Submesoscales variability from surface drifter and HF radar measurements: scale and wind dependence of kinematic properties

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Outline

- Motivation
- Flow kinematic properties at the submesoscales in different areas of interest:
  - Northern Current variability (Med Sea): synoptic response to wind events from HF radars
  - Submesoscale variability Northern Gulf of Mexico: scale dependence and seasonality from X-band radars and drifters
- Wrap up and future directions of investigation

Motivation

- The transport and spreading of surface tracers at sea is relevant in many contexts, such as oil spills, search and rescue, marine litter, and biochemical properties and ecosystems.

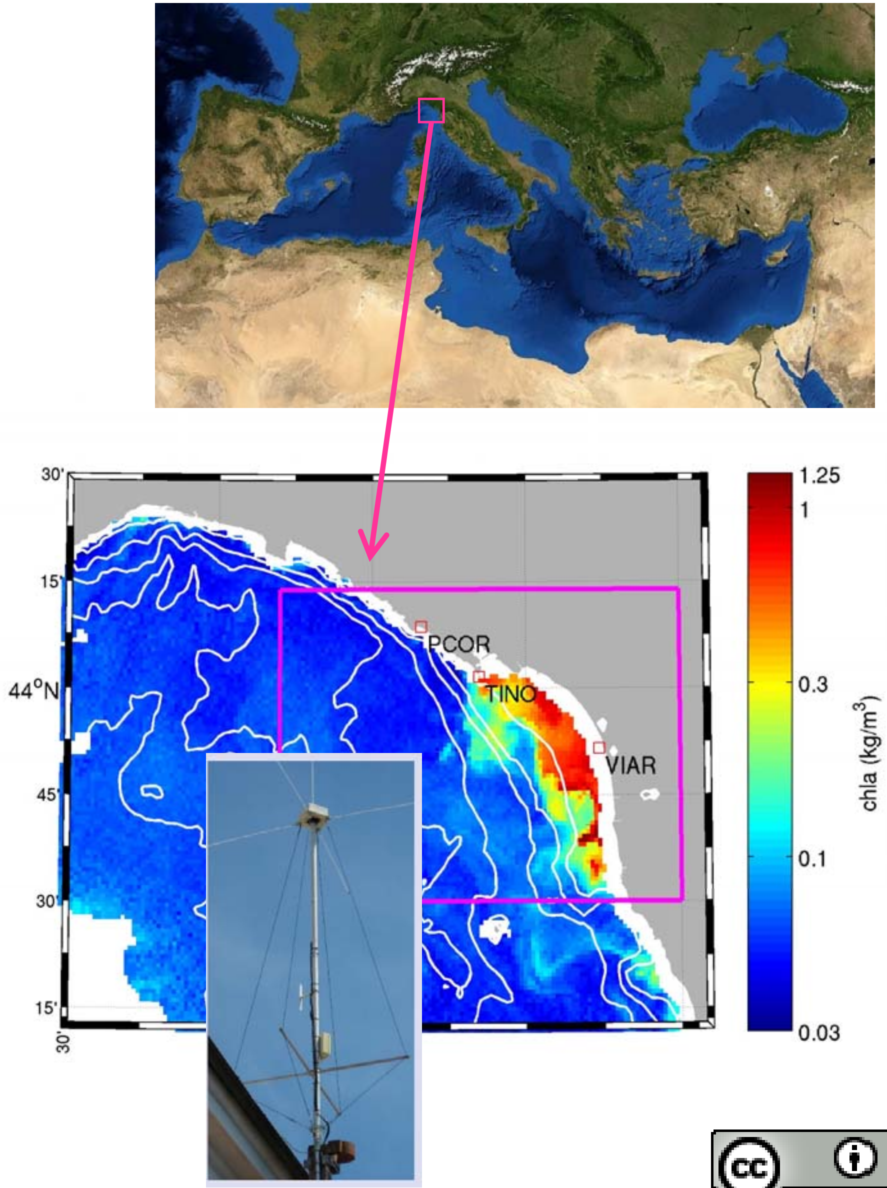
- Dispersion in the ocean results from mechanisms acting simultaneously at different scales which can be difficult to disentangle. In particular the submesoscale range (a few hundred meters to 10 km, hours to a few days) remains particularly challenging to observe directly, due to the high variability in both time and space.

- Investigate the scale-dependence of kinematic properties (divergence, vorticity and strain) in the submesoscale range, as well as their response to atmospheric forcing, is investigated in two distinct geographic regions: the Ligurian (NW-Mediterranean) Sea and the Northern Gulf of Mexico.

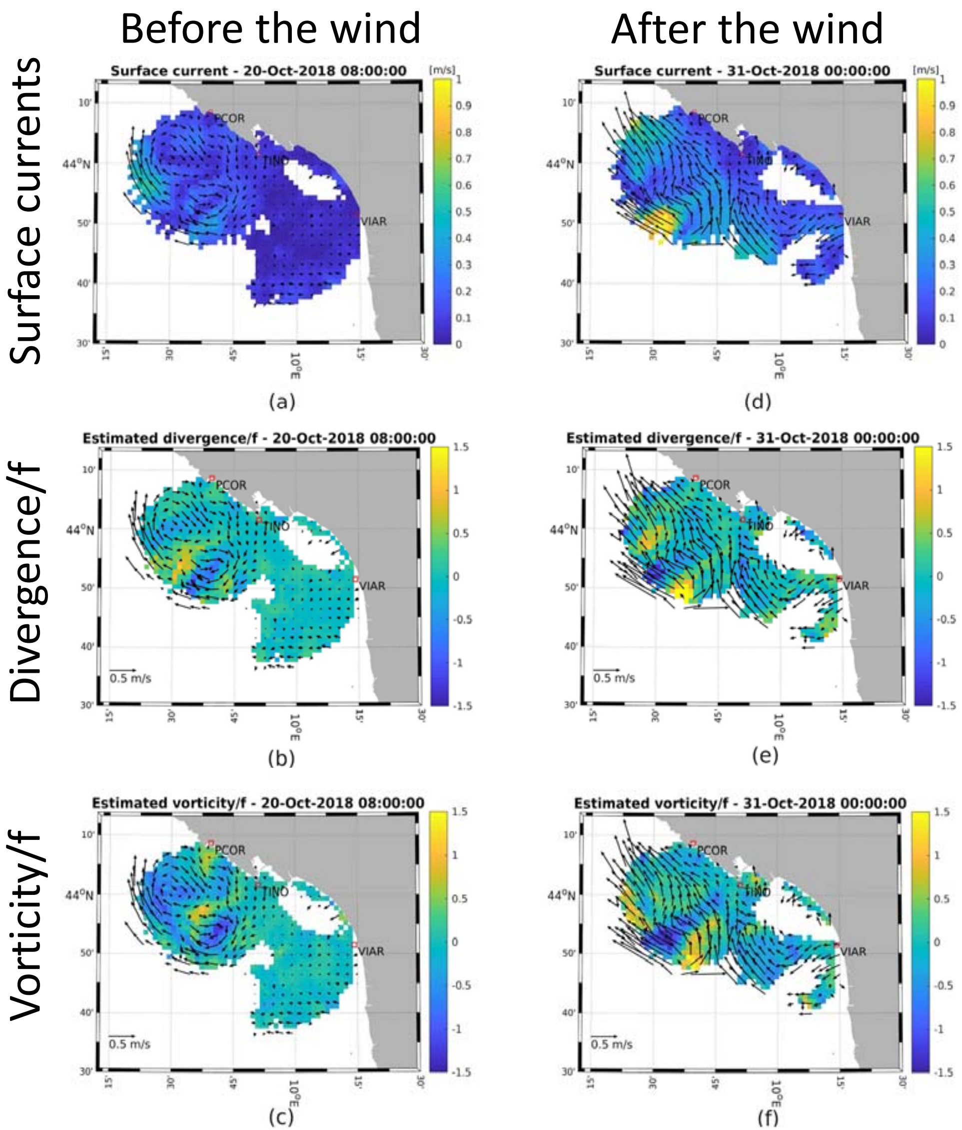
- The two applications are characterized by different dynamics, and the estimates of kinematic properties are derived from distinctly different observational approaches: in situ GPS drifters observations and remote radar data.

Area of interest nr.1

- Important area in the Med Sea for environmental reasons (5 Terre Marine Protected Area), and economical reasons (fishery and tourism)
- Strong Chlorophyll signal because of Magra river, showing small scale features (map in Oct 20, 2018)
- CNR HF radar network from 2016 (25 MHz): surface current observations approximately 40 km in range, 1.5 km resolution, available hourly
- The velocity fields are used to estimate the kinematic properties with an Eulerian approach.



Results: KPs spatial pattern from HF radars



- The northern area is more energetic than the southern part, and is characterized by jets and eddies (typically 5-6 km), smaller than the mesoscale Rossby radius (10-15 km).

- The structures have relatively low velocity (about 10-30 cm/s), but their vorticity and divergence reach order f, indicating ageostrophic (submesoscale) dynamic.

- .During and immediately after the storm, areas characterized by high velocities and kinematic properties are wider and stronger than before the event, exceeding f and suggesting enhanced horizontal and vertical velocities in the water column which might impact biological quantities, nutrients and pollutants with potential consequences on the ecosystem.

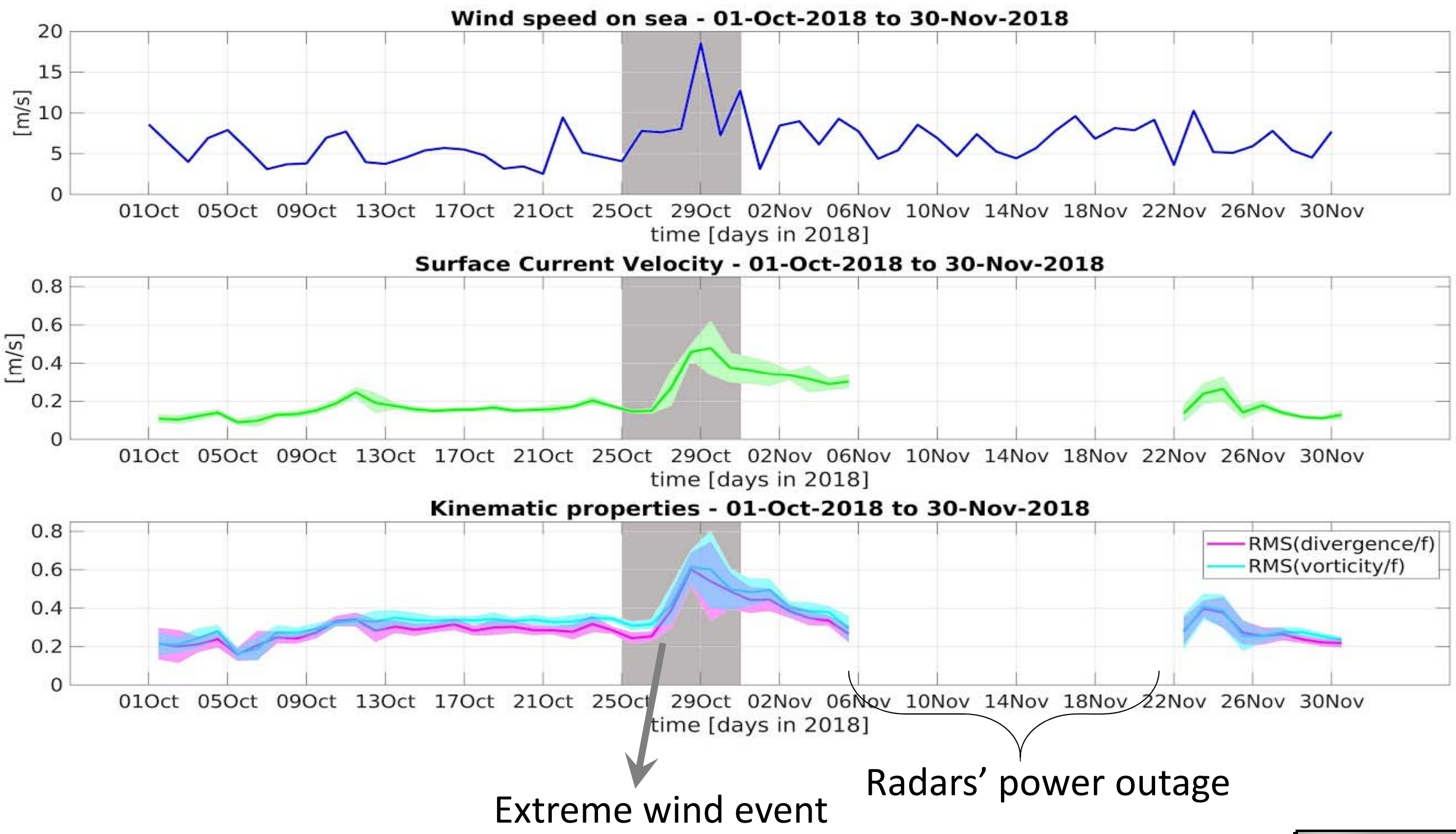
Results: KPs time series from HF radars

- Daily wind (top panel), surface current speed (middle panel) and the RMS of KPs (lower panel), averaged over the HFR domain.

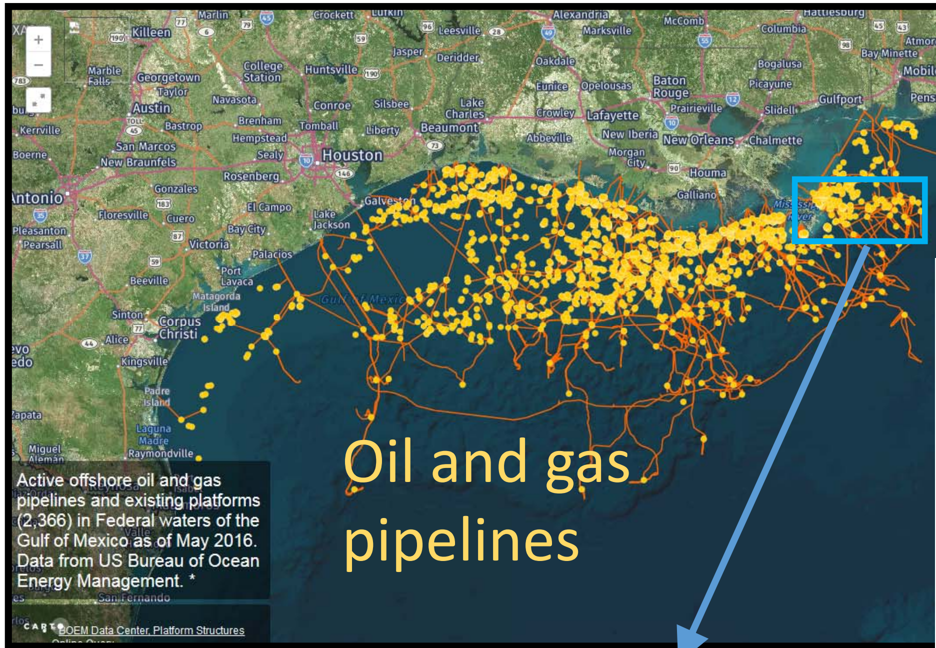
- Before the storm, kinematic property values are approximately 0.3-0.4f.

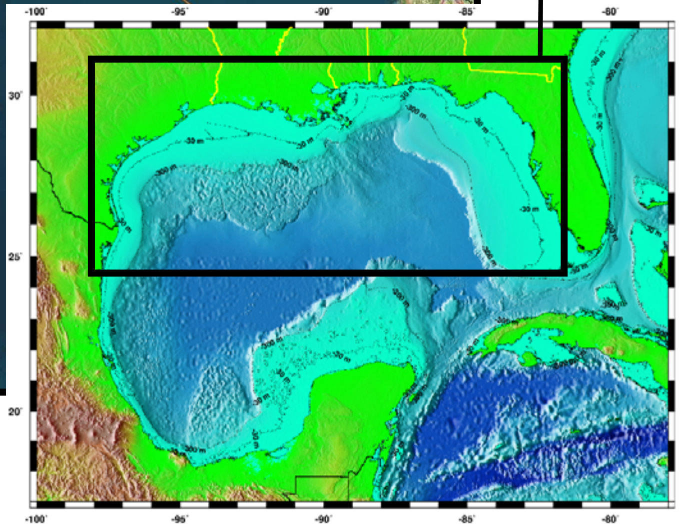
- As the wind speeds up (October 25), kinematic properties increase and reach average values exceeding 0.6f, while currents increase from 0.1 to 0.4 m/s.

- After the storm values of velocity and kinematic properties tend to decrease to pre-storm conditions.

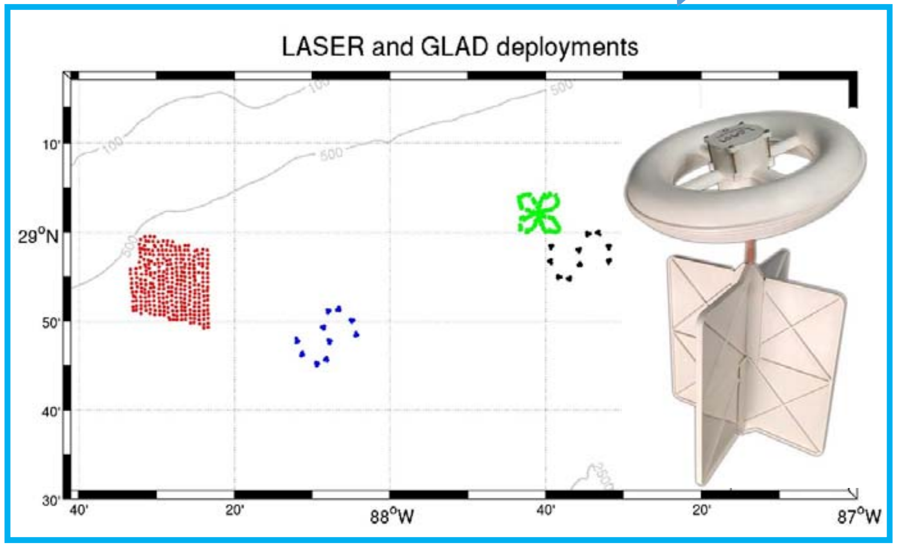


Area of interest nr.2





- northern Gulf of Mexico;
- near the 2010 Deepwater Horizon oil spill;
- home to many oil platforms.



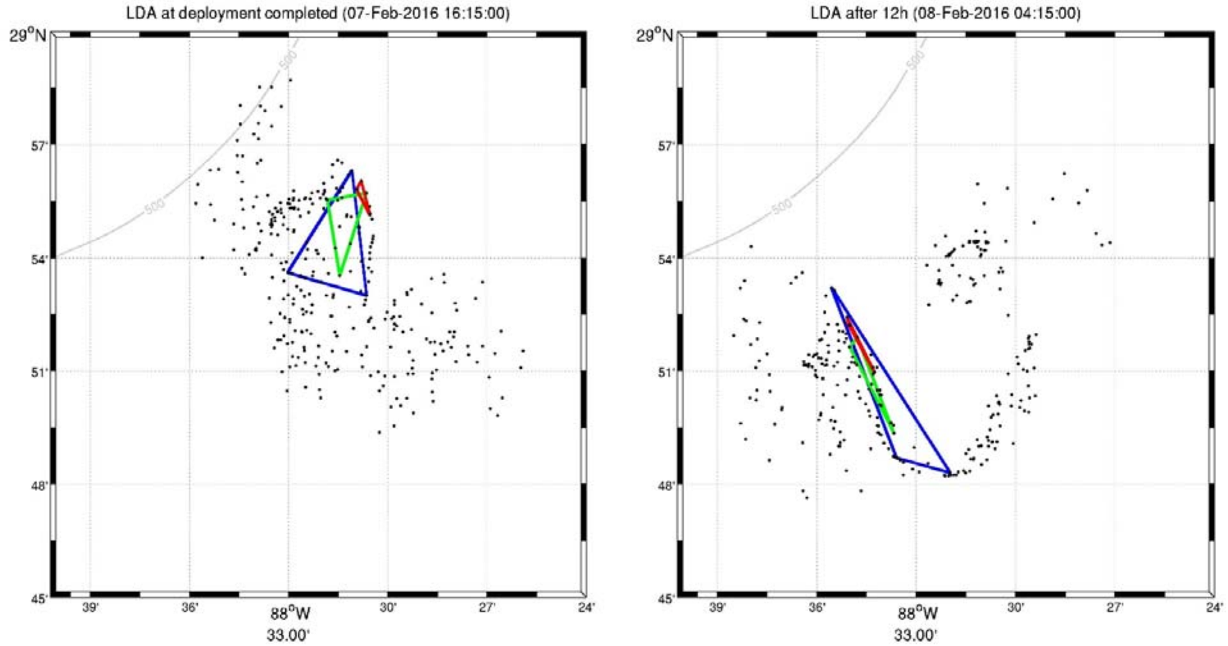
- Grand Lagrangian Deployment (GLAD), summer 2012 (about 300 drifters)
- LAgrangian Submesoscale ExpeRiment (LASER), winter 2016 (about 1000 drifters)

Flow KPs from drifter triplets evolution

- Drifter triplets are the minimum configuration to describe the deformation of tracer patches and associated flow kinematic properties (divergence, vorticity, strain)

- KPs allow to diagnose meso (KP/f<1) submesoscale (KP/f>1) regimes possibly related to vertical transport mechanism (biological and pollutant dispersion application)

- From the evolution and deformation of each triplet, the flow's KPs are computed at scales between 100 m and 5 km.



Molinari and Kirwan, 1975

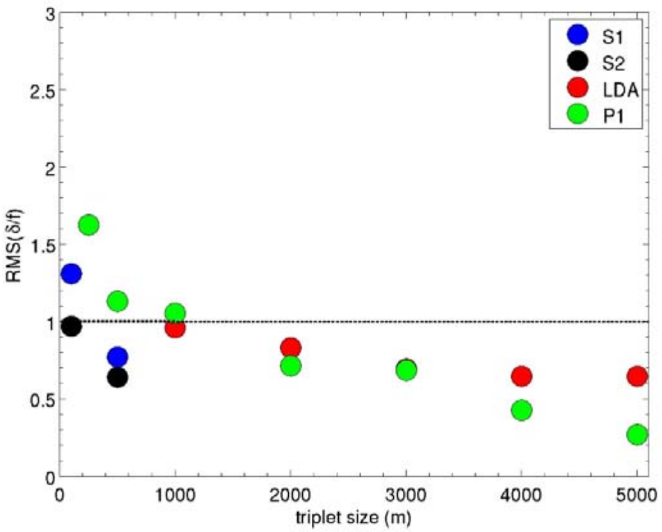
- divergence: *1/A*dA/dt=∂u/∂x+∂v/∂y*

Under specific rotation of velocity vectors:

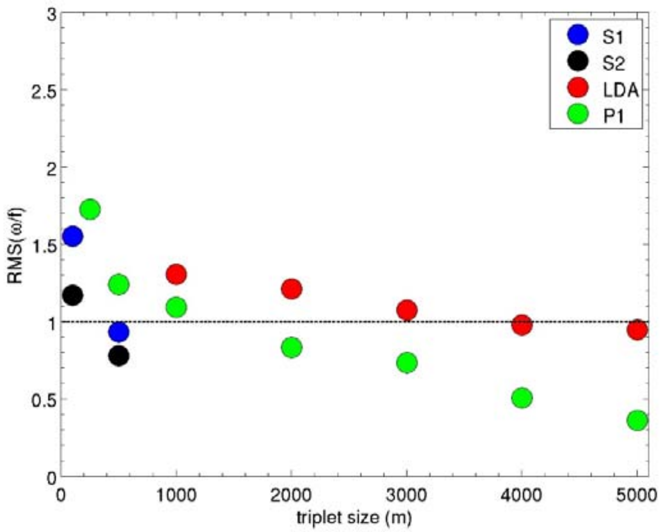
- vorticity: $\left.\begin{matrix} U \rightarrow -V' \\ V \rightarrow U' \end{matrix}\right\}$
- strain: $\left.\begin{matrix} U \rightarrow U'' \\ V \rightarrow -V'' \end{matrix}\right\}$

Results: KPs scale dependence and seasonality from drifter triplets

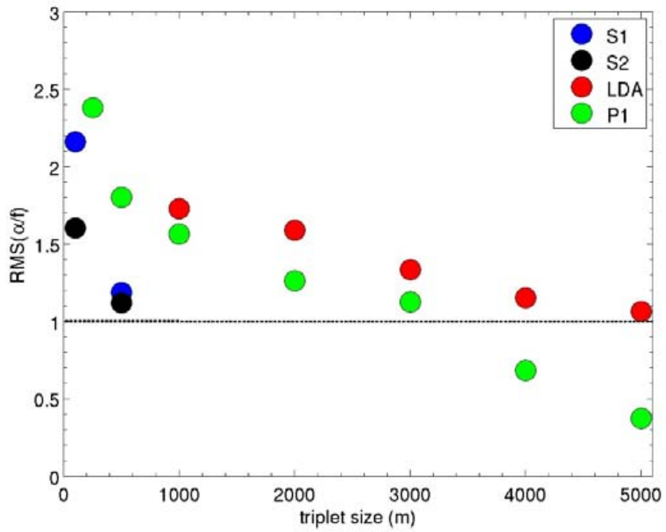
Divergence/f



Vorticity/f

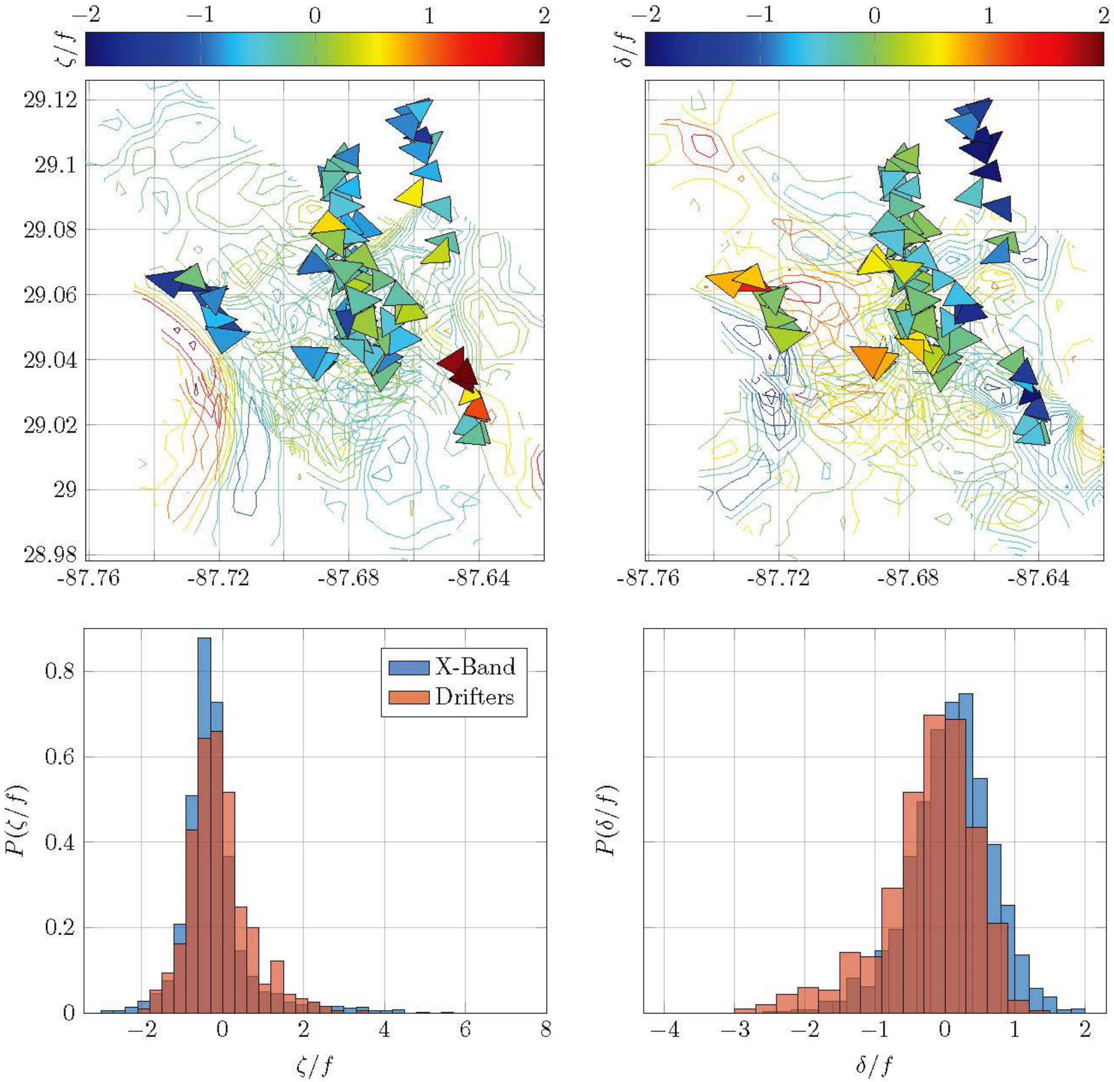


Strain/f

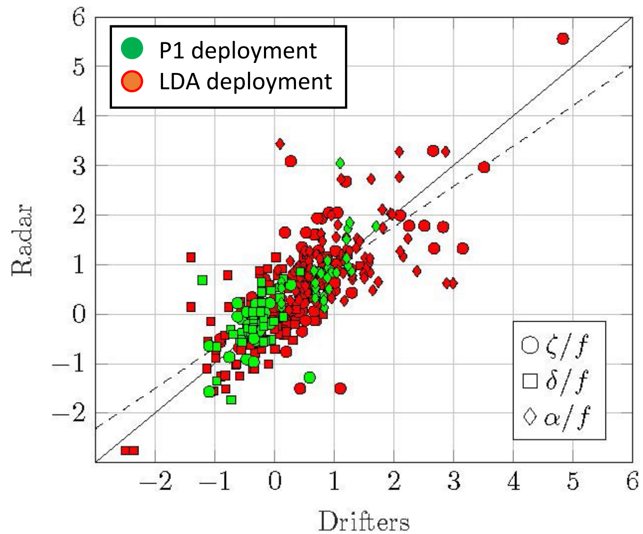


- KP values increase at decreasing scales in both seasons
- KP values at given scales are consistently higher in winter than in summer
- The two winter realizations show qualitativey similar behaviour, even though LDA has higher values of vorticity and strain, consistent with the fact that it samples a cyclonic eddy
- The scale where submesoscale is dominant, L_{SM}, defined as the scale where rms vorticity and divergence reach order f, is O(1 km) for winter and O(100- 500 m) for summer

Results: KPs comparison from X-band radar and drifters



- Divergence and vorticity from X-band radar (500m resolution, contours) and 1km drifter triplets (P1 deployment) show good agreement in spatial location; PDF distribution consistent between the two datasets and methodologies
- Divergence, vortivity and strain for P1 and LDA deployments estimated from drifter triplets and co-located X-band radar measurements show very good correlation



Conclusions and future perspectives

• We investigate the scale dependence and seasonality of KPs described by triplets deformation and radar observations to characterize the underlying flow at the submesoscale range.

• The deformation of the spatial structures suggests nonlinear interactions with the extreme wind forcing, and the kinematic properties' magnitudes are almost doubled (exceeding the Coriolis parameter, f).

• Deployments are characterized by high values of KPs, i.e., strain rate, vorticity, and divergence, increasing at decreasing scales, indicating ageostrophic flows capable of trapping flotsam and inducing vertical velocities.

• Seasonality can be seen in:

- KP values, that are consistently higher in winter than in summer,
- the scale L_{SM} at which ageostrophy dominates (KPs of order f or larger), that is larger in winter, L_{SM} O(1 km), than in summer L_{SM} O(100-500 m) consistent with shallower stratification

• KPs Lagrangian estimates show good correlation with Eulerian estimates from concurrent X-band radar measurements, validating the comparison across observational methods.

• KPs metric provides a robust complementary methodology to characterize submesoscales and can be used both with Lagrangian and Eulerian observations.

• Application in progress in the Alboran Sea with drifter triplets at different depths.

Thank you for your attention!!

More info:

- «Small scale ocean weather during an extreme wind event in the Ligurian Sea», Berta M., L. Corgnati, M. Magaldi, A. Griffa, C. Mantovani, A. Rubio, E. Reyes and J. Mader. Manuscript submitted to CMEMS- Ocean State Report nr. 4.
- «Submesoscale kinematic properties in summer and winter surface flows in the Northern Gulf of Mexico», Berta M., A. Griffa, A.C. Haza, J. Horstmann, H.S. Huntley, R. Ibrahim, B. Lund, T.M. Ozgokmen, and A.C. Poje. Manuscript submitted to JGR: Oceans.