In situ measurements of ε and Kz compared to numerical models in the Gulf of Lion

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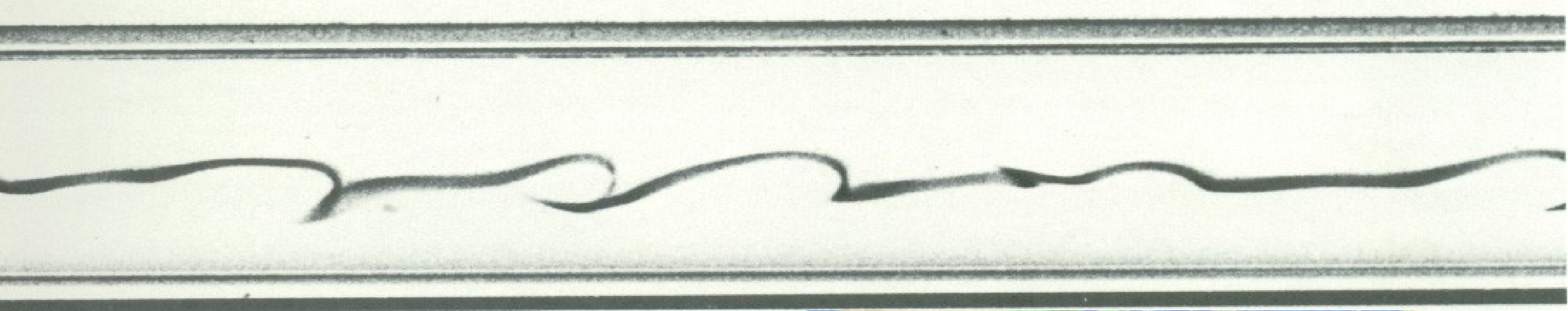
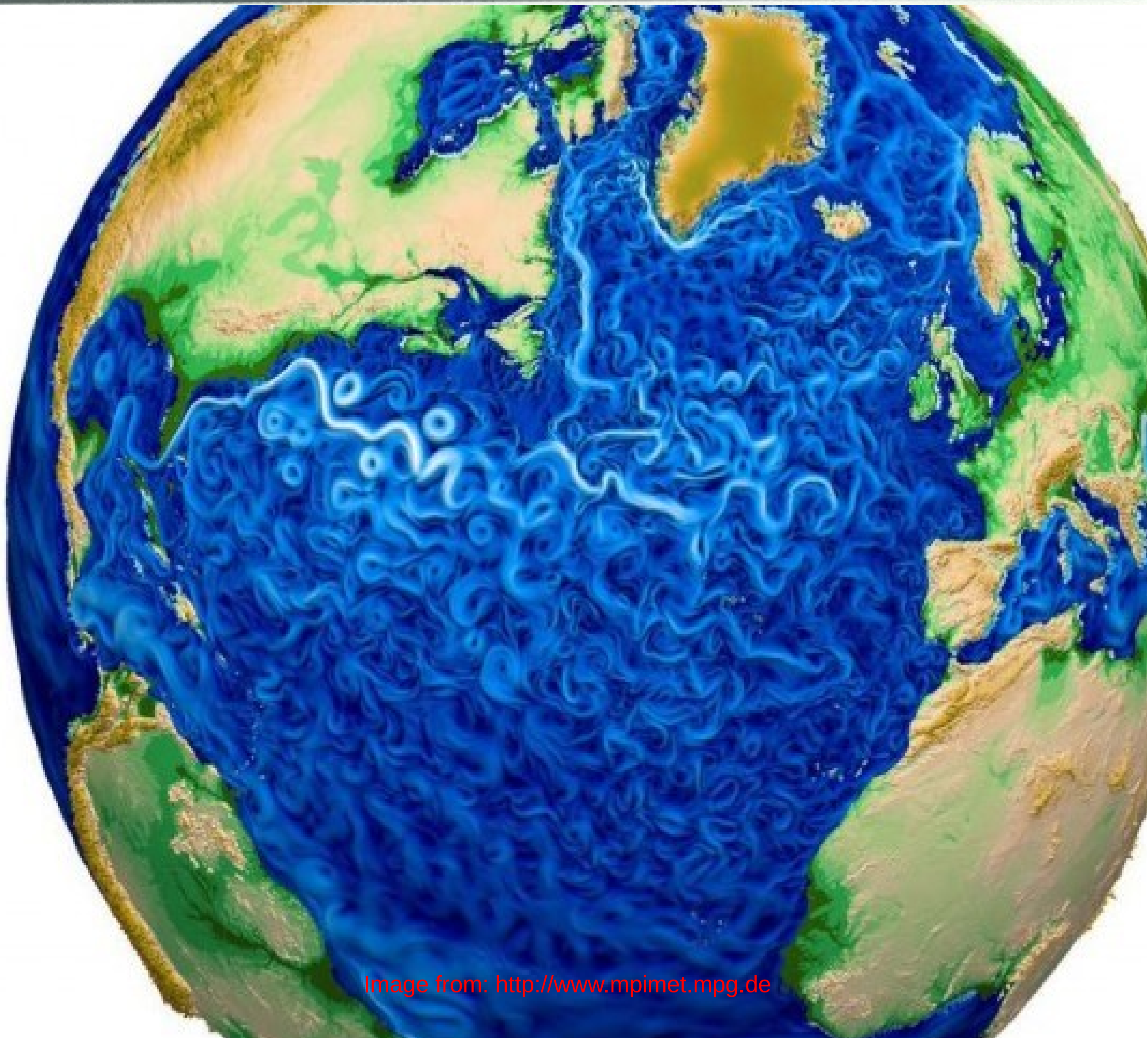
IRD Institut de recherche pour le développement
Aix-Marseille université
Université Toulon-Var
MIO Mediterranean Institute of Oceanography

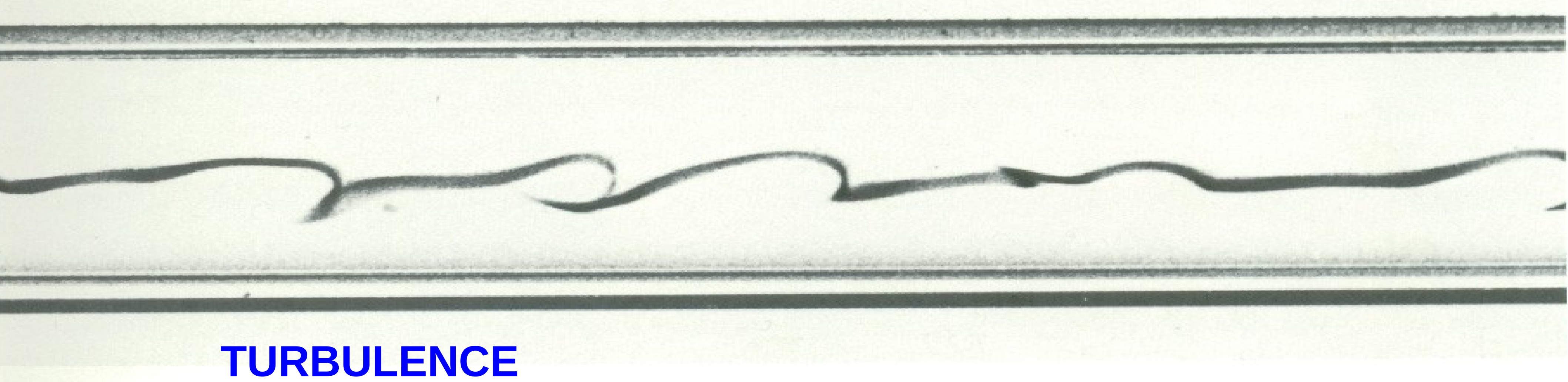


TURBULENCE

Ubiquitous phenomenon.

- Energy balance



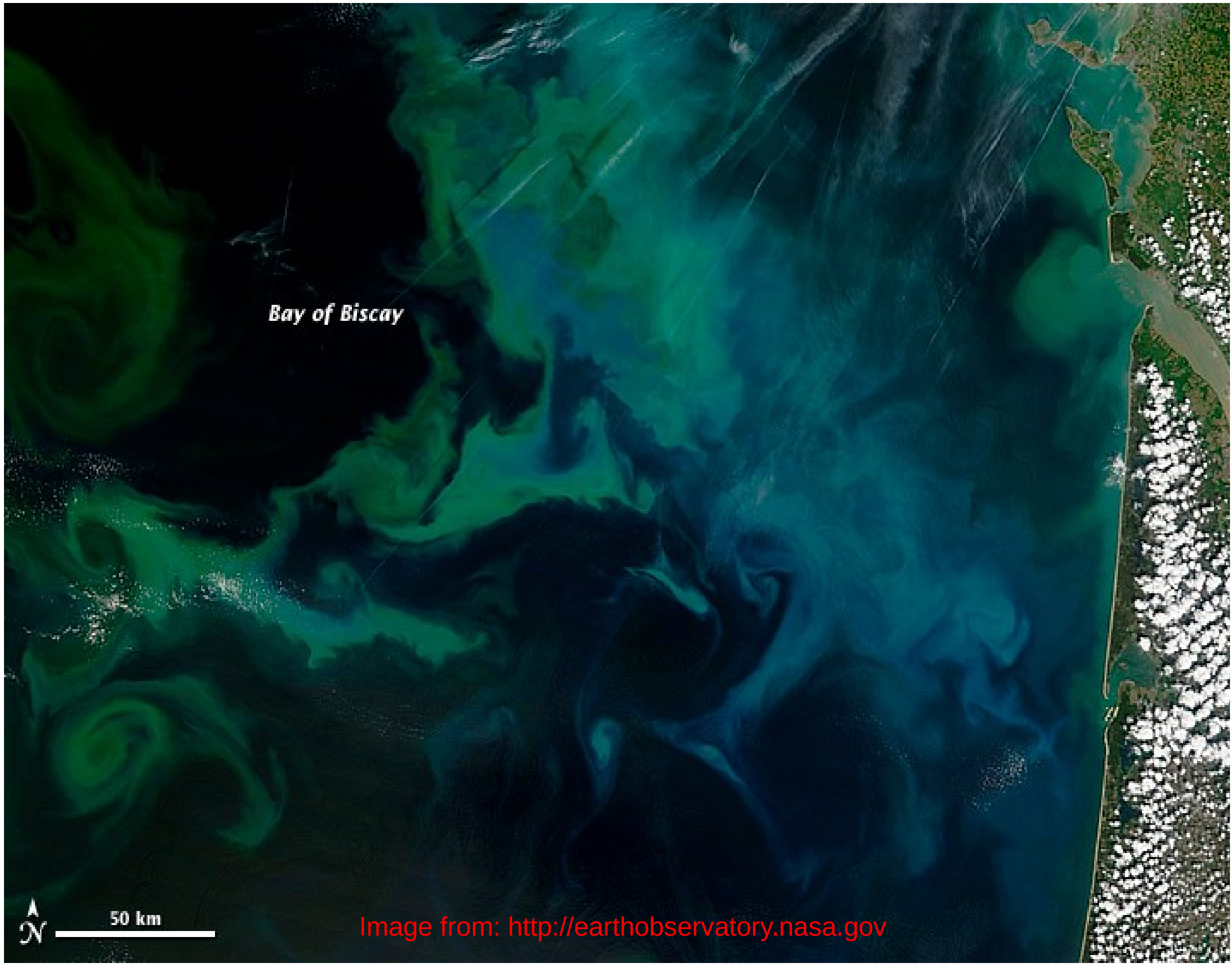


TURBULENCE

Ubiquitous phenomenon.

- Energy balance

- Forcing of bio-chemical processes



What ε and K_z are

$$\frac{D\overline{u}_i}{Dt} = \frac{-\partial \overline{p}}{\partial x_i} + \nu \frac{\partial^2 \overline{u}_i}{\partial x_i \partial x_j} - \frac{\partial \overline{u'_i u'_j}}{\partial x_i}$$

Momentum conservation

↓ *closure problem*

$$-\overline{u'_i u'_j} = \nu_T \frac{\partial \overline{u}_i}{\partial x_j}$$

Boussinesq's hypothesis

↓ *parametrization*

$$\epsilon = -\nu \overline{\frac{\partial u'_i}{\partial x_j} \frac{\partial u'_j}{\partial x_i}}$$

TKE equation

$$\frac{DT}{Dt} = K_T \frac{\partial T}{\partial x_i} - \frac{\partial \overline{T' u'_i}}{\partial x_i}$$

Heat conservation

↓ *closure problem*

$$-\overline{T' u'_i} = K_{Turb} \frac{\partial T}{\partial x_j}$$

Boussinesq's hypothesis

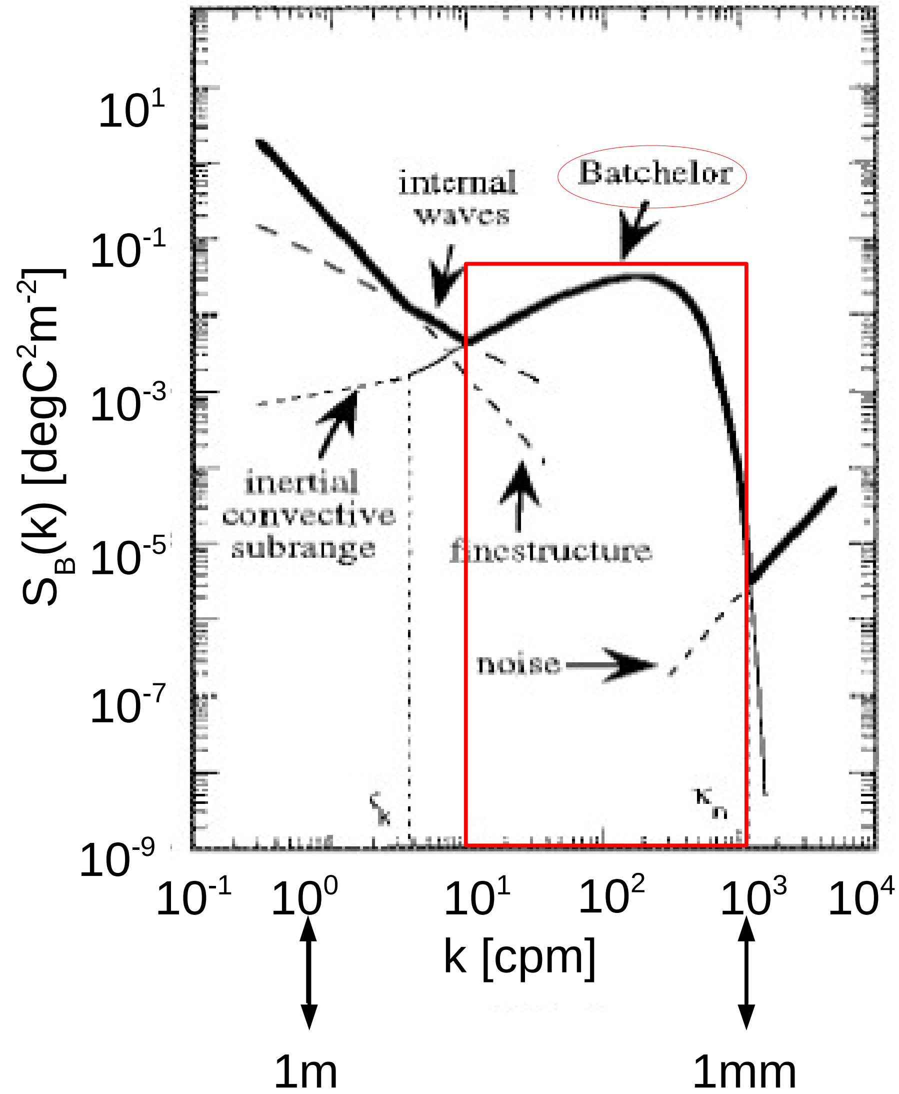
ε from temperature measurements

HOMOGENEOUS TURBULENCE

Batchelor spectrum (Batchelor, 1968)

$$S_B(k) = f(\chi_T, D_T, \epsilon)$$

- χ_T: Temperature variance dissipation rate
- D_T: Temperature diffusivity
- ϵ: Kinetic energy dissipation rate



ε from temperature measurements

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Batchelor spectrum (Batchelor, 1968)

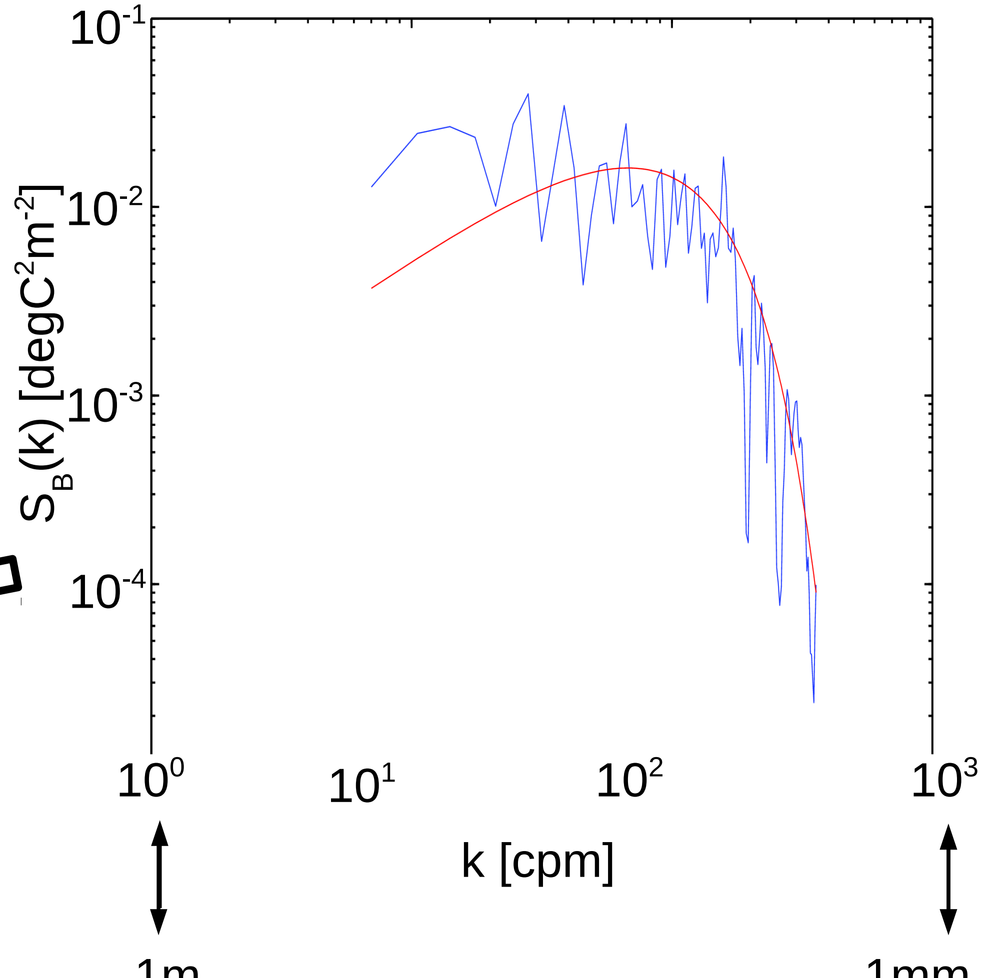
$$S_B(k) = f(\chi_T, D_T, \epsilon)$$

Temperature variance dissipation rate

Temperature diffusivity

Kinetic energy dissipation rate

$$\epsilon = \frac{\nu D_T^2}{L_B^4}$$

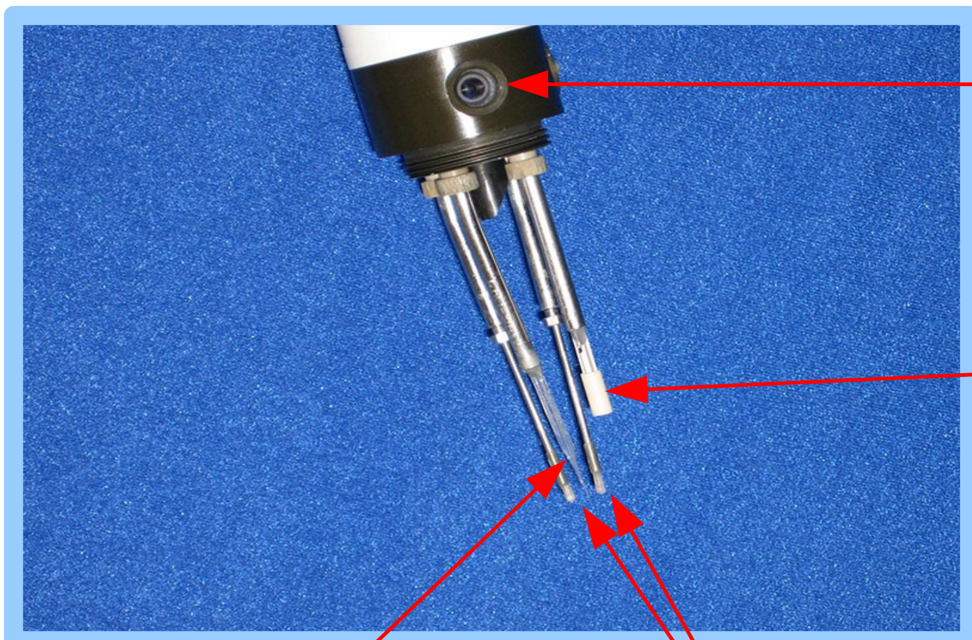


How this can be done

By measuring the temperature microstructure (<1cm) gradient in the water column.

Self Contained Autonomous Microstructure Profiler

(SCAMP)

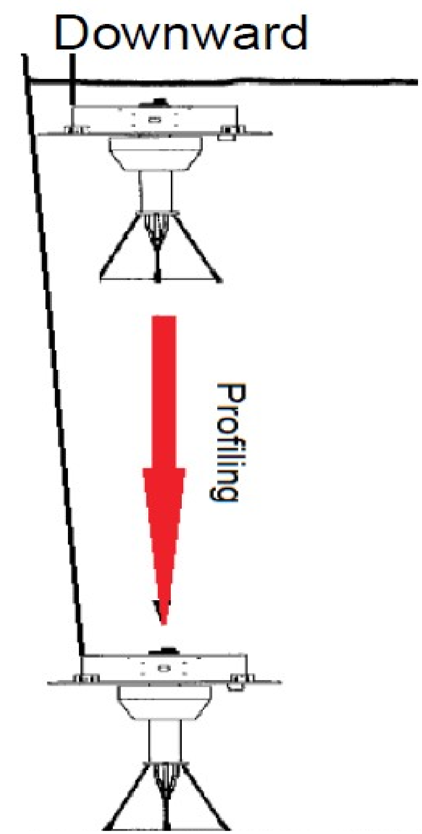


Fluorometer

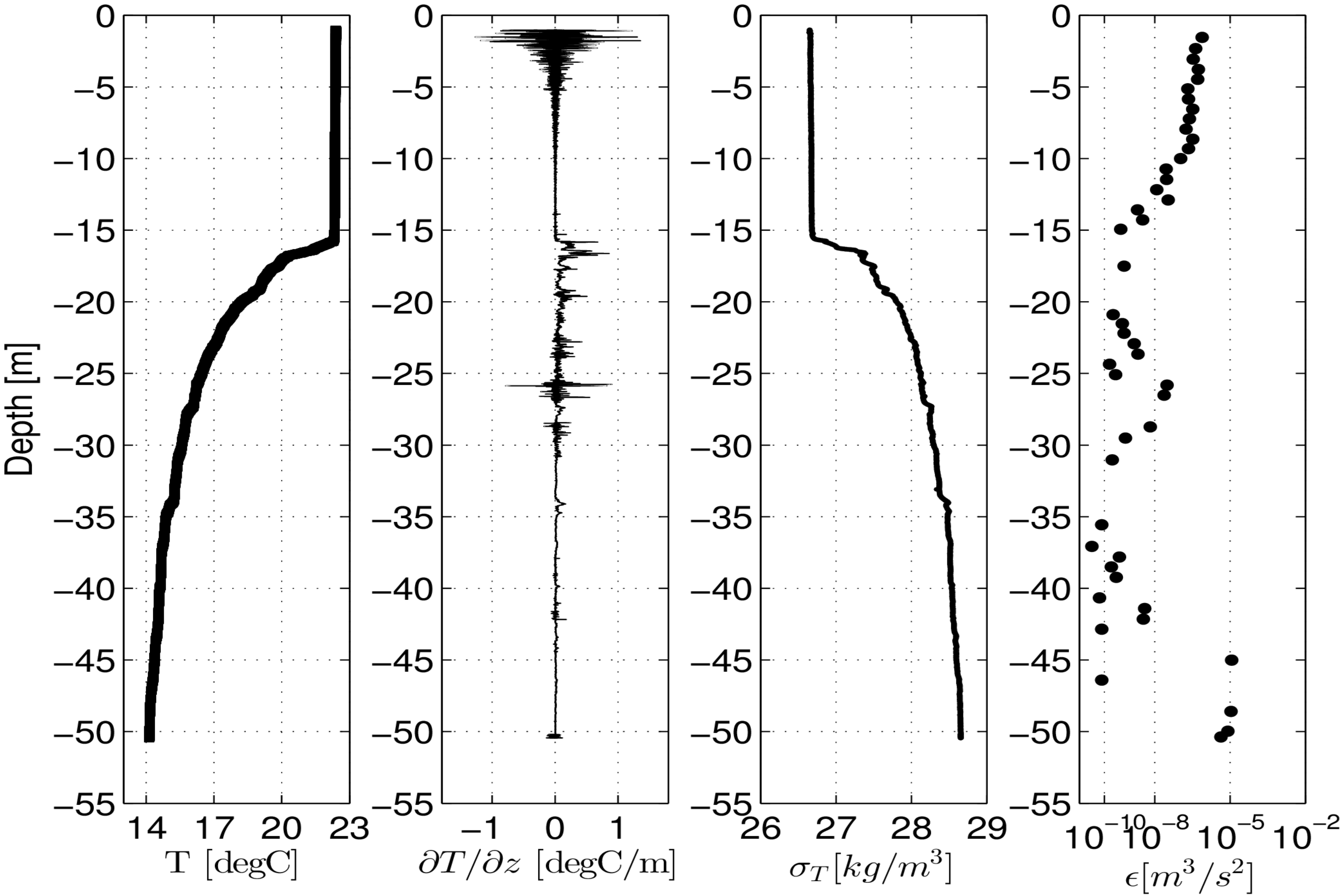
Conductivity (4-ceramic electrode, spatial resolution ~cm) sensor

Microconductivity sensor (spatial resolution ~mm)

Two thermometrics FP07 fast-response thermistors (temporal resolution **100*Hz***)



13 September 2011 long:42°14'23, lat:5”5°15,298 (NW Mediterranean), bottom at 100m



Obtaining K_z

Osborn, (1980)

Hypothesis: - steady state balance of TKE

- buoyancy flux is a fixed ratio of the dissipation

$$K_{Turb} = \Gamma \frac{\epsilon}{N^2}, \qquad \Gamma = 0.2$$

(Sanchez et al., 2011)

Shih et al., (2005)

Turbulent scalar diffusivity depends on turbulence intensity $I = \frac{\epsilon}{\nu N^2}$

DIFFUSIVE REGIME	INTERMEDIATE REGIME	ENERGETIC REGIME
$I < 7$	$7 < I < 100$	$100 < I$
$K_{Turb} = D_T$	$K_{Turb} = \Gamma \frac{\epsilon}{N^2}$	$K_{Turb} = 2\nu\sqrt{5I}$

Following Park et al. (2014): $\nu = 1.7 x 10^{-6} m^2/s$

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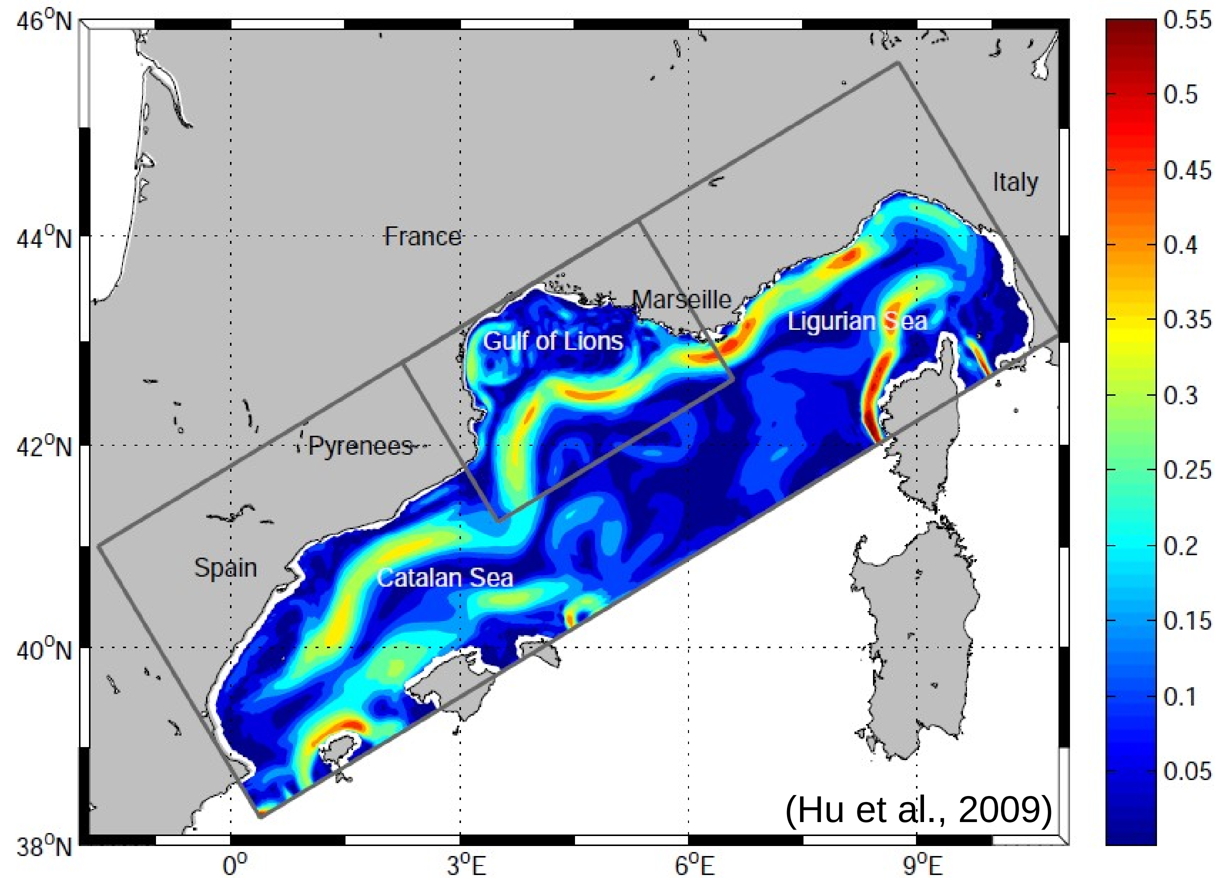
Numerical Model

	CLOSURE SCHEME	HORIZONTAL RESOLUTION	VERTICAL RESOLUTION	OUTPUT FREQUENCY
SYMPHONIE[(1)]	Gaspar et al. (1990)	1km x 1km	from 70cm to 2m	24 hours



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1) Marsaleix et al., Energy conservation issues in sigma-coordinate free-surface ocean models. *Ocean Modelling,* (2008)

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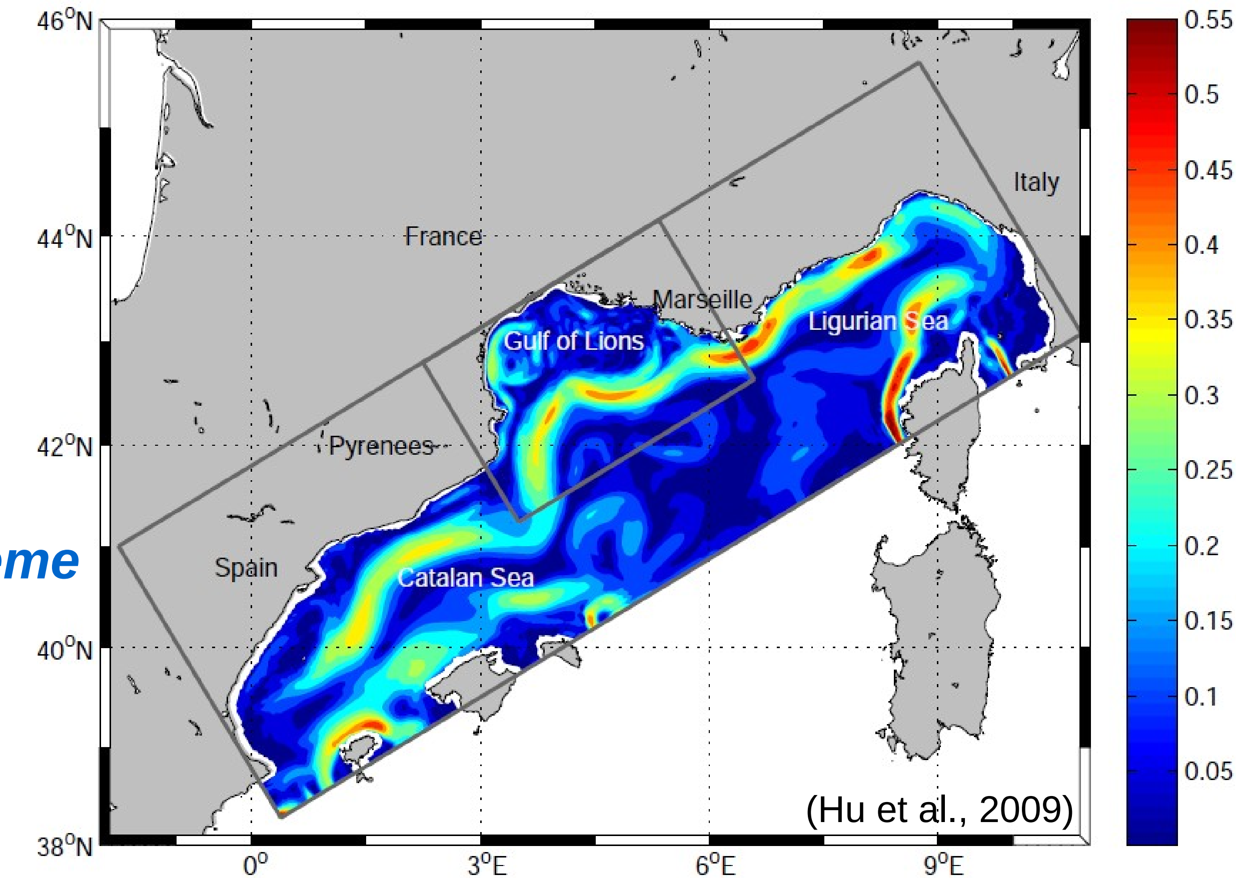
$$\epsilon = 0.7 \frac{Q^{3/2}}{L_\epsilon}$$

$$K_Z = 0.1\, L_Z Q^{1/2}$$

one-equation closure scheme



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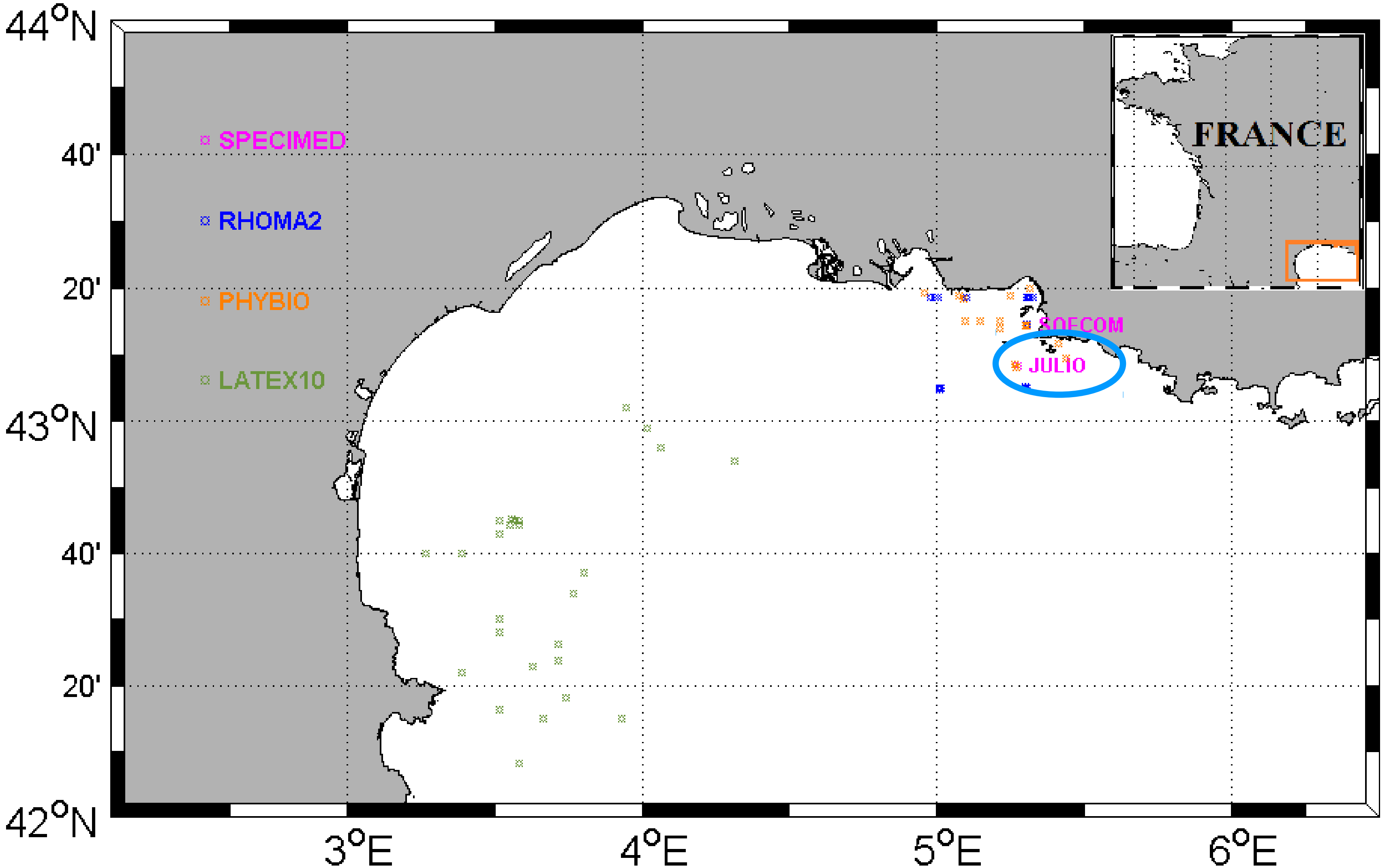
DATA SET



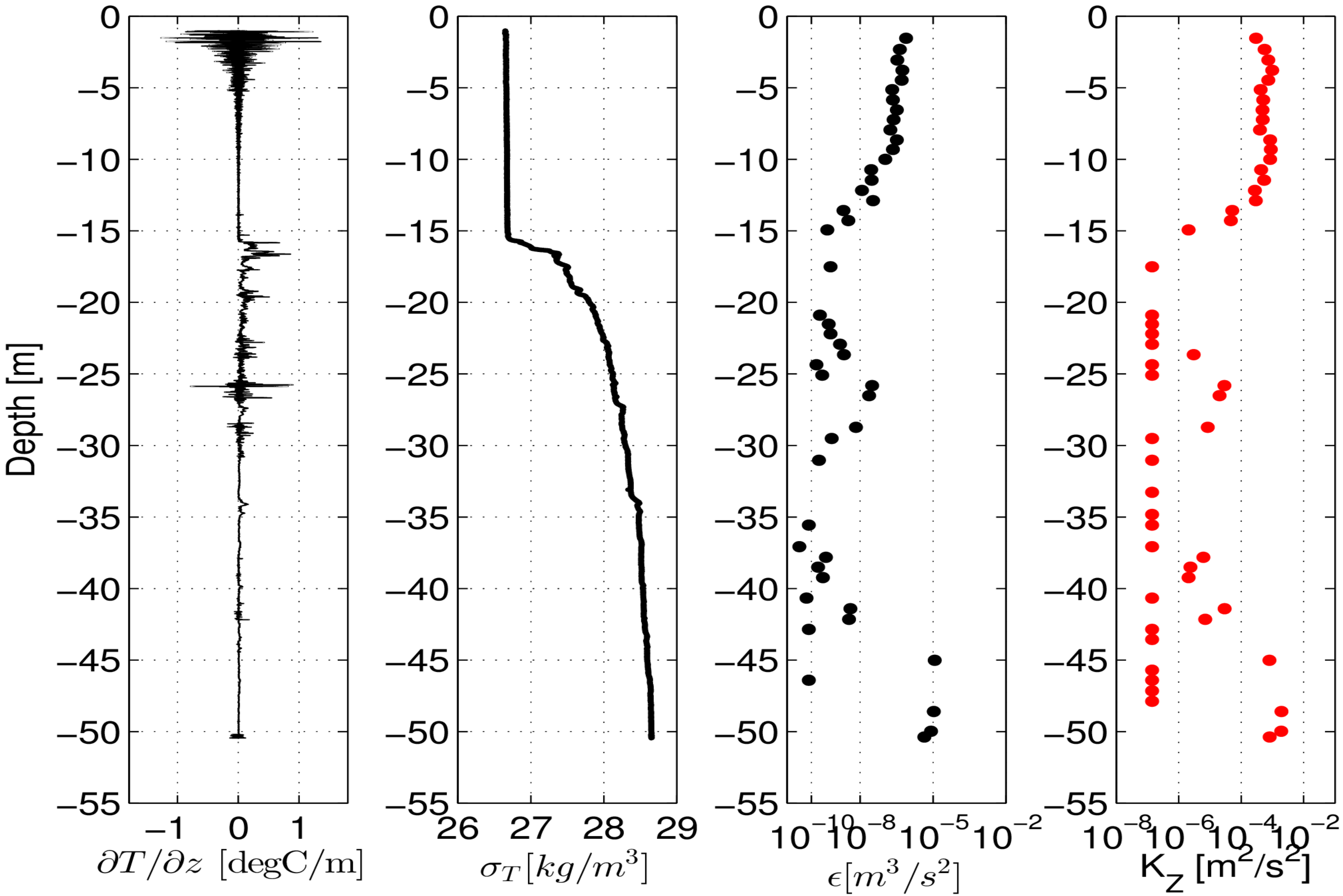
More than 300 profiles in last 3 years.

11 profiles in coastal environment.

Depth from 50m to 100m.

Direct comparison at JULIO

13 September 2011 long:42°14'23, lat:5°15,298 (NW Mediterranean), bottom at 100m



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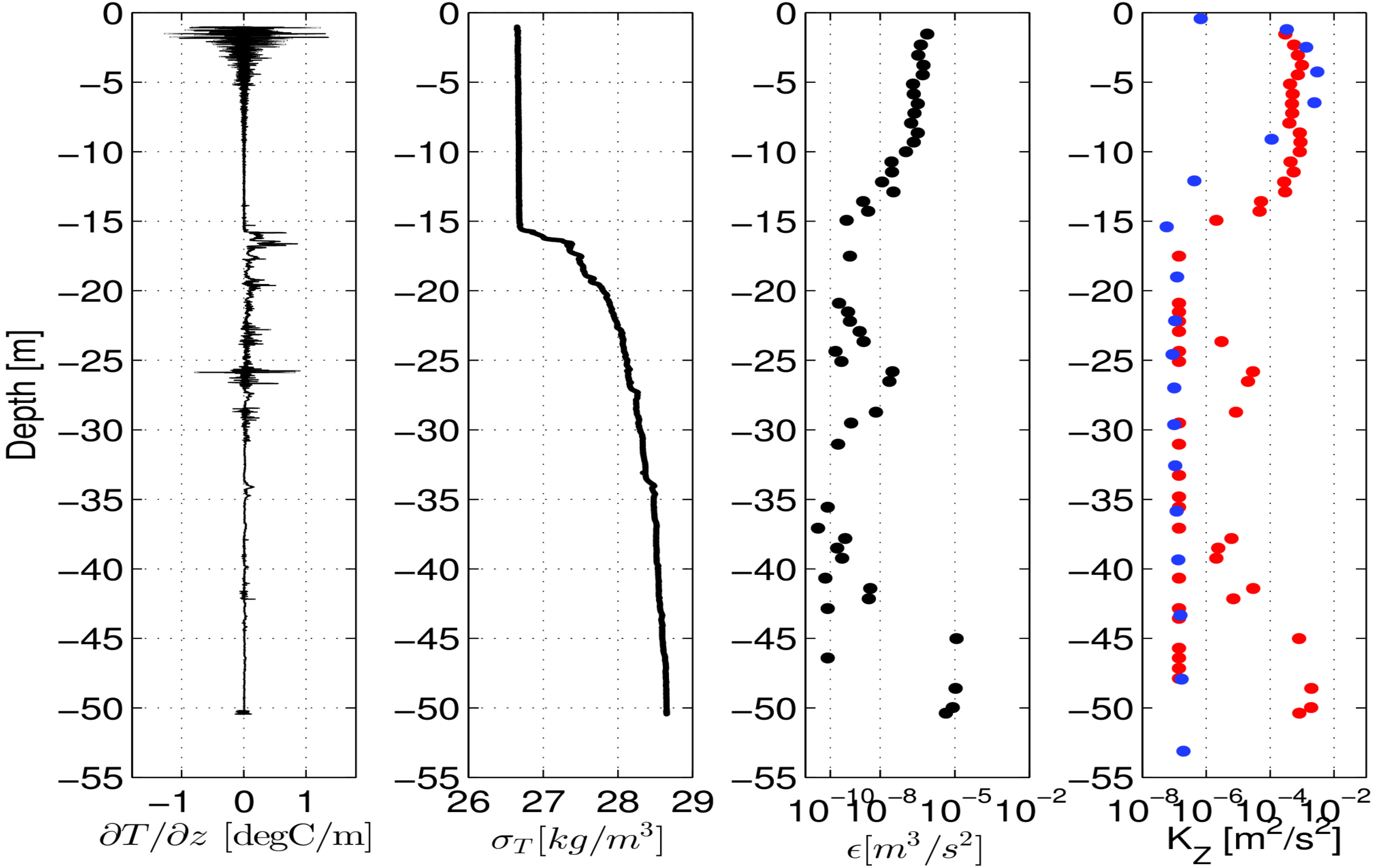

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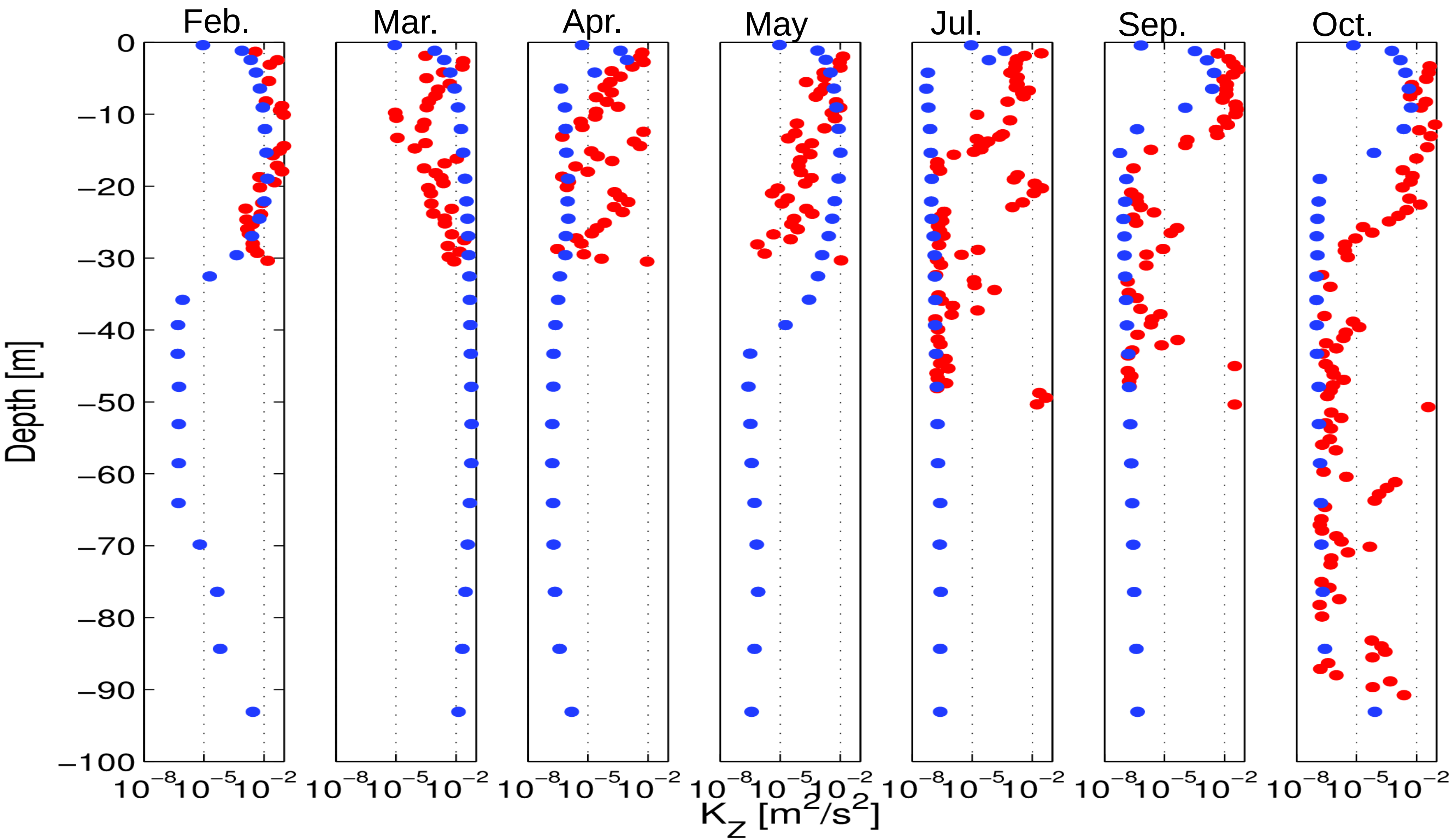

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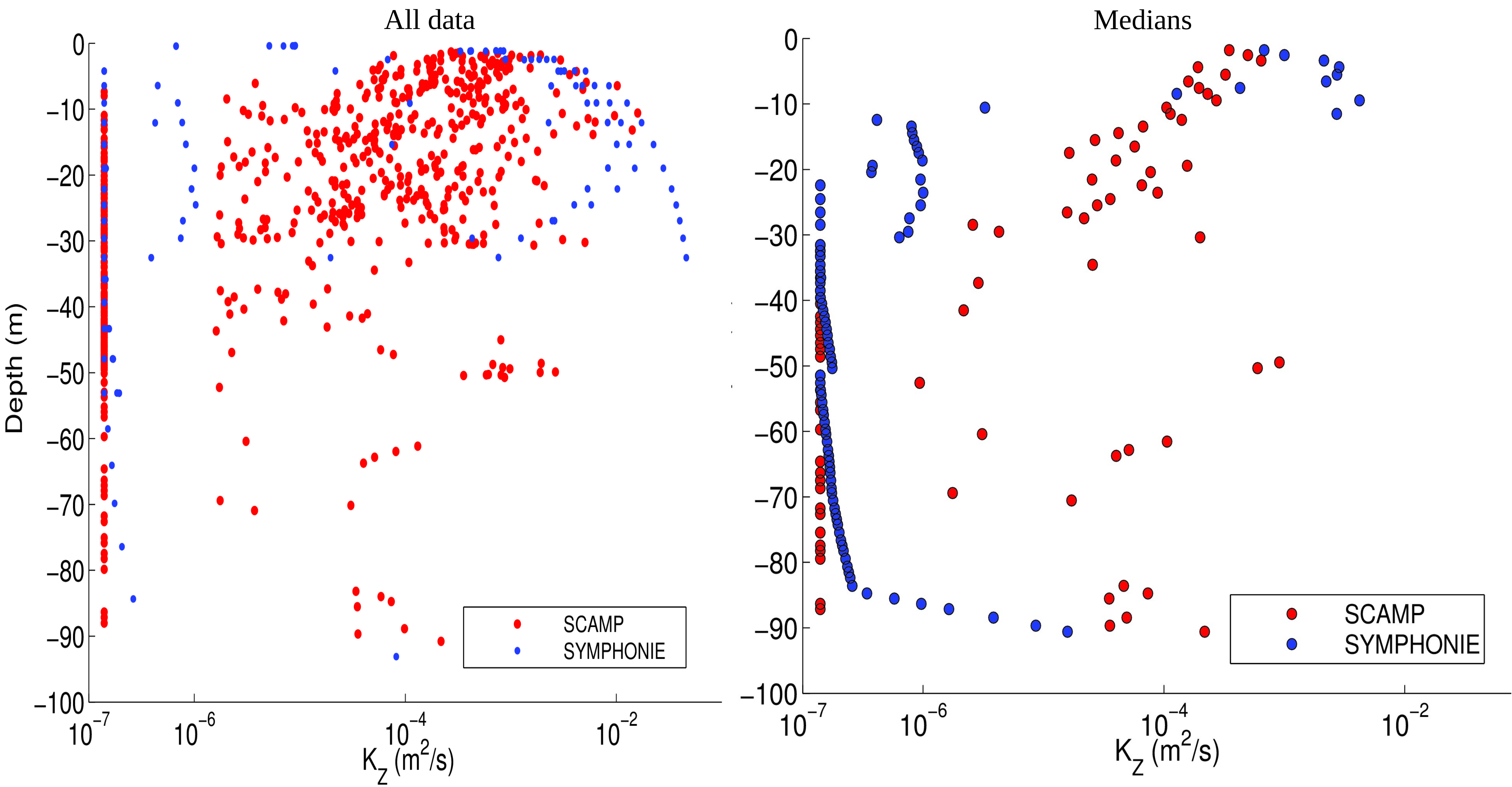

Correlation coefficient

ρ=0.80

Direct comparison at JULIO

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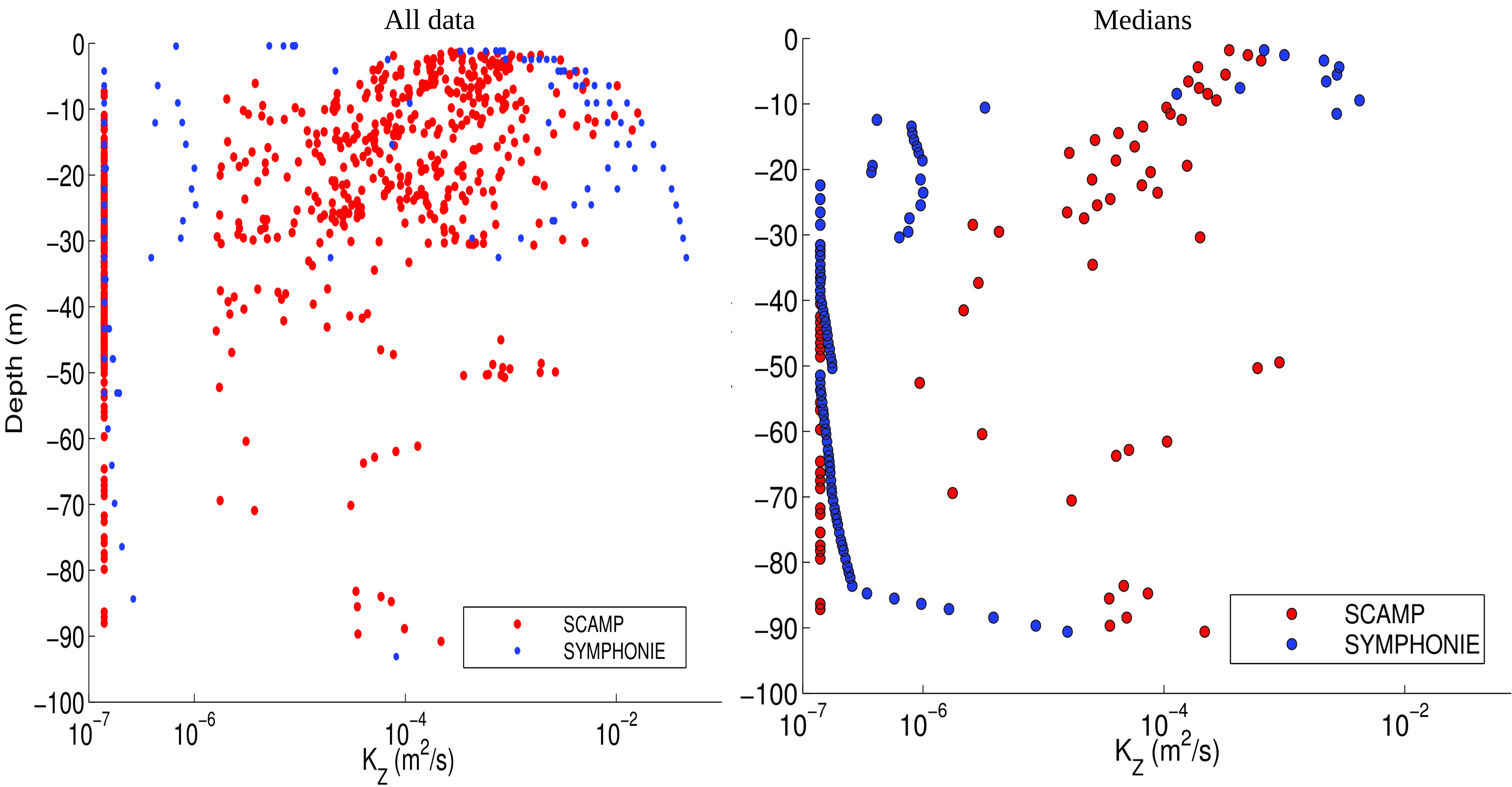


but difference in magnitude!

Perspectives

ACHIEVED:

- SCAMP data treatment
- Methodology to confront numerical models to in situ data
- Mixing-length closure scheme seems inaccurate

WE WILL DO:

- Comparison with numerical values of ε
- Study of different closure schemes
- Effect of wind on mixing

THANK YOU

FOR

YOUR

KIND ATTENTION

EXTRA SLIDES

$$\frac{\partial E_{CT}}{\partial t} + \bar{u}_j \frac{\partial E_{CT}}{\partial x_j} = -\frac{\partial}{\partial x_j}\left(\overline{u'_j E'_{CT}} + \frac{\overline{p' u'_j}}{\rho}\right) - \overline{u'_i u'_j}\frac{\partial \bar{u}_i}{\partial x_j} - \frac{\overline{\rho' u'_i}}{\rho_0} g \delta_{i3} - \nu \overline{\frac{\partial u_i}{\partial x_j}\frac{\partial u_j}{\partial x_i}}$$

$$\epsilon = -\nu \overline{\frac{\partial u_i}{\partial x_j}\frac{\partial u_j}{\partial x_i}}$$

SYMPHONIE and MARS3D:

$$\epsilon = \frac{C_\epsilon E_{CT}^{3/2}}{l_G} \qquad \nu_T = C_K \sqrt{E_{CT}}\, l_G$$

$$\frac{\partial T}{\partial t} + \bar{u}_j \frac{\partial T}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\kappa_T \frac{\partial T}{\partial x_j} - \overline{T' u'_j}\right) + \phi_T$$

$$-\overline{T' u'_j} = K_{Turb} \frac{\partial T}{\partial x_j}$$

$$P_{rT} = \frac{\nu_T}{K_{Turb}}$$

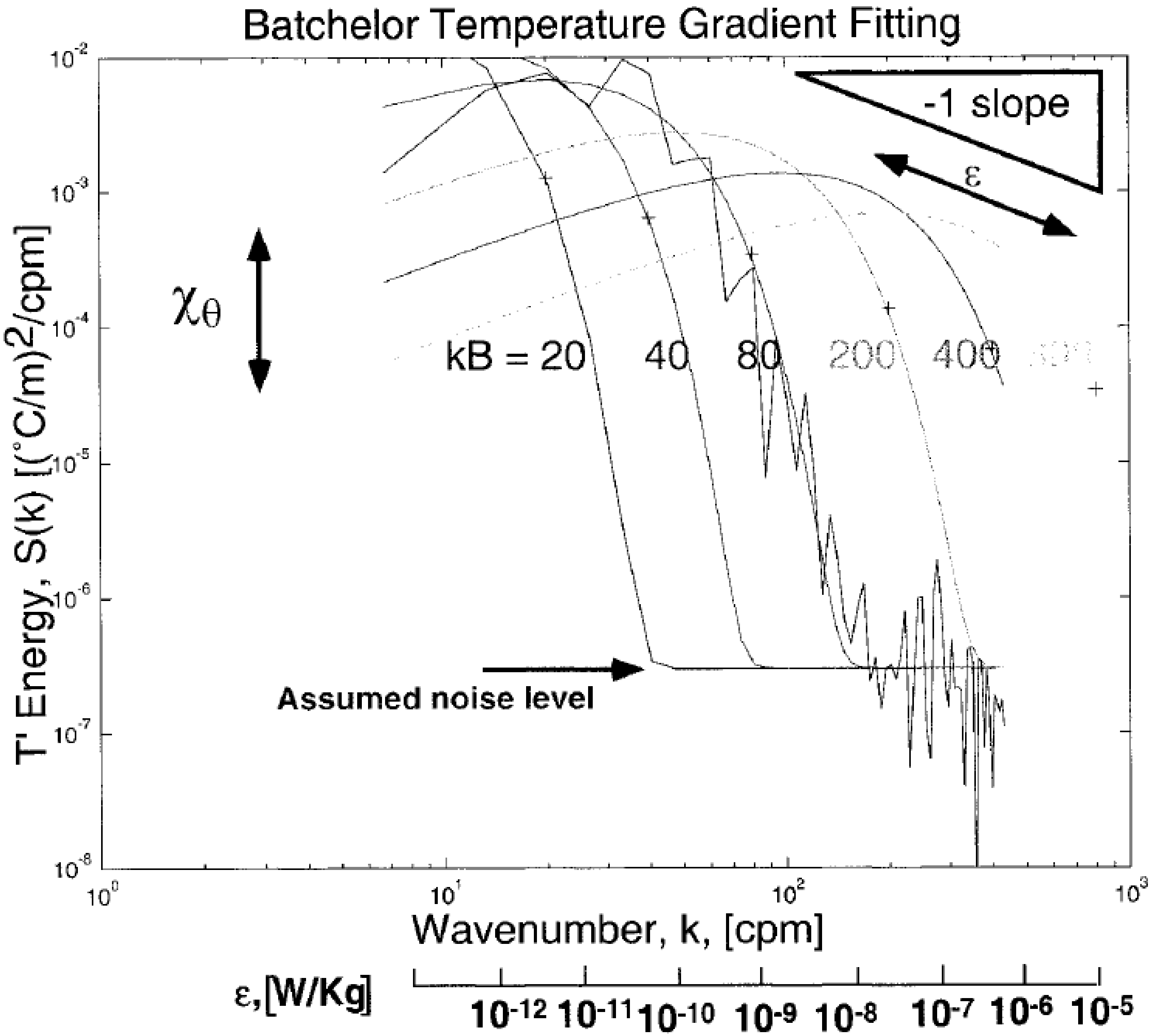


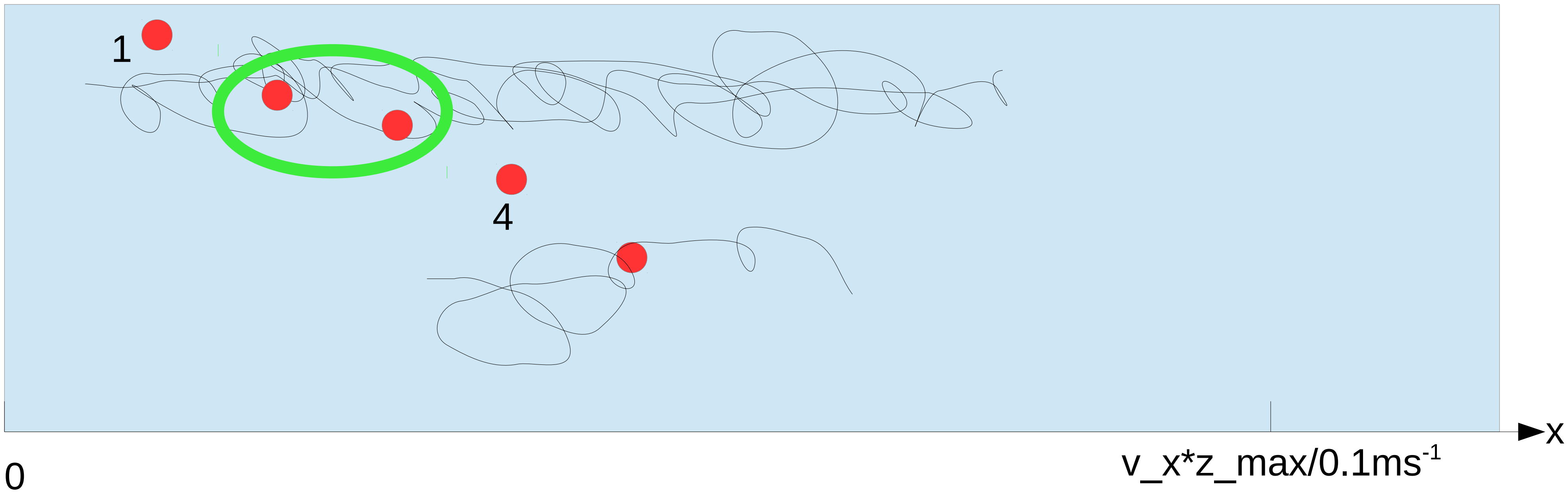
FIG. 2. Batchelor spectrum for various k_B, including estimated SCAMP instrumental noise level [3×10^{-7} (°C m^{-1})^2 (cpm)$^{-1}$], with χ_θ constrained according to Eq. (9). The k_B value corresponding to each curve is indicated with a plus, and the approximate corresponding dissipation level, ε, is shown by the second logarithmic scale below the k axis. The effects of changing χ_θ and ε on the spectrum are indicated by arrows. An observed spectrum is shown.

$$\bar{u} = \varphi(t) = \varphi\left(\frac{x}{u}\right)$$

4.0) Stationarity/Homogeneity table **and physics**

Why are they checking OR the stationarity OR the the homogeneity??

My idea is the following:



The two green points belongs to a structure (vortex) that is stationary in time and homogeneous in space, by definition of coherent structure. At least at our timescales.

So stationarity ensures homogeneity and vice versa.

?

0) Stationarity, Homogeneity, Isotropy

Stationarity

All the mean quantities are invariant under a translation in time. A stationary variable is **ergodic** if the time average converges to the mean as the time interval extends to infinity.

Homogeneity

All the mean quantities are invariant under any spatial translation. Then an ergodic hypothesis allows an ensamble average to be calculated as a spatial average

Isotropy

All the mean quantities are invariant under any arbitrary rotation of coordinates.

Axisymmetry

Invariant under a rotation about one particular axis only (stratified turbulence).

4.0) **Stationarity/Homogeneity table** and physics

Methods for assessing **stationarity** <u>in the literature</u>:

- Imberger and Boashash (1986): Wigner-Ville distribution (see after for explanation)

- Imberger and Ivey (1991): AR model

- Chen et al (2002): wavelet analysis

Methods for **homogeneity**:

- Sanchez, Roget et al. (2012): variance in subsegments

Methods for **confident** people:

- Cuypers et al. (2012?), Moniz et al. (2014): constant segments → Anyway Cuypers was severe with fits

So...

As Imberger himself changed his mind from 1986 to 1991, I'd discard the Wigner-Ville distribution method.

The AR model is interesting but is it adeguate for nonlinear phenomenon?

Wavelet method seems better for this but it is not implemented

An even better improvement could be the Hilbert-Huang transform (ask to monsieur Nerini)

Roget's method could be good for the homogeneity.

BUT!

3) var vs std AND 1/n*sum vs < >

$$E[var(Y_i)] = \frac{2}{d}$$

Suggested threshold (==Rqualitcheck) with d=6:

17*2/d = 5.7 =~ 6

R = std(PSD_bat./Batchelor_spect) * dof^0.5 (Yannis, 1000 points)

R1 = var(PSD_bat./Batchelor_spect) / dof (Io)

R2 = var(PSD_bat./Batchelor_spect) (Me again)

Anyway I don't think that the sqrt(d) by Yannis is due to the use of std as the ratio is independent from d

---

$$MAD2 = \frac{1}{n} \sum_{k_i = k_1}^{k_n} \left| \frac{S_{obs}(k_i)}{S_{Th}(k_i)} - \left\langle \frac{S_{obs}}{S_{Th}} \right\rangle \right| > 1.2$$

I'm inclined to see this as a variance, so I think that the two notations are the same.