Lagrangian reconstructions of tracer fields at ocean surface

Stefano Berti and Guillaume Lapeyre

Laboratoire de Météorologie Dynamique
ENS Paris

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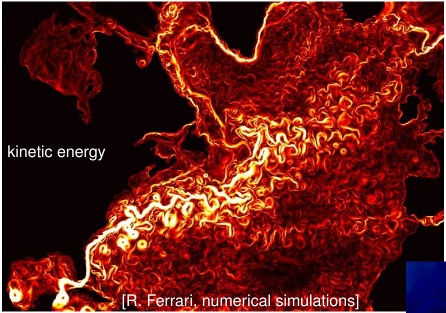
Motivation

turbulent ocean: spatiotemporal variability over a large range of scales



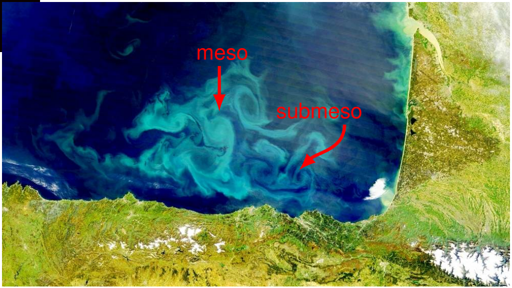
[R. Ferrari, numerical simulations]

interactions between mesoscale eddies ($\sim$ 100 km)

$\Rightarrow$ smaller scale structures ($\sim$ 10 km)

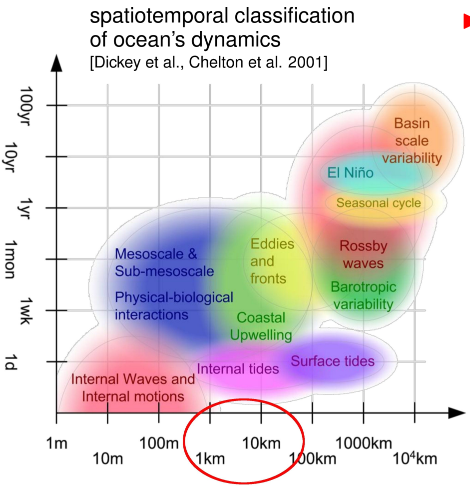
submesoscale:

- vertical transport
  [Lévy 2008; Klein and Lapeyre 2009]
- strongly energetic
  [Capet et al. 2008; Klein et al. 2009]



[MODIS Aqua, sea colour, Bay of Biscay]

Motivation



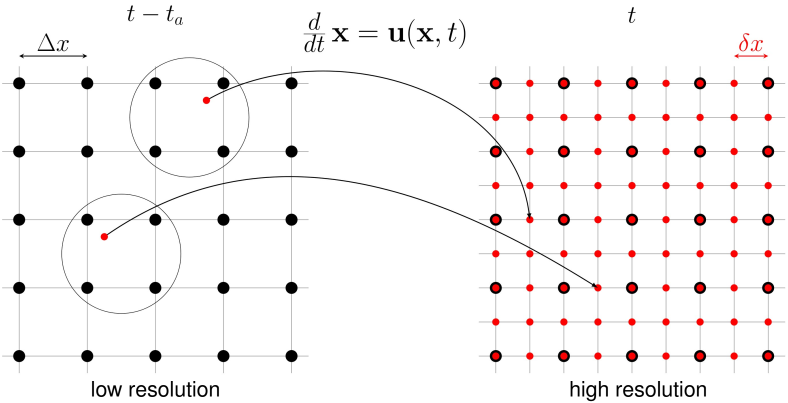
- Spatial resolution of satellite data:
  - Sea Surface Height - SSH
    (T/P, Jason, ...) $\rightarrow \Delta x \approx$ 100 km
  - Sea Surface Temperature - SST
    (AMSR-E) $\rightarrow \Delta \approx$ 50 km
  - Sea Surface Temperature - SST
    (AVHRR) $\rightarrow \Delta \approx$ 1 km (but clouds)
  - Chlorophyll - CHL
    (SeaWiFS, MODIS) $\rightarrow \Delta \approx$ 1 km (but clouds)

$\Rightarrow$ Practically **no access** to submesoscales on a global scale

Reconstructions: Lagrangian method

available databases (SSH, SST, CHL) $\Rightarrow$ **tools for reconstruction**

time series at low resolution $(\phi_{LR}(t), \phi_{LR}(t-\Delta t), \phi_{LR}(t-2\Delta t), ...)$ $\rightarrow$ small scales



For each particle at $\boldsymbol{x}_i = i\delta\boldsymbol{x}$ at time t: reverse trajectory to time $t - t_a$

SST evolution in the SQG regime (1)

$$\boxed{\partial_t\theta + \boldsymbol{u}\cdot\nabla\theta + \beta v = F + D}$$

Sea Surface Temperature: $\phi = \theta + \beta y$

Large scale temperature gradient: $\beta = \frac{\partial\phi}{\partial y}$

Velocity field: $(u, v) = (-\partial_y\psi, \partial_x\psi)$

Forcing: $F = -\kappa\left(\langle\theta\rangle_x - \bar{\theta}_{\text{forcing}}\right)$ (relaxation)

Dissipation: D

SST evolution in the SQG regime (2)

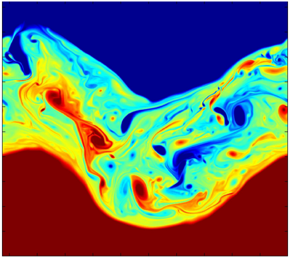
Surface Quasi Geostrophy: interior PV$= 0$; $N =$const

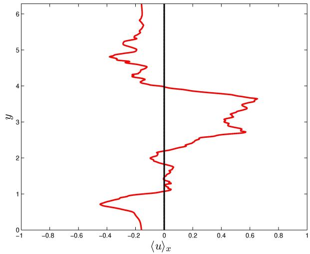
$$\begin{cases} Q = \nabla^2\psi + \frac{\partial^2\psi}{\partial z^2} & \text{(PV)} \\ \frac{\partial\psi}{\partial z}\Big|_{z=0} = \theta_s & \text{(BC)} \end{cases}$$

PV inversion $\Rightarrow$ $\hat{\psi} = \frac{1}{k}\hat{\theta}$ at the surface

- SQG correctly represents mesoscale and submesoscale dynamics of upper ocean layers

SST

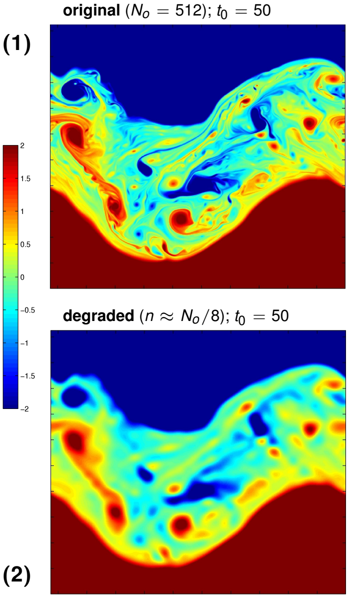




zonally averaged velocity

[Held et al. 1995; Lapeyre and Klein 2006; Isern-Fontanet et al. 2006; Klein et al. 2008]

Reconstruction of SST fields



(1) Direct numerical simulations (SQG) with N_o

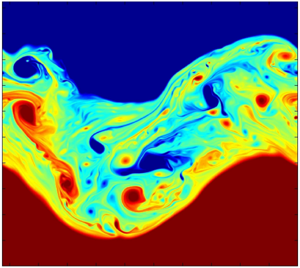
(2) Degradation of both $\boldsymbol{u}$ and ϕ at $n \approx N_o/8$

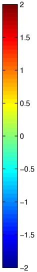
(3) Lagrangian reconstruction with $N = N_o$ particles

Reconstruction of SST fields

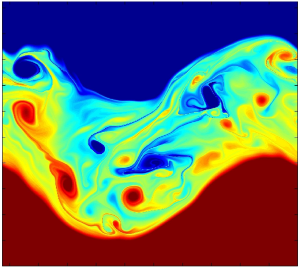
original ($N_o = 512$); $t_0 = 50$

(1)





reconstructed ($N = 512$); $t_0 = 50$



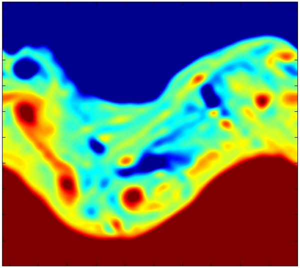
(3)

backward advection with $t_a = 1.5$

best for $1 < t_a < 2$

timescale of large eddies: $t_E \approx 0.3 \div 0.4$

degraded ($n \approx N_o/8$); $t_0 = 50$



(2)

(1) Direct numerical simulations (SQG) with N_o

(2) Degradation of both $\boldsymbol{u}$ and ϕ at $n \approx N_o/8$

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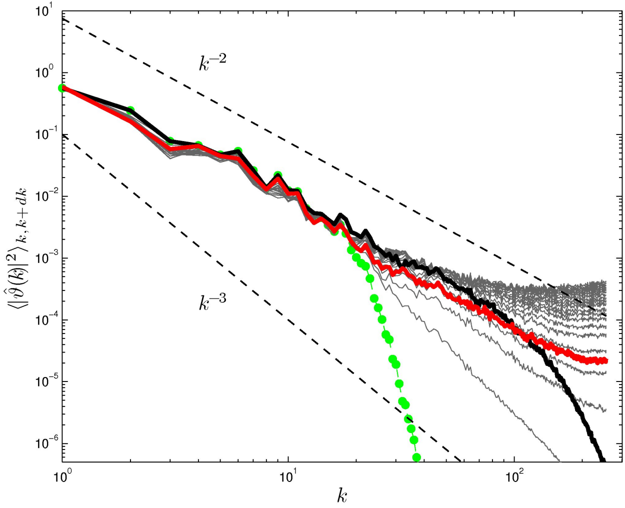
Spectra of temperature fluctuations

temperature fluctuation $\vartheta = \theta - \langle\theta\rangle_x$; $\theta = \phi - \beta y$



- original at t_0
- degraded at t_0
- reconstructed with $t_a = 0.5, 1.0, 1.5, \ldots$
- reconstructed with $t_a = 1.8$

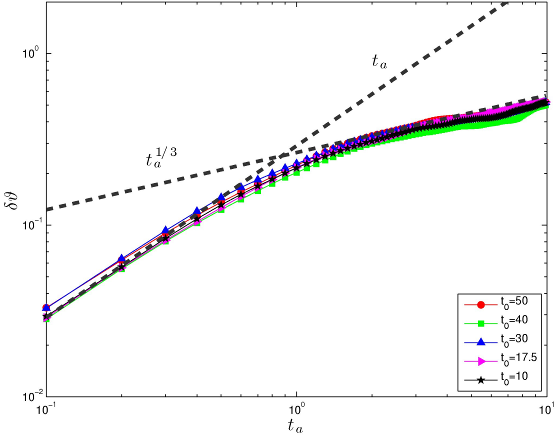
SQG: $\hat{\psi} = \hat{\vartheta}/k \;\Rightarrow\; E(k) \propto \langle|\hat{\vartheta}(k)|^2\rangle$ kinetic energy spectrum

Growth of rms difference

root mean square difference $\delta\vartheta(t_a) = \langle[\vartheta(t_a;t_0) - \vartheta(t_0)]^2\rangle^{1/2}$

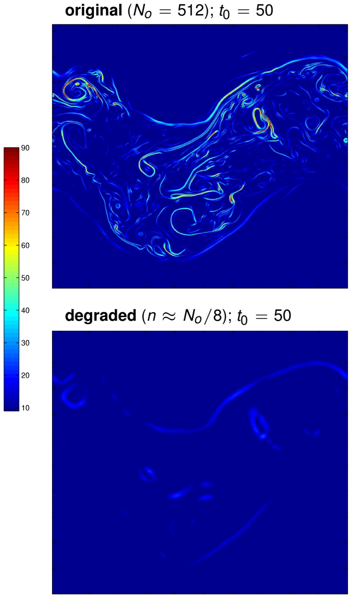
$\vartheta(t_a;t_0)$ reconstruction with t_a

$\vartheta(t_0)$ degraded at t_0 ($t_a = 0$)



crossover for $1 < t_a < 2$

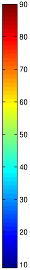
Gradients of SST fields



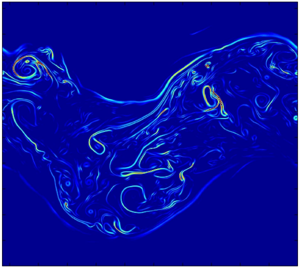
interest: detection of fronts

intensity of tracer gradients $|\boldsymbol{\nabla}\vartheta| = \sqrt{(\partial_x\vartheta)^2 + (\partial_y\vartheta)^2}$

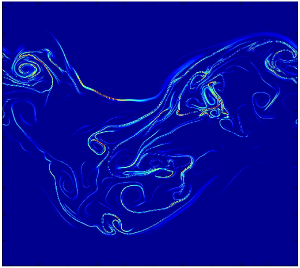
Gradients of SST fields



original ($N_o = 512$); $t_0 = 50$



reconstructed ($N = 512$); $t_0 = 50$

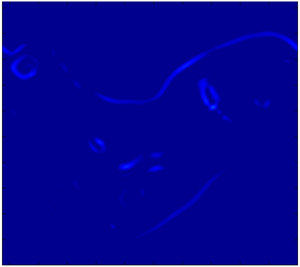


backward advection

with $t_a = 1.7$

best for $1 < t_a < 2$

degraded ($n \approx N_o/8$); $t_0 = 50$



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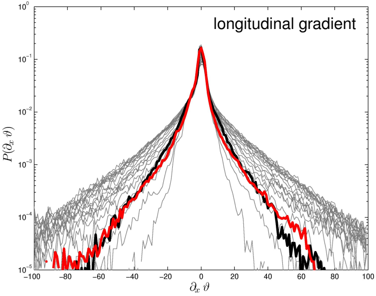
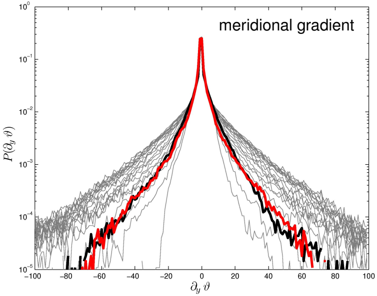
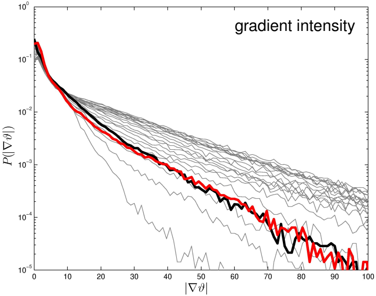
Probability distribution of SST gradients







- original at t_0
- reconstructed with $t_a = 0.5, 1.0, 1.5, \ldots$
- reconstructed with $t_a = 1.7$

Conclusions

Summary

Lagrangian technique for the reconstruction of tracer fields at ocean surface:

1. good agreement in a range of advective timescales, even in the presence of an external forcing;
2. optimal advection time for reconstructions;
3. capability to reproduce the statistics of fronts.

Next steps

1. Quantifying the importance of forcing.
2. Implementation with satellite data.
3. Propagation at depth, using the SQG framework.

S. Berti, G. Lapeyre, to be submitted to J. Phys. Oceanogr.