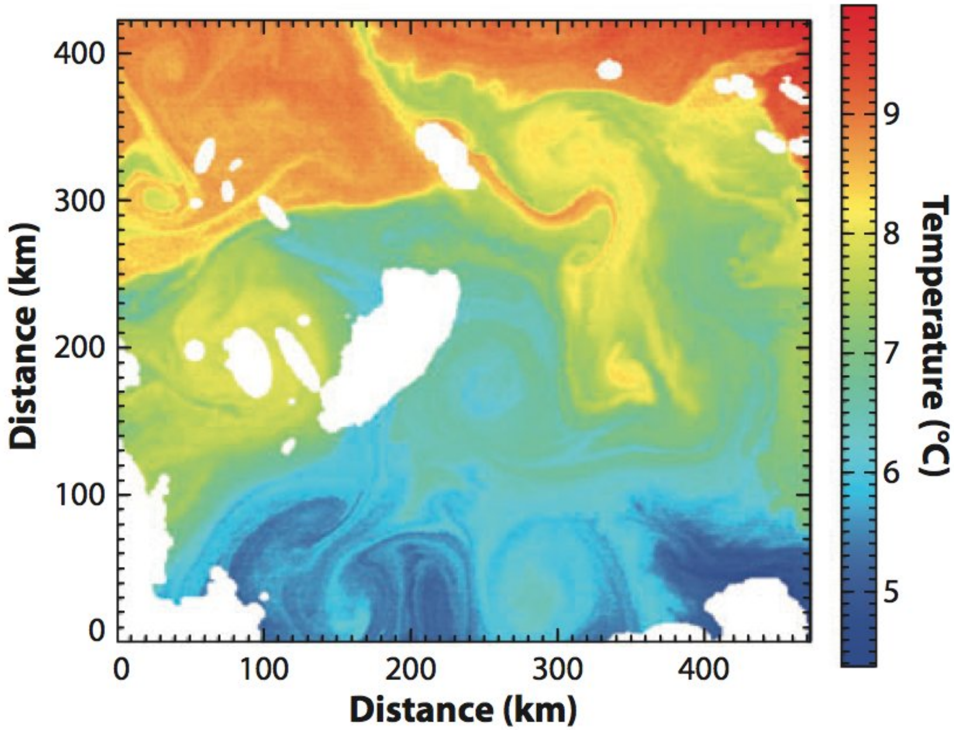
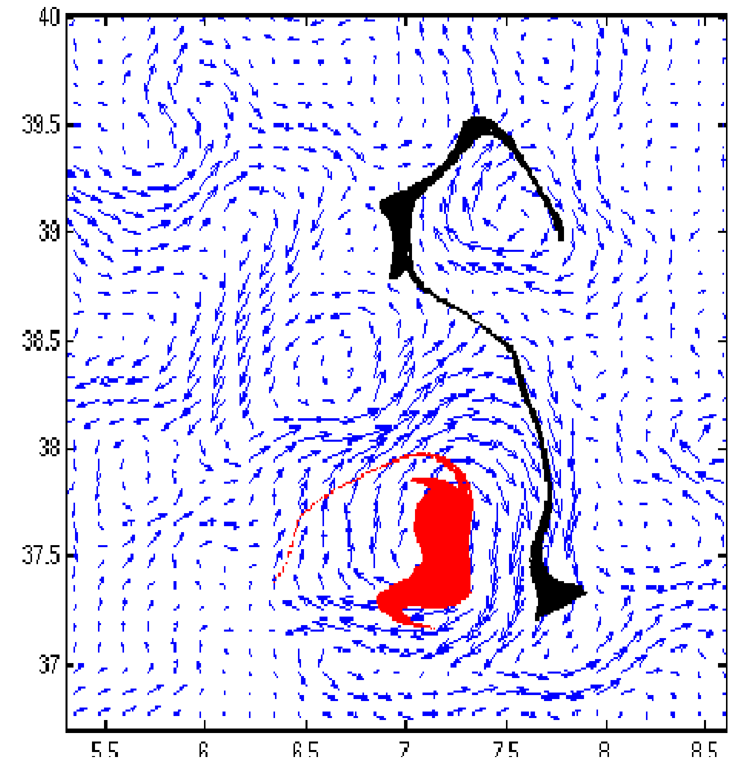




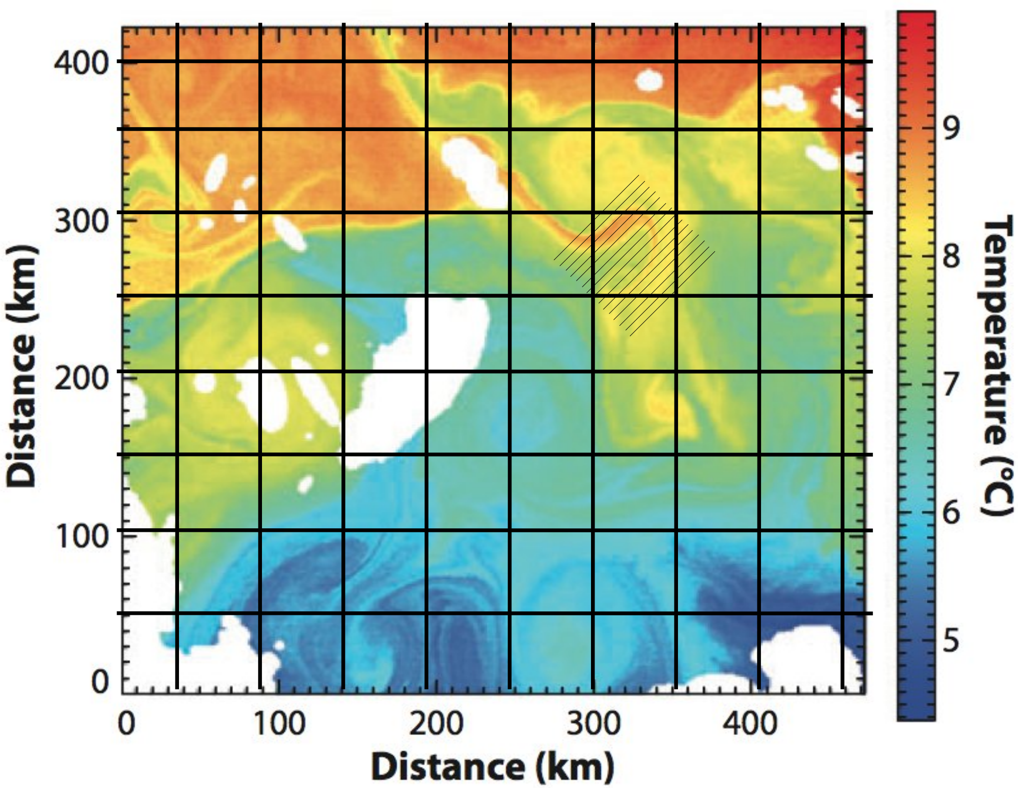
LABORATOIRE DES ECOULEMENTS GEOPHYSIQUES ET INDUSTRIELS

Diagnosing submesoscale tracer fluxes in the global ocean with existing satellite products

J. Le Sommer, F. d'Ovidio, R. Morrow and G. Madec

Lisbon, Oct 22nd 2010 OST-ST Applications Workshop 2010

~50km



(IR satellite SST from Klein and Lapeyre 2009)

$$\mathcal{V}_\theta = \widehat{\theta^2} - \widehat{\theta}^2$$

submesoscale SST variance

Jimenez et al (2001)

Stirring *Mixing*

$$\partial_t \mathcal{V}_\theta = \mathcal{T} + \mathcal{P} - \mathcal{D}_m - \mathcal{D}_f$$

- $\mathcal{T}$ Variance transport
- $\mathcal{P}$ Variance production
- $\mathcal{D}_m$ Destruction by small scale mixing
- $\mathcal{D}_f$ Destruction by air-sea fluxes

What is the mean balance ? locally vs globally ?

What is the rate controlling process in this mean balance ? *(cf Garret 2001)*

What can be learn about $\mathcal{P}$ with the existing satellite observing system ?

1. Motivation : submesoscale SST variance budgets

2. Tracer variance production by mesoscale stirring

3. Modeling stirring by mesoscale flows

4. Diagnosing submesoscale SST variance production

Tracer variance production by mesoscale stirring (1/2)

RANS

Stepping backward, consider that variance budget build wrt a **time average** (e.g.>18month) see e.g. Garrett 2001

$$\partial_t \tau + \nabla \cdot (u\tau) = \dots \longrightarrow \partial_t \overline{\tau'^2} + \dots = 2\,\overline{u'\tau'} \cdot \nabla \overline{\tau}$$

If in addition we assume a mixing length theory to hold,

$$\overline{u'\tau'} \simeq -\kappa_t \nabla \overline{\tau} \qquad \boxed{\mathcal{P} \simeq 2\,\nabla \overline{\tau} \cdot (\kappa_t \nabla \overline{\tau})}$$

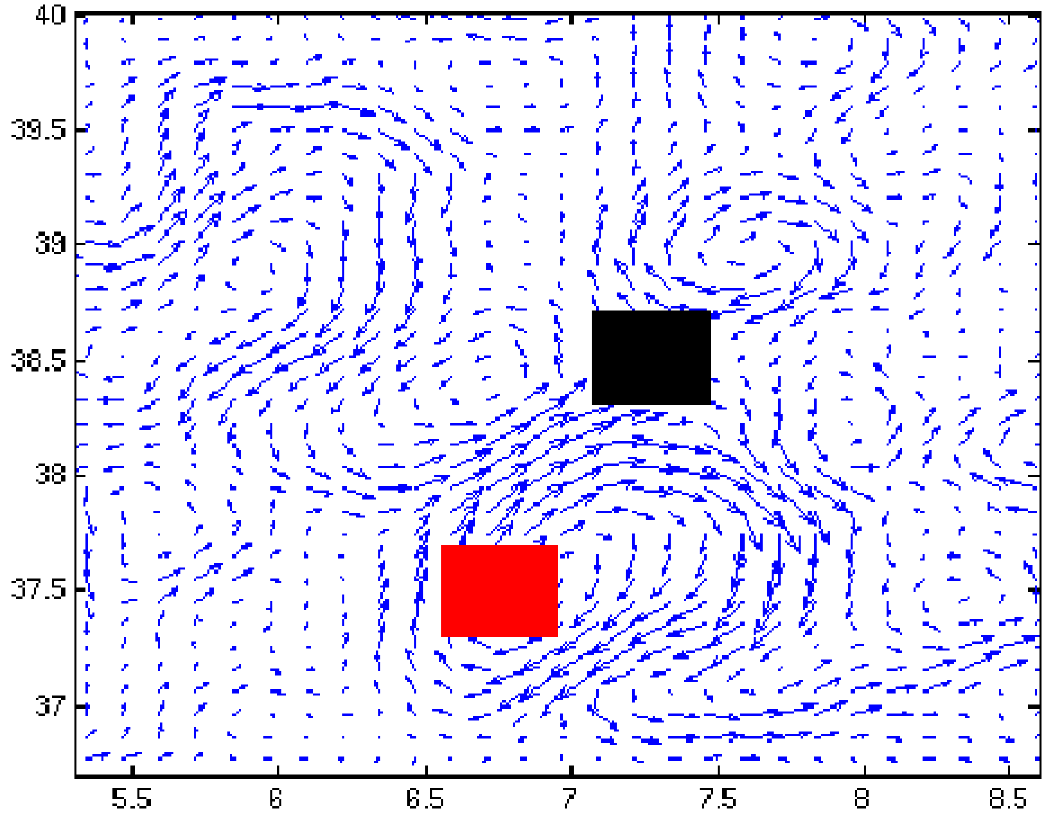
=> **Eddy-stirring is producing tracer variance**

For stirring to be balanced by irreversible mixing, i.e. $< \mathcal{P} > \simeq < \mathcal{D}_m >$

=> **Tracer variance must be cascaded forward to smaller scales**

LES

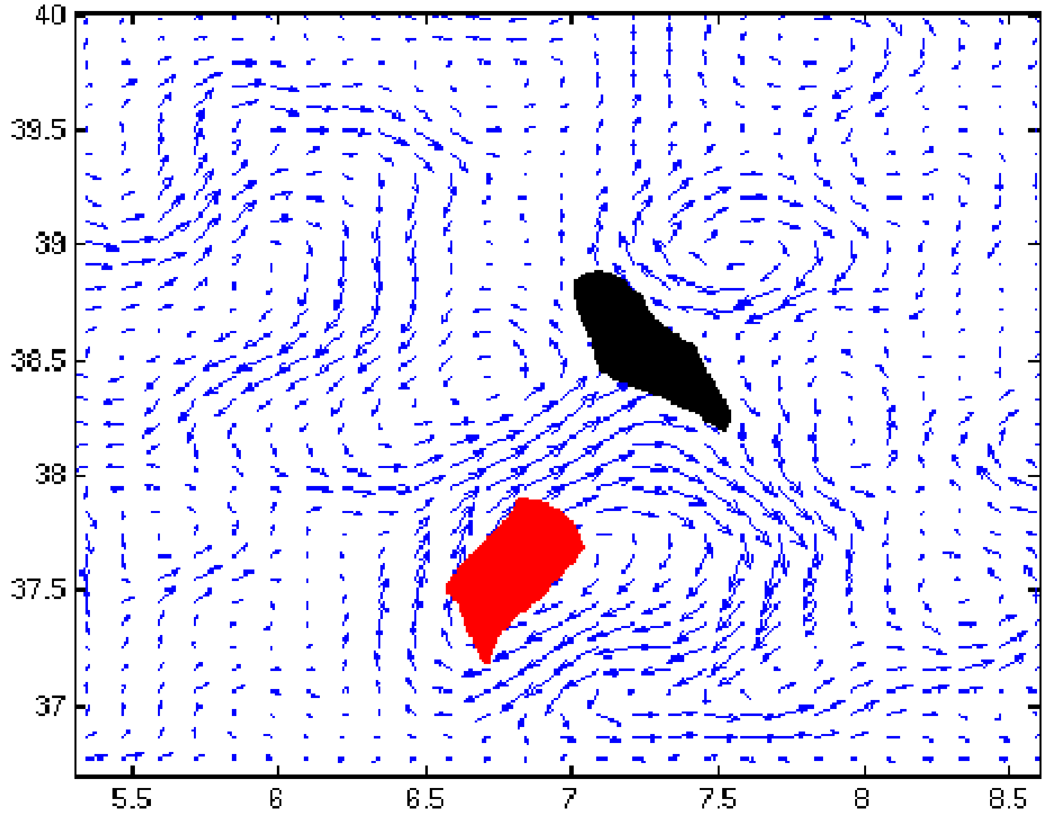
day 1



Mesoscale stirring drive a forward tracer cascade toward submesoscales

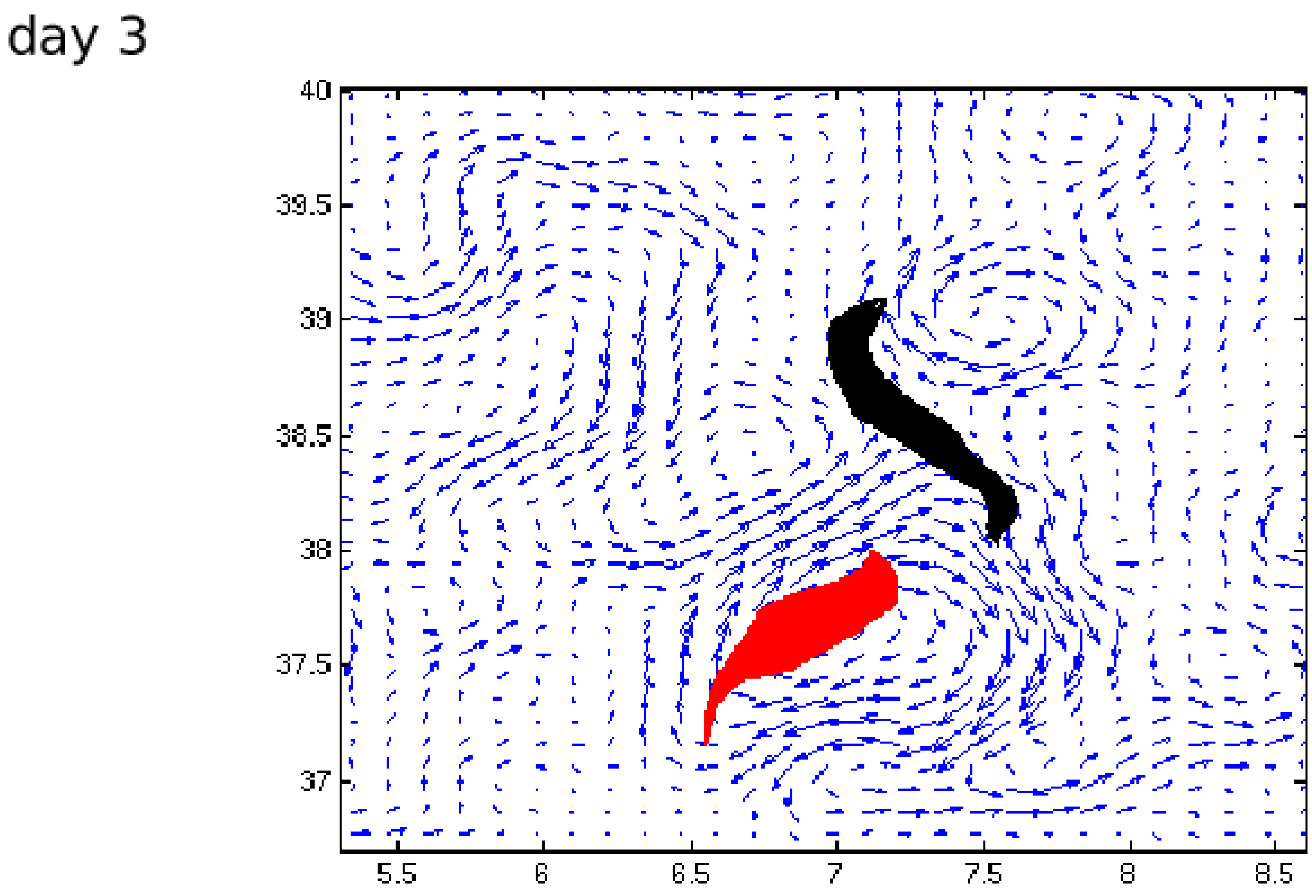
Tracer variance production by mesoscale stirring (2/2)

day 2



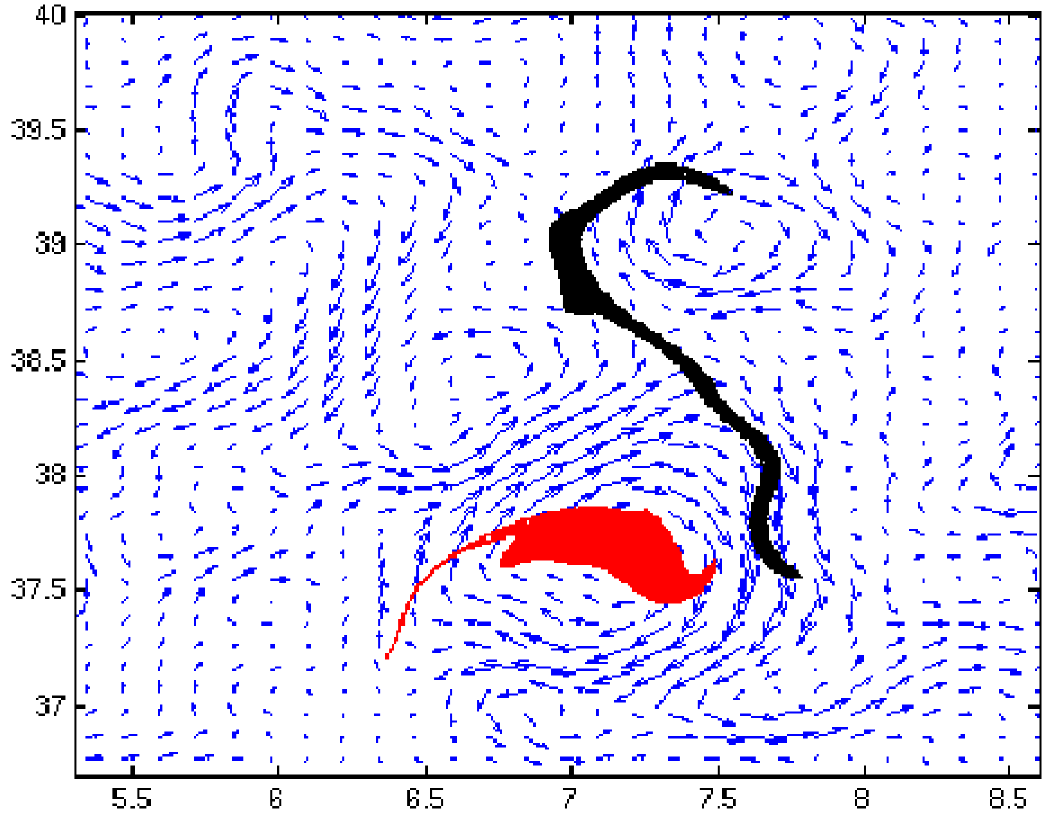
Mesoscale stirring drive a forward tracer cascade toward submesoscales

Tracer variance production by mesoscale stirring (2/2)



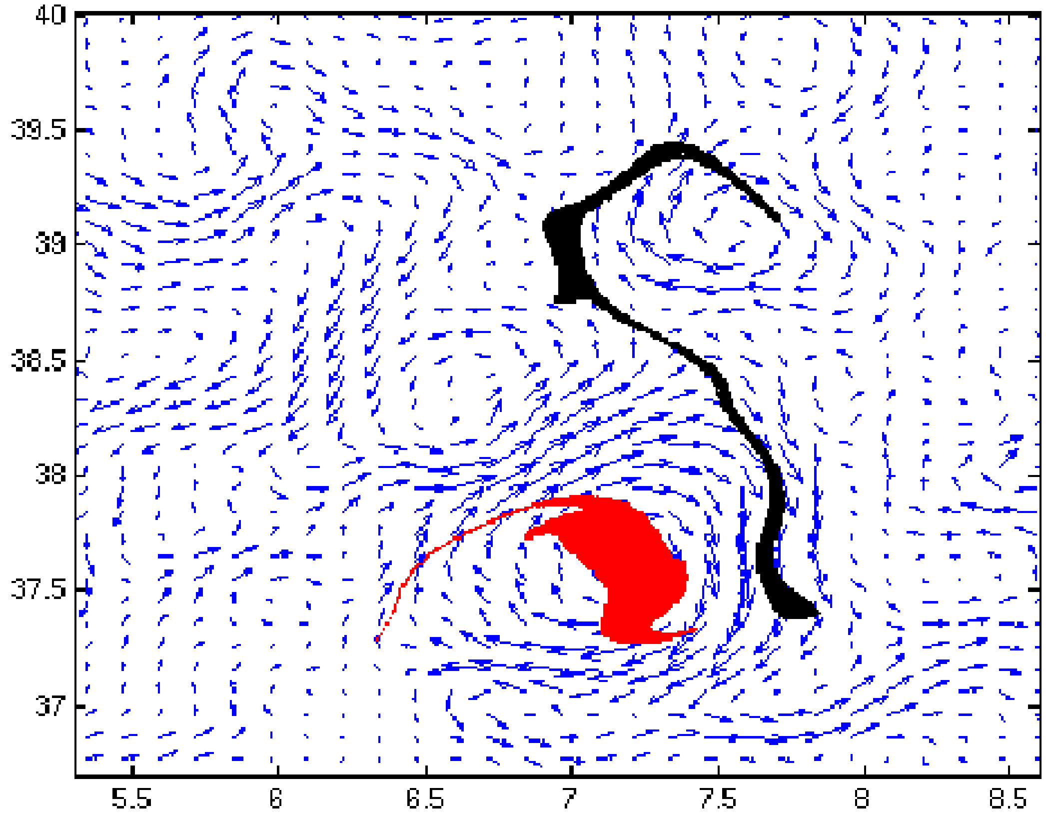
Mesoscale stirring drive a forward tracer cascade toward submesoscales

day 4



Mesoscale stirring drive a forward tracer cascade toward submesoscales

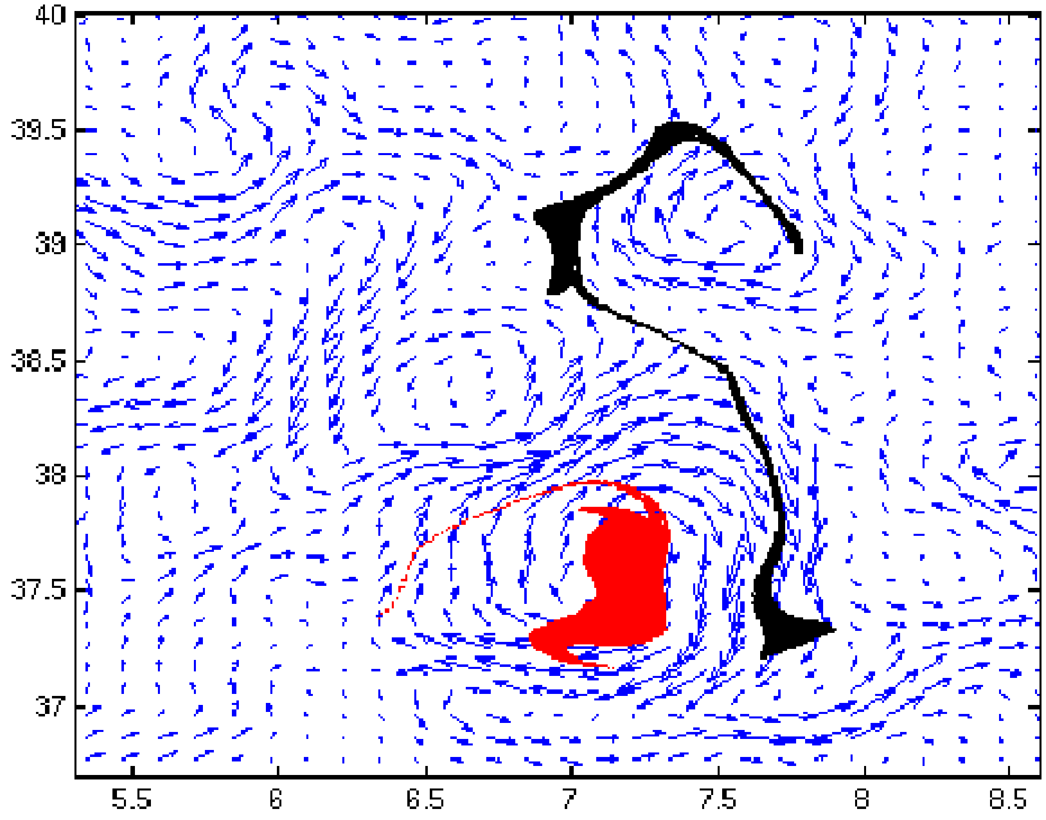
day 5



Mesoscale stirring drive a forward tracer cascade toward submesoscales

Tracer variance production by mesoscale stirring (2/2)

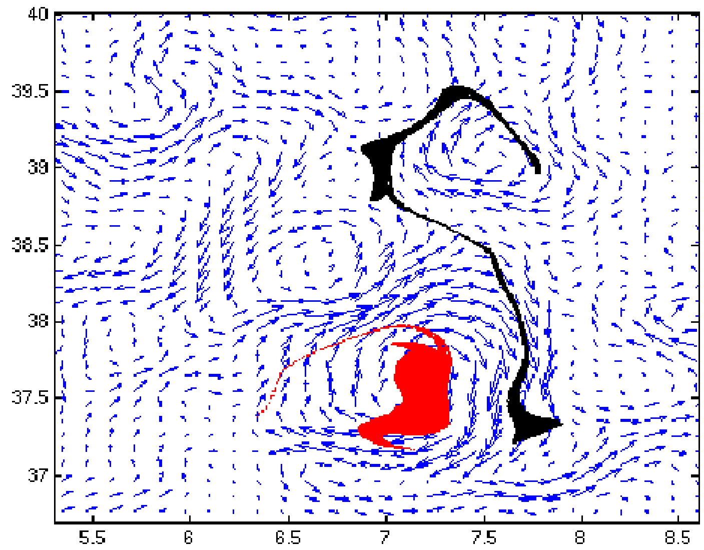
day 6



Mesoscale stirring drive a forward tracer cascade toward submesoscales

Tracer variance production by mesoscale stirring (2/2)

day 6



- stirring by mesoscale flows is a intrinsically **anisotropic** mechanism
- **mesoscale** velocity fields carry some information about the **submesoscales**
- several methods exist for extracting this information, including
  - Effective diffusivity diagnostics
  - Finite-size Lyapunov exponents (see e.g. the new CTOH product)

(mesoscale stirring is obviously not the only process contributing to forming submesoscale features...)

Outline

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LES

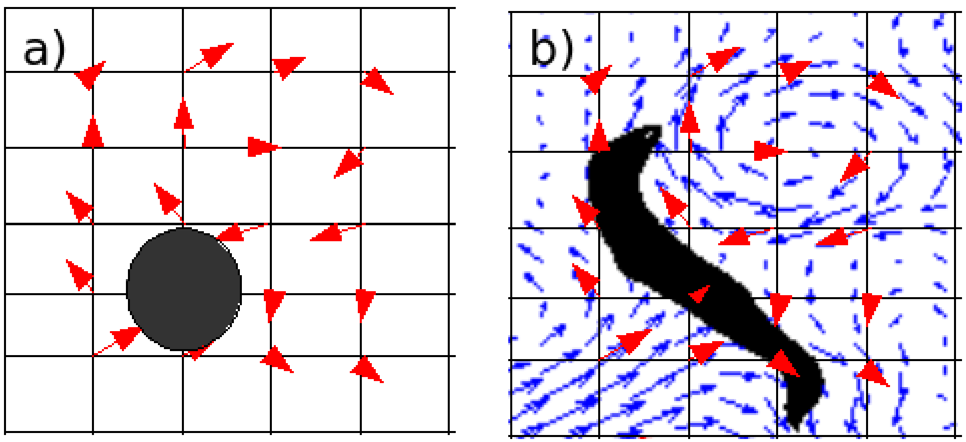
For diagnosing $\mathcal{P}$ we need to model $\mathcal{M}(u,\tau) = \nabla \cdot (\widehat{u\tau} - \widehat{u}\widehat{\tau})$

<u>Two-dimensional sketch flow</u>

Close to stagnation points :

$$\nabla \cdot (\widehat{u}\widehat{\tau}) \simeq 0$$

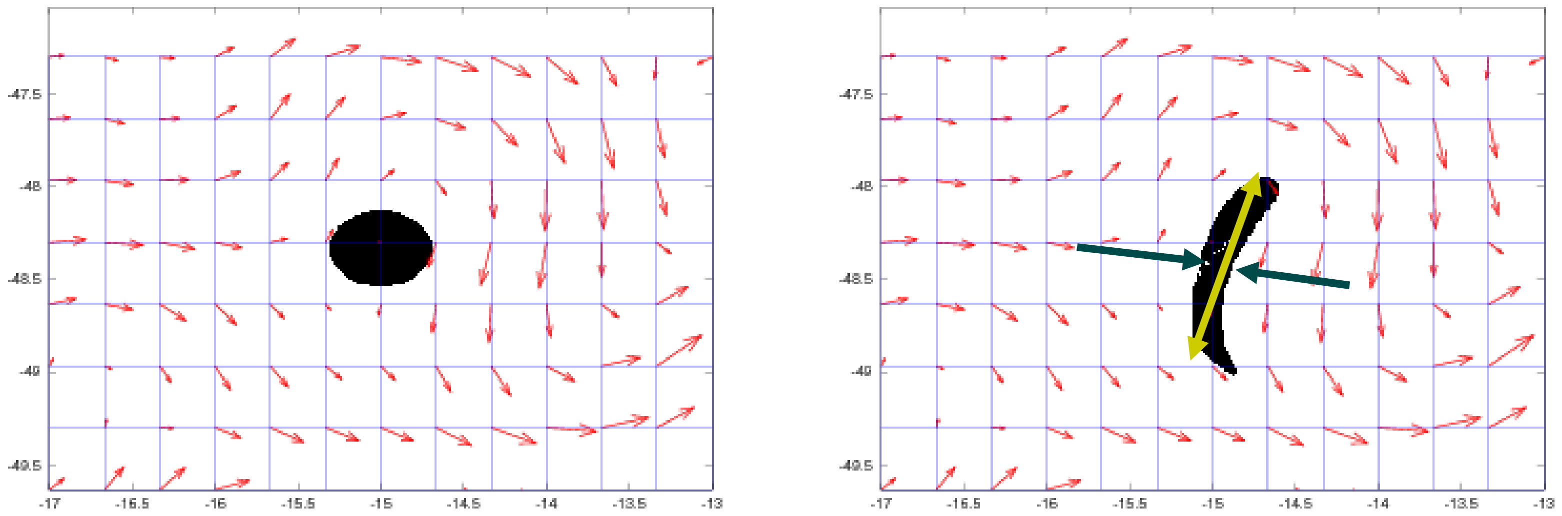
But : $\mathcal{M}(u,\tau) \neq 0$



<u>One-dimensional sketch flow:</u>

$$u = r\,x \qquad \hat{\tau} = \int \tau(x+l)e^{l^2/2\sigma^2}dl$$

Here we get $\partial_t\hat{\tau} + \hat{u}\,\partial_x\hat{\tau} \simeq \frac{\sigma^2}{2}\,\partial_x(r\,\partial_x\hat{\tau})$



LES

"Strain diffusivity operator"

Proposed by Leonard and Winckelmans, 1999 ...

$$\nabla \cdot (\widehat{u\theta} - \widehat{u}\widehat{\theta}) \simeq \nabla \cdot (\kappa_{ij} \nabla \widehat{\theta})$$

$$\kappa_{ij} \propto h^2 s_{ij}$$

Compression : production of submesoscale variance

$$\kappa_{ij} = \kappa_+ + \kappa_-$$

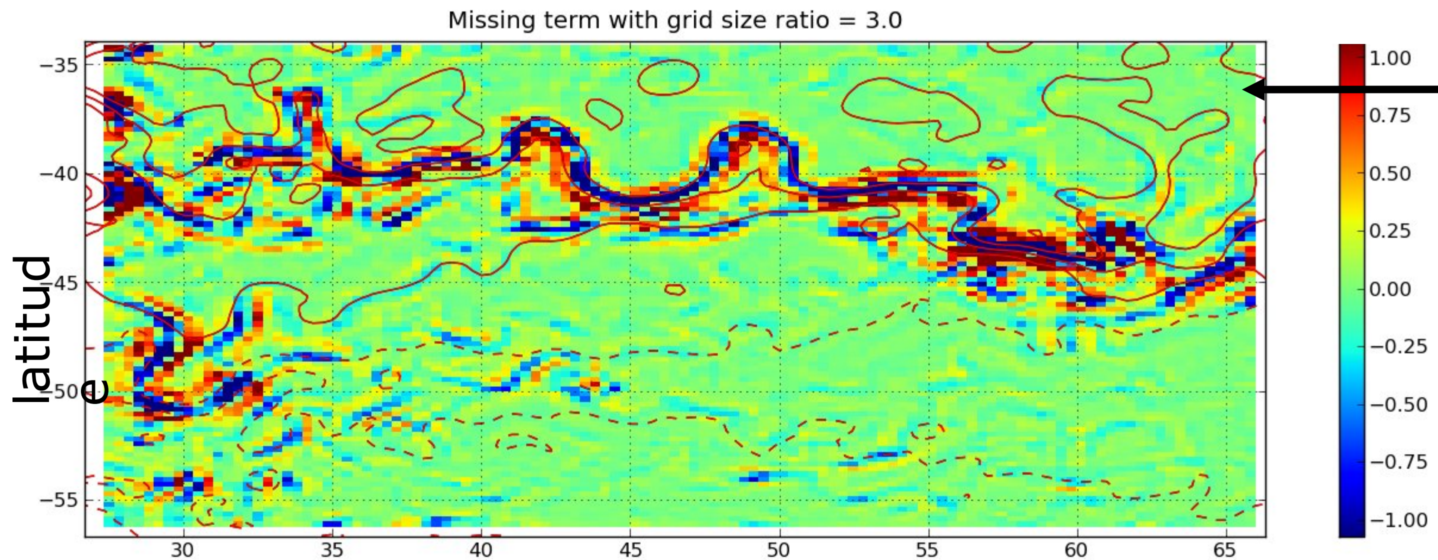
$$s_{ij} = \frac{1}{2}(\nabla u + \nabla u^T)$$

Stretching : destruction of submesoscale variance

Related to the LOM parameterization which retains only the stretching effect for use in OGCMs *(Le Sommer, d'Ovidio and Madec 2010)*

Modeling stirring by mesoscale flows (3/3)

θ Reynolds OI SST u Ssalto/Duacs



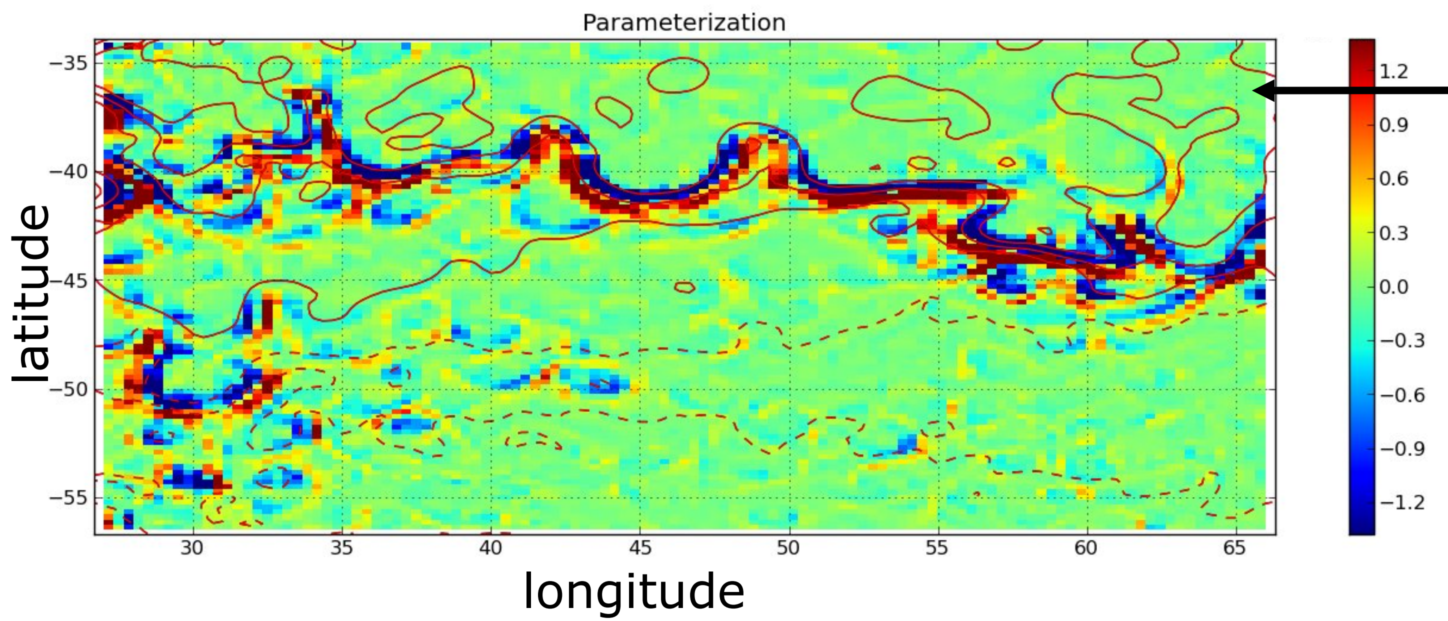
$$\nabla \cdot (\widehat{u\theta} - \widehat{u}\widehat{\theta})$$

$\widehat{u\theta}$

Interpolated fields on a hi-res grid

$\widehat{u}\,\widehat{\theta}$

From lo-res fields (on a hi-res grid)



$$\nabla \cdot (\kappa_{ij} \nabla \widehat{\theta})$$

LOM parameterization on the lo-res grid

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Datasets and methods

Data

Surface velocities :

from Ssalto/Duacs MADT (upd) distributed by AVISO
Global 1/3° mercator grid, 7 days

Sea surface temperature :

OI AMSR+AVHRR distributed by NOAA *(Reynolds et al. 2007)*
Global 1/4°, daily

Period

Jan 2003- Dec 2005 : optimal quality of the two blended products

SSH : 4 satellites : T/P, Envisat, GFO, Jason-1
SST : AMSR-E available since 2002

Processing

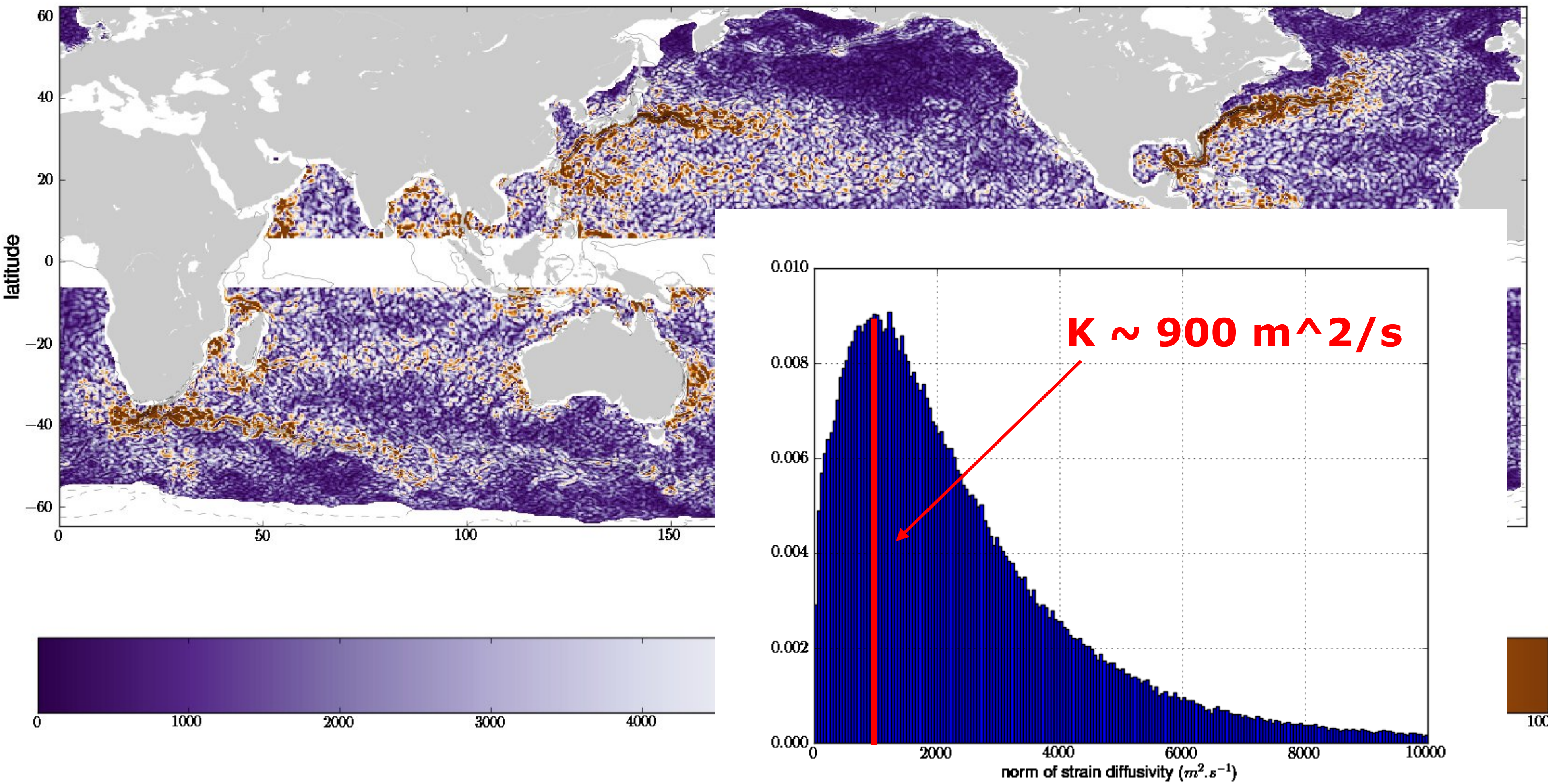
- **Strain diffusivity** is computed every 7 days on AVISO grid
- **Variance production** computed every day on AVISO grid

$$\mathcal{P} = 2\,\nabla\tau \cdot (\kappa_{ij}\nabla\tau)$$

- Time average over Jan 2003 – Dec 2005

Diagnosing variance production (1/3)

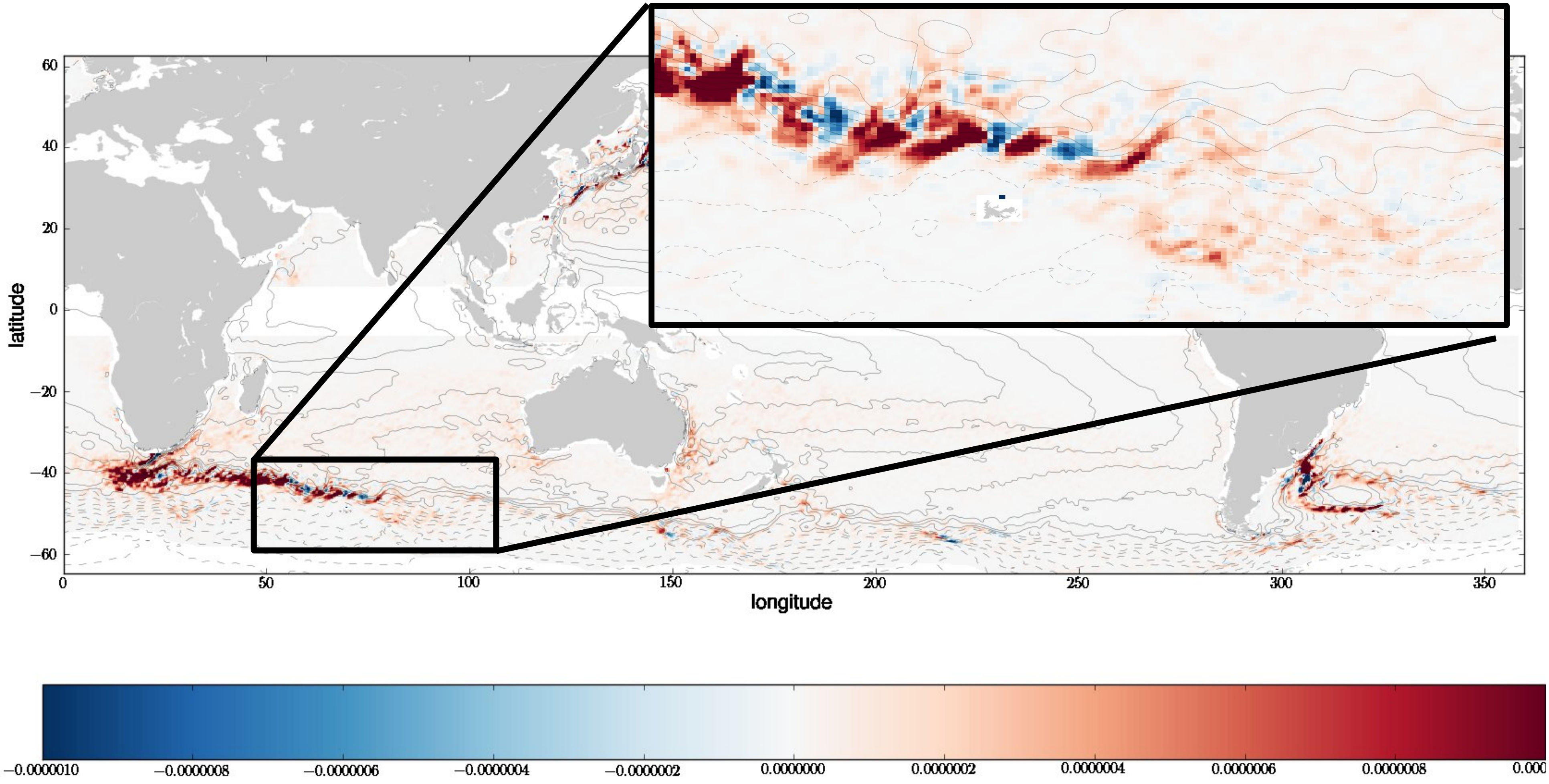
Norm of the instantaneous Strain Diffusivity operator



(m2.s-1)

$$\overline{\mathcal{P}} = \overline{2\,\nabla\tau\cdot(\kappa_{ij}\nabla\tau)}$$

Time-averaged submesoscale variance production rate

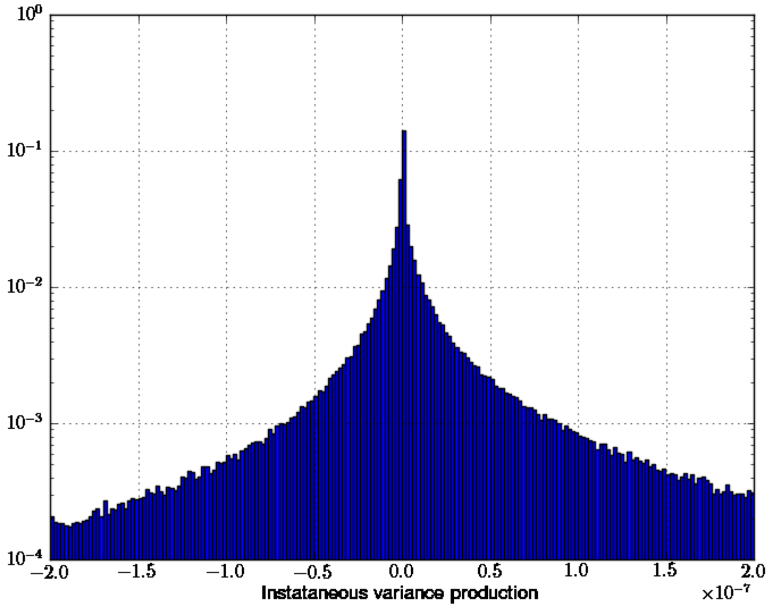


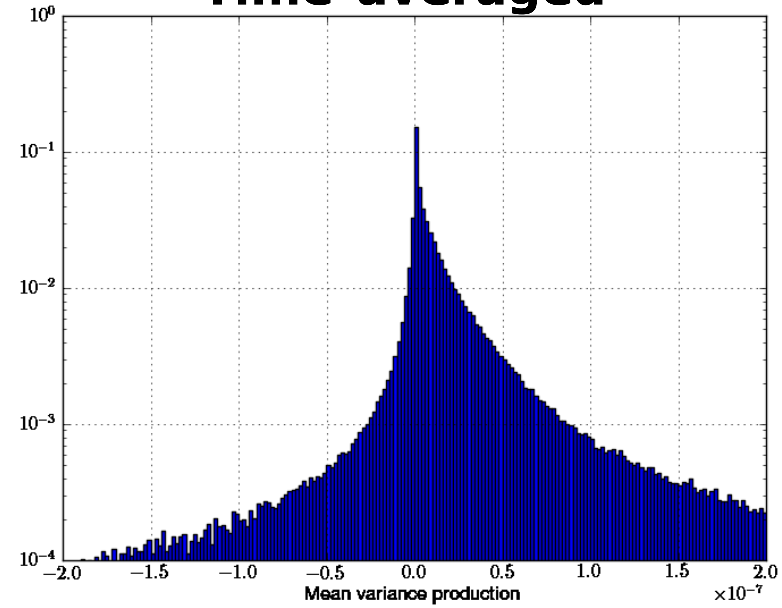
(K^2.s-1)

Diagnosing variance production (3/3)

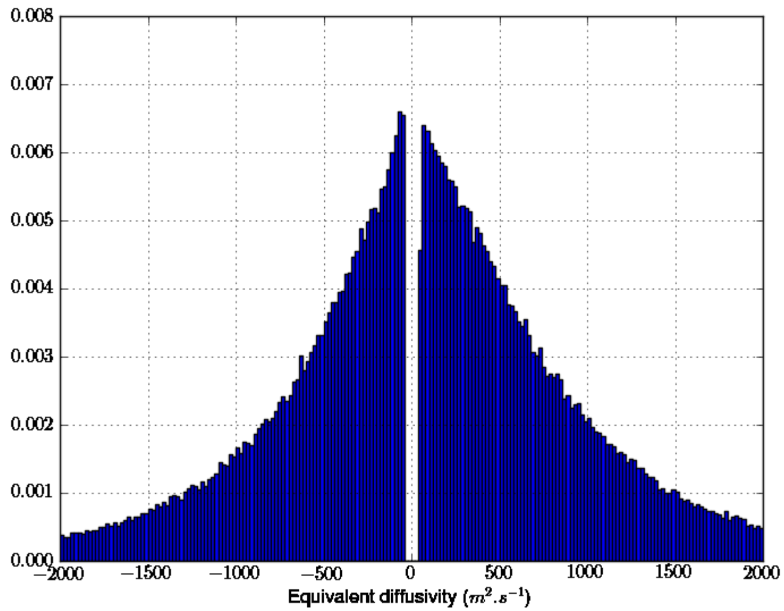
Instantaneous | **Time-averaged**

$$\mathcal{P}$$

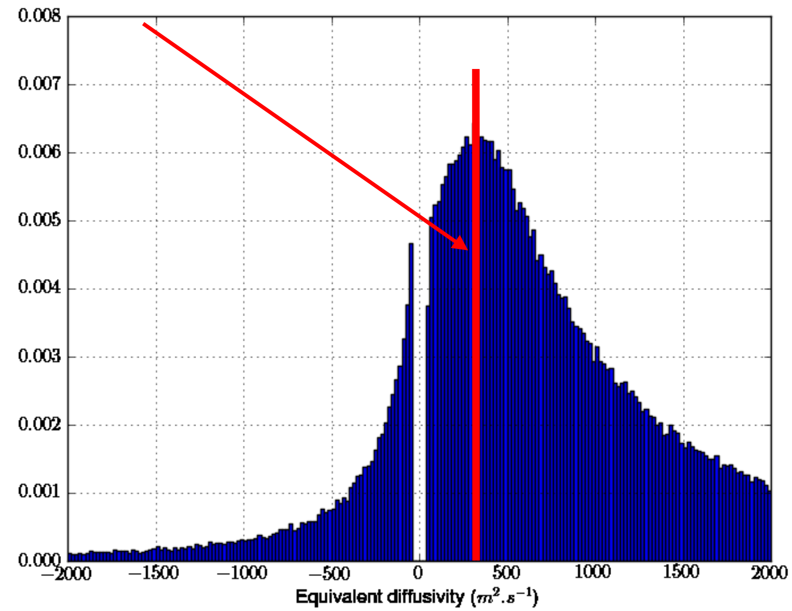




$$\frac{\mathcal{P}}{||\nabla\widehat{\theta}||^2}$$



K ~ 300 m^2/s



Conclusions

Take home messages :

- Stirring by mesoscale flows forms submesoscale structures in SST field
- This mechanism can be diagnosed with satellite data (SSH + SST)
- Variance production due to mesoscale stirring is highly **inhomogeneous**
- Strain due to **persistent mesoscale jets** contribute to variance production
- On average, variance production is positive but there exists large regions where **mesoscale stirring is destroying** submesoscale SST variance