Sensor synergies in studies of mesoscale and submesoscale dynamics

- Numerous Remote sensing measurements
  - Very high resolution SST, Ocean Colour, radar roughness images
  - Low resolution Altimetry
  - Mesoscale Scatterometry and Microwave
- Increased In Situ measurements
  - Fixed networks
  - ARGO floats
  - Drifters
- Dynamical frameworks
  - Operational models
  - Assimilation and statistical methods
  - Surface Quasi-geostropy, Ekman

New needs

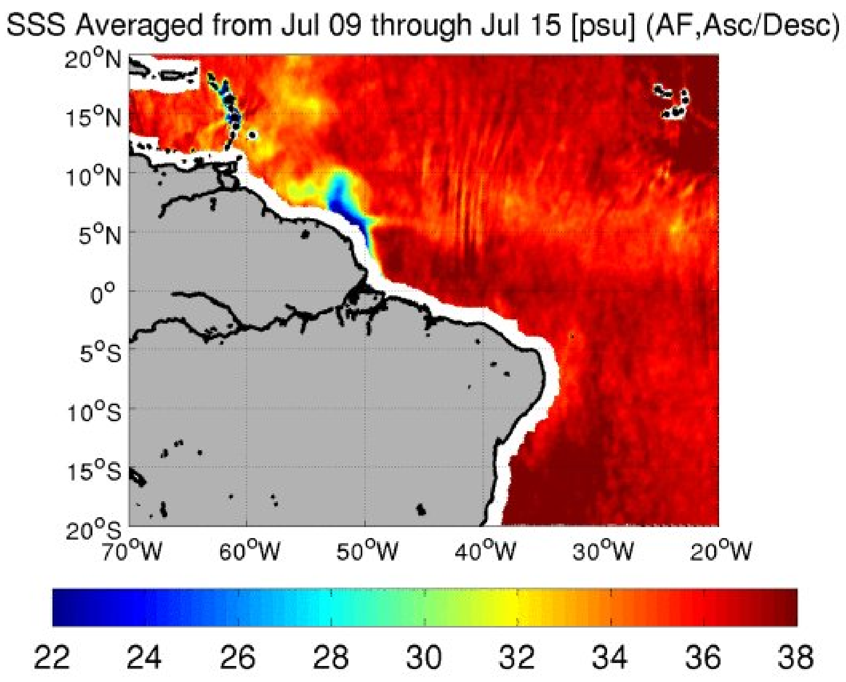
P. Niiler (2009) Oceanography in 2025

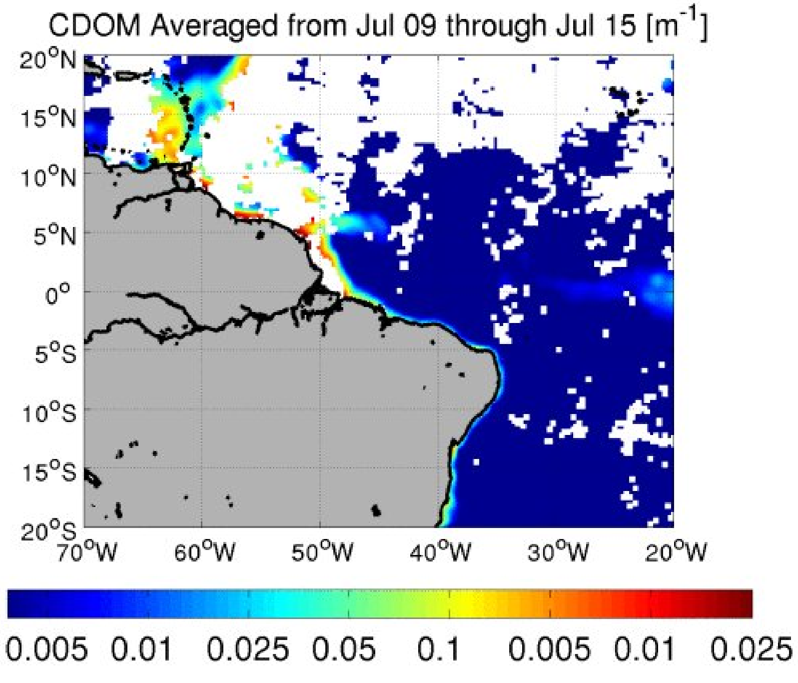
Oceanography of 2025 will require observations and realistic modeling of the circulation patterns that contain the vertical motion of the upper 200 m. Models will be compared not by how well they assimilate or replicate the sea level or reproduce the geostrophic velocity, but rather by how their internal vorticity and thermal energy and fresh water balances maintain ageostrophic velocity structures and the associated vertical circulations. This task calls for development and implementation of continued new methods and instruments for direct velocity observations of the oceans.

- … most observations are not yet sufficiently explored and used

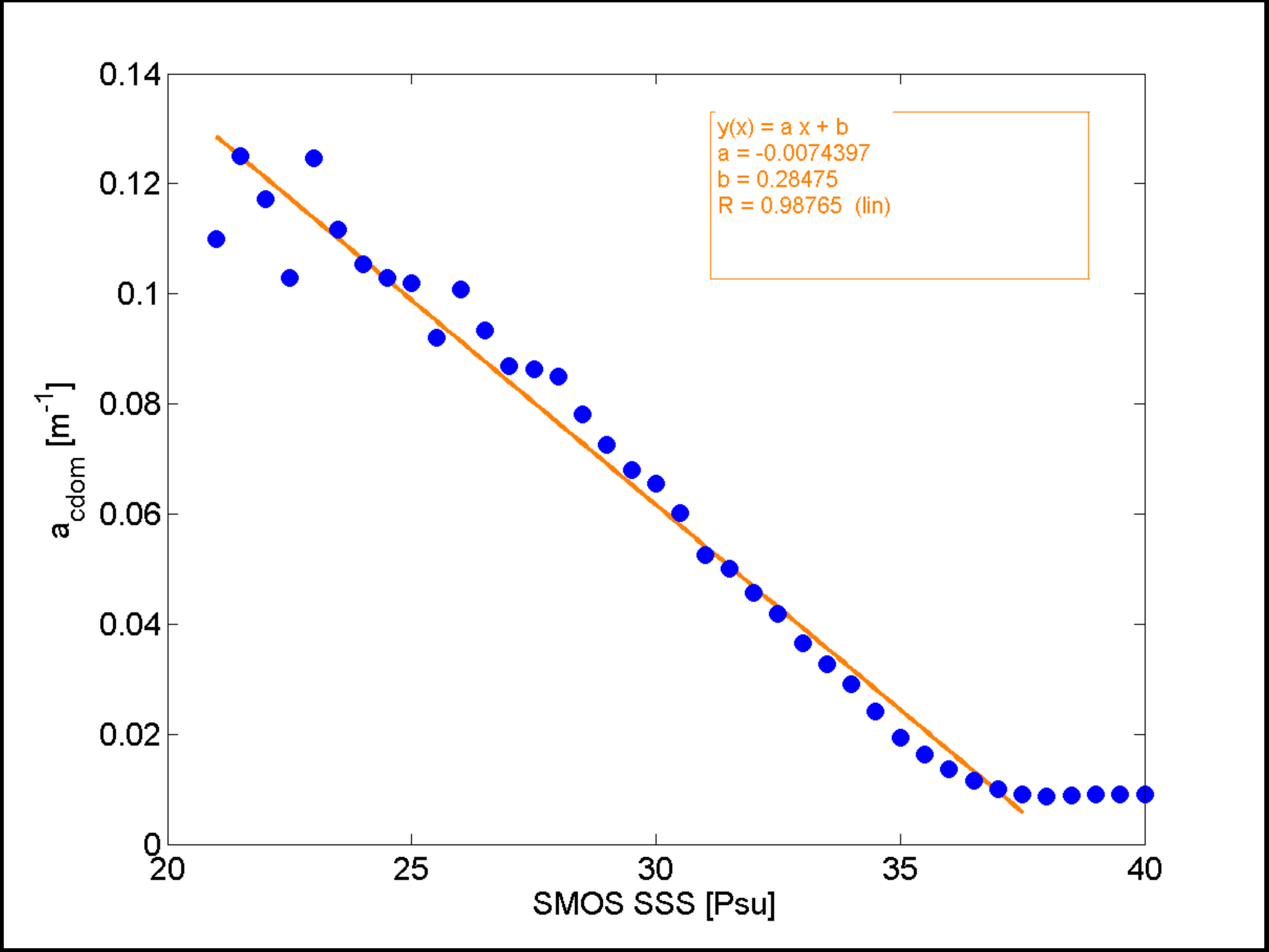
Synergy between high resolution observations to reveal near-surface dynamics, convergence/divergence fronts and roughness contrasts

NewSSS products

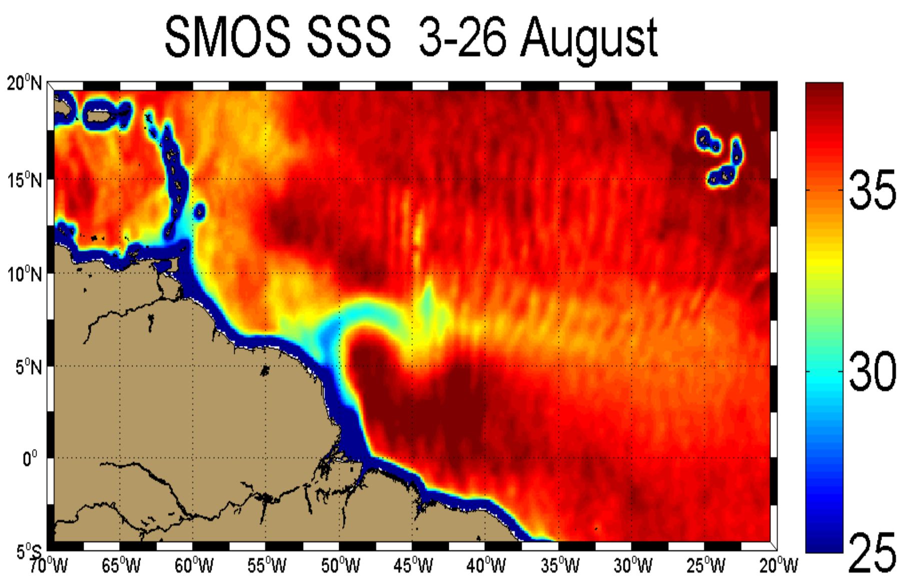


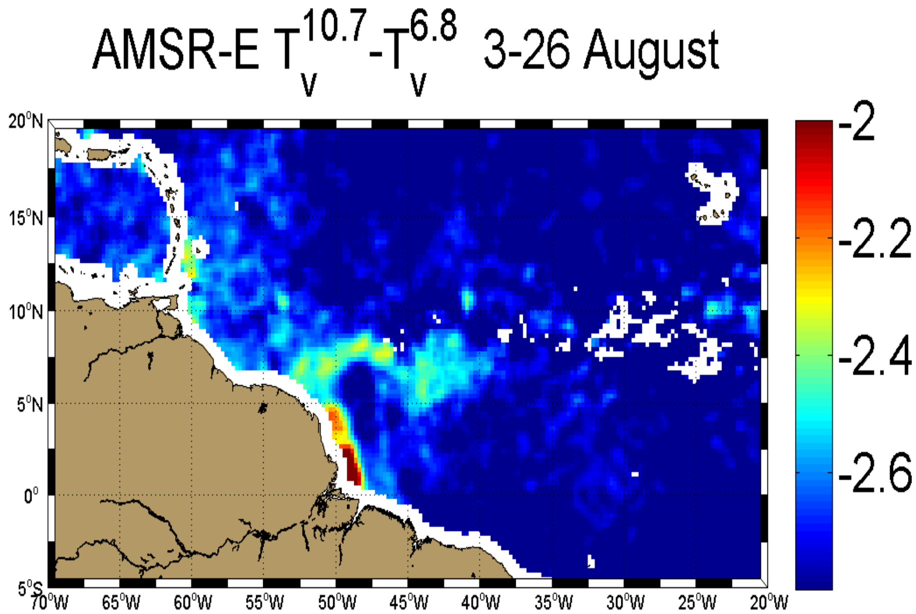


Correlation between Cdom and SMOS SSS



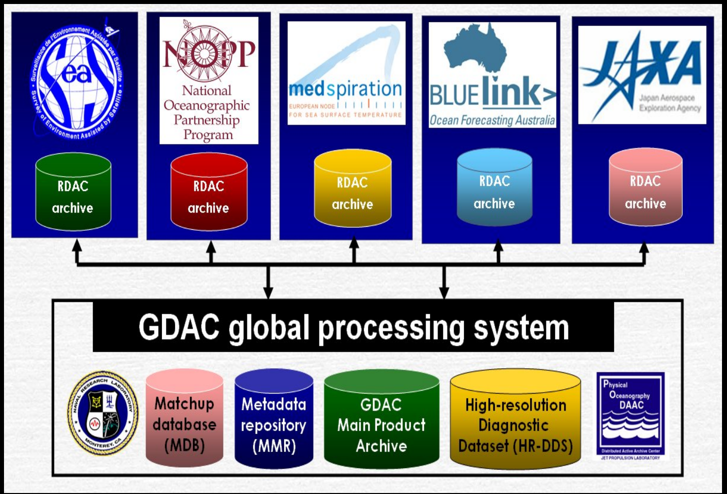
Correlation between AMSR-E brightness and SMOS SSS





The SST example

- The GODAE / GHRSST-PP project
  - Delivering a new generation of global and multi-sensor high resolution SST datasets, as defined by the GHRSST Science Team, reflecting a general consensus opinion (format, content, processing)
  - Distributed approach for the operational production and dissemination of GHRSST data products : Regional Data Assembly Center
    - Regional areas
    - Specific sensors
  - Same processing model, format, content,…
    - Quality control, flags, ancillary data, confidence
    - products can be used individually or together with equal confidence
- Medspiration (ESA)
  - European node for the GHRSST-PP system
  - Funded by ESA
- MyOcean SST TAC (EU)
  - Operational service for global SST



L4 SST products (GHRSST-PP project, Medspiration (ESA))

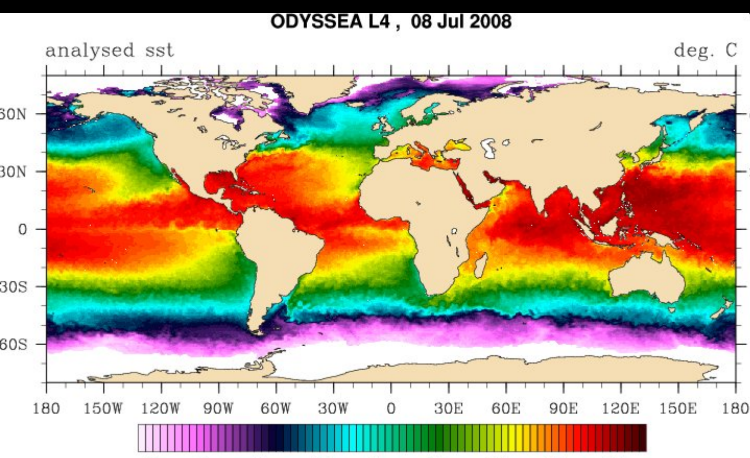
Objective : high resolution gap free maps of SST fundation

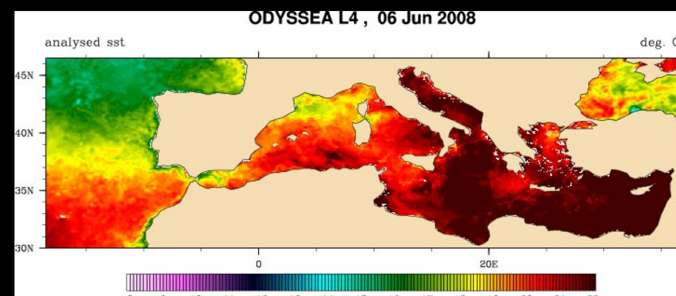
Optimal interpolation

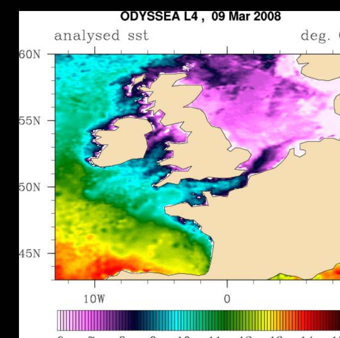
Merging all sensors available (high resolution IR [AVHRR NOAA&METOP, MSG, AATSR, GOES] and low resolution MW [AMSRE,TMI])

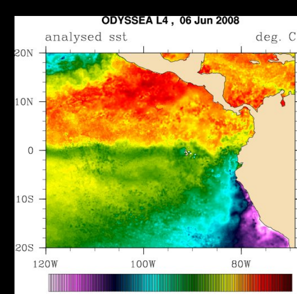
Intercalibration of all sensors against AATSR

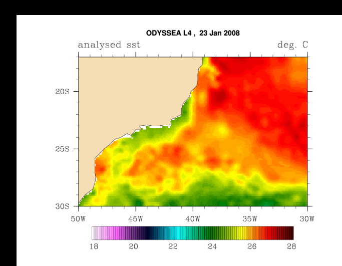
High (10km) to very high resolution (2km)

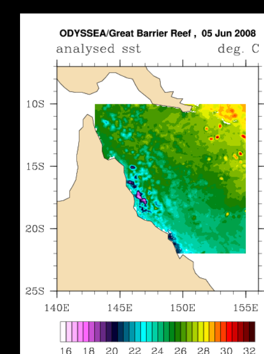


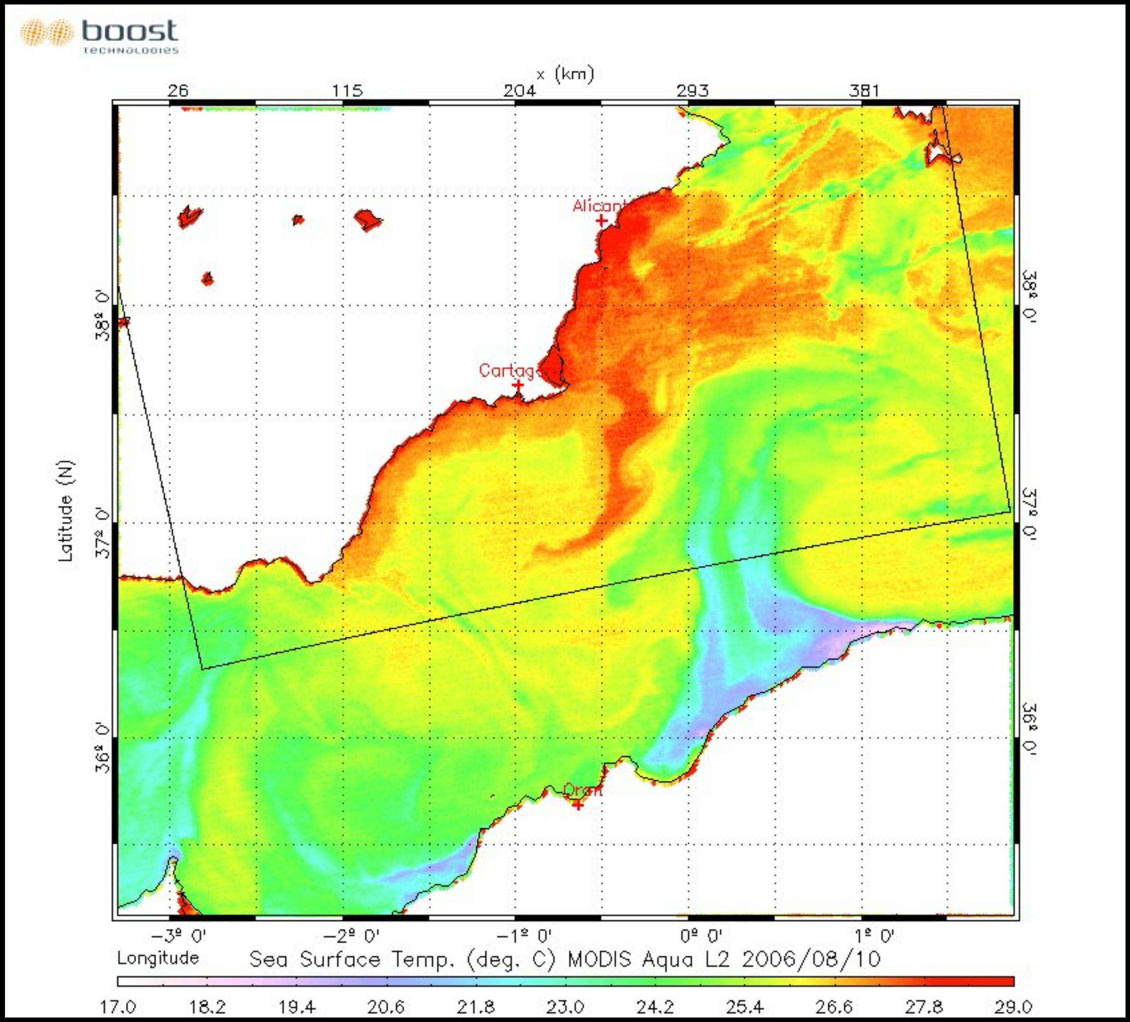




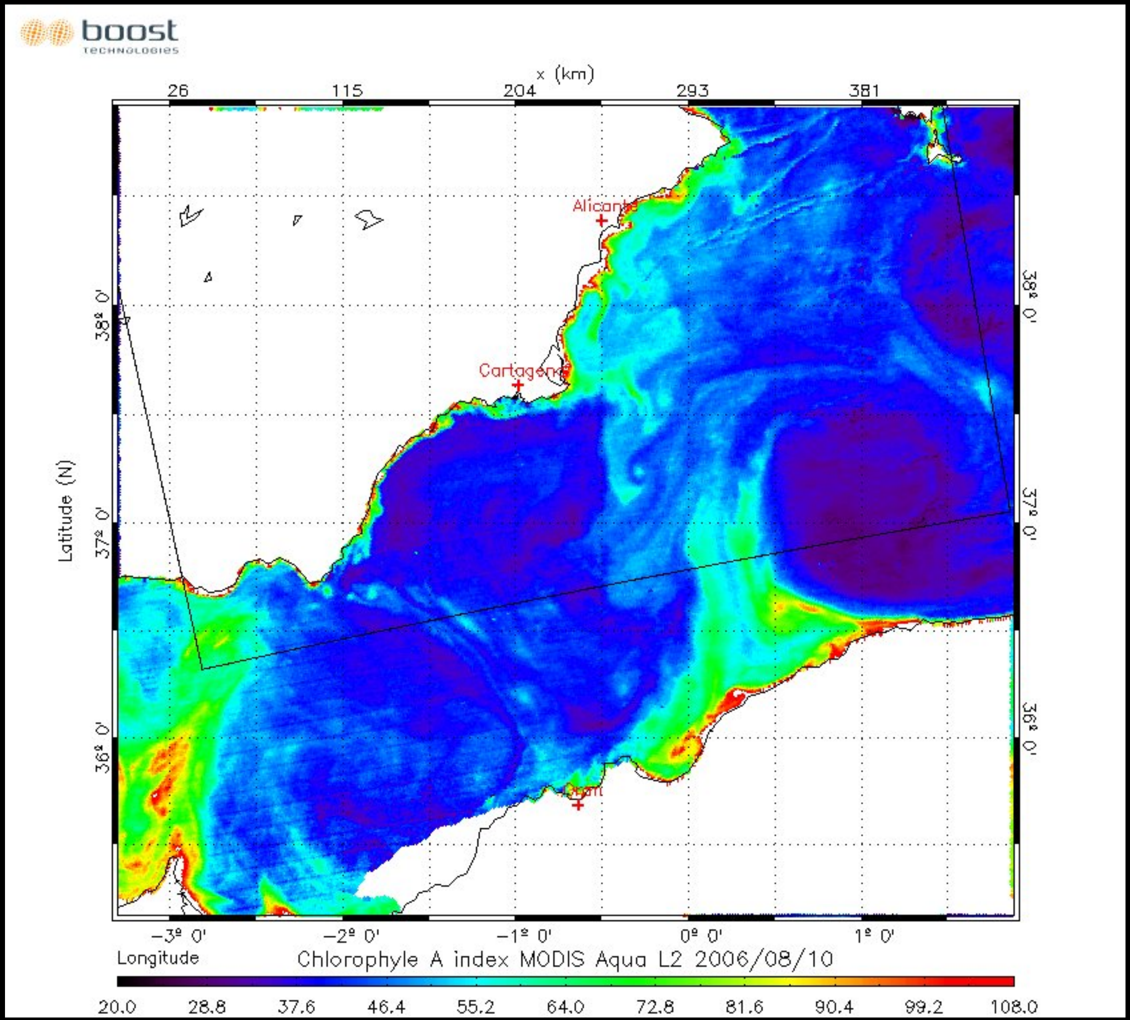




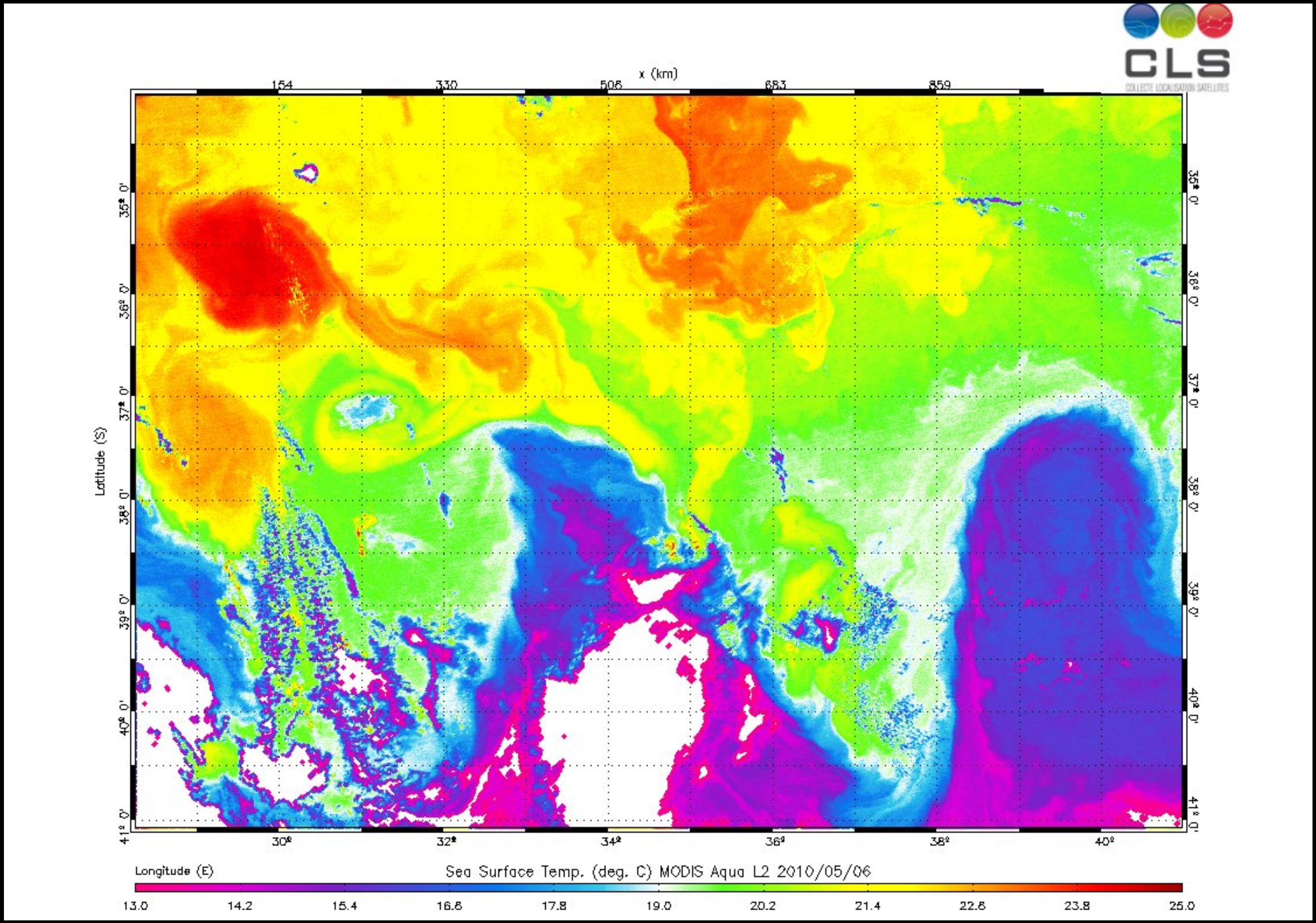




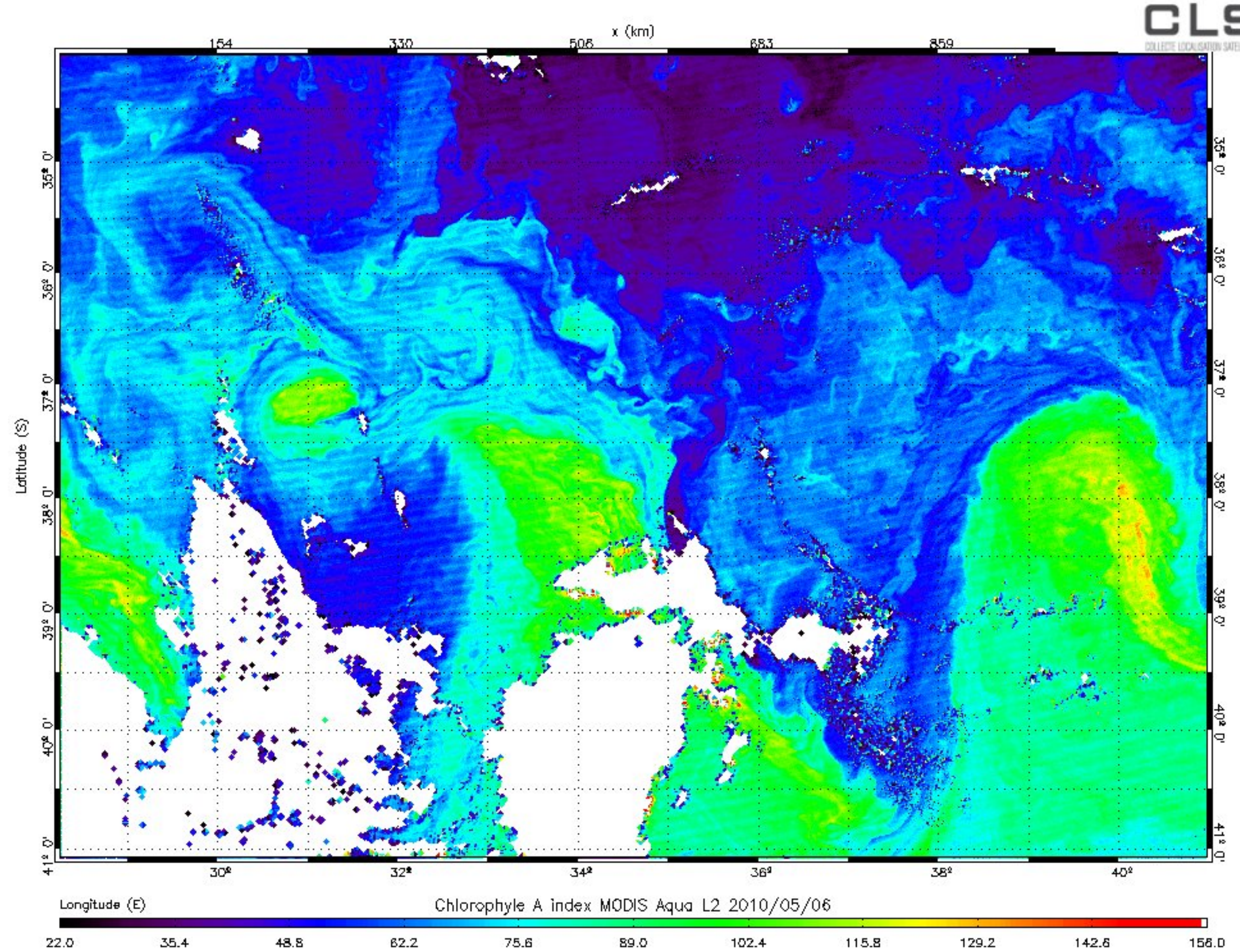
Numerous contemporaneous MODIS Brightness temperature and Ocean Colour surface signatures



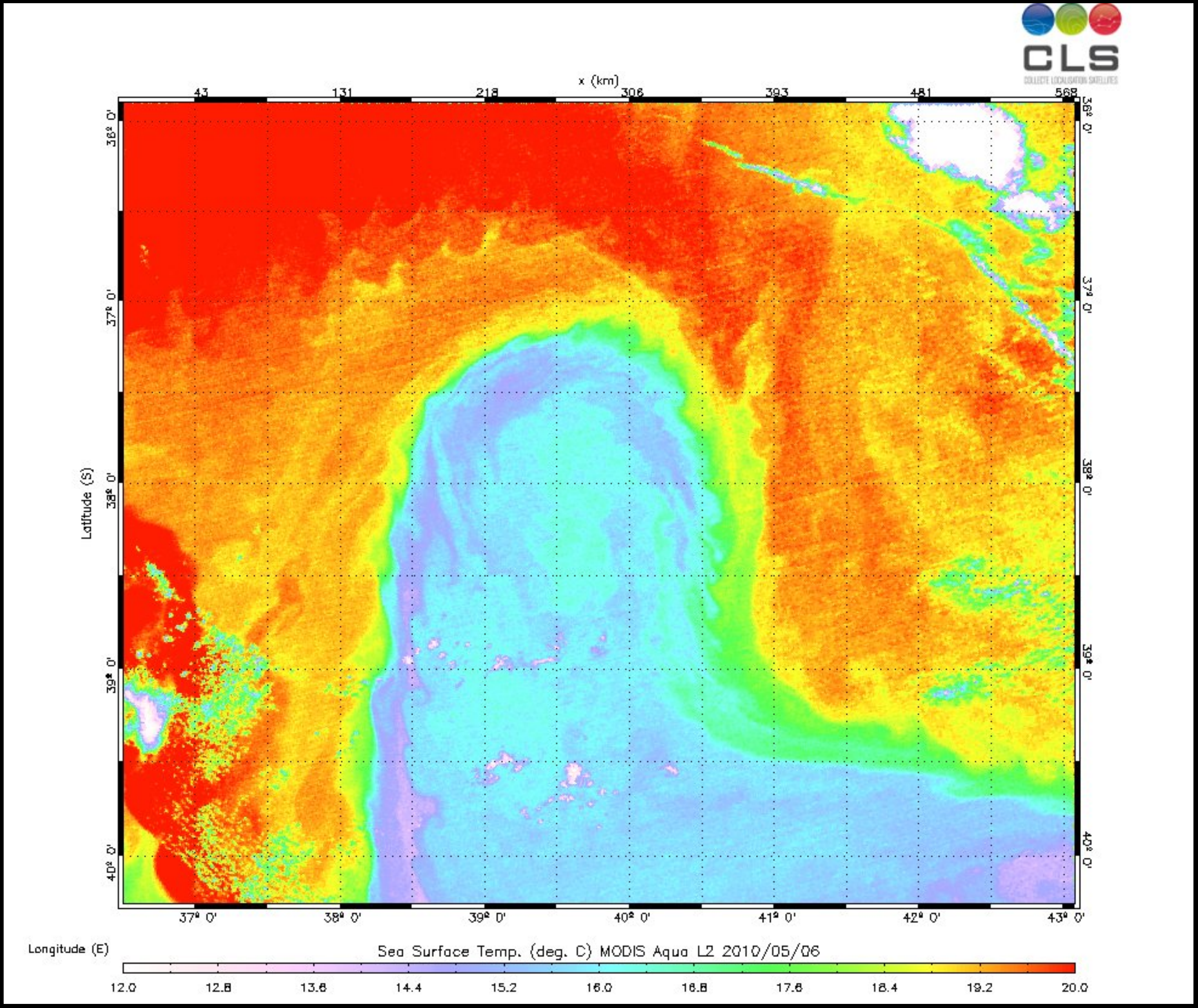
Numerous contemporaneous MODIS Brightness temperature and Ocean Colour surface signatures

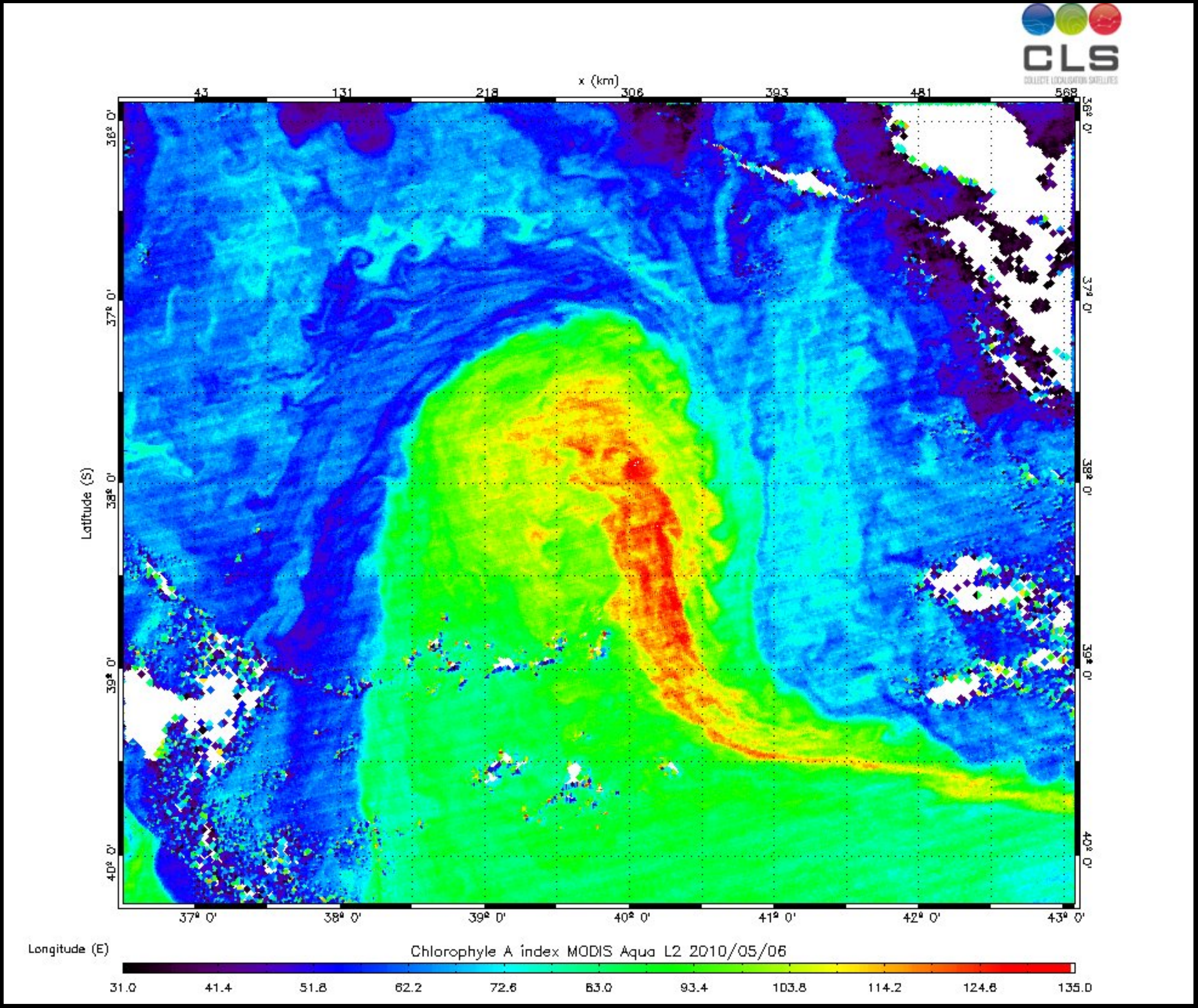


Numerous contemporaneous MODIS Brightness temperature and Ocean Colour surface signatures



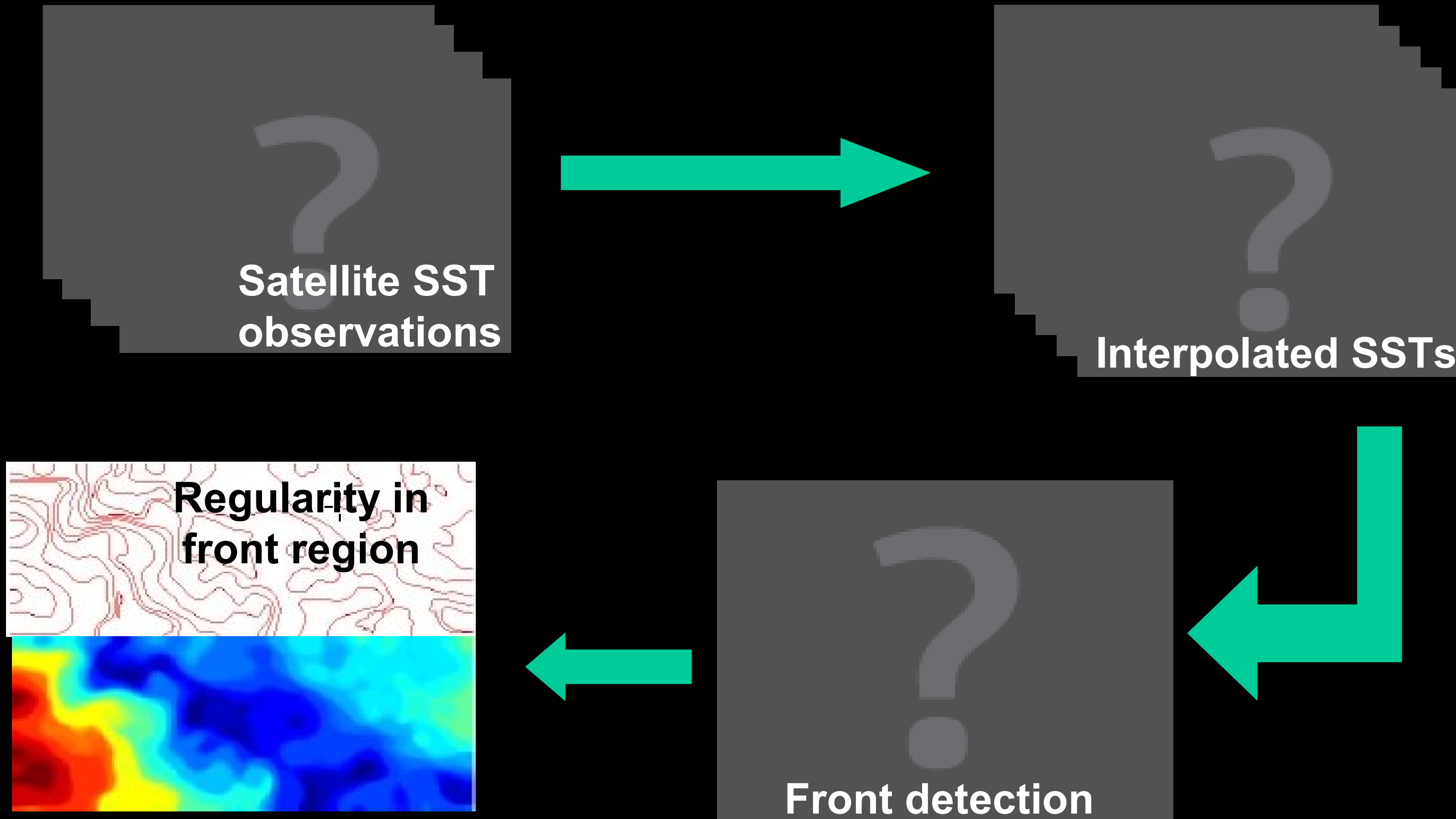
Numerous contemporaneous MODIS Brightness temperature and Ocean Colour surface signatures


CLS
COLLECTE LOCALISATION SATELLITES
x (km)
43
131
218
306
393
481
568
Latitude (S)
36º 0'
37º 0'
38º 0'
39º 0'
40º 0'
37º 0'
38º 0'
39º 0'
40º 0'
41º 0'
42º 0'
43º 0'
Longitude (E)
Sea Surface Temp. (deg. C) MODIS Aqua L2 2010/05/06
12.0
12.8
13.6
14.4
15.2
16.0
16.8
17.6
18.4
19.2
20.0



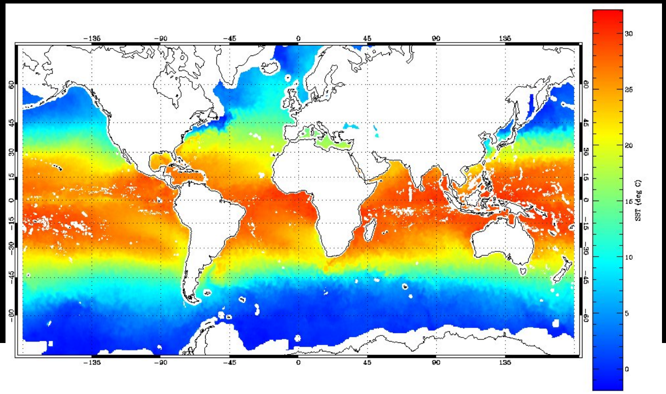
CLS
x (km)
43
131
218
306
393
481
568
Latitude (S)
36° 0'
37° 0'
38° 0'
39° 0'
40° 0'
37° 0'
38° 0'
39° 0'
40° 0'
41° 0'
42° 0'
43° 0'
Longitude (E)
Chlorophyle A index MODIS Aqua L2 2010/05/06
31.0
41.4
51.8
62.2
72.6
83.0
93.4
103.8
114.2
124.6
135.0

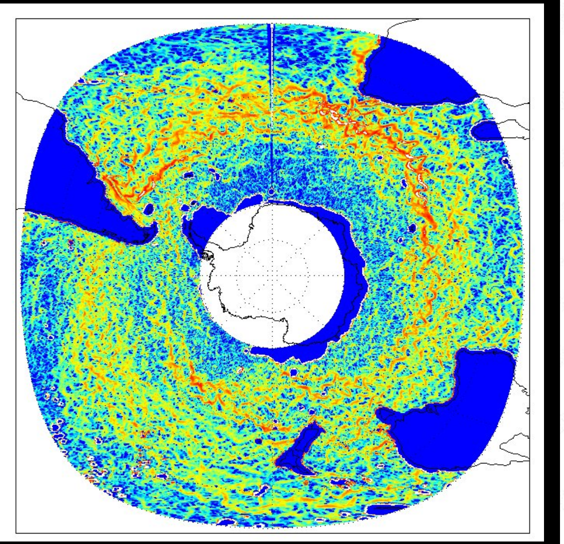
Oceanic regimes from SST observations: our approach

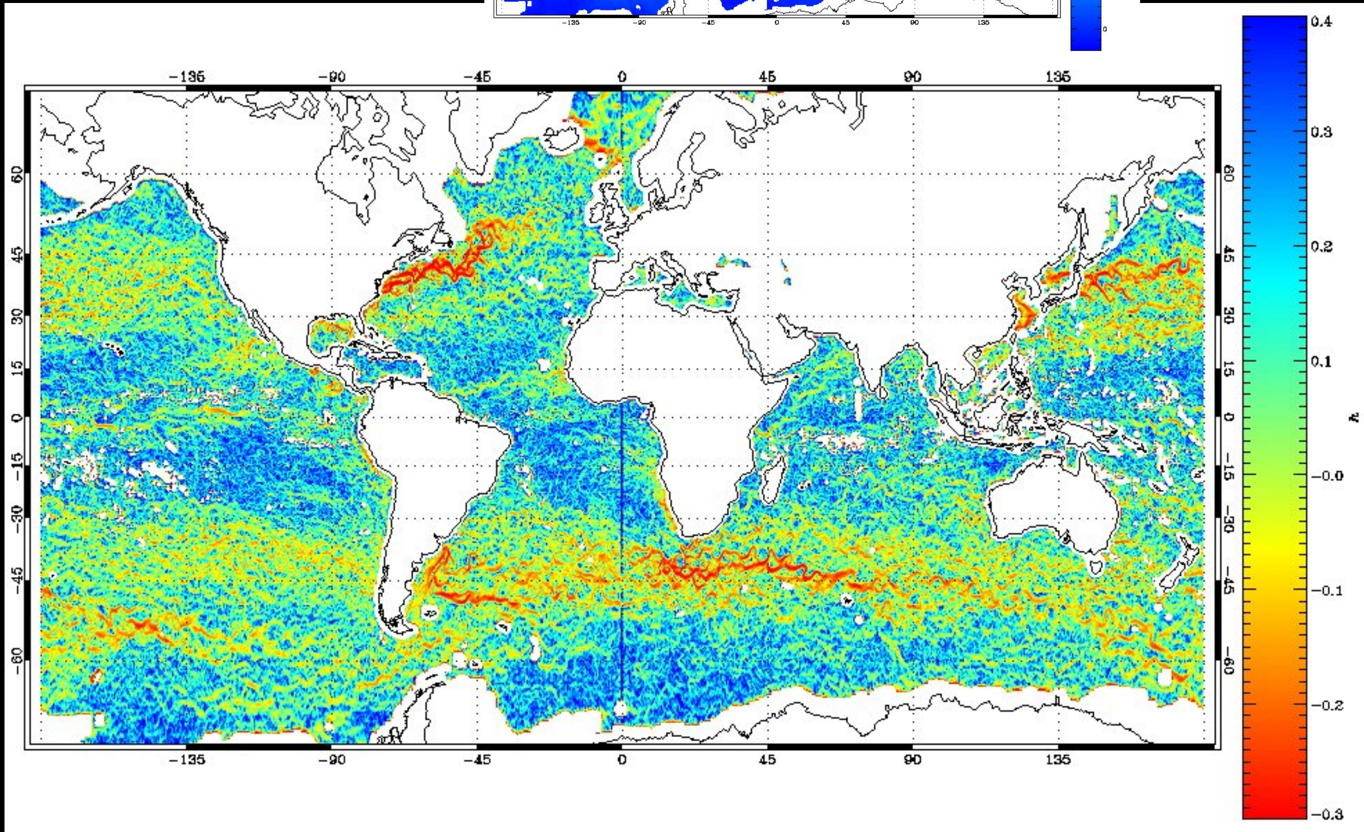


Singularity exponents

- AMSR-E SST 3 day mean
- March 1, 2008
- More examples in Turiel et al, RSE 2008



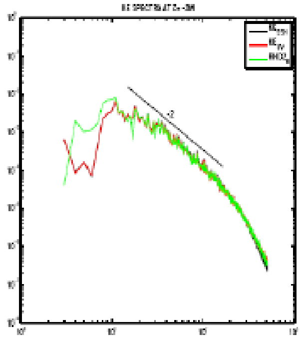




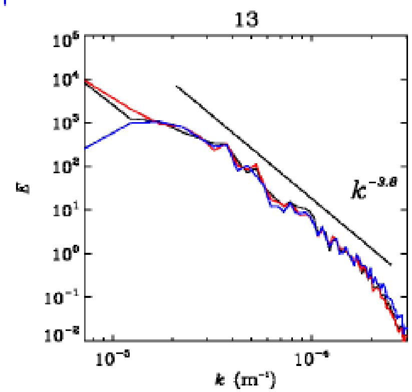
Eulerian Statistical Analysis: SSH and SST spectra

- Observed spectral slope of SST (Viehoff IJRS 1989): $|\hat{T}|^2 \sim k^{-\frac{5}{3}}$

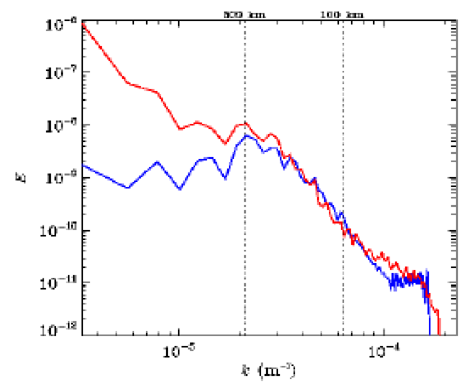
- Numerical simulations of forced turbulence (Klein et al. JPO 2008): $E(k) = c_1 k^2 |\hat{\eta}|^2 = c_2 |\hat{T}_s|^2 \sim k^{-\frac{5}{3}}$



Klein et al. JPO 2008



Isern-Fontanet et al. JGR 2008



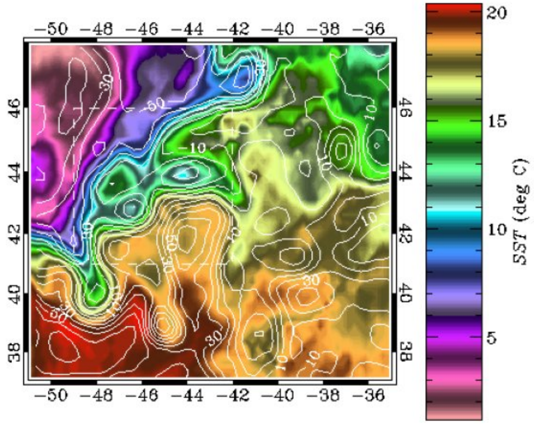
Isern-Fontanet et al. GRL 2006

- Numerical simulations of North Atlantic (Isern-Fontanet et al. JGR 2008): $c_1 k^2 |\hat{\eta}|^2 = c_2 |\hat{T}|_s^2$

- Comparison between observed SSH and SST spectrum (Isern-Fontanet et al. GRL 2006): $c_1 k^2 |\hat{\eta}|^2 = c_2 |\hat{T}_s|^2$

- Observed spectral slope of SSH (Le Traon et al. JPO 2008): $|\hat{\eta}|^2 \sim k^{-\frac{11}{3}}$ ($\Rightarrow E(k) \sim k^{-\frac{5}{3}}$)

Practical application medium resolution data

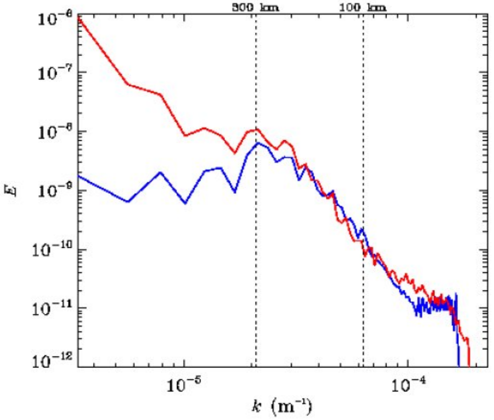


1. Given SST, ρ_s is computed using constant salinity.
2. Surface stream-function is computed $\hat{\psi}_e(\vec{k},0) \propto k^{-1}\hat{\rho}_s(\vec{k})$.
3. Results are compared to altimetry $\hat{\psi}_{altim}(\vec{k},0) \propto \hat{\eta}(\vec{k})$

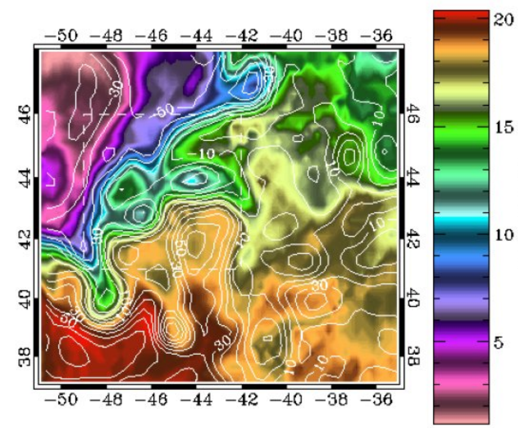
$$\hat{E}_e \propto |\hat{\rho}_s|^2 \qquad (6)$$

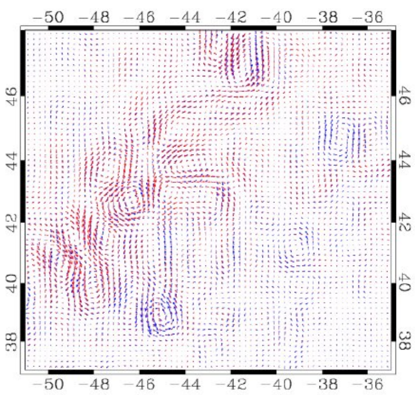
$$\hat{E}_{altim} \propto k^2|\hat{\eta}|^2 \qquad (7)$$

- We focus on the band between 100 and 300 km.



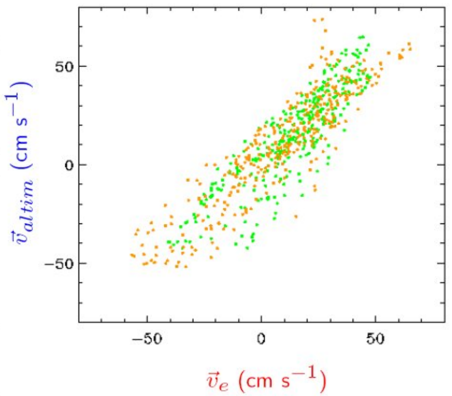
Practical application to medium resolution data



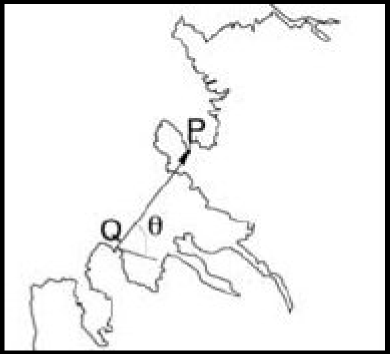


- N_1 is such that the scatter plot between $\vec{v}_e$ and $\vec{v}_{altim}$ has slope 1.
- Results are better for large thermal gradients.

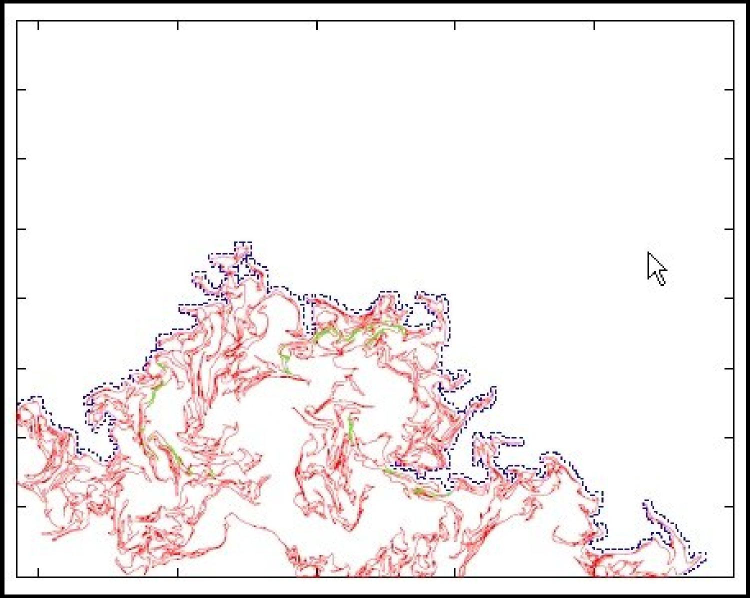
	Whole image		*Large thermal gradient*			
	R	ν	R	ν	$\langle R \rangle$	$\langle \nu \rangle$
u	0.71	0.49	0.87	0.24	0.71	0.50
v	0.67	0.55	0.90	0.19	0.69	0.53

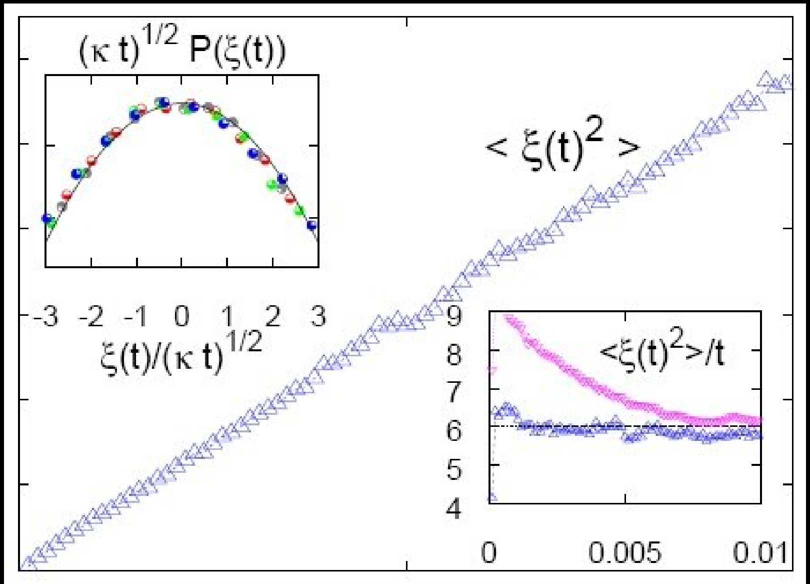


New Eulerian Statistical Descriptors

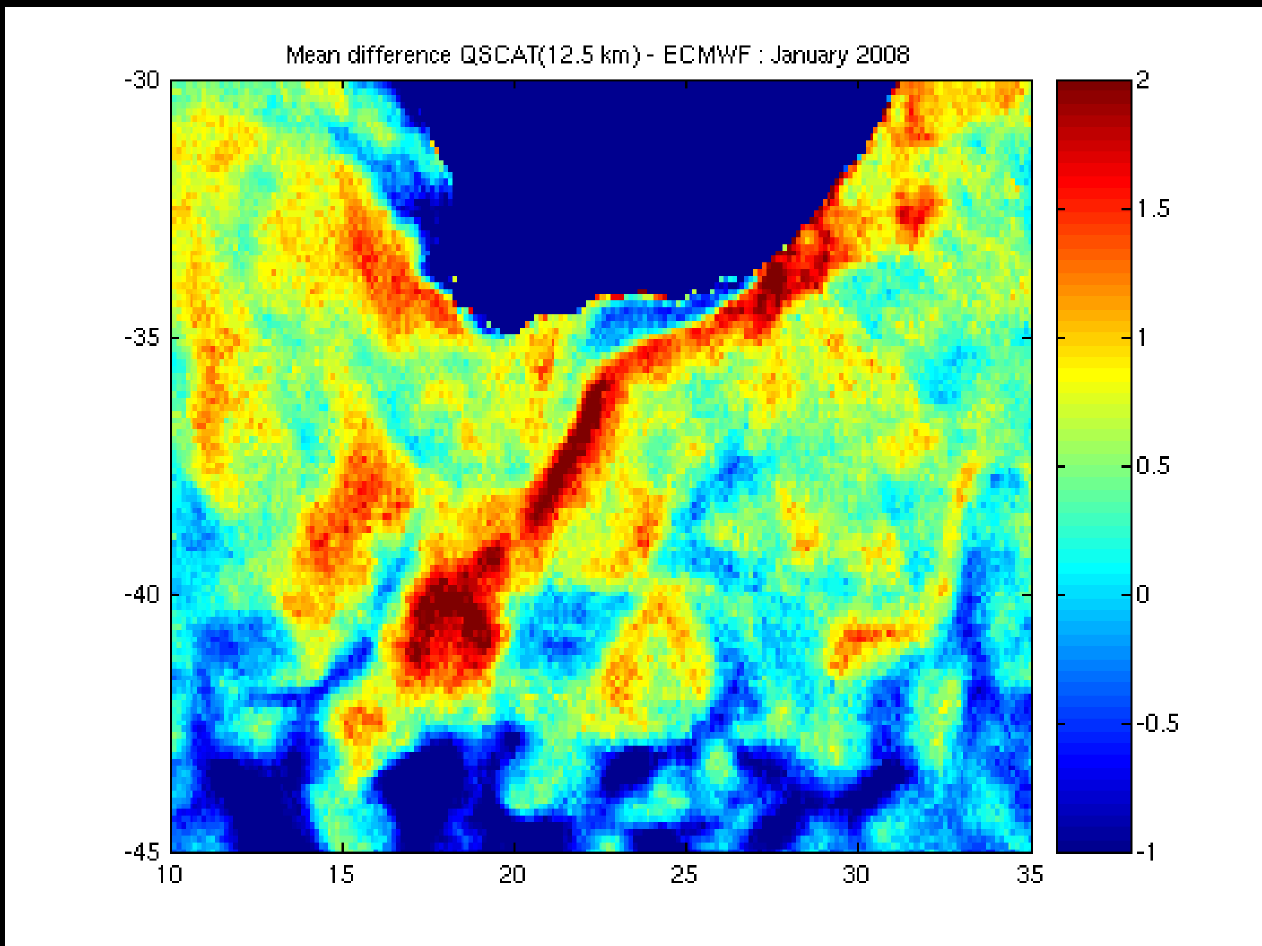


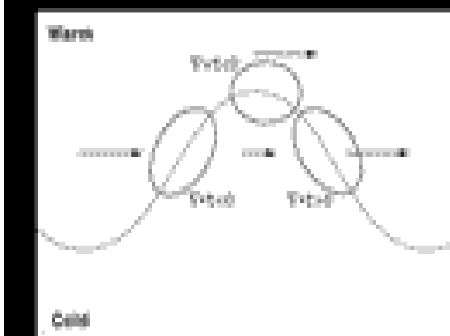
Winding
angle statistics, statistical properties
of turbulent fields : e.g., Bernard et al. (2006)
Use of SLE analysis

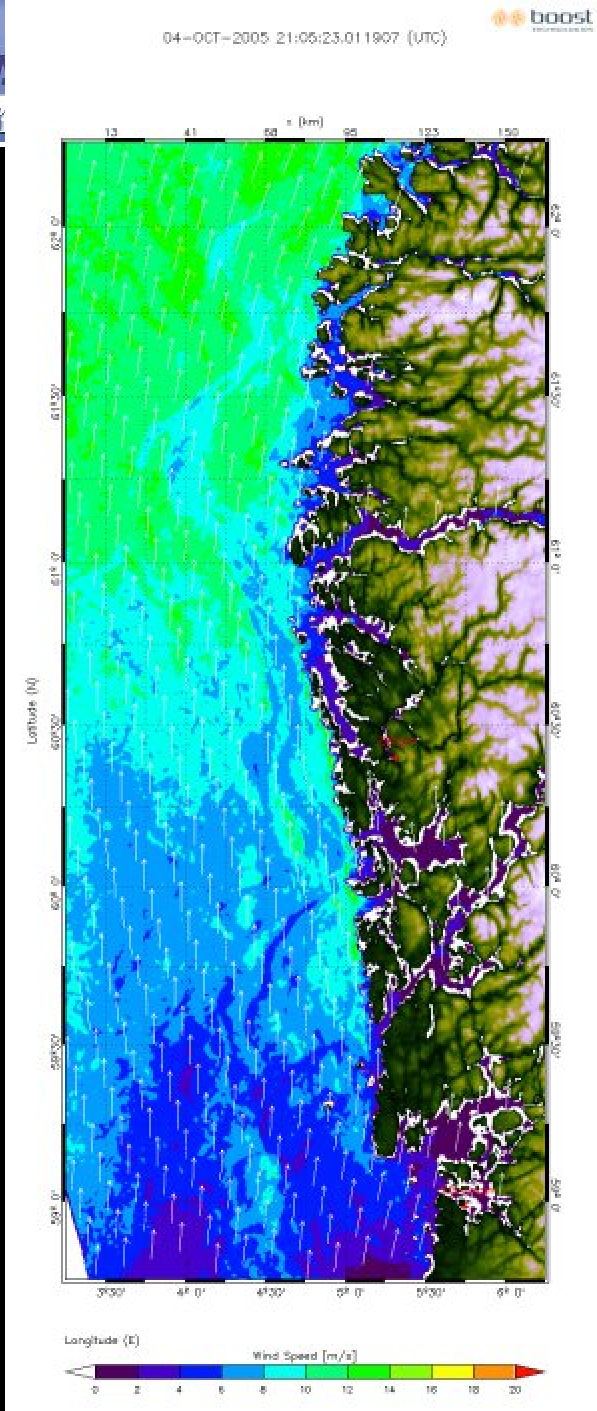




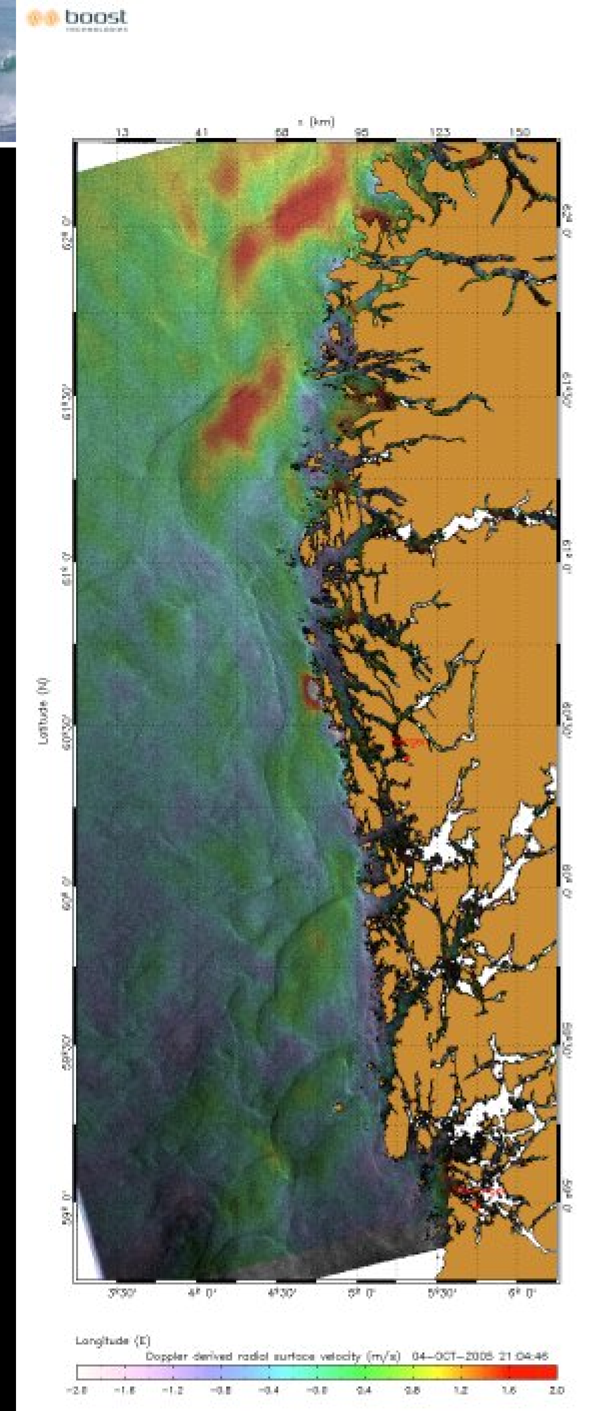
Sea surface roughness







04-OCT-2005 21:05:23.011907 (UTC)
boost
x (km)
13 41 68 95 123 150
Latitude (N)
62° 0'
61°30'
61° 0'
60°30'
60° 0'
59°30'
59° 0'
3°30' 4° 0' 4°30' 5° 0' 5°30' 6° 0'
Longitude (E)
Wind Speed [m/s]
0 2 4 6 8 10 12 14 16 18 20

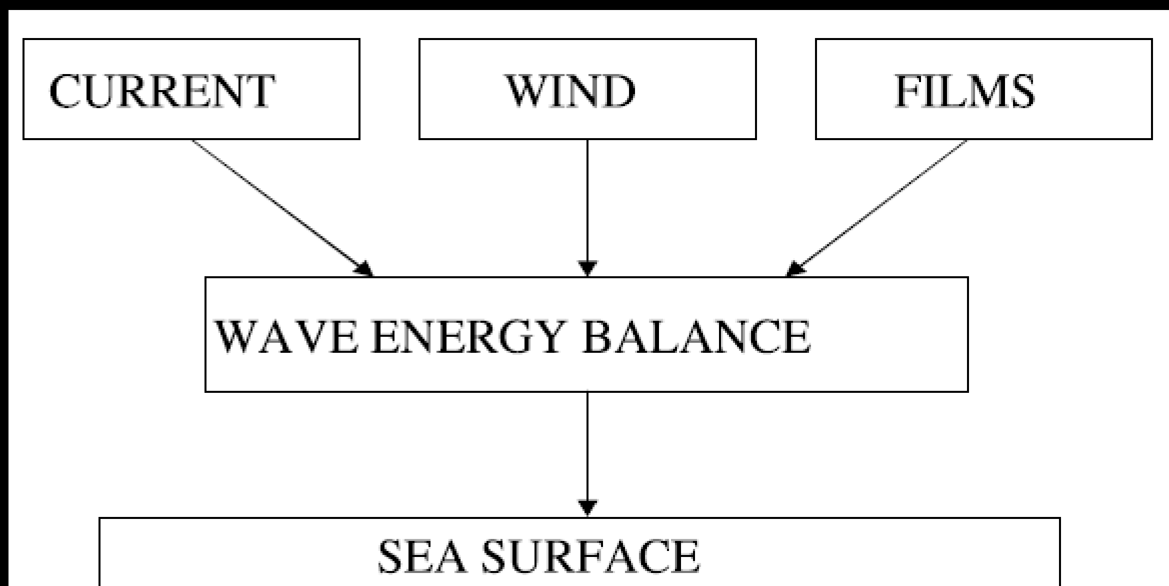


boost
x (km)
13 41 68 95 123 150
Latitude (N)
62° 0'
61°30'
61° 0'
60°30'
60° 0'
59°30'
59° 0'
3°30' 4° 0' 4°30' 5° 0' 5°30' 6° 0'
Longitude (E)
Doppler derived radial surface velocity (m/s) 04-OCT-2005 21:04:46
-2.0 -1.6 -1.2 -0.8 -0.4 -0.0 0.4 0.8 1.2 1.6 2.0

Sea Surface Roughness

$$\frac{\partial N(\mathbf{k})}{\partial t} + \left(c_{gi} + u_i\right)\frac{\partial N(\mathbf{k})}{\partial x_i} - k_j \frac{\partial u_j}{\partial x_i}\frac{\partial N(\mathbf{k})}{\partial k_i} = Q(\mathbf{k})/\omega$$

$$Q(\mathbf{k}) = \beta_\nu(\mathbf{k})\omega E(\mathbf{k}) - D(\mathbf{k}) - Q^{nl}(\mathbf{k}) + Q^{wb}(\mathbf{k})$$



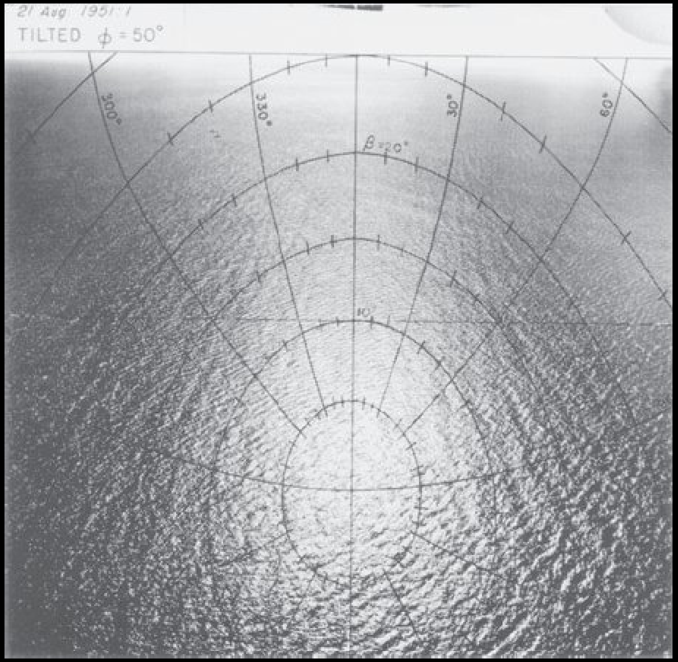
$$\partial\tilde{N}(\mathbf{k})/\partial t + c_{gi}\partial\tilde{N}(\mathbf{k})/\partial x_i = \omega^2 k^{-5}\left[\omega^{-1} m_k^{ij} u_{i,j} B_0 - \tilde{B}/\tau + \tilde{\beta} B_0 + \tilde{I}_{sw}\right]$$

$$m_k^{ij} = k_j \partial \ln N_0/\partial k_i$$

1. Classical scattering problem Cox & Munk, 1954.

$$B \equiv I \cdot \cos\theta_v = \frac{\rho E_0}{4\cos^4\beta} P(Z_x, Z_y)$$

$$Z_x = \frac{\sin\theta_s \cos\varphi_s + \sin\theta_v \cos\varphi_v}{\cos\theta_s + \cos\theta_v}, \quad Z_x = \frac{\sin\theta_s \sin\varphi_s + \sin\theta_v \sin\varphi_v}{\cos\theta_s + \cos\theta_v}$$



2. Decomposition of brightness field on *mean* (sun glint width scale) and its *variations (inner scale)*

$$B = \bar{B} + \tilde{B}$$

3. Retrieval of the MSS variations *w/o a priori defined PDF*

$$\frac{\tilde{B}}{\bar{B}} = -T \frac{\tilde{s}^2}{s^2},$$

$$T = 1 + \frac{1}{2}\left(\frac{\xi}{p}\frac{\partial p}{\partial \xi} + \frac{\eta}{p}\frac{\partial p}{\partial \eta} \right), \text{ Transfer Function}$$

$$\frac{\xi}{p}\frac{\partial p}{\partial \xi} = Z_x \frac{\nabla_l \ln B \cdot \nabla_n Z_y - \nabla_n \ln B \cdot \nabla_l Z_y}{\Delta} - \frac{4Z_x^2}{1 + Z_x^2 + Z_y^2}$$

$$\frac{\eta}{p}\frac{\partial p}{\partial \eta} = Z_y \frac{\nabla_n \ln B \cdot \nabla_l Z_x - \nabla_l \ln B \cdot \nabla_n Z_x}{\Delta} - \frac{4Z_y^2}{1 + Z_x^2 + Z_y^2}$$

Radar and Optical Imaging Model (RIM and OIM)

Kudryavtsev et al., 2005; Johannessen et al., 2005

Wave - Current Interaction :

$$M \equiv \mathring{B}(\mathbf{k}) / B(\mathbf{k}) \propto \omega^{-1}(c/u_*)^2 m_k^{i,j} u_{i,j}$$

Integral Parameters governs by :

$$M \propto \omega^{-1}(c/u_*)^2 m_k \nabla \cdot \mathbf{u}$$

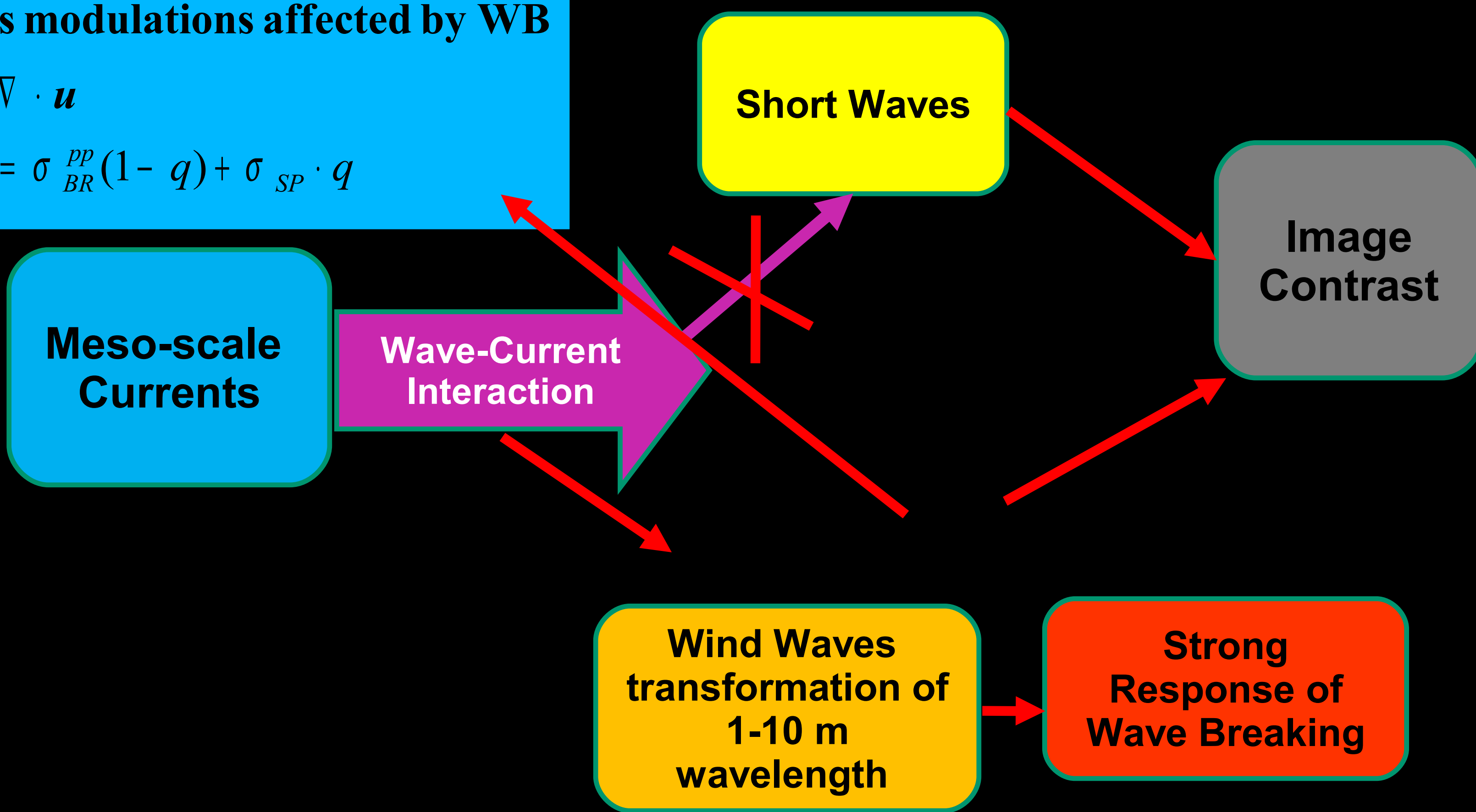
$$\mathring{s}^2 \propto \int M k^2 B(\mathbf{k}) d\mathbf{k} \propto \nabla \cdot \mathbf{u}$$

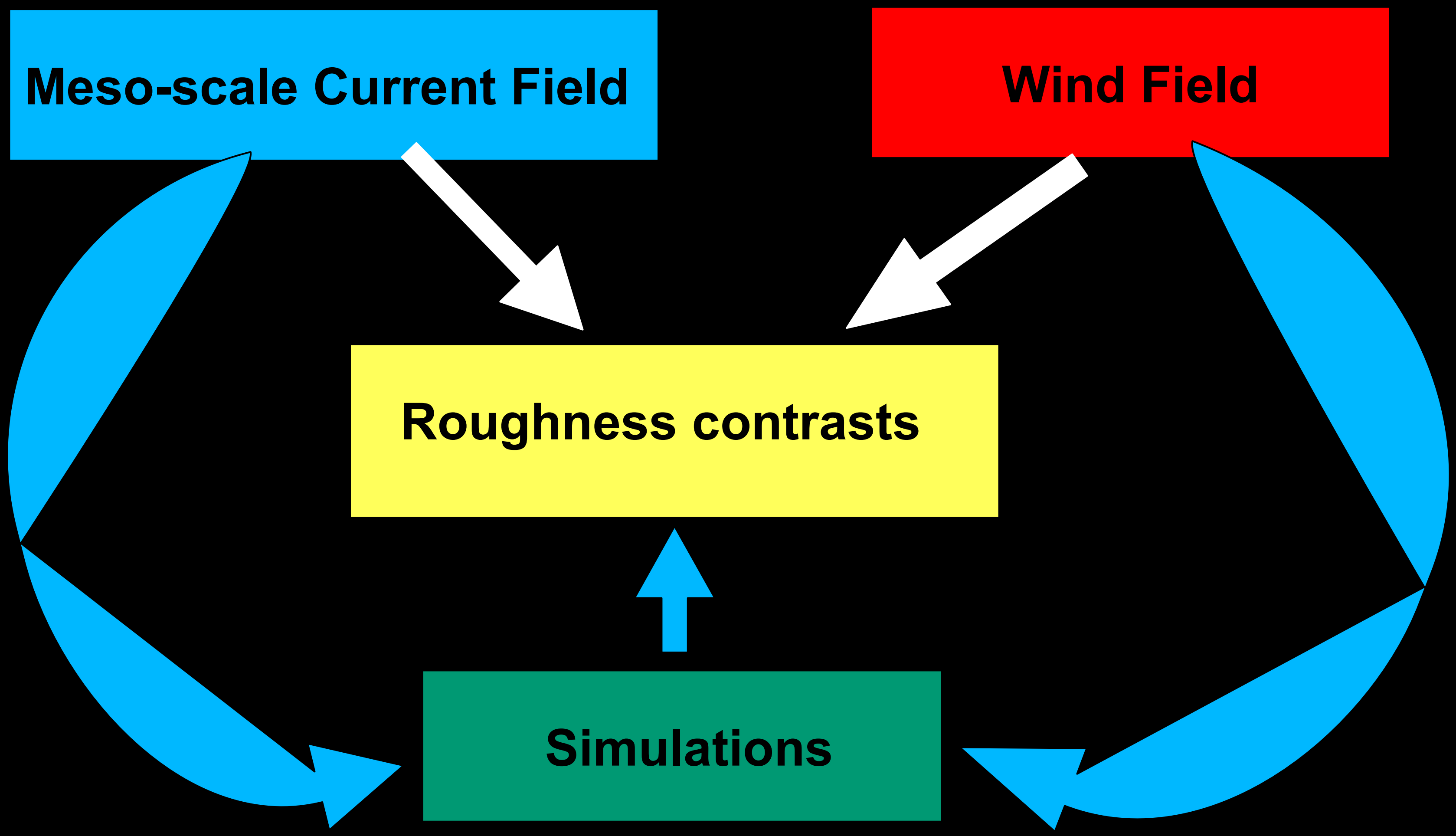
$$\tilde{q} \propto \int M k^{-2} \beta B(\mathbf{k}) d\mathbf{k} \propto \nabla \cdot \mathbf{u}$$

Bragg Waves modulations affected by WB

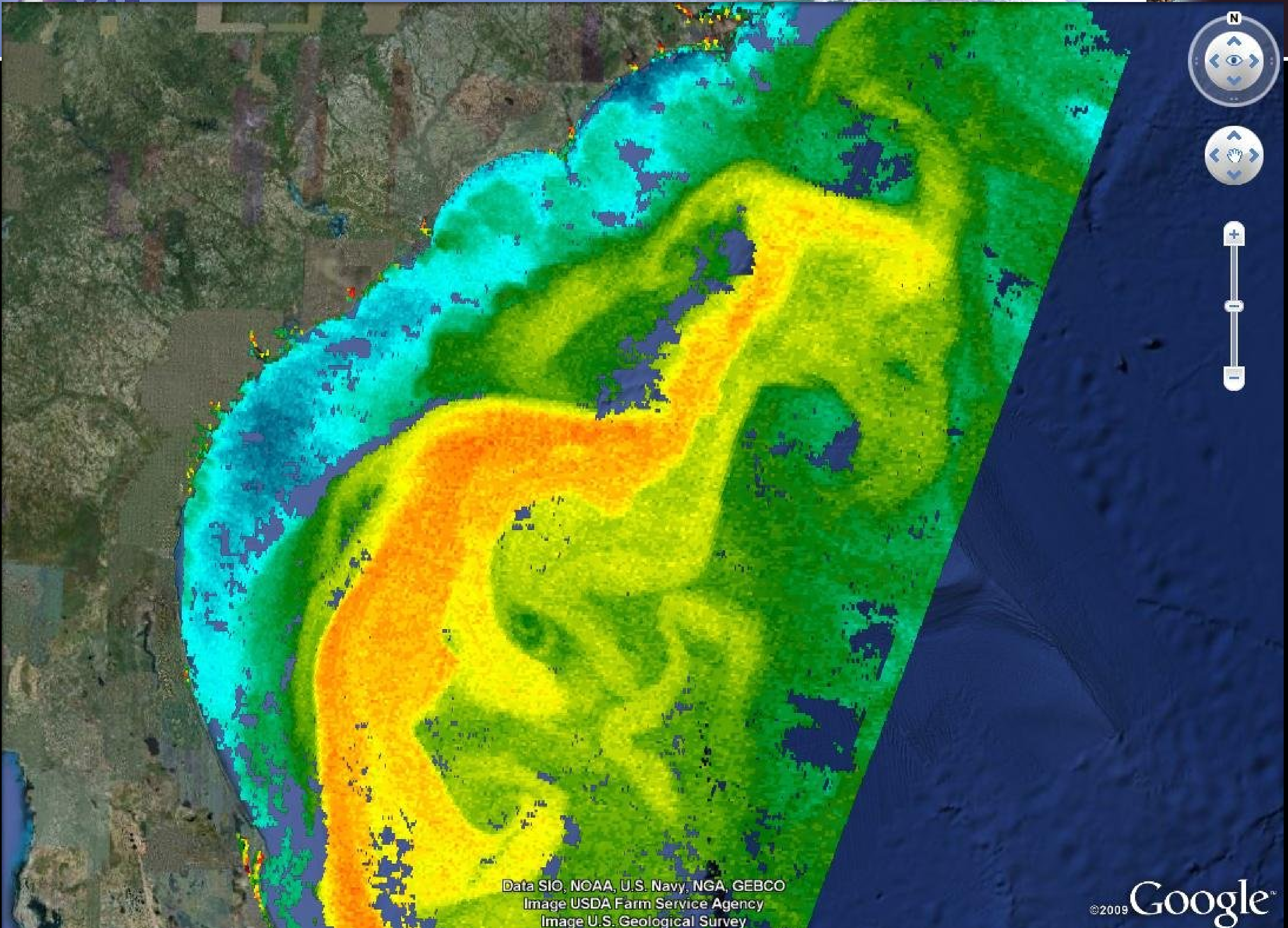
$$\mathring{B}(\mathbf{k}_{br}) \propto \tilde{q} \propto \nabla \cdot \mathbf{u}$$

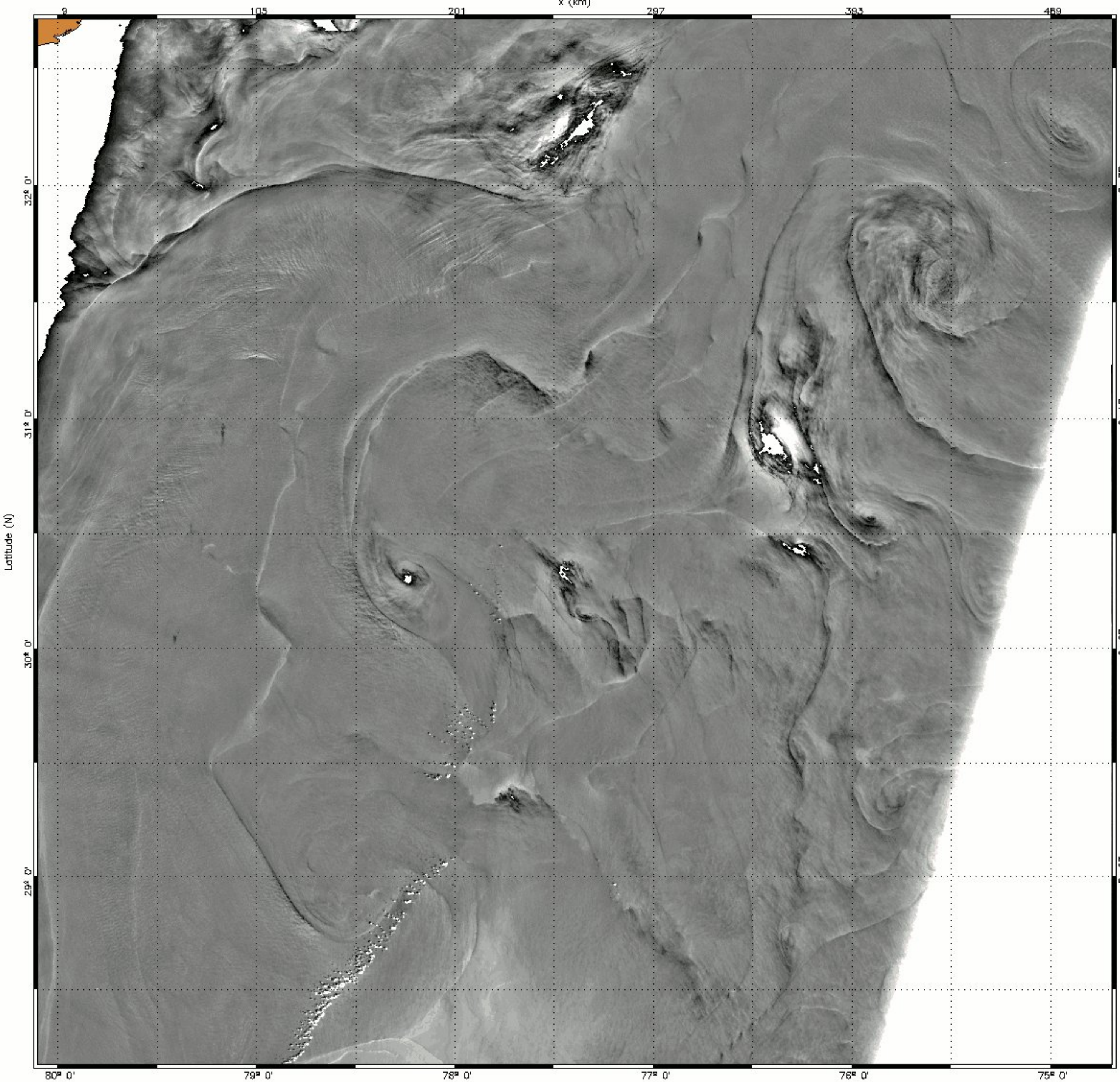
NRCS : $\sigma_0^{pp} = \sigma_{BR}^{pp}(1-q) + \sigma_{SP} \cdot q$




Meso-scale Current Field
Wind Field
Roughness contrasts
Simulations

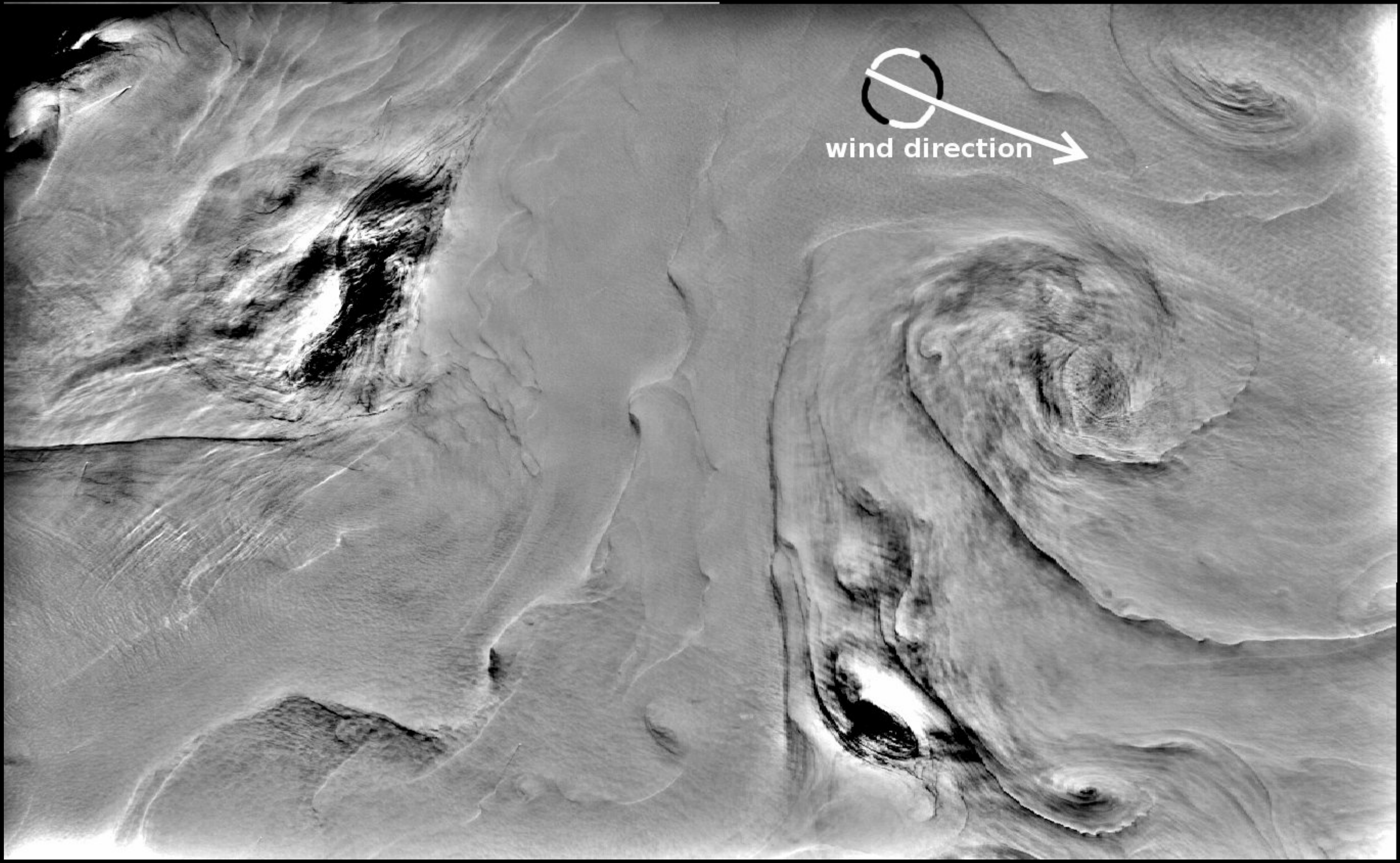
MERIS Glitter analysis

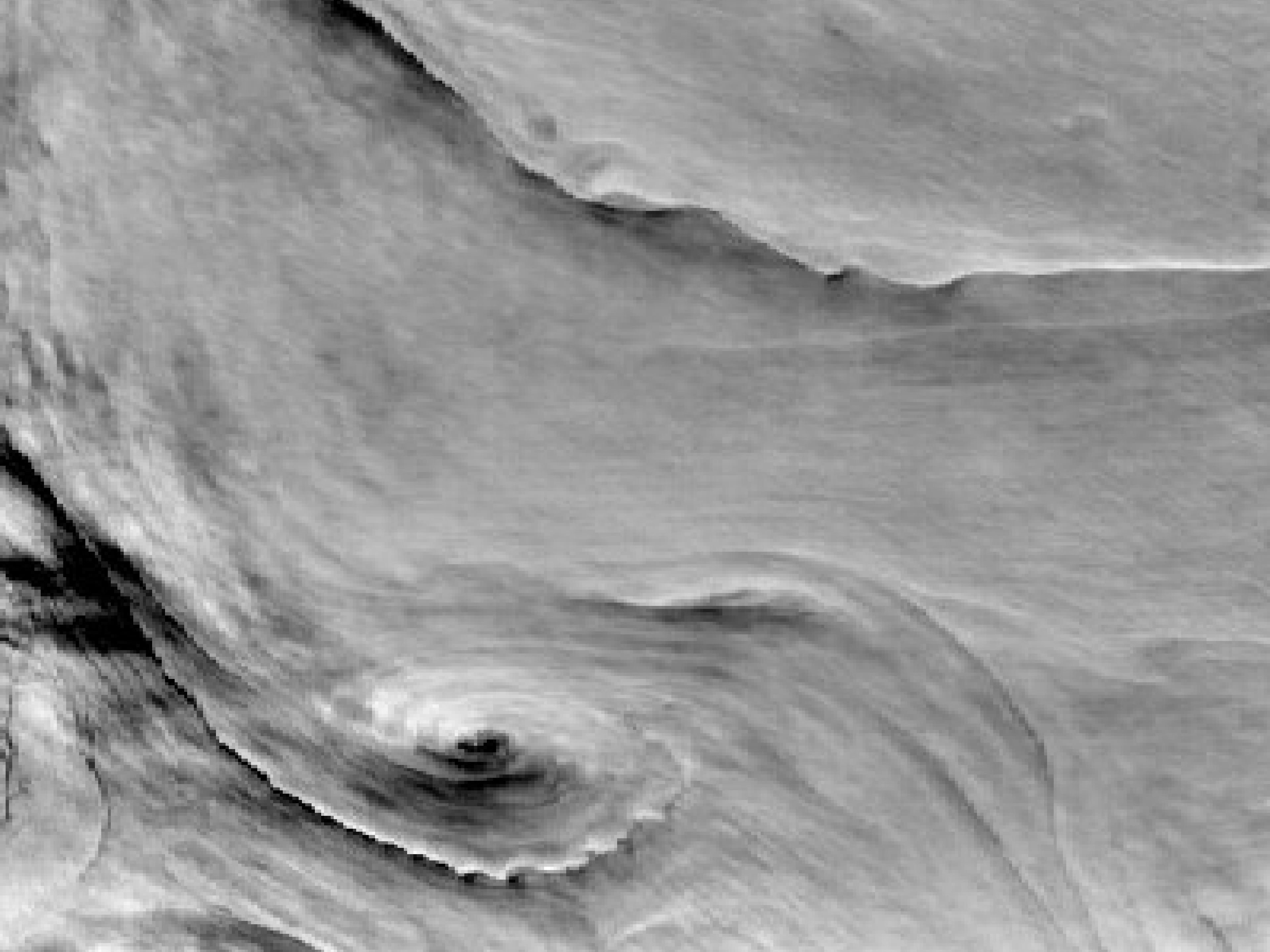

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image USDA Farm Service Agency
Image U.S. Geological Survey
©2009 Google

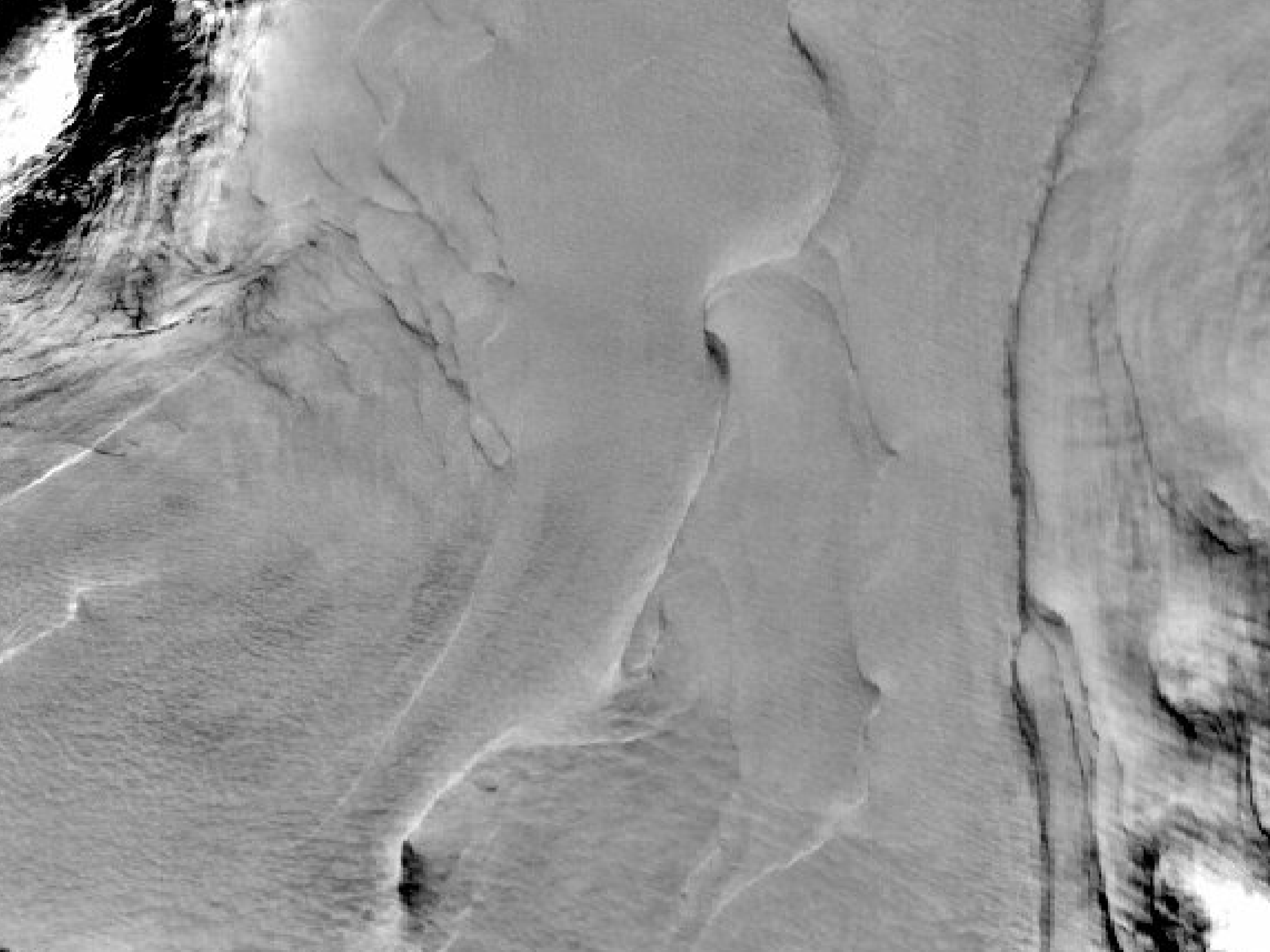


x (km)
9
105
201
297
393
489
Latitude (N)
32° 0'
31° 0'
30° 0'
29° 0'
80° 0'
79° 0'
78° 0'
77° 0'
76° 0'
75° 0'

Meso- and submeso-scale details







Reconstruction of Surface Currents from SST

Surface Quasi – Geostrophy fields

QG Stream-function

$$\mathrm{SST}\,(\hat{T}_s) \rightarrow \hat{\psi}(\boldsymbol{k},z) = \frac{g\alpha\,\hat{T}_s(\boldsymbol{k})}{f n_b k}\exp(n_0 k z)$$

Vorticity of the surface QG current

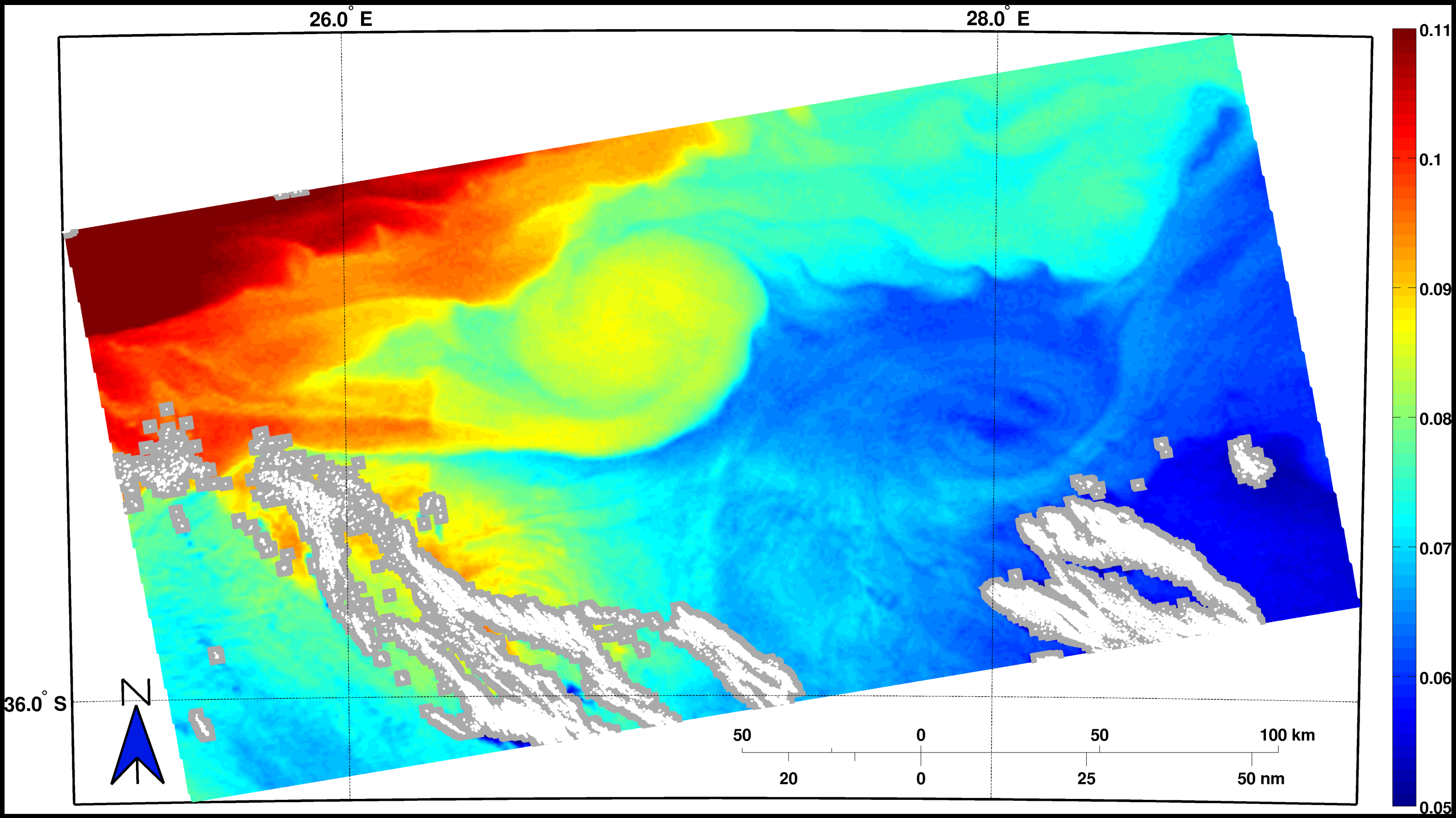
$$\hat{\Omega}_z(\boldsymbol{k}) = k^2\hat{\psi}(\boldsymbol{k}) = \frac{g\alpha}{f n_b k}k^2\hat{T}_s(\boldsymbol{k})$$

. Interactions Ekman and SQG currents (after Klein and Hua, 1990)

$$\tilde{u}_1 = -f^{-1}\overline{u}_j\frac{\partial U_2}{\partial x_j}, \quad \tilde{u}_2 = f^{-1}\overline{u}_j\frac{\partial U_1}{\partial x_j}$$

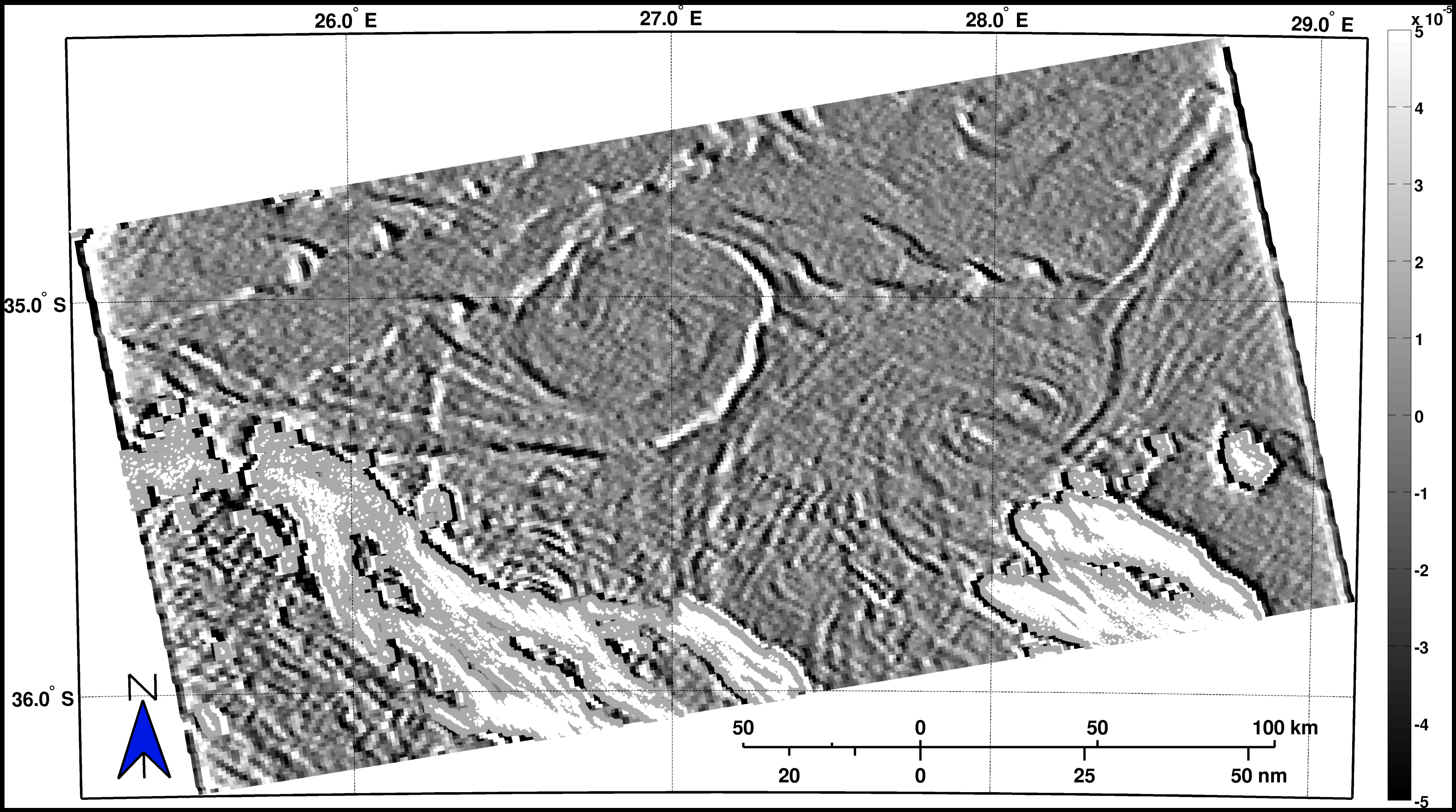
Generation of vertical pumping (convergence/divergence)

$$\nabla\cdot\boldsymbol{V} = -f^{-1}\overline{u}_j\frac{\partial}{\partial x_j}\Omega_z$$

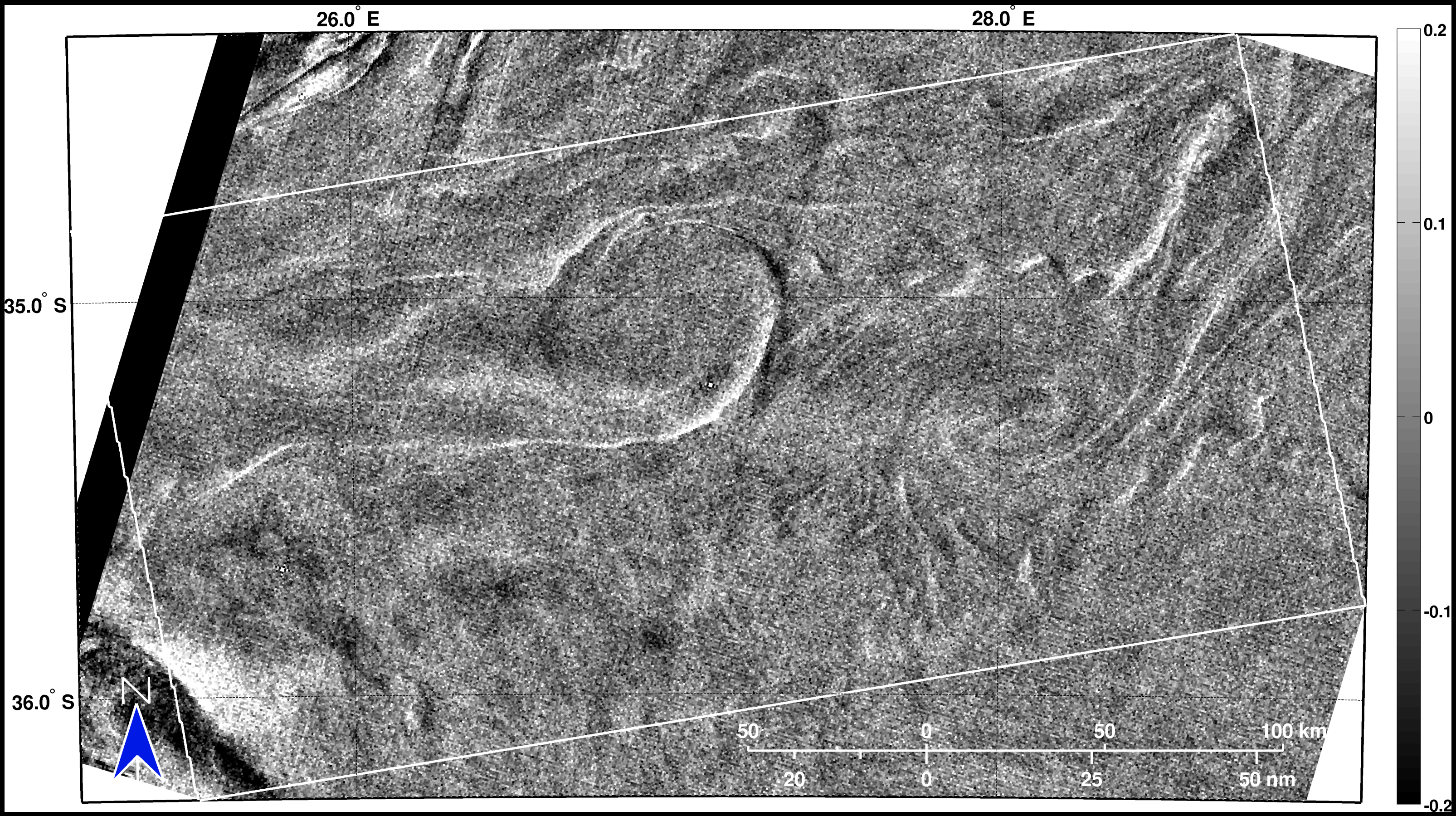


26.0° E
28.0° E
36.0° S
N
50
0
50
100 km
20
0
25
50 nm
0.11
0.1
0.09
0.08
0.07
0.06
0.05

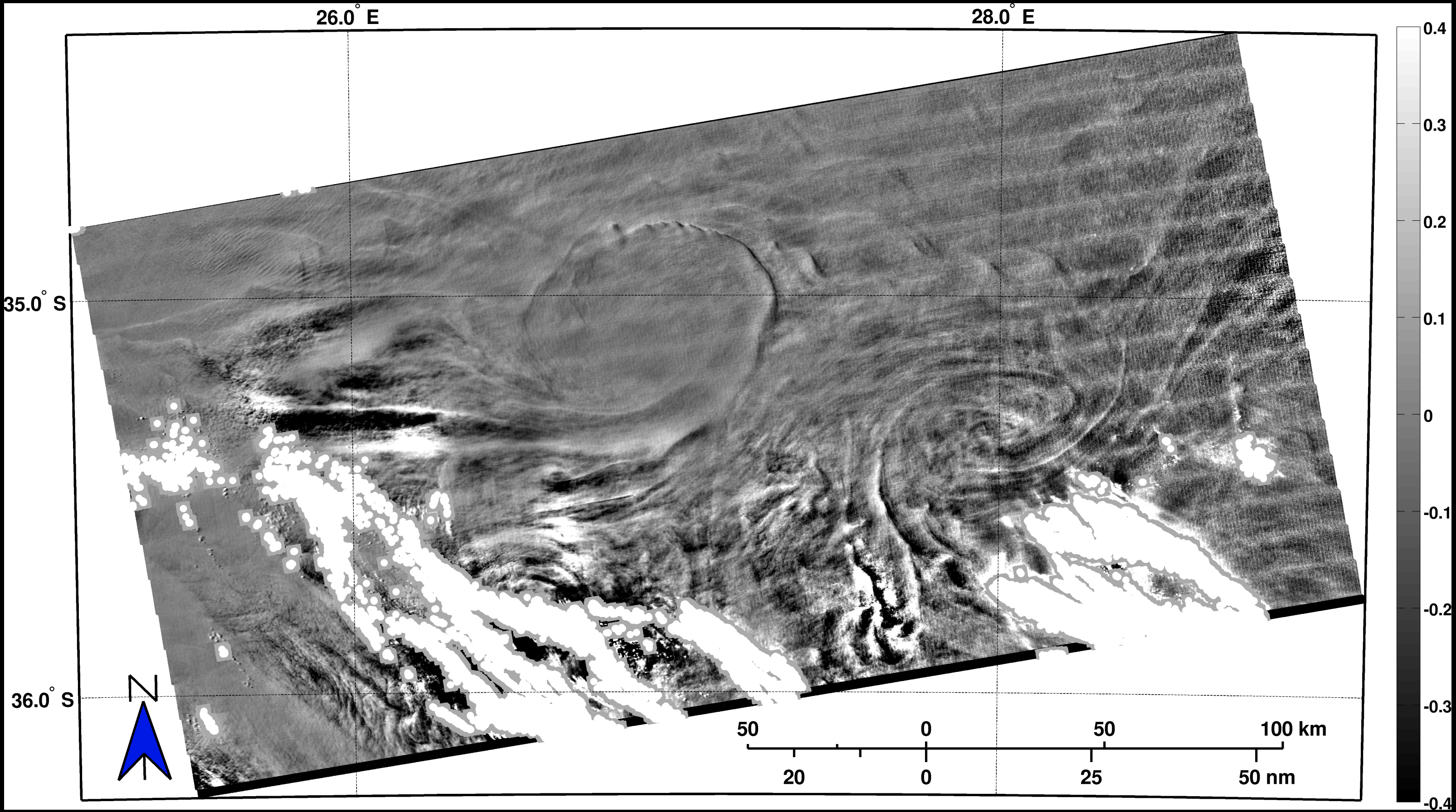
Simulated roughness variations



Radar roughness contrasts



Relative mss contrasts



Summary …

- Study meso-scale and sub meso-scale phenomena = the combined use of observations, including in situ measurements, Eulerian and Lagrangian descriptors
- Very (too) large number of scales
-
- Observations and numerical simulations resolving the same scales are necessary (including sensor physics, observability conditions and instrument capabilities)
- Roughness contrasts as local quantitative proxies to trace divergence/convergence areas

Ready for experiments !