Parameterization of energy dissipation and turbulent mixing in the Indonesian Throughflow from the INDOMIX experiment

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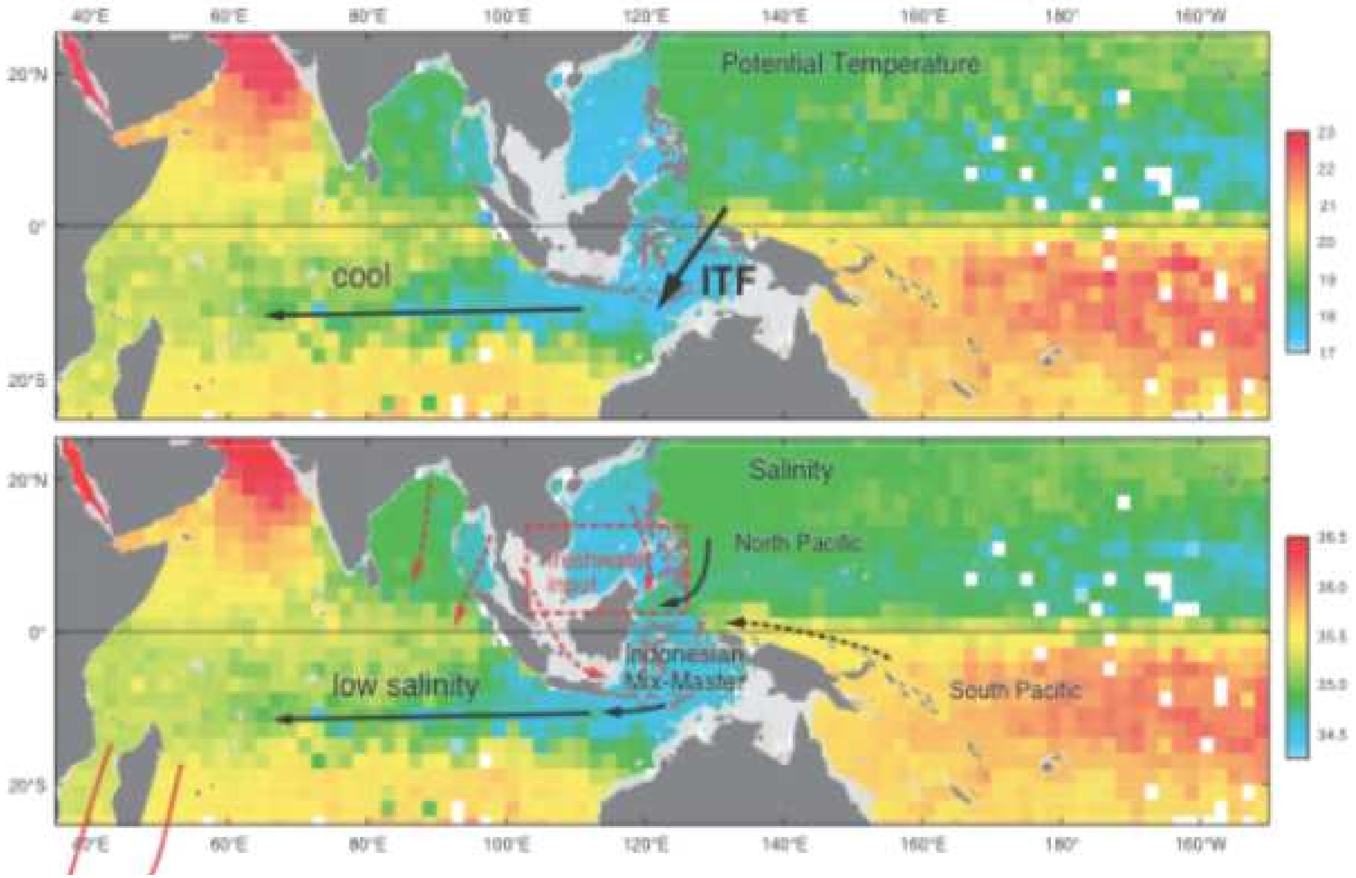
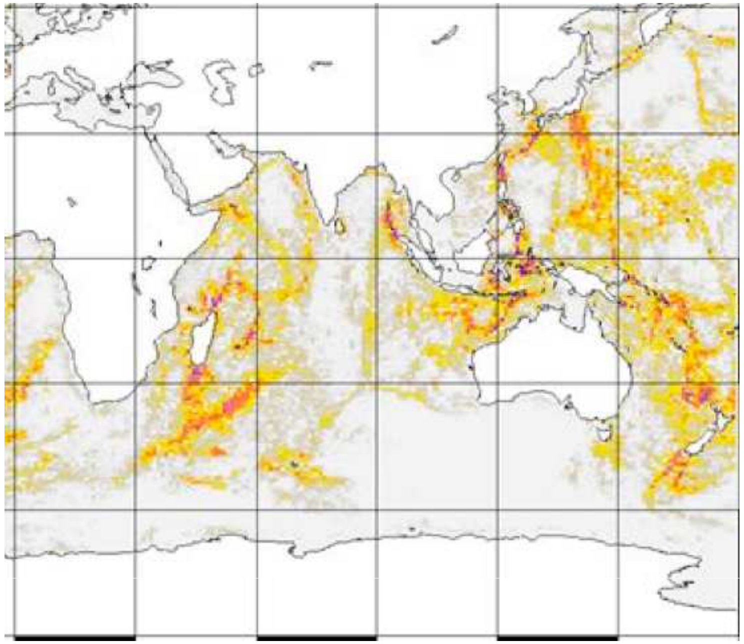
A region of intense watermass transformation



Potential temperature and salinity along isopycnal s=25.5
in the main thermocline (from Gordon, 2005)

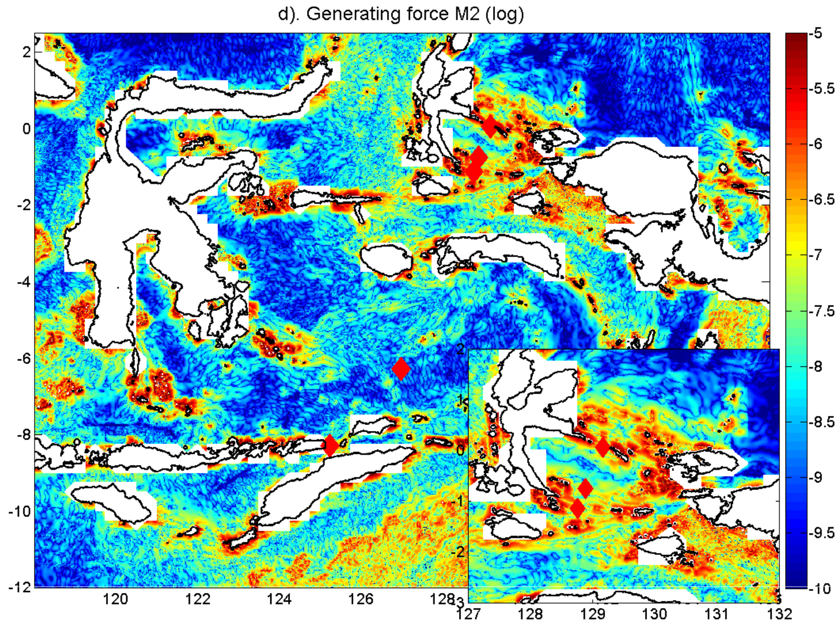
=> Freshening & cooling of thermocline waters originating from the Pacific

A region of strong internal tide generation



Power conversion from barotropic to baroclinic tides for M2
(Le Provost & Lyard, 2002)

✓~0.11 TW to be compared to a total value of 1.1TW



Zoom : the M2 generating force

- ➢Numerous regions of maximum generation force
- ➢ Radiation from different spots, either near passages or along the shelf
- ➢Complex picture

⇒turbulent mixing induced by internal tides:
one main process responsible for watermass transformation

* Indonesian seas are a region of intense internal tides which induce turbulent mixing, enhanced impact of internal tides since they break locally, Indonesian seas being almost enclosed

- However few measurements that enable to characterize internal tides and turbulent mixing,
- previous cruises focused on the characterization of transport through the numerous passages and their interannual variability (e.g. INSTANT program)

=> main objective of INDOMIX cruise (July 2010) on board Marion Dufresne

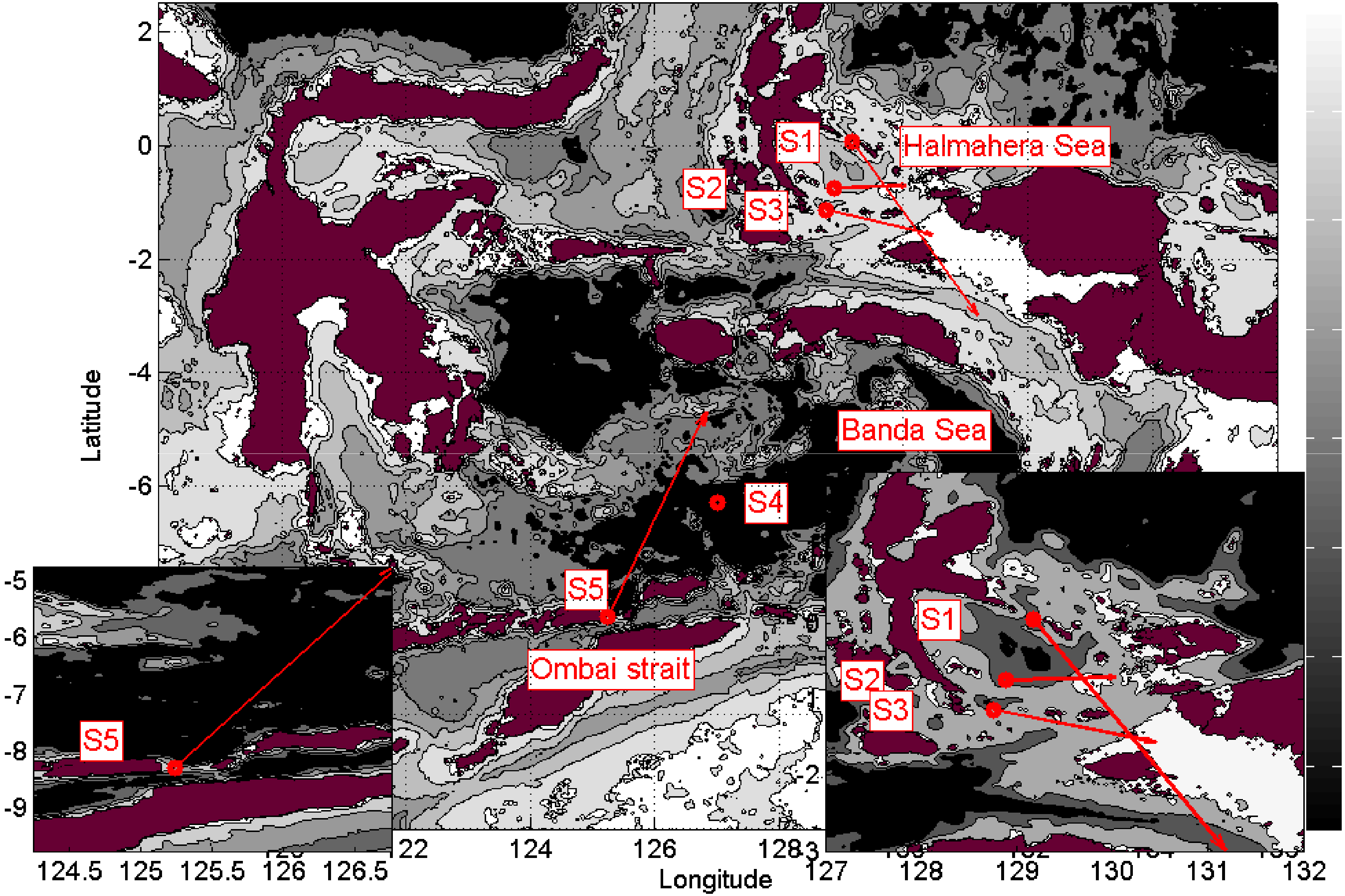
Main objectives

- ✓ Spatial distribution of dissipation rate of turbulent kinetic energy and how it relates with baroclinic & barotropic tides?

- ✓ Do finescale parameterizations of dissipation induced by internal wavebreaking provide a relevant estimate even for strongly nonlinear internal wave field?

- ✓ Parameterization in numerical models: test the scaling of dissipation function of tidal energy and stratification proposed by Koch-Larrouy et al (2007) against microstructure measurements

INDOMIX cruise



Joint microstructure measurements and CTD/LADCP profiles during 2 M2 cycles

VMP6000- Velocity microstructure profiler

- Microstructure sensors:

temperature, vertical shear, conductivity

- Seabird sensors + pressure sensors
- Fall velocity U_{fall} ~0.5m/s
- Sensor time response:

-Shear and conductivity : 3 ms

-Temperature: 10 ms

=> Vertical resolution $\Delta x = U_{fall} \Delta t \approx$ mm-cm

Turbulent kinetic energy dissipation rate inferred from vertical wavenumber shear spectra

Figure 5: Sensor head of the MSS profiler. The microstructure sensors are standing in front of the other sensors. arrangement guarantees undisturbed measurements of the micro-scale stratification and velocity fluctuations.

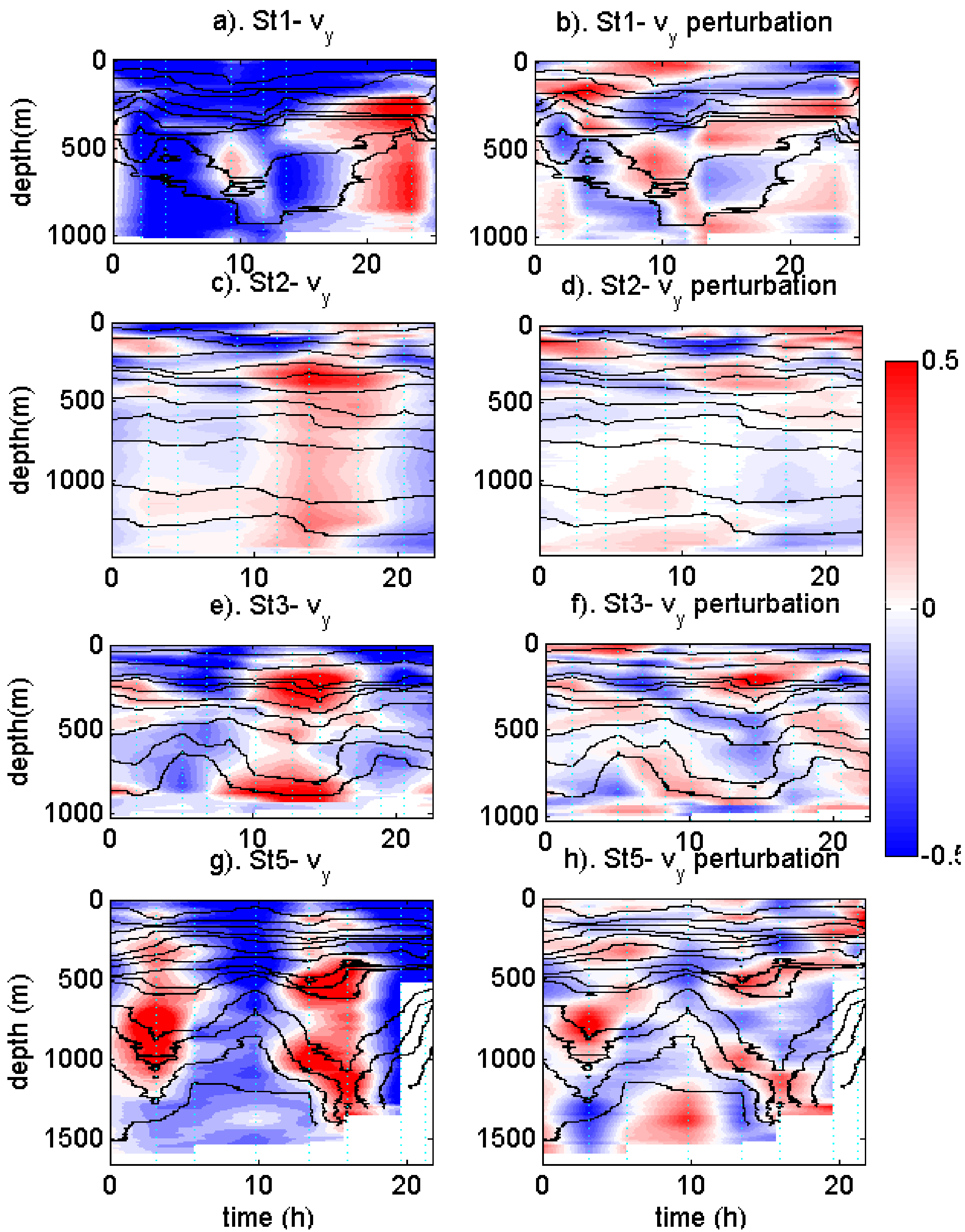
Dynamics

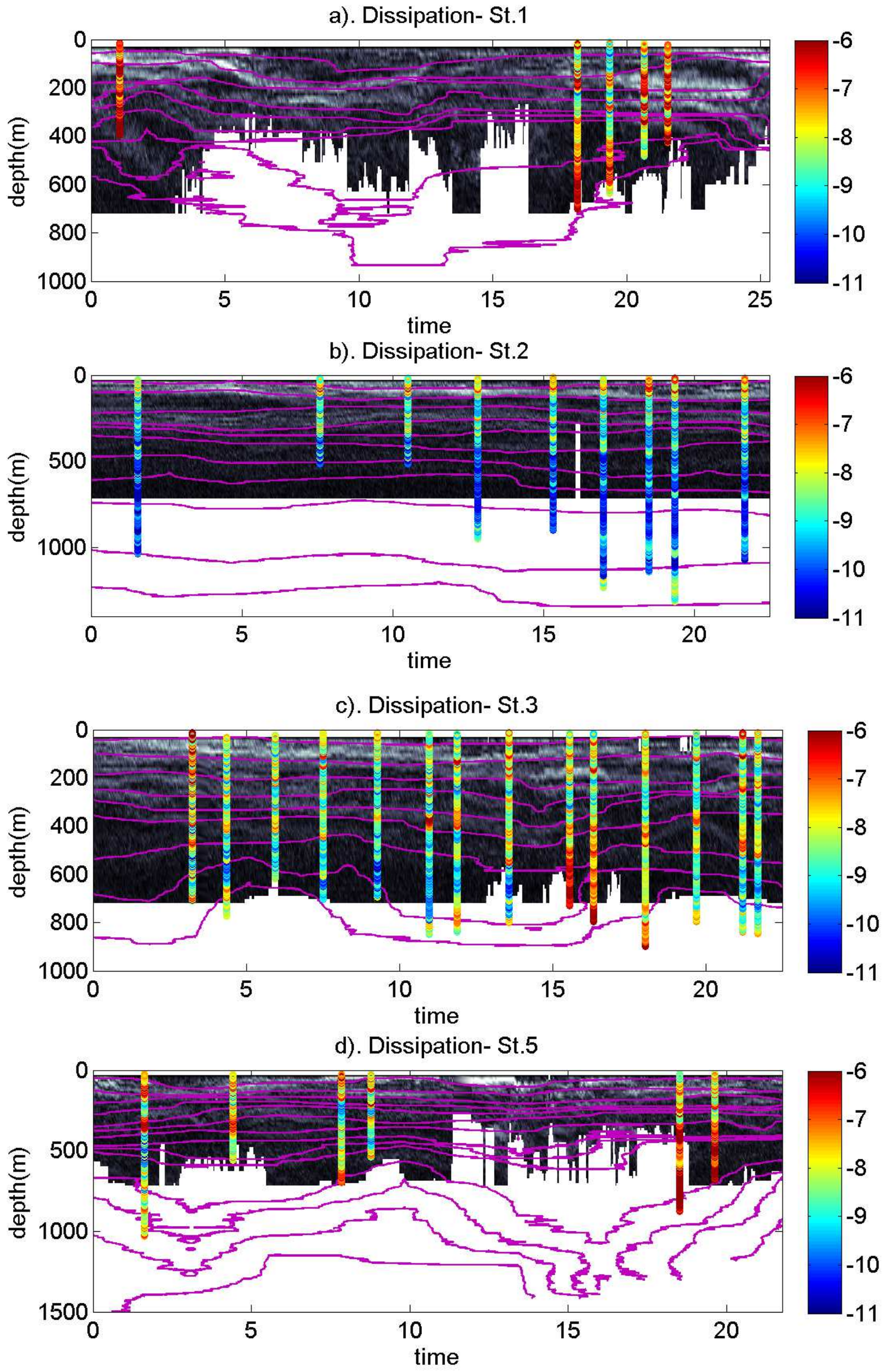
- Strong currents within straits: meridional current up to 1.3m/s (St.1), 1m/s (St.3) and 1.4m/s (St.5)

- Weaker currents at stations remote from generation area: 0.7m/s at St2, 0.4m/s in Banda Sea

- Perturbation of the baroclinic current: same contrast
High isopycnal displacements at depth (~200m)

- Semi-diurnal & diurnal constituents more than 58% total variance





Overview of dissipation profiles

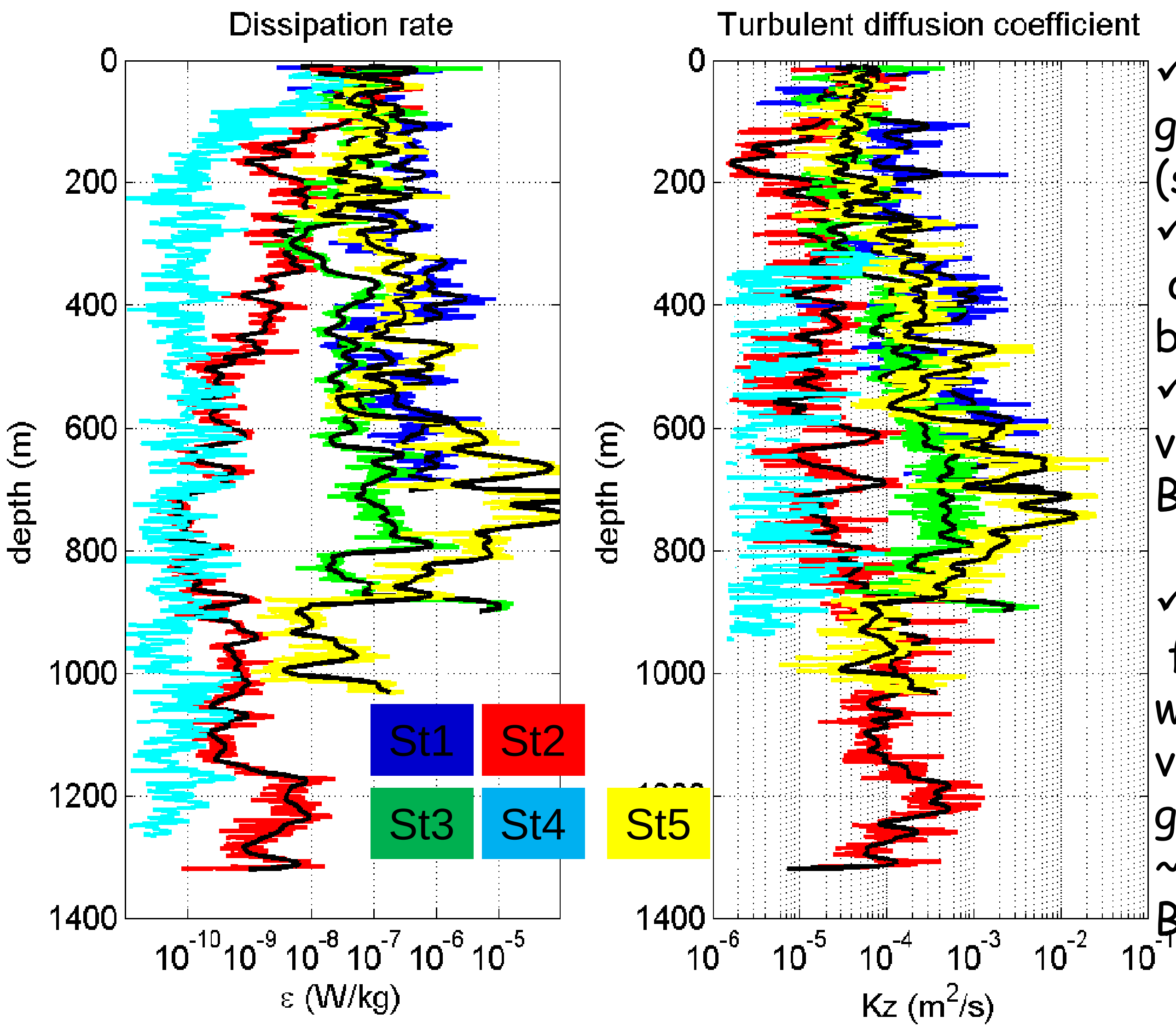
with shear & isopycnals superimposed

- Highest dissipation at St.1 & 5 throughout the water column
  At depth these strong values are correlated with large isopycnal displacements
  else a correlation with strong shear is sometimes evidenced

- Weaker dissipation at Station 2, consistent with a weaker signal both in shear & isopycnal displacement

- Enhanced dissipation in the bottom boundary layer

Mean profiles of dissipation and vertical diffusion coefficient: a contrasting situation



✓ highest ε values near gation areas within passages (st. 1 & 3 & 5)
✓ ε values smaller by a few orders of magnitude in Banda below 200m depth
✓St2 – « far-field » smaller values except first 200m & Bottom boundary layer

✓ mean Kz ~similarly from 10^(-3) to 10^(-2)m^2/s within passages & the lowest values at stations far from generation area, ~[10^(-6);10^(-5)]m^2/s in Banda

Test of fine-scale parameterizations of dissipation rates

We tested 2 kinds of fine-scale parameterizations:

❖Parameterization based on the assumption of an energy cascade toward small-scales through resonant wave- wave interactions, with the Gregg-Henyey formulation- hyp.: IW ~ GM,

$$\epsilon_{IW} = 1.8 \times 10^{-6} \left[f cosh^{-1} \left(\frac{N_0}{f} \right) \right] \left(\frac{N^2}{N_0^2} \right) \left(\frac{S_{10}^4}{S_{GM}^4} \right)$$

GH param

with $S_{GM}^4 = 1.66 \times 10^{-10} \left(N^2 / N_0^2 \right)^2$

❖ A different formulation more adequate when one internal wave mode dominates: we test here the McKinnon & Gregg formulation (2005), in which dissipation scales like the shear

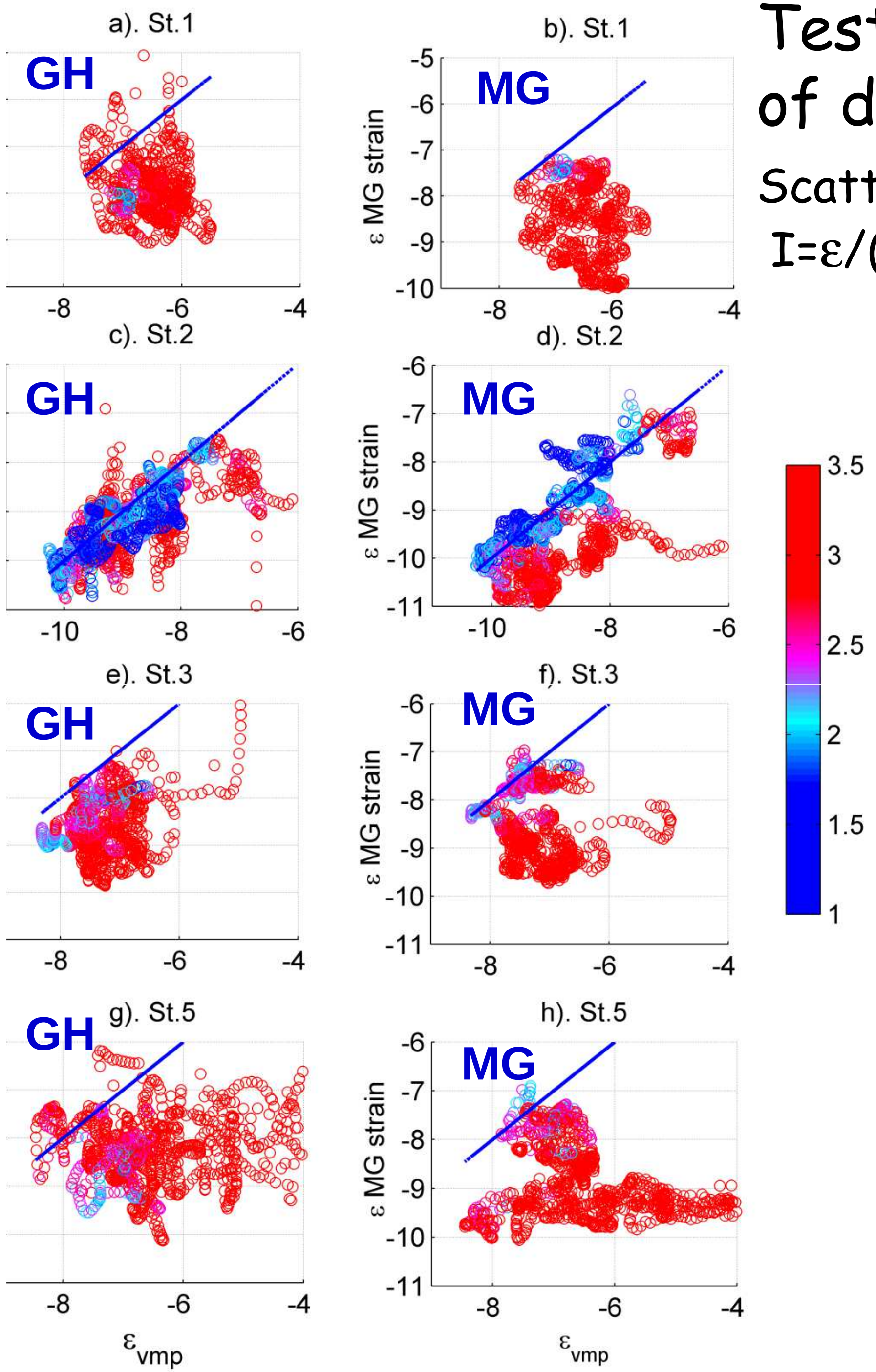
MG param

ε=ε0 (N/N0) S/Sgm
or alternatively in terms of strain ε=ε0 (N/N0) Str/Strgm

with ε0 is an adjustable parameter

Test of fine-scale parameterizations of dissipation rates:

Scatter plots of ε_param with turbulence intensity I=ε/(νN^2), displayed with colorscale (log10)



✓ Both GH and MG parameterizations provide a relevant estimate of dissipation rate for intermediate & moderately turbulent regimes (I up to 100-1000)

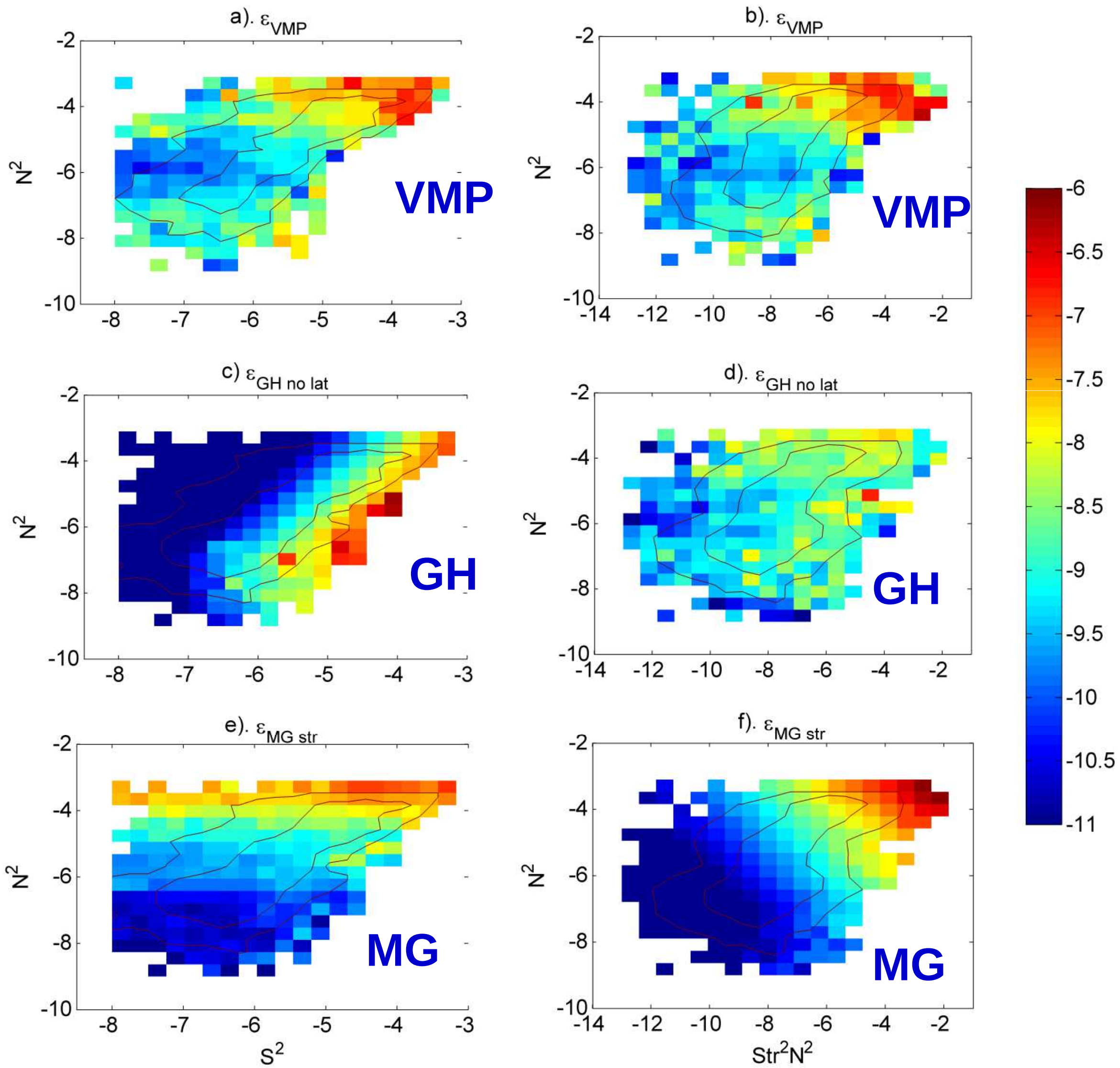
✓These parameterizations are relevant for Station 2 (remote from generation area) except in the bottom boundary layer and to a lower extent at Station 3 in the first 300m

✓Under-estimate by a few orders of magnitude within straits where turbulent regimes prevail throughout the water column (St.1 & 5, and most of St.3)

⇒there either strong nl wave wave interactions & other processes of instability come into play

Test of fine-scale parameterizations of dissipation rates

Bin-averaged dissipation rates at station 2 in 2D space (S^2,N^2), 1st column, and (Str^2N^2,N^2) 2nd column



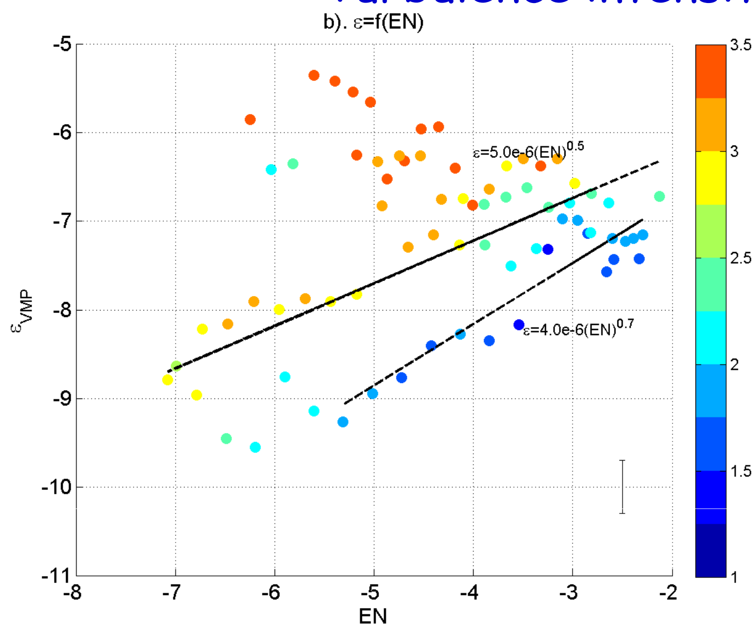
✓ highest dissipation in regions of strong stratification & shear, strain => in the thermocline

✓ MG parameterization reproduces this pattern well as opposed to GH parameterization which varies like the Ri number

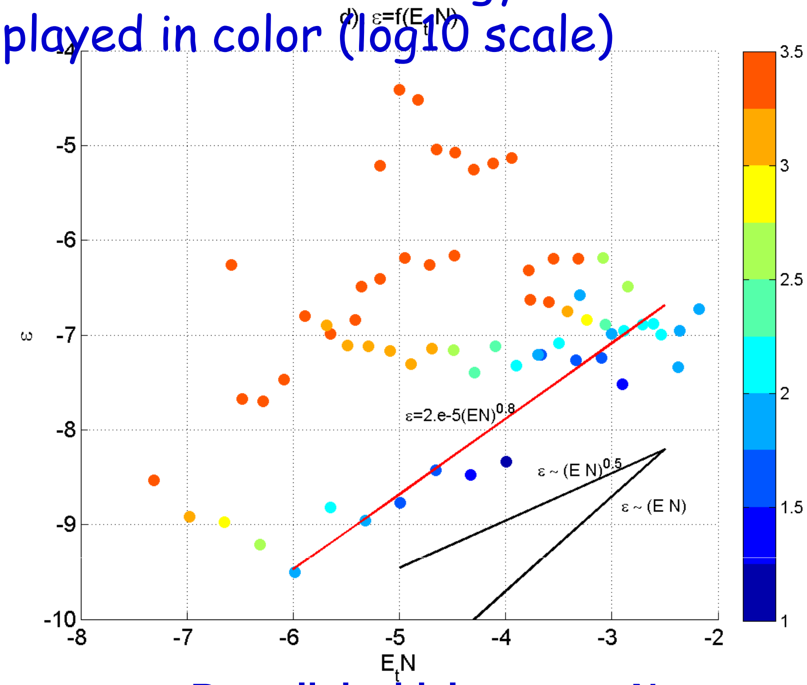
⇒MG parameterization more relevant

Scaling for dissipation as a function of energy and stratification

Bin-averaged dissipation rates as a function of energy times N
Turbulence intensity is displayed in color (log10 scale)



Baroclinic energy x N



Baroclinic tidal energy x N

✓Scaling law that depends on the turbulence intensity,
typically (EN)^0.7 for I<100 (intermediate regime)
(EN)^0.5 for 100<I<1000 (moderately turbulent regime)

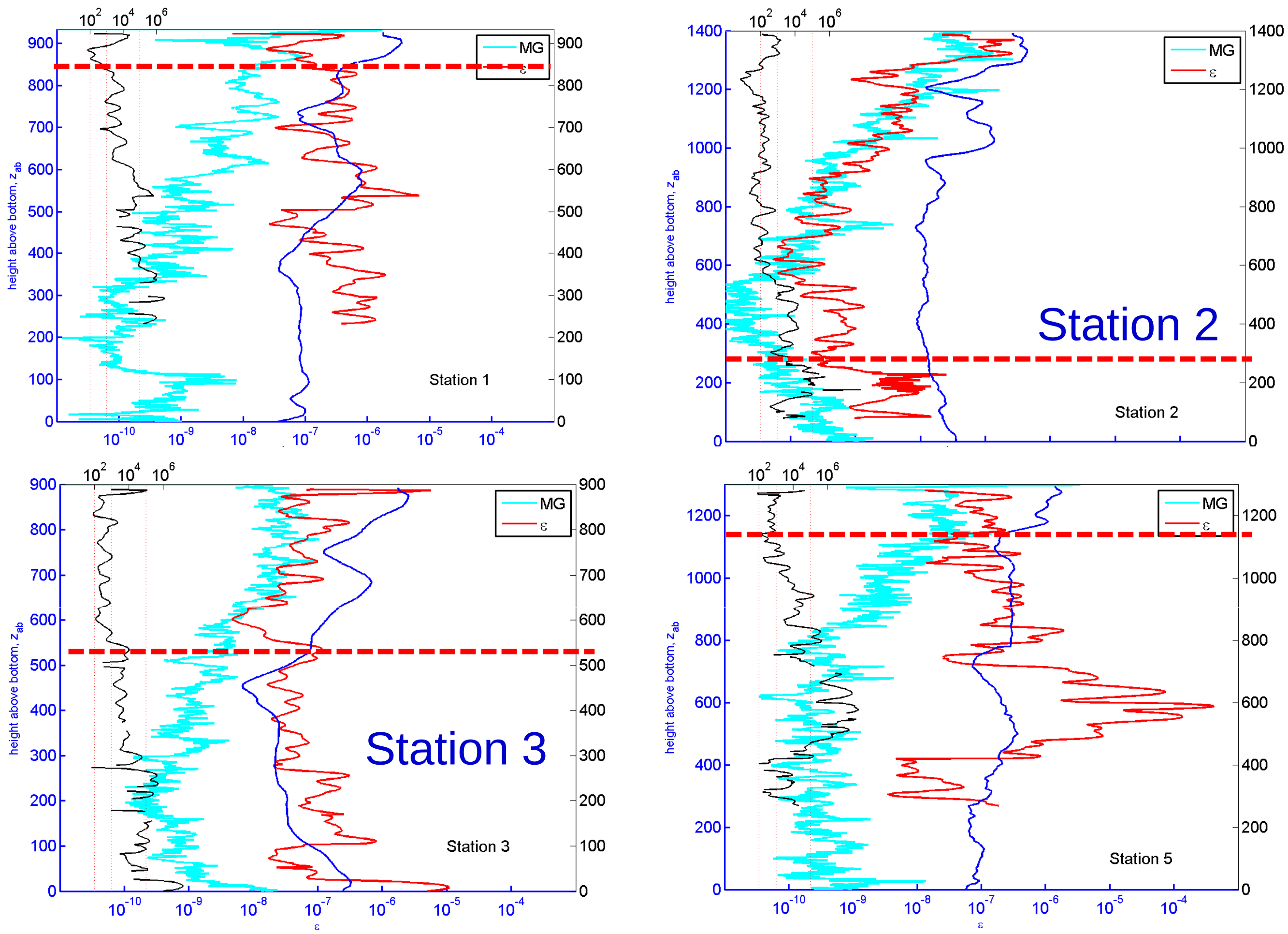
⇒Mostly within the thermoline except within straits,

⇒1st scaling mostly at Station 2, 2nd partly at Station 3

✓No scaling law for strongly turbulent regimes

✓ Clear scaling when I<100 (EtN)^0.8 (mostly valid at station 2)

Toward a parameterization of dissipation rate in regions of strong turbulence intensit



Comparisons between VMP dissipation rate (red) and Cv^3 (blue) and MG (cyan) at the different stations

➢Weak effects of stratification => we assume that dissipation scales like the power of the flow: ε=C v^3 (here C=5.e-6m^-1)

➢ significant improvement at stations 1 & 5 and station 3 for the first 500m above the bottom

➢ when I>1000 C v^3 predicts dissipation within a factor of 10

Summary

- Strong contrast in dissipation rates with the highest dissipation within straits & above the bottom, weaker values at stations remote from generati areas with a local increase within the thermocline
=>variations consistent with the internal tidal signal, a dynamics sometimes strongly nonlinear and an intense barotropic current
Typical range: [10^-6,10^-3]m^2/s for vertical eddy diffusivity in the thermocline and up to 10^-2m^2/s within straits

- Finescale parameterization of internal wavebreaking: relevance of *MG* parameterizations for moderate turbulent intensity (<1000) only,
for higher turbulence intensity, within straits, typically, a parameterization proportional to v^3 is proposed

- Parameterization in numerical models: a scaling in (EN)^α is obtained for moderate turbulence intensity typically within the thermocline except in Straits where dissipation rate is higher by a few orders of magnitude
$\Rightarrow$Refine existing parameterization in this region in numerical models which under-estimate dissipation in regions of strong dissipation

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