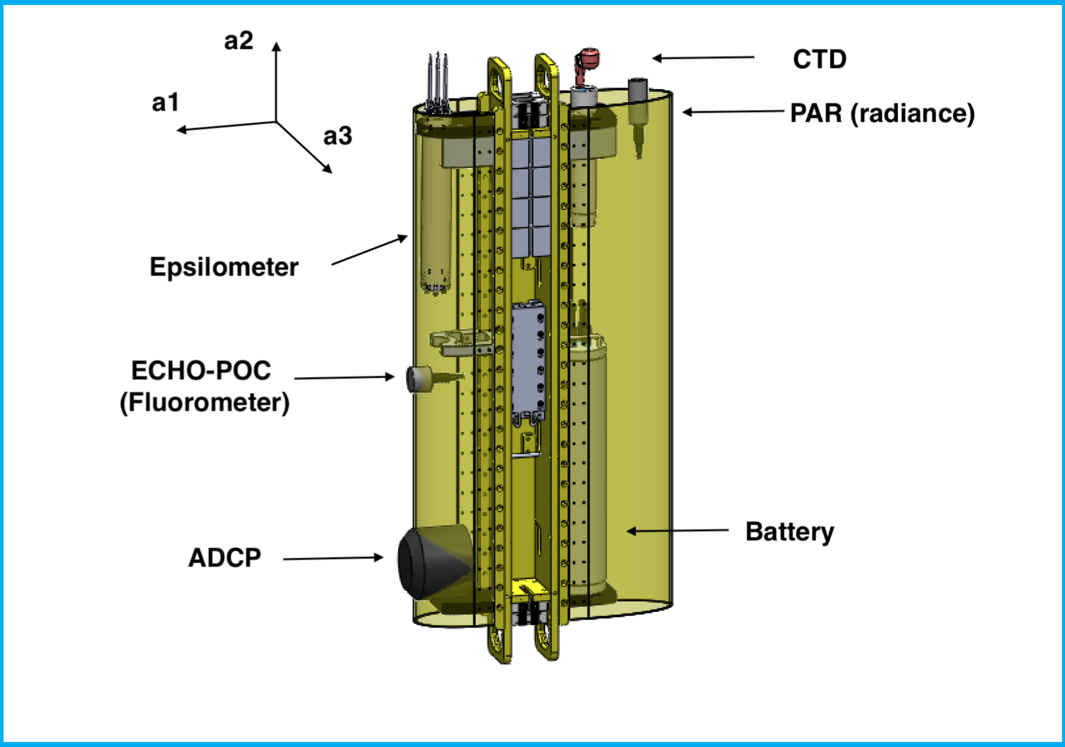
# EPSI-WW report
# November 2018

**Multi-Scale Ocean Dynamic group (MOD)**
Marine Physical Laboratory (MPL)
Scripps Institution of Oceanography (SIO)




Multiscale Ocean Dynamics
Scripps Institution of Oceanography
U.C. San Diego

# EPSI-WW report

## November 2018

Project duration: November 2018
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An electronic version of this report is available at `https://mod2.ucsd.edu/confluence/display/EP`.

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# Contents

## 0.1. Preamble

This report describes the processing of data collected during an EPSI WW mission. One wirewalker was deployed and was instrumented with a micro-structure profiler (Epsilometer), CTD, GPS, and ADCP.

The main goal of this analysis is to compute depth-time maps of the shear and temperature turbulent dissipation rates $\epsilon$ and $\chi$, respectively.

$\epsilon$ and $\chi$ are defined as follows:

$$\epsilon = 7.5\nu(s,T,P)\int_{k_0}^{k_u} \phi_{\frac{\partial u}{\partial z}} dk_v \quad [Wkg^{-1}] \tag{1}$$

where $\nu$ (s,T,P) is the kinematic viscosity dependent on salinity (S), temperature (T) and pressure (P), $k_0$ and $k_u$ are the lower and upper cutoffs determined by the record length and the character of the data. $k_v$ is the vertical wavenumber and $\phi_{\frac{\partial u}{\partial z}}$ is the wavenumber spectrum of vertical shear.

$$\chi = A_{1-3} 2\kappa_T \int_{k_0}^{k_u} \phi_{\frac{\partial T}{\partial z}}(k_v) dk_v \quad [K^2 s^{-1}] \tag{2}$$

The factor $A_{1-3}$ is the degree of isotropy. $\phi_{\frac{\partial T}{\partial z}}$ is the wavenumber spectrum of the temperature gradient. $\kappa_T$ is the thermal diffusivity in $m^2\ s^{-1}$ and $k_v$ is the vertical wavenumber.

# 1

# Instrumentation

## 1.1. WireWalker

The wirewalker is a self-powered platform capable of sampling the upper ocean and is manufactured by DMO (`http://delmarocean.com/wirewalker`). It travels along a cable with a surface buoy at one end and a weight at the other. The wirewalker has an internal cam, which grabs the cable and causes it to 'step' down the cable with every surface wave period. At the bottom of the desired profiling range, the profiler contacts a mechanical 'stop' which releases the cam, and enables the wirewalker to freely ascend to the top of the wire under its own positive buoyancy. Given the halting nature of the downcasts and relatively smooth ascent, only data collected on upcasts are used to measure turbulence.

## 1.2. Epsilometer (EPSI)

The wirewalker is instrumented with an epsilometer (EPSI) designed and manufactured at Scripps Institution of Oceanography (SIO) by the Multi-Scale Ocean Dynamic Group (MOD) in the Marine Physical Laboratory (MPL). The EPSI is a self-recording micro-structure profiler with two FPO7 thermistors to measure temperature and two piezo-electric beams to measure shear. The custom designed circuitry uses 24 bit analog-to-digital converters (ADCs) to sample the two temperature channels, two shear channels and three acceleration (X,Y,Z) channels at 320 Hz. The EPSI outputs 0.5 second blocks of binary data and stores them in 1 hour files on an SD card.

The two temperature channels are named 't1' and 't2', while the two shear channels are 's1' and 's2'. The three acceleration channels are denoted 'a1', 'a2', and 'a3'. Channels 'a1' and 'a3' correspond to the horizontal accelerations and 'a2' corresponds to the vertical acceleration.

## 1.3. CTD

The wirewalker is equipped with a concerto from RBR (`https://rbr-global.com/`). The concerto is configured in a self-recording mode with a 6 Hz sampling frequency. The concerto sensors are listed in table 1.1

## 1.4. GPS

The wirewalker is instrumented with a Rover Iridium Beacon from Xeos (`https://xeostech.com/rover`) The Rover is an independently powered, self-contained satellite transceiver designed to track buoys or autonomous vehicles on the surface. The user can choose the rate of transmission. For this deployment, it was set to an hourly transmit.

## 1.5. ADCP

The wirewalker is equipped with a side looking Signature 1000 from Nortek (`https://www.nortekgroup.com`). The Signature 1000 is a 5-beam acoustic Doppler current profiler (ADCP). It is self-recording with a 16 Hz sampling frequency. The ADCP profiles have 43 cells, with each cell spaced by 1 m. Technical issues occurred during the deployment and, consequently, the ADCP data are not available.

| Channel Name | Description |
|---|---|
| P | Pressure |
| T | Temperature |
| C | Conductivity |
| v1 | Backscatter |
| v2 | Chlorophyll |
| v3 | Dissolved Oxygen (CDOM) |
| v4 | Photosynthetically Active Radiation (PAR) |
| v5 | Irradiance 1 |
| v6 | Irradiance 2 |
| v7 | Irradiance 3 |
| v8 | Sea Pressure |
| v9 | Depth |
| v10 | Salinity |
| v11 | Speed of sound |
| v12 | Specific Conductivity |

Table 1.1: RBR concerto sensors

# 2

# Data Processing

## 2.1. CTD

The CTD data are collected and converted into a MATLAB format using the RSKtool package from RBR (`https://rbr-global.com/products/software`). Once collected, the data are split into upcasts and downcasts (as shown in Fig. 2.1). The up/downcasts are identified using the low-pass filtered speed of the wirewalker. The speed is estimated with the temporal derivative of the pressure ($\frac{dP}{dt}$) and filtered with a third-order low-pass Butterworth filter with a cutoff frequency of $\frac{1}{60}$ sec$^{-1}$. A full profile cycle (i.e. down and upcast) is about 15 min for a 250 m length cable. The upcasts are defined by $\frac{dP}{dt} < -0.1$ m s$^{-1}$ and the downcasts are defined by $\frac{dP}{dt} > 0.1$ m s$^{-1}$. Typical ascent speeds were about 0.4 m s$^{-1}$, while the descent speed can vary from 0.3 to 0.6 m s$^{-1}$. The number of upcasts can differ from the number of downcasts since the downcast speed depends on the sea state and the upcast speed only depends on the buoyancy of the wirewalker. While this can make the number of estimated downcast inaccurate, the number of upcasts reflects the true number of wirewalker profiles.

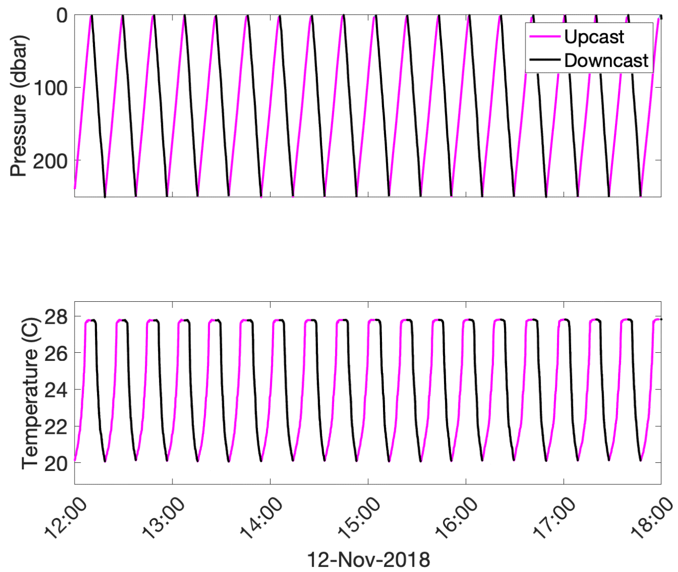


Figure 2.1: The pressure (top panel) and temperature (bottom panel) time series on November 12, 2018, from 12:00 to 18:00 PM (UTC). The time series are split in upcasts (magenta) and downcasts (black).

Once the casts are defined, the upcasts are split into three seconds segments with 50% overlap. The speed, temperature, and salinity are averaged over these segments (Fig. 2.2), and the latter two are used to to construct the temperature, salinity, and stratification (N$^2$) gridded products (Fig. 2.3). The timestamps of the

CTD on each upcast are then used to identify the concurrent EPSI data, which are processed according to the methods described in Section 2.3.

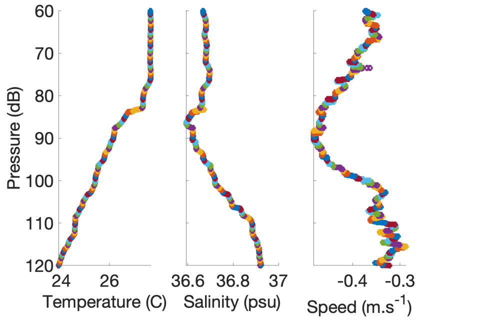


Figure 2.2: Profiles of temperature, salinity and speed (left panel, middle panel and right panel, respectively) between 60 and 120 m. The colors show the 3 seconds segments used for the EPSI data processing and the computation of the gridded products.

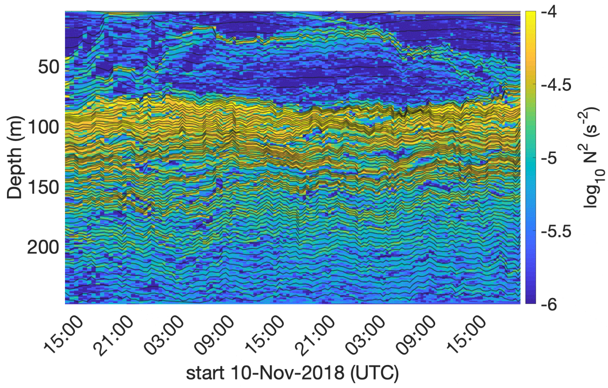


Figure 2.3: Depth-time plot of the buoyancy frequency squared ($N^2$) computed from the temperature and salinity of each upcast. The contours represent isopycnal layers spaced by an average of 2 m.

## 2.2. GPS

The GPS data are gathered from the Xeos website (`https://xeostech.com/xeosonlinetm`) and recorded in a .csv file. A MATLAB routine reads the .csv file and the buoy positions.

## 2.3. Epsilometer

The processing of the EPSI data is performed on each upcast (defined in section 2.1). If the isolation of upcast data was successful, we should observe that the signal in the EPSI temperature, shear, and acceleration channels is much less variable than for the downcasts (Fig. 2.4).

*Note*: If the CTD and the EPSI data appear out of phase (i.e. incorrectly identifying upcasts and downcast), it likely means that there is a discrepancies between the EPSI timestamps and the CTD timestamps. The user can find common features in the CTD and EPSI time series (e.g. EPSI acceleration and shear should be much less variable on the upcasts) and adjust the timestamps accordingly.

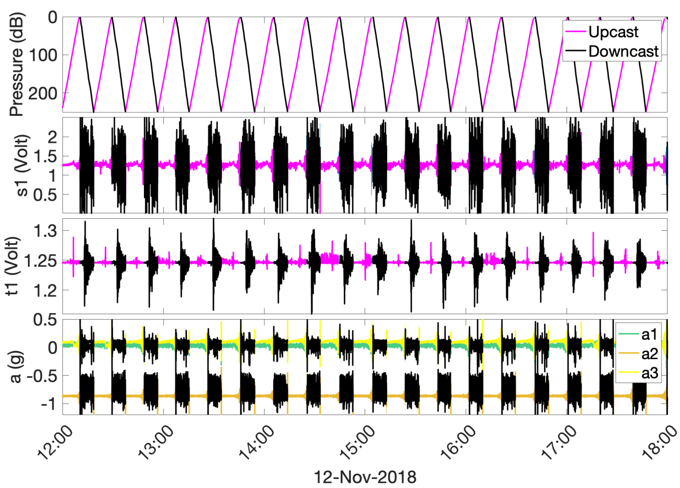


Figure 2.4: Time series of CTD pressure (top), EPSI s1 (second from top), EPSI t1 (second from bottom), and all EPSI acceleration channels (bottom). EPSI data that occur during wirewalker downcasts are in black, while upcasts are in color, which shows significantly different signals between up/downcasts.

The EPSI data can be used to estimate the shear and temperature turbulent dissipation rates, $\epsilon$ and $\chi$, respectively. These calculations are elucidated in Sections 2.3.1 and 2.3.2, but briefly, we:

- use the raw shear and temperature data (in volts) to compute the frequency spectra over 3 sec segments (defined in section 2.1).
- convert the raw voltage frequency spectra to physical parameters using the calibration coefficients unique to each sensor. We also scale spectra by various transfer functions.
- convert the frequency spectra into vertical wavenumber spectra using the ascent speed of the wire-walker.
- integrate these spectra up to a dynamically defined cutoff wavenumber. $\epsilon$ and $\chi$ are the products of these integrations. The wavenumber cutoff is designed to isolate integration over 'clean' bands of the spectra and ignore data contaminated with noise.

### 2.3.1. Temperature channels and $\chi$ computation

The two temperature channels are instrumented with FPO7 thermistors with a nominal resistance of 150 kΩ. The high frequency fluctuations in voltage associated with the variability in water temperature are amplified by a differential electric circuit (TDIFF). The voltage output of this circuit is sent to an analog to digital converter (ADC). The sampling frequency of this ADC is set by a sinc$^4$ filter (sinc4) to 320 Hz.

The true temperature signal is transformed by these different analog circuit elements, but this can be corrected by modifying the temperature outputs by the appropriate transfer functions. The transfer functions associated with the different elements of the temperature channels are shown in the lower panel of figure 2.5.

**Frequency spectrum and data conversion:**

The frequency spectrum of temperature data is defined as:

$$\phi_T(f) = \frac{\beta^2}{H^2_{sinc4}(f) H^2_{FPO7}(f,w) H^2_{TDIFF}} \phi_R(f) \quad [^\circ C^2 Hz^{-1}] \tag{2.1}$$

where $\phi_R$ is the initial spectrum of the raw data (in volts$^2 Hz^{-1}$), $\phi_t$ the temperature spectrum and $f$ is the frequency. $H_{sinc4}$, $H_{FPO7}$ and $H_{TDIFF}$ are the frequency responses of the sinc4 filter, FPO7 thermistor (also dependant on the speed $w$) and the differential filters, respectively. The raw spectra and the spectra corrected by the transfer functions are presented in Fig. 2.5.

The $\beta$ parameter is a calibration coefficient that converts the raw voltage output into temperature (°C). It is defined as $\beta \equiv \frac{dT}{dV}$, where T is temperature (in Celsius) and V is voltage. $\beta$ is the chosen in a manner that optimally rescales the FPO7 voltage spectrum to match the CTD temperature spectrum (Fig. 2.6). In practice, $\beta$ is computed at the beginning, middle, and end of the deployment. If the $\beta$ values are consistent (differing by only a few percent), we use the same $\beta$ for the entire deployment.

**Wavenumber spectrum and cutoff:**

In order to estimate $\chi$, the temperature frequency spectra need to be converted into temperature gradient wavenumber spectra ($\phi_{\frac{\partial T}{\partial z}}$), such that

$$\phi_{\frac{\partial T}{\partial z}}(k_v) = (2\pi k_v)^2 \frac{\phi_T(f)}{w} \quad [^\circ C^2 m^{-2}/cpm] \tag{2.2}$$

where $w$ is the vertical speed of the wirewalker, and $k_v$ is the vertical wavenumber ($k_v = f/w$).

Estimates of $\chi$ are obtained by integrating $\phi_{\frac{\partial T}{\partial z}}$ over a variable wavenumber band,

$$\chi = A_{1-3}(2\kappa_T) \int_{k_0}^{k_u} \phi_{\frac{\partial T}{\partial z}}(k_v) dk_v \quad [^o C^2 s^{-1}] \tag{2.3}$$

Here, $A_{1-3}$ is a coefficient that can range between one and three, depending on the degree of isotropy. Assuming full isotropy, we use a value of 3. $\kappa_T$ is the thermal diffusivity and is usually near $1.5 \times 10^{-7}\mathrm{m}^2\ /\mathrm{s}^{-1}$. The lower bound of integration, $k_0$, is defined as $k_0 = \frac{0.\bar{3}s^{-1}}{w}$, which is the lowest resolved wavenumber in the three second temporal segments used to estimate $\chi$. The upper bound of integration, $k_u$, corresponds to the wavenumber for which the observed temperature gradient spectrum becomes indistinguishable from

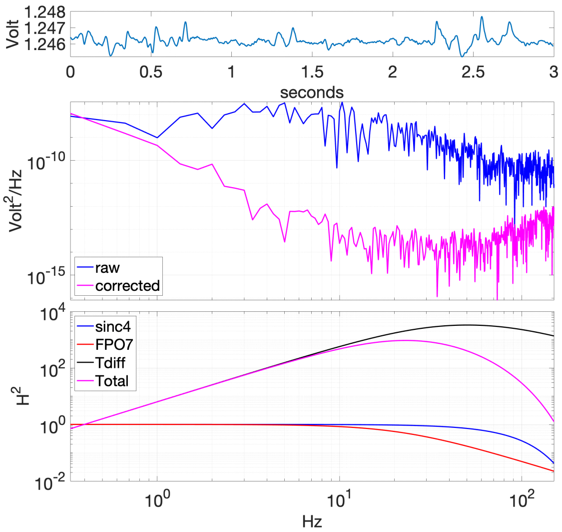


Figure 2.5: Top: 3 sec segment of the t1 channel. Middle: Frequency spectra of the recorded data (blue) and the data corrected from the frequency response of the different filters (magenta). Bottom: Frequency response of the sinc4 filter (blue), the FPO7 thermistor (red) and the TDIFF circuit (magenta). The black line is the sum of all the transfer functions.

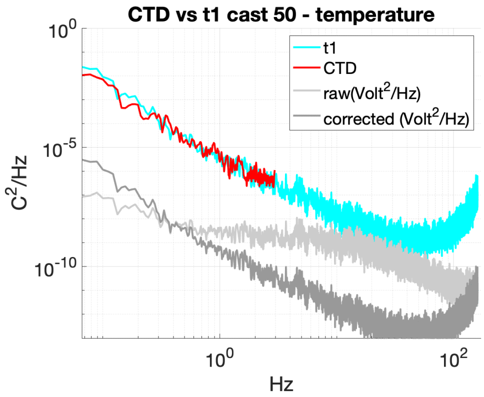


Figure 2.6: Frequency spectra of the CTD temperature (red) and the t1 temperature (cyan). The light gray and dark gray lines are the raw and corrected spectra, respectively (in $V^2 Hz^{-1}$). The corrected spectrum is multiplied by the constant $\beta$ to obtain the t1 temperature spectrum.

instrumental noise. To estimate the spectrum induced by noise alone, we collect raw data while the EPSI is in a controlled, in-air lab setting (to virtually eliminate any physical signal). These data represent the voltage signal arising from electrical noise in the circuitry of the EPSI, and by applying Eqs. 2.1 and 2.2 we compare this to the observed temperature gradient spectrum to choose $k_u$ (Fig. 2.7). Since the observed spectrum varies with the physical conditions sampled, $k_u$ is uniquely selected for every three second segment of data (the noise spectrum is assumed constant).

The shape and level of the observed spectrum can be compared to the theoretical Batchelor spectrum, which predicts the turbulent temperature gradient spectrum for a given $\chi$ and $\epsilon$ (Fig. 2.7, magenta line). The computation of epsilon is described in section 2.3.2.

### 2.3.2. Shear channels and $\epsilon$ computation

Shear is indirectly computed from the charge variations (Δq) of piezo-electric beams deformed by the small variations of horizontal velocity in the ocean. The nominal capacitance of these beams is about 700 pF. Δq is sent to a charge amplifier (CA) which outputs a variable voltage (ΔV) proportional to Δq. This ΔV is then sent to an ADC configured to sample the analog signal at 320 Hz using a sinc4 filter. The beams are encapsulated in custom designed probes and calibrated in order to transform the observed voltage signal to ocean velocity ($u$). Osborn and Crawford (1980) describe the probes and their sensitivities ($S_v$). EPSI carries two airfoils, both oriented with their sensitive axis in the same direction so their outputs can be compared during data analysis. The rubber tips are made with parabolic cross-sections to provide constant lift for velocities parallel to the sensitive axis ($u$). The output voltage is

$$E_0(t) = S_v \frac{w^2}{2g} \frac{u'(t)}{w} \quad [Volt] \tag{2.4}$$

where $u'$ is the horizontal velocity relative to the EPSI, $S_v$ is the probe sensitivity calibration coefficient, g is the gravitational constant (9.81 m/s$^2$), and $w$ the vehicle speed. Typical sensitivities are $S_v$ = 30 to 60 volts per meter. All the different elements (probe, CA and ADC) of the analog circuit transform the 'true' ocean signal into the 'measured' signal, which can be corrected by applying their associated transfer functions to the EPSI shear channel outputs. The transfer functions associated with the different elements of the shear channels are presented in the lower panel of figure 2.8.

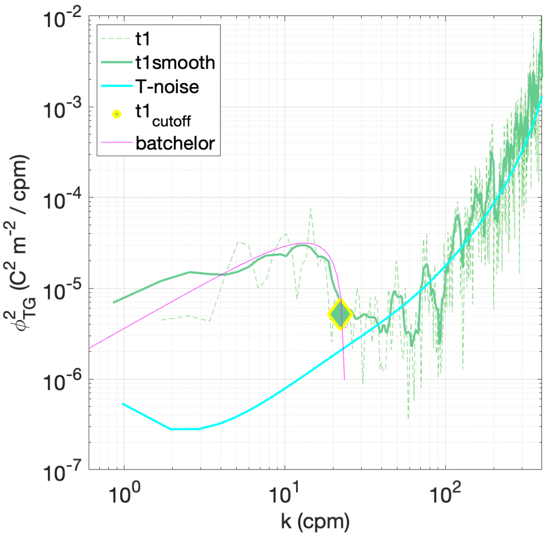


Figure 2.7: Wavenumber spectra of the temperature gradient (green) and Electronic noise from the benchtest (cyan). The integration to compute $\chi$ is performed on the wavenumbers lower than the cutoff (yellow diamond). The batchelor spectrum is in magenta.

### Frequency spectrum and data conversion

The frequency spectrum of the velocity data can be defined as:

$$\phi_u(f) = \left(\frac{2g}{S_v w}\right)^2 \frac{1}{H^2_{sinc4}(f) H^2_{PROBE}(f,w) H^2_{elec}} \phi_R(f) \quad [m^2 s^{-2} Hz^{-1}] \tag{2.5}$$

with $\phi_R$ the recorded data spectrum, $\phi_u$ the velocity spectrum and $f$ the frequency. $H_{sinc4}$, $H_{FPO7}$ and $H_{elec}$ are the frequency responses of the sinc4 filter, the spatial response of the airfoil probe (also dependent on the speed $w$) and the electronics transfer function, respectively. The correction of the recorded data spectrum by the combined frequency responses is presented in figure 2.8.

### Wavenumber spectrum and cutoff

The vertical wavenumber spectrum of shear ($\phi_{\frac{\partial u}{\partial z}}$) is derived from the frequency spectrum of velocity,

$$\phi_{\frac{\partial u}{\partial z}}(k_v) = (2\pi k_v)^2 \frac{\phi_u(f)}{w} \quad [s^{-2}/cpm] \tag{2.6}$$

where once again, $w$ is the vertical speed of the wirewalker, and $k_v$ is the vertical wavenumber. $\epsilon$ is then computed using:

$$\epsilon = 7.5\nu(s,T,P) \int_{k_0}^{k_u} \phi_{\frac{\partial u}{\partial z}} dk_v \quad [W kg^{-1}] \tag{2.7}$$

where $\nu$(s,T,P) is the kinematic viscosity, and $k_0$ and $k_u$ are the lower and upper wavenumbers of integration, respectively. Again, $k_0 = \frac{0.\overline{3}s^{-1}}{w}$, but now the upper cutoff ($k_u$) corresponds to the Kolmogorov scale, $k_g$,

$$k_u = k_g = \frac{1}{2\pi}\left(\frac{\epsilon}{\nu^3}\right)^{1/4} \tag{2.8}$$

Using equations (Eqs. 2.7 and 2.8), we employ an iterative process to estimate $\epsilon$. First, we use the integrated shear variance between 2 and 10 cpm to form an initial guess of $\epsilon$ (using the theoretical Panchev spectrum that most closely matches the variance in the wavenumber band). This allows us to estimate $k_u$, which in turn yields a second estimate of $\epsilon$. This procedure is repeated a total of three times. The third $\epsilon$ and $k_u$ are considered the final observed values. The shape and level of the observed spectra can be compared to the theoretical Panchev spectra, which predict the turbulent shear spectrum for a given $\epsilon$ and $\nu$ (Fig. 2.9).

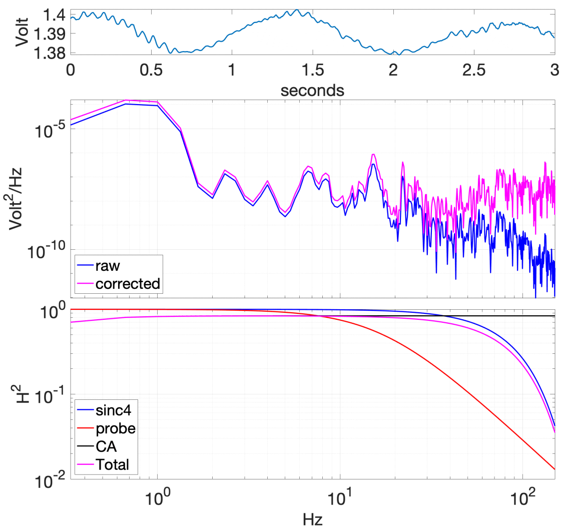


Figure 2.8: Top: 3 sec segment of the s1 channel. Middle: Frequency spectra of the recorded data (blue) and the data corrected by the frequency response of the different filters (magenta). Bottom: Frequency response of the sinc4 filter (blue), the shear probe (red) and the CA circuit (black). The magenta line is the sum of all the transfer functions.

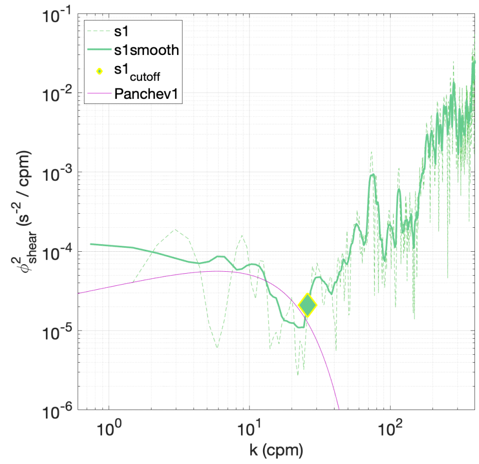


Figure 2.9: Smoothed (green) and raw (dashed green) wavenumber spectra of shear. The integration to compute $\epsilon$ is calculated over all wavenumbers lower than the cutoff (yellow diamond). The Panchev spectrum is in magenta.

### 2.3.3. Gridded $\epsilon$ and $\chi$

Once $\epsilon$ and $\chi$ values have been estimated for each profile, we construct products gridded in time and depth. Profile data are linearly interpolated to a depth grid ranging from the surface to the deepest measurement collected, spaced by 0.5 m. Every profile is then assigned a uniform time, equal to that of the midpoint of the profile. Examples of $\epsilon(t,z)$ and $\chi(t,z)$ are given in Figs. 2.10 and 2.11, respectively. Estimated values for $\epsilon$ are unreasonably high, which is investigated further in Section 2.3.4.

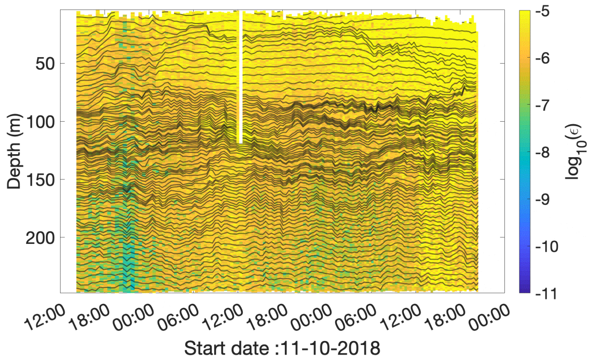


Figure 2.10: Gridded $\epsilon$ from channel 1 on the wirewalker during the EPSIWW deployment. Contours are of isopycnals, spaced by an average of 2 m. Data are likely contaminated by wirewalker accelerations, which results in erroneously high values of $\epsilon$.

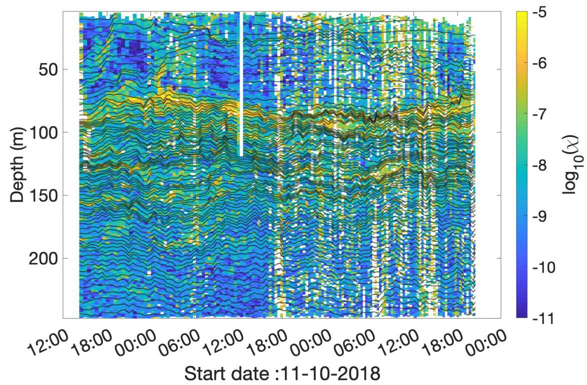


Figure 2.11: Gridded $\chi$ from channel 1 on the wirewalker during the EPSIWW deployment. Contours are of isopycnals, spaced by an average of 2m. Gaps in data (white) are segments for which the cutoff wavenumber is the Nyquist frequency. In this case, $\chi$ is too high for the EPSI resolution.

Although the shear-based observations of $\epsilon$ are too contaminated to be useful, it is possible to estimate $\epsilon$ from the measurements of $\chi$ ($\epsilon_\chi$),

$$\epsilon_\chi = \frac{\chi N^2}{\Gamma\left(\frac{\partial T}{\partial z}\right)^2} \tag{2.9}$$

where $N^2$ and $(\partial T/\partial z)^2$ are the squares of the buoyancy frequency and vertical temperature gradient, respectively (both estimated from CTD data). $\Gamma$ is the mixing efficiency, and is canonically assumed to be 0.2. This estimate yields much more typical magnitudes and patterns of $\epsilon$ (Fig. 2.12). The median value of the $\epsilon_\chi$ estimate are ~ 350 lower than the median value of the 'observed' $\epsilon$.

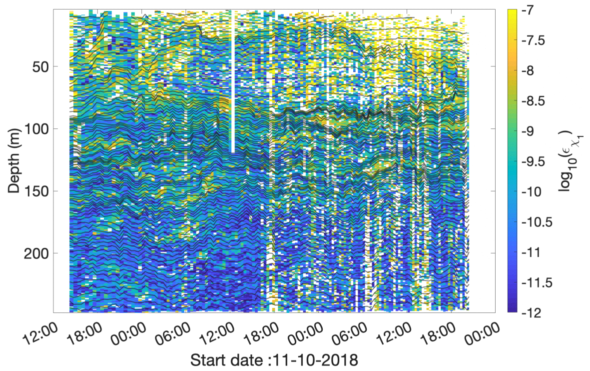


Figure 2.12: $\epsilon$ computed from $\chi_1$ using eq.2.9. Contours are of isopycnals, spaced by an average of 2 m.

### 2.3.4. Acceleration channels and vibration issues

The EPSI is equipped with an accelerometer measuring accelerations X (a1), Y (a2), Z (a3) of the EPSI. While profiling, channels 'a1' and 'a3' measure the horizontal accelerations and 'a2' is the vertical acceleration. a2 is near g because the vehicle was nearly vertical (Fig. 2.14). The voltage signal recorded by the accelerometer is sent to three ADCs (one for each channel) configured to sample at 320 Hz using the same sinc4 filter as the temperature and shear channels.

The accelerometer voltage ouptuts are converted into acceleration units g (g = 9.81 m s$^{-2}$),

$$A_g = \frac{A_V - C_{offset}}{C_{sensi}} \quad [g] \tag{2.10}$$

where $A_g$ is the acceleration in g, $A_V$ is the acceleration in volts. $C_{offset}$=1.65 V is the zero-g offset and $C_{sensi}$=0.66 V/g is the sensitivity. Both constants are provided by the manufacturer. Spectrally, the accelerometer has a white noise of about 45 $\mu$V Hz$^{-1/2}$.

#### Frequency spectrum:

The frequency spectrum of the acceleration data is defined as:

$$\phi_A(f) = \frac{1}{H^2_{sinc4}(f)}\phi_R(f) \quad [g^2 Hz^{-1}] \tag{2.11}$$

where $\phi_R$ is the spectrum of $A_g$ and $\phi_A$ is the acceleration spectrum after correcting for the sinc4 transfer function (both in $g^2 Hz^{-1}$).

#### Acceleration impacts on epsilon:

The piezo-electric beams used to characterize shear are also sensitive to mechanical accelerations. Although designed to be as 'quiet' as possible, the wirewalker is still subject to various sources of vibration on its upcasts, which can consequently contaminate the shear and $\epsilon$ measurements. During the EPSIWW deployment, peaks in the acceleration spectra (measured by the accelerometers) often align with peaks in the shear spectra (~ 10 Hz peaks in Fig. 2.13). These peaks are usually highly coherent (Fig. 2.14), further suggesting that wirewalker vibrations are contaminating the observations of shear. Shear is most coherent with lateral acceleration a1, but is also coherent with vertical acceleration a2 (Fig. 2.14). This is consistent with wirewalker oscillations rotating around the a3 axis. Unfortunately, these peaks occur within the range of wavenumbers usually used to estimate $\epsilon$, and are responsible for skewing our estimates (Fig. 2.10 and 2.15). Efforts to correct the shear spectra by removing the portions coherent with the acceleration channels were unsuccessful.

The vibrations observed during the EPSIWW deployment have spectral levels up to several orders of magnitude higher than previous EPSI deployments (Fig. 2.16). The best (lowest vibration) vehicle performances

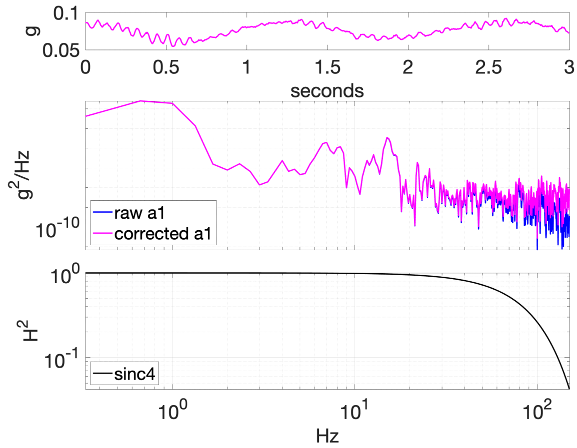


Figure 2.13: Top: 3 sec segment of the a1 channel. Middle: Frequency spectra of the recorded data (blue) and the data corrected by the frequency response of the sinc4 filter (magenta). Bottom: Frequency response of the sinc4 filter (black).

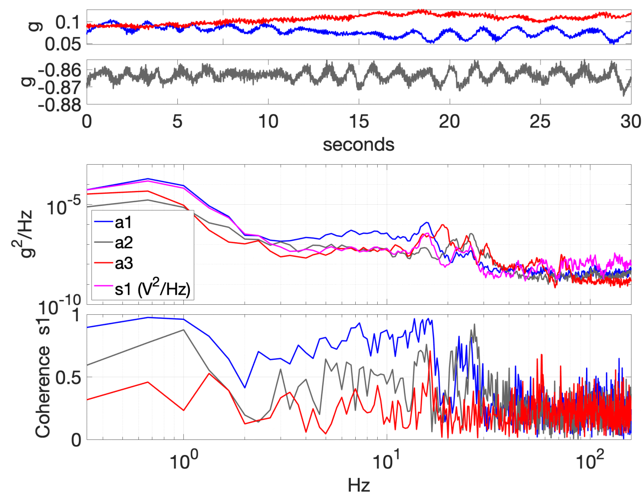


Figure 2.14: Top panels: 30 sec time series of a1 (blue), a3 (red) and a2 (grey). The middle panel shows the frequency spectra of a1, a2 and a3 compared with the frequency spectra of s1 (magenta). The lower panel shows the spectral coherence of each of the acceleration channels with s1.

are observed when EPSI is deployed on an epsifish (the custom designed vehicle for loosely-tethered deployments) using an electric fishing reel to recover the instrument after casts. In this configuration, the acceleration level is about $10^{-9}$ $g^2Hz^{-1}$ for frequencies greater than 10 Hz, which is the noise floor of the accelerometer chip. At lower frequencies, the spectrum shows a $f^{-1}$ slope (where $f$ is frequency) with a maximum at 0.3 Hz. A previous wirewalker deployment (in June, 2017) also show vibrations 100 times lower than during EPSIWW. The sources of the ~1 Hz acceleration peak is currently under investigation. The length and tension in the wire as well as the buoyancy distribution in the wirewalker are potential factors that could explain this behavior.

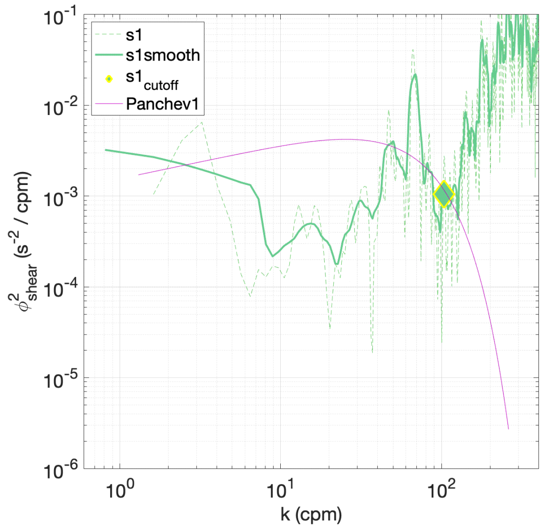


Figure 2.15: Same as Fig. 2.9. For this three second segment of data acceleration signals clearly skew the computed value of epsilon. The low (< 10 cpm) and high (~ 65 cpm, equivalent to ~ 25 Hz) wavenumber peaks cause our estimates of $\epsilon$ to be at factor of two to three orders of magnitude too high (cf. section 2.3.3). Furthermore, the acceleration induced signal is so broad in wavenumber it is difficult to isolate a wavenumber band that clearly follows the general shape of the Panchev spectrum.

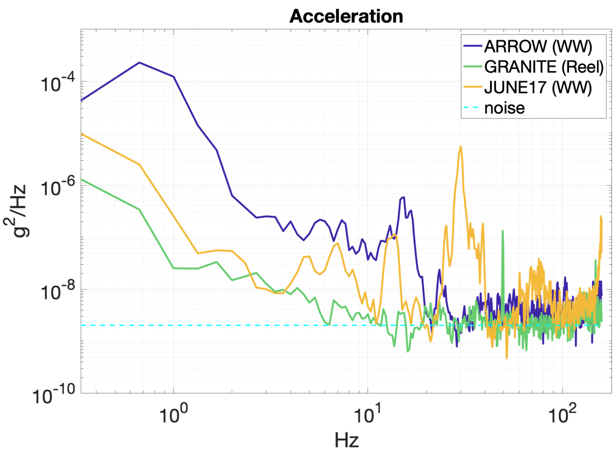


Figure 2.16: Acceleration spectra (a1) for different deployments and vehicles. The EPSIWW deployment (blue) has a strong vibration peak at 0.8 Hz. It is compared to another wirewalker deployment made in June 2017 (orange) and a deployment using an epsifish. Both deployments show a lower vibration peak at lower frequency. The spectra were computed well below the mixed layer in a quiet part of the water column where the stratification is almost constant.