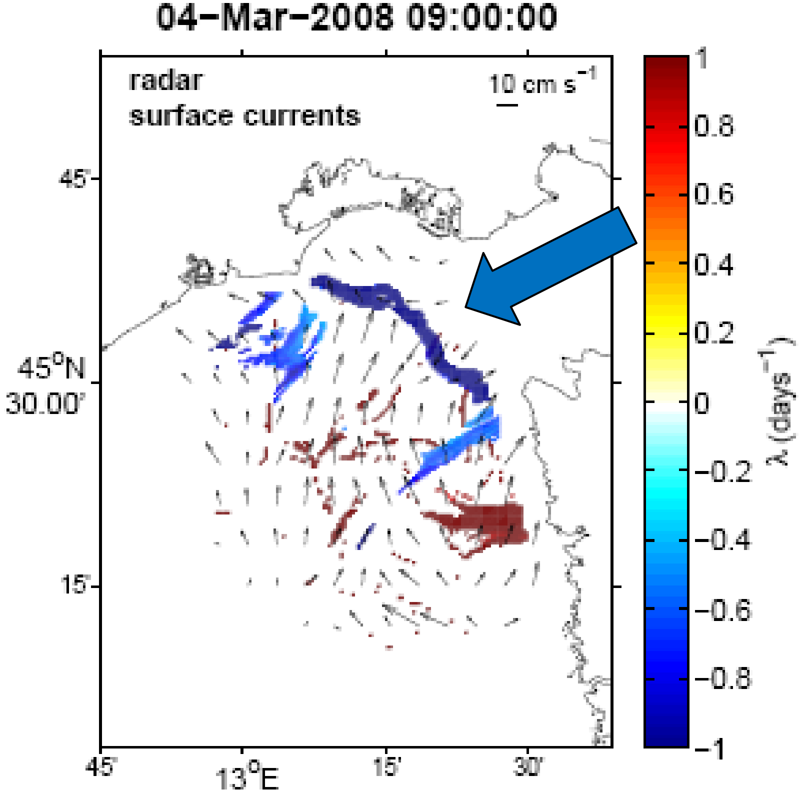
CALM WIND → Ten days period with wind intensity lower than 3 m/s.

- Current field rich in transport structures
- Evolution of transport structures slower that currents variability
- Line of transport detached from the Italian coast

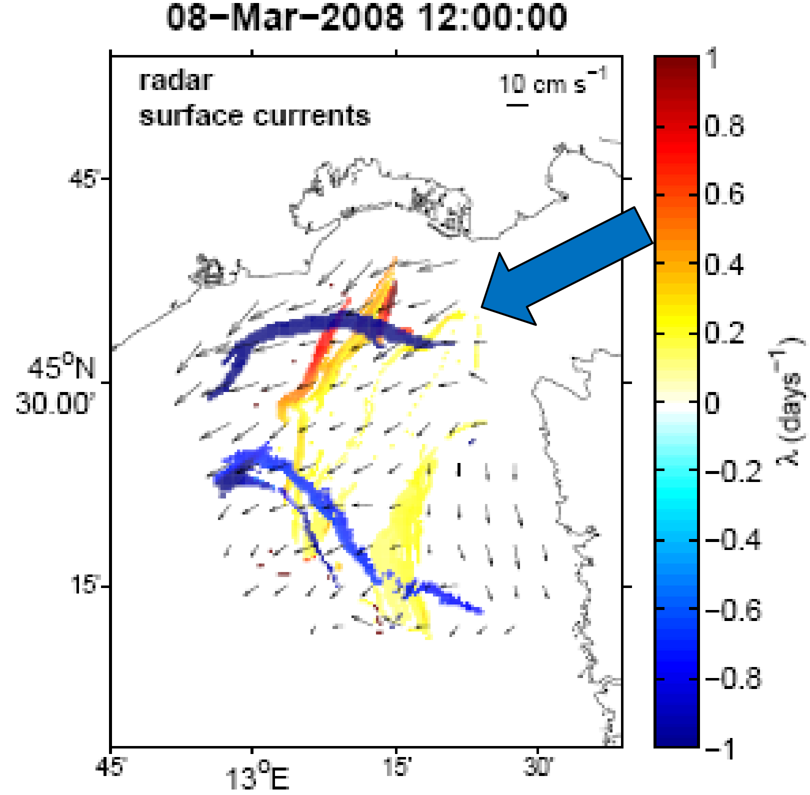


FSLE during Bora (case 1)

BEGINNING

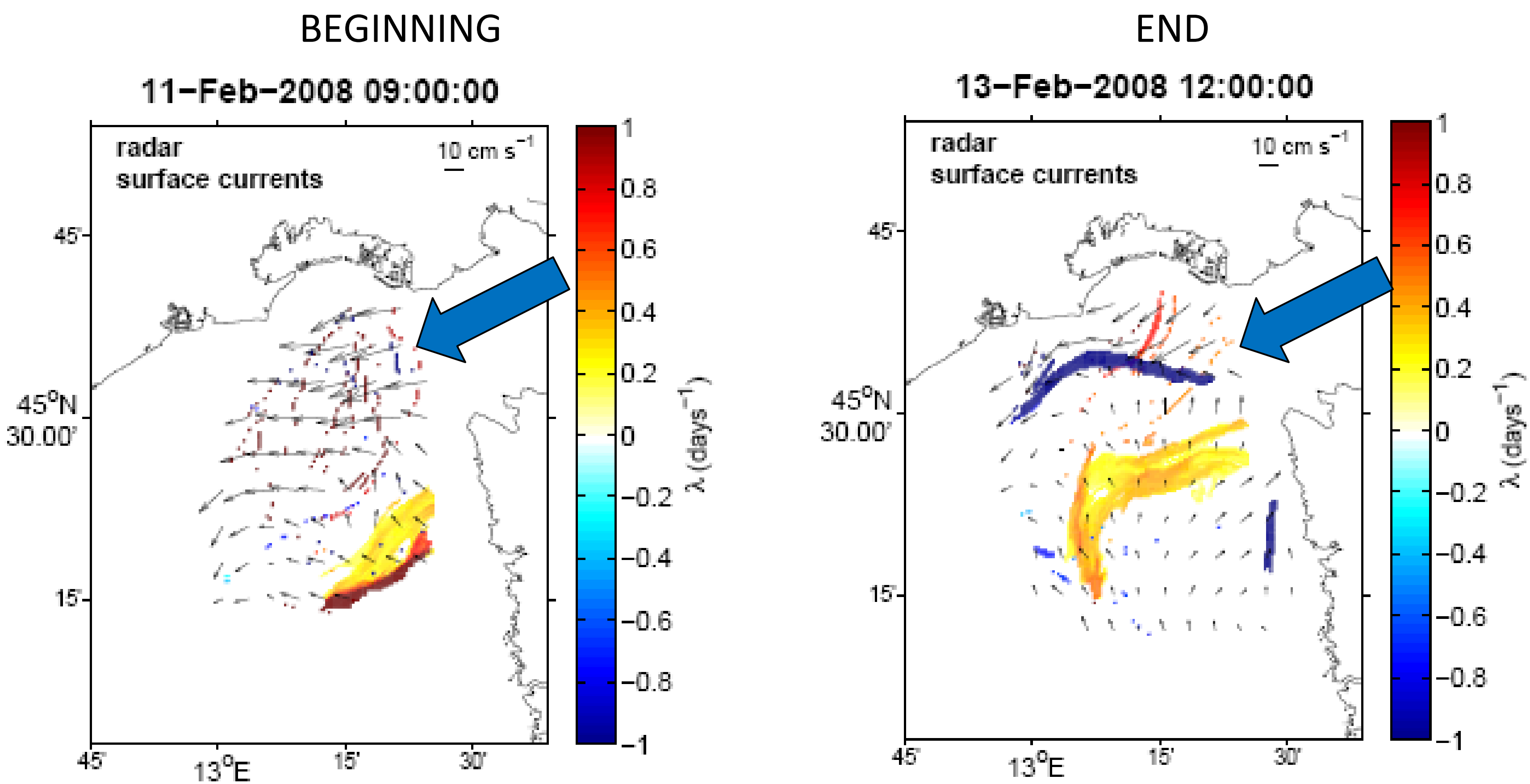


END



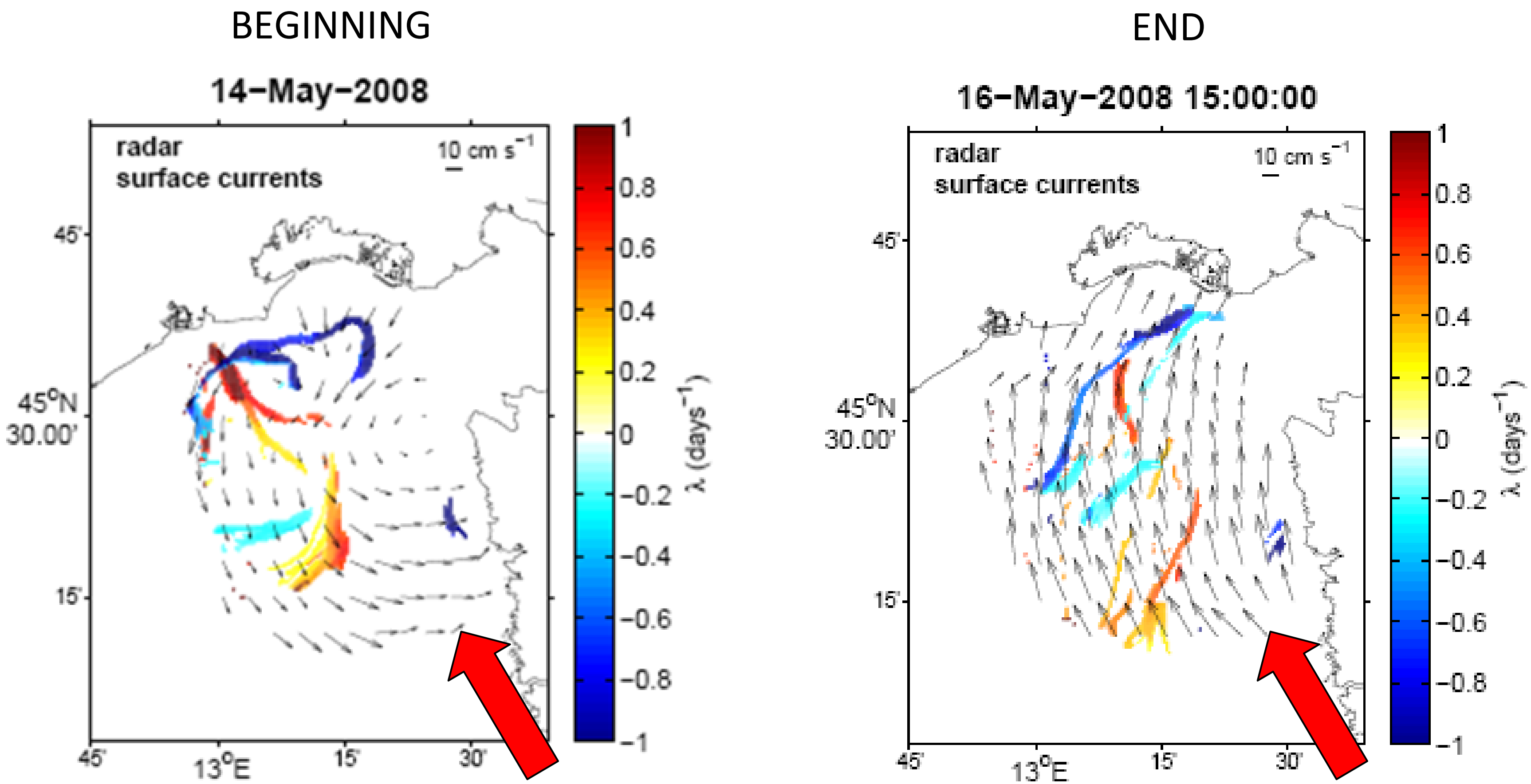
- Bora drives significant spatial variability in surface currents
- new structures develop and pre-existent ones change spatial configuration
- transport structures evolve slower that the current field

FSLE during Bora (case 2)



- Reduced coverage does not allow to identify attractive LCS at the beginning
- Development of repulsive LCS in front of the Istrian coast and northward propagation
- At the end of the event appearance of attractive structure along Italian coast

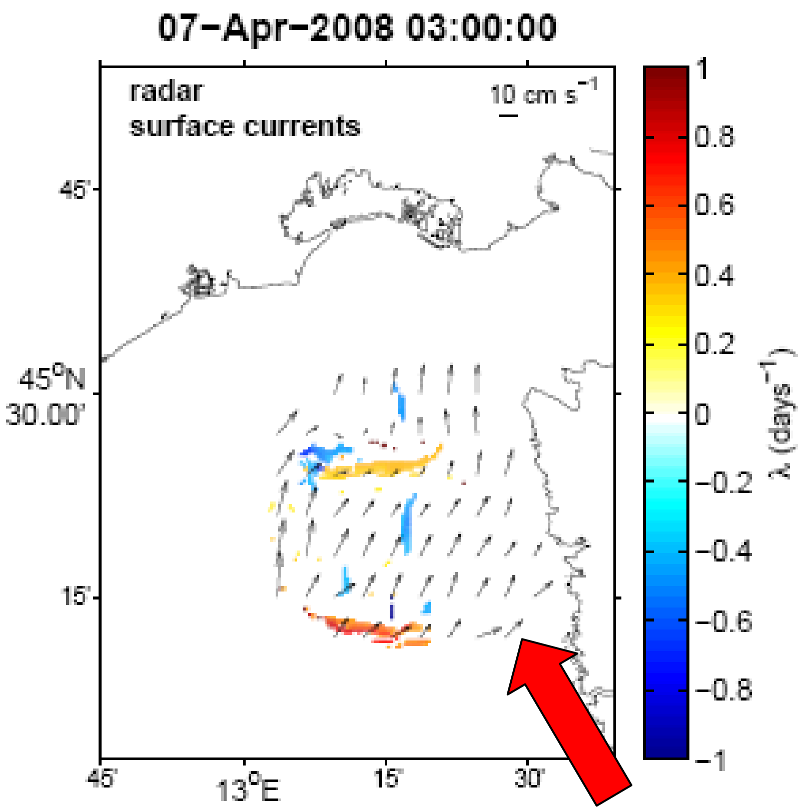
FSLE during Sirocco (case 1)



- Sirocco drives coherent surface velocities
- line of transports align perpendicularly to dominant wind direction
- transport reversed from “mean condition”: particles moving from W to E

FSLE during Sirocco (case 2)

BEGINNING



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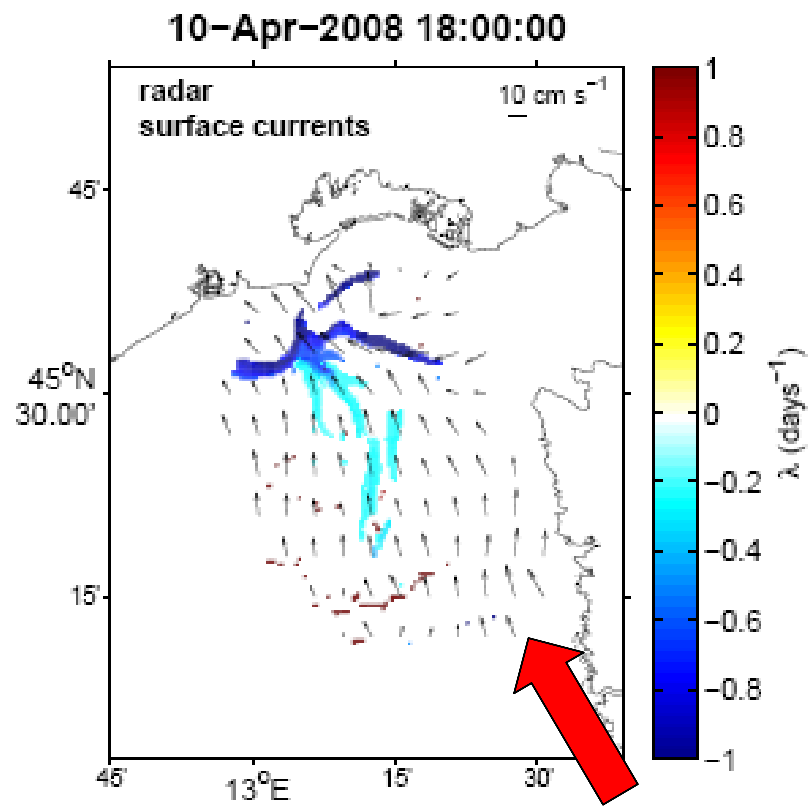


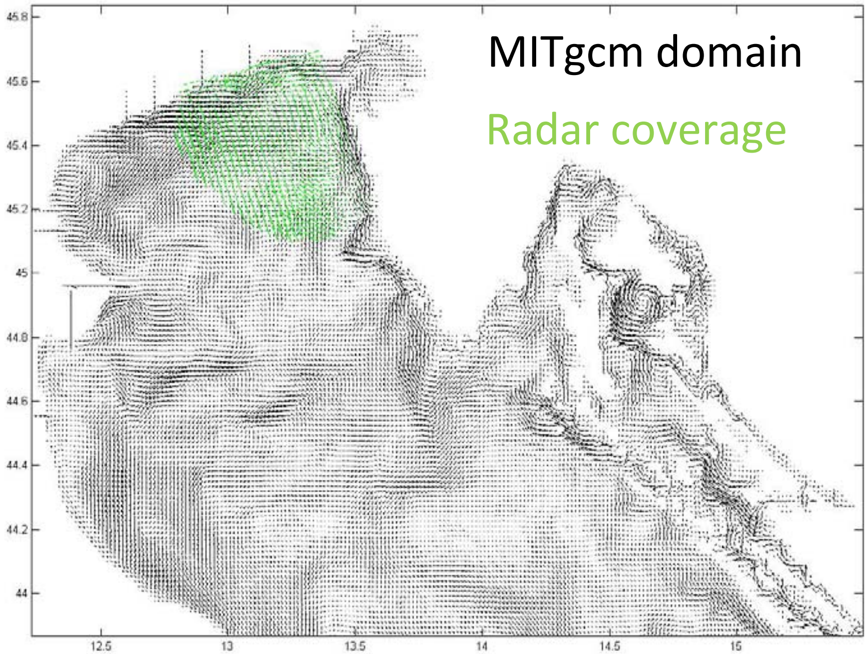
- At the beginning reduced radar coverage to identify any structures
- At the end of the event, the transport line along Italy comes out
- Meridional area does not show strong transport features

WORK IN PROGRESS…

APPLICATION OF FSLE TO MODELED CURRENTS IN THE SAME AREA COVERED BY RADARS

Model: MITgcm*

* General Circulation Model



- Simulates physical variables (velocity, temperature and salinity)
- non hydrostatic ,
- finite volume,
- free surface
- 1/64 ° spatial res. , 1h temporal res.
- Z- levels (surface - 40m depth)
- forced by ALADIN wind field (also used for wind events identification)

FSLE evaluation:

•Particles: same radar launch grid, but evolution all over MITgcm domain

•δ_i = 0.4 km, δ_f = 1.6 km (same radar parameters)

•Maximum evolution time (forward and backward): 6 days

http://mitgcm.org

MITgcm

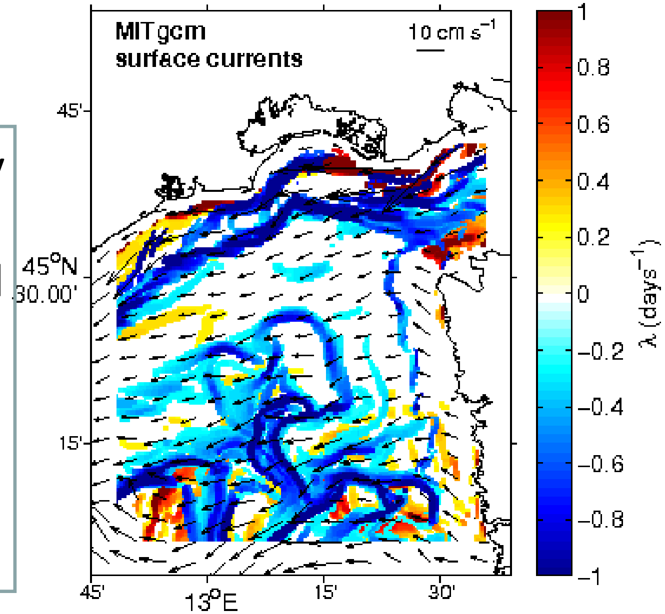
SIMILARITIES AND DIFFERENCES …

Model currents forced by ALADIN wind
(more homogeneous and less intense than actual wind)
↓
Long-lived structures

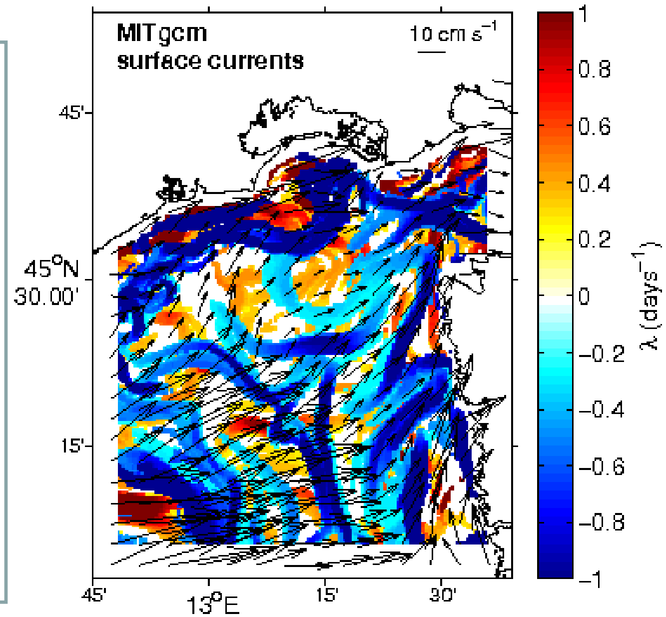
Model domain wider
↓
Particles have higher chance to satisfy the final distance criteria
↓
Tangle of structures

MITgcm domain

08–Feb–2008 03:00:00

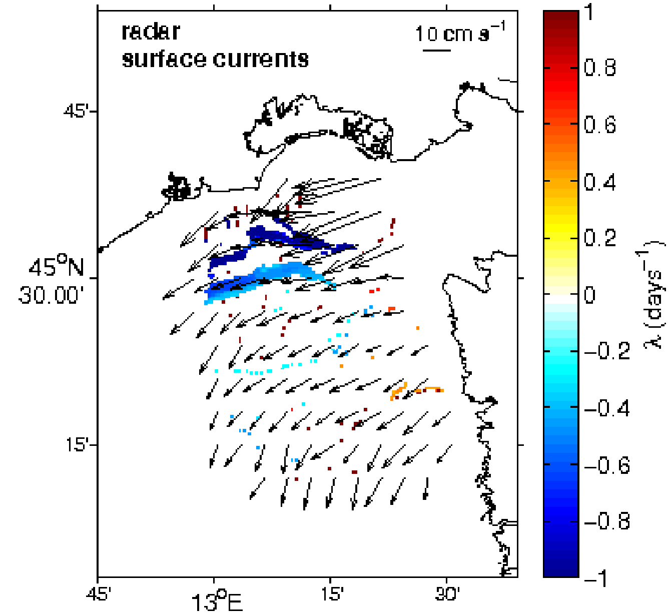


15–May–2008 15:00:00

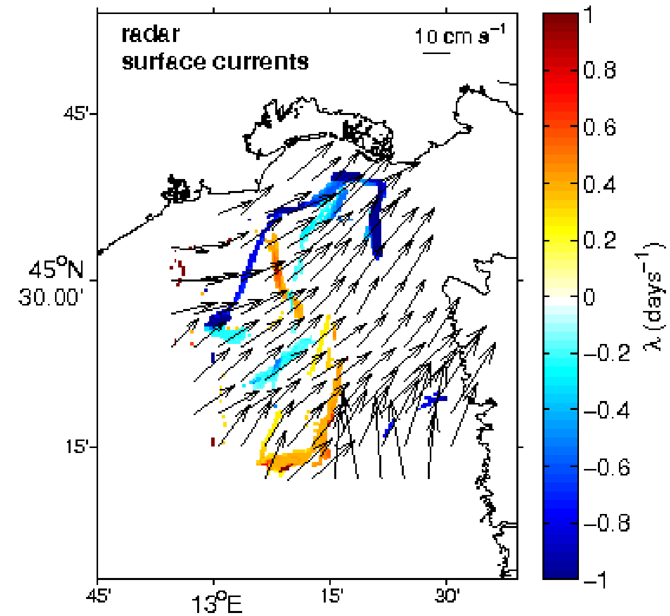


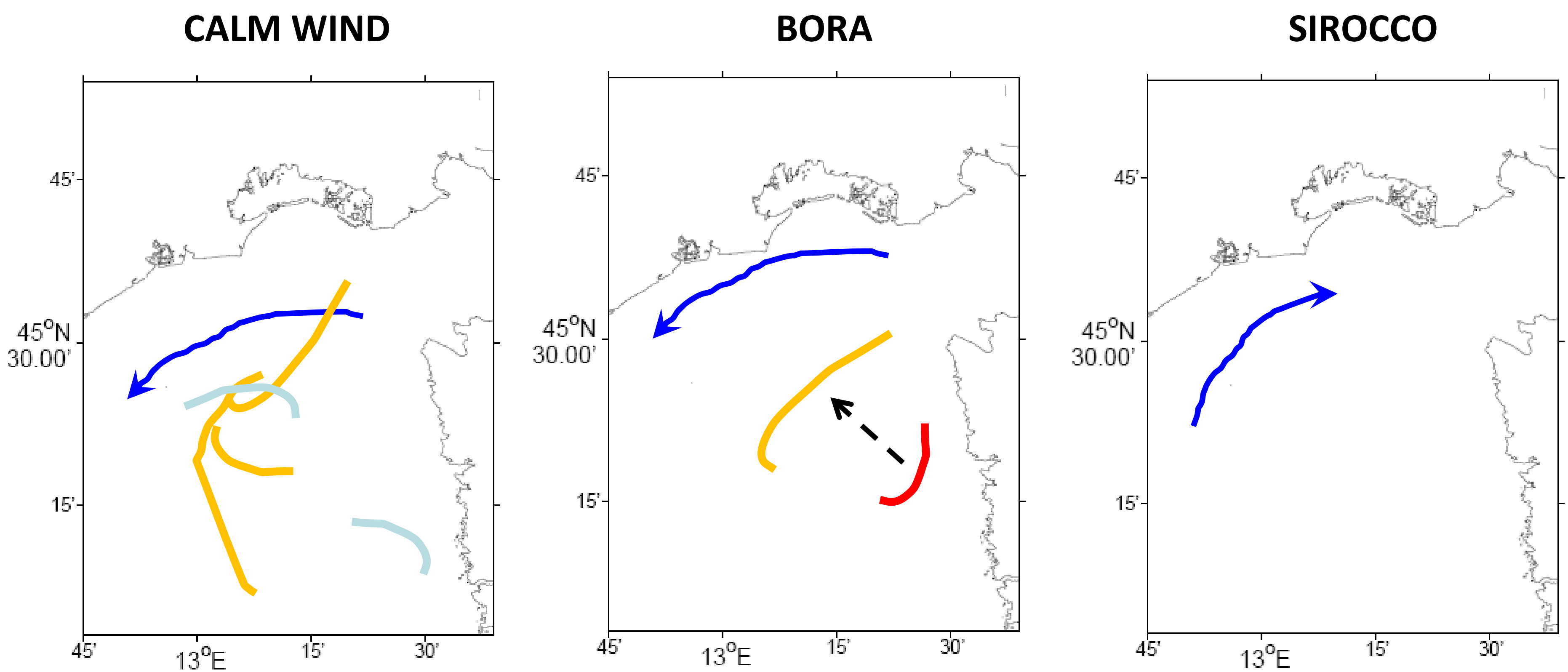
Radar field

08–Feb–2008 03:00:00



15–May–2008 15:00:00





- High variability (spatial and temporal) of the velocity field affects structures configuration and persistence
- Line of transport along the Italian coast: different meandering and detachment from coastline according to wind conditions
- Greater variability of transport structures in the meridional part of the domain, due to close orographic influence on winds.

CONCLUSIONS

- One of the first FSLE application on HF radar current field :
  (see also *Haza et al. 2010* for application on VHF radars)

  - Radar measurements → high resolution but small domain

  Preliminary tests on initial and final separation between particles

- Application of FSLE method both on modeled and radar currents:
  combination of the surface dynamics information from model and radar field

- FSLE transport analysis on deeper layers of modeled currents can give important information on water column dynamics.

- FSLE method in association with advection of clusters of drifters (at the surface and deeper deployments) to compare trajectories with the transport structures identified from radar and model.

THANK YOU !!!