Turbulent measurements in North Western Mediterranean using SCAMP (Self Contained Autonomous MicroProfiler)

Anna RUMYANTSEVA

supervised by Anne Petrenko and Andrea Doglioli

30 September 2010
The energy and temperature dissipation rates.

The budget equation:

\[
\frac{\partial}{\partial t} \rho \frac{1}{2} (u'^2 + v'^2 + w'^2) = -\bar{\rho} (u' w') \frac{\partial \bar{u}}{\partial z} - g (\rho' w') - \bar{\rho} \varepsilon
\]

- Turbulent kinetic energy
- Turbulent motion
- Potential energy
- Molecular diffusion dissipation

\[
\varepsilon = -v \left( \frac{\partial u'_i}{\partial x_j} \left( \frac{\partial u'_i}{\partial x_j} + \frac{\partial u'_j}{\partial x_i} \right) \right)
\]

The budget equation:

\[
\frac{\partial (\bar{T}'^2)}{\partial t} = -2 (w' T') \frac{\partial \bar{T}}{\partial z} - \chi
\]

- Variance of thermal anomalies
- Turbulent heat flux
- Molecular heat diffusion

\[
\chi = 2D \left( \nabla_{\text{avg}} T'^2 \right)
\]

where D is thermal diffusivity.
# Turbulent lengthscales

<table>
<thead>
<tr>
<th>Lengtscale</th>
<th>Symbol</th>
<th>Definition</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozmidov</td>
<td>$L_o$</td>
<td>$(\varepsilon/N^3)^{1/2}$</td>
<td>The scale at which buoyancy forces balance inertial forces</td>
</tr>
<tr>
<td>Kolmogorov</td>
<td>$L_k$</td>
<td>$(\nu^3/\varepsilon)^{1/4}$</td>
<td>The scale at which viscous forces balance inertial forces</td>
</tr>
<tr>
<td>Batchelor</td>
<td>$L_B$</td>
<td>$D^{1/2}(\nu^3/\varepsilon)^{1/4}$</td>
<td>The scale at which molecular diffusion smooths locally enhanced scalar gradients</td>
</tr>
</tbody>
</table>
Batchelor spectrum

Small-scale behaviour of passively convected, diffusive scalars in the presence of turbulence.

\[ S_B(k; k_B, \chi) = (q/2)^{1/2} \chi k_B^{-1} D^{-1} f(\alpha) \]

where

\[ \alpha = kk_B^{-1} \sqrt{2} \]
Brunt–Väisälä frequency

Frequency of the inertial oscillations of the volume of water in case of stable stratification of the ocean:

\[ N^2 = \frac{g}{\rho_0} \frac{\partial \rho}{\partial z} \]

- Brunt–Väisälä frequency
Thrope scale

Thrope displacement:

\[ d_n = z_m - z_n \]

Thrope scale:

\[ L_T = (\bar{d}^2)^{1/2} \]

Thrope scale scale is proportional to the mean eddy size as long as the mean horizontal density gradient is much smaller than vertical gradient.
**Osborn's method**

\[
\frac{u'w'}{\partial z} \frac{\partial \bar{u}}{\partial z} = -\varepsilon \frac{\rho'w'g}{\bar{\rho}}
\]

- **Turbulent production**
- **Dissipation**
- **Work against buoyancy**

**Richardson flux number:**

\[
R_f = \frac{\frac{\rho'w'g}{\bar{\rho}}}{\frac{u'w'}{\partial z} \frac{\partial \bar{u}}{\partial z}} = \frac{\text{Work against buoyancy}}{\text{Turbulent production}}
\]

Critical flux Richardson number — maximum value of \(R_f\), above which the turbulent cannot appear. \(R_{fcrit} = 0.15\) (Ellison 1957)
Osborn's method

Buoyancy flux: \[ B = -b'w' = K_b \frac{\partial b}{\partial z}, \quad N^2 = \frac{\partial b}{\partial z} \]

Buoyancy fluctuations: \[ b' = -(g/\rho) \rho' \]

Coefficient of eddy diffusivity: \[ K_b = \frac{g w' \rho' \rho^{-1}}{N^2} \]

\[ K_b = \frac{R_f \varepsilon}{(1 - R_f) N^2} \leq 0.2 \frac{\varepsilon}{N^2} \]
Self Contained Autonomus MicroProfiler (SCAMP)

Measurements on a small scale (≈ 1mm)
Frequency measures: 100Hz
Light ≈ 6kg
Move Free (fall and rise)
Travel speed ≈ 10cm/s
Maximum depth: 100m

manufactured by Presecion Measurement Engineering, California
SCAMP SENSORS

Two Thermometrics FP07 fast-response (time constant~7ms) thermistors

Temperature (Thermometrics T1201 thermistor, time constant~ms) and conductivity (PME 4-electrode ceramic, spatial resolution~cm) sensor pair

Four-electrode microconductivity sensor (spatial resolution~mm)

Pressure sensor (Keller PSI PAA-10)
Estimation of $k_b$. 

Measure $T$ and $\Theta$ using $s_{\text{getseg}}$. 

Discrete Fourier transformation (FFT method).

Spectrum calculated $S_{\text{exp}}(k)$ and $S(k)$ using $s_{\text{psd}}$. 

Maximizing the likelihood of $S_{\text{exp}}(k)$ and $S(k)$ using $s_{\text{c11}}$. 

Theoretical Batchelor spectrum of $S(k)$ with $k_b$ parameter, $\chi$ fixed using $s_{\text{bspect}}$. 

Final Batchelor spectrum $s_{\text{bspect}}$. 

Estimation $\chi$ using $s_{\text{X}}$. 

Noise spectrum of SCAMP $S_{\text{n}}(k)$ using $s_{\text{snoise}}$.
Segmentation

2 methods:

- Complex, statistical-stationarity, based-methods (ddt)
- Small fixed-size bins (scans)

Big values of dissipation rate without turbulence

<table>
<thead>
<tr>
<th>Depth, m</th>
<th>Eddy diffusivity, Kb, m²/s</th>
<th>Thrope scale, Lt, m</th>
<th>Dissipation rate, ε, m²/s³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>$10^{-4}$</td>
<td>0.03</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>8-12</td>
<td>$10^{-8}$</td>
<td>0.01</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>13-37</td>
<td>$10^{-6} ÷ 10^{-7}$</td>
<td>0.1 ÷ 0.01</td>
<td>$10^{-9} ÷ 10^{-10}$</td>
</tr>
</tbody>
</table>
Profile 23SEP2010 084152. Calm morning after wind night conditions (6-7 m/s)
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<tr>
<td>1-6</td>
<td>$10^{-3} \div 10^{-1}$</td>
<td>2</td>
<td>$10^{-7} \div 10^{-6}$</td>
</tr>
<tr>
<td>7-10</td>
<td>$10^{-5} \div 10^{-4}$</td>
<td>1÷2</td>
<td>$10^{-9} \div 10^{-7}$</td>
</tr>
<tr>
<td>10-14</td>
<td>$10^{-4} \div 10^{-3}$</td>
<td>0,2÷0,6</td>
<td>$10^{-8} \div 10^{-7}$</td>
</tr>
<tr>
<td>15-24</td>
<td>$10^{-7} \div 10^{-6}$</td>
<td>0,1÷0,4</td>
<td>$10^{-10} \div 10^{-8}$</td>
</tr>
<tr>
<td>25-27</td>
<td>$10^{-7}$</td>
<td>0,05÷0,2</td>
<td>$10^{-10} \div 10^{-9}$</td>
</tr>
</tbody>
</table>
Profile 23SEP2010 112935. Wind conditions (wind speed = 5 m/s)

Example of the spectrum in the wind mixed layer (Luketina, Imberger 2001)

Spectrum from profile 23SEP2010 112935 depth 1 — 2 m
Profile 23SEP2010 112935. Wind conditions (wind speed = 5 m/s)
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<tr>
<td>1-5</td>
<td>0.1-1</td>
<td>1.6</td>
<td>$10^{-6} \div 10^{-5}$</td>
</tr>
<tr>
<td>5-8</td>
<td>$10^{-4} \div 10^{-3}$</td>
<td>1.6</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>8-10</td>
<td>$10^{-4} \div 10^{-5}$</td>
<td>0.5÷1</td>
<td>$10^{-9} \div 10^{-8}$</td>
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<tr>
<td>14-25</td>
<td>$10^{-8} \div 10^{-6}$</td>
<td>0.1÷0.5</td>
<td>$10^{-10}$</td>
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Profile 20SEP2010 153028. «Step»
temperature profile.
**Profile 20SEP2010 153028. «Step» temperature profile.**

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<tr>
<td>1-5</td>
<td>$10^{-4}$÷$10^{-2}$</td>
<td>0,6÷1</td>
<td>$10^{-7}$</td>
</tr>
<tr>
<td>6-9</td>
<td>$10^{-5}$÷$10^{-4}$</td>
<td>0,4÷1</td>
<td>$10^{-10}$÷$10^{-8}$</td>
</tr>
<tr>
<td>10-12</td>
<td>$10^{-6}$</td>
<td>0,01÷0,1</td>
<td>$10^{-9}$÷$10^{-8}$</td>
</tr>
<tr>
<td>12,5 – 13,5</td>
<td>$10^{-4}$</td>
<td>0,06</td>
<td>$10^{-7}$</td>
</tr>
<tr>
<td>14 – 17</td>
<td>$10^{-7}$÷$10^{-5}$</td>
<td>0,01÷0,1</td>
<td>$10^{-10}$÷$10^{-8}$</td>
</tr>
<tr>
<td>18</td>
<td>$10^{-4}$</td>
<td>0,1</td>
<td>$10^{-7}$</td>
</tr>
<tr>
<td>20 - 24</td>
<td>$10^{-7}$÷$10^{-6}$</td>
<td>0,01÷0,1</td>
<td>$10^{-10}$÷$10^{-8}$</td>
</tr>
<tr>
<td>25 - 26</td>
<td>$10^{-5}$</td>
<td>0,6</td>
<td>$10^{-9}$÷$10^{-8}$</td>
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SCAMP Matlab program modifications by Hodges et al. 2006
Conclusions

- Big values of coefficient of eddy diffusivity (0.1 — 1) are observed in profile, taken during the wind conditions at depth 1 — 5 m with sizes of vertical overturnes in the order of 1 m. Also these layer is characterized by large values of turbulence dissipation rate (up to $10^{-5}$).
- In diurnal thermocline the values of $K_b$ are estimated as $10^{-4}$ and sizes of the the overturnes in order 0.01 with dissipation rate $10^{-6}$.
- In the regions of the seasonal thermocline decrease to $10^{-8}$. 