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THE DIURNAL CYCLE OF SUBMESOSCALE CIRCULATIONS

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Research questions

- What is the imprinting of diurnal variations in submesoscale circulations on the statistics of Lagrangian drifters?
- How does it change seasonally, interannually and across model resolutions?

Dynamics at the ocean submesoscales

Characteristic scales:

- L ~ 100 m - 10 km (here ≥ 300 m)
- H ~ 10 - 3300 m
- t ~ hours – days

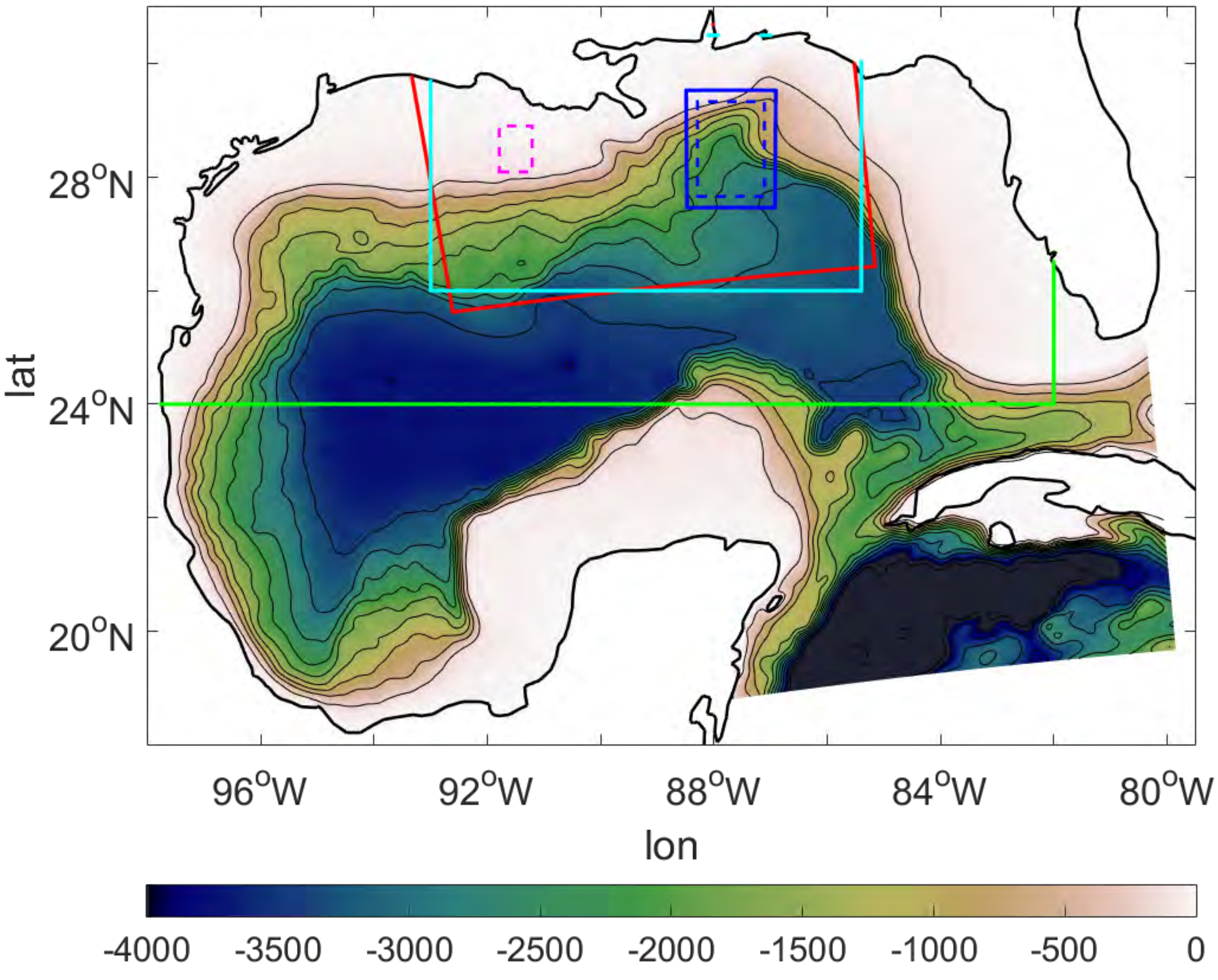
✓ Below ~3 km rotation and stratification are still important but are not asymptotically overwhelming

✓ Ageostrophic motions cannot be neglected near vertical boundaries (surface, bottom)

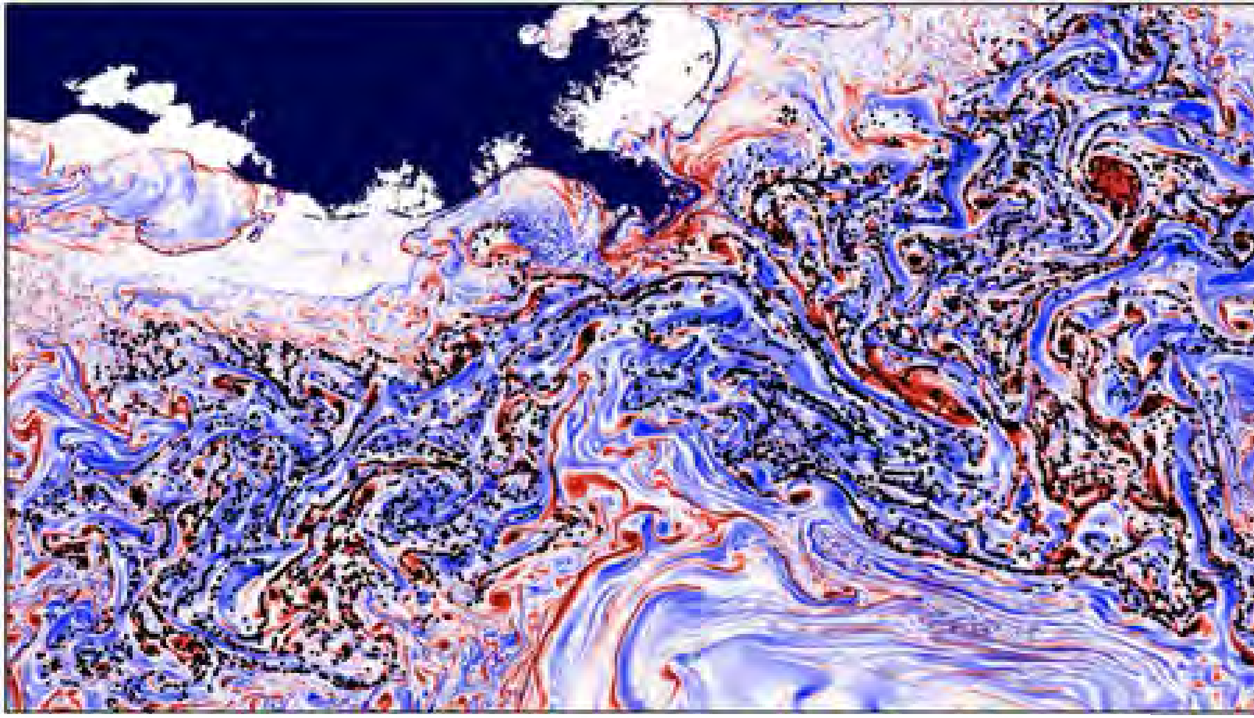
- Limited measurements
- Most progress through modeling using nested techniques to investigate finer and finer scales
- <u>Approaching the limits of hydrostatic models</u>

Submesoscale dynamics in the Gulf in winter

- ROMS, climatological forcing, runs at 1.5, 0.5 and 0.15 km horizontal resolution
- ROMS, realistic forcing, 1 and 0.5 km horizontal resolution 2015-2016
- dashed areas: Lagrangian releases

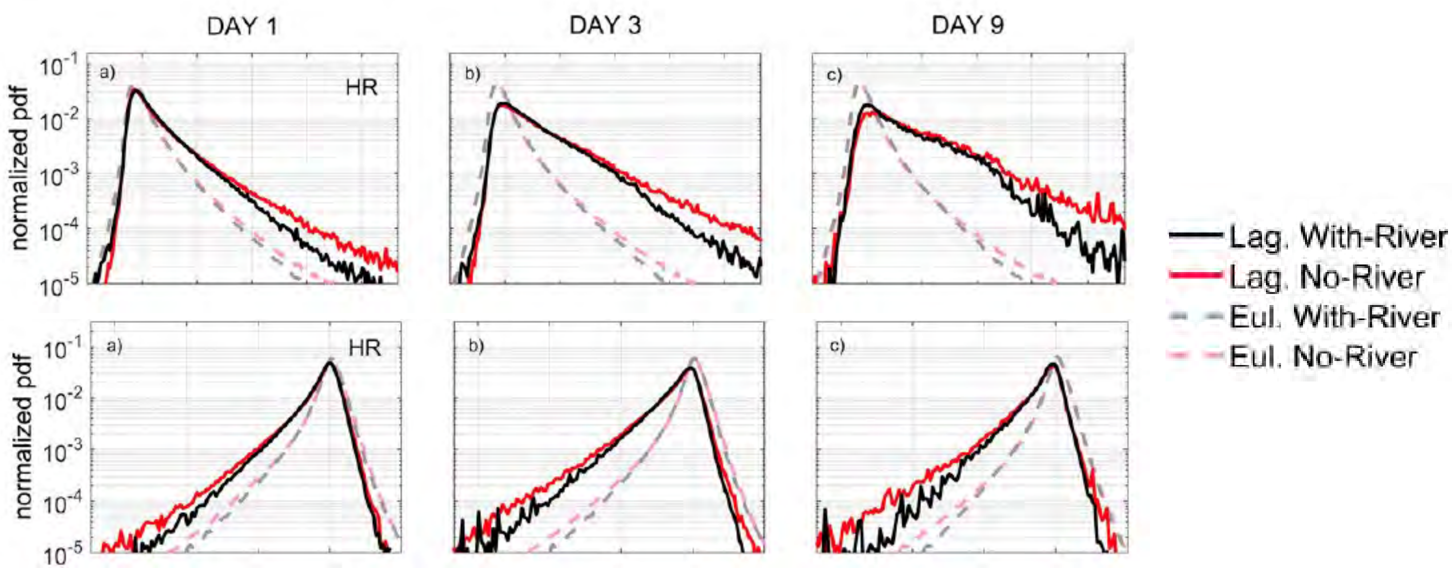


Choi, Bracco et al., JPO 2017



ζ/f

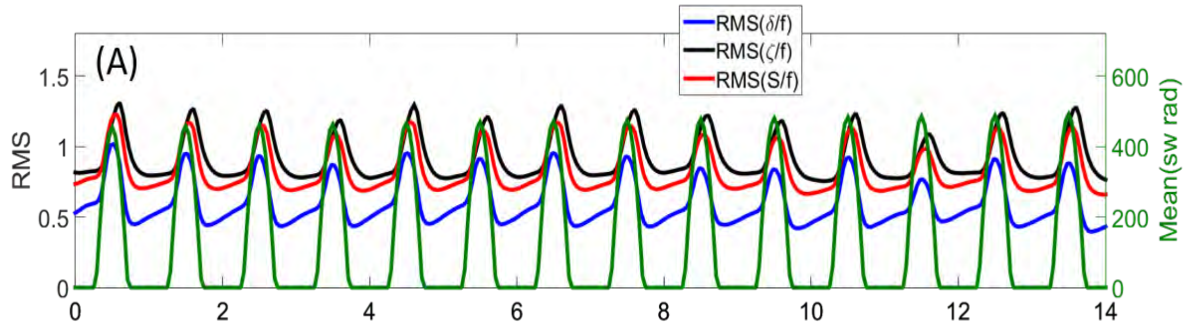
δ/f



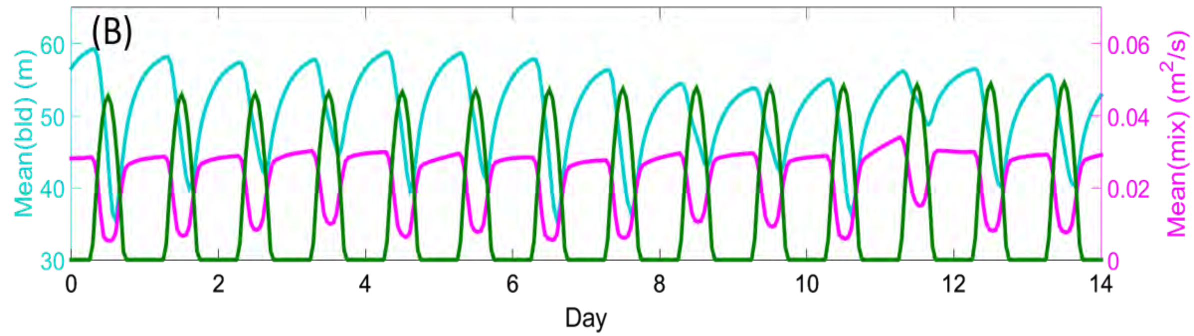
Choi, Bracco et al., JPO 2017

Diurnal cycling in 500 m climatological simulation

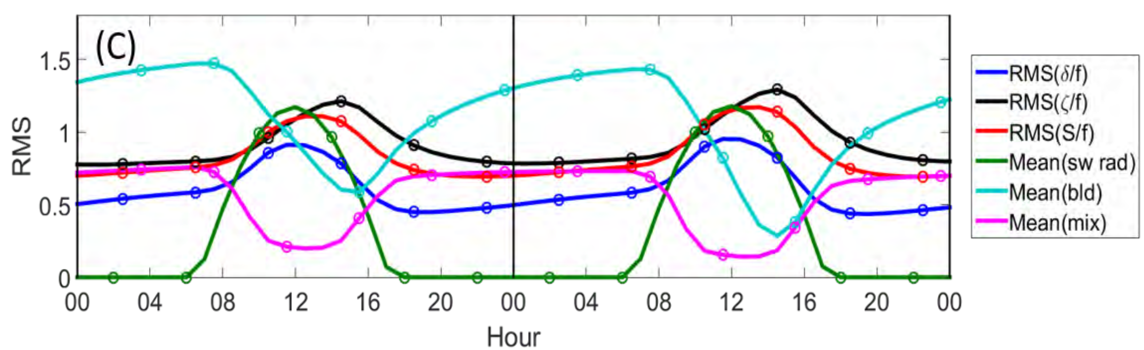
Two weeks evolution in February of ζ/f, δ/f and S/f RMS and of mean short-wave radiation averaged over the De Soto region



Evolution of upper ocean boundary layer depth, mixing coefficient and shortwave radiation (rescaled)



Zoom over two days; all quantities



Mechanism

Surface vertical mixing increases in response to surface cooling and/or an increase in surface stress

Turbulent thermal wind horizontal momentum balance relation (T^2W; Gula et al. 2014; McWilliams et al. 2015): balance between Coriolis force, pressure gradient, and vertical mixing

From T^2W: the strength of the ageostrophic circulations is proportional to the vertical mixing coefficient. Not true in models (Dauhajre et al. (2017): individual submesoscale fronts and filaments exhibit secondary circulations at times of weak k_v and vice versa)

Mechanism

time-memory by adding acceleration and the time evolution of buoyancy by vertical eddy diffusion and advection

The ageostrophic accelerations that control the diurnal phasing are driven by inertial and diffusive dynamics operating in concert

→ **transient turbulent thermal wind (T^3W) balance**

allows for predicting the diurnal evolution of near-surface divergence and vertical relative vorticity, their phasing and relative lag, as function of latitude, ML depth, and strength of the diurnal forcing

Resolution Dependence

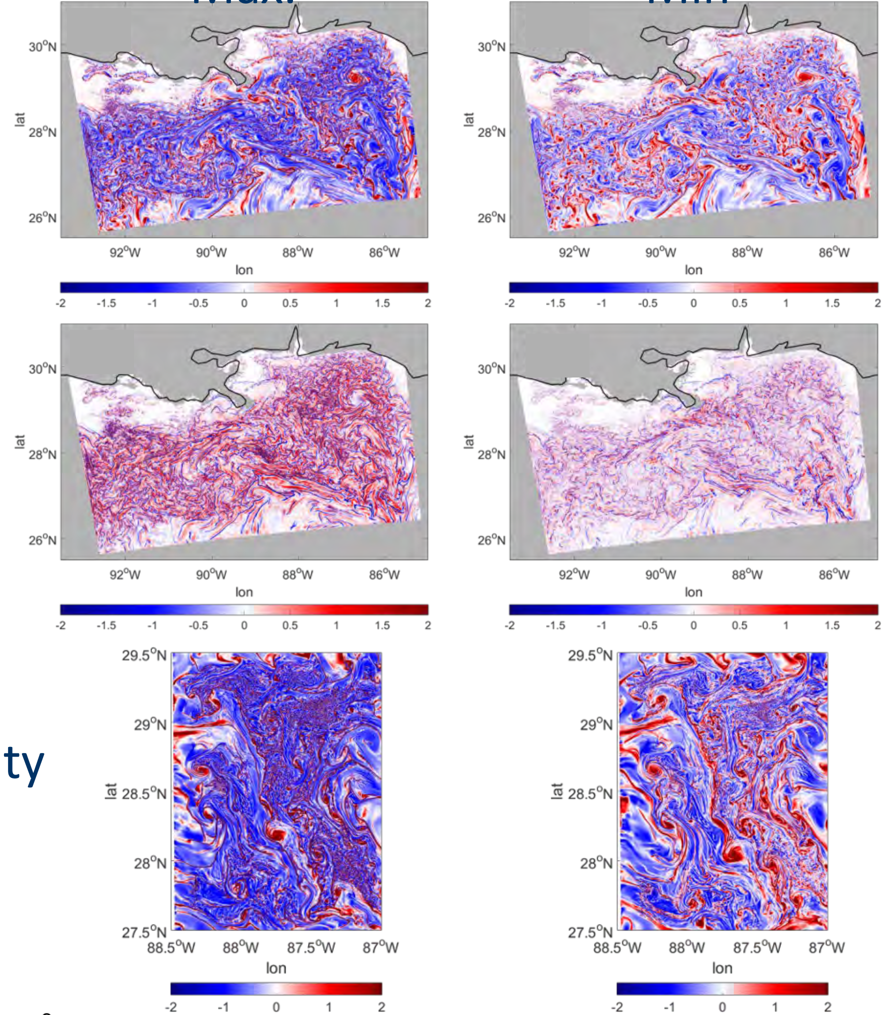
Max. Min

Relative vorticity

500 m

Lateral divergence

150 m Relative vorticity



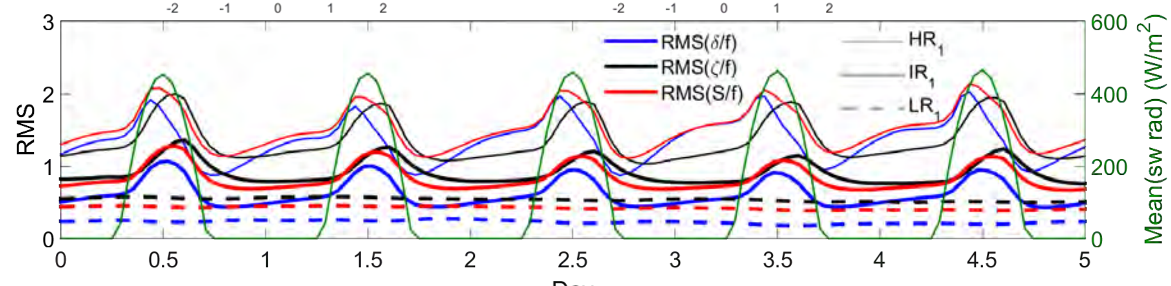
Mean vorticity RMS:

1500m 500m 150m

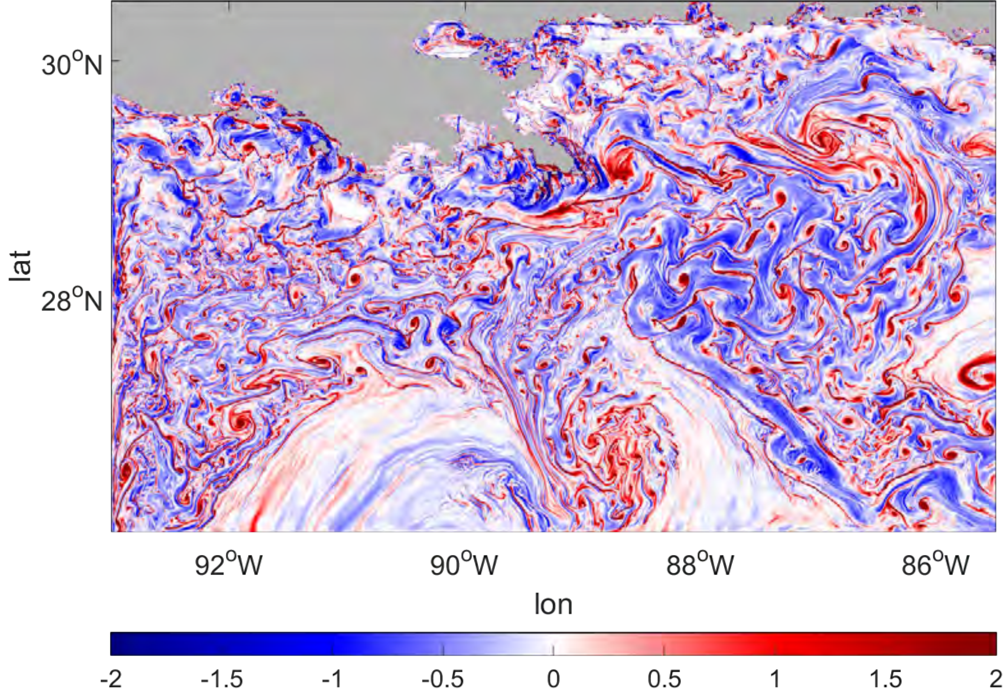
0.6 -> 0.9 -> 1.4

Mean divergence RMS:

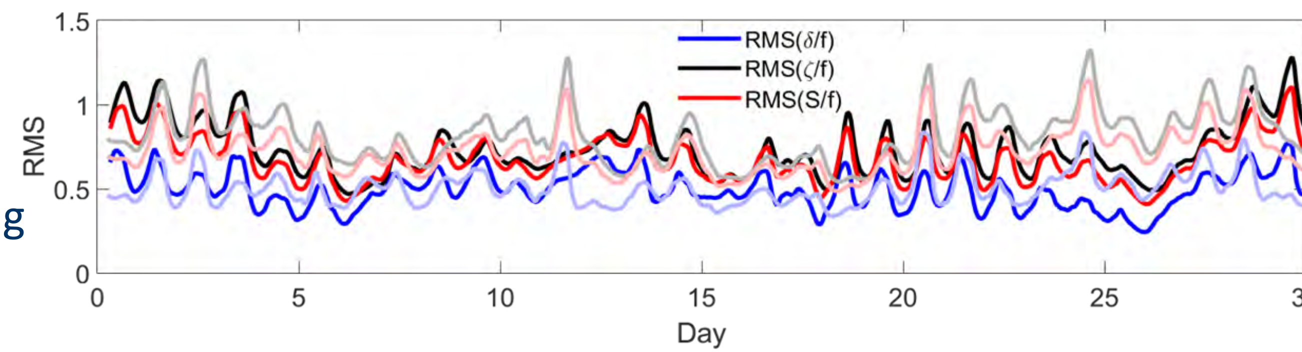
0.2 -> 0.6 ->. 1.3



500 m
Variable atmos
January 29, 2016

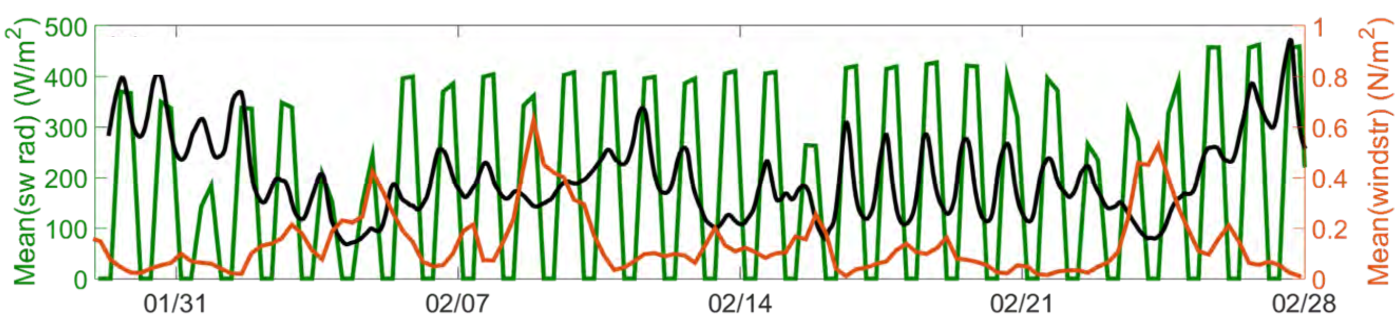


Interannual variability and impact of variable forcing

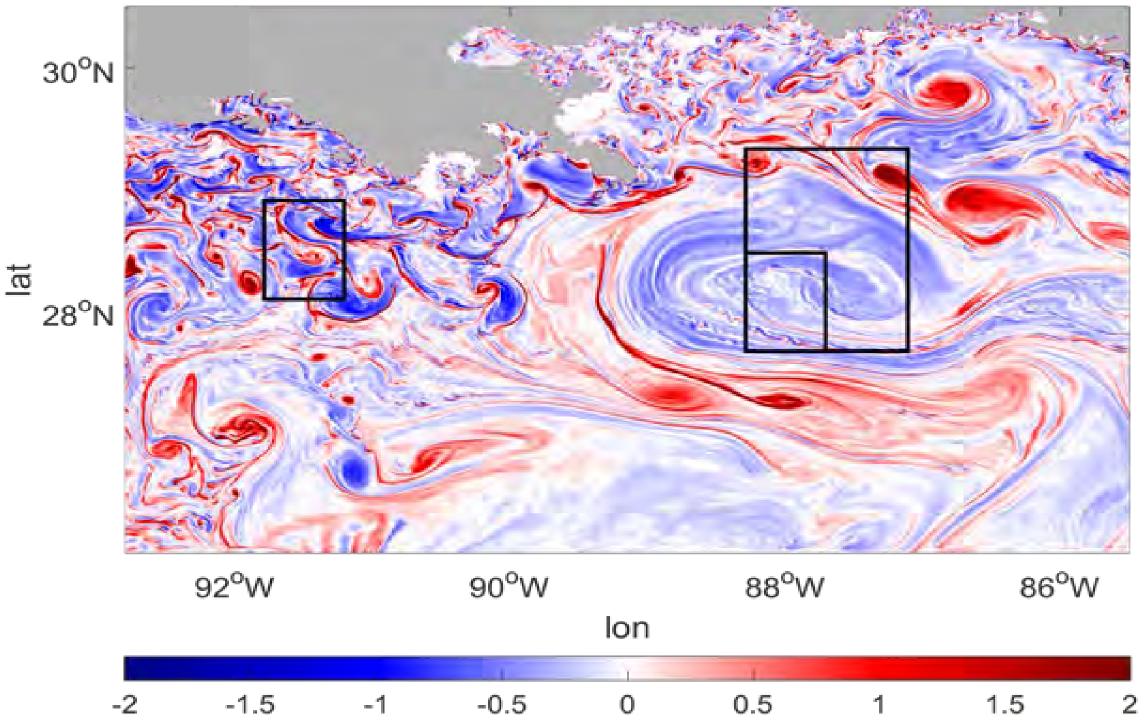


dark color 2016
RMS vorticity
0.73+/- 0.15

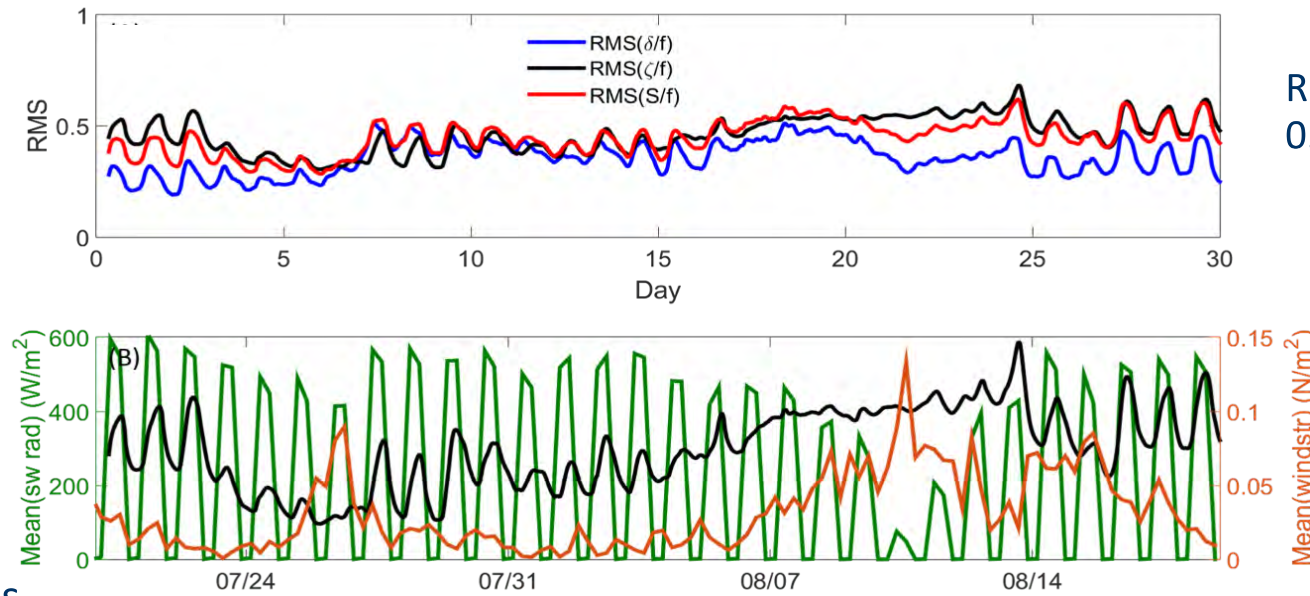
light color 2015
0.82+/-0.16



500 m
Variable atmos
July 19, 2016



In summer: Weaker submesoscale but also weaker winds. Weaker submesoscales in Loop Eddy than in ‘soup’ where riverine water supplies density gradients



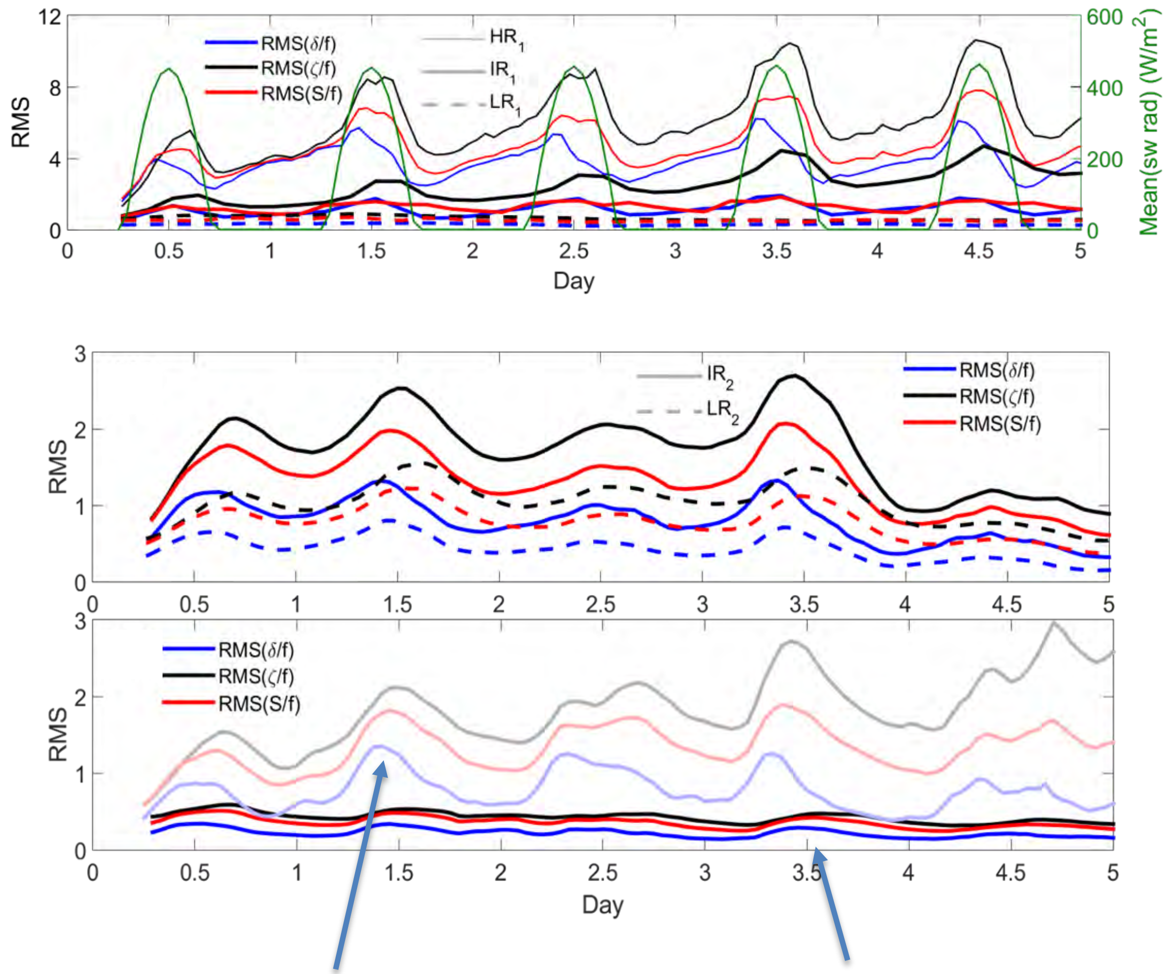
RMS vorticity 0.52+/-0.1

Diurnal cycle seen by Lagrangian tracers

Clima runs
Further amplification by Lagrangian sampling (2-3 times)
Strong resolution dependence (150, 500 and 1500 m)

Realistic forcing
500 and 1000 m res
Similar resolution dependence

Strong regional differences



winter

winter 2016

summer 2016

submesoscale soup

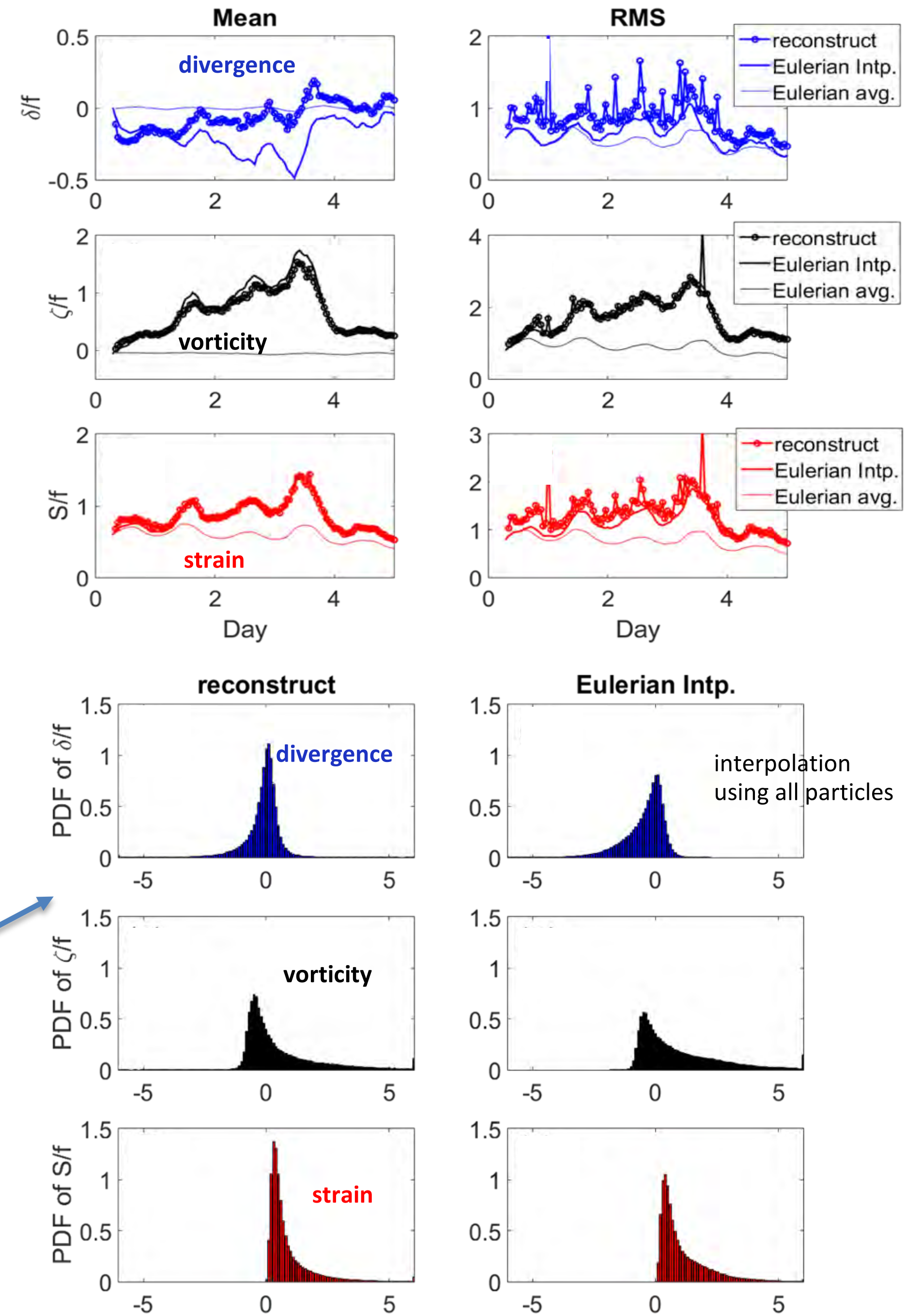
Loop Eddy

What about reconstructions from Lagrangian data?

Here using least-square method on triplets (Molinari and Kirwan,1975) and removing triplets with aspect ratio < 0.07

Winter example:
~20,000 Lagrangian particles in De Soto region

Great job but for divergence mean value. Many triplets in frontal systems stretch too quickly and AR < 0.07



Dependence on number of particles

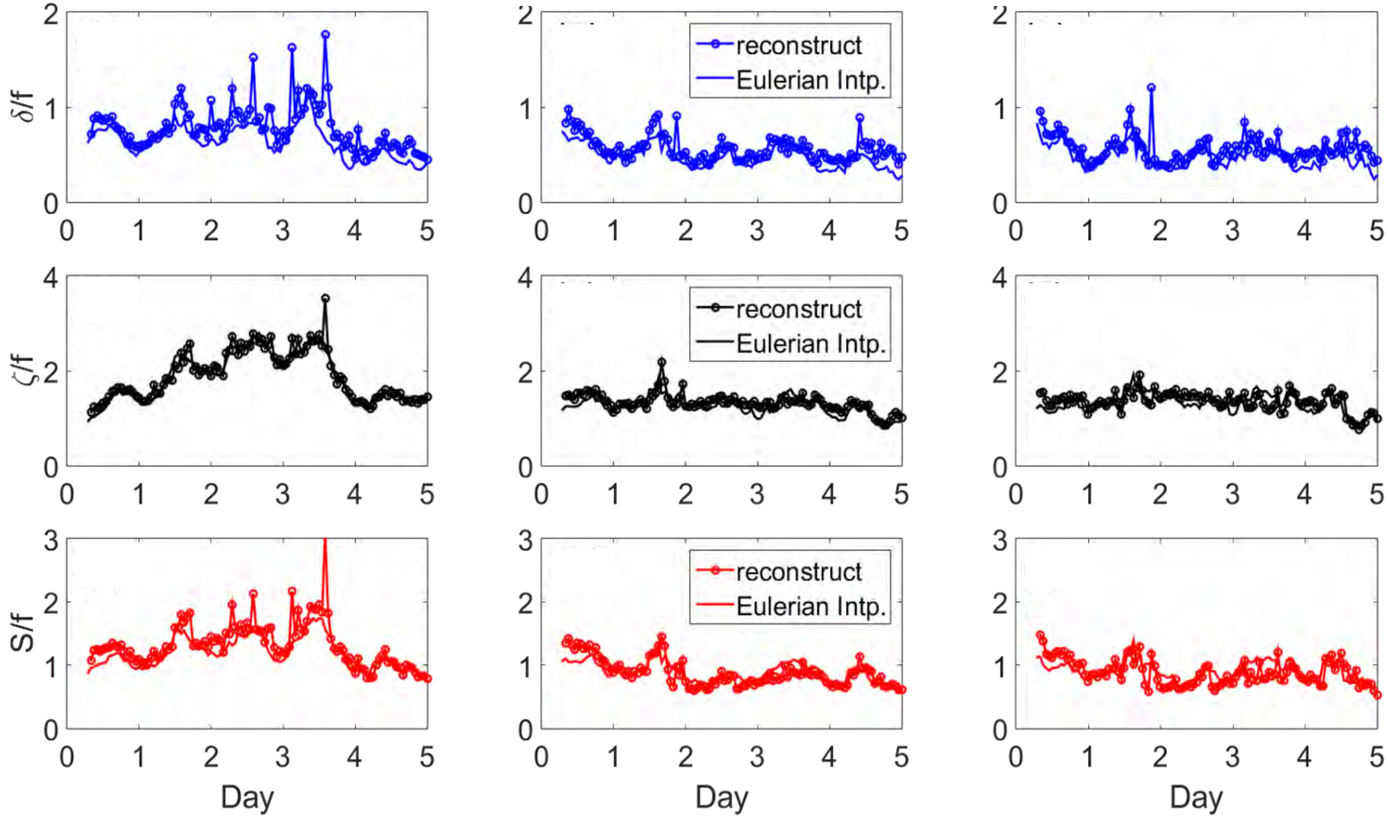
winter

1680 | 420 triplets | 210

divergence

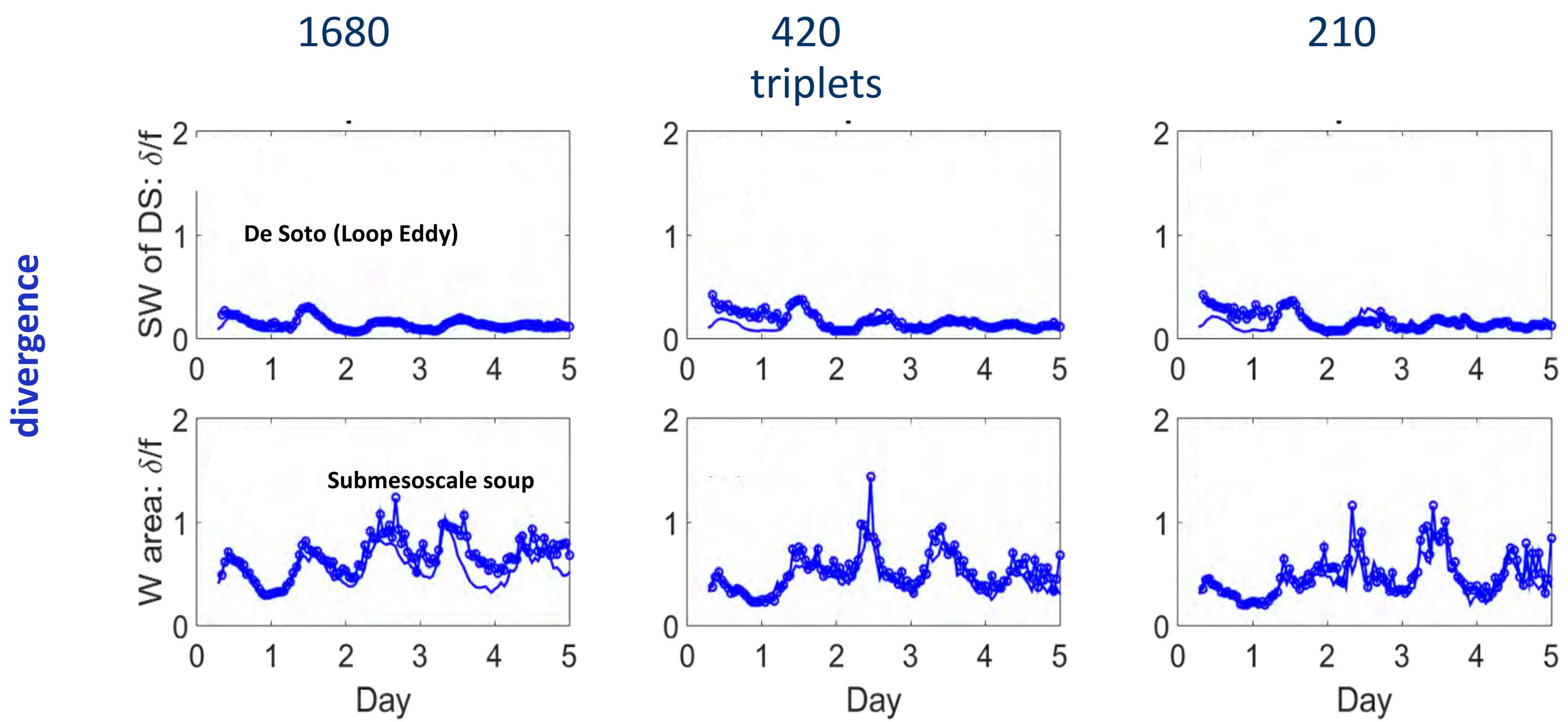
vorticity

strain

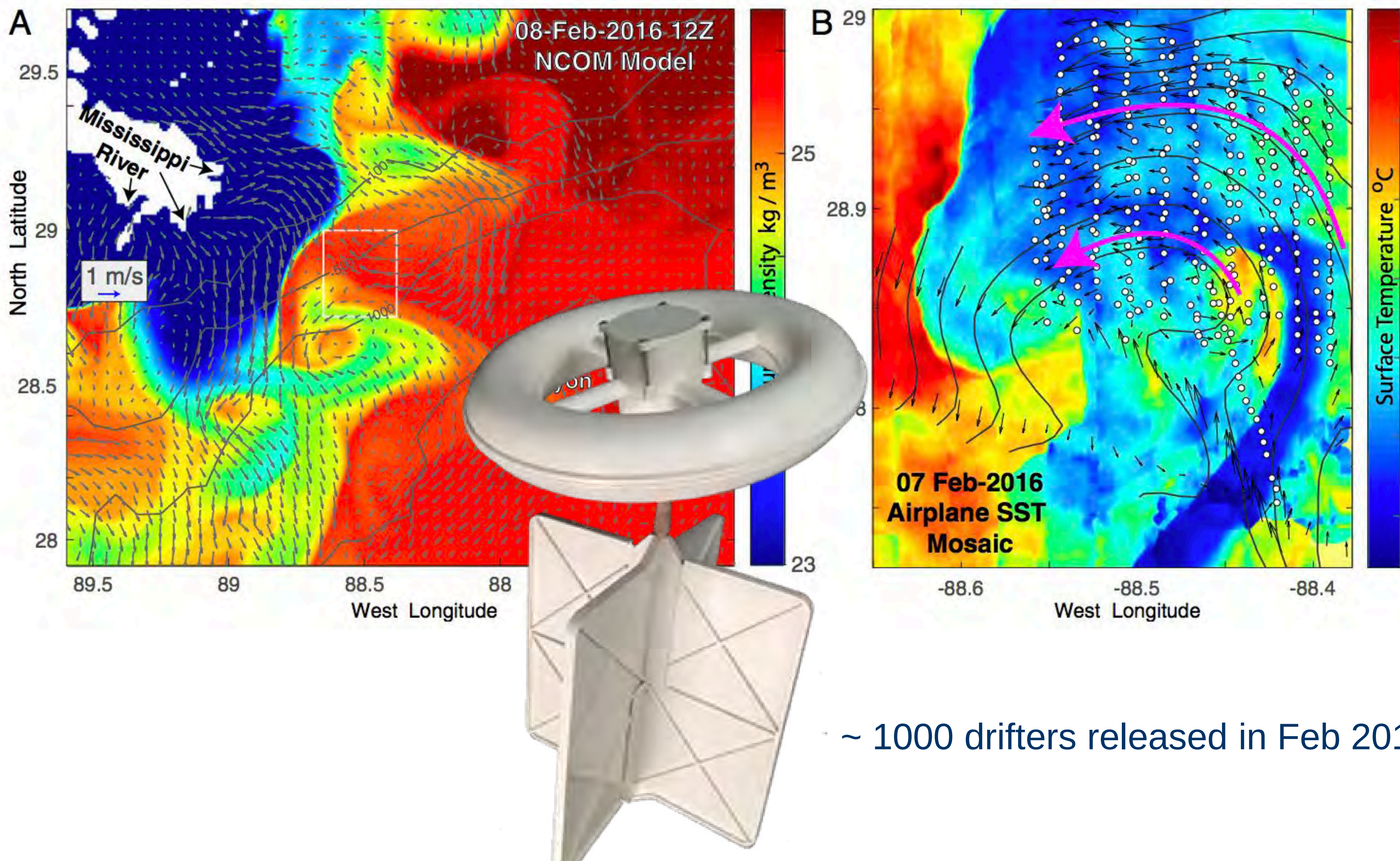


Dependence on number of particles

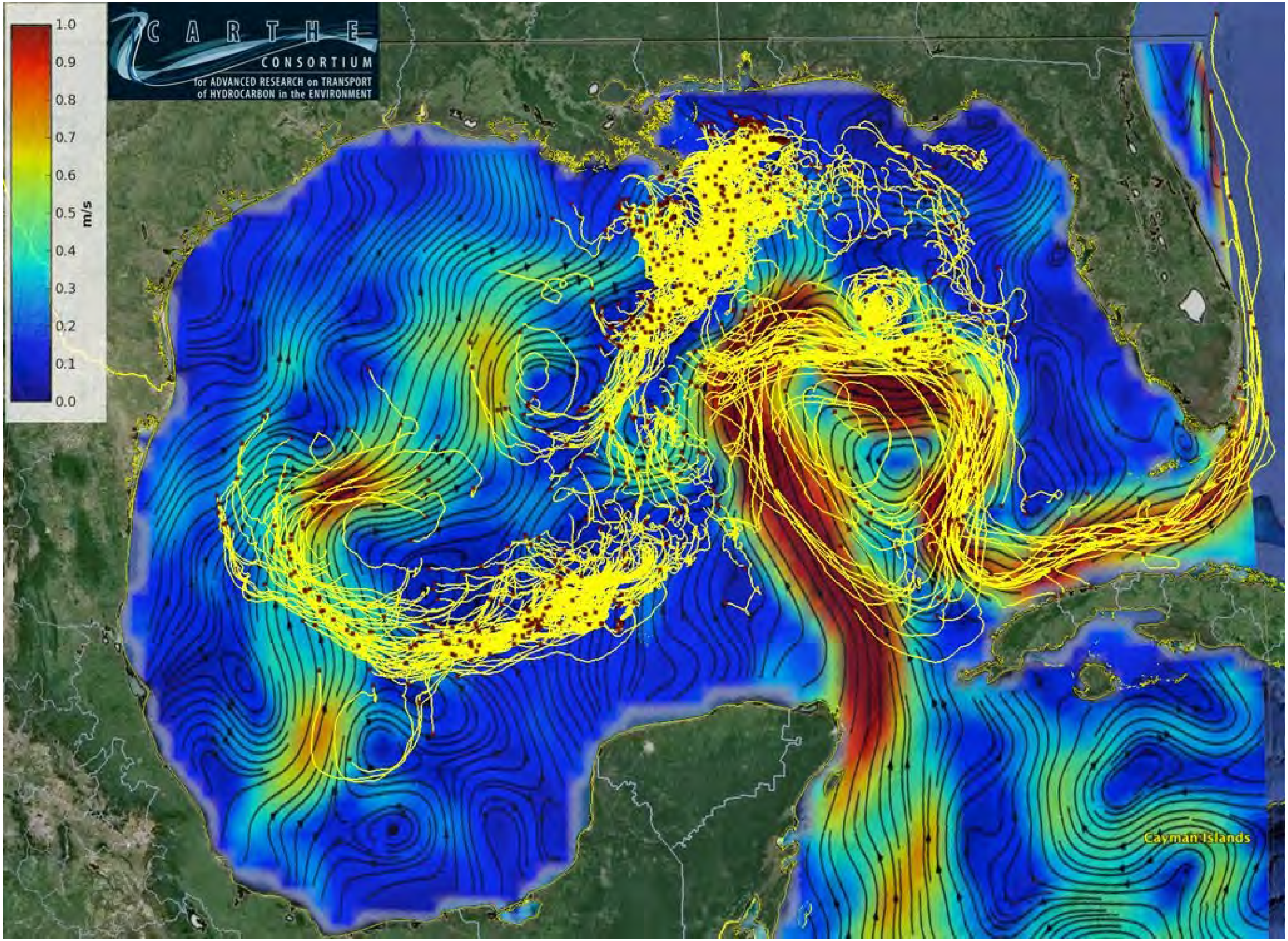
Summer



On to the Observations:
The LASER experiment

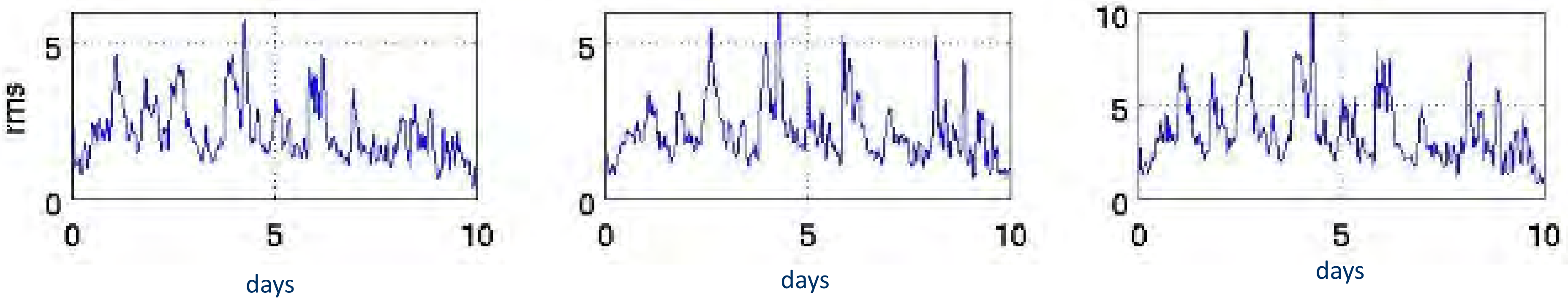


~ 1000 drifters released in Feb 2016

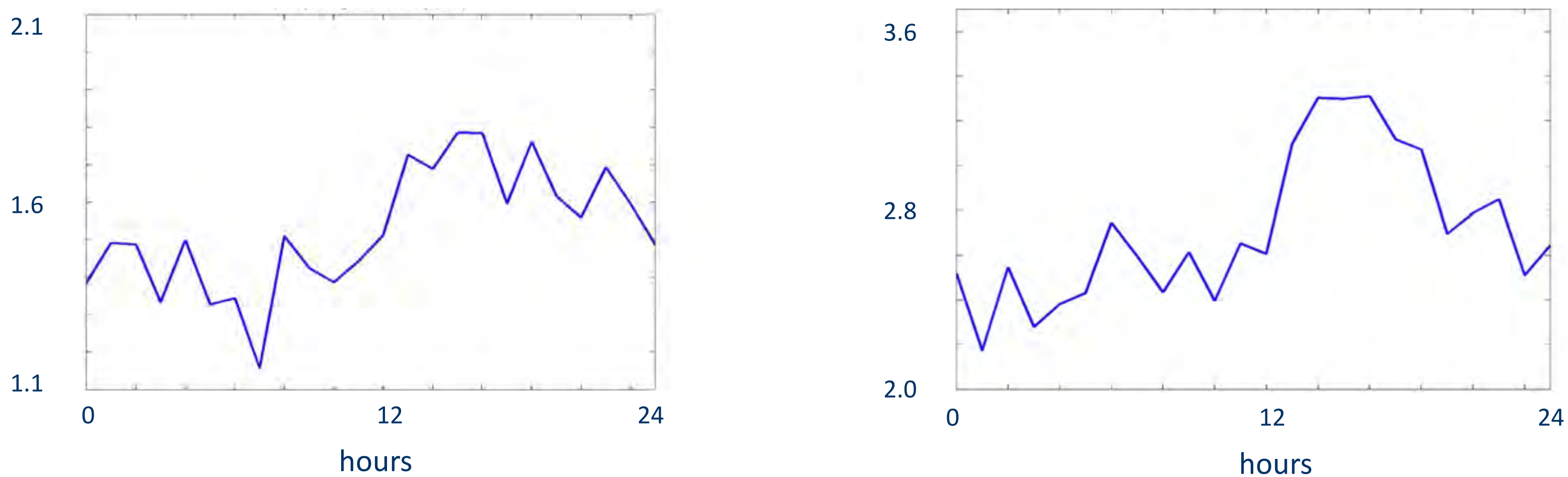

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
m/s
CARTHE
CONSORTIUM
for ADVANCED RESEARCH on TRANSPORT
of HYDROCARBON in the ENVIRONMENT
Cayman Islands

Diurnal cycle from LASER drifters

Divergence RMS for 50 drifters along a front



Divergence RMS over two days for 120 drifters sampling a submesoscale eddy



The drifter analysis supports the need for a model resolution between 500 and 150m

Conclusions

- Submesoscale circulations in coastal areas present strong interannual, seasonal and even DAILY variability

- The daily cycle, associated with changes in boundary layer depth following the diurnal cycle of heat fluxes (and winds) can be explained by the T^3W model accounting for ageostrophic accelerations

- Surface-trapped material with a drifter-like behavior does not sample the Eulerian flow homogenously

- Lagrangian and Eulerian statistics diverge proportionally to the strength of the submesoscale circulations

- Unexplored implications for ecosystems