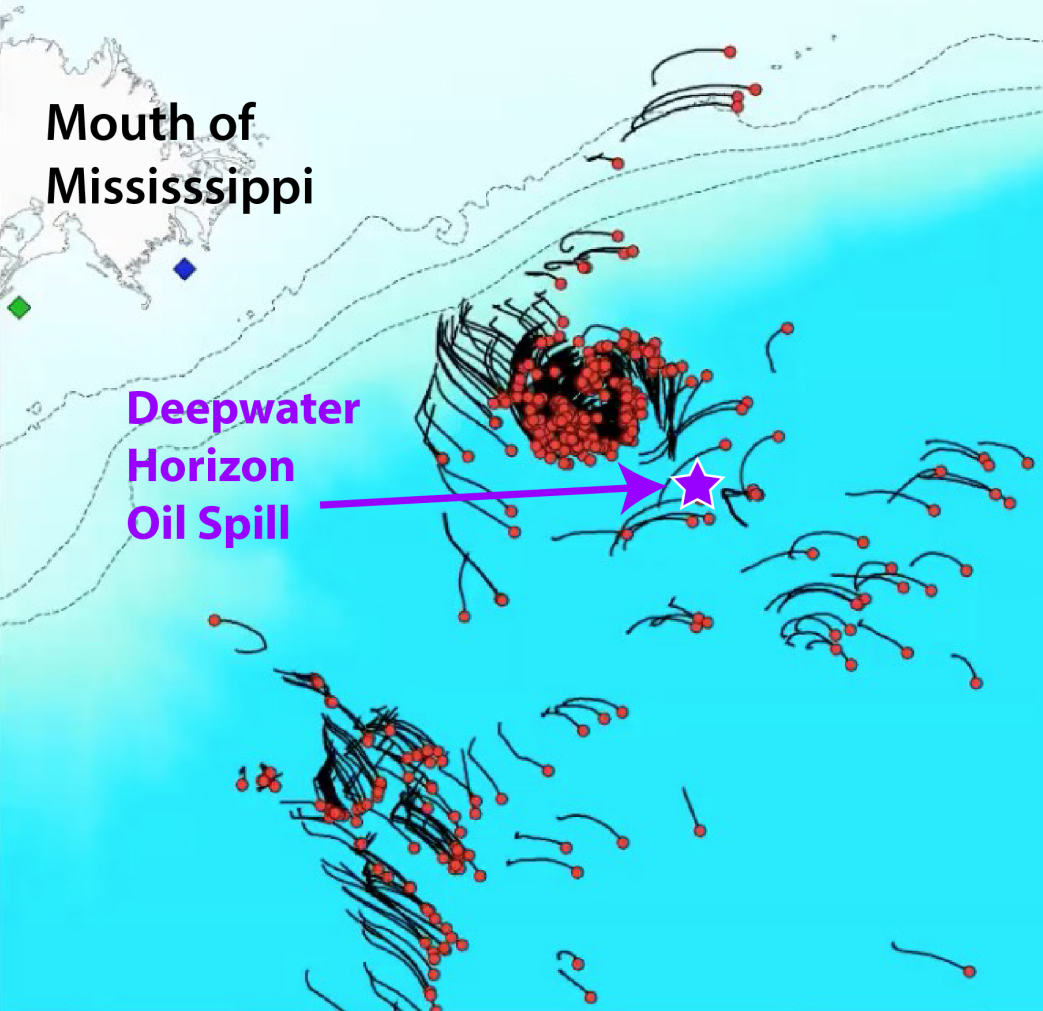
Massive Submesoscale Surface Drifter Releases

Eric D'Asaro & Andrey Shcherbina
Applied Physics Laboratory
University of Washington, Seattle, USA

Tamay Ozgokmen
Rosenstiel School of Marine and Atmospheric Science
University of Miami, Miami, USA

LASER Experiment - Jan-Feb 2016



CARTHE Consortium

Funded by BP Oil Spill - GOMRI

New Surface Drifter Design

Massive Surface Drifter Releases

~300 GLAD - Aug 2012
~1100 LASER - Jan/Feb 2016

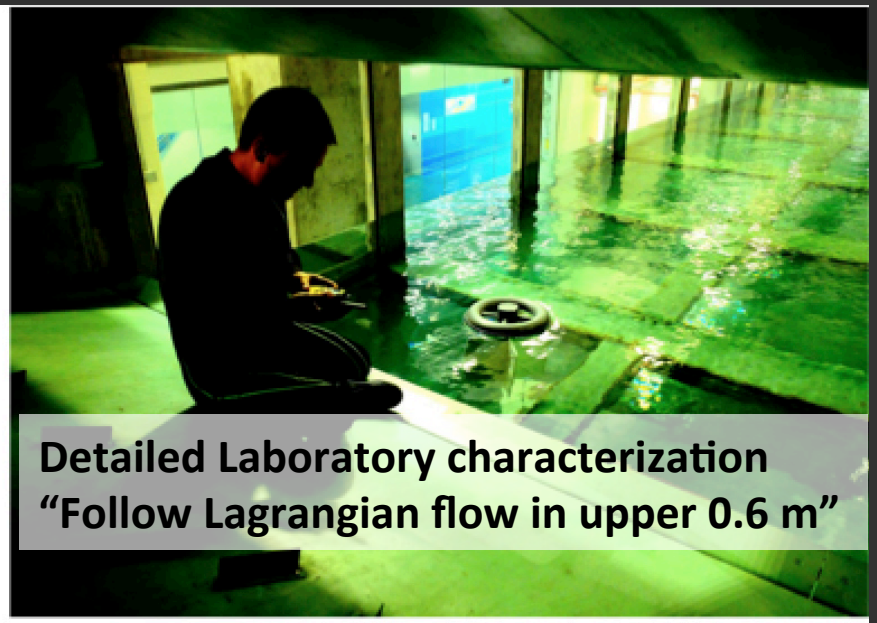
Submesoscale Structures

Cyclonic vortices & fronts - "Soup"
Vorticities >> f
Strong convergence at fronts

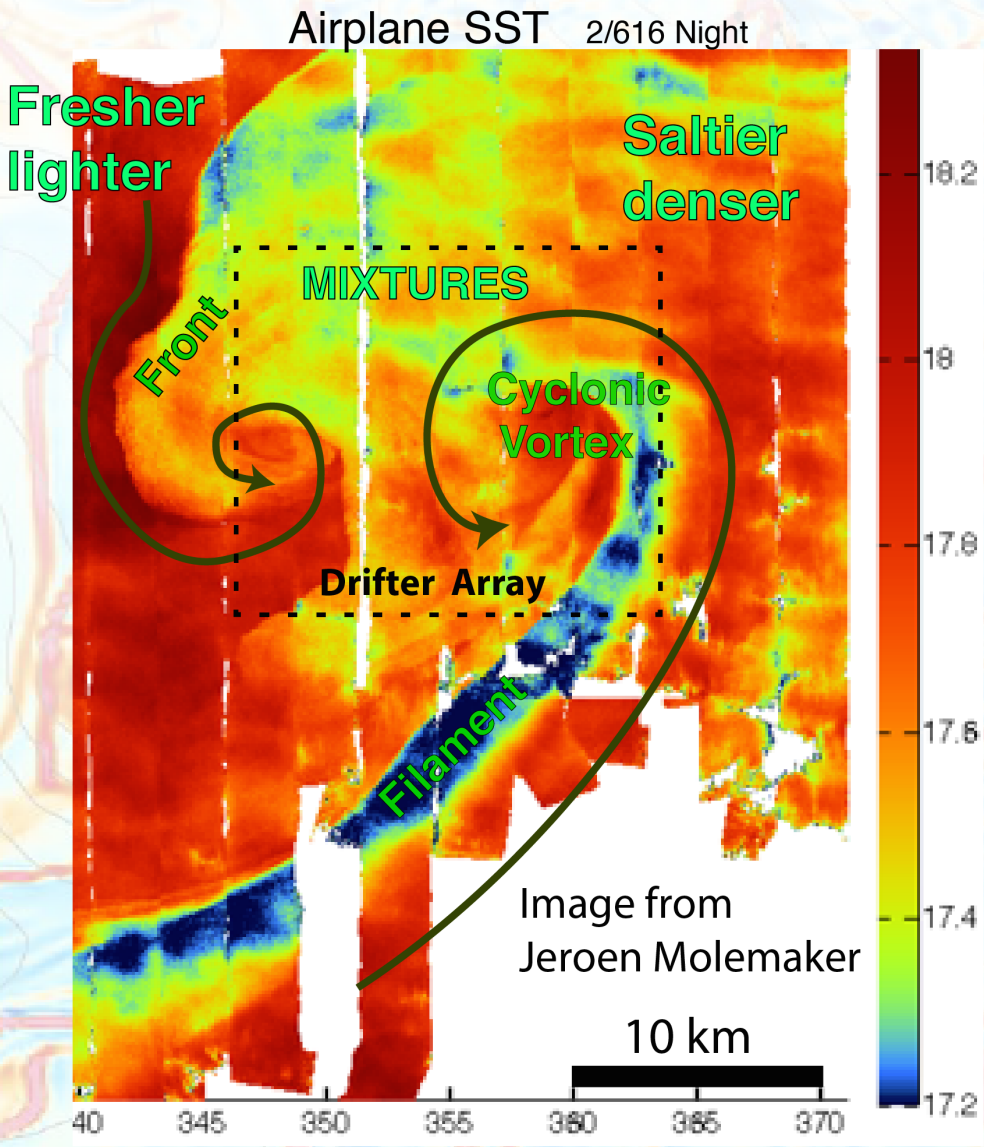
Submesoscale SSH estimation

CARTHE Drifter Design

"$500 - $1000", Satellite tracked, 3 months biodegradable plastic, 1100 deployed in LASER, ~30% drogue failures (fixes underway)



LASER Submesocale Geography



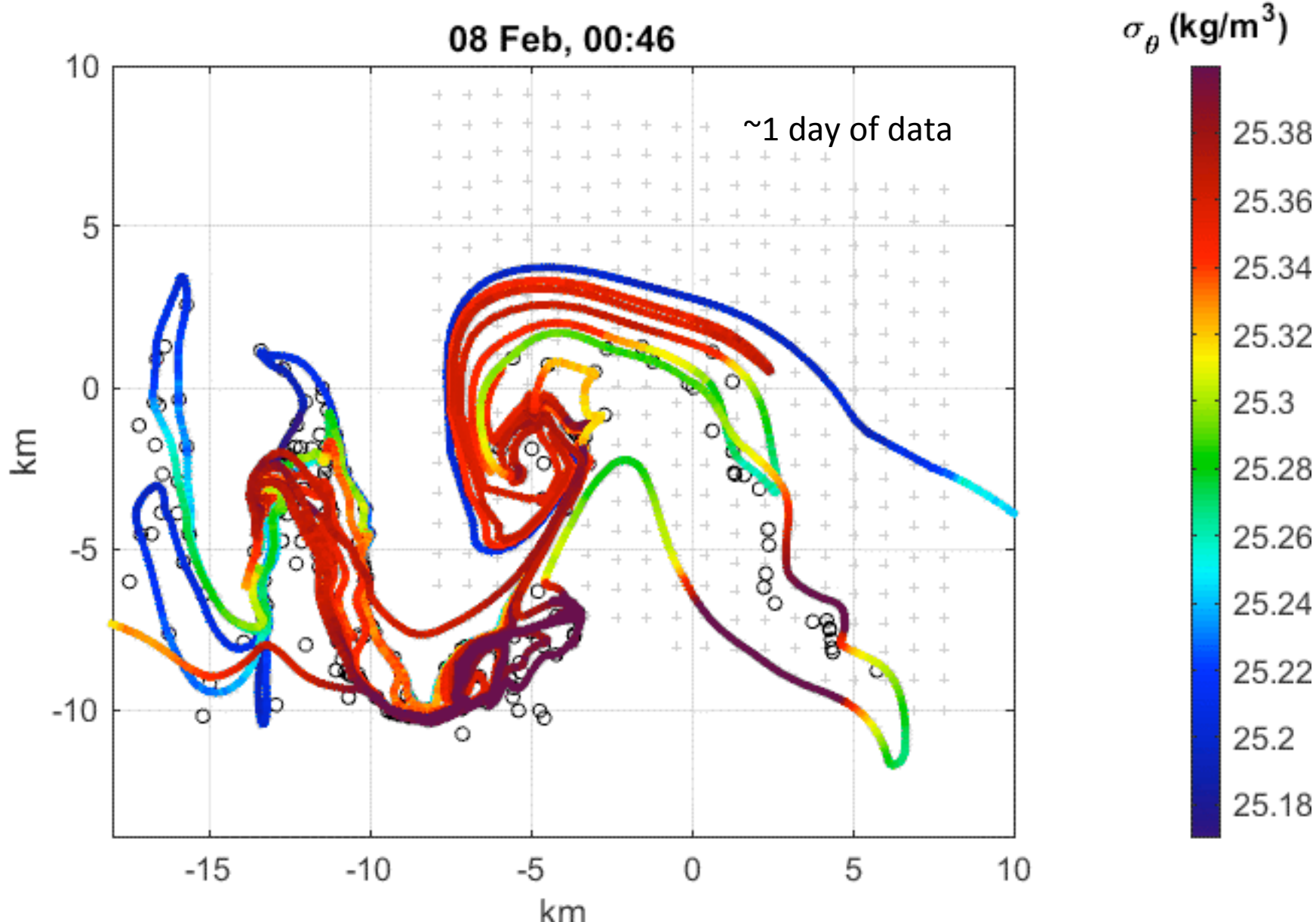
Lateral density gradients are stirred by cyclonic vortices to form fronts and filaments

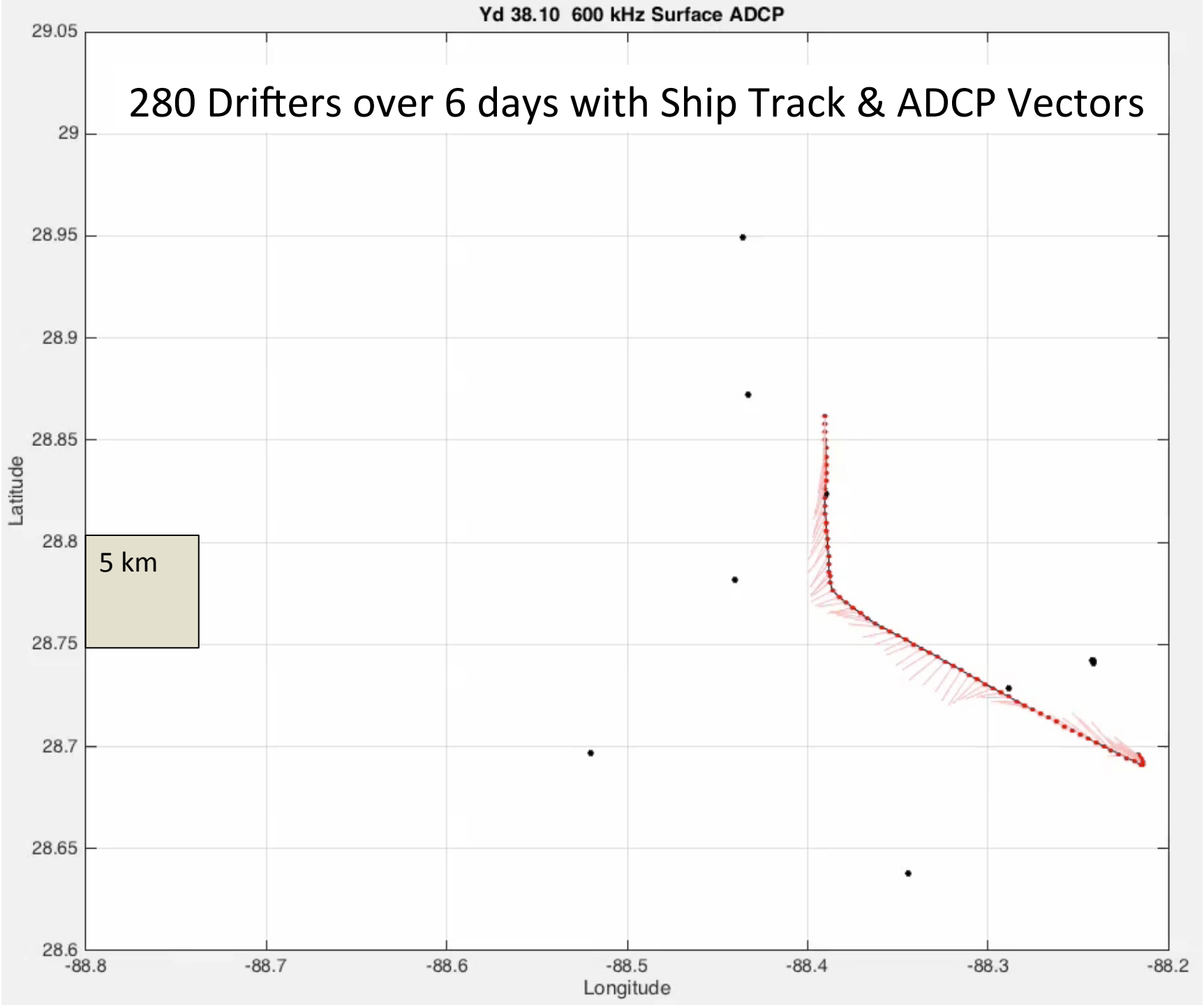
Qualitatively similar to ‘ Submesocale Soup’ in models
(Shcherbina et al. 2013)

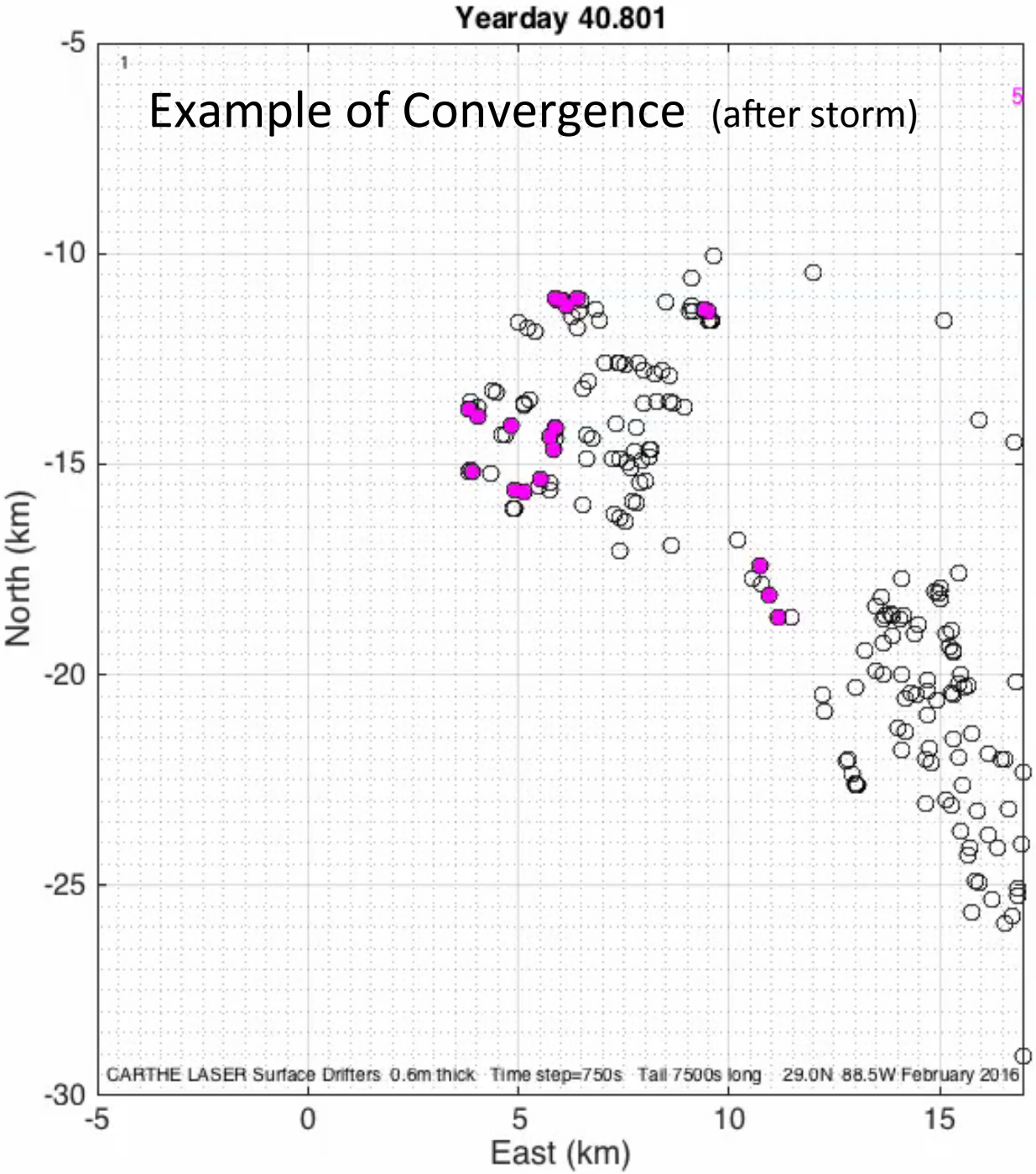
This talk: “Last Drifter Array”
18 x 18 @ 1 km spacing
12 hours with 2 ships

Cyclonic eddies Strain density gradient into fronts and filaments

Distort density from ship's underway system using drifter trajectories

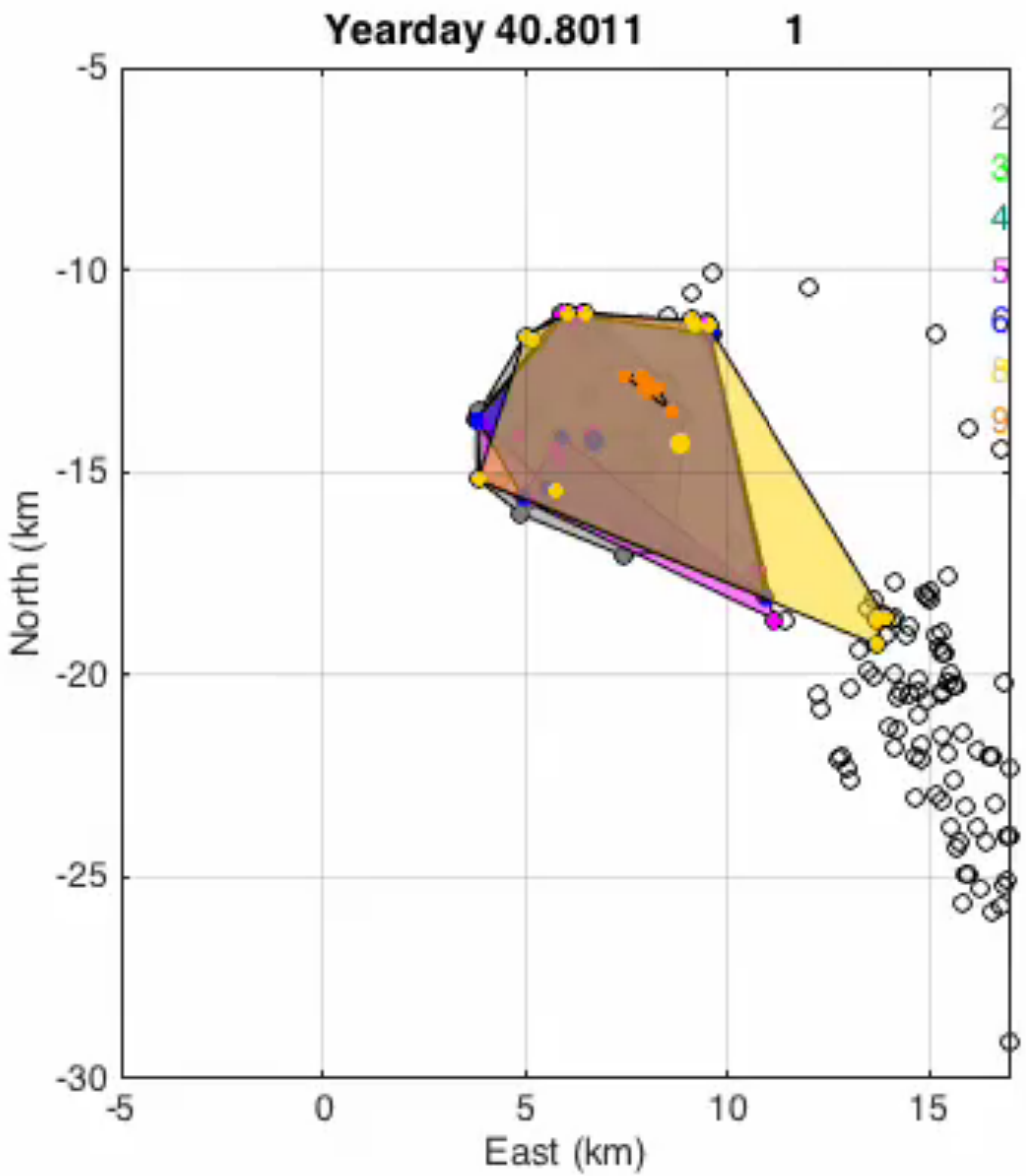



Yd 38.10 600 kHz Surface ADCP
280 Drifters over 6 days with Ship Track & ADCP Vectors
5 km
Latitude
Longitude
29.05
29
28.95
28.9
28.85
28.8
28.75
28.7
28.65
28.6
-88.8
-88.7
-88.6
-88.5
-88.4
-88.3
-88.2

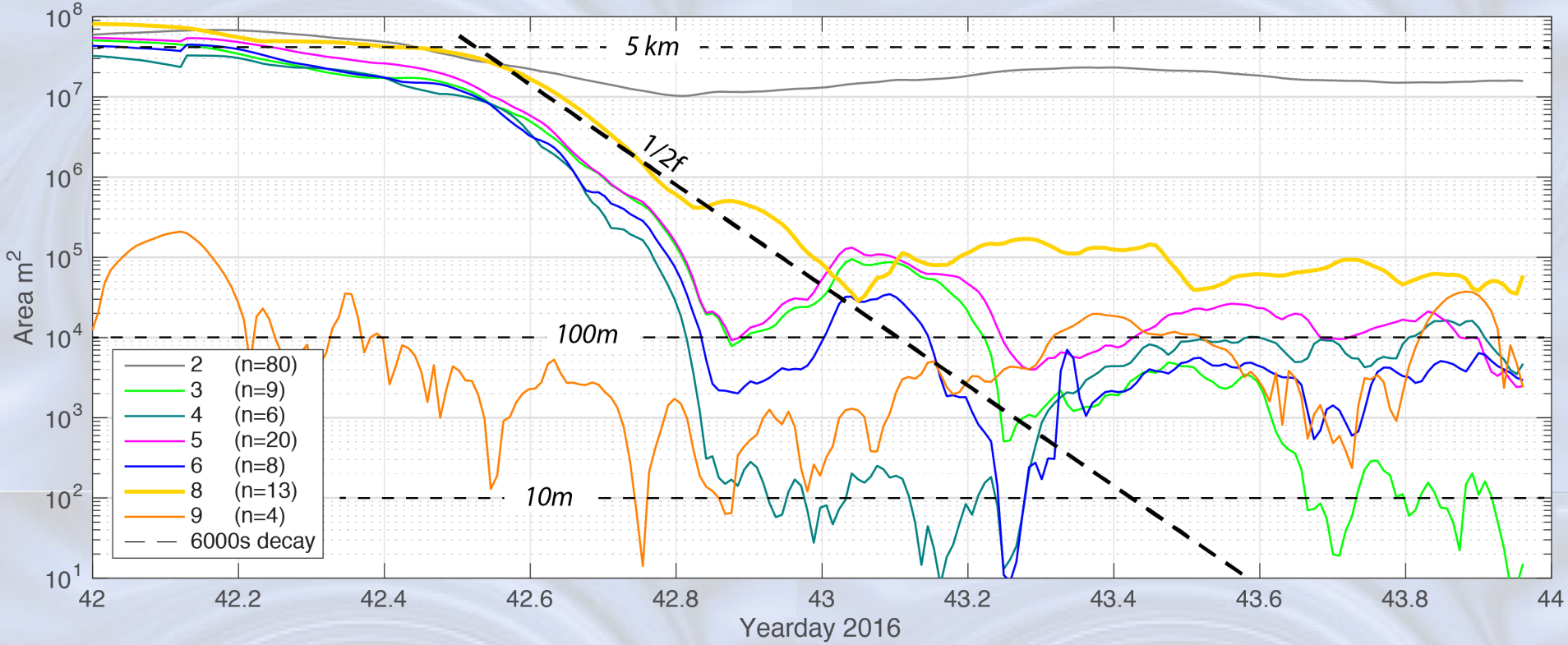

Yearday 40.801
Example of Convergence (after storm)
North (km)
East (km)
-5
-10
-15
-20
-25
-30
-5
0
5
10
15
CARTHE LASER Surface Drifters 0.6m thick Time step=750s Tail 7500s long 29.0N 88.5W February 2016

Convergence of Convex Hulls (after storm)

Defined by sets of drifters



Area of Selected Convex Hulls (Same as in video)

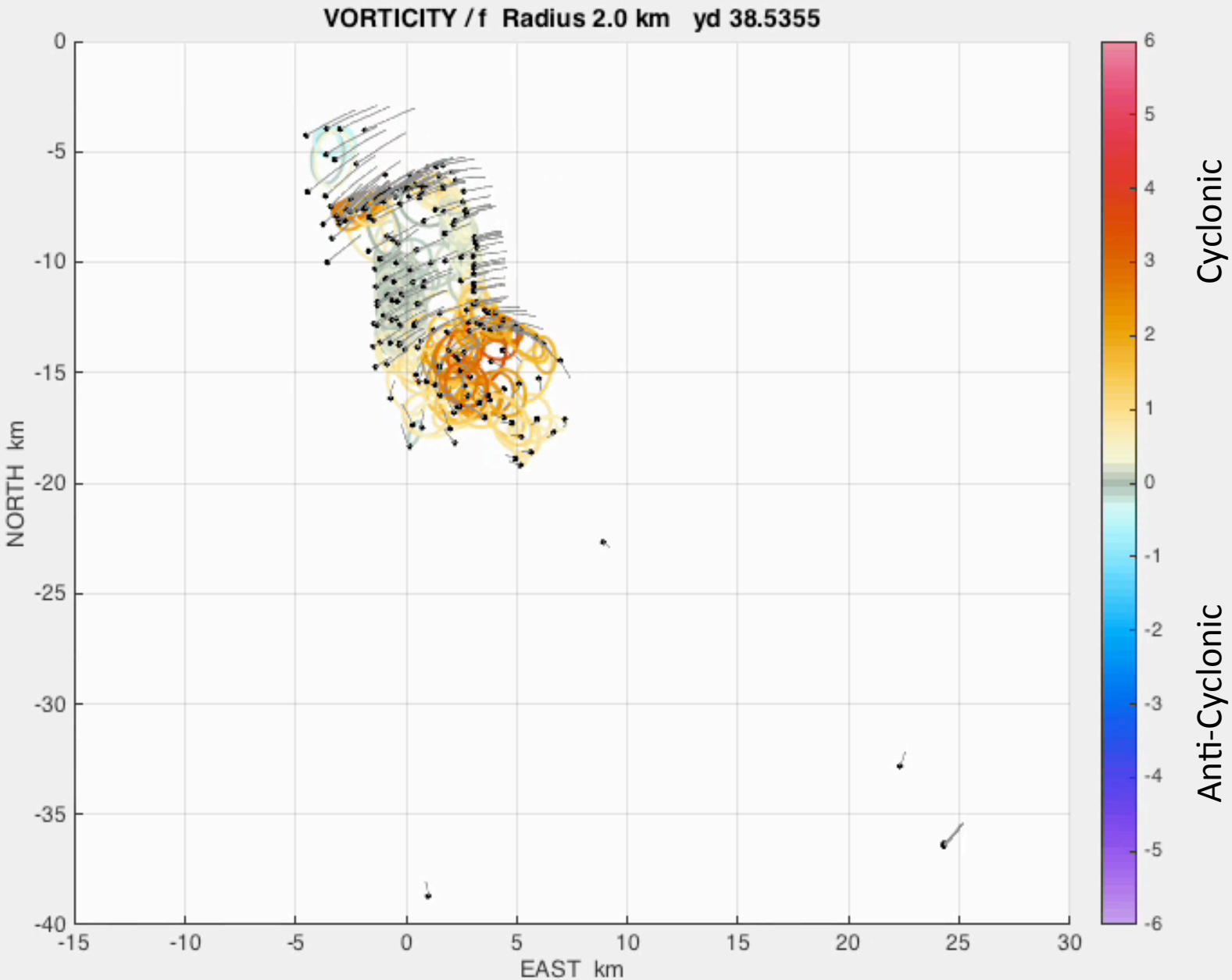


A new paradigm?

Strong submesoscale convergence competes with mesoscale dispersion

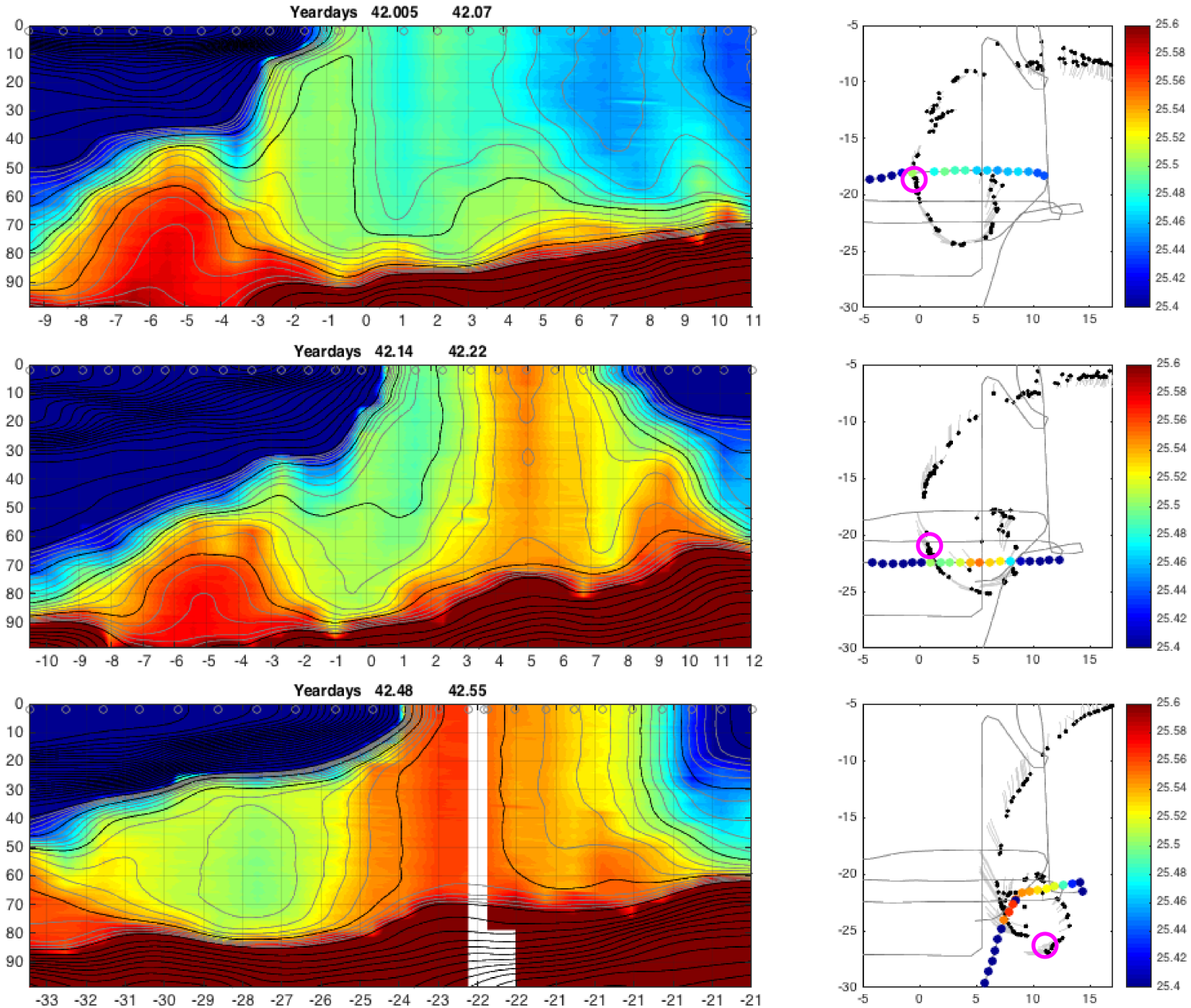
Stops at ~100m scale. Is this competition with boundary layer turbulence?

Vorticity from plane fit of velocity from all drifters in a 2km radius



Frontal Subduction from Directed Ship Sections

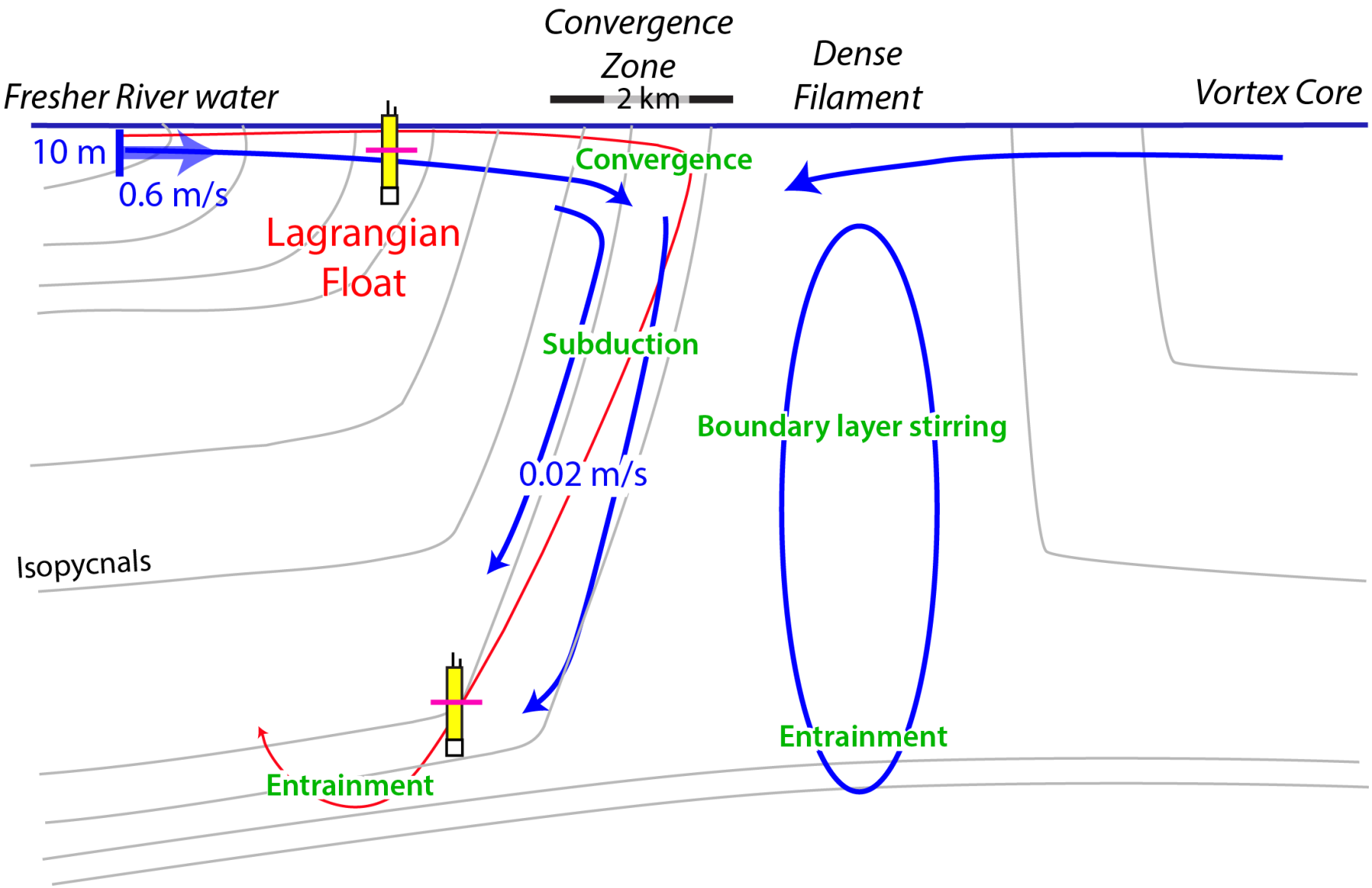
"Difficult to do this with ship surveys alone"



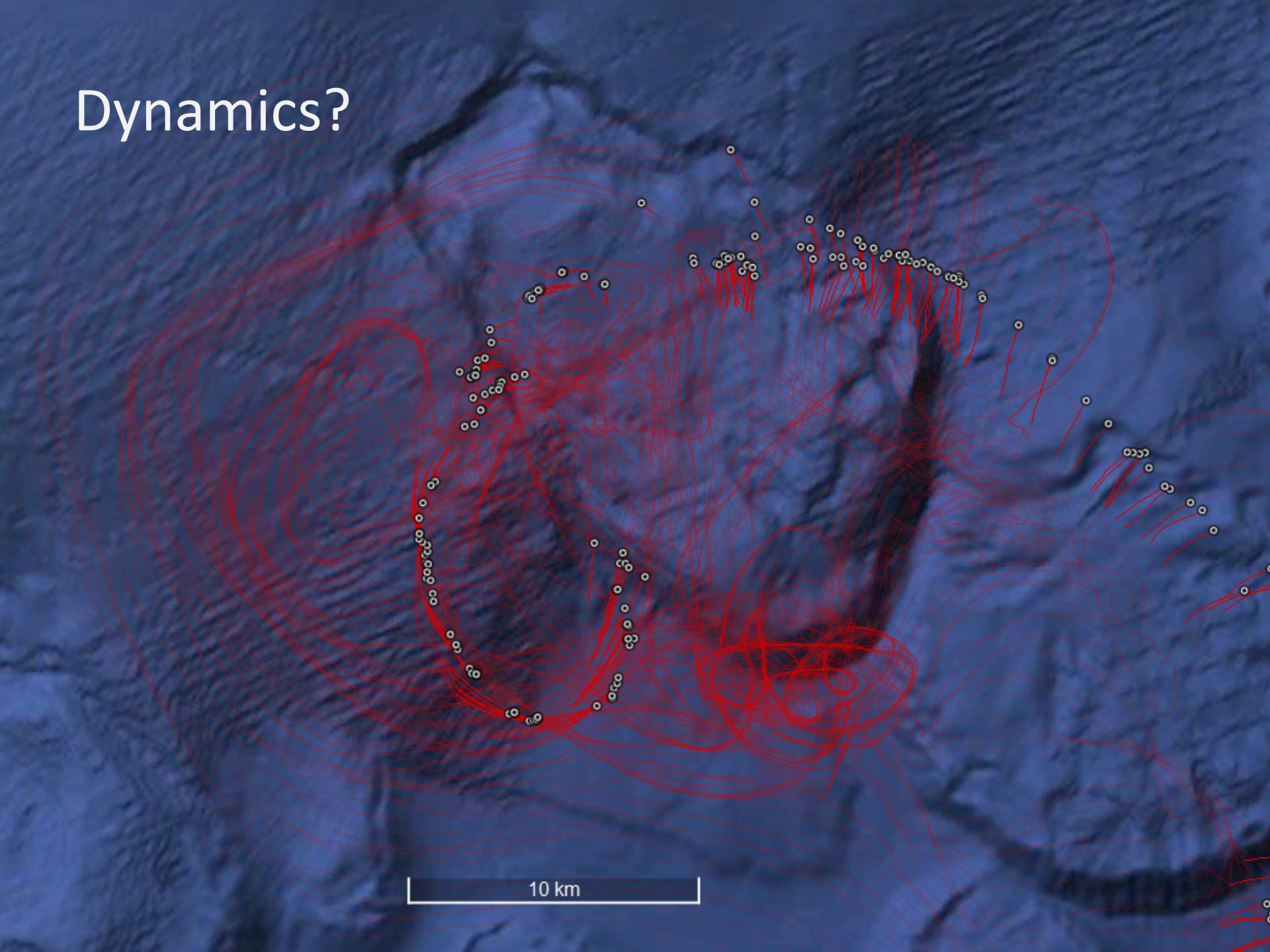
Possible Vertical Circulation at Subduction Region

Mapping from ship and drifters **Drifter convergence rates**

Lagrangian float deployed into zipper: trajectory and upward looking ADCP



Dynamics?



Diagnosing dynamical balance

from surface drifter observations

Lagrangian particle momentum equation:

$$d/dt\, V + f \times V + -\tau / \rho_0 H = -g \nabla \eta + visc.$$

① ② ③ ④ ⑤

<u>Terms:</u>

① Acceleration
② Coriolis
③ Wind stress
④ Pressure (SSH) gradient
⑤ ~~Viscosity~~

Diagnosing dynamical balance

from surface drifter observations

In <u>streamwise</u> (intrinsic) coordinates:

$$d/dt\, U + \qquad -\tau_x/\rho_0 H = -g\partial\eta/\partial x + visc.$$

$$U^2/R + fU + -\tau_y/\rho_0 H = -g\partial\eta/\partial y + visc.$$

① ② ③ ④ ⑤

<u>Terms:</u>

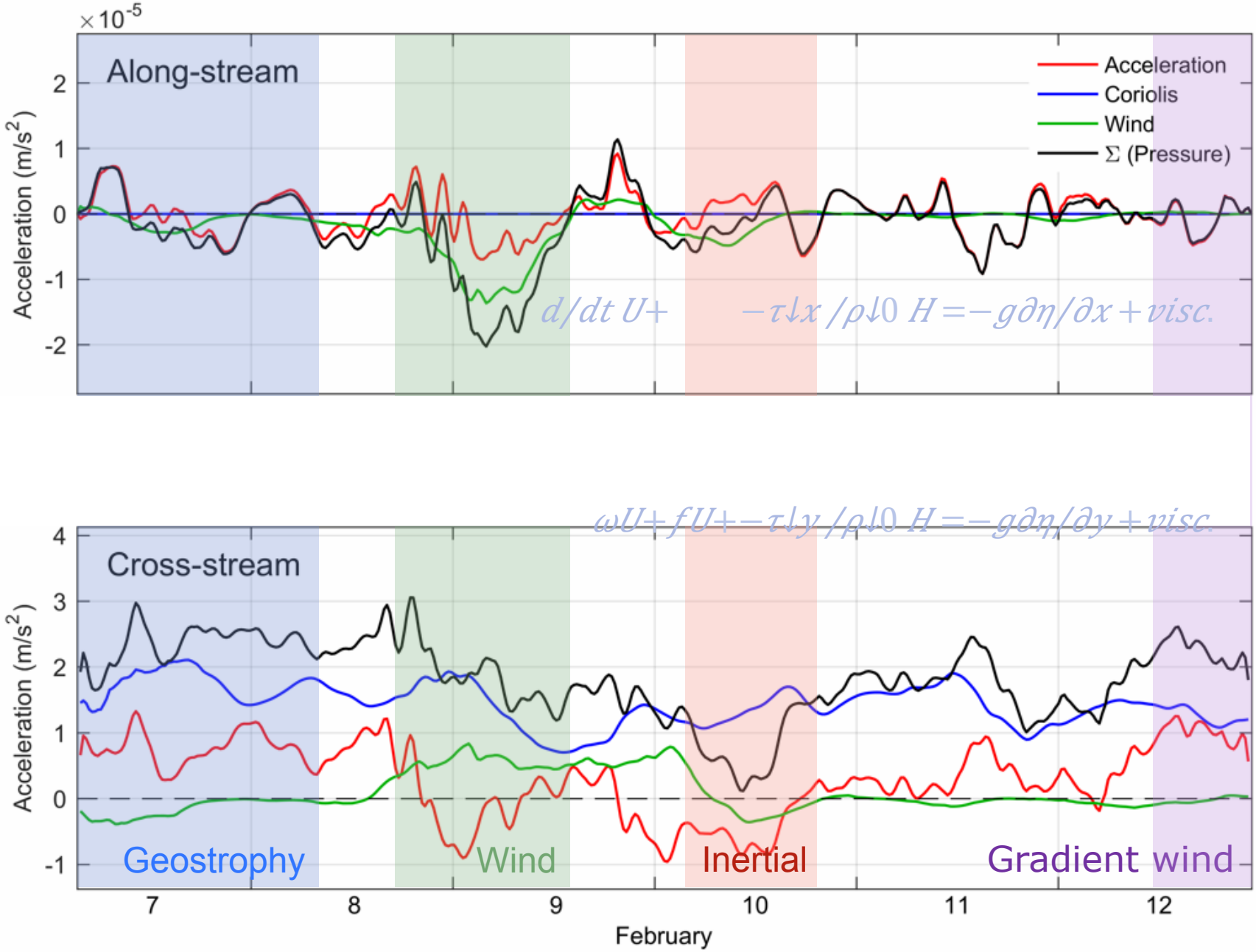
① Acceleration (tangential/centripetal)
② Coriolis
③ Wind stress
④ Pressure (SSH) gradient
⑤ ~~Viscosity~~

<u>Balances:</u>

② ~ ④ : Geostrophy
② ~ ③ : Ekman
$①_y$ ~ ② : Inertial oscillations
$①_x$ ~ ④ : Cyclostrophy
$①_y$ ~ ④ : Hydraulic control +waves

...

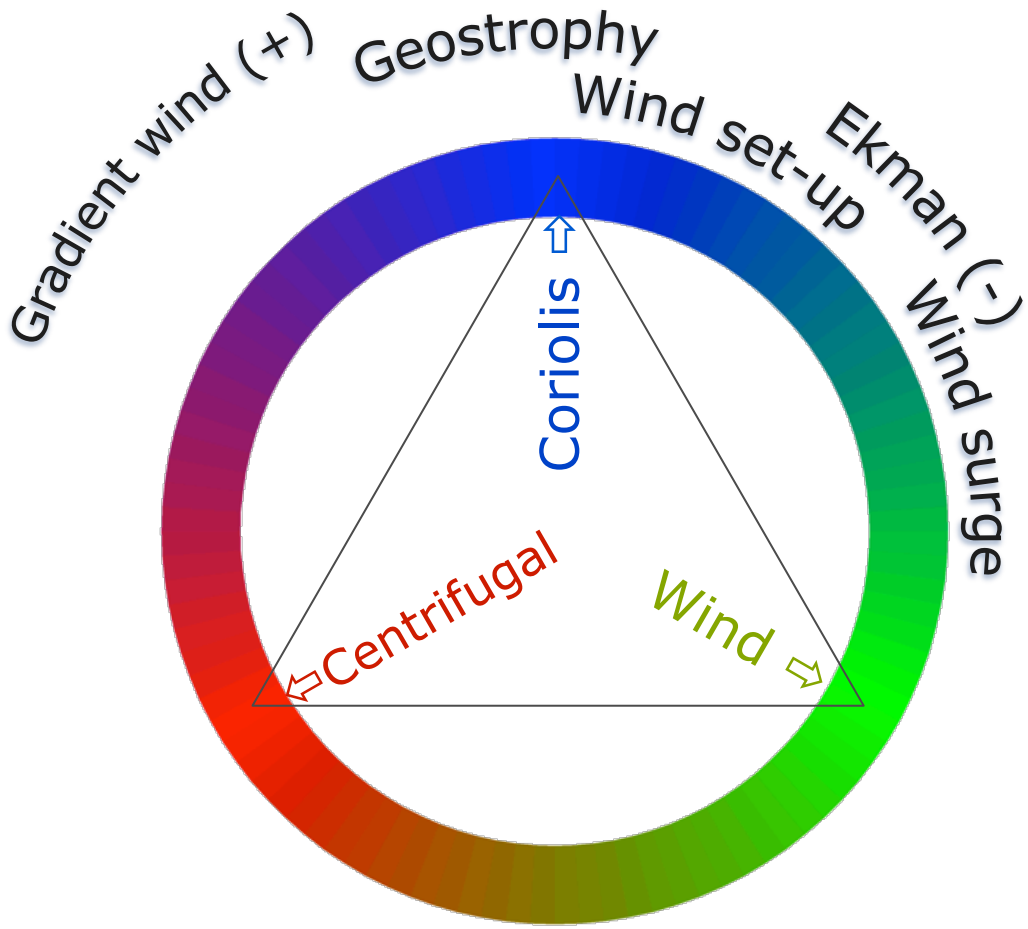
Evolution of Lagrangian acceleration balance



Visualizing the balance

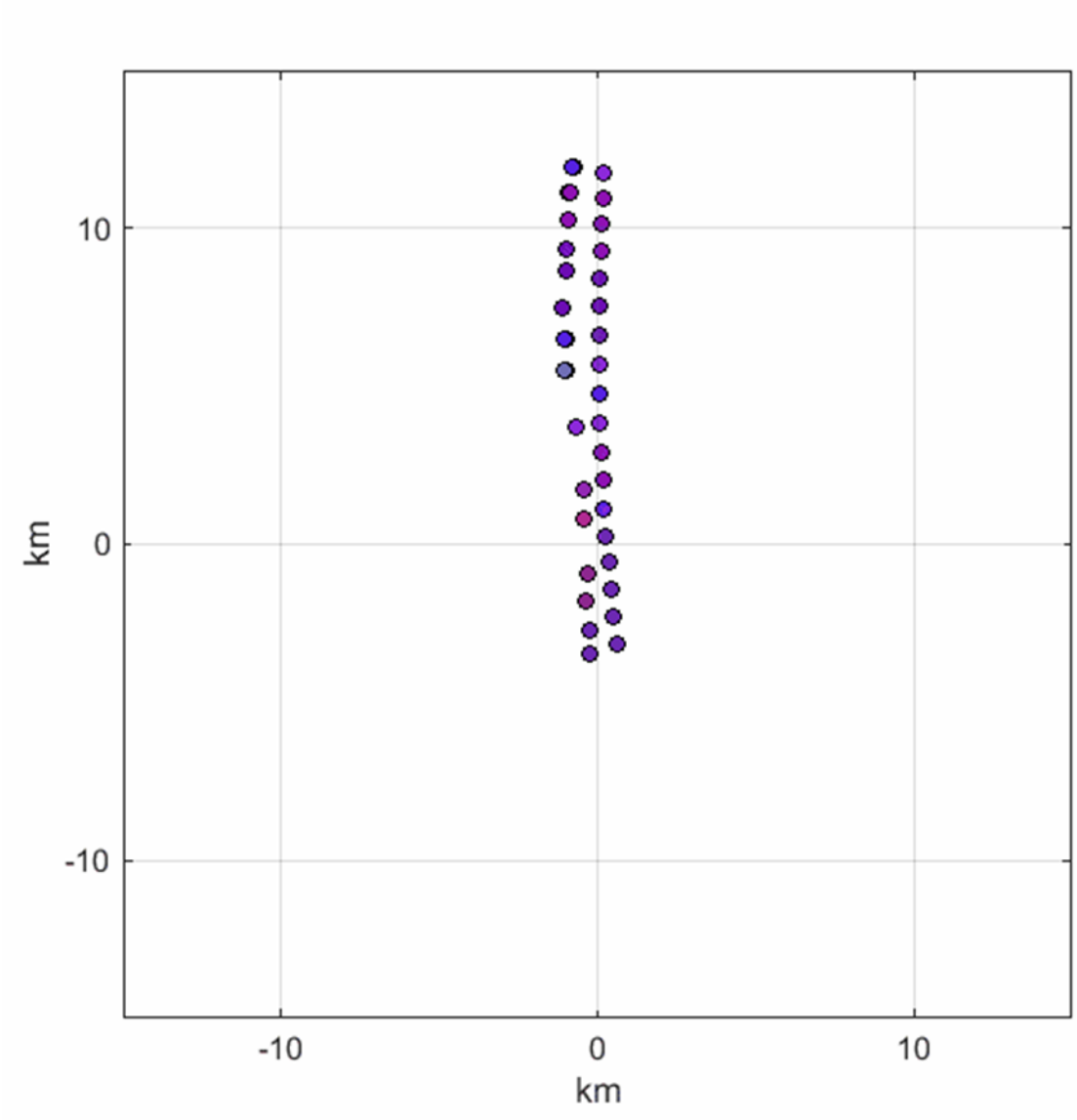
Mapping magnitudes of the equation terms to colors

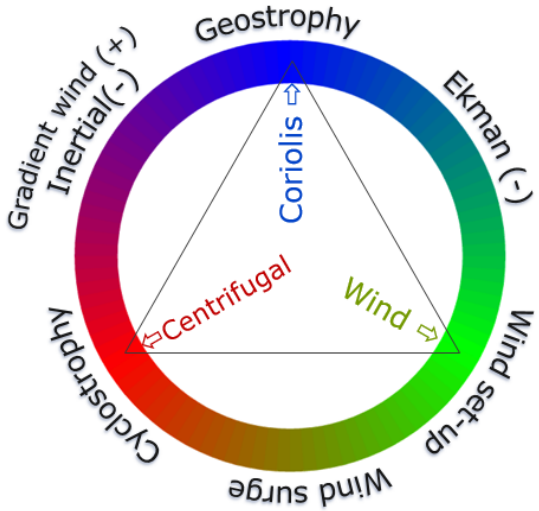
$$U^2/R + fU + -\tau_y/\rho_0 H = -g\partial\eta/\partial y + visc.$$



Dynamic balance visualized

Different colors = different dominant terms





Dynamic balance visualized

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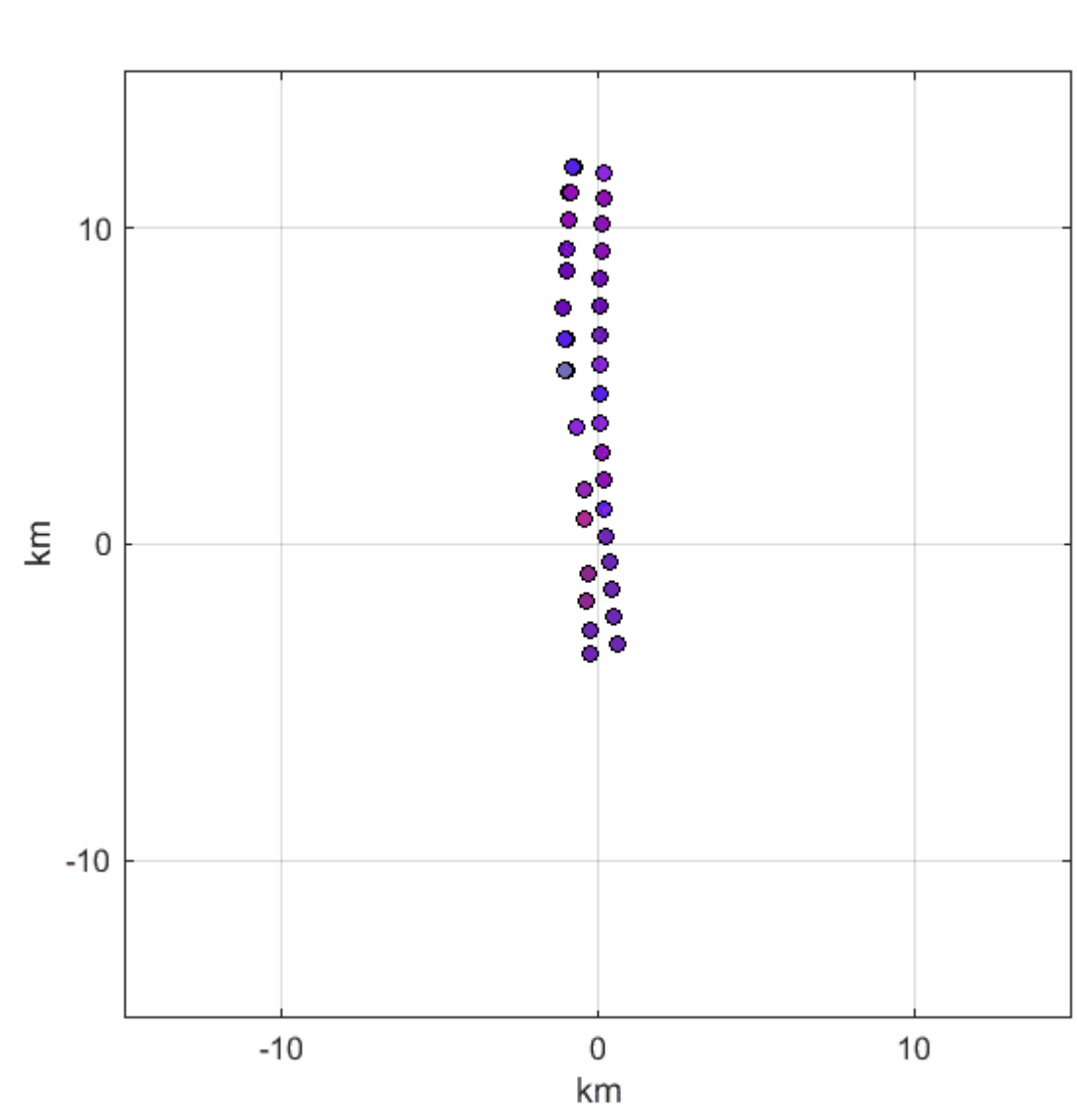
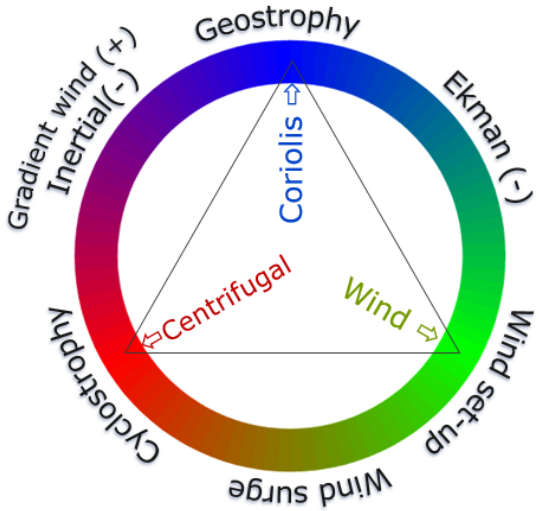




Quantify submesoscale SSH from drifters?

Dense drifter array allows integration

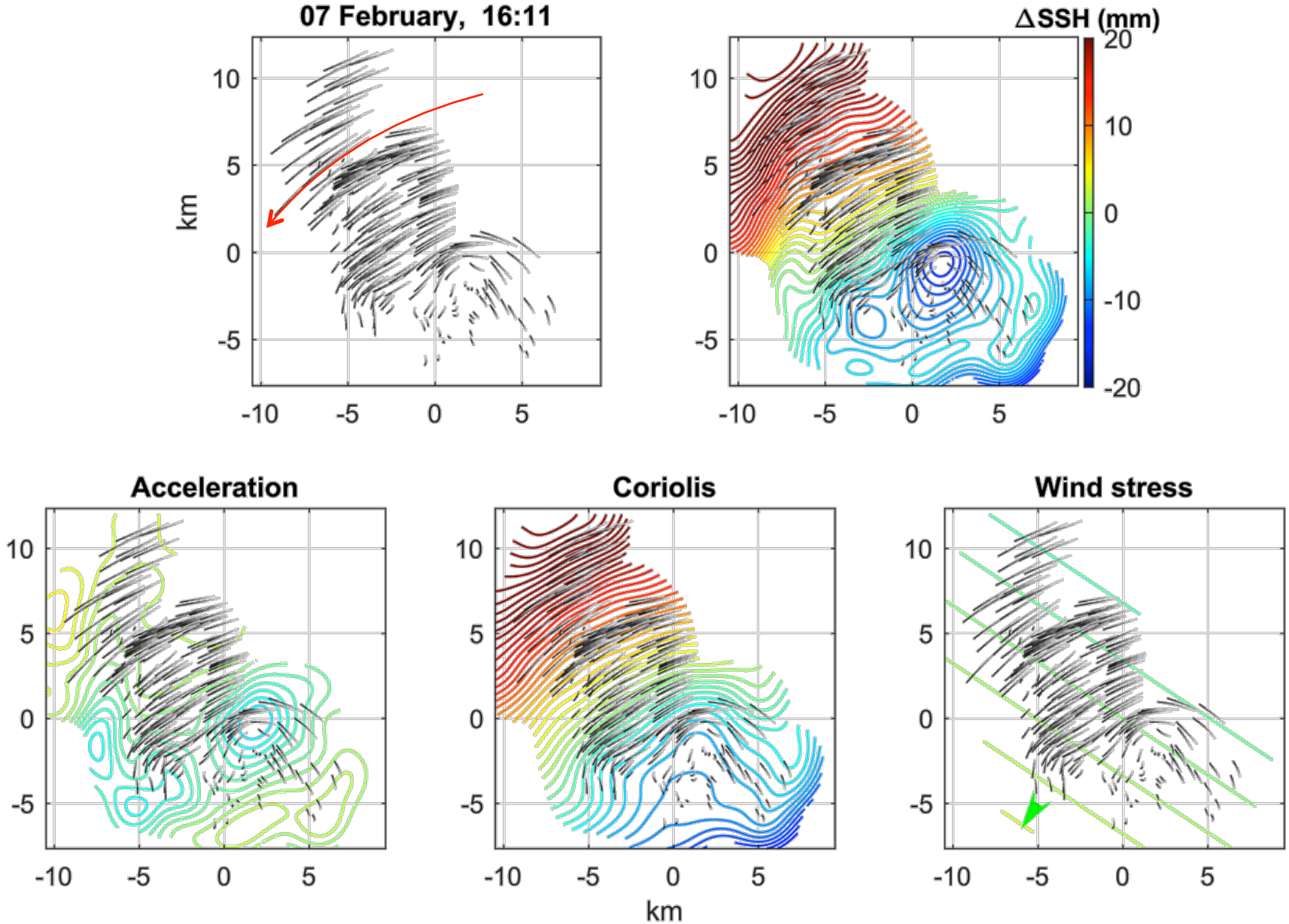
$$d/dt\, V + f \times V + -\tau / \rho_0 H = -g \nabla \eta$$

Re-write in terms of SSH gradients:

$$\nabla \eta_a + \nabla \eta_c + \nabla \eta_\tau = \nabla \eta$$

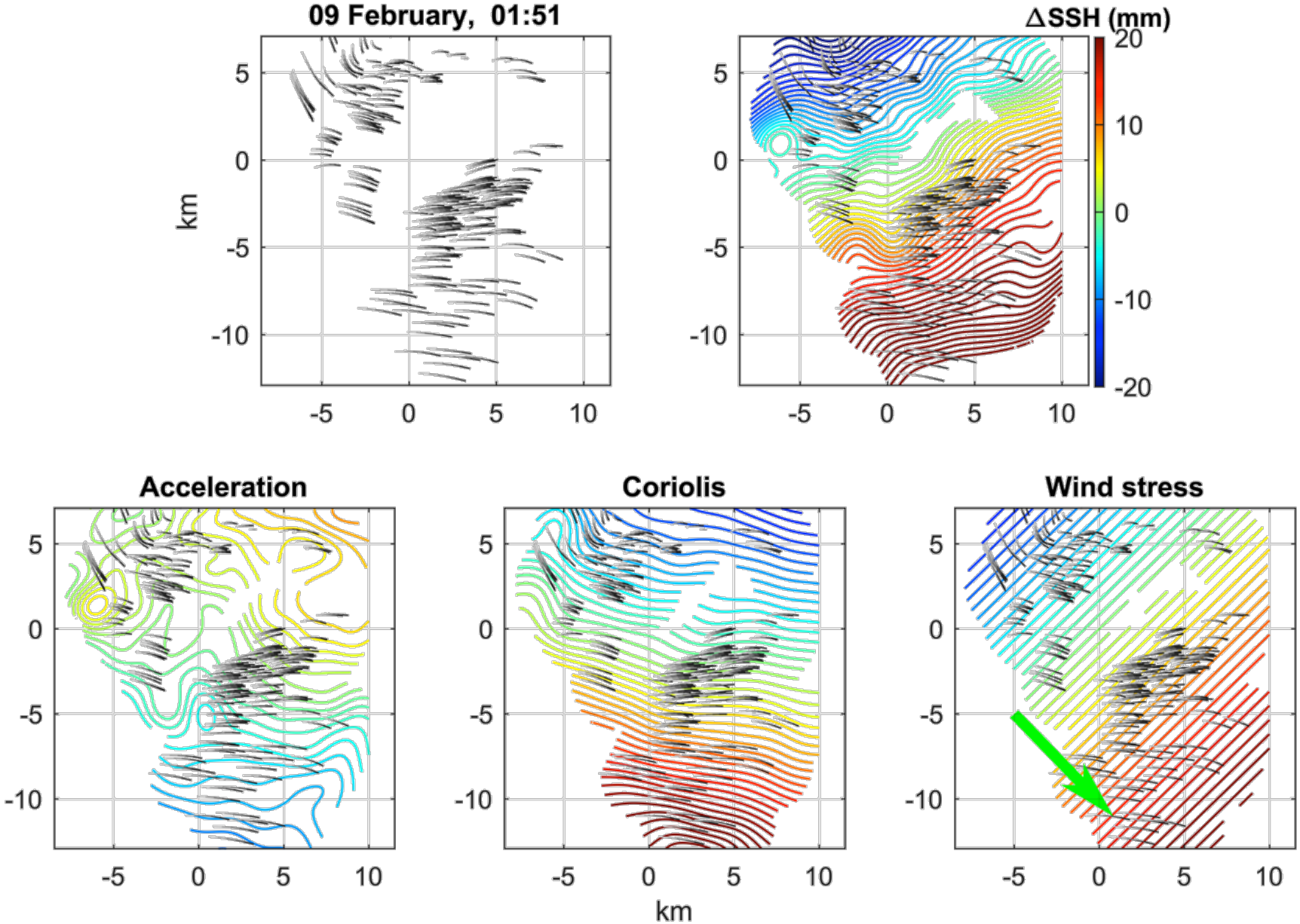
… and integrate to obtain fields of SSH anomaly contributions

Mostly-geostrophic eddy

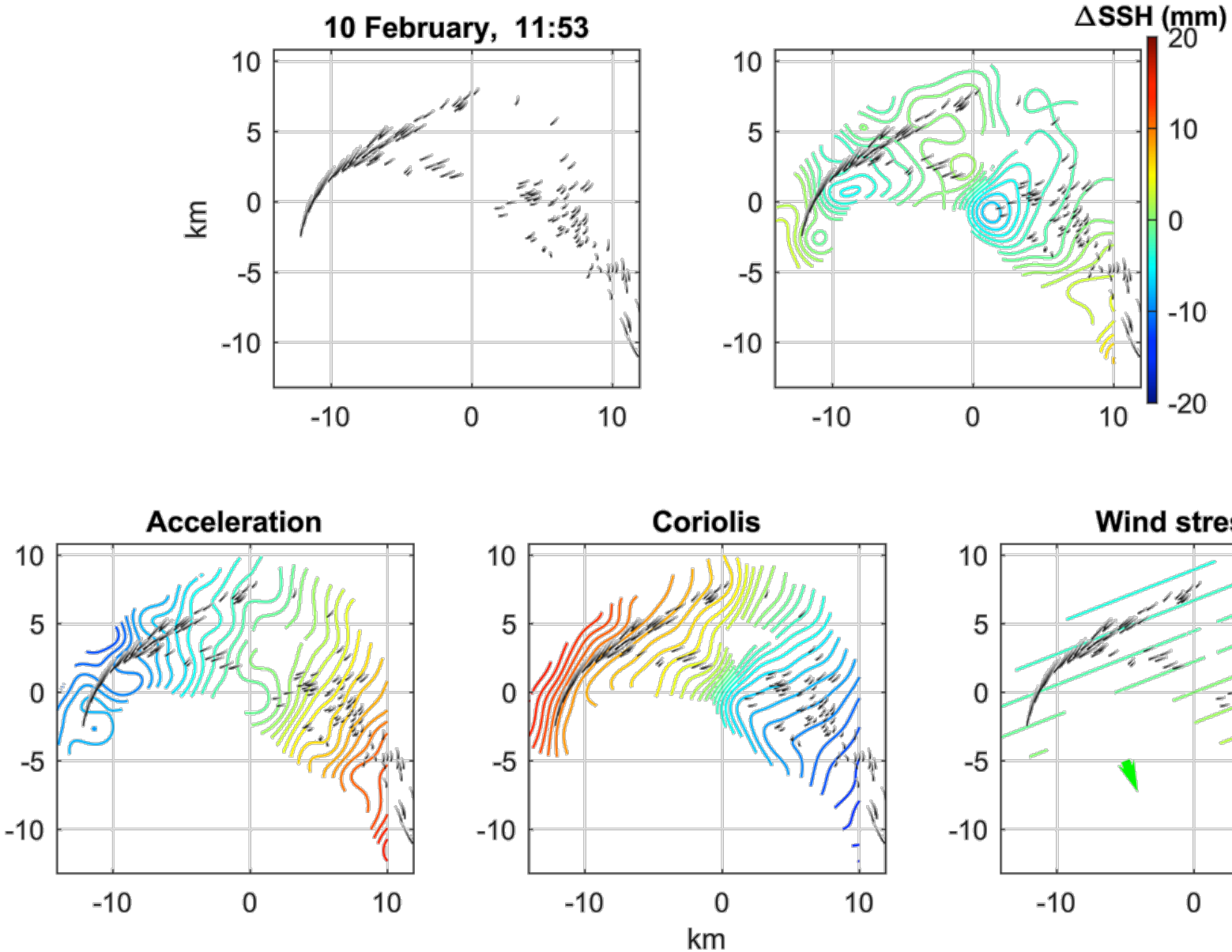


Wind burst

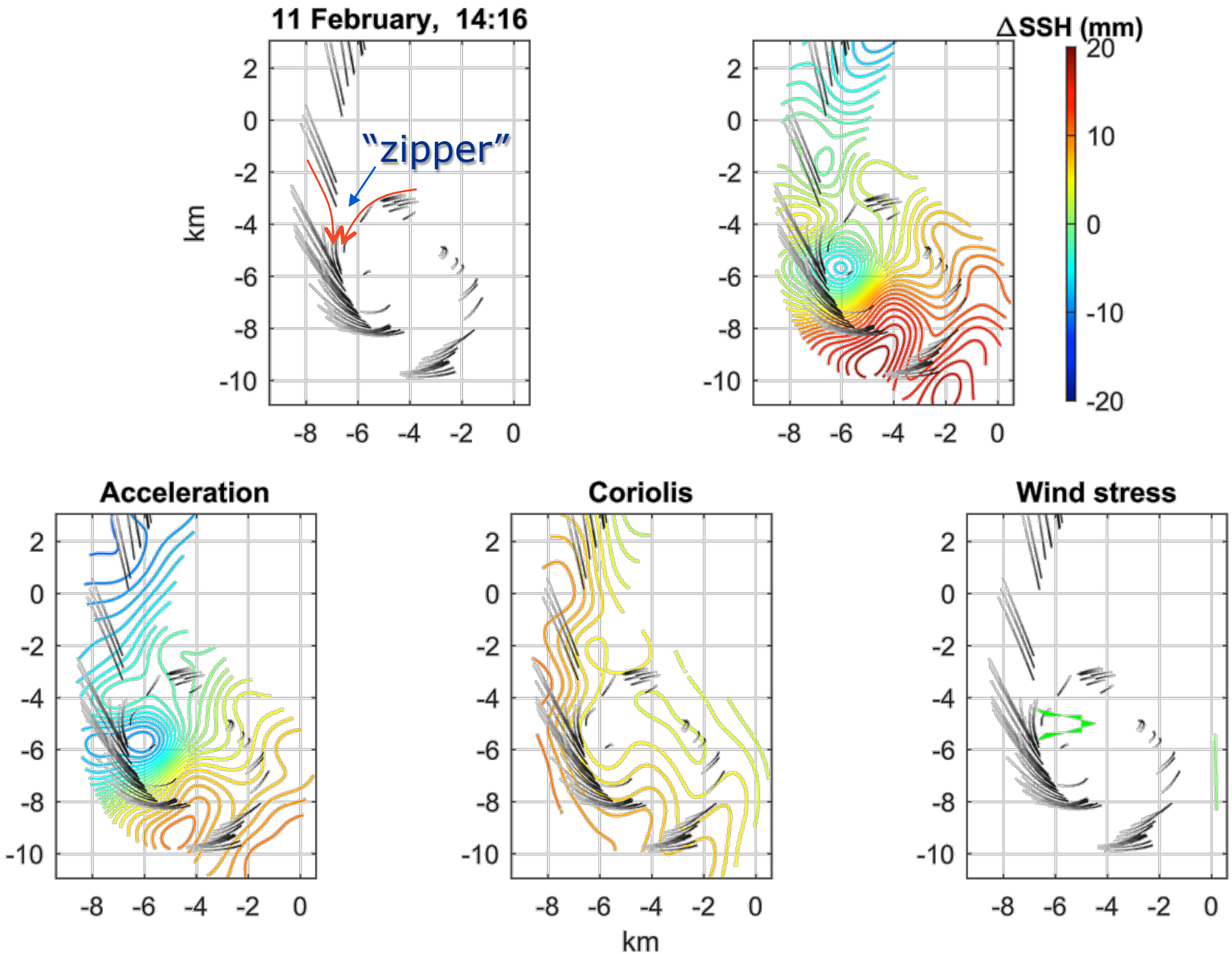
17 m/s sustained gale



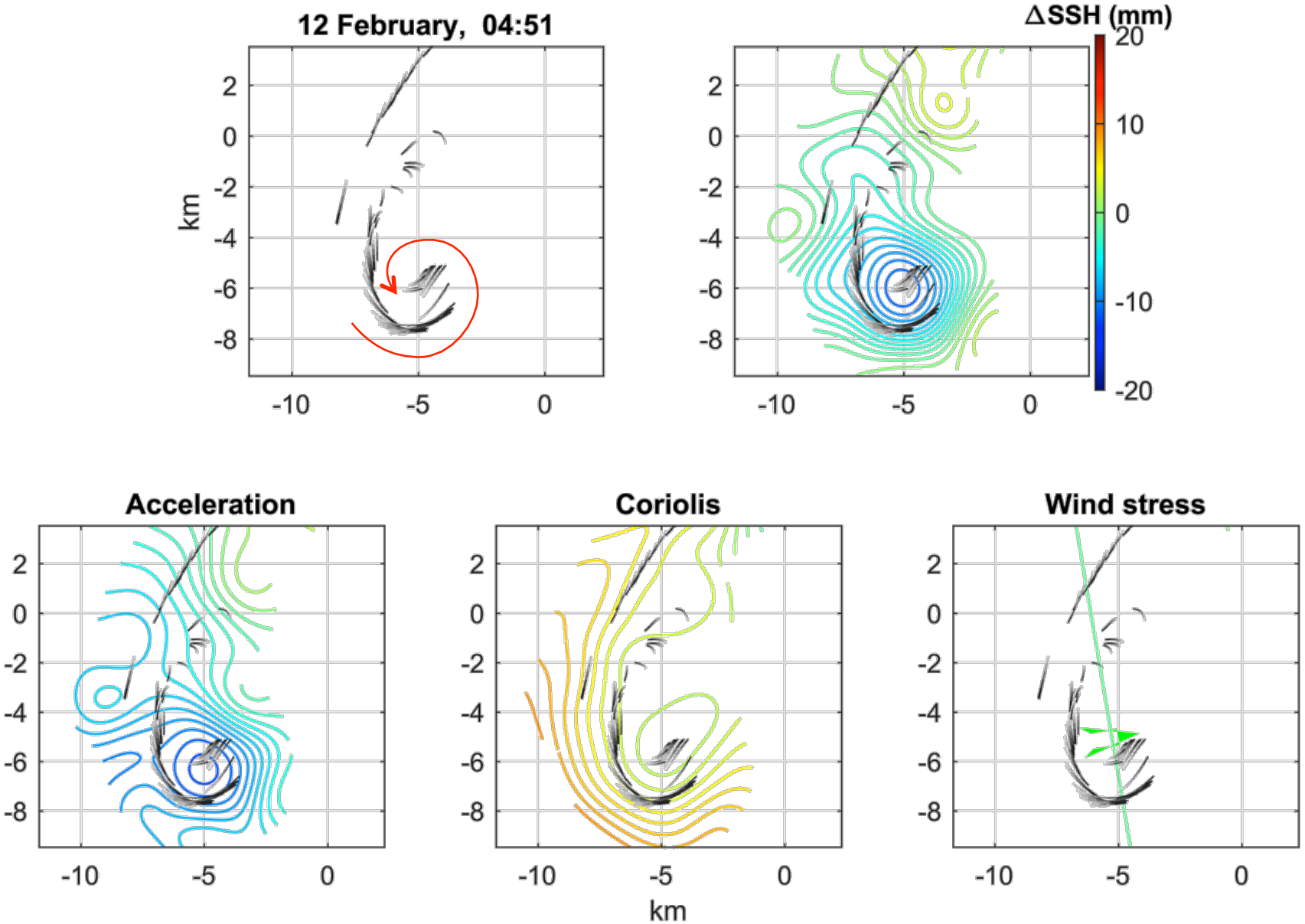
Free inertial oscillation



Confluence


11 February, 14:16
"zipper"
km
ΔSSH (mm)
20
10
0
-10
-20
Acceleration
Coriolis
Wind stress
2
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
km

Cyclostrophic eddy



SUMMARY

- Massive Surface Drifter releases can effectively sample the submesocale
- Can effectively direct ship surveys to interesting features
- Found strong convergences with scales of 10 km to 100m
- Found characteristic structures: *fronts, "zippers", km-scale cyclones*
- Could diagnose SSH variations of 4 cm over 10 km
- Dynamical balance varies: *geostrophic/wind/inertial/cyclostrophic*
- Submesoscale structures and dynamical balances vary over a few hours

EXTRAS

Massive drifter releases are an effective way to sample the submesoscale

Measured 100m -100 km scales in two horizontal dimensions

Drifters concentrated at fronts - non-uniform sampling

Effectively guided ship & other measurements to interesting places.

All analyses were Lagrangian

Observed a 'soup' of cyclonic vortices and fronts on 1-50 km scales

Qualitatively consistent with models

Submesoscale vertical velocities create surface convergences at km scales

Vorticity and convergence are >>f

'Zipper' structures may be important

These compete and coexist with surface dispersion

Convergence: Particles cluster

Dispersion : The clusters separate

New Dispersion Paradigm?

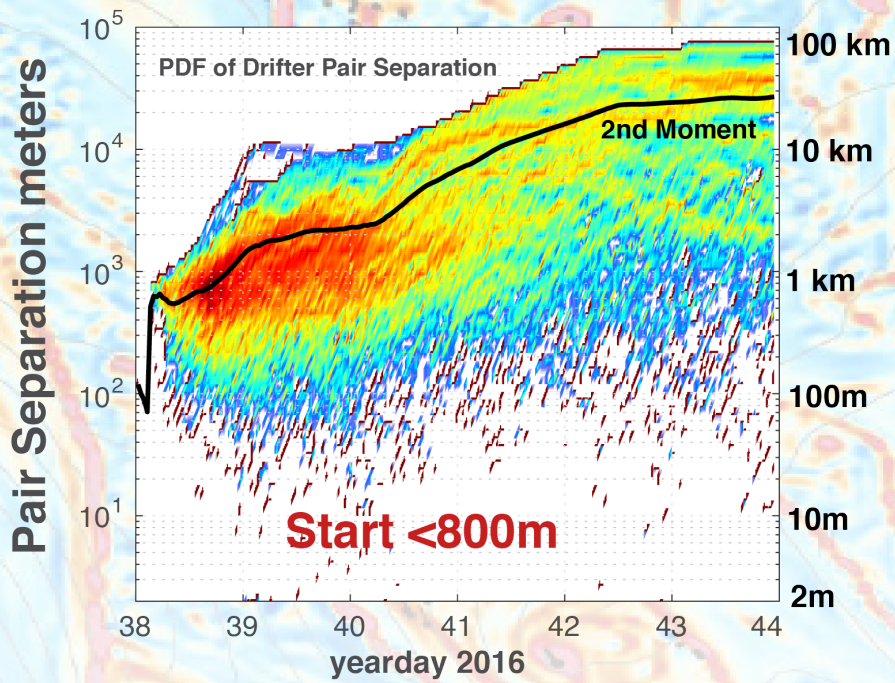
Drifter clusters have a dominant ~100m scale

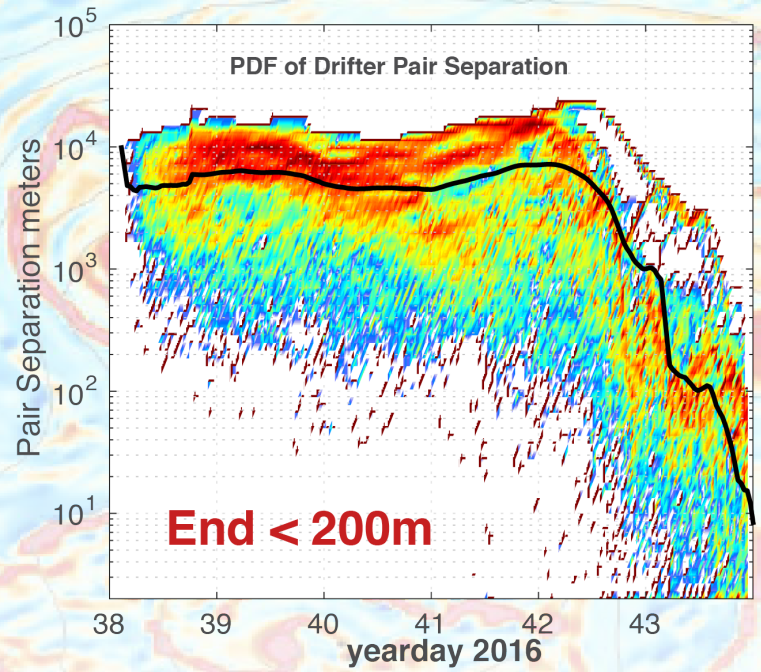
Does this mark the small-scale limit of 'submesoscale dynamics'?

DISPERSION v CONVERGENCE

"Particles get further apart with time"
Stocastic models, Okubo curves, Richardson dispersion...

"Floating particles collect at downwellings"
Strongest at small scales where w is bigger





CONVERGENCE: new and interesting

Occurs at **Fronts** interacting with cyclonic vortices

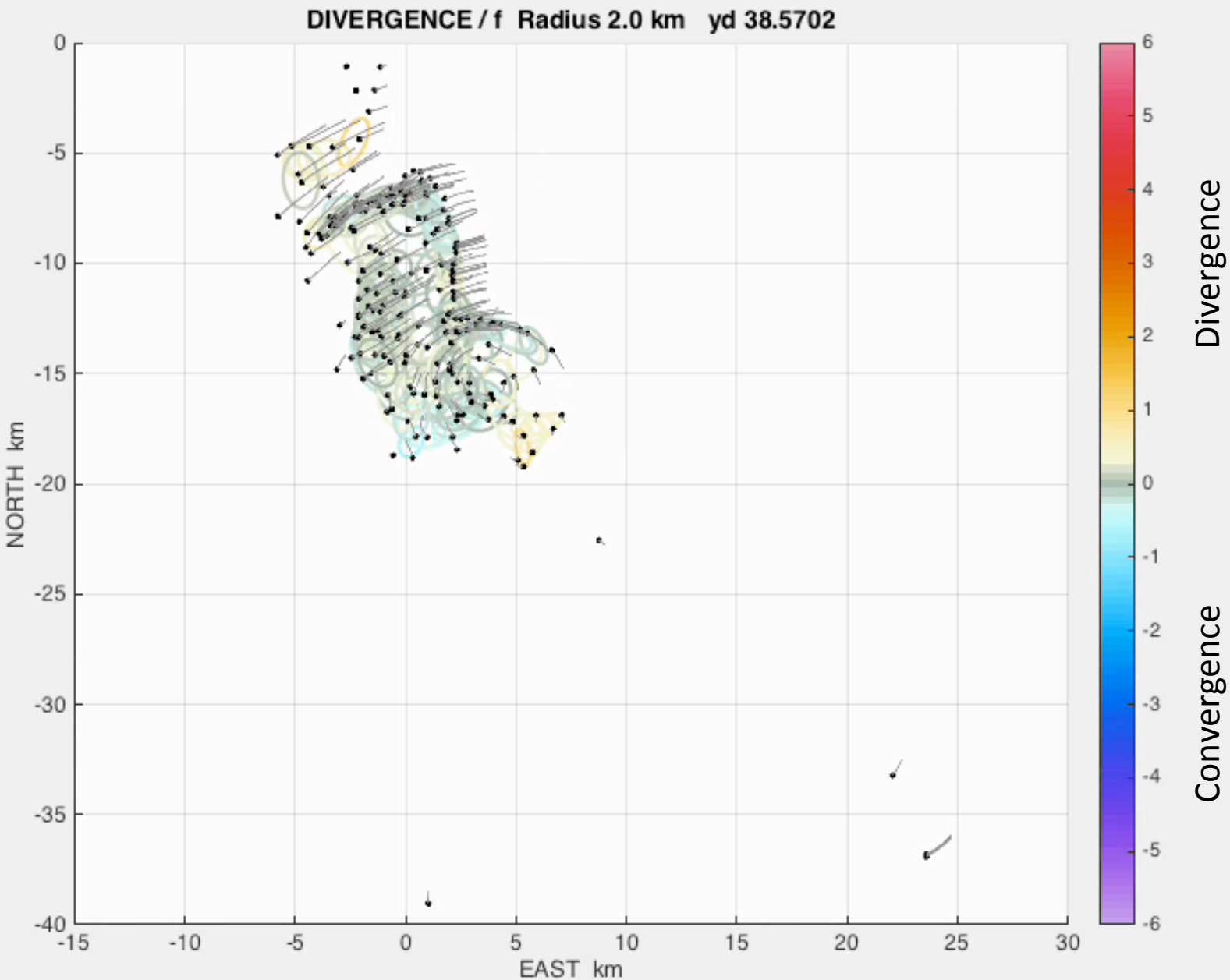
Very small scales: km's to ~100m. Hours.

Large Ro: Vorticity, divergence >> f

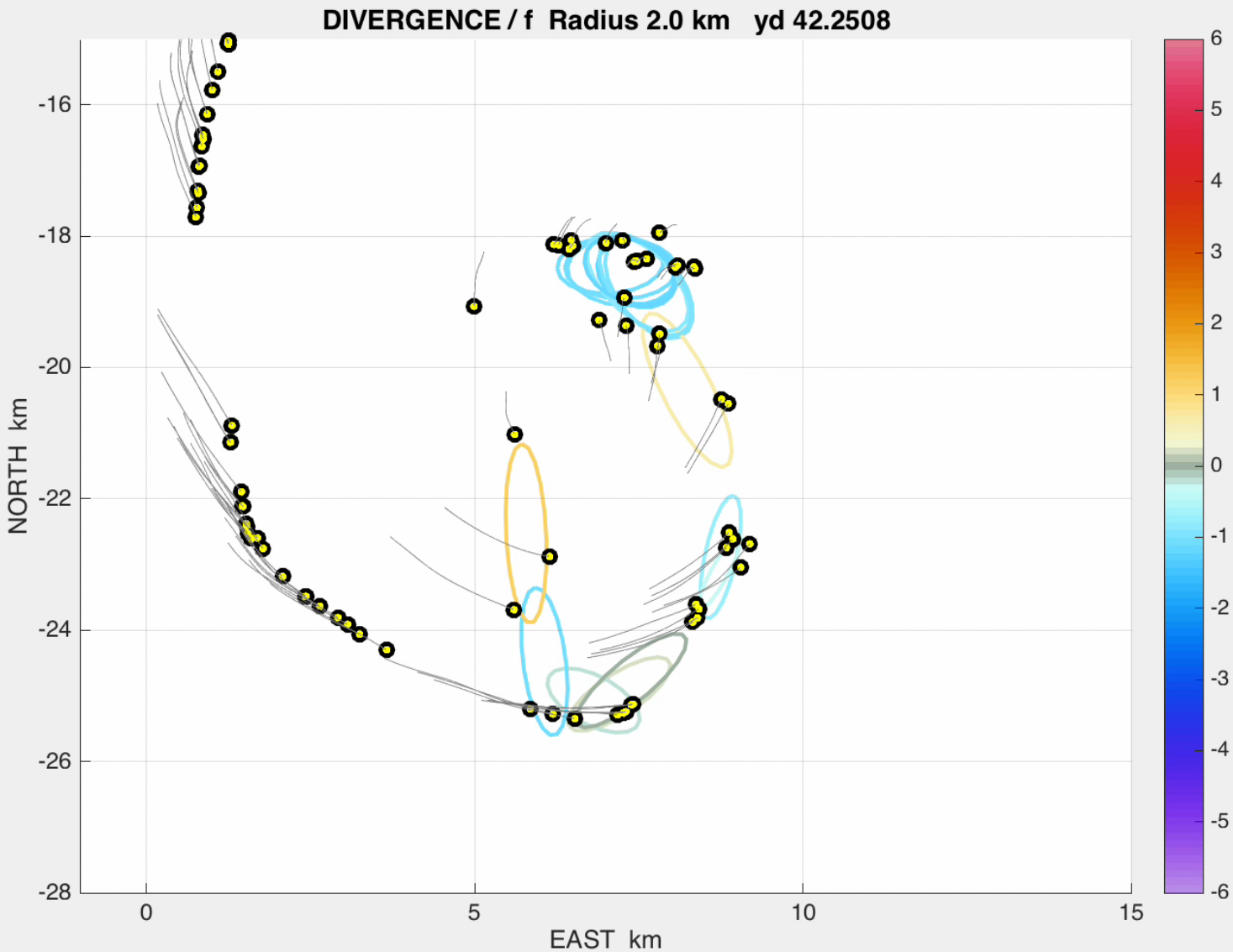
Characteristic structures & dynamics - **'Zipper'**

Coexists with dispersion through the dispersion of drifter clumps

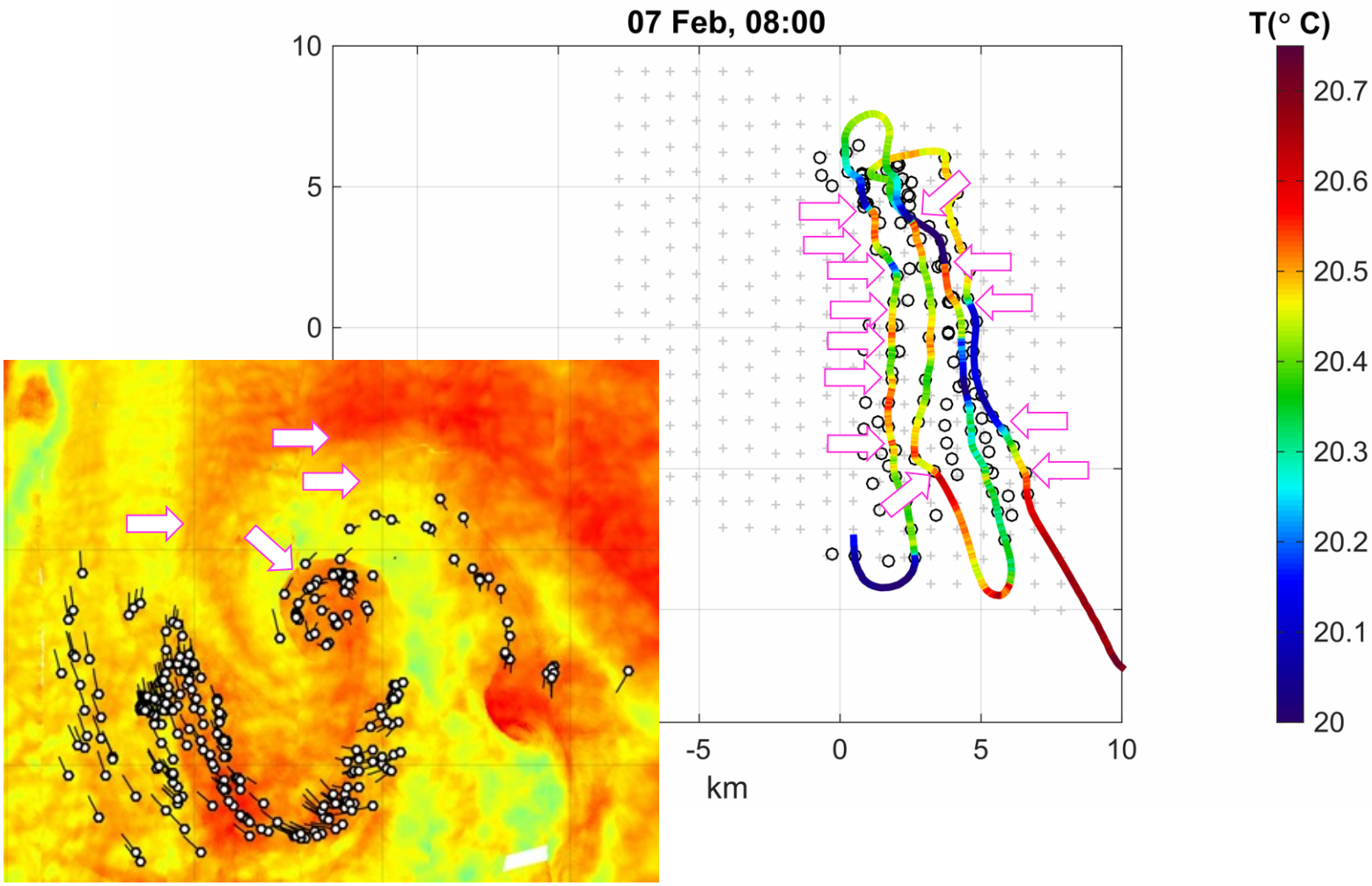
DIVERGENCE from plane fit of velocity from all drifters in a 2km radius



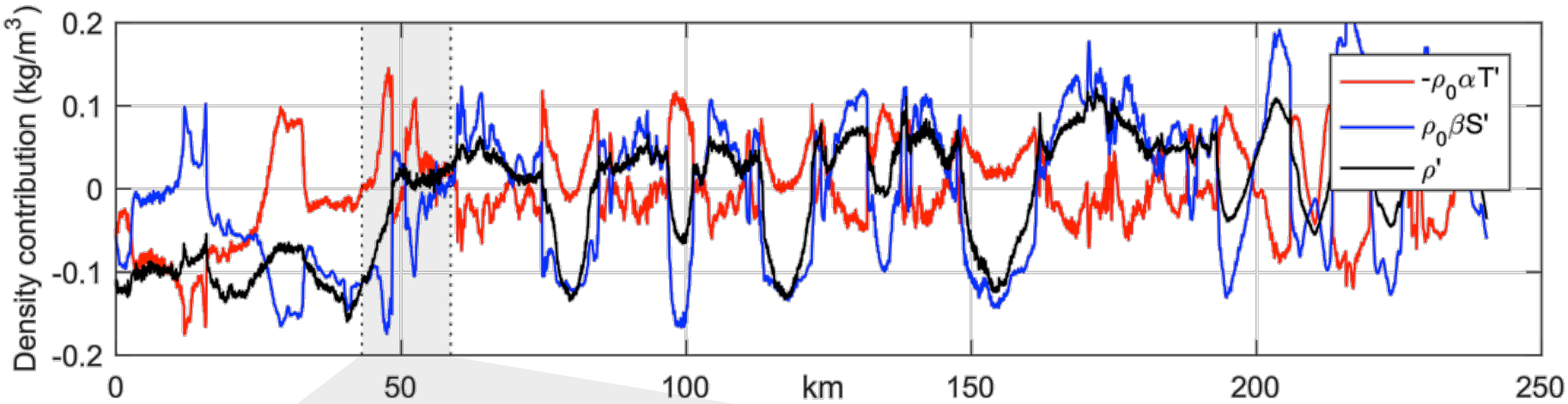
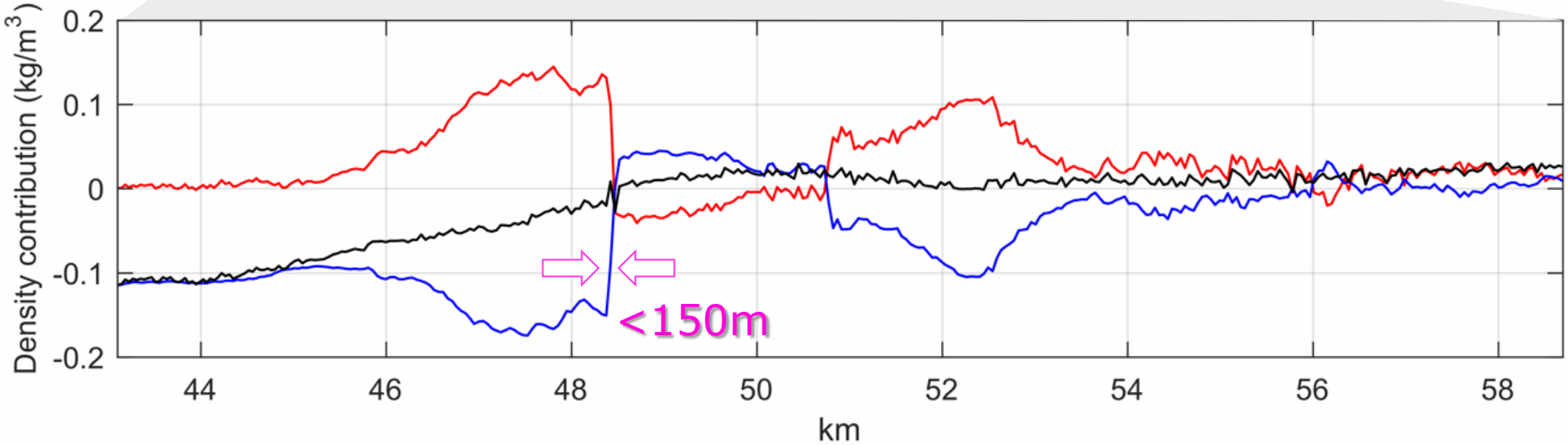
The ‘Zipper’ structure - divergence colored



Multiple rolled-up SST fronts



SST fronts in LDA area…



… are often fully-compensated in density