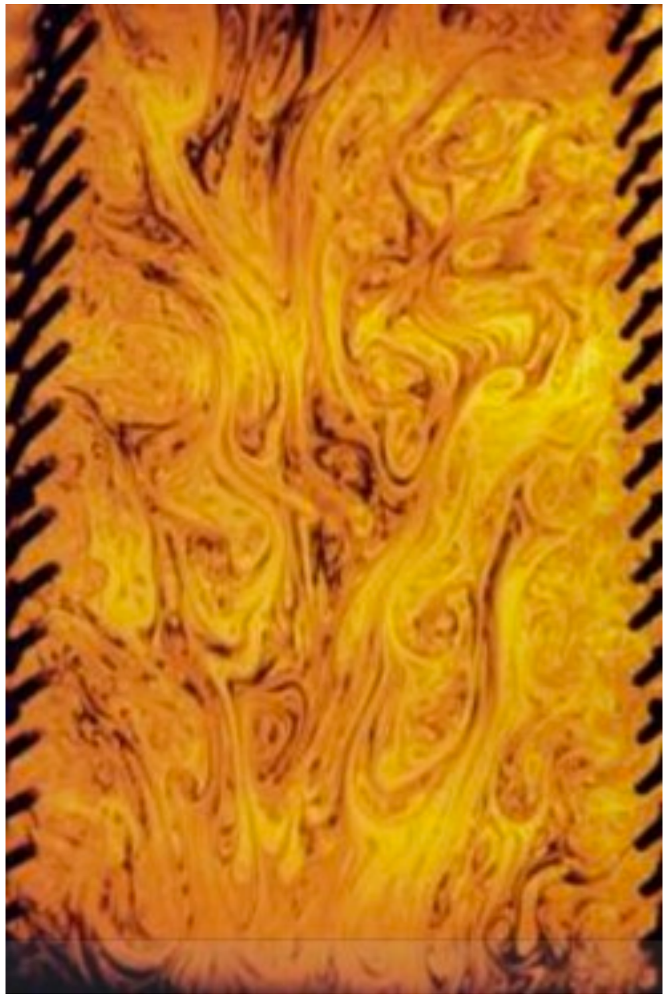
Ocean turbulence and mesoscale eddies

X. Capet, L. Hua

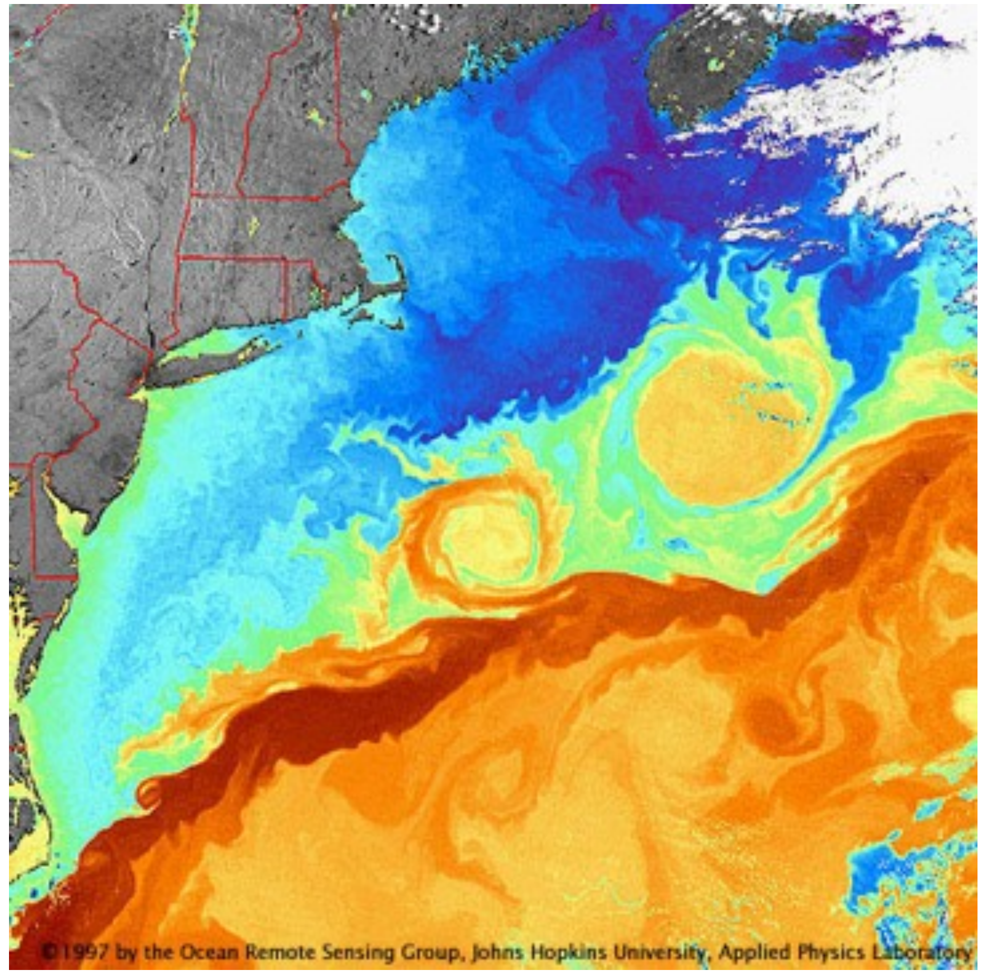
Winter 2011

Emploi du temps et emails annoncant seminaires.
Notes

Motivations



2D turbulence in a soap film,
Ward-Close et al.



SST off Eastern U.S.

define mesoscale (related to Rd)

there is no general theory of turbulence.

show movies if possible

rotation, stratification

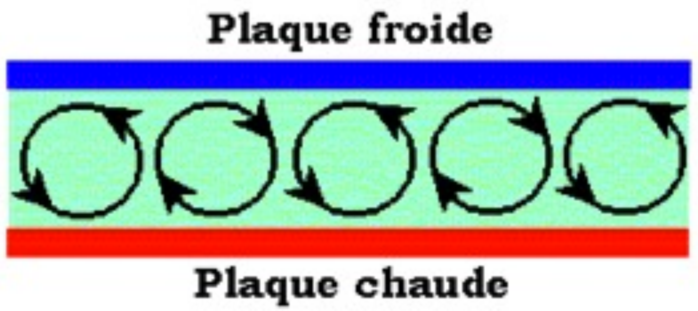
Rayleigh-Benard flow

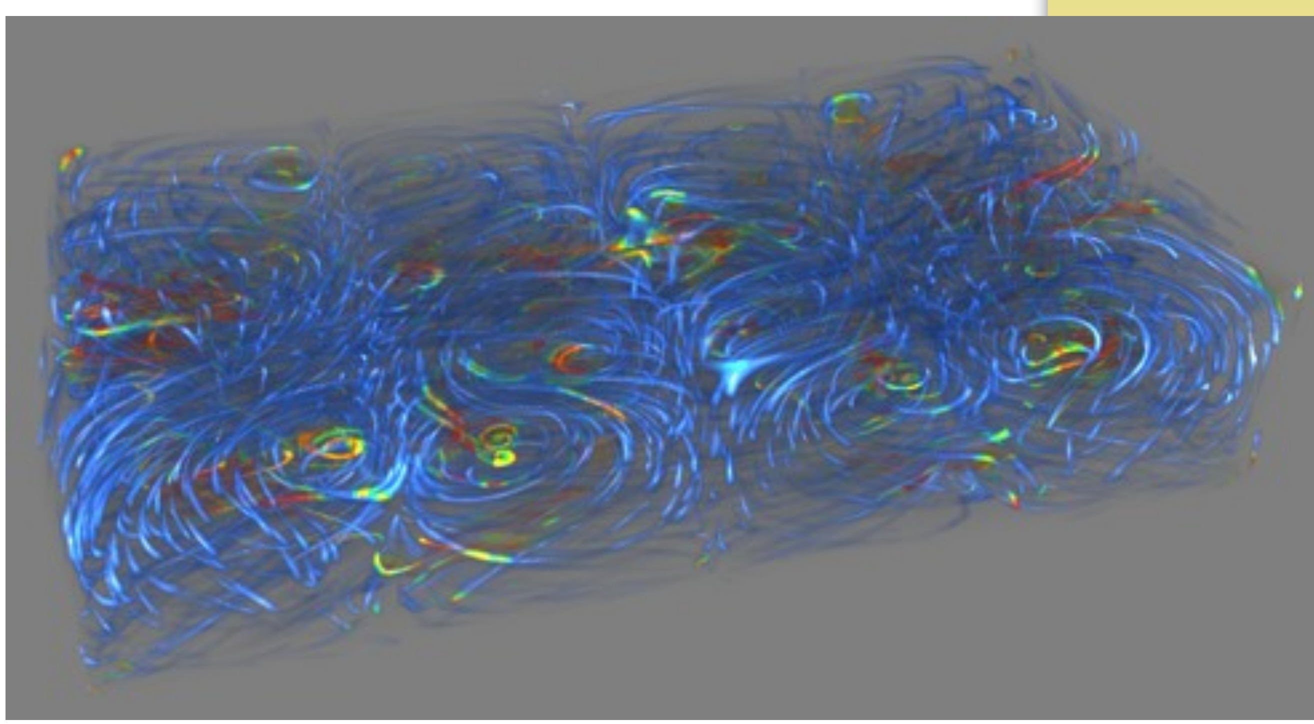
- **Why do we care about ocean turbulence ?**
- **What is mesoscale ?**
- **Why study ocean turbulence and mesoscale eddies in the same course ?**
- **What is ocean turbulence and how does it differ from classical 3D turbulence ?**

Motivations

Why do we care about ocean turbulence ?
Eddy fluxes that is correlations between fluctuations of different (or not) quantities.

Ex I Rayleigh Benard (heat flux between two plates)
correlations between w and T

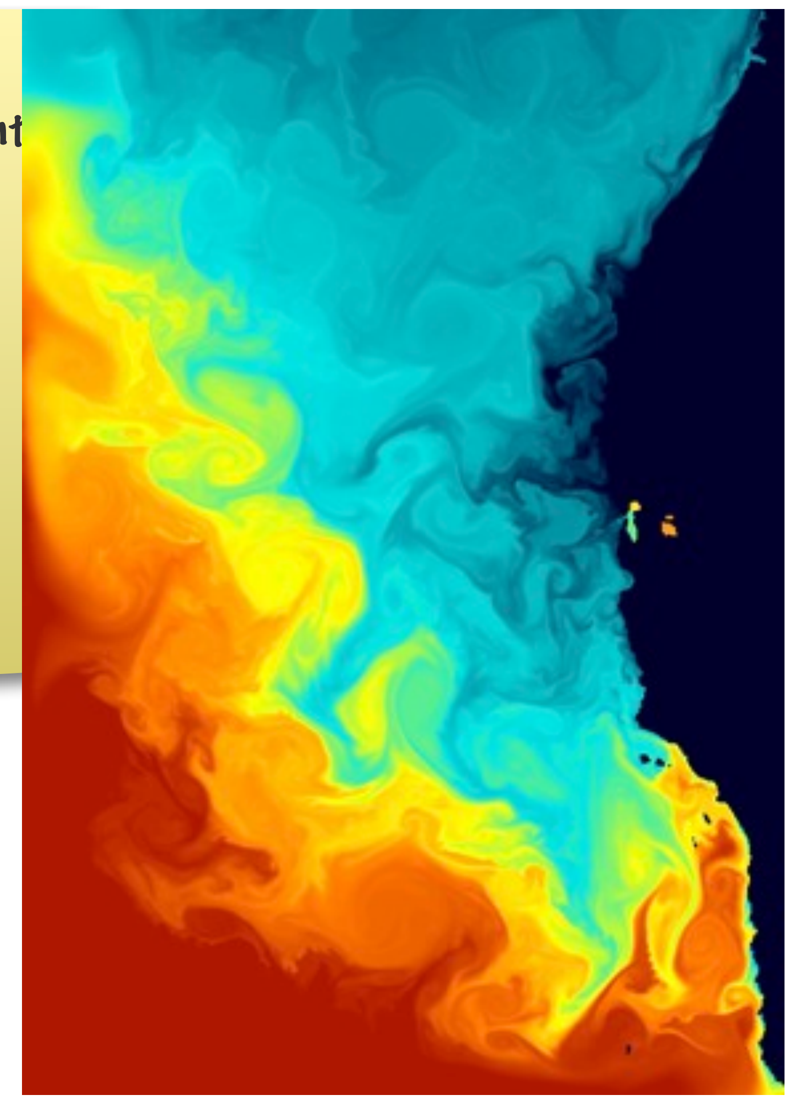




Ex II Ocean heat flux in eastern boundary systems
correlations between (u,v) and T

insist on the notion of turbulent correlation

there is no general theory of turbulence.



- Introduction - Phenomenology
- Theory elements useful to understand the presence of ocean turbulence (the early stages and generation of ocean turbulence - instability/ growth of structures)
- Theory elements useful to undertand the functioning of ocean turbulence:
  - building blocks (isolated mesoscale coherent eddies, fronts)
  - statistical description of fully developed turbulence and its effect on the "mean" flow

different approximations of the fundamental approximations are possible when developing theoretical insight

pas de regle generale mais souvent plus utile sur le long terme d'avoir bien compris et de s'etre convaincu de certaines notions (comme par ex celles de correlations turbulentes) plutot que de connaitre toutes les equations du probleme

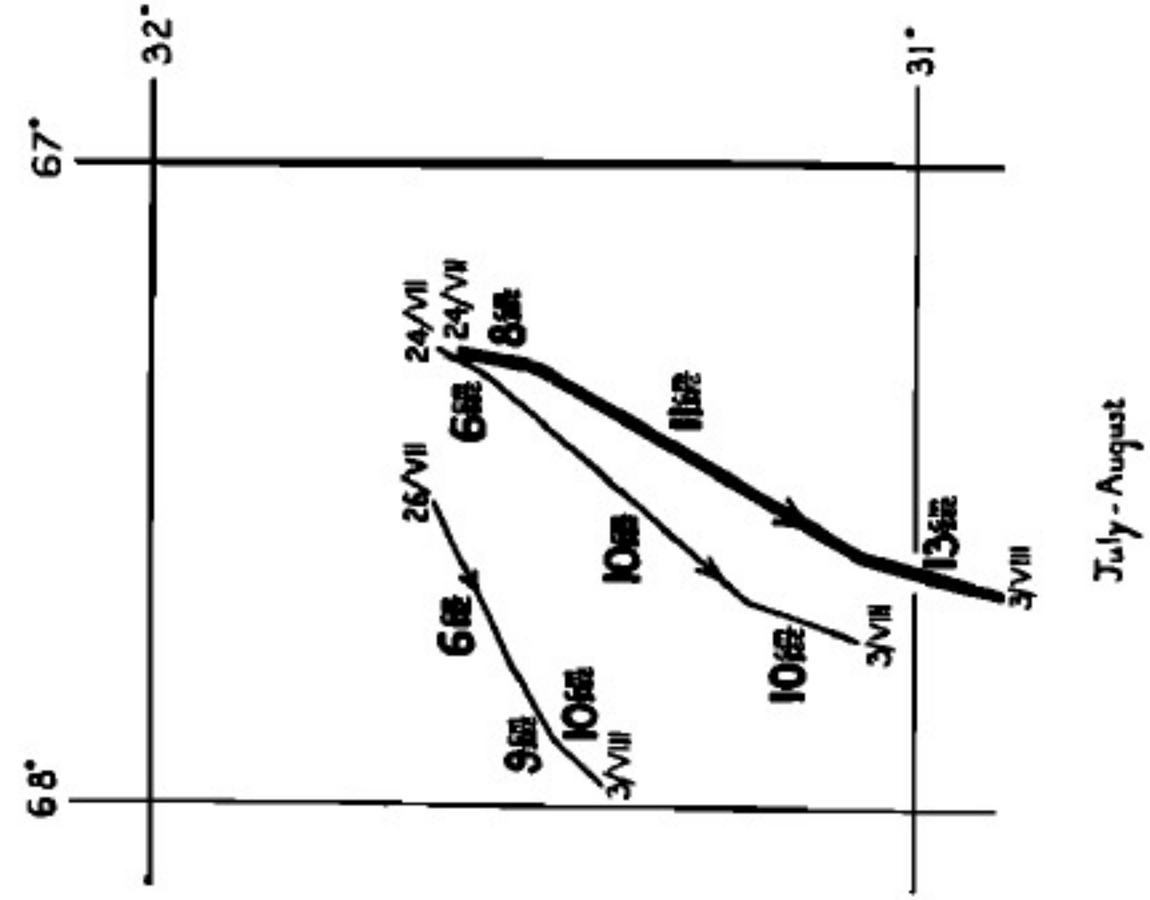
All of these are ways/tools to (try to) understand and describe something that is fundamentally very complex and cannot be grasped in its entirety by the human's mind. Some of these tools may seem more telling to you than others.

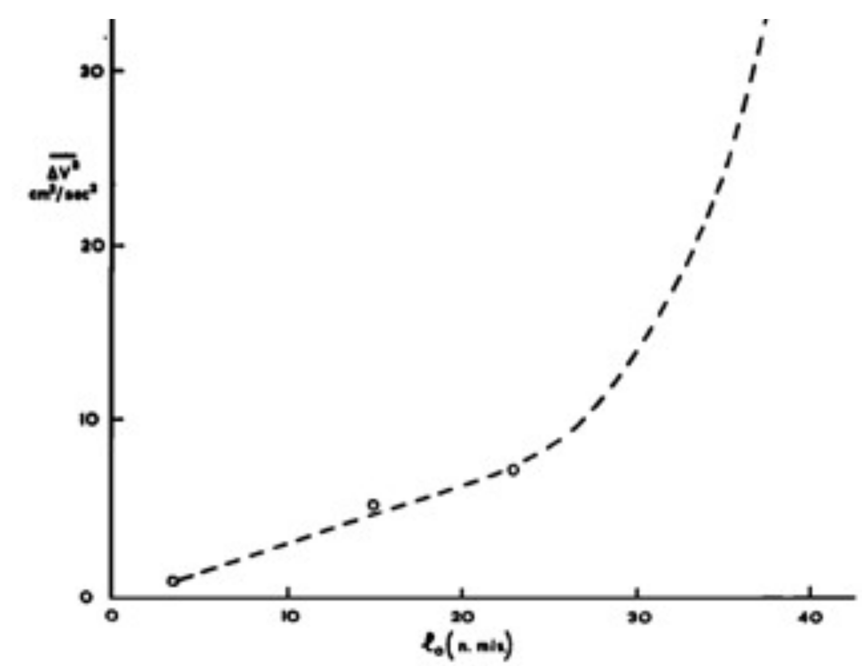
Discovery of mesoscale turbulence

Evidences of subinertial eddy activity accumulate:

- Swallow, J.C. (1958-1960, Bermuda)
- Poligon 67 (Arabian sea)
- Poligon 70 (equatorial Atlantic)
- Mode (1973, Sargasso sea)
- Polymode (1977-1978, Sargasso sea)

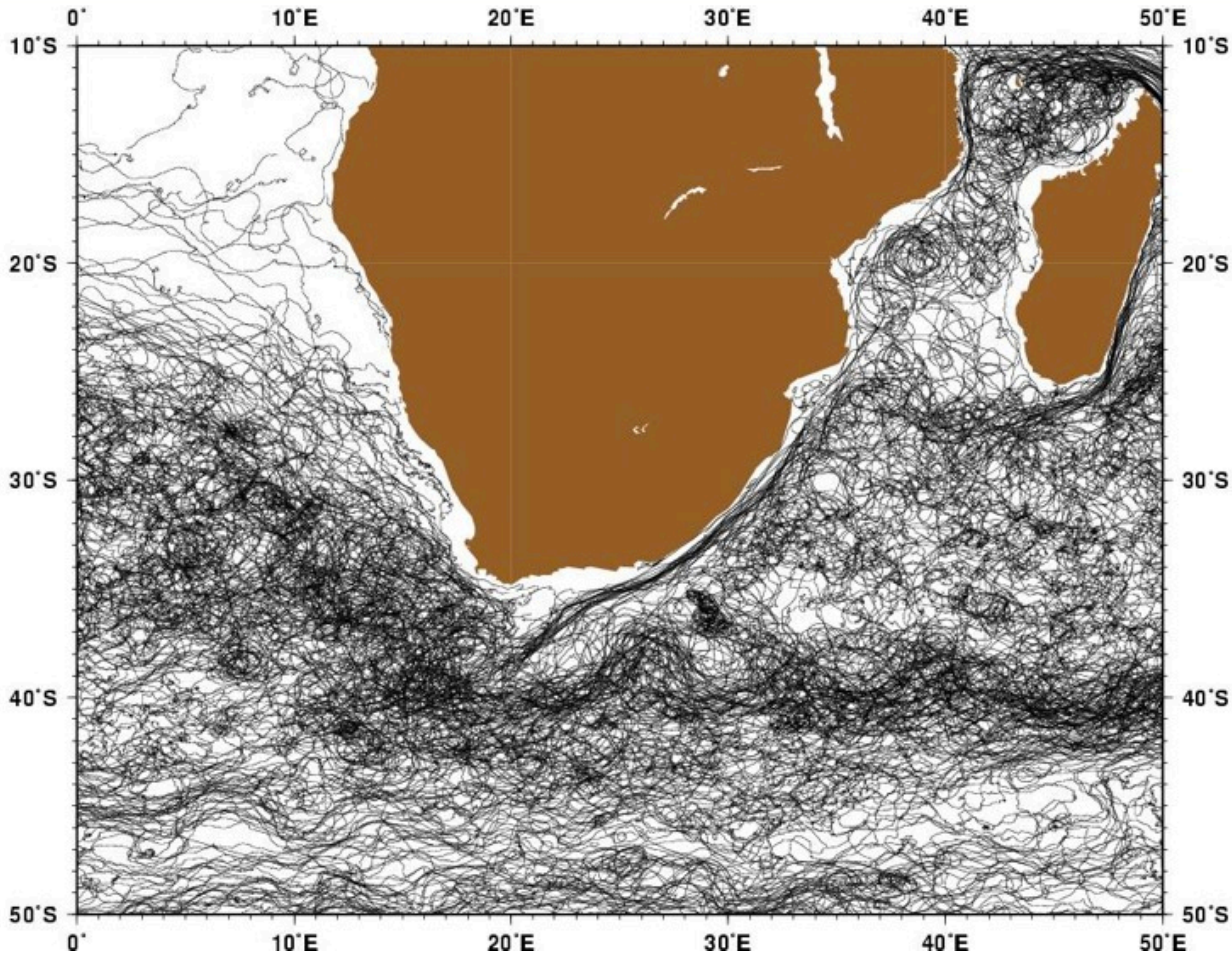
Velocity variance is distributed unevenly across scales: there is much more variance at scales of the order of about 50-60 km. Also $\overline{\Delta V^2}(r) \approx u^2 = \sigma^2$ **for r = 40 nm i.e. the turbulent structures of larger size are not very energetic.**
No external forcing seems able to explain this distribution (atmospheric forcings or topography).





Velocity Measurements in the Deep Water of the Western North Atlantic. Summary, 1962 J. CREASE

Discovery of mesoscale turbulence



It is much easier to understand why nowadays. Mesoscale meandering and looping is ubiquitous and straight trajectories are the exception.

Velocity Measurements in the Deep Water of the Western North Atlantic. Summary, 1962 J. CREASE

Discovery of mesoscale turbulence

Evidences of subinertial eddy activity accumulate:

- Swallow, J.C. (1958-1960, Bermuda)
- Poligon 67 (Arabian sea)
- Poligon 70 (equatorial Atlantic)
- Mode (1973, Sargasso sea)
- Polymode (1977-1978, Sargasso sea)

Confirmation that there is substantial energy at time scales of the order days to a few weeks

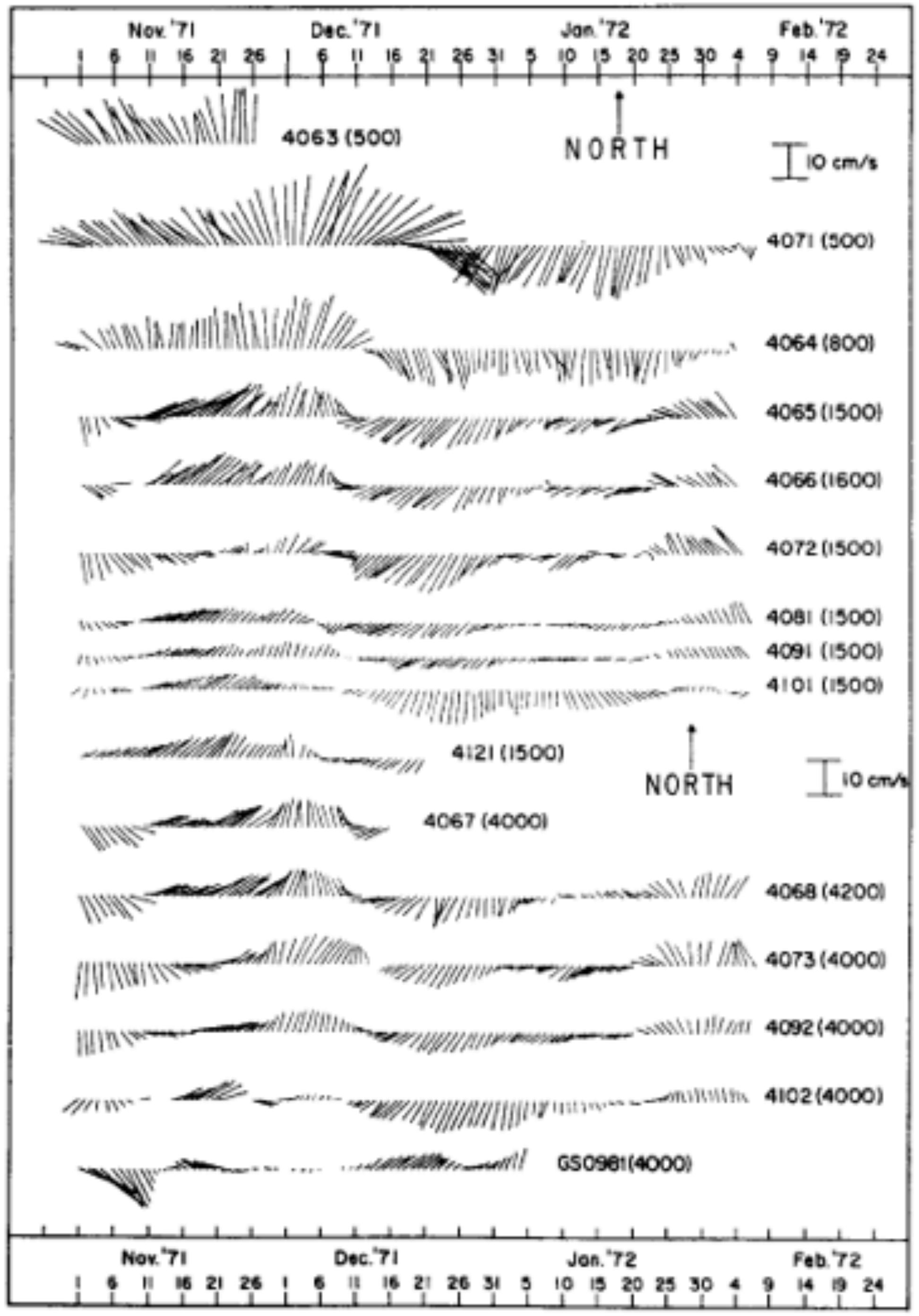


Fig. 2. Vector time series for the low frequency data from array 1. Numbers on each line are record numbers. Numbers in parenthesis are nominal depth in meters.

Preliminary field results for a Mid-Ocean Dynamics Experiment (MODE-O), 1974
W. J. GOULD, W. J. SCHMITZ and C. WUNSCH

Discovery of mesoscale turbulence

Evidences of subinertial eddy activity accumulate:

- Swallow, J.C. (1958-1960, Bermuda)
- Poligon 67 (Arabian sea)
- Poligon 70 (equatorial Atlantic)
- Mode (1973, Sargasso sea)
- Polymode (1977-1978, Sargasso sea)

There are numerous vortices in the subsurface too

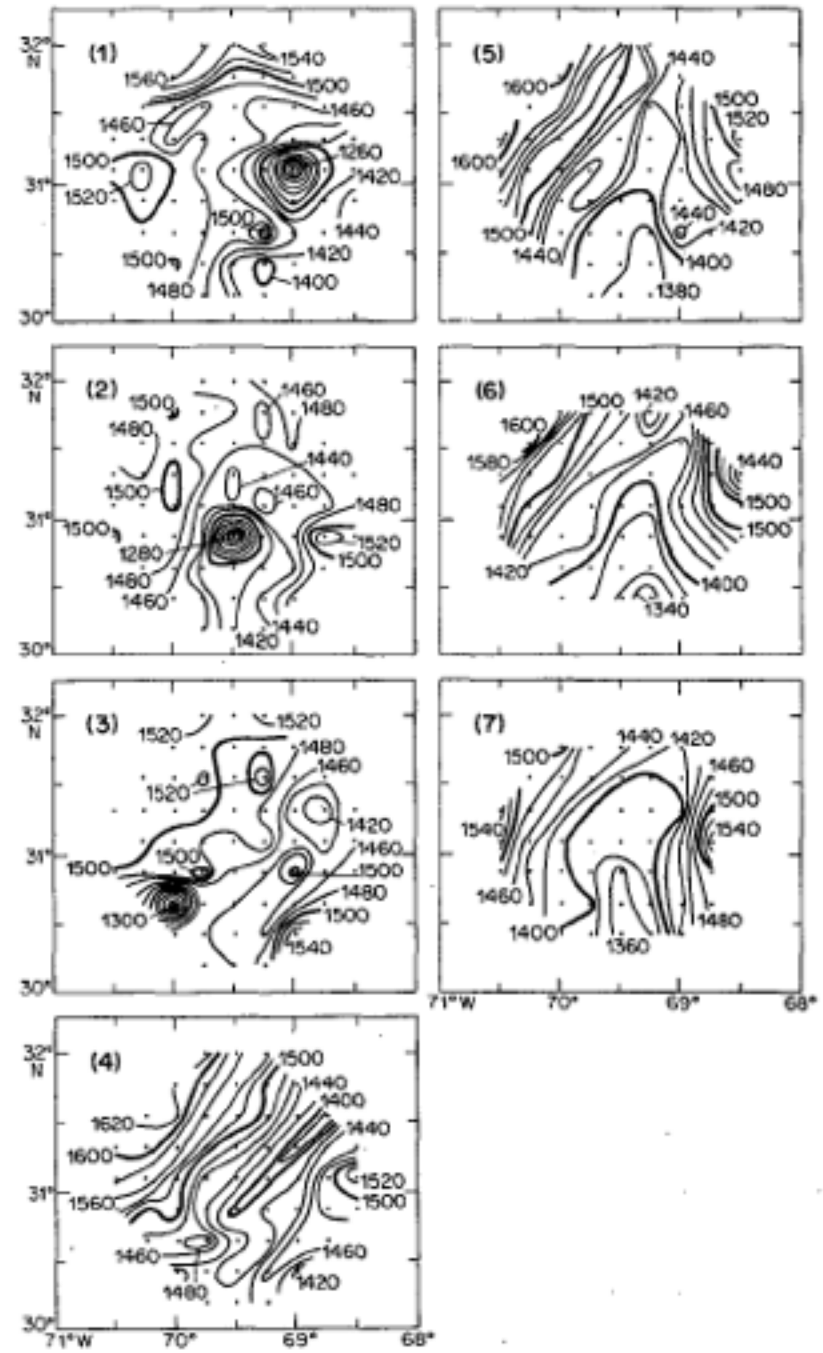
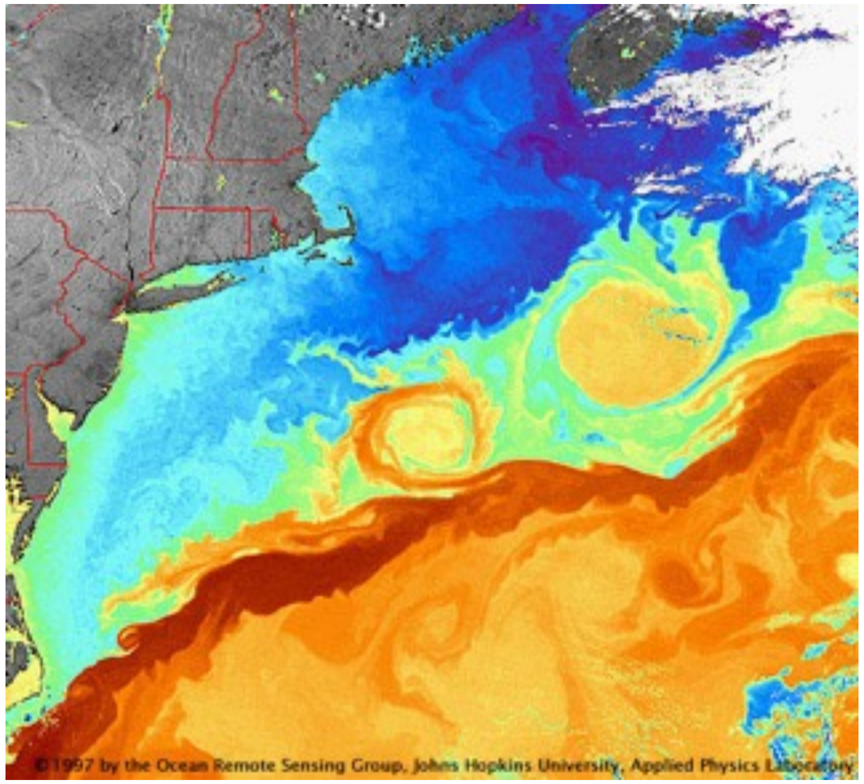


FIG. 15. As in Fig. 13 but of pressure (db) of 4.5°C isotherm.

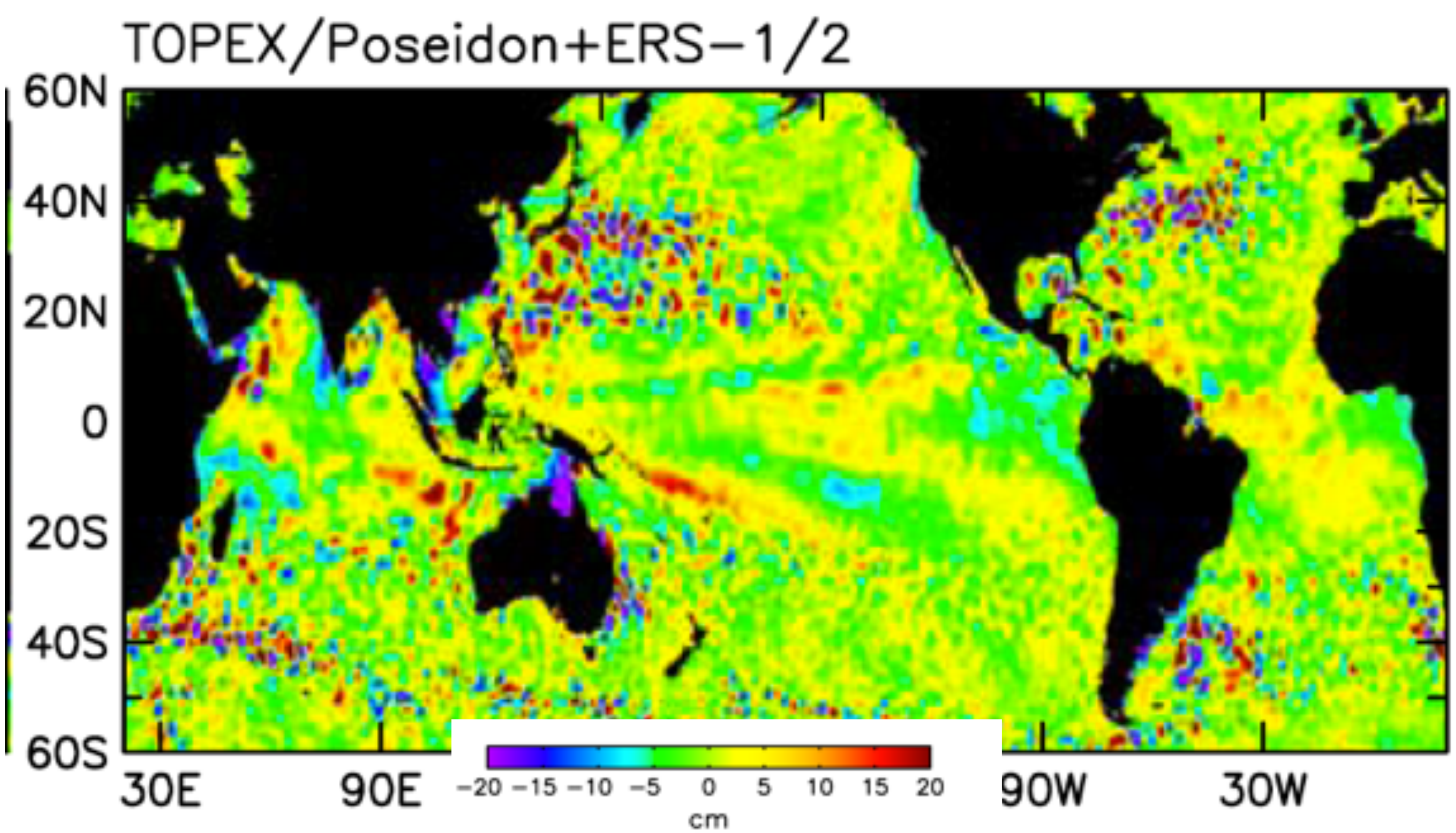
Water mass structure during the POLYMODE local dynamics experiment Experiment,1986
B.A Taft et al.

Modern ways to detect (surface) eddies

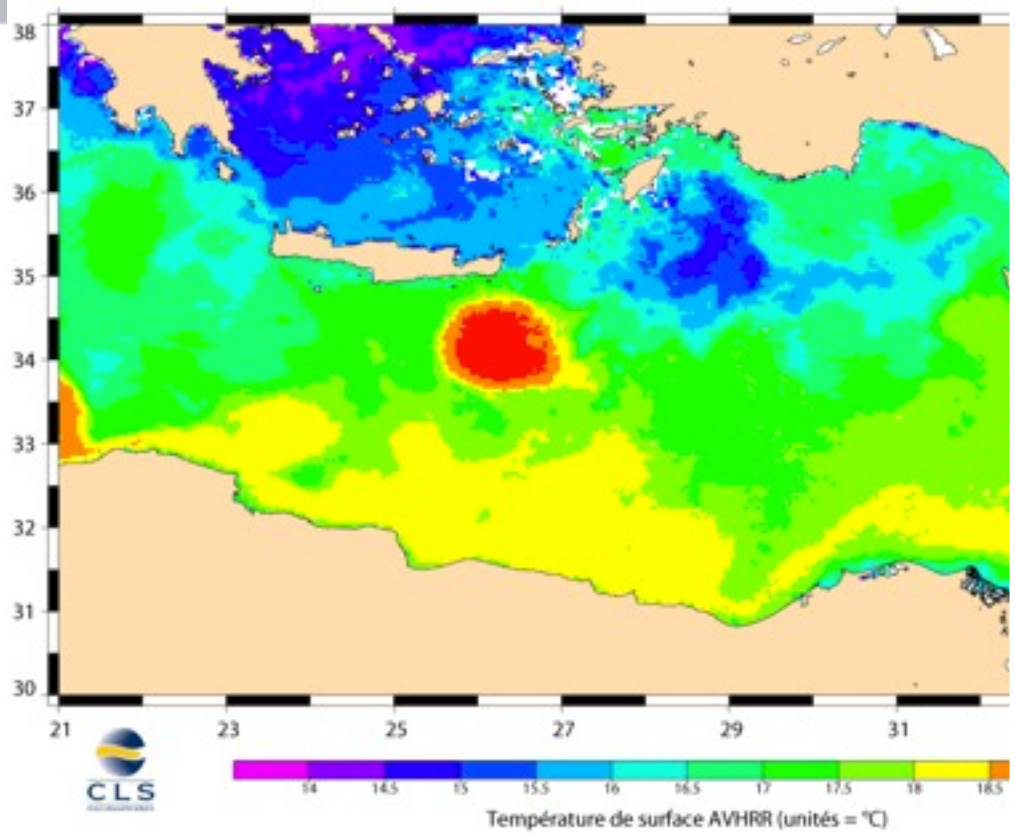


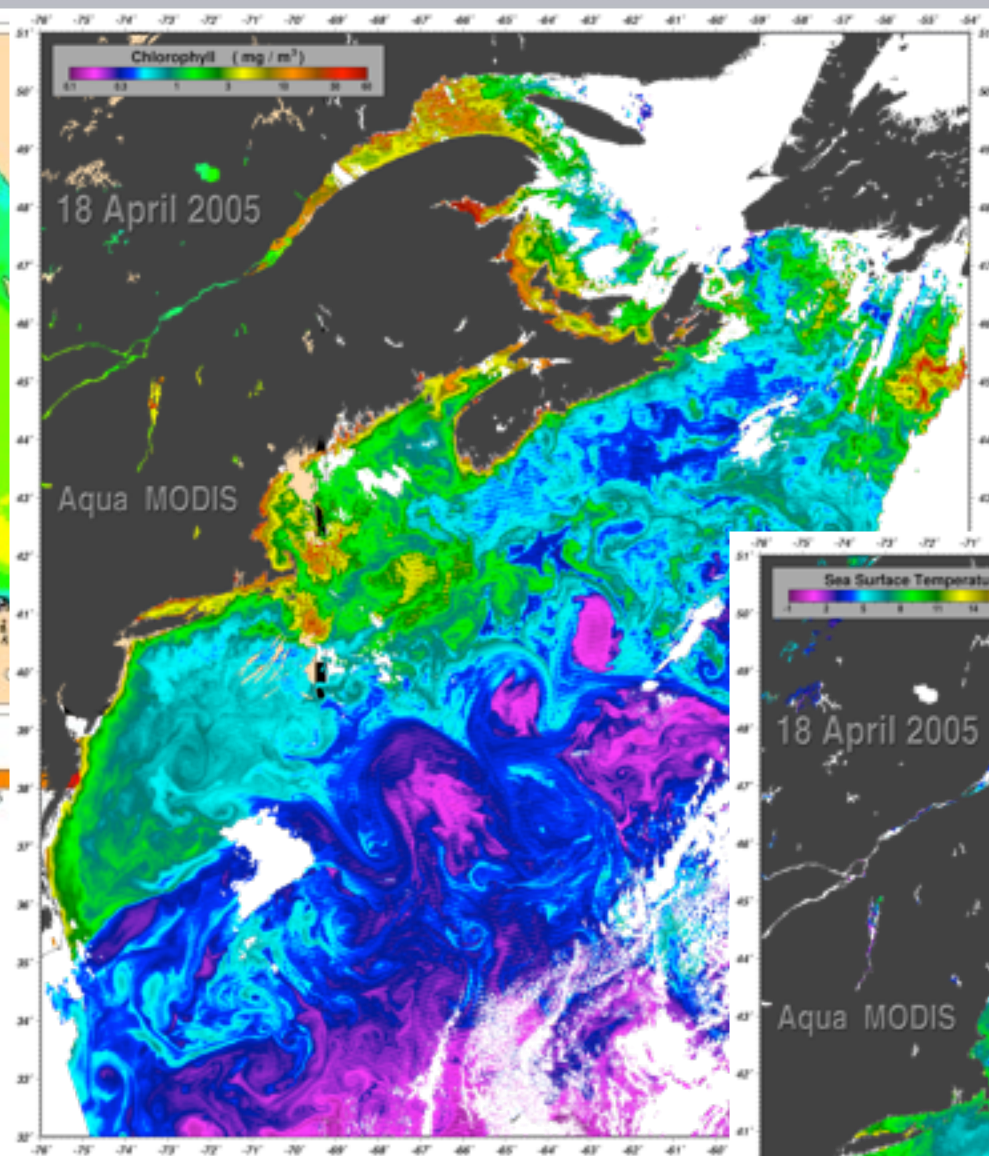
Flight missions with embarked radiometers in the early 1970's. Confirmation of ocean variance at mesoscale.

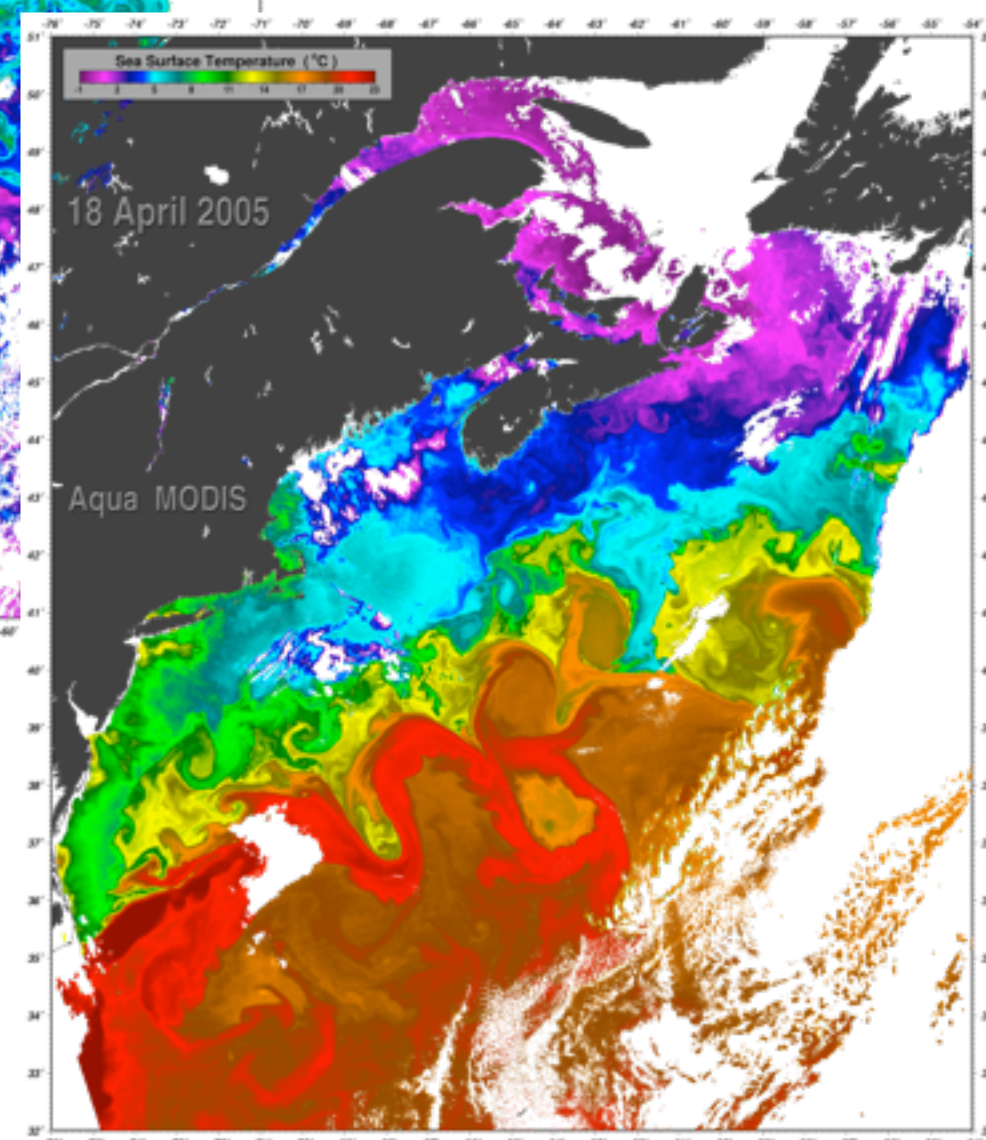
With the advent of satellite instruments (ocean color - CZCS, 1978 ; SST - AVHRR, 1982) eddy ubiquity becomes obvious. With sea level anomaly (SLA) measurements we have ways to detect and track eddies.

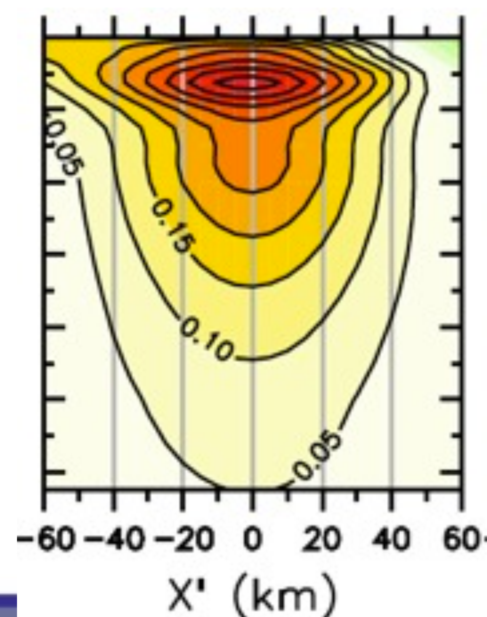


Why is SLA more effective than tracers ?





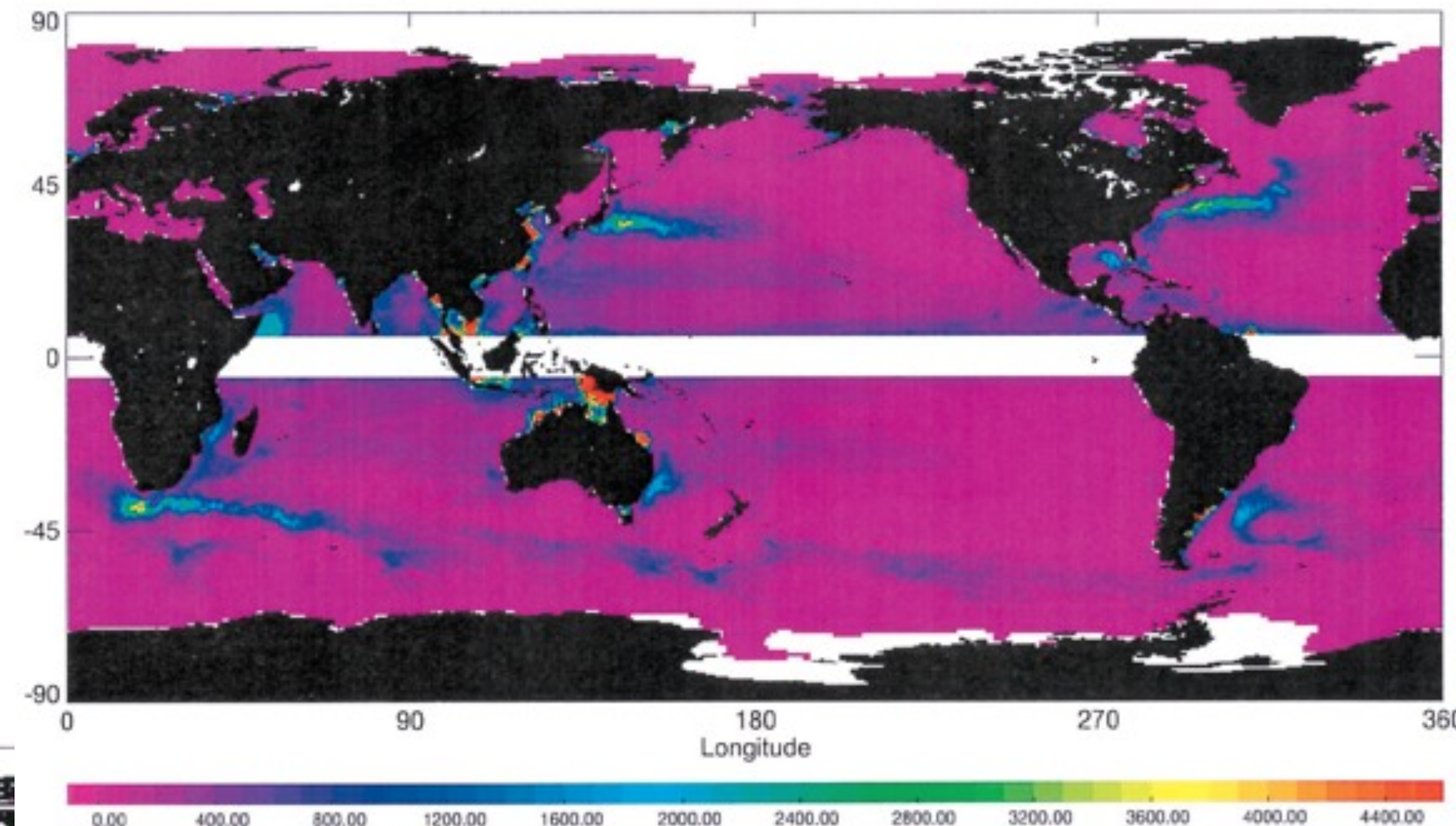


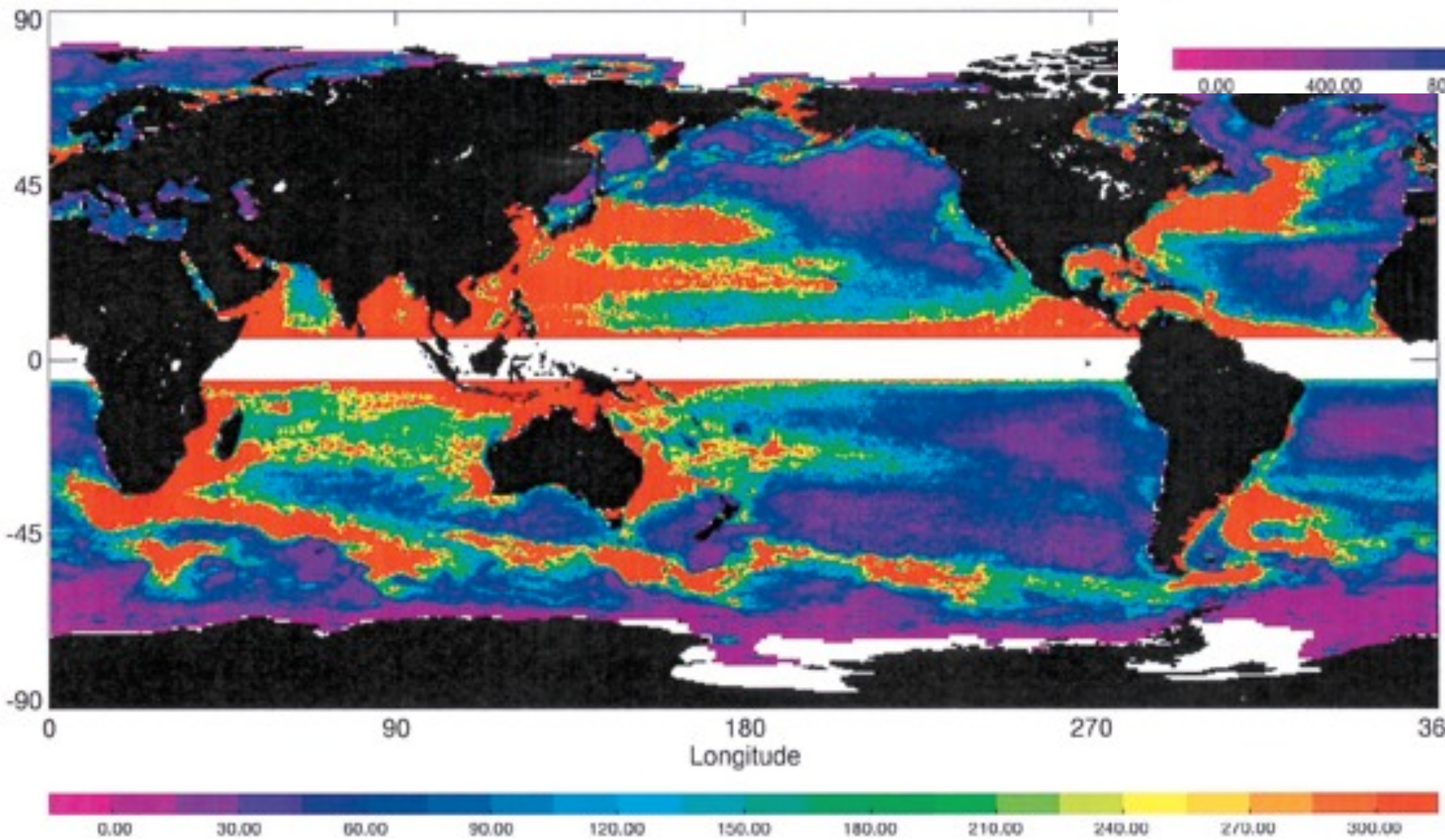


Eddies have a vertical structure: the anomaly they are associated with at every depth contributes to the SSH signal. The signal cannot be blurred by upper ocean processes.

$$EKE = \frac{1}{2}(\overline{u'^2} + \overline{v'^2})$$

EKE is not just at the mesoscale but as we have seen before the mesoscale makes up the bulk of it (see also below)

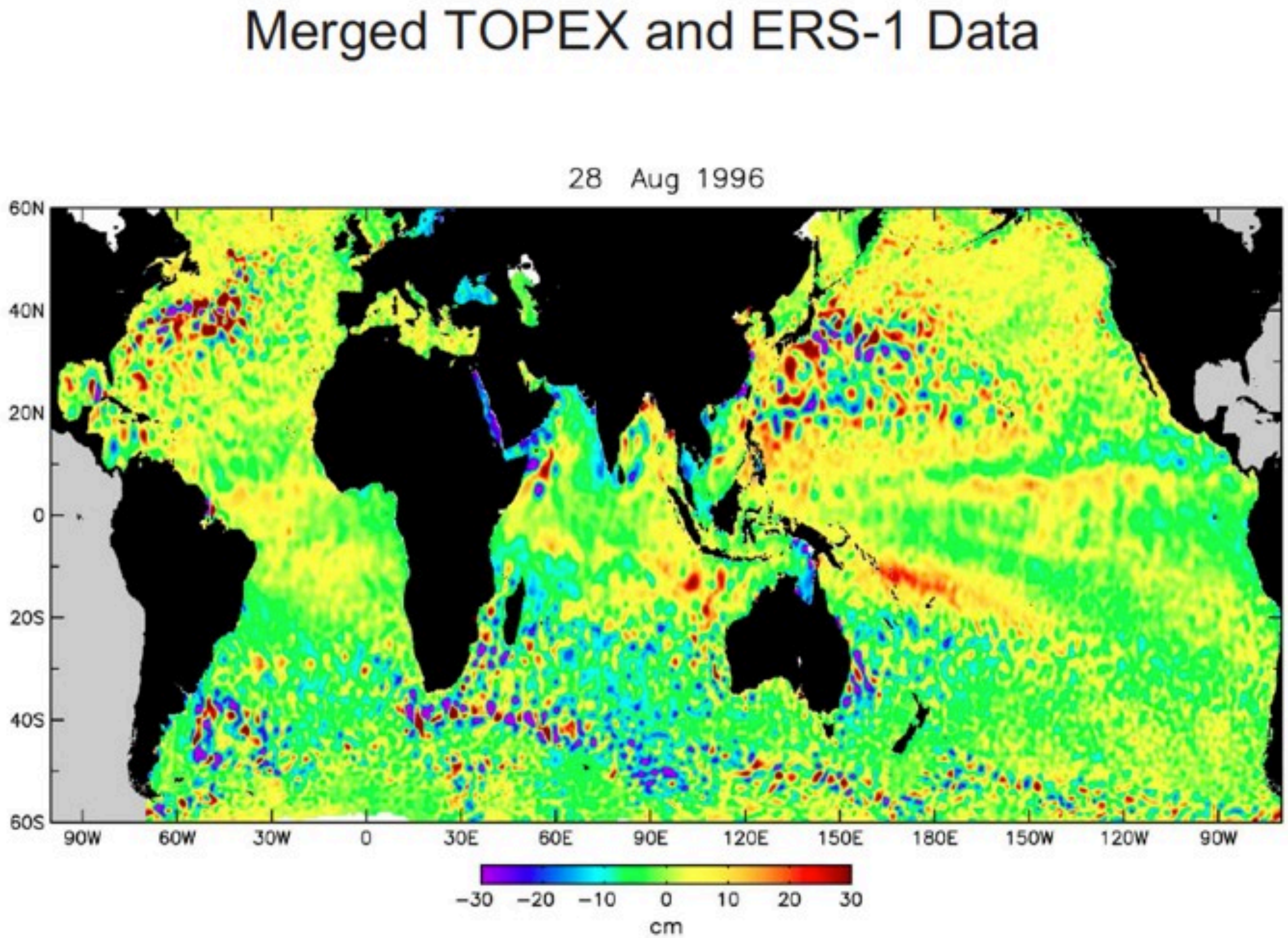




Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and -2,2000, N Ducet and Y. Le Traon

Characterizing surface mesoscale variability (2)

We can identify mesoscale eddies by using some of their properties. Simplest way: they correspond to closed contours of SLA

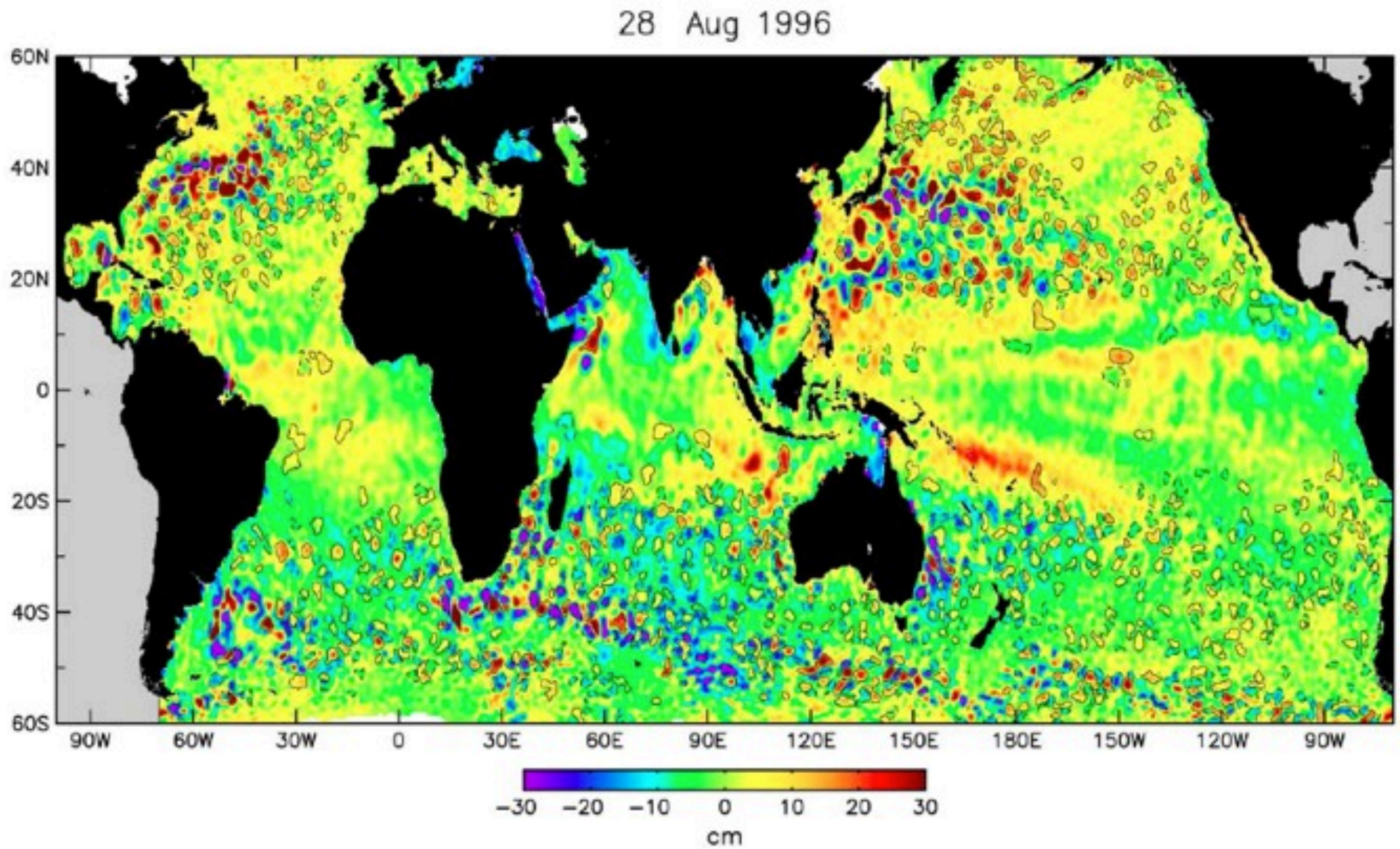


Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

Characterizing surface mesoscale variability (2)

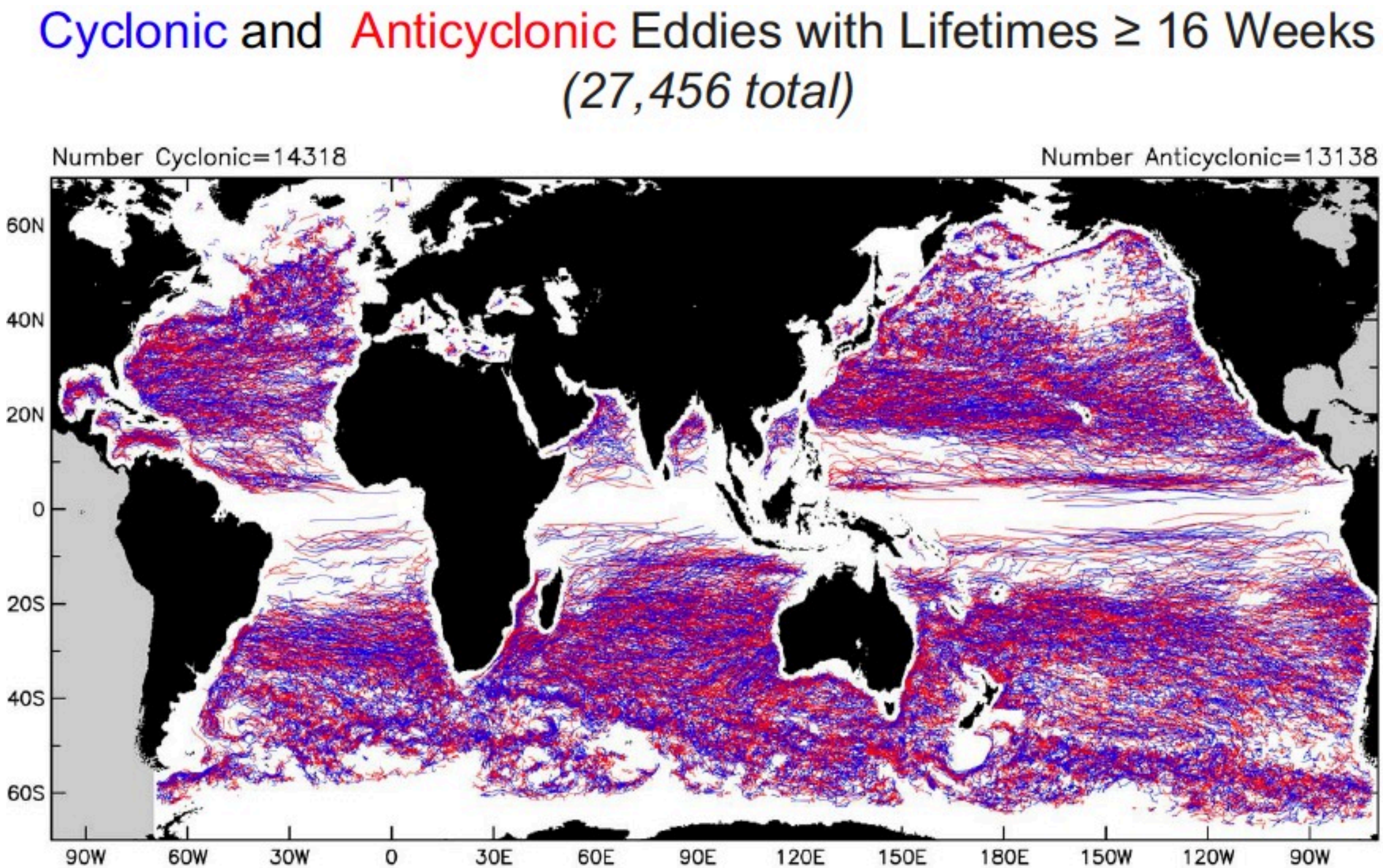
We can identify mesoscale eddies by using some of their properties. Simplest way: they correspond to closed contours of SLA

Merged TOPEX and ERS-1 Datawith contours of eddies with lifetimes ≥16 weeks



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

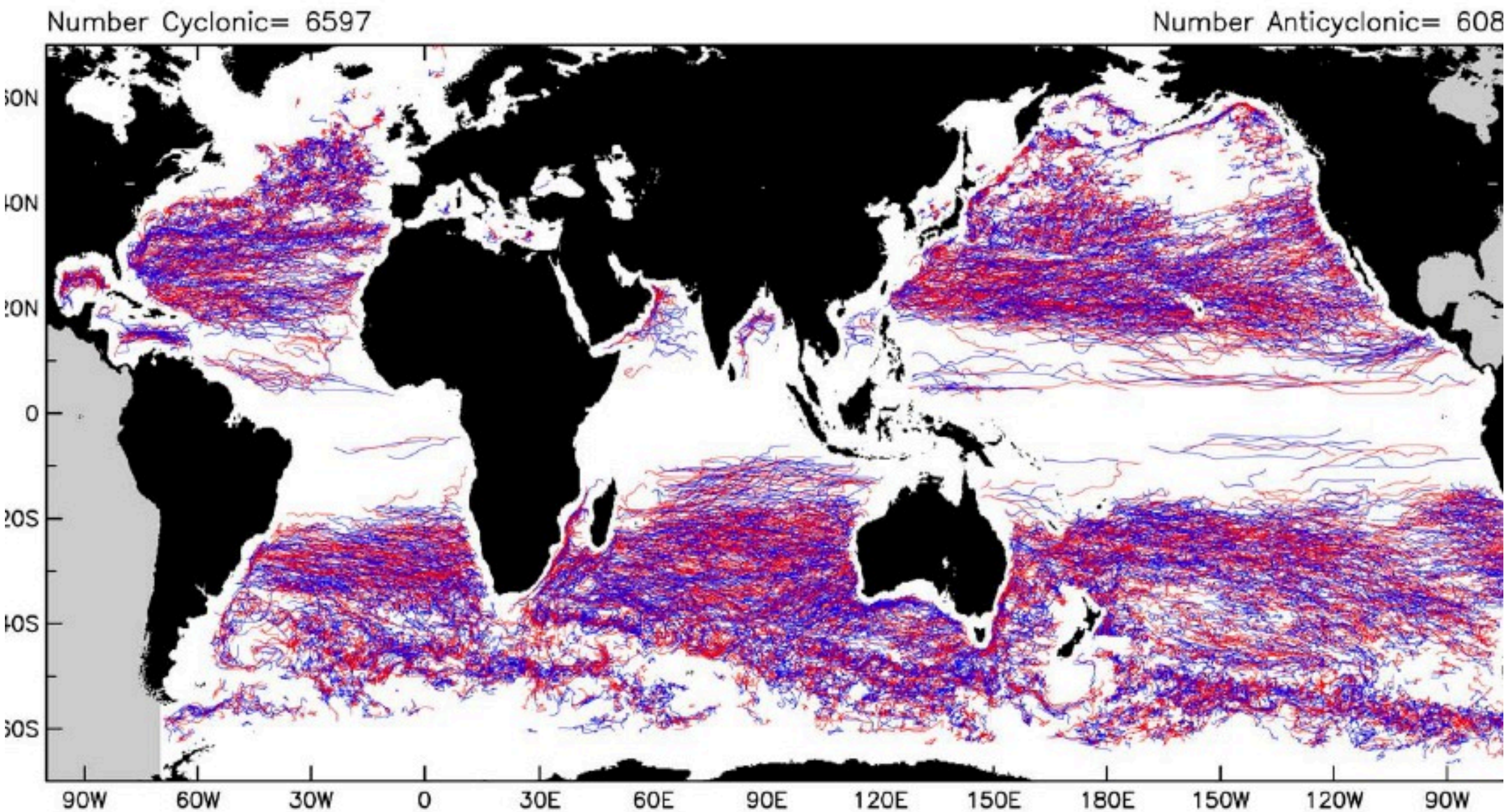
Characterizing surface mesoscale variability (2)



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

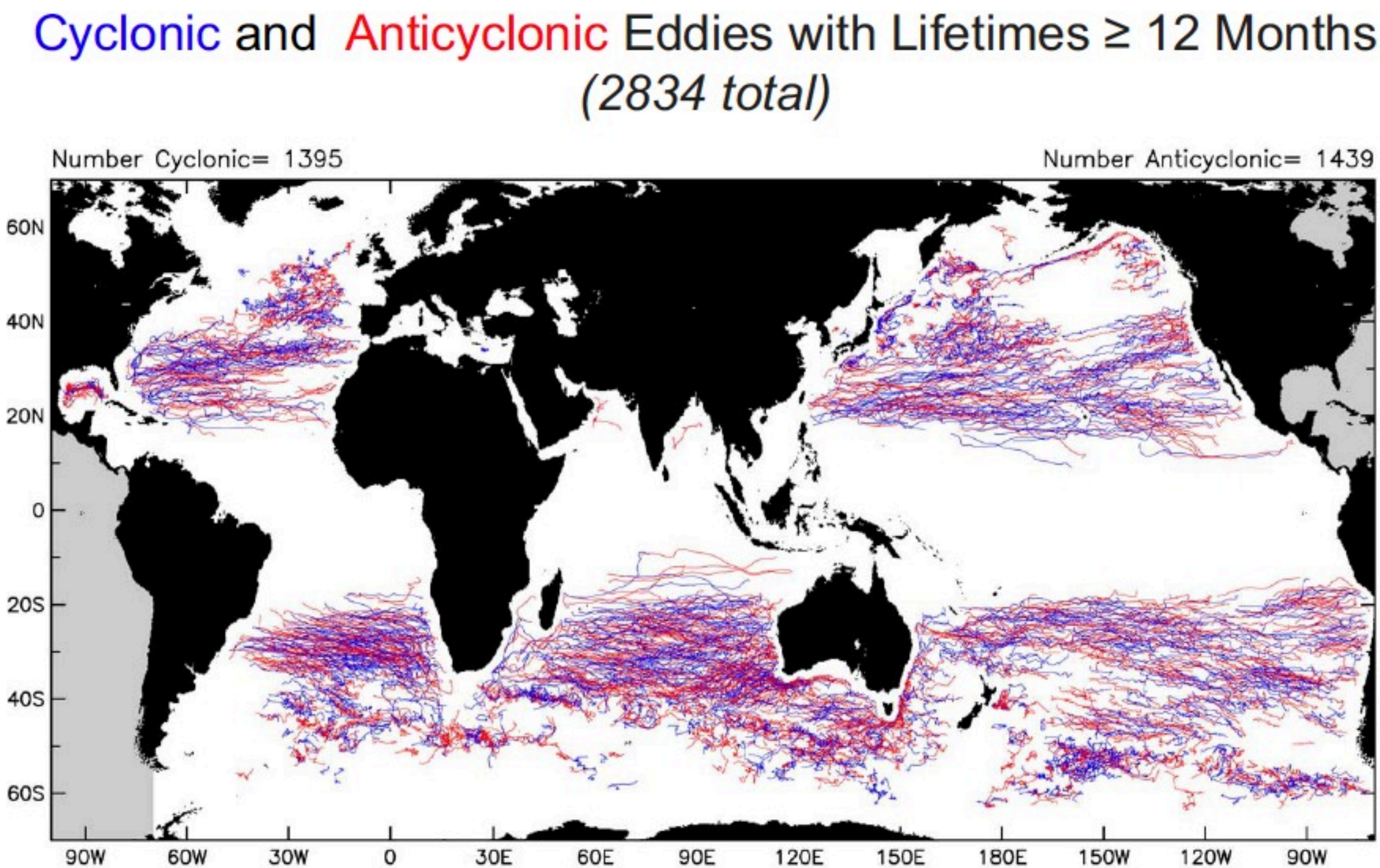
Characterizing surface mesoscale variability (2) INTRODUCTION

Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 6 Months
(12,680 total)



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

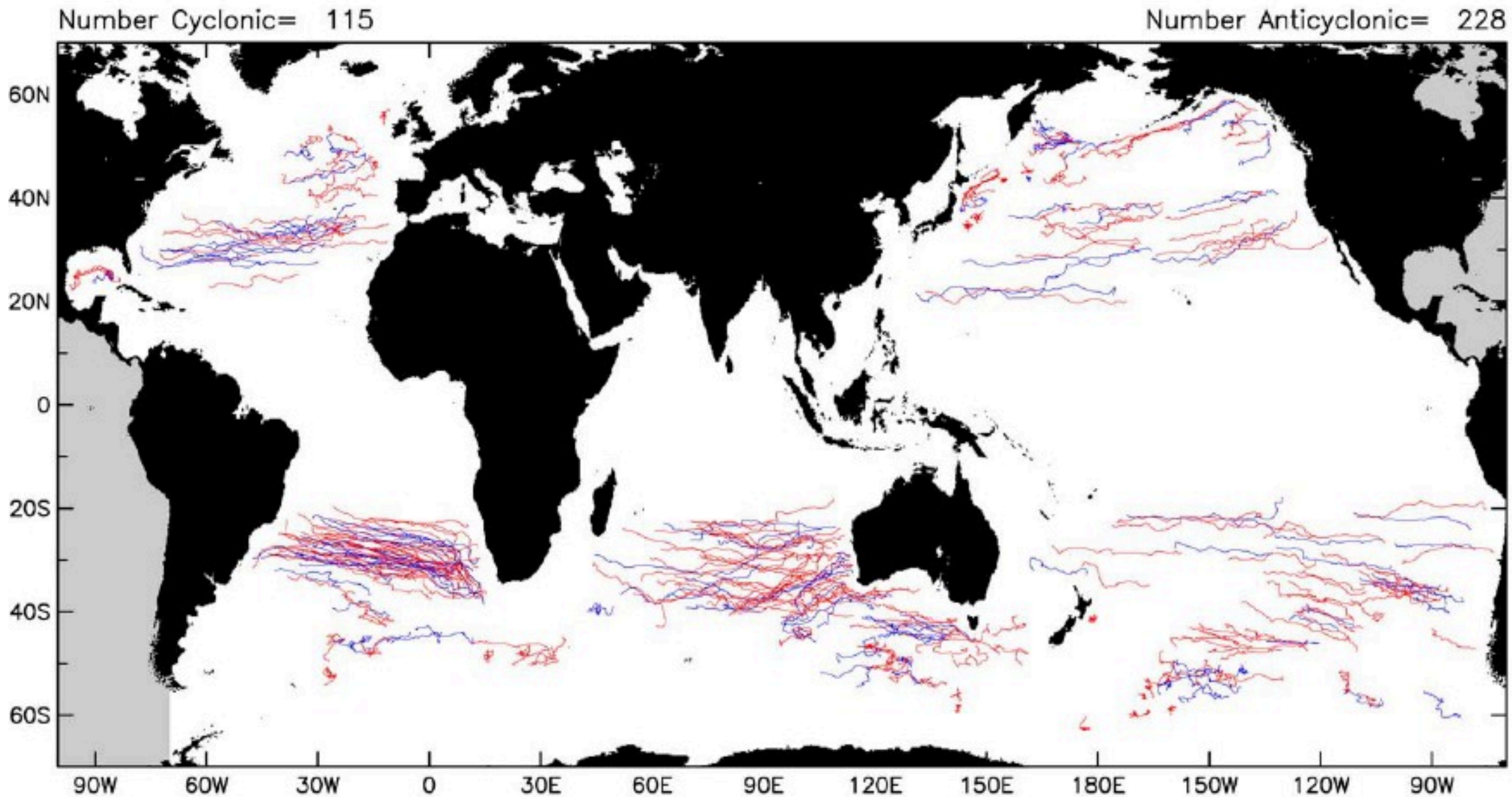
Characterizing surface mesoscale variability (2) INTRODUCTION



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

Characterizing surface mesoscale variability (2)

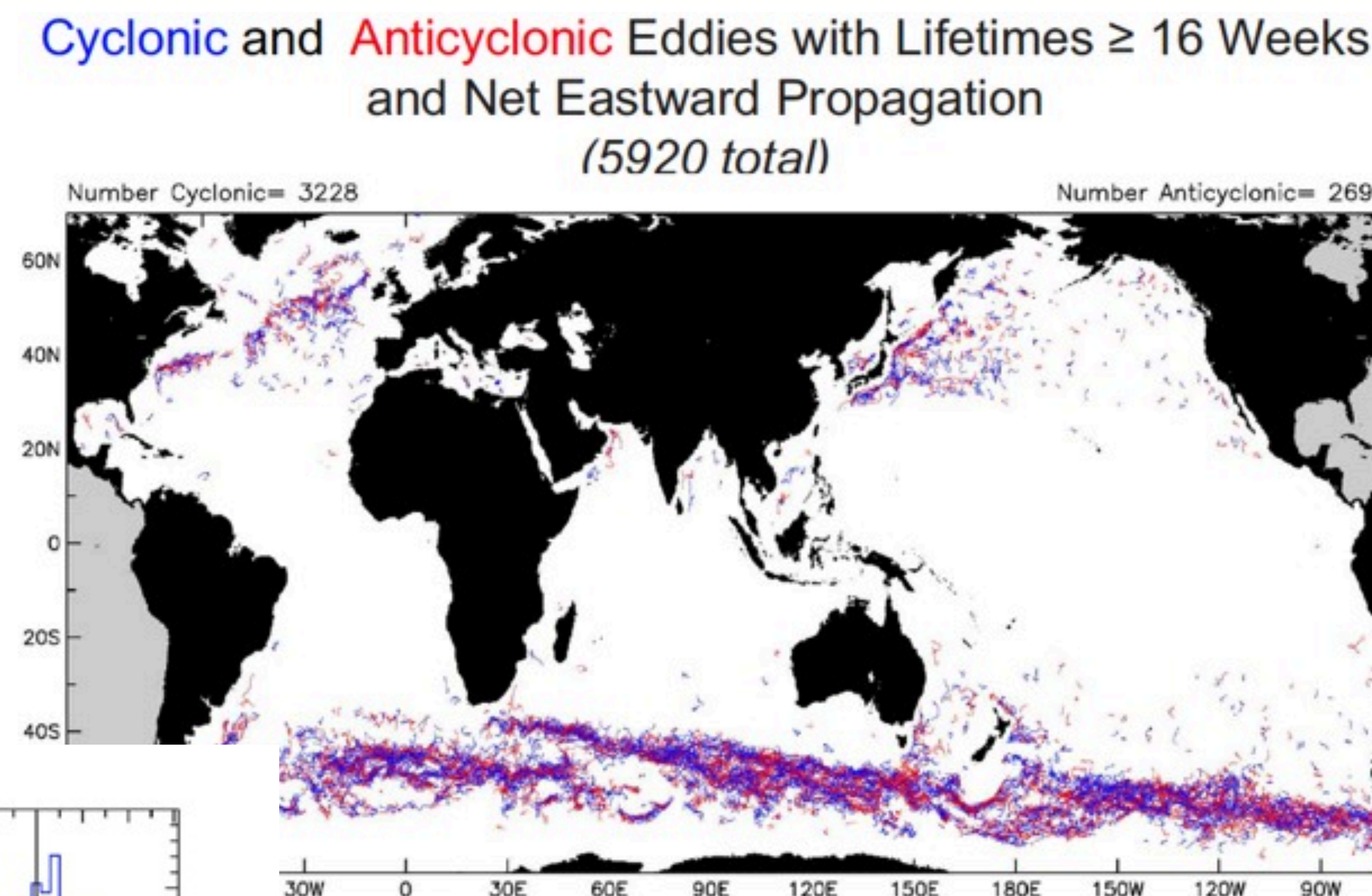
Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 24 Months *(343 total)*



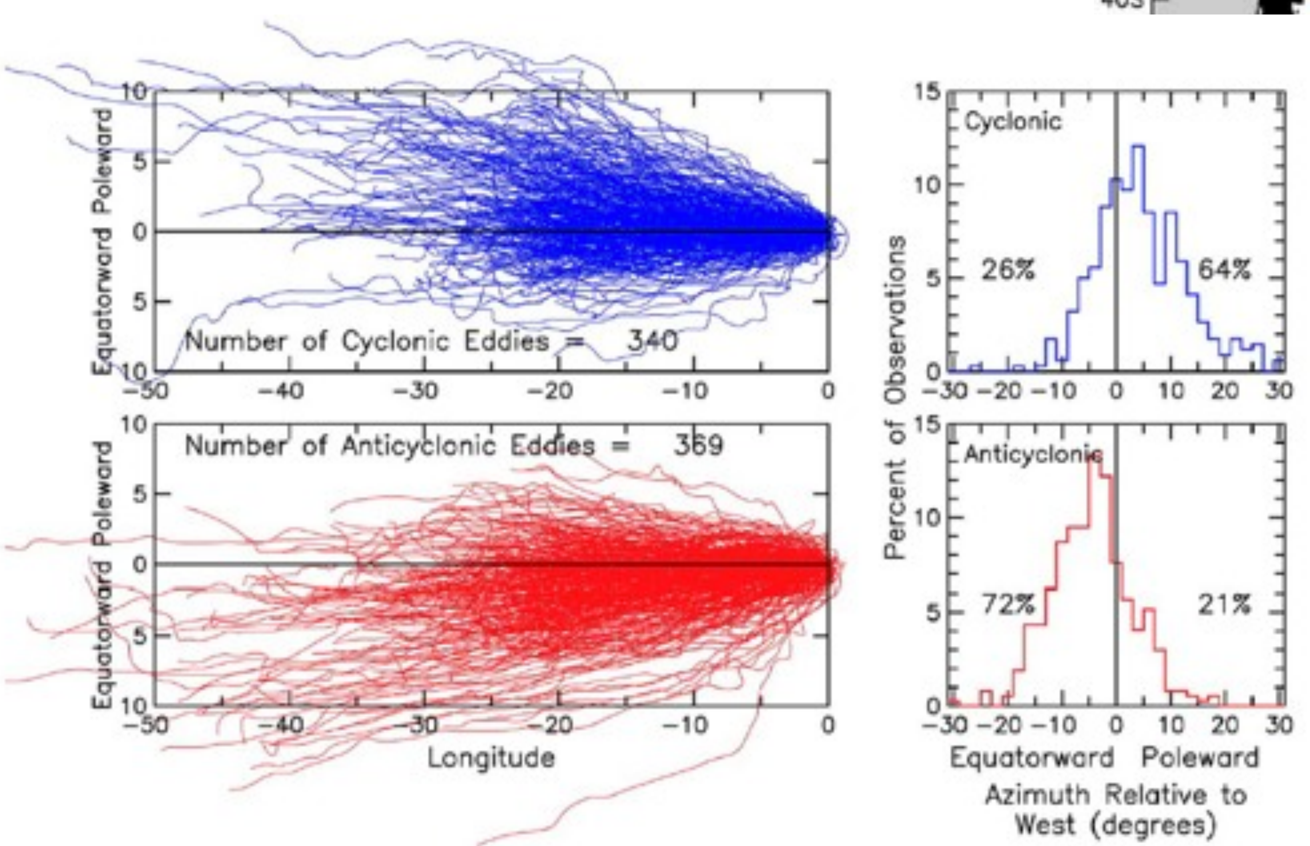
Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

Characterizing surface mesoscale variability (2)

Cyclones tend to move poleward whereas anticyclones tend to move equatorward.

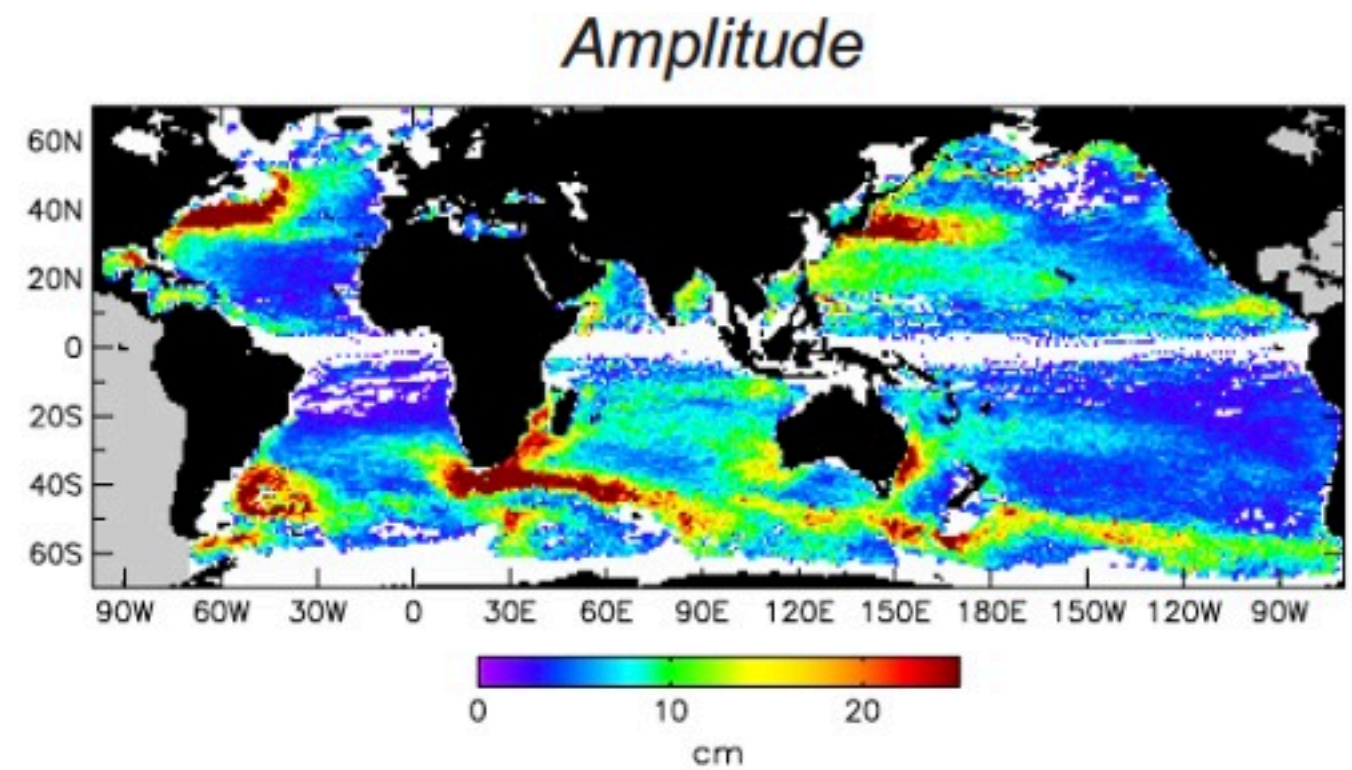


Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

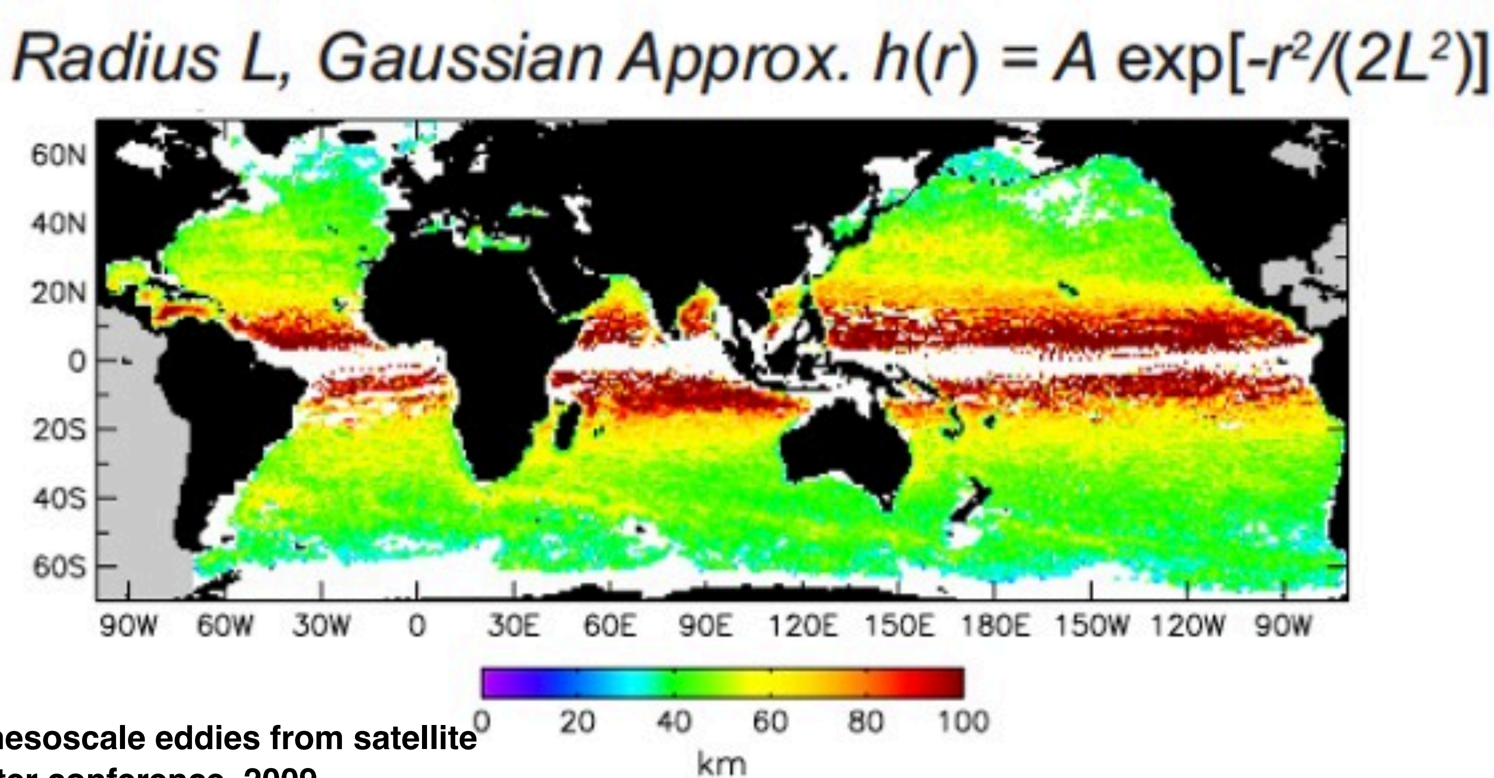


Characterizing surface mesoscale variability (2)

Mesoscale eddies tend to be more intense in regions ...



Mesoscale eddies tend be larger in regions ...



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

Characterizing surface mesoscale variability (2)

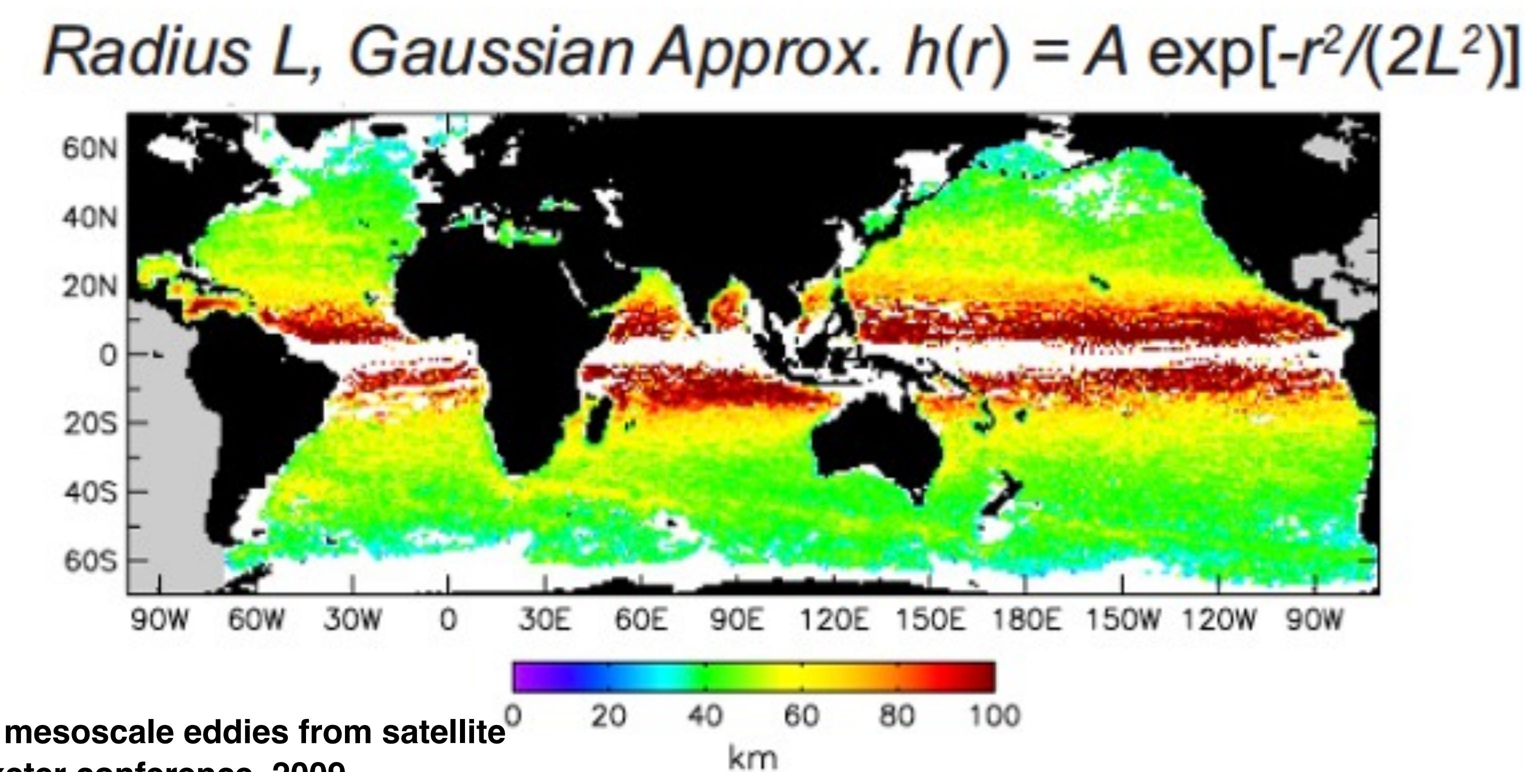
$$q = \nabla^2\psi + \partial_z\left(\frac{f^2}{N^2}\partial_z\psi\right)$$

$$q^* = \nabla^{*2}\psi - \frac{L^2}{R_d^2}\psi$$

when adimensionalized with L a typical length scale for the processes of interest

L ~ Rd is a special case for which vorticity and stretching are a priori of the same order of magnitude so that potential vorticity can be exchanged between both forms. Such exchanges are key for the development of instability processes (baroclinic instability).
Rd depends on 1/f

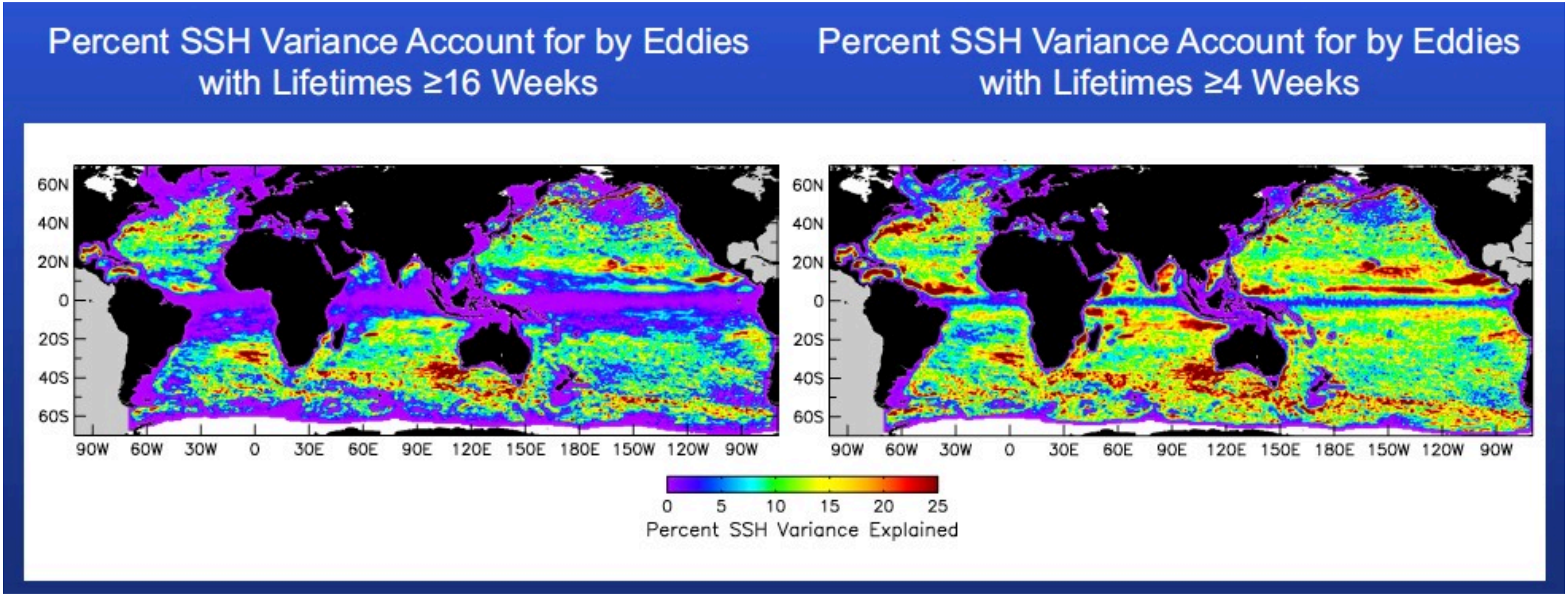
Mesoscale eddies tend be larger in regions ...



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

Characterizing surface mesoscale variability (2) INTRODUCTION

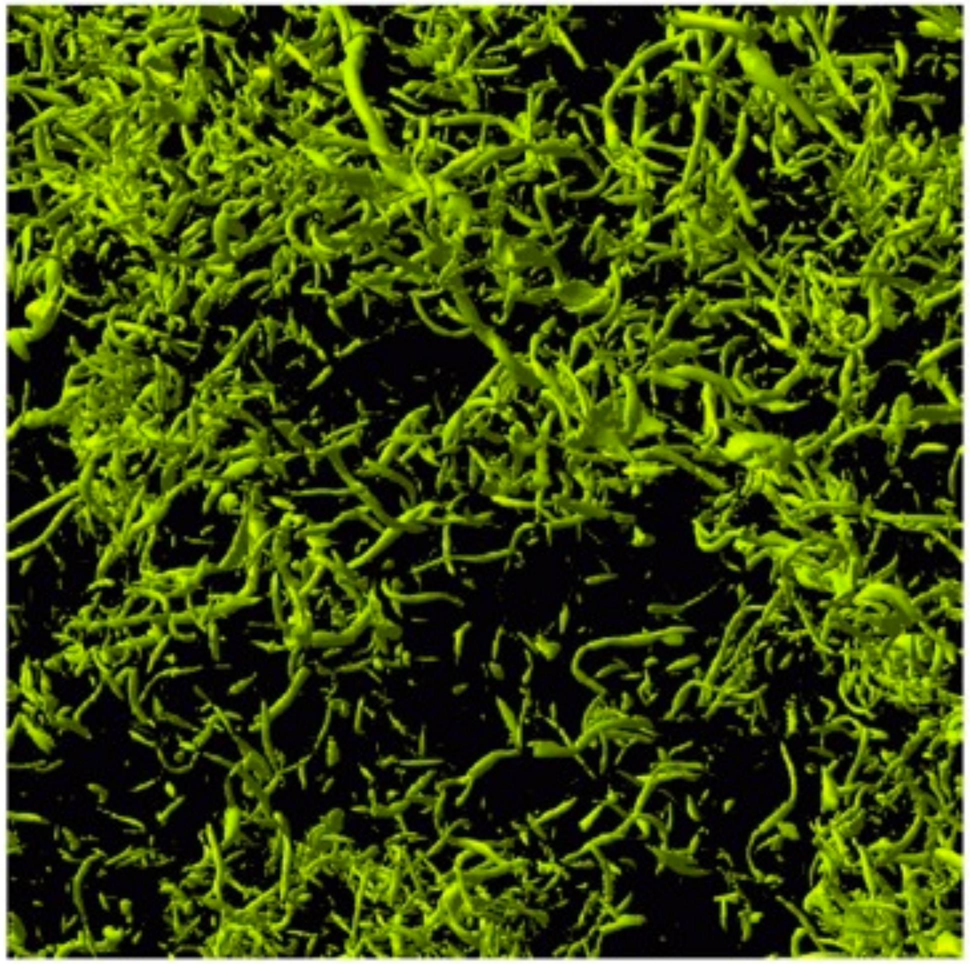
- The detected eddies are associated with a small fraction of the total SSH variance (or EKE)
- They are nonetheless considered as the key building block of oceanic turbulence in particular because they shape turbulent motions outside their core ➔ classes on developed turbulence/on submesoscale turbulence



Global observations of mesoscale eddies from satellite altimetry, D Chelton, Exeter conference, 2009

Several important questions (to be addressed in the course):

- Origin and preferential locations → generation processes
- Preferential displacement → propagation theories
- Life time longer over a certain band of latitude → propagation theories + ???
- Absence of identified eddies over an equatorial band, rarer at low latitudes → waves versus nonlinear eddies
- Latitudinal change of eddy size → generation processes



Conclusion

The study of turbulence produces permanent encounters with the notion of scales (time and space).
Resolved and unresolved scales, separation into scales ...
There are turbulent motions at all scales. Building blocks may differ from one scale range to the next but they interact with each other thanks to

$$\mathbf{u} \cdot \nabla \mathbf{u}$$

$$\mathbf{u} \cdot \nabla \mathbf{T}$$