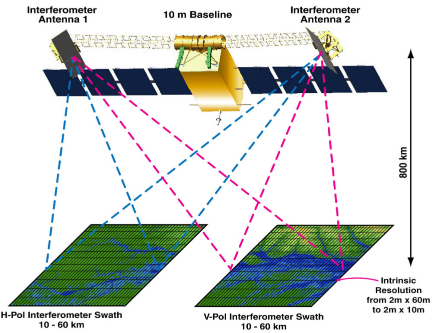
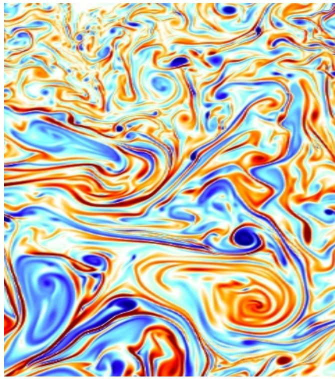
“Ocean Turbulence from SPACE”

Patrice Klein (Caltech/JPL/Ifremer)

(X-III) –
How to exploit the synergy between satellite data using the dynamical framework of 3D-QG (or 2D) and SQG turbulence? (a)





Satellite data have different resolutions and therefore different spectral gaps

How to exploit the synergy between these satellite data, using the dynamical framework of 3D-QG (or 2D) and SQG turbulence, to better identify the dynamical regimes in the world ocean?

SSH (present) : scales > 70 km and 10 days – 20 days ;

SSH (future: SWOT) : scales >10 km – 30 km and 10 days – 20 days

SST at L.R. (AMSR-E) : scales > 50 km to 100 km and 1 day ;

SST at H.R. (Modis): scales > 2-4 km but affected by clouds

Ocean Color (Modis, Sentinel): scales > 2-4 km and even down to 100 m!

SAR images: scales > 100 m but useful only with moderate winds

GLITTER images: same as SAR

SSS (Aquarius, SMOS): low resolution

Satellite altimeters (70 km – 10000 km):

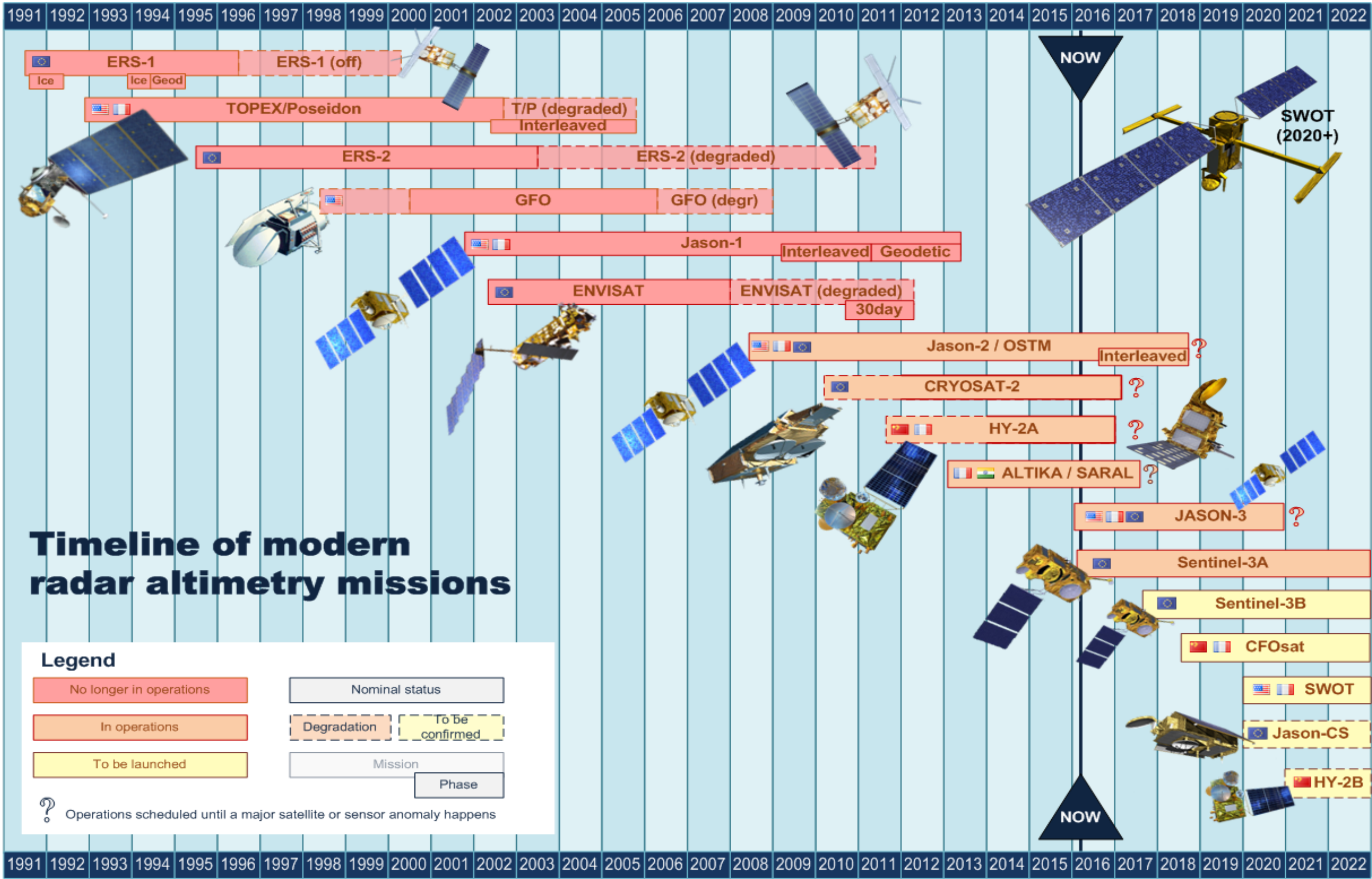
- One of the most important satellite technics for oceanography.
- It **provides, global, real-time, all weather SSH measurements**.
- Using the geostrophic approximation, these measurements allow to recover surface motions.

These data have contributed to a much better understanding and recognition of the role and importance of mesoscale eddies (Le Traon OS'13).

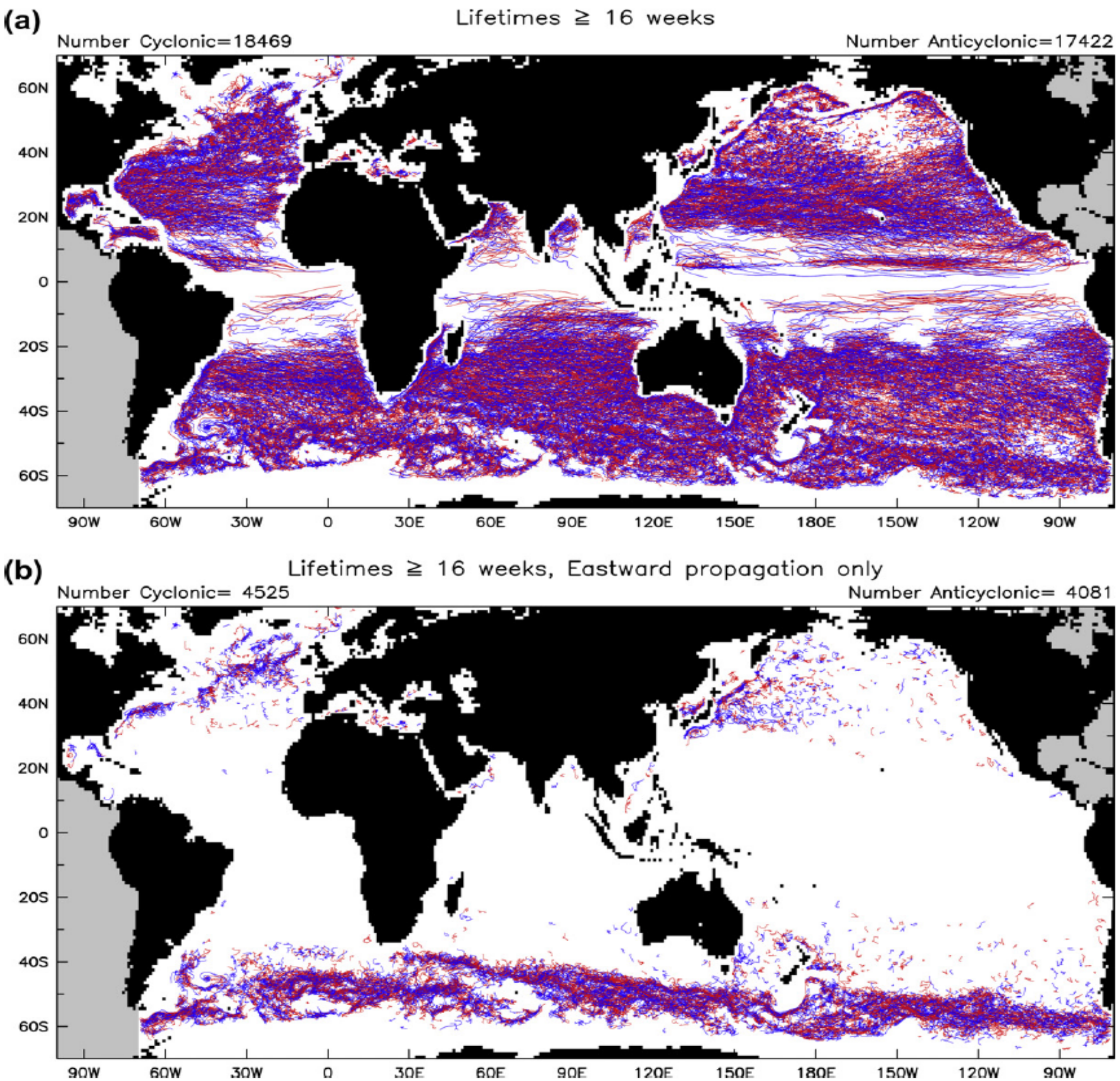
=> AVISO (gridded) products
=> Along track analysis

Satellite altimetry provides:

global coverage, all weather, real-time SSH measurements

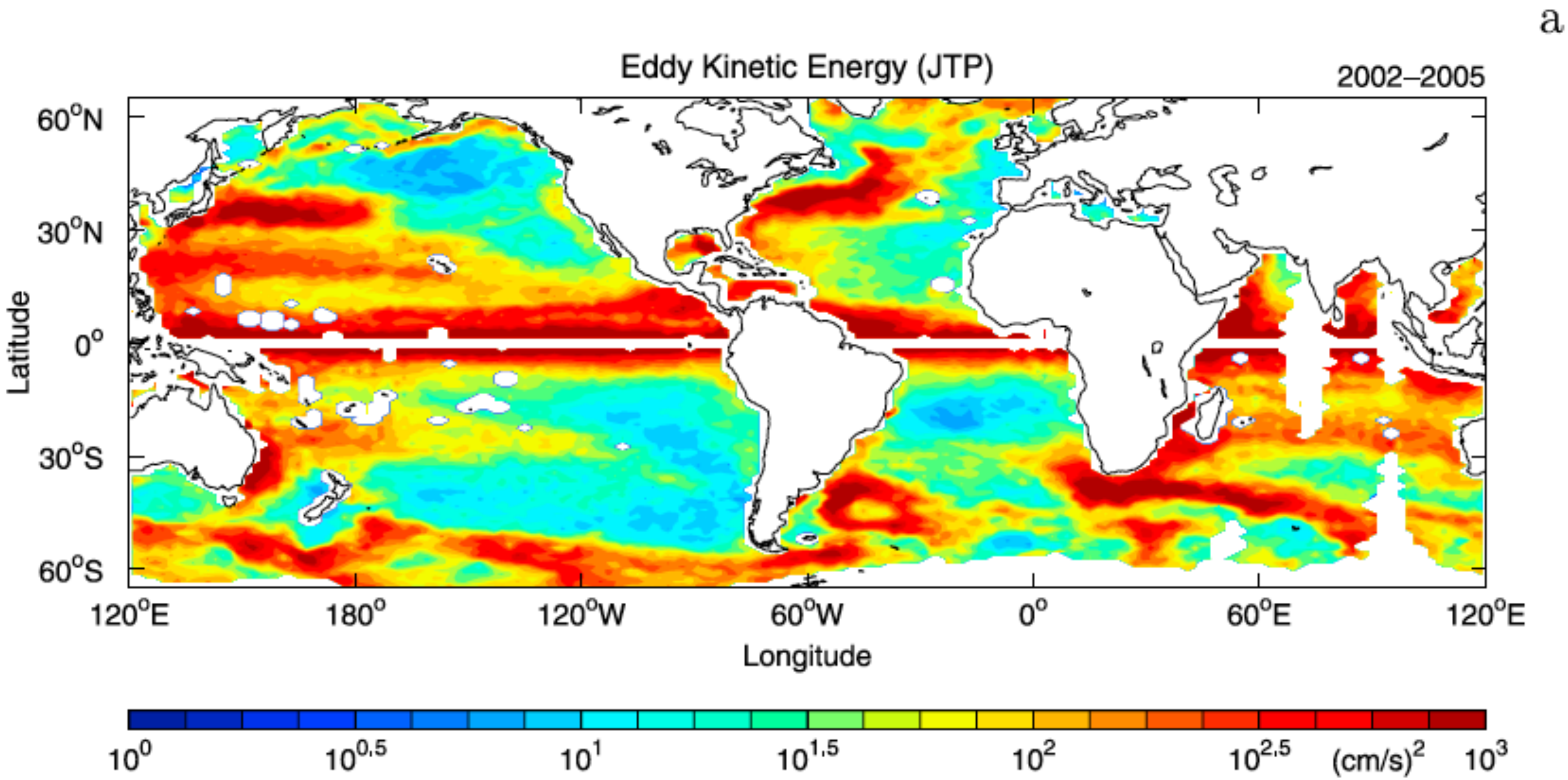


Tracking of eddies around the world's ocean using OW parameter
(Chelton et al. PO 2011 from **AVISO (gridded) products**)



ig. 4a and b. The trajectories of cyclonic (blue lines) and anticyclonic (red lines) eddies over the 16-year period October 1992–December 2008 for (a) lifetimes ⩾16 weeks nd (b) lifetimes ⩾16 weeks for only those eddies for which the net displacement was eastward. The numbers of eddies of each polarity are labeled at the top of each panel.

Scharffenberg & Stammer JGR 2010: Using T/P & Jason 1 mission data



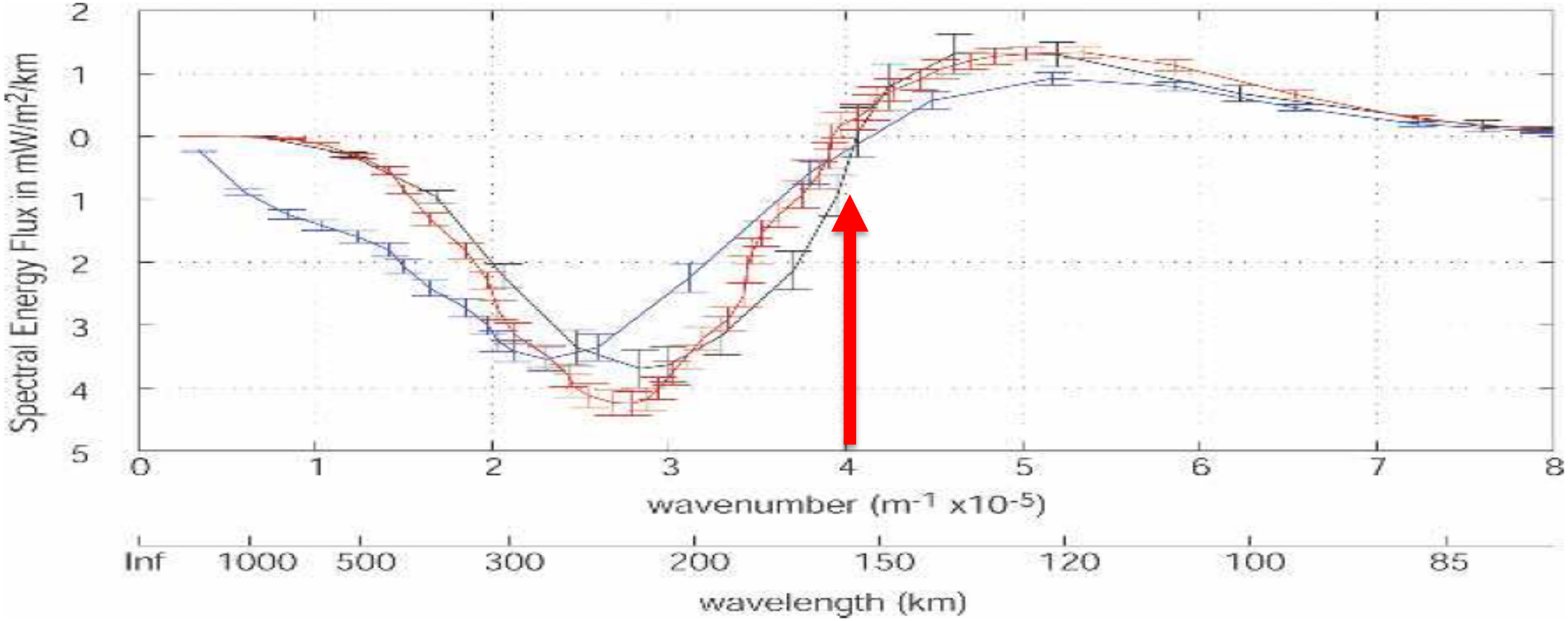
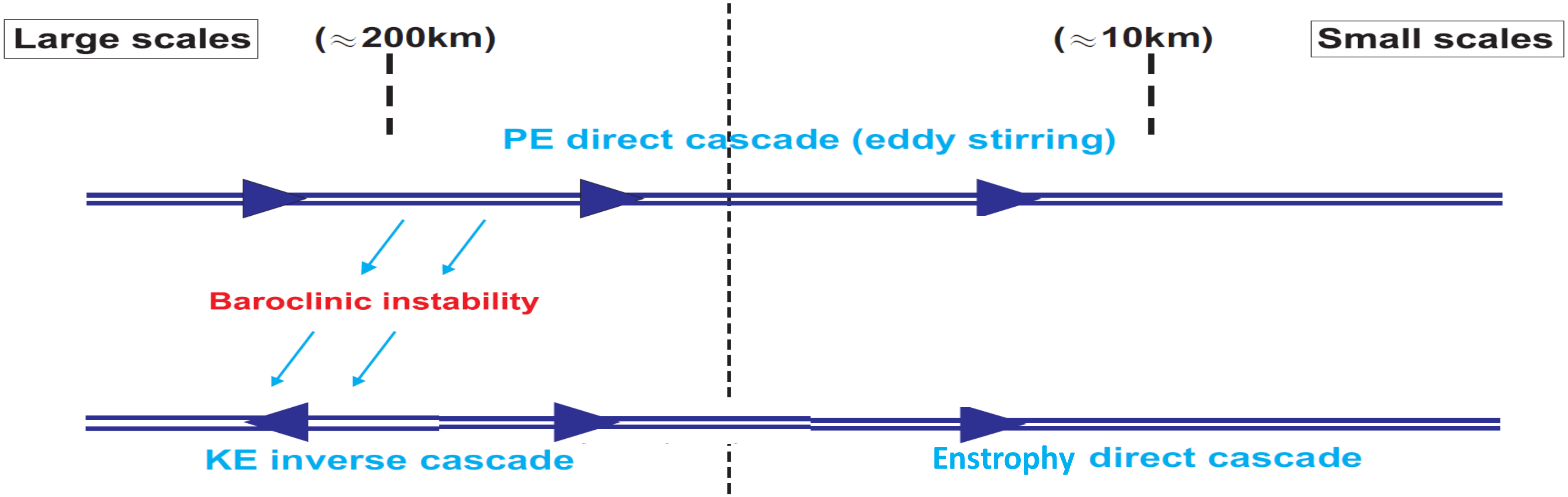


FIG. 2. Time mean, spectral kinetic energy flux $\overline{\Pi}(K)$ vs total wavenumber K in a homogeneous ACC region (rectangles centered at 57°S, 120°W): black curve using SSH on a 32 × 32 grid, red curve using SSH on a 64 × 64 grid, blue curve using velocity on a 64 × 64 grid. Positive slope reveals a source of energy. The larger negative lobe reveals a net inverse cascade to lower wavenumber. Error bars represent standard error.

Spectral kinetic energy fluxes estimated from **AVISO** data
- inverse KE cascade for scales larger than ~150 km ! :
- direct KE cascade for scales smaller than ~150 km !

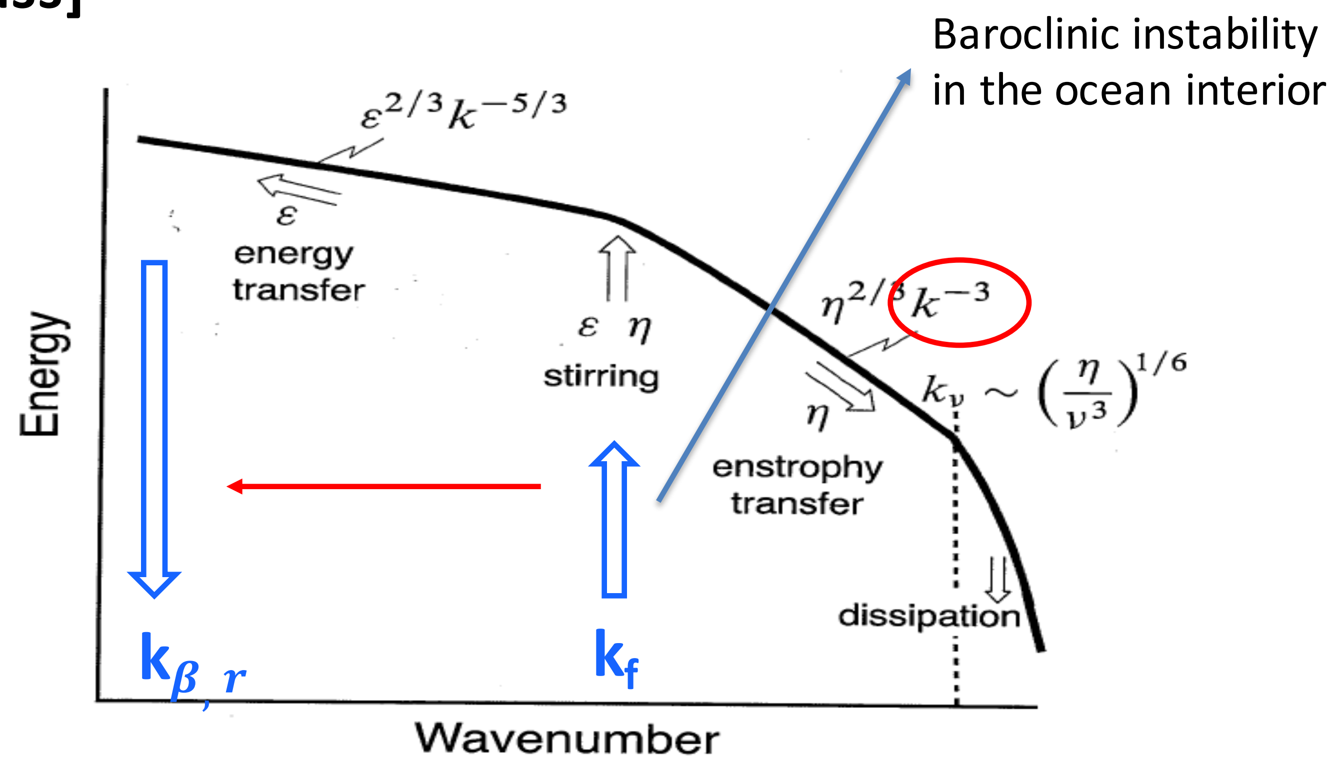
(Scott and Wang, JPO 2005)

Classical energy route (Salmon '80s) has been assumed



<u>Vision suggested by altimeter data :</u>
The upper ocean dynamics is driven by mesoscale (geostrophic) eddies with, as a result, the surface properties close to <u>geostrophic turbulence</u> (Charney, 1971).

From classical properties of **Geostrophic turbulence in the ocean [see next class]**

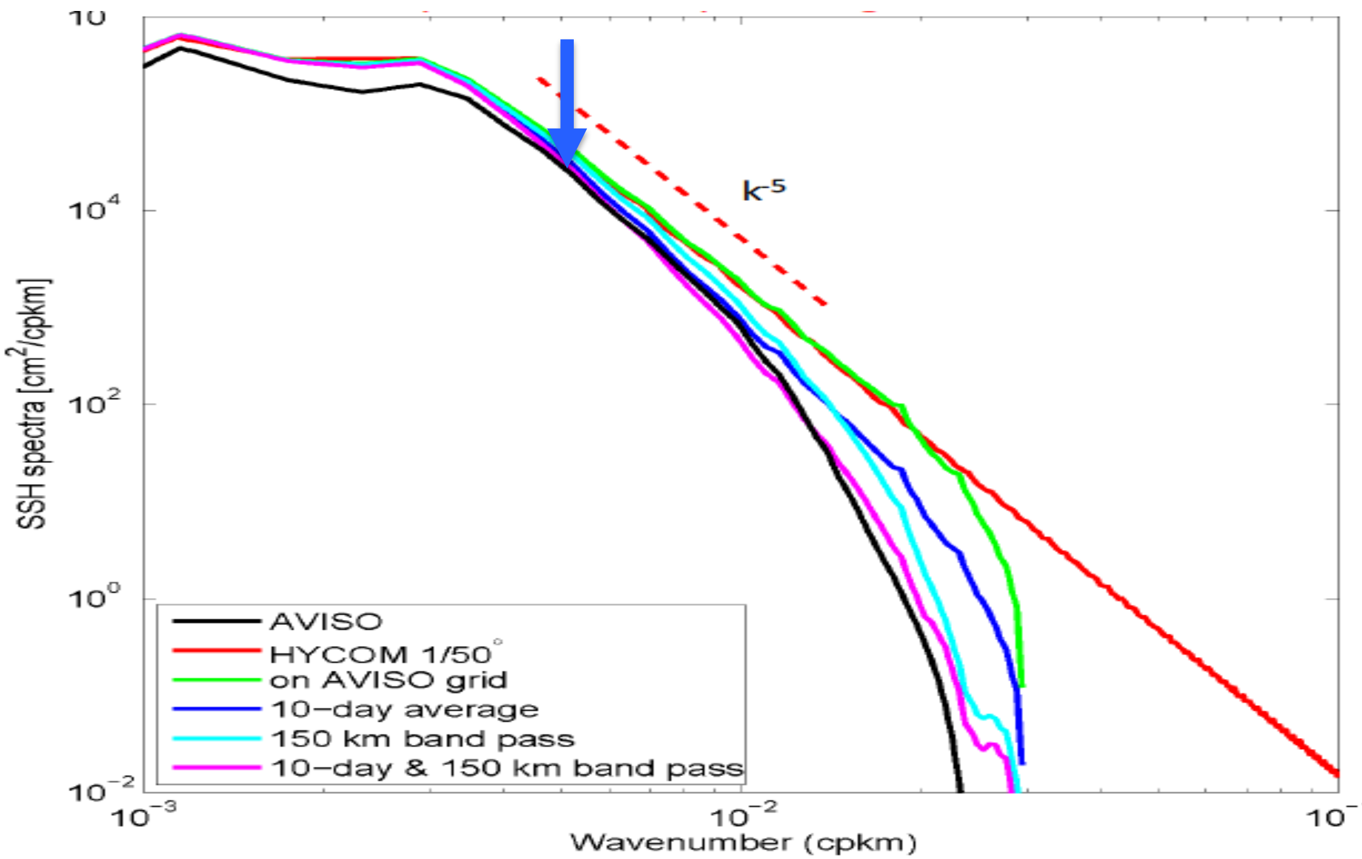


Turbulent geostrophic motions have been considered **so far** to be forced only by the baroclinic instability, **whose scales ,** k_f **(**$\sim 150-200\ km$), **are close to the** $\boldsymbol{\beta}$ **scale,** $k_{\beta,r}$ $(\sim 300\ km)$. In that case, **<u>only a k^{-3} spectrum slope should be observed.</u>**

But HR numerical models point to the limitations of altimeter data …

Their limitations are illustrated …

Satellite altimetry (AVISO:1/3°) only resolves scales larger than 150 km (from E. Chassignet, Ocean Sciences, 2016)



Impact of small scales is totally neglected

Strong underestimation of the inverse KE cascade by satellite altimeter data !

(Arbic JPO'13)

Two-layer QG turbulence model

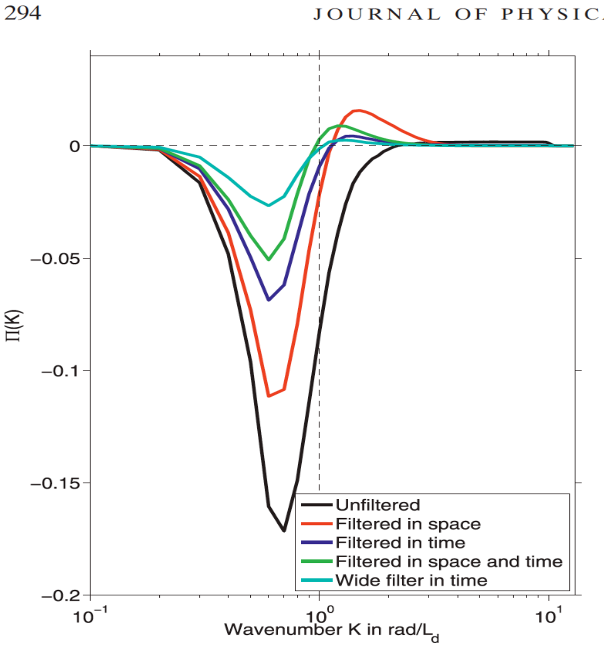
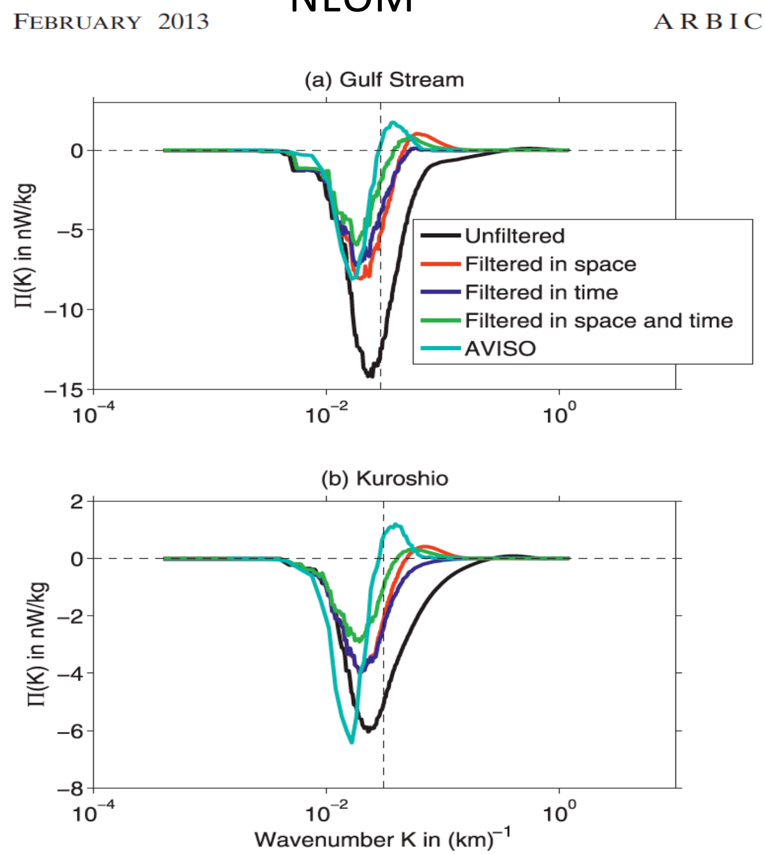


FIG. 6. Spectral flux $\Pi_{KE,1}(K)$ of upper-layer kinetic energy computed from the $\nu = 0$, $F_L = 0.4$ two-layer QG simulation ("unfiltered") and from filtered versions of this simulation. See text for descriptions of filters used. All fluxes normalized by $(\overline{u}_1 - \overline{u}_2)^3/L_d$.

NLOM



Small scales significantly impact the inverse KE cascade

Recent reanalysis of altimeter data also point to some significant departures from the classical geostrophic turbulence

Zhai et al. GRL 2008: **AVISO Jan. 1995 – Dec. 2006:**

<u>Strong seasonality not well understood …</u>

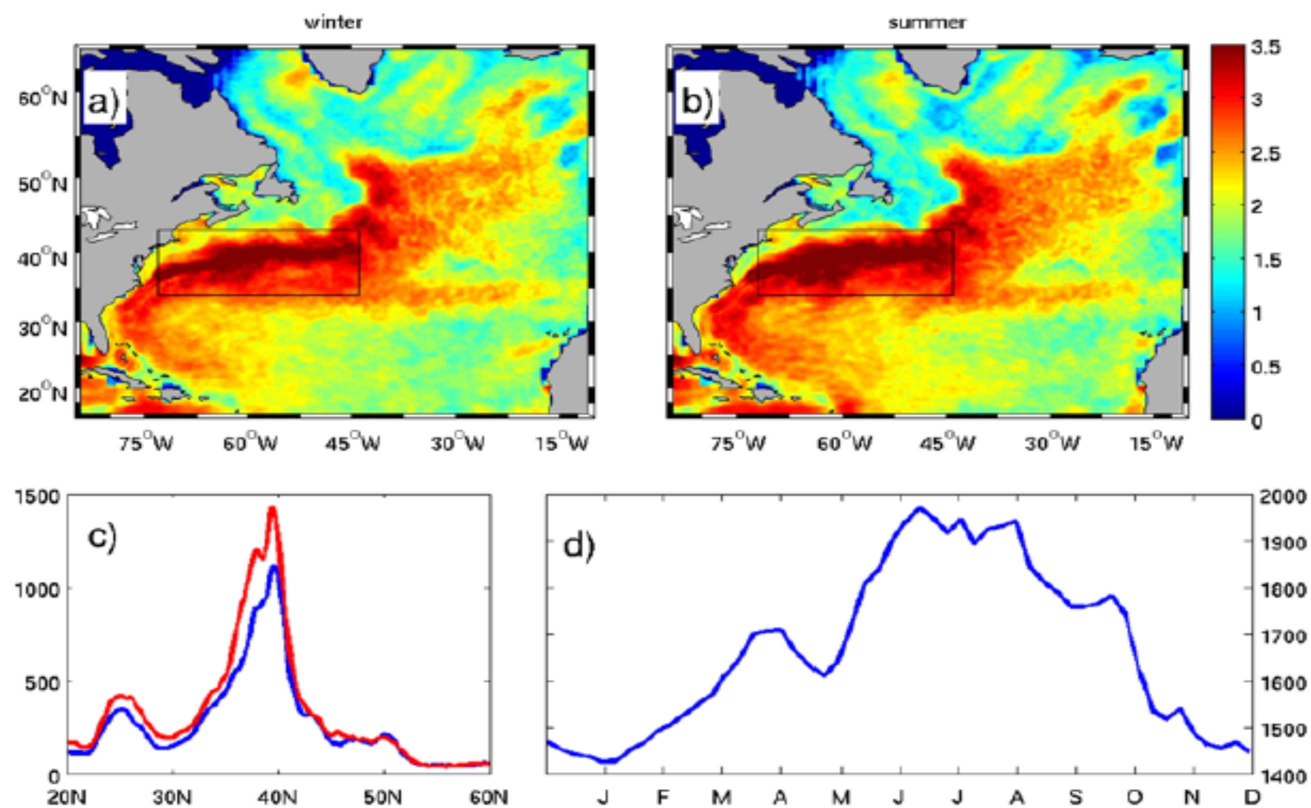


Figure 1. *EKE* averaged over (a) December, January and February and (b) June, July and August plotted on a log scale with base 10. (c) Cross-basin average of *EKE* from (Figure 1a; blue) and (Figure 1b; red) as a function of latitude and (d) seasonal cycle of *EKE* averaged in the rectangular box. Units: $cm^2\ s^{-2}$.

Zhai et al. GRL 2008: AVISO Jan. 1995 – Dec. 2006:

Strong seasonality not understood …

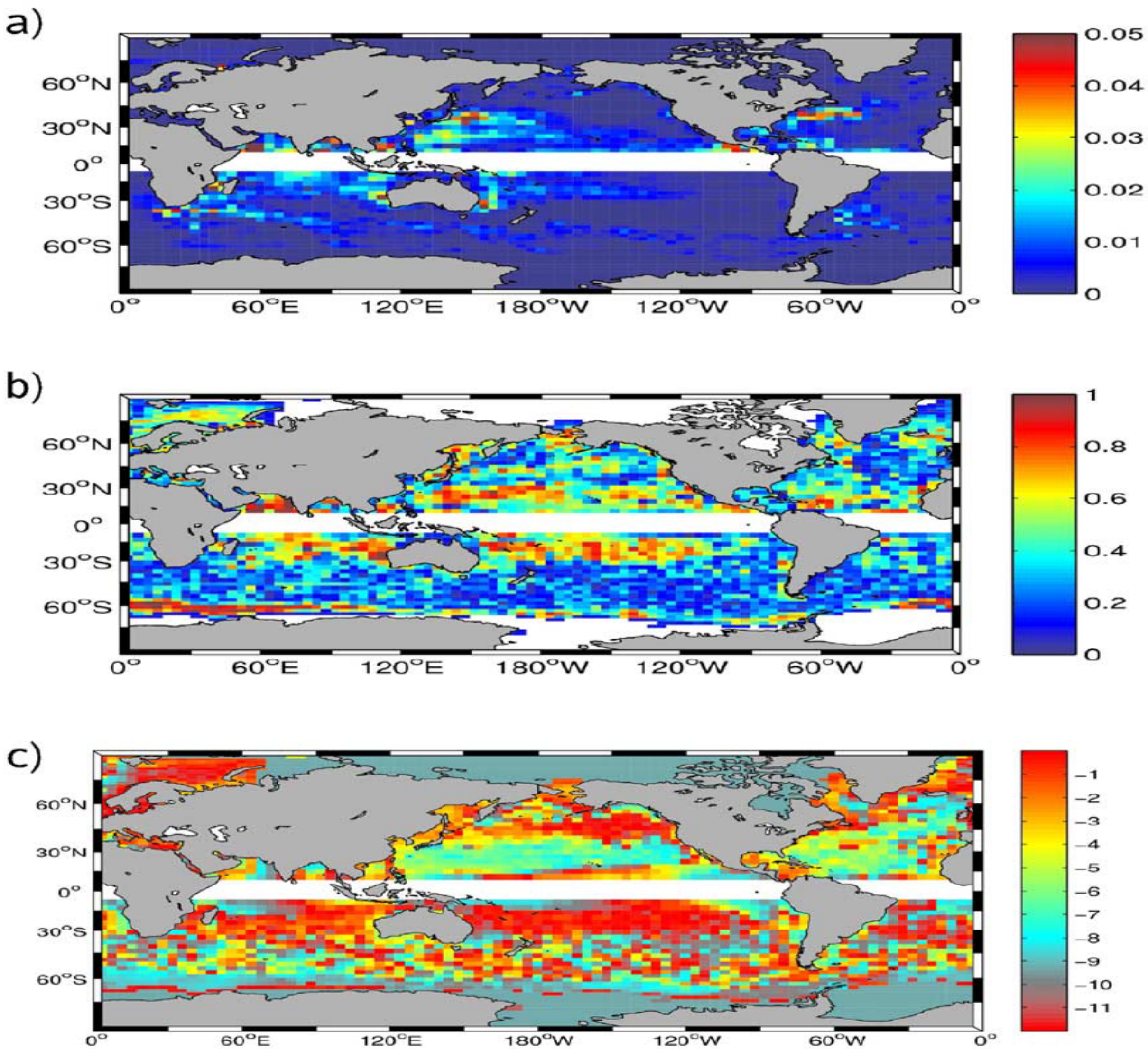


Figure 4. (a) Amplitude of the seasonal cycle of *EKE* in $m^2\ s^{-2}$; (b) amplitude of the seasonal cycle normalized by the total variance; (c) phase of the seasonal cycle relative to January (e.g., −8 means the maximum is in August).

Recent reanalysis of altimeter data also point to some significant departures from the classical geostrophic turbulence: **spectral slope differ from k^{-3} (k^{-5} for SSH)**

Yongsen Xu and Lee L. Fu JPO 2012: SSH spectrum slope from Jason 1

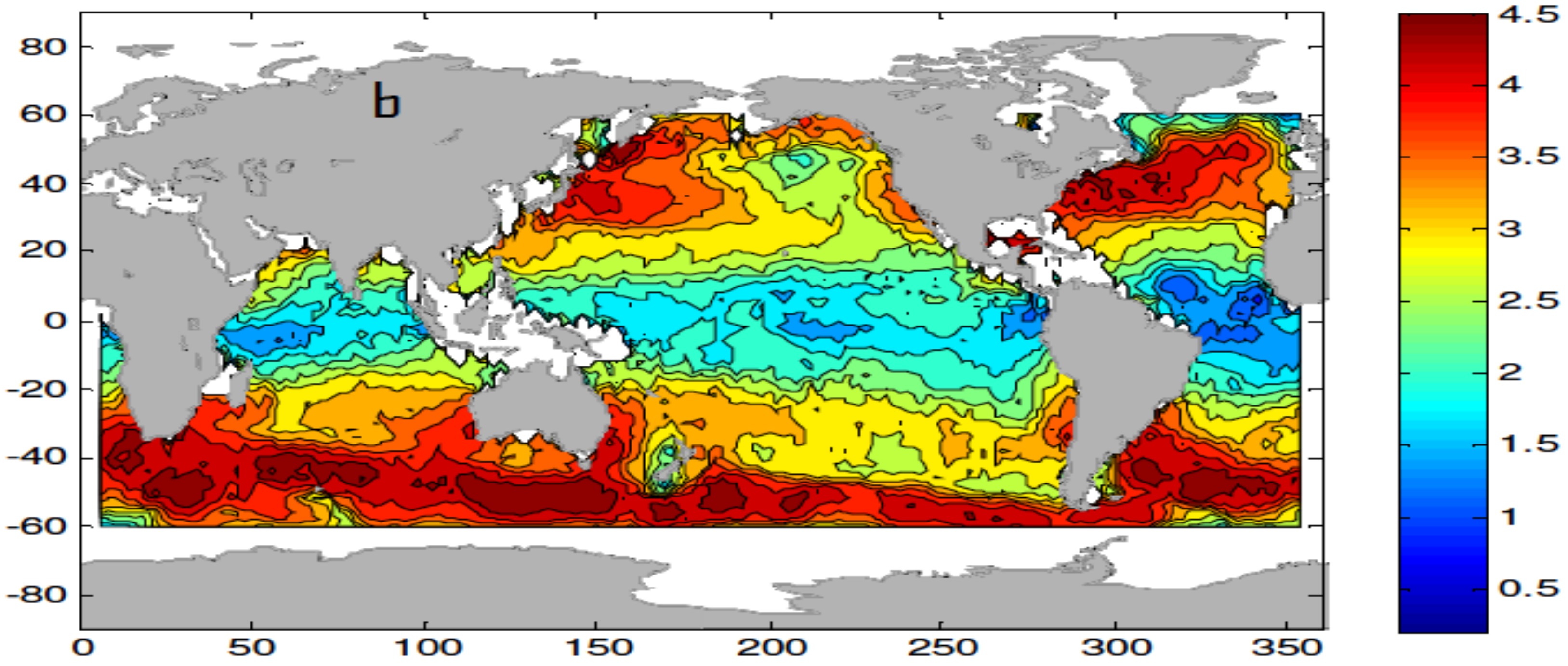
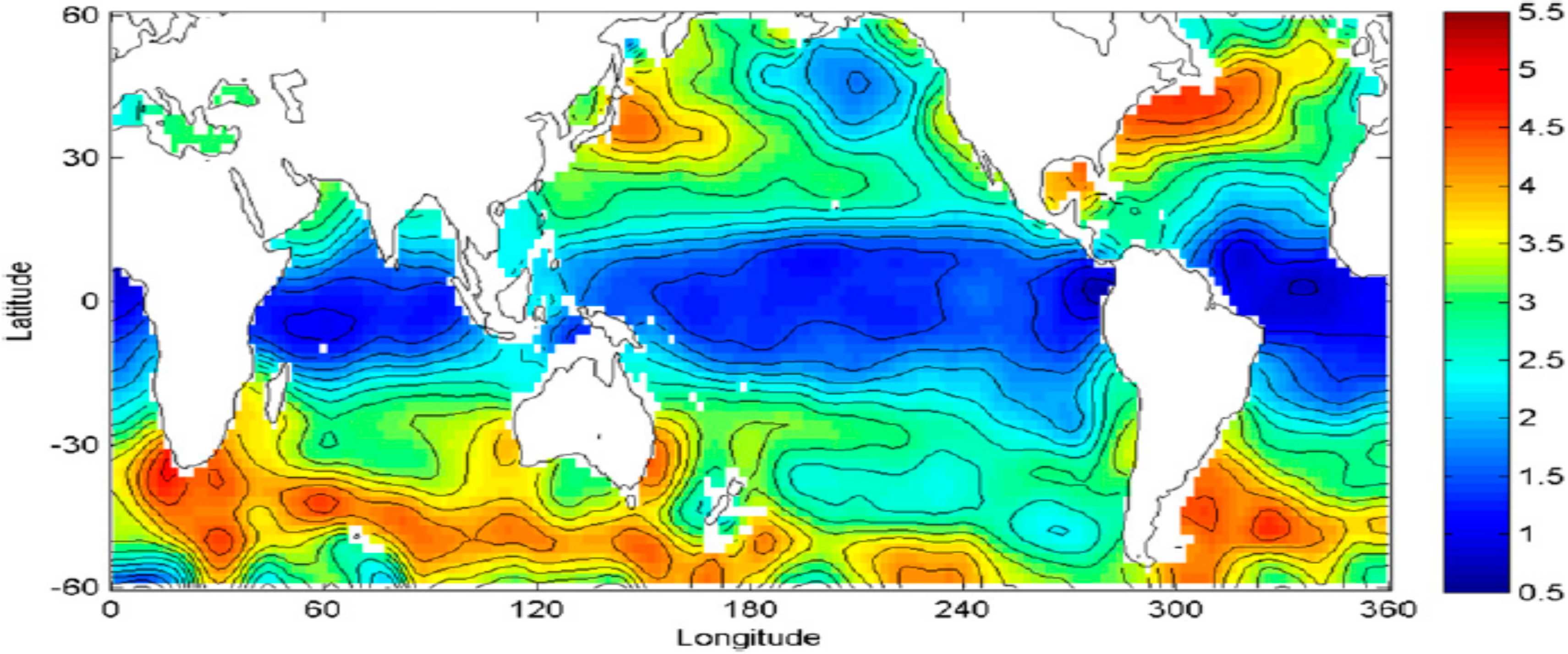


Fig. 3. The global distribution of the spectral slopes of SSH wavenumber spectrum in the wavelength band of 70–250 km estimated from the Jason-1 altimeter

These results do not indicate the existence of a universal wavenumber spectrum and therefore of a universal dynamical regime in the world ocean

Recent reanalysis of altimeter data also point to some significant departures from the classical geostrophic turbulence: **spectral slope differ from k^{-3} (k^{-5} for SSH)**

Zhou et al.JPO 2015: SSH spectrum slope from Topex/Poseidon (1992-2002)

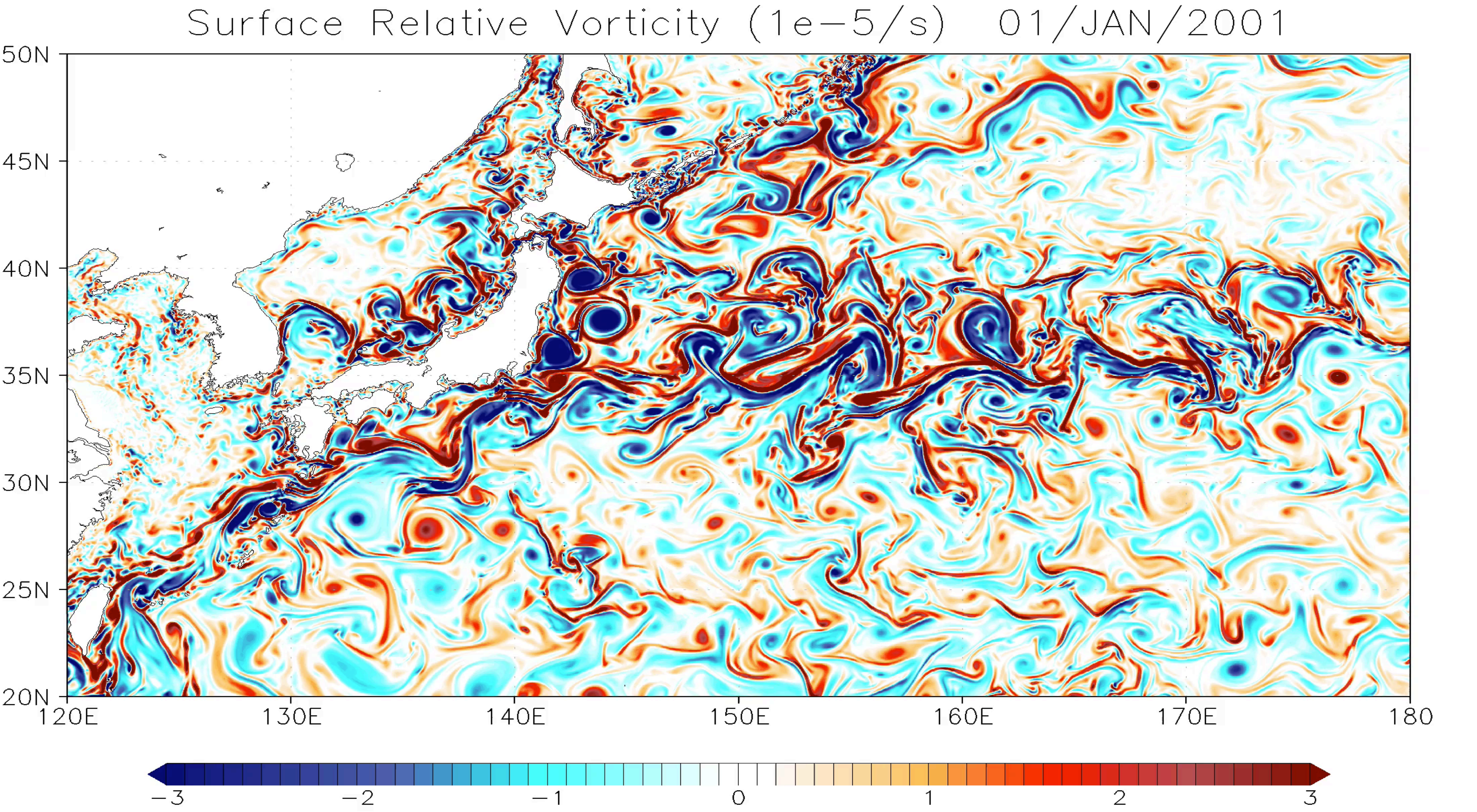


These results do not indicate the existence of a universal wavenumber spectrum and therefore of a universal dynamical regime in the world ocean.

Recent reanalysis of altimeter data also point to some significant departures from the classical geostrophic turbulence

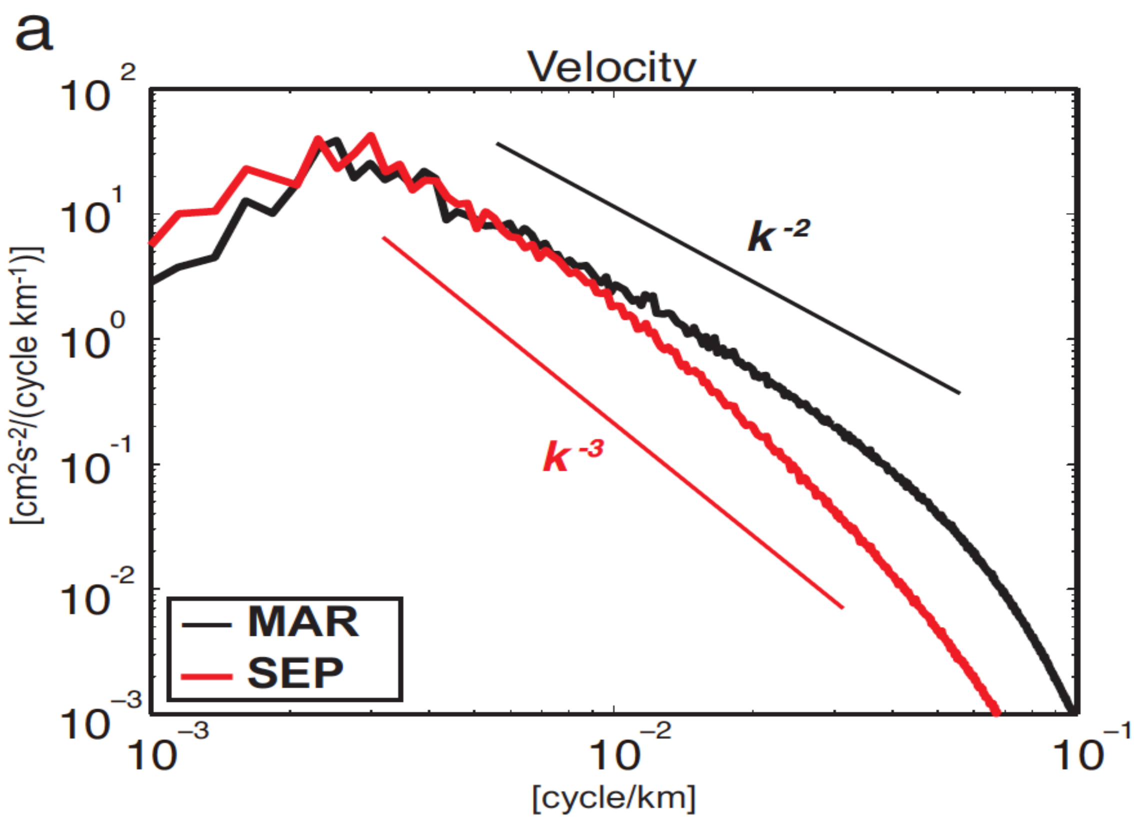
HR numerical models have recently highlighted the importance of small scales (not resolved by conventional altimetry) on larger scales

Strong seasonality of the submesoscales (10 -20 km) illustrated by the RV field that involves **smaller scales and larger amplitudes** in Jan.-March



<u>Velocity spectra in march and september:</u>

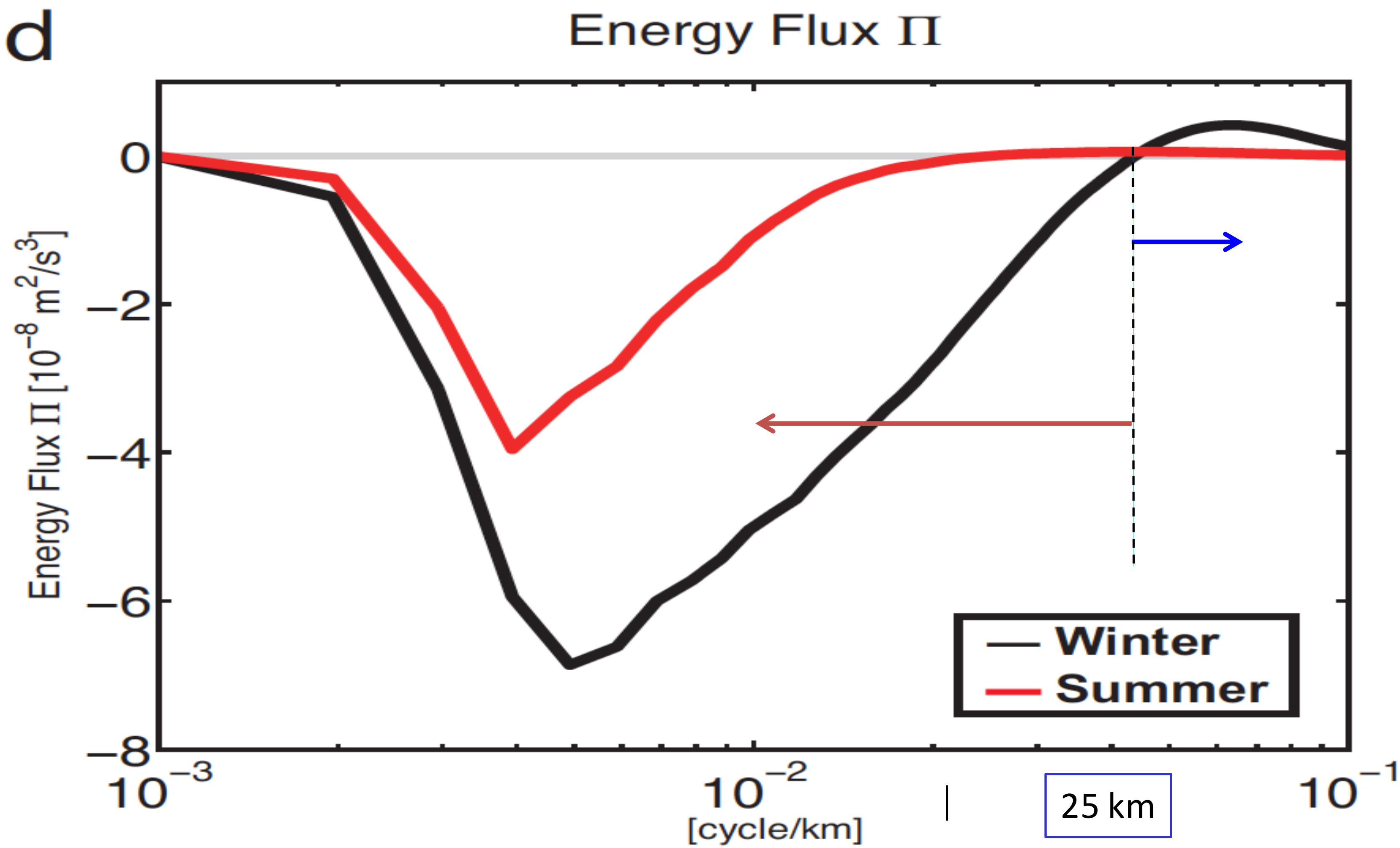
shallower in march (k^{-2}) because of the energetic MLIs



An illustration of the inverse KE cascade …

Impact of MLIs on larger scales: spectral kinetic energy flux, $\pi(k)$

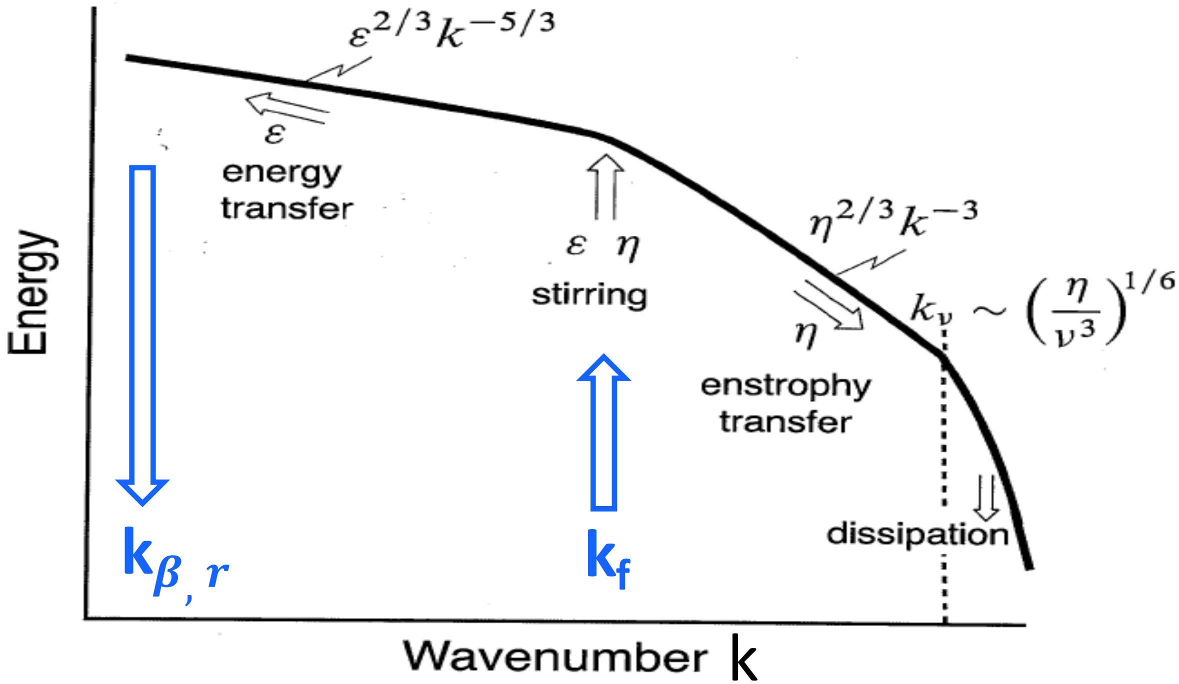
$\Rightarrow$ **Inverse KE cascade is extended to scales as small as 25 km in winter!**



Coming back to some classical properties of …

Geostrophic turbulence (analogue to 2-D turbulence)

[see next class]



Extension of the inverse cascade (k$^{-5/3}$ spectrum slope) depends on whether the forcing scale, k_f (source of KE) is close or not to the β scale. $k_{\beta,r}$ **(removal of KE)**

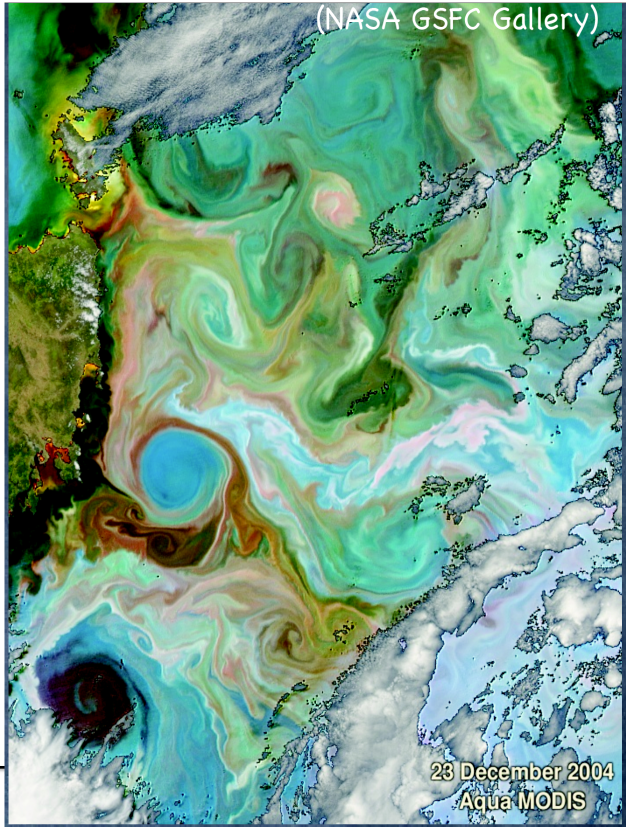
A careful analysis of the velocity (ssh) spectrum slope should help to be understand the impact of small scales on larger ones.

Results from satellite altimeter data indicate the existence of several dynamical regimes in the world ocean depending on the region and on the season.

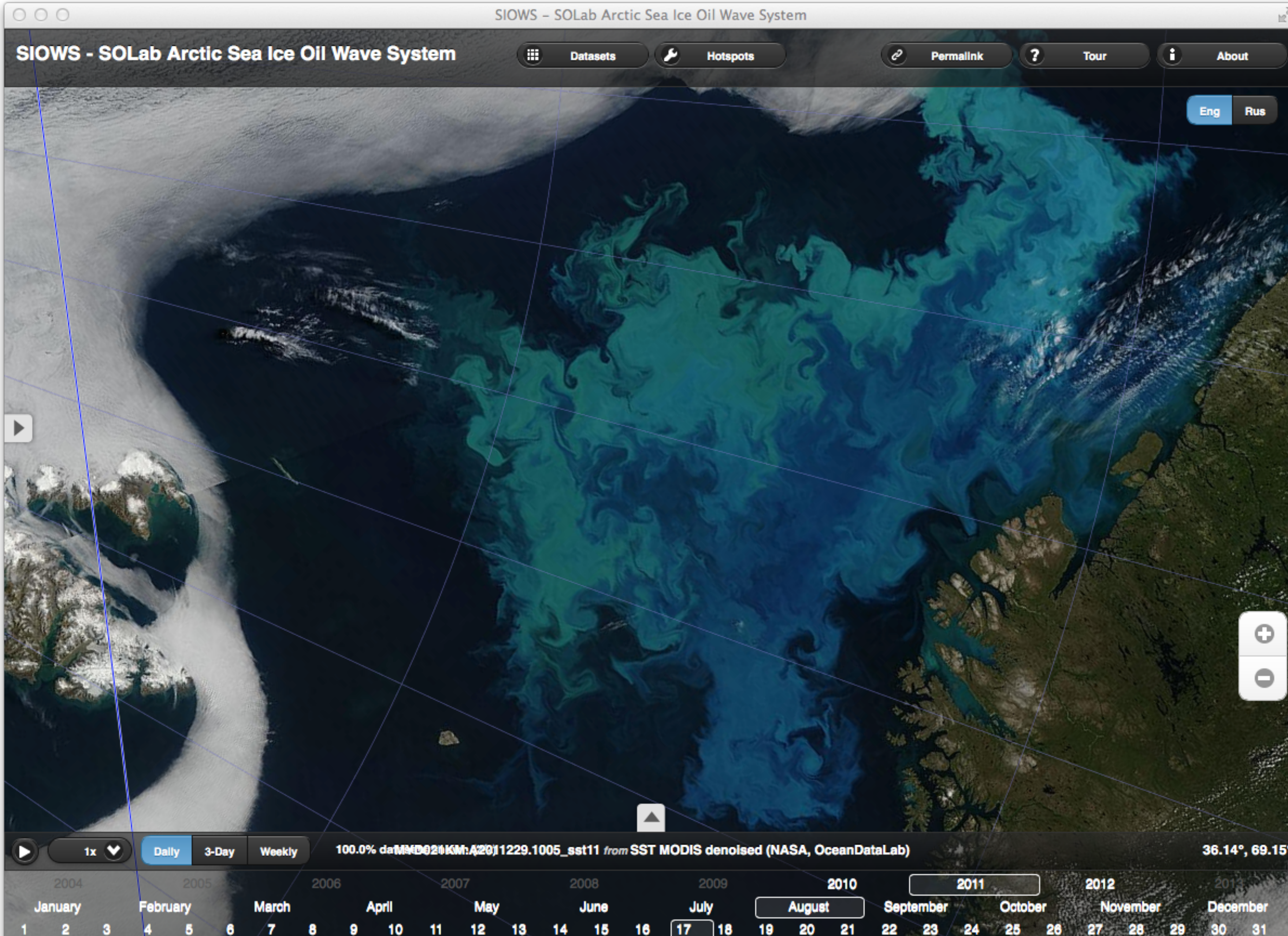
Identification of these dynamical regimes can be done through the interpretation of th spectral properties of SSH (or velocity) in terms of :

3D-QG (2D) and SQG turbulence [see next class]

High resolution satellite images, such as SST and ocean color images, reveal not only mesoscale eddies (200km) but also a large number of smaller scales (1 km-50 km)



<u>The strong correspondance between these images</u> suggest both fields are stirred by mesoscale eddies and, consequently, behave **as tracers driven by a direct cascade.**


SIOWS – SOLab Arctic Sea Ice Oil Wave System
SIOWS - SOLab Arctic Sea Ice Oil Wave System
Datasets
Hotspots
Permalink
Tour
About
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Rus
1x
Daily
3-Day
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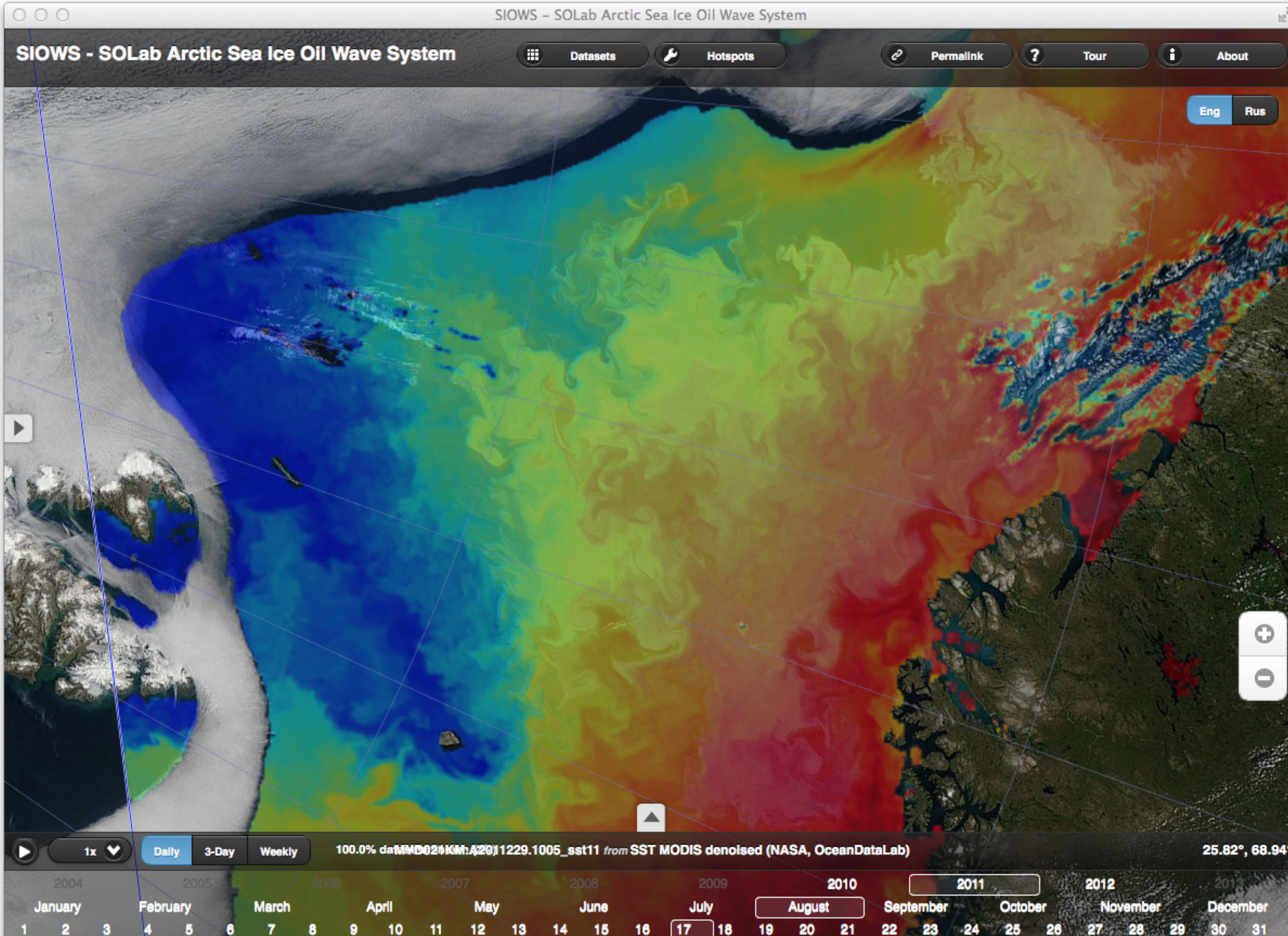
100.0% data MMD021KM.A2011229.1005_sst11 from SST MODIS denoised (NASA, OceanDataLab)
36.14°, 69.15°
2004 2005 2006 2007 2008 2009 2010 2011 2012
January February March April May June July August September October November December
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31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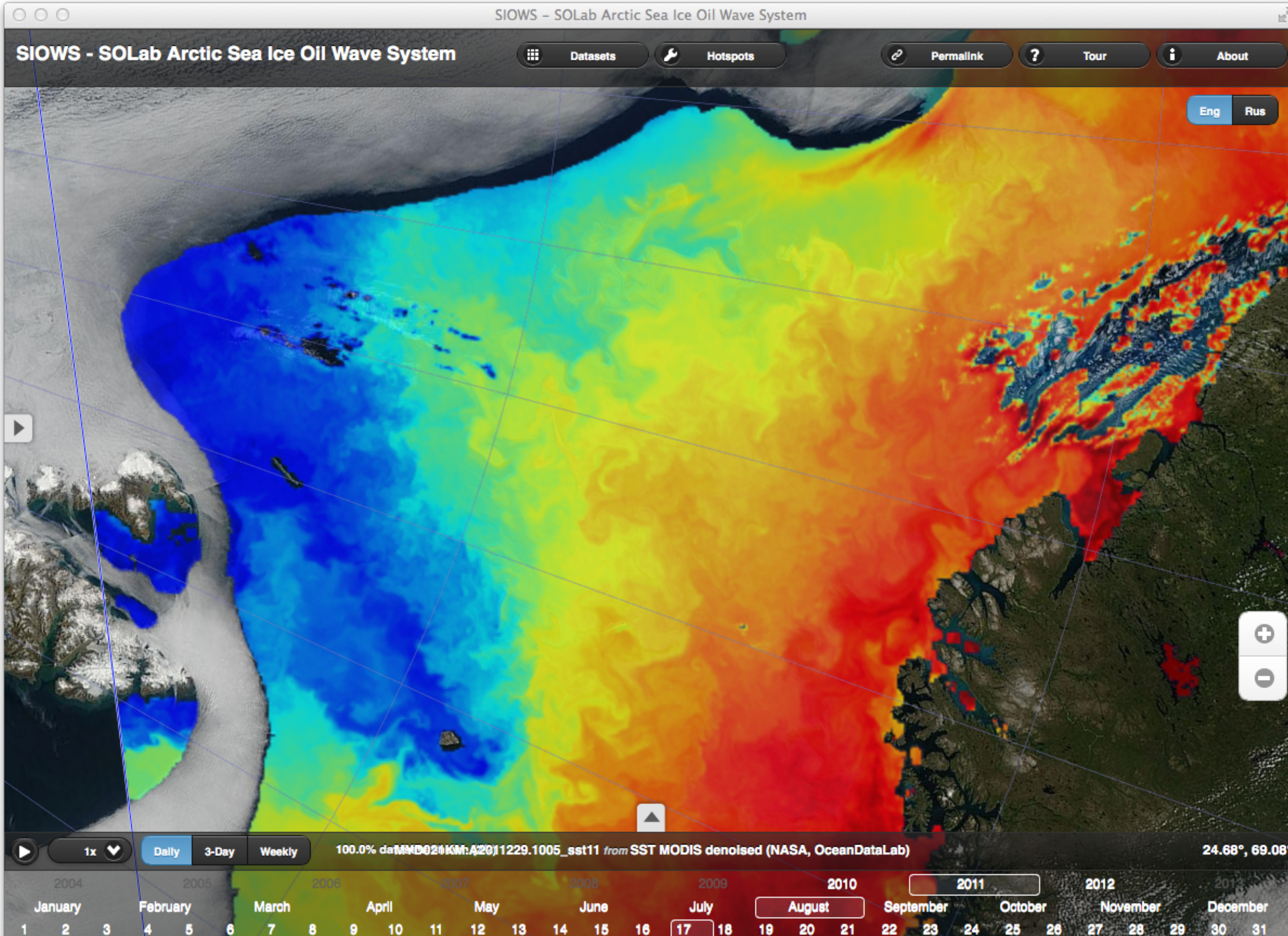
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24.68°, 69.08°
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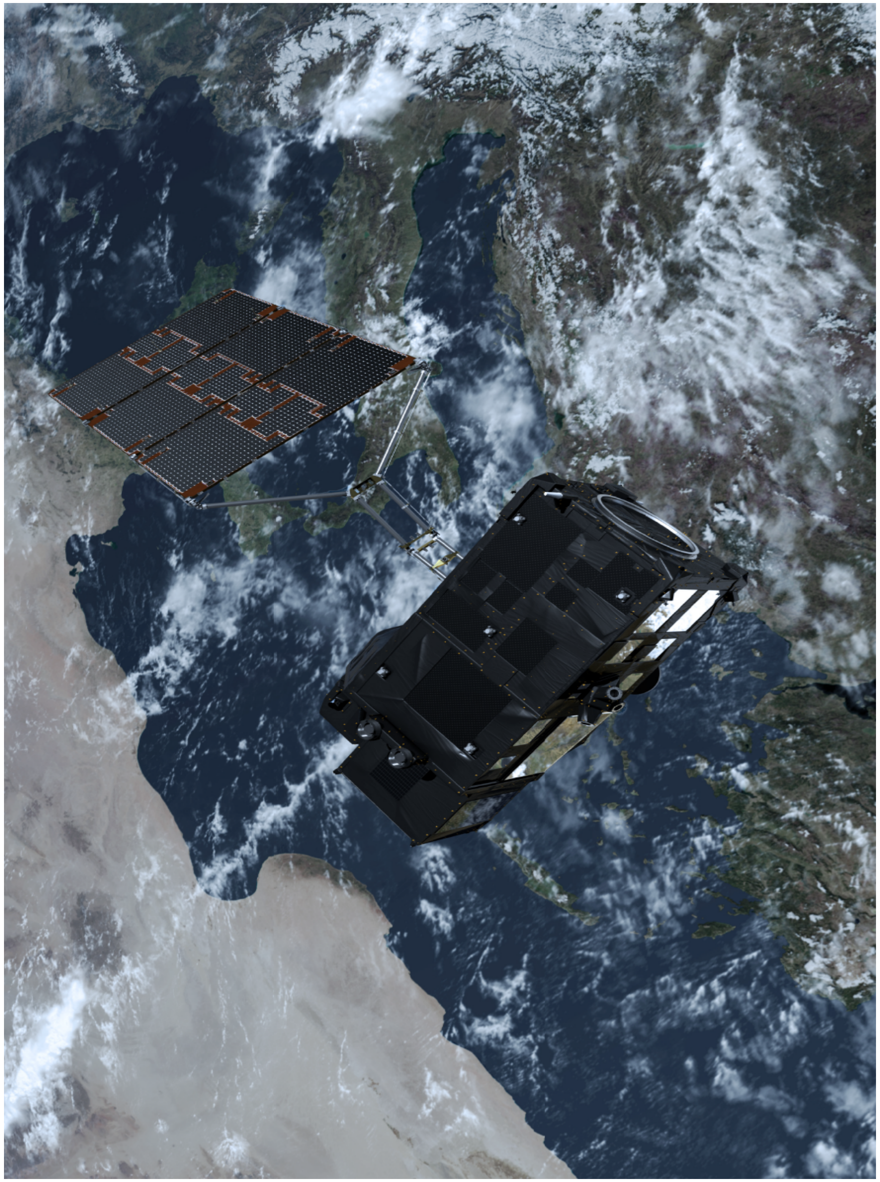
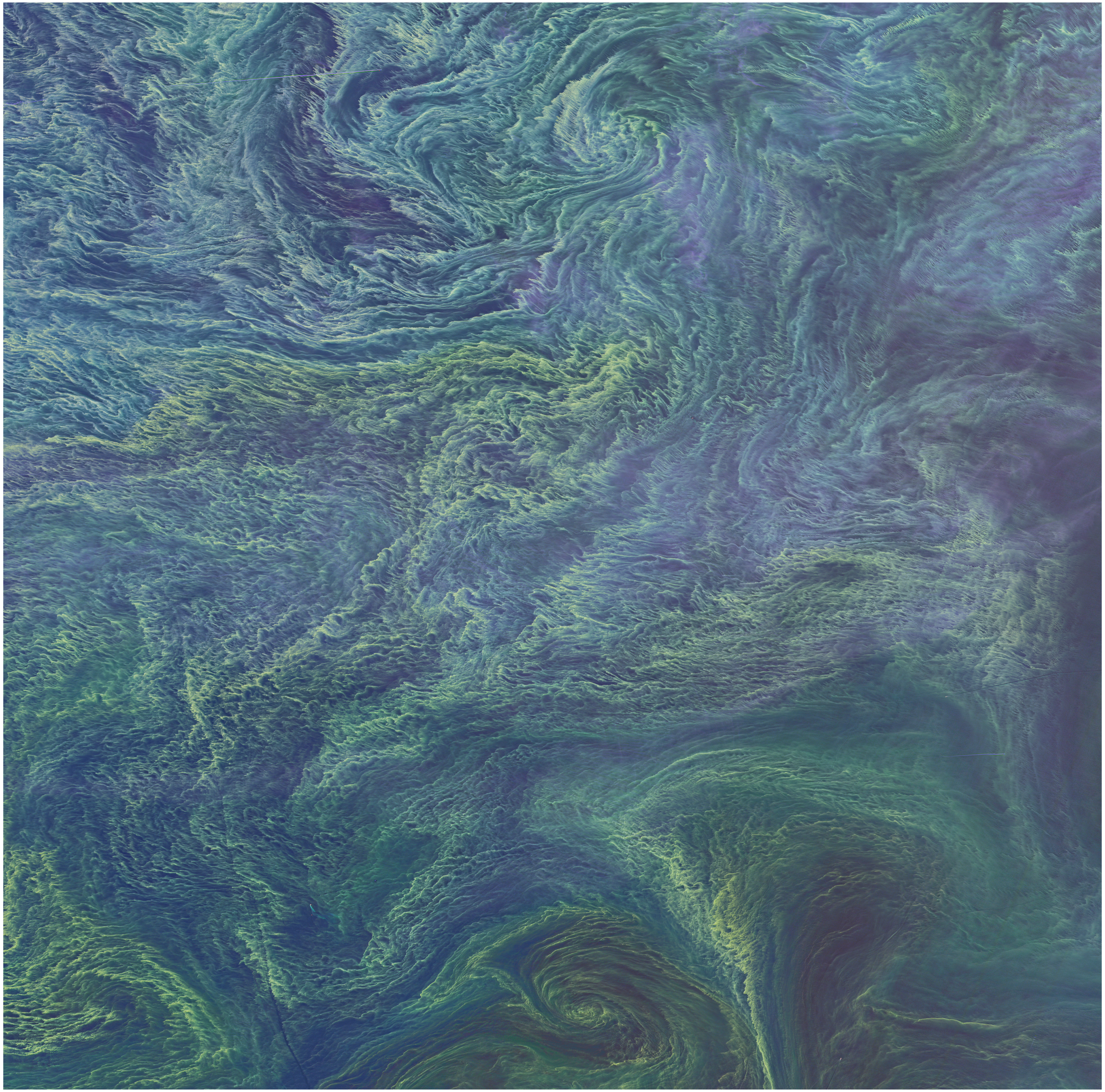
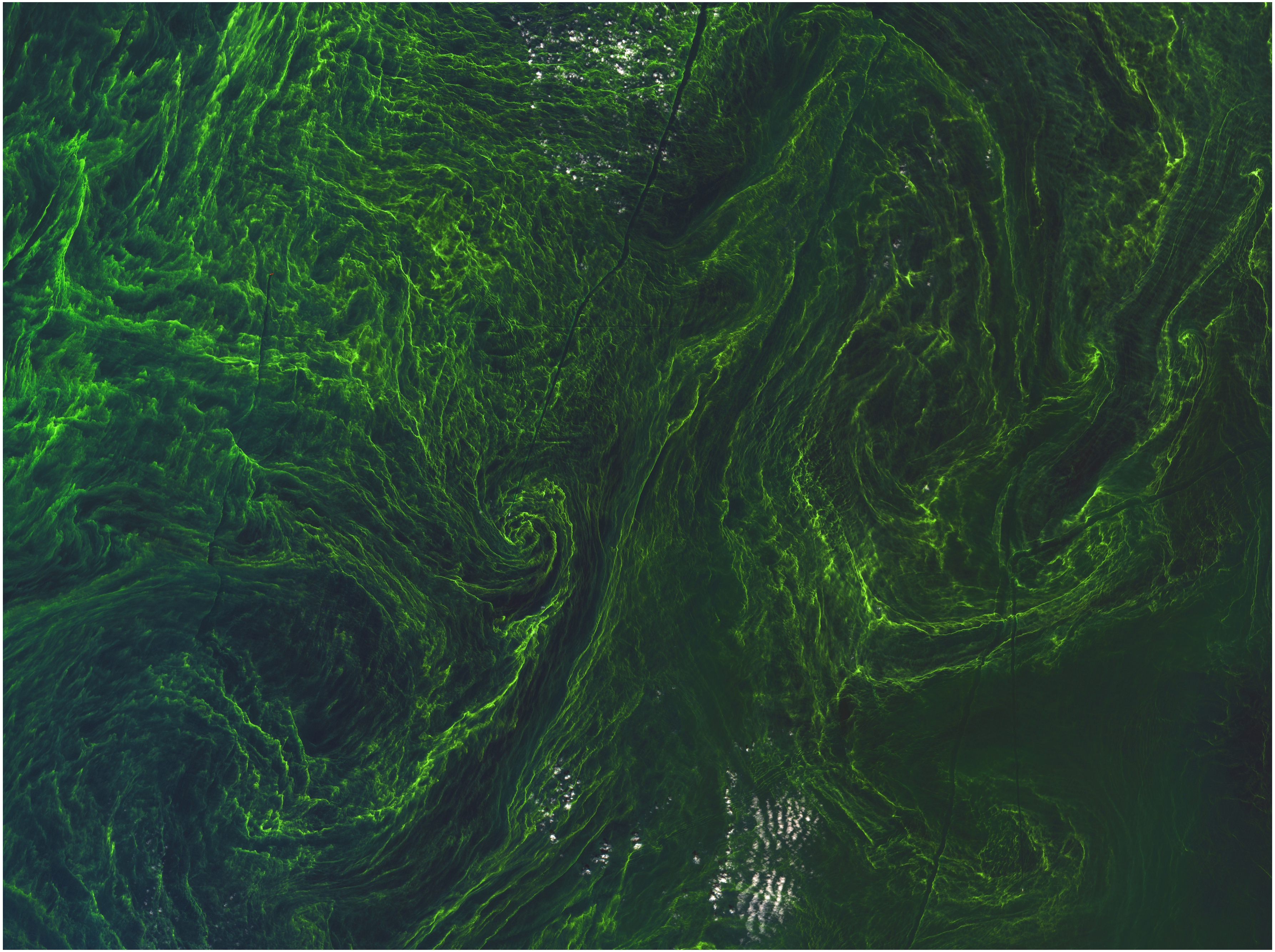
The strong correspondance between these images suggest both these fields are stirred by mesoscale eddies and, consequently, behave **as tracers driven by a direct cascade.**

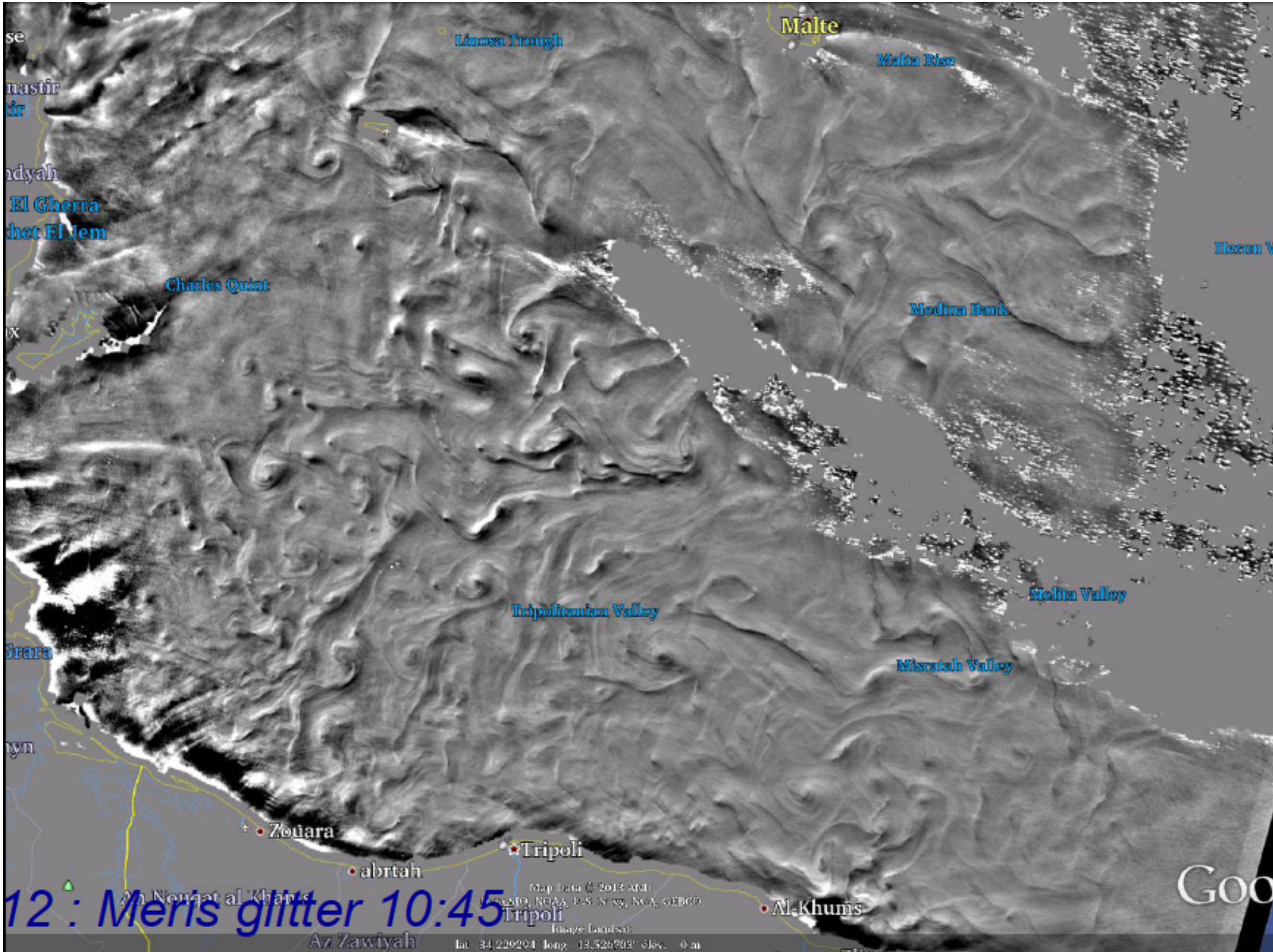


Optical imagery with a resolution of 10 m ! from Sentinel 2A mission





A similar correspondance exists between these SST and OC images and SAR images as well as GLITTER images


Malte
Linosa Trough
Malta Rise
El Gherra
Charles Quint
Medina Bank
Tripolitanian Valley
Melita Valley
Misratah Valley
Zouara
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abrtah
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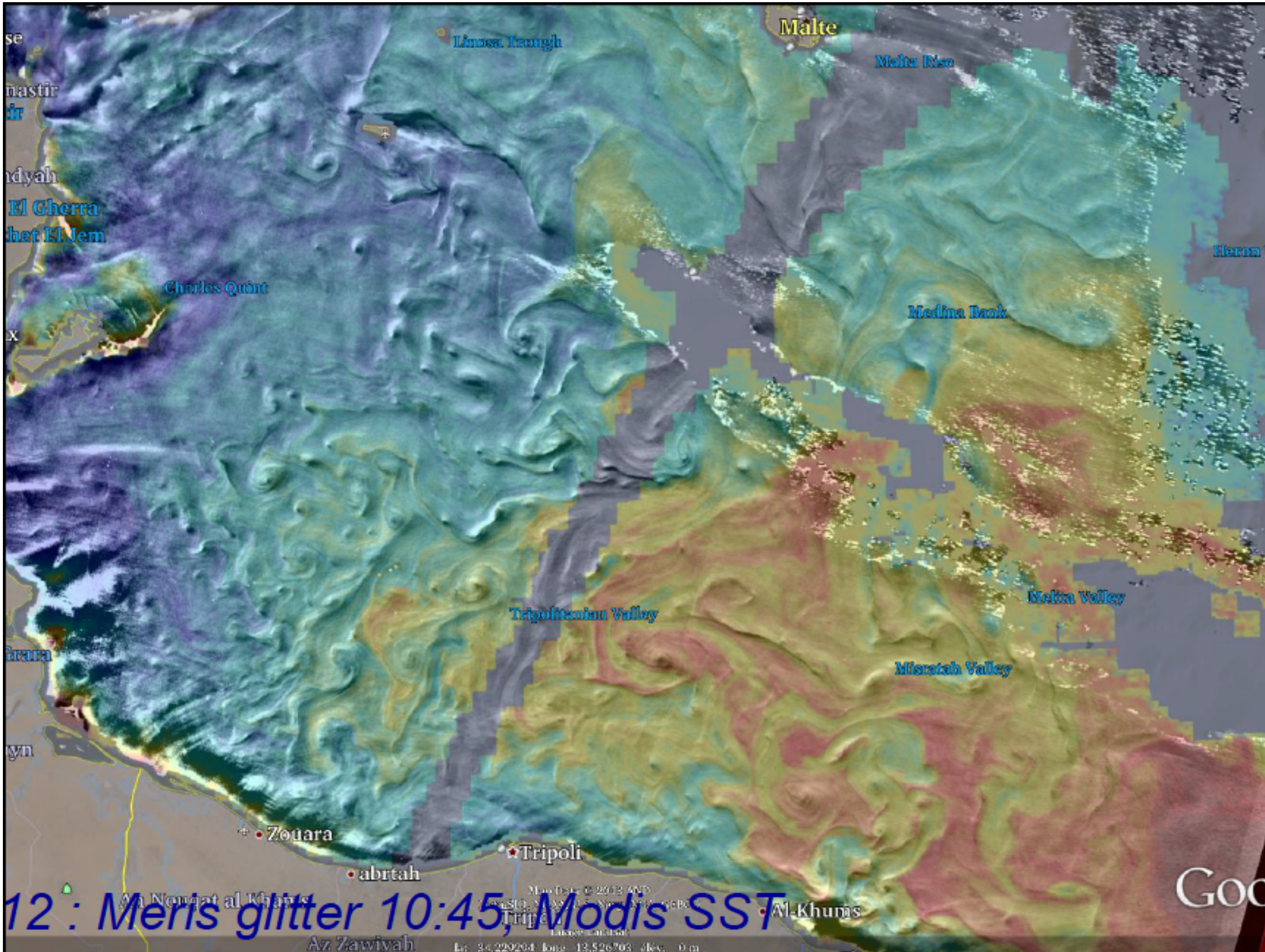
Az Zawiyah
12 : Meris glitter 10:45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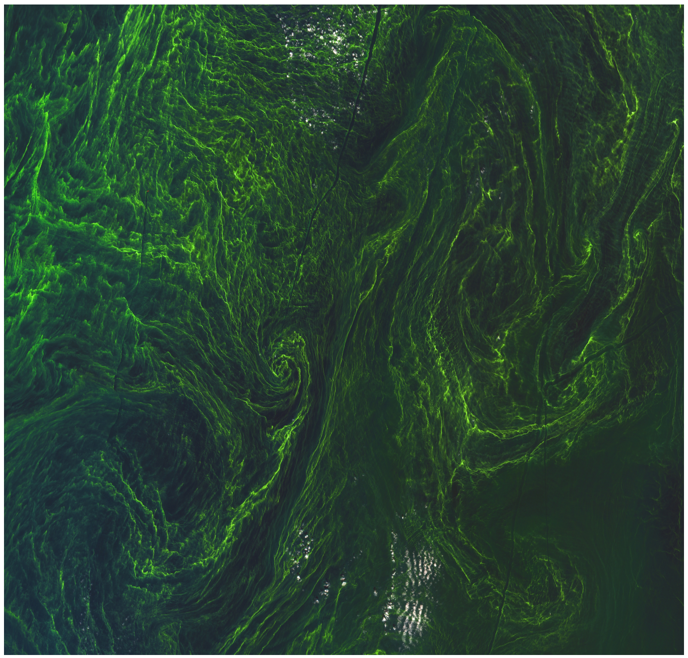
Al-Khums
Az Zawiyah
12 : Meris glitter 10:45, Modis SST

Sentinel 2A



10 km

From Munk et al. (2000)

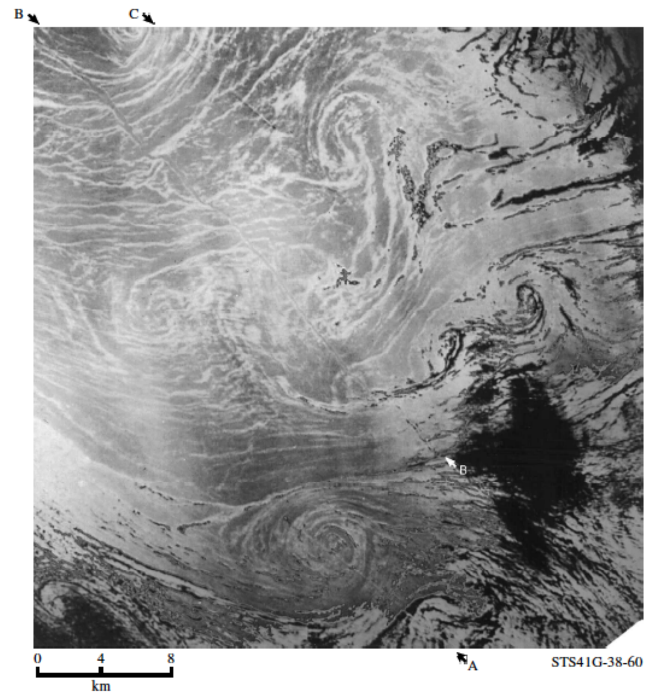


Figure 7. Ship tracks in the Ionian Sea. Tracks A and C are young with the ships visible. Track A shows minor distortion during passage through the developing core, the centre of which is *ca.* 3 km aft of the ship. Ship track B is old and shows significant offsets at cyclonic sharp fronts coincident with streaks. The rendition of the streaks changes from light in the inner sunglitter to the upper left, to dark in the outer sunglitter in the lower and right hand portion of the image.

If SST and OC are **tracers driven by mesoscale and submesoscale eddies**, they should have spectral properties close to those expected from **3DQG (or 2D) or SQG turbulence**

What are these spectral properties => see next class