Finite-scale dispersion in the southwestern Atlantic Ocean: analysis of Lagrangian drifters data

S. Berti [1], F. dos Santos [2], G. Lacorata [3], A. Vulpiani [4]

[1] Laboratoire de Météorologie Dynamique, ENS - CNRS, Paris (France)

[2] Prooceano Ltda., Rio de Janeiro (Brazil)

[3] Institute of Atmospheric and Climate Sciences, CNR, Lecce (Italy)

[4] Department of Physics, CNR-ISC, University “Sapienza”, Roma (Italy)

Atmospheric and Oceanic Fluid Dynamics
2011 - Spokane, USA

Outline

1. Lagrangian dispersion
2. Analysis of Lagrangian drifters data
3. Conclusions

Motivation

Lagrangian data from experimental campaigns:

- test theories and models
- advection-diffusion properties in applications

$\triangleright$ analysis of trajectory pair dispersion $\Rightarrow$

$\Rightarrow$ locally dominant physical mechanism

(e.g. chaotic advection, turbulence, diffusion)

Turbulent dispersion

δ_R: Rossby radius of deformation; $\quad k_R = 2\pi/\delta_R$

$k > k_R \Rightarrow$ down-scale (direct) enstrophy cascade $E(k) \sim k^{-3}$

$k < k_R \Rightarrow$ up-scale (inverse) energy cascade $E(k) \sim k^{-5/3}$

Relative dispersion perspective:

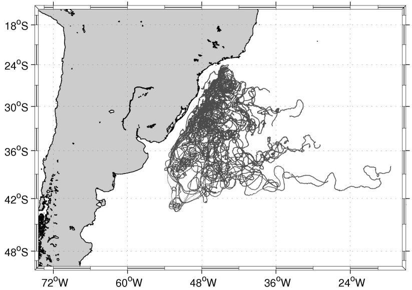
$\delta < \delta_R \Rightarrow \langle R^2(t) \rangle \simeq e^{2\lambda_L t}$ exponential growth

$\delta > \delta_R \Rightarrow \langle R^2(t) \rangle \sim t^3$ superdiffusion (Richardson)

Obhukov (1941); Batchelor (1950); Kraichnan (1967); Charney (1971); Lin (1972)

LaCasce, Progress in Oceanography (2008)

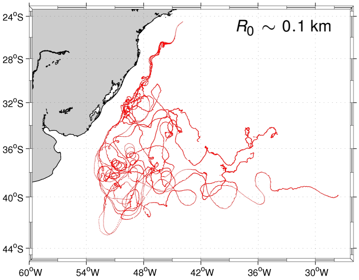
Drifter data set (MONDO project)

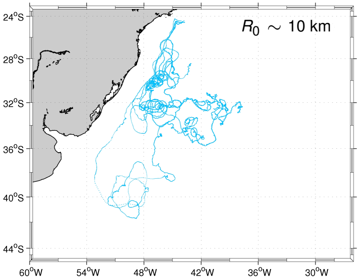


period: 21/9/2007 - 14/11/2008

37 SVP/WOCE drifters

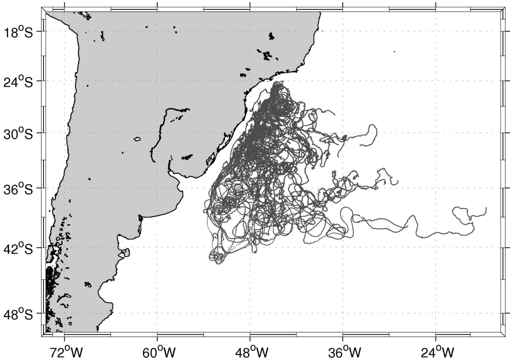
25 in clusters of 5





Berti et al., Journal of Physical Oceanography (2011)

Local oceanography



intense mesoscale activity

$\delta_M = (126 \pm 50)$ km

$\delta_m = (65 \pm 22)$ km

$\tau_L = (1 \div 5)$ days

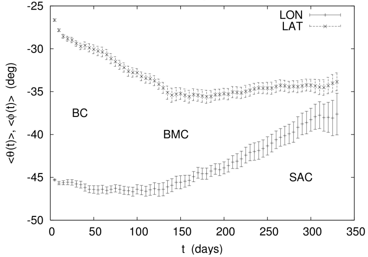
$\delta_E = (19 \div 42)$ km $\approx \delta_R$

$\mathrm{EKE} = (0.7 \div 0.9)\,\mathrm{TKE}$

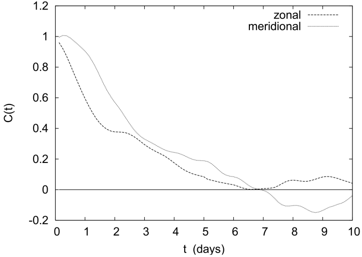
Lentini et al., Geophysical Research Letters (2002); Houry et al., Journal of Physical Oceanography (1987); Assireu et al., Continental Shelf Research (2003) Piola et al., Journal of Geophysical Research (1987)

1-particle statistics

average displacement

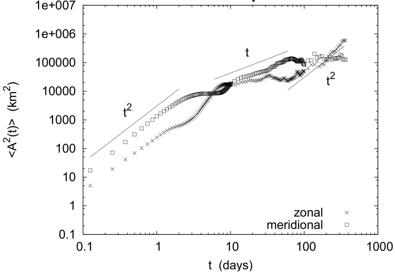


autocorrelation of velocity



$\tau_L \simeq 5$ days

absolute dispersion

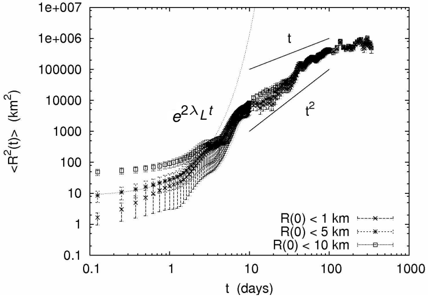


$$\langle A^2(t)\rangle = \langle[\boldsymbol{r}(t) - \boldsymbol{r}(0)]^2\rangle - \langle[\boldsymbol{r}(t) - \boldsymbol{r}(0)]\rangle^2$$

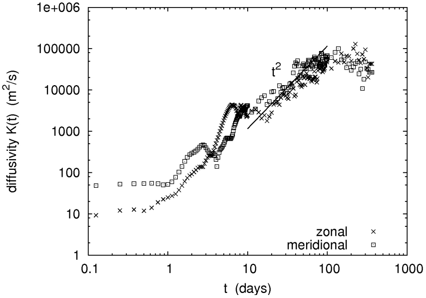
reflects anisotropy of the flow

2-particle statistics: fixed time

relative dispersion



diffusivity



$$\langle R^2(t)\rangle = \langle|\boldsymbol{r}^{(1)}(t) - \boldsymbol{r}^{(2)}(t)|^2\rangle$$

$\lambda_L \simeq 0.6$ days^{-1}

(exp. separation for $t \to 0$)

$\langle R^2(t)\rangle \sim 4K_E t$ for $t \to \infty$

$$K(t) = \frac{1}{4}\frac{dR^2(t)}{dt}$$

$K(t) \to K_E$ for $t \to \infty$

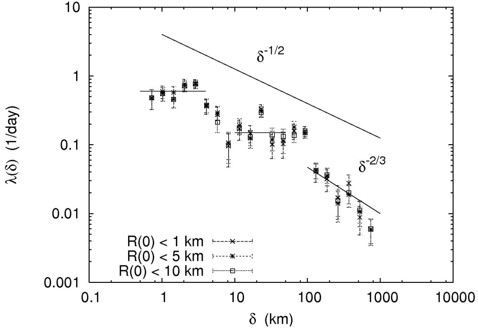
$K(t) \sim t^2$ superdiffusion

(Richardson: $\langle R^2(t)\rangle \sim t^3$)

LaCasce, Ohlmann, Journal of Marine Research (2003);
Ollitrault et al., Journal of Fluid Mechanics (2005); Koszalka et al., Journal of Marine Research (2009)

2-particle statistics: fixed scale

FSLE: $\lambda(\delta) = \frac{1}{\langle\tau(\delta)\rangle} \ln \rho$ (dispersion rate)



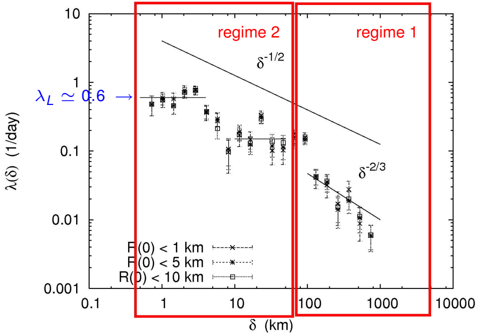
$\delta_k = \rho^k \delta_0; \quad k = 1, ..., N$

$\rho = \sqrt{2}$

Berti et al., Journal of Physical Oceanography (2011)

2-particle statistics: fixed scale

FSLE: $\lambda(\delta) = \frac{1}{\langle\tau(\delta)\rangle} \ln \rho$ (dispersion rate)



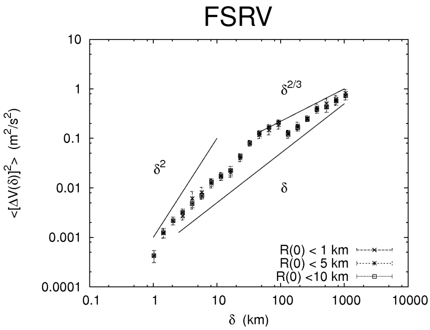
$\delta_k = \rho^k \delta_0$; $k = 1, ..., N$

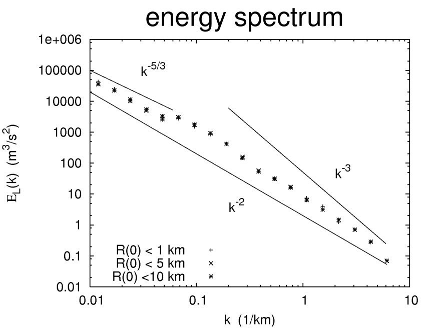
$\rho = \sqrt{2}$

1. $\delta \gg \delta_R \simeq 30$ km: Richardson dispersion $\lambda(\delta) \sim \delta^{-2/3}$
   (inverse cascade)
2. $\delta \lesssim \delta_R \simeq 30$ km: exponential dispersion $\lambda(\delta) \sim$ const
   (direct cascade; submesoscale structures?)

Berti et al., Journal of Physical Oceanography (2011)

2-particle statistics: fixed scale





$$\langle [\Delta V(\delta)]^2 \rangle = \langle |\boldsymbol{v}^{(1)} - \boldsymbol{v}^{(2)}|^2 \rangle_\delta \qquad E_L(k) = \frac{\langle [\Delta V(\delta)]^2 \rangle}{k} \,;\; k = 2\pi/\delta$$

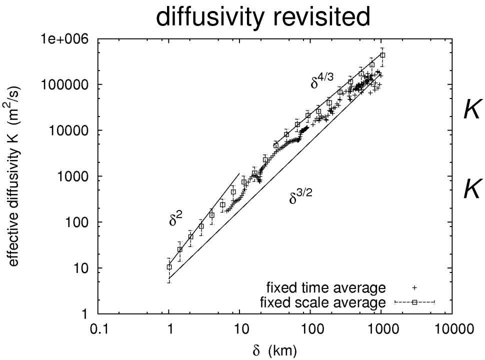
▷ turbulent double cascade scenario

$\delta \approx 100$ km (rings)

$\delta \approx 10$ km (submeso.)

$\Rightarrow$ possible “trapping events”

2-particle statistics



$$K(\delta) = \frac{1}{2}\delta\langle[\Delta V(\delta)]^2\rangle^{1/2} \quad \text{(fixed scale)}$$

$$K(t) \text{ vs. } \delta = \langle R^2(t)\rangle^{1/2} \quad \text{(fixed time)}$$

mesoscale ($\delta > \delta_R$): $K(\delta) \sim \delta^{4/3} \leftrightarrow E(k) \sim k^{-5/3}$ (inverse cascade)

$\delta = O(\delta_R)$: $K(\delta) \sim \delta^2 \leftrightarrow E(k) \sim k^{-3}$ (direct cascade)

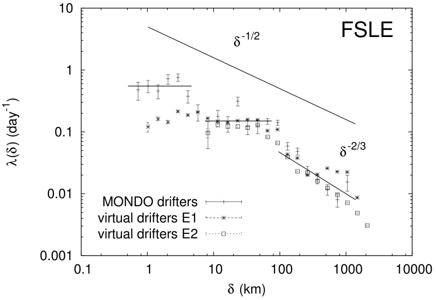
$K(\delta) \sim \delta^{3/2} \leftrightarrow E(k) \sim k^{-2}$ connects meso and submesoscales

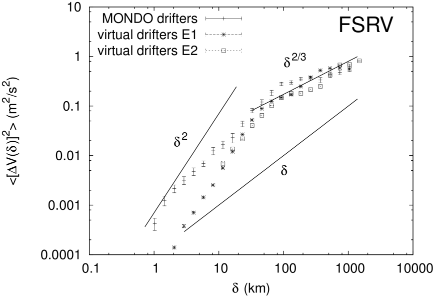
Capet et al., Journal of Physical Oceanography (2008); Klein et al., Journal of Physical Oceanography (2008)

Numerical results

HYCOM model; $(1/12)^\circ$ resolution

$N_p = 100$; (E1): $\langle R(0) \rangle \simeq 5$ km; (E2): $\langle R(0) \rangle \simeq 40$ km





- supports a double cascade scenario
- no deviations from QG turbulence
  (finite spatial resolution)

Conclusions

- Fixed-time indicators: turbulence double cascade (small scale: exp. separation; large scale: superdiffusion).
- Fixed-scale indicators:
  Richardson superdiffusion at mesoscales ($\delta = (100 \div 500)$ km);
  exponential separation (step-like FSLE) for $\delta < 100$ km:
  - direct cascade at $\delta \approx \delta_R \simeq 30$ km;
  - coherent structures at $\delta \lesssim 10$ km.
- Deviations from the "classical" scenario possibly due to submesoscale structures (but no clear scaling of the indicators).

More numerical results

HYCOM model; $(1/12)^\circ$ resolution

$N_p = 100$; (E1): $\langle R(0) \rangle \simeq 5$ km; (E2): $\langle R(0) \rangle \simeq 40$ km