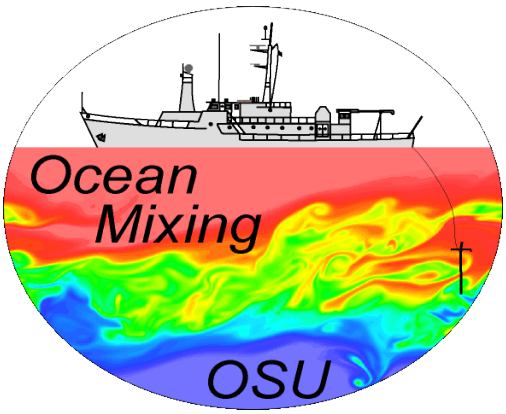

The χpod and gusT processing package

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Contents

Part I

Calibration

Chapter 1

Compass

It can be confusing how the angles from the compass in χpods compare to flow direction, and how to ensure correct compass calibration. This document will cover the following:

1. How the compass is orientated within the χpod
2. How to convert from χpod compass angle to flow angle
3. How to include a compass offset
4. How to include magnetic declinations
5. Checking compass calibration with Pitot and ADCP
6. Errors to be aware of

1.1 Compass orientation within the χpod

If the compass is placed correctly within the χpod, it will be orientated such that it points towards the sensor tips. Therefore, it will read 0° when the sensor tips are pointed northward. Figure 1.1 shows a diagram of how the compass is orientated within the χpod.

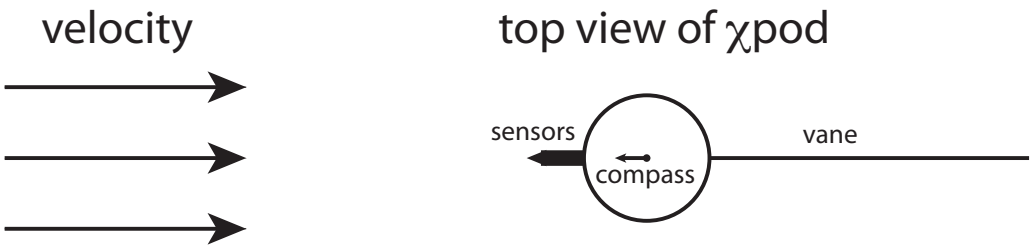


Figure 1.1: *A perfectly installed compass should align with the sensors. The χpod vane will steer the sensors into the flow.*

1.2 Converting from χpod compass to flow direction

Converting between compass angle and flow direction is confusing for 2 reasons:

- The compass uses heading orientation with north = 0°, and increasing clockwise such that east = 90°, south = 180°, and west = 270° = -90°. This is different from velocity for which we typically use vector notation with east = 0°, and angles increasing counterclockwise such that north = 90°, west = 180°, and south = 270° = -90°.

- Additionally, the sensors point *toward* the flow so they indicate the direction the flow is *coming from* not the direction to which it is going. Therefore, flow to the north would give a compass reading of 180° since the sensors would be pointed to the south. See Figure 1.2 for a complete comparison of angles.

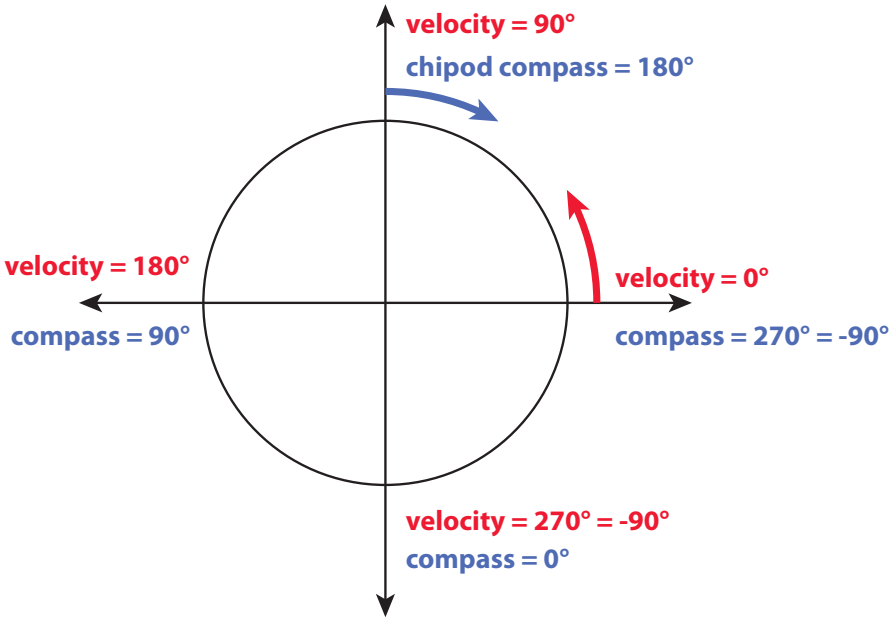


Figure 1.2: *Angles of flow direction in vector notation (red) and the corresponding compass readings within the χpod. This assumes, of course, that the χpod sensors are vaned to face directly into the flow.*

The formula that can be used to convert χpod compass angle to flow direction (in vector reference frame) is:

$$\theta_{flow} = -\left(\theta_{compass} + 90°\right) \tag{1.1}$$

Alternatively, to convert from flow direction to compass:

$$\theta_{compass} = -\left(\theta_{flow} + 90°\right) \tag{1.2}$$

1.3 How to find the compass offset

When the χpods are built, the compass may not be put into the χpod casing precisely such that the compass points directly to the sensors. Therefore, the compass is calibrated prior to deployment so we know what the offset is between the sensor direction and the compass direction. To do this, the engineers take the χpod into the woods away from magnetic sources and point the sensors to the north. They wait a minute, then rotate the χpod 10° clockwise. They repeat this all the way around the circle until the χpod sensors are again pointing toward the north.

Compass calibrations will be saved in a folder called something like "/Calibrations/compass/" within each χpod deployment folder. To view the compass calibrations:

```
% load compass calibration file, which would have a name like CMP_00000000.U
[data, head] = raw_load_chipod('CMP_00000000.UNT');
figure
plot(data.CMP/10)
```

This will create a figure that shows the compass calibrations (see Fig. 1.3 for an example). There should be 37 steps of 10° increments. Use `ginput` to select the first and last values to get the offset between the sensor tips and the compass.

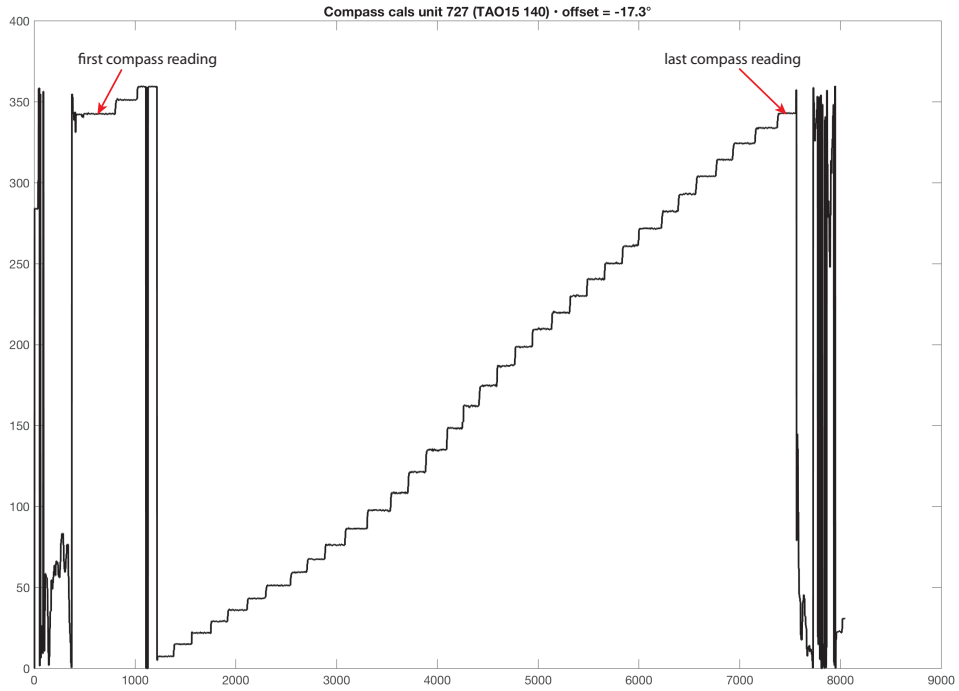


Figure 1.3: *Data from χpod compass calibration. Compass angle in degrees between 0° and 360° on y-axis, unimportant time steps on x-axis. Use `ginput` to get first and last value. In this case, the offset was found to be 342.7° = -17.3°.*

To apply this offset to the header.mat calibration file, use the following commands in MATLAB. `UNT` is the unit number, `DIR` is the directory of the χpod processing which contains folders like calib, mfiles, input, proc, raw, etc., and `OFFSET` is the angle found using ginput from the compass calibration file. It is important to include the negative offset in the header file (head.mat) because this is the value that is *added* to all of the compass readings.

```
% move to the correct directory
    cd DIR
% load the header file that includes all of the calibrations
    load calib/header.mat
% display the compass calibration which should be [0; 1; 0; 0; 0]
    head.coef.CMP
% add the offset to the header. **Input the NEGATIVE of OFFSET**
    head.coef.CMP(1) = -OFFSET
% save the updated header
    save calib/header.mat head
```

1.4 How to include magnetic declinations

Magnetic declination arises because the magnetic field of the earth is not uniform. This is especially important in the Pacific Northwest: a compass pointing directly north will give a reading of about 15° east of north due to the large mass of the Cascade mountains to the east. Note that the magnetic declination changes slowly over time. This needs to be included in the compass calibrations!

Look up the magnetic declinations in Corvallis where the instrument was calibrated and at the deployment location on the following website:

`https://www.ngdc.noaa.gov/geomag-web/#declination`

In 2017, the magnetic declination in Corvallis was about 15°E (Fig. 1.4). The magnetic declination at 0°, 140°W, where many χpods are deployed is 9.3°.

Now, instead of just inputting the OFFSET into the header calibrations, you'll want to include the declinations. Repeat the steps in the previous section, but include the declinations:

```
% add the offset and declinations to the header
    head.coef.CMP(1) = -OFFSET - DECL_CORVALLIS + DECL_DEPLOYMENT
% don't forget to save the updated header
    save calib/header.mat head
```

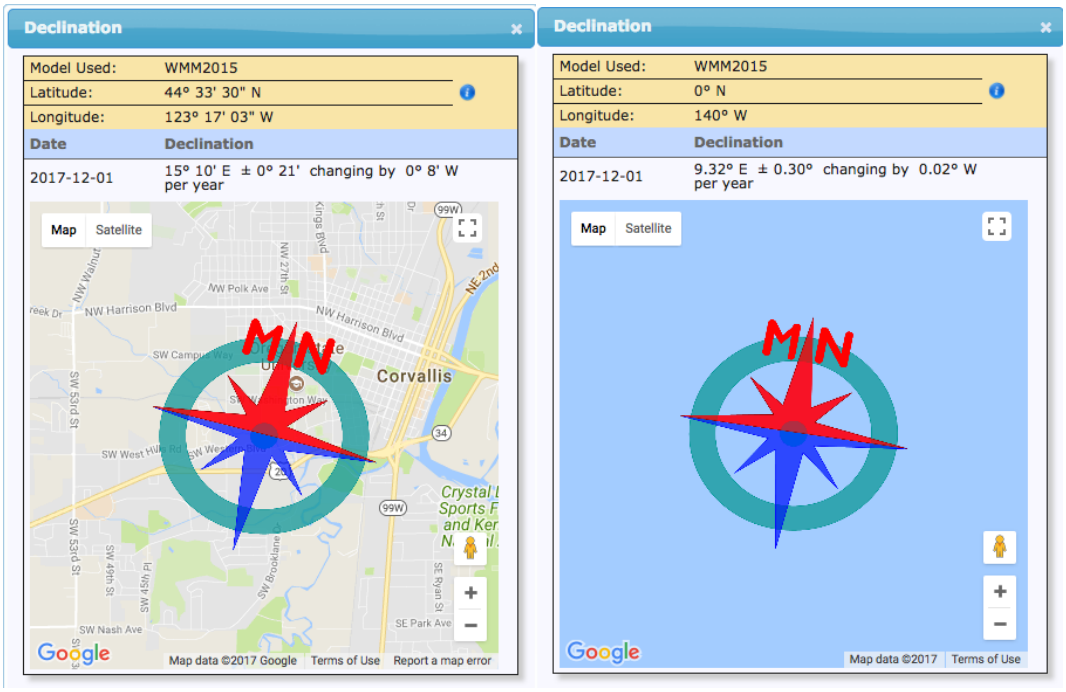


Figure 1.4: *The magnetic declination in Corvallis and at 0°, 140°W on December 1, 2017.*

For our example, the offset was -17.3°, the magnetic declination in Corvallis was 15.2°, and the magnetic declination at the deployment location was 9.3°. Therefore, we set the header coefficient to be 11.4° ($--17.3-15.2+9.3=11.4$).

Alternately, within the χpod_gust software, you can include the compass offset and magnetic declinations in `pre_driver.m` (shown with example values input into code):

```
LINE 24       modify_header = 1;    % if 1, specify header corrections below
LINE 25                             % (e.g. declination)
LINE 26
LINE 27       % get declination: https://www.ngdc.noaa.gov/geomag-web/#decli
LINE 28       CompassOffset = -17.3; % exact value from calibration file
LINE 29                             % (no sign changes!)
LINE 30       DeployDecl = 9.3; % at deployment location
LINE 31       CorvallisDecl = 15+10/60; % at corvallis
...
LINE 81       head.coef.CMP(1) = -CompassOffset - CorvallisDecl + DeployDecl,
```

1.5 Checking compass calibrations with Pitot and ADCP

If you have ADCP data and the compass has been calibrated correctly, pitot derived velocities should match up very well with ADCP velocities. Fig. 1.5 shows the output from `calibrate_pitot`. Additonally, when `calibrate_pitot` is run, an angle offset between the ADCP and pitot is printed to the screen. This should be small (i.e. $< 5°$).

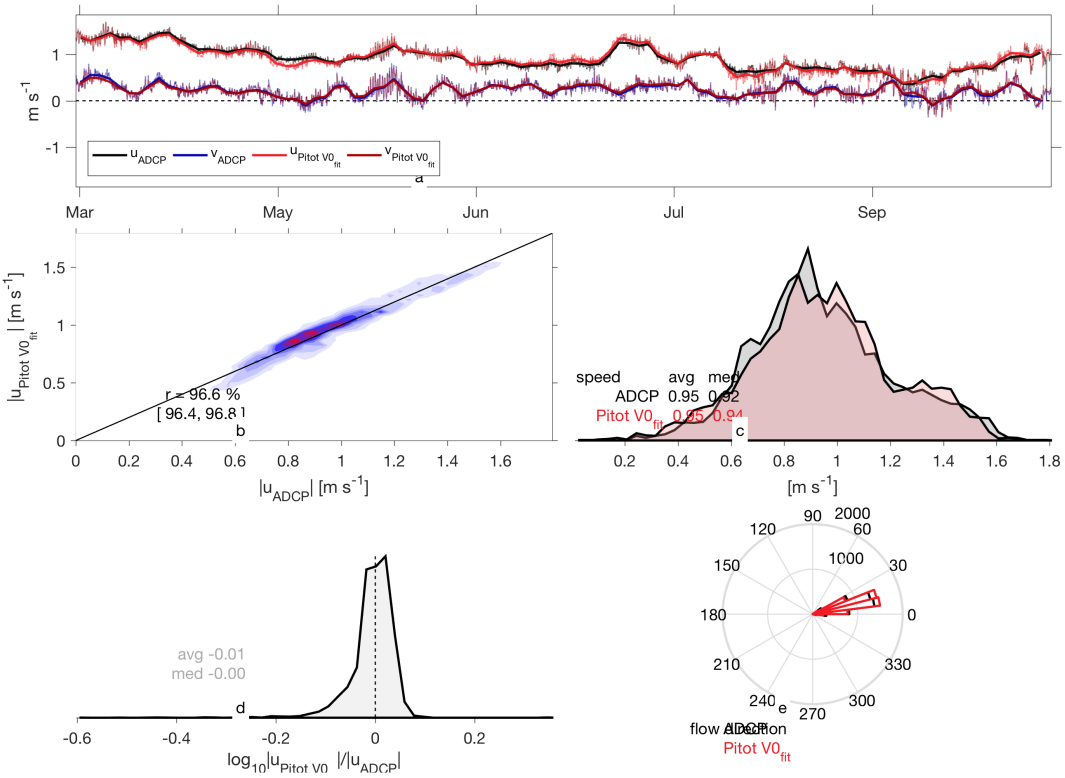


Figure 1.5: *Output of `calibrate_pitot` when the compass has been correctly calibrated. ADCP and pitot velocities match closely.*

1.6 Errors to be aware of

There are a few problems that can arise.

1.6.1 Nonlinear compass calibrations

There have been a few cases where the compass calibrations look very nonlinear (e.g. Fig. 1.6). In other words, the compass steps during the calibration are not all 10°. Some are as big as 50°, and many are $< 5°$.

To fix this, we did not use the compass calibration from Fig. 1.6, which was 195.6°. Instead, we manually found the offset that got the compass direction to match the flow direction as measured by the ADCP (Fig. 1.7). The new offset is found to be 91.4°. A big difference! This would not work as well in cases where the current was not uniformly flowing in one direction as it was for this χpod.

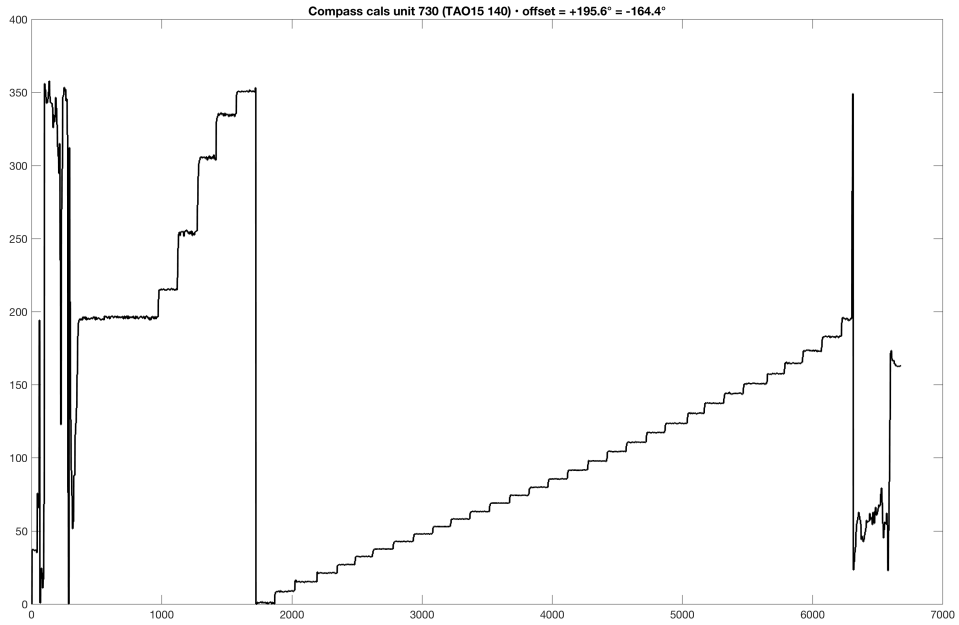


Figure 1.6: *Example of bad compass calibrations. Not all steps are equal.*

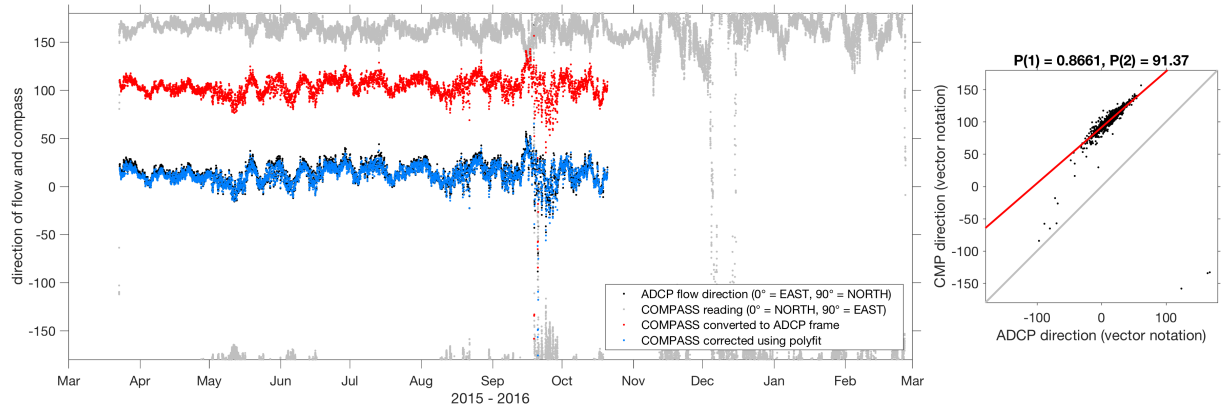


Figure 1.7: *Manually finding the compass offset that makes the compass match the ADCP. Flow direction from ADCP (black dots), compass readings in heading coordinates (gray dots), compass readings converted to vector coordinates (red), compass readings in vector coordinates with an offset of 91.37° applied.*

1.6.2 Bad comparison between ADCP and Pitot

Sometimes, the comparison between the ADCP and the pitot are just plain bad. This is somewhat hard to diagnose. Maybe the pitot goes bad. Try doing the calibration over a

shorter period of time and look for jumps in the signal. Maybe the compass calibrations are bad, in which case trust the angle given in the ADCP vs pitot comparison.

You can ignore the compass in the χpod processing by setting

```
pflag.master.use_compass = 0;
```

in `main_driver.m`. This will assume that the χpod is always perfectly vaned directly into the flow. When the compass is bad, the pitot will be able to give speed but not direction unless there is an ADCP to compare to.

1.6.3 Declinations already included in the calibration

There were some cases where the magnetic declination was being included in the compass calibrations. I'm not sure how this was being done. It's impossible to know whether they were or weren't included unless a note is added in the calibration folder. If you suspect this may be the case, (1) ask Pavan if he remembers how the compass was calibrated, (2) try adding and subtracting the declination in Corvallis to see if that helps, or just (3) use the ADCP to pitot comparisons to get the compass offset.

Chapter 2

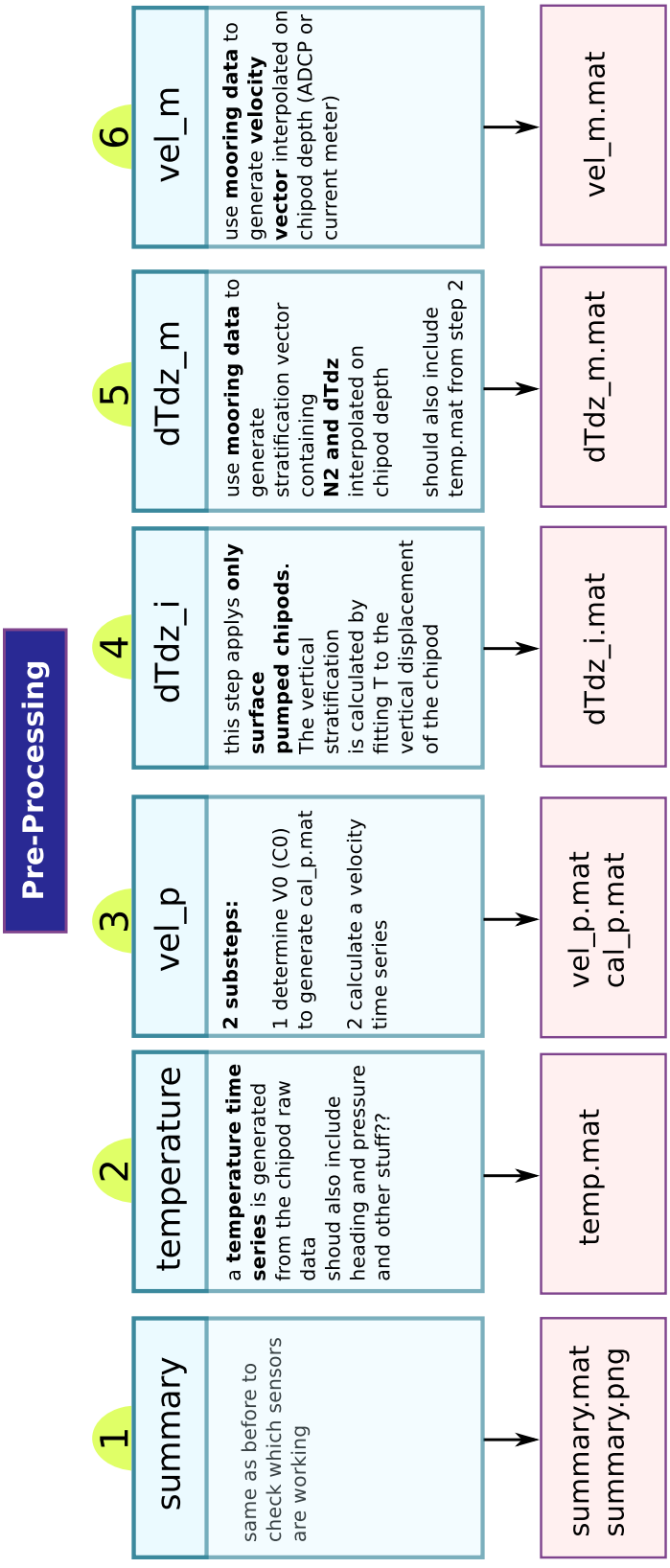
Pitot-static tubes

Part II

Processing

Chapter 3

`pre_driver`


Pre-Processing
1
summary
same as before to check which sensors are working
summary.mat
summary.png
2
temperature
a temperature time series is generated from the chipod raw data
shoud also include heading and pressure and other stuff??
temp.mat
3
vel_p
2 substeps:
1 determine V0 (C0) to generate cal_p.mat
2 calculate a velocity time series
vel_p.mat
cal_p.mat
4
dTdz_i
this step applys only surface pumped chipods. The vertical stratification is calculated by fitting T to the vertical displacement of the chipod
dTdz_i.mat
5
dTdz_m
use mooring data to generate stratification vector containing N2 and dTdz interpolated on chipod depth
should also include temp.mat from step 2
dTdz_m.mat
6
vel_m
use mooring data to generate velocity vector interpolated on chipod depth (ADCP or current meter)
vel_m.mat

Chapter 4

`main_driver`

Chapter 5

`combine_turbulence`

This is the final step.

5.1 Masking criteria/thresholds

5.1.1 Background stratification: `min_dTdz, min_N2, additional_mask_dTdz`

Minimum dT/dz, N^2 required for valid computation of χ, K_T, J_q^t

The Seabird SBE-37 datasheet says (`http://www.seabird.com/sbe37si-microcat-ctd`)

- T is accurate to $2 \times 10^{-3}\,^{\circ}\mathrm{C}$
- conductivity is accurate to $3 \times 10^{-3}\,\mathrm{psu}$ (approx!)

i.e.,

- dT/dz is accurate to (2x2e-3)/dz
- dS/dz is accurate to (2x3e-3)/dz

5.1.2 Sensor deaths: `T1death, T2death; nantimes{1,2,3}`

5.1.3 Averaging: `avgwindow, avgvalid`

5.1.4 Orientation / sensed-volume-flushing

5.1.5 Background flow speed: `min_inst_spd, min_spd, additional_mask_`

5.1.6 Maximum thresholds on $\epsilon, \chi, K_T, J_q^t$

5.1.7 Deglitching: `deglitch_window, deglitch_nstd`

5.2 Useful Functions

5.2.1 ChooseEstimates

5.2.2 chiold (variable)

combine_turbulence saves the *unmasked* chi structure as chiold after calculating Kt, Jqt but before doing any processing. Useful in checking masking.

5.2.3 TestMask

Lets you quickly iterate through various thresholds for a particular criterion.

Throws up a figure with histograms of counts to compare.

Example usage:

```
TestMask(chi, abs(chi.dTdz), '<', [1e-4, 3e-4, 1e-3], 'Tz');\\
```

This will iterate and mask using chi.dTdz < 1e-4, then chi.dTdz < 3e-4 and finally chi.dTdz < 1e-3. Each iteration is **independent** of the previous one.

5.2.4 DebugPlots

Usually, you want to see the effect of different masking thresholds in a small subset of the time series of χ, ε etc.

Example usage:

```
chi = chiold; \% reset to unmasked structure\\
\% apply 3 different thresholds\\
chi1 = ApplyMask(chi, abs(chi.dTdz), '<', 1e-4, 'T\(_{\text{z}}\) < 1e-4');\\
chi2 = ApplyMask(chi, abs(chi.dTdz), '<', 1e-3, 'T\(_{\text{z}}\) < 1e-3');\\
chi3 = ApplyMask(chi, abs(chi.dTdz), '<', 2e-3, 'T\(_{\text{z}}\) < 2e-3');\\
\vspace*{1em}
t0 = datetime(2016, 12, 10);\\
t1 = datenum(2016, 12, 12);\\
tavg = 600;\\
\vspace*{1em}
hf = figure;\\
\% plot 10 minute averages (tavg) of quantities in structure chi\\
\% between [t0, t1] and label them as 'raw' in figure window hf\\
DebugPlots(hf, t0, t1, chi, 'raw', tavg);\\
\vspace*{1em}
\% compare different masking; label appropriately\\
DebugPlots(hf, t0, t1, chi1, '1e-4', tavg);\\
DebugPlots(hf, t0, t1, chi2, '1e-3', tavg);\\
DebugPlots(hf, t0, t1, chi3, '2e-3', tavg);\\
```

5.2.5 DebugRawData

The idea is to connect Turb.() to the raw-ish data.

Requires structure T from temp.mat.

5.2.6 Histograms2D

Part III

Appendix

Appendix A

Using the CEOAS MATLAB servers

A.1 SSH configuration

A.2 Usage

1. login in to maltab server 1) open terminal 2) type: mats

2. logout type twice: exit

3. open matlab on server type: mat or : matno #(for no display)

4. How to copy from ganges to server-ganges cd /ganges/ sh pullFromGanges data/(dir you want to copy)/ otherwise use scp

Appendix B

Useful references

Moum & Nash (2009) : General χpod paper

Moum (2015) : Pitot tube paper

Perlin & Moum (2012) : Among others, this paper systematically compares estimates after turning off angular rate sensors, accelerometers, pressure sensors and compass in sequence. It also compares χpod estimates with nearby Chameleon estimates. Things look good!

Zhang & Moum (2010) : Initial IC estimate paper

References

Moum, J. N., & Nash, J. D. 2009. Mixing Measurements on an Equatorial Ocean Mooring. *Journal of Atmospheric and Oceanic Technology*, **26**(2), 317–336.

Moum, James N. 2015. Ocean Speed and Turbulence Measurements Using Pitot-Static Tubes on Moorings. *Journal of Atmospheric and Oceanic Technology*, **32**(7), 1400–1413.

Perlin, A., & Moum, J. N. 2012. Comparison of Thermal Variance Dissipation Rates from Moored and Profiling Instruments at the Equator. *Journal of Atmospheric and Oceanic Technology*, **29**(9), 1347–1362.

Winters, Kraig B., & D'Asaro, Eric A. 1996. Diascalar Flux and the Rate of Fluid Mixing. *Journal of Fluid Mechanics*, **317**(-1), 179.

Zhang, Yanwei, & Moum, James N. 2010. Inertial-Convective Subrange Estimates of Thermal Variance Dissipation Rate from Moored Temperature Measurements. *Journal of Atmospheric and Oceanic Technology*, **27**(11), 1950–1959.

Appendix C

git commands and workflows

Appendix D

Sensor orientations

D.1 χpod

D.2 Pitot

from Moum (2015)

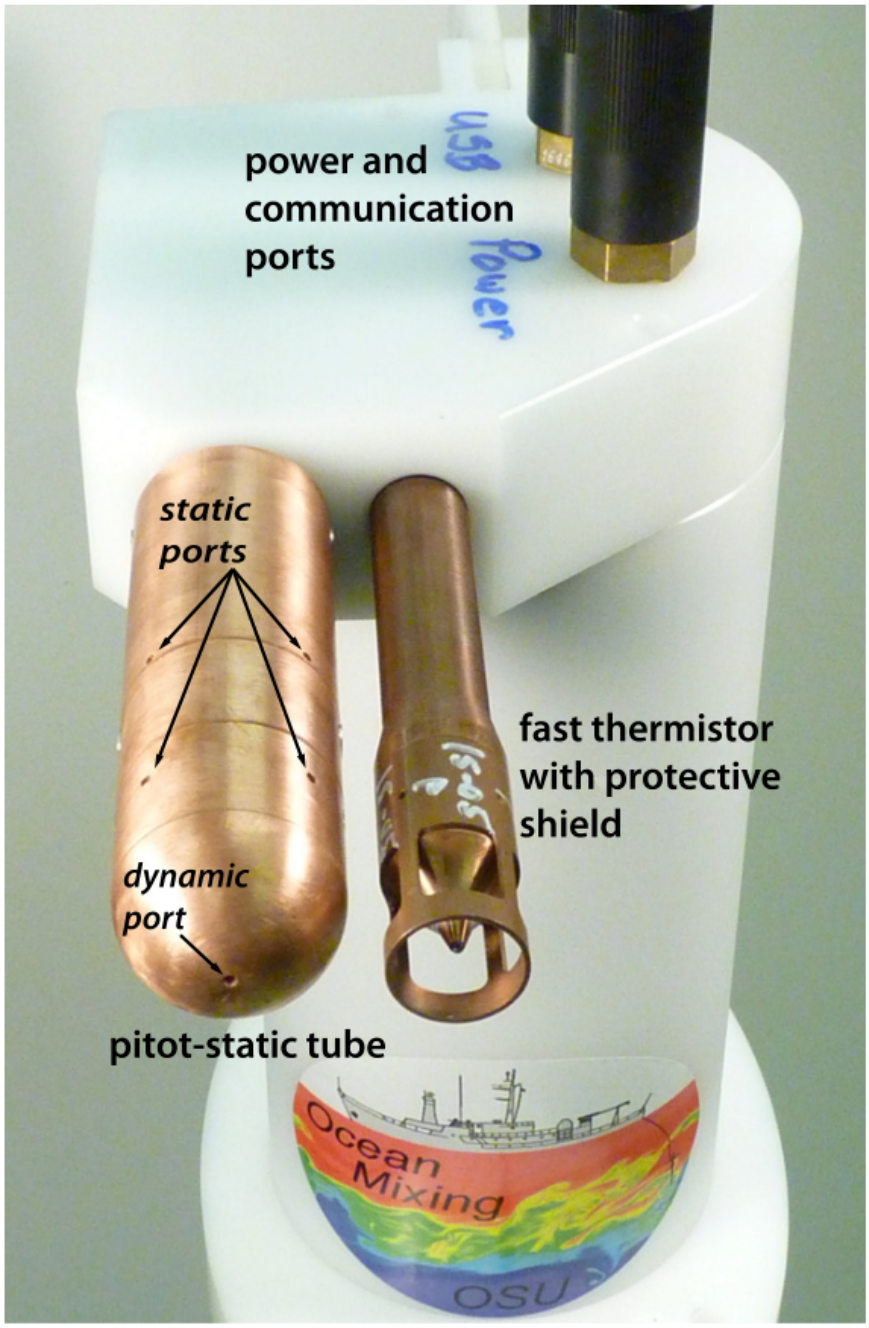


FIG. 1. Pitot-static tube mounted beside fast thermistor on χpod. Each is plugged into a connector in the end cap of the pressure case that houses electronics and batteries. For reference, the visible length of the pitot-static tube extending from the χpod end cap is 10.6 cm. (Photo courtesy of Craig Van Appeldorn.)

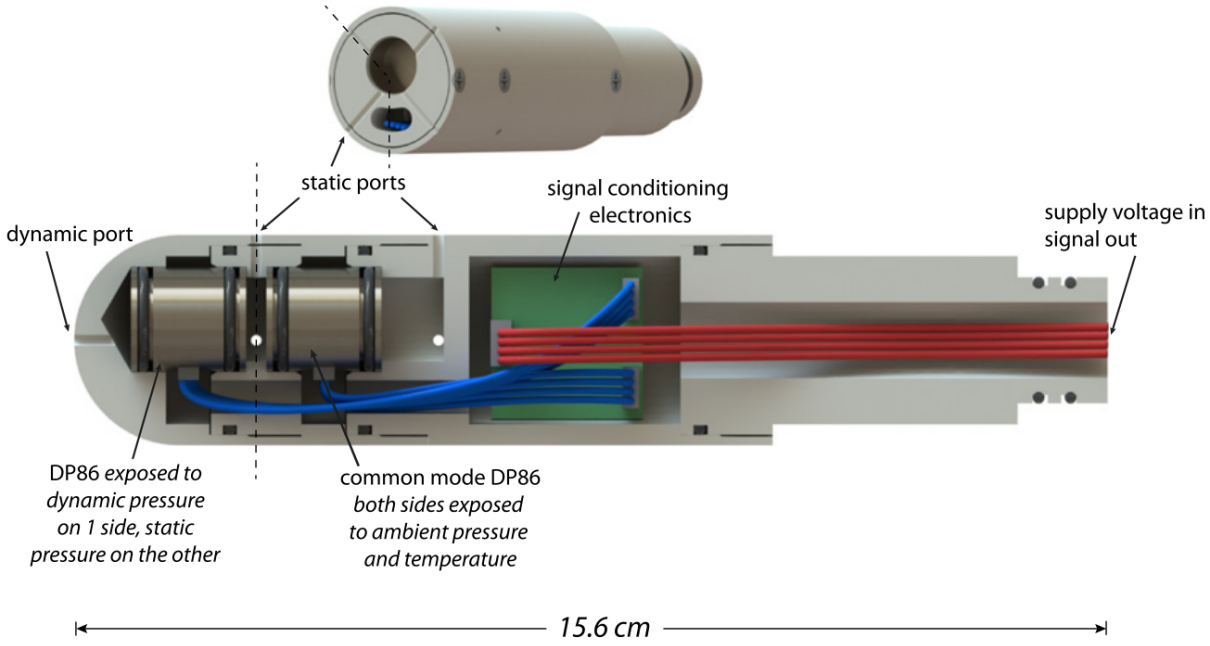
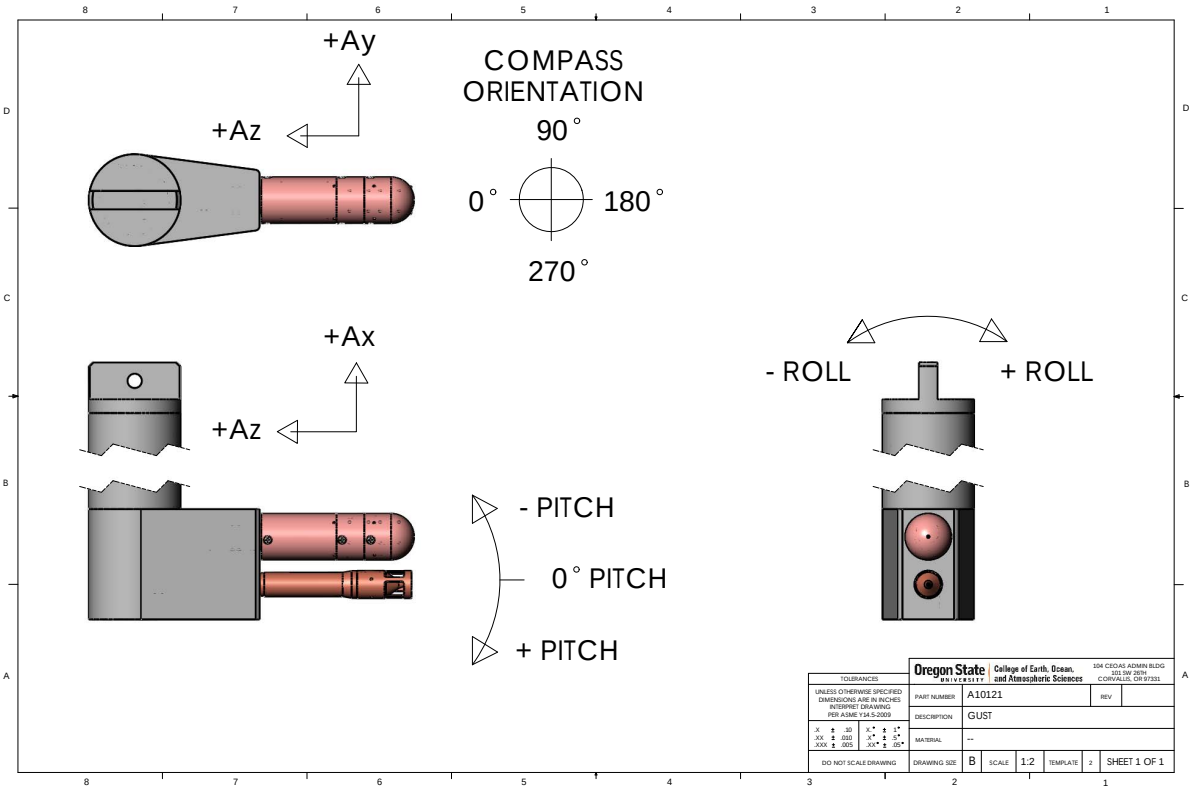


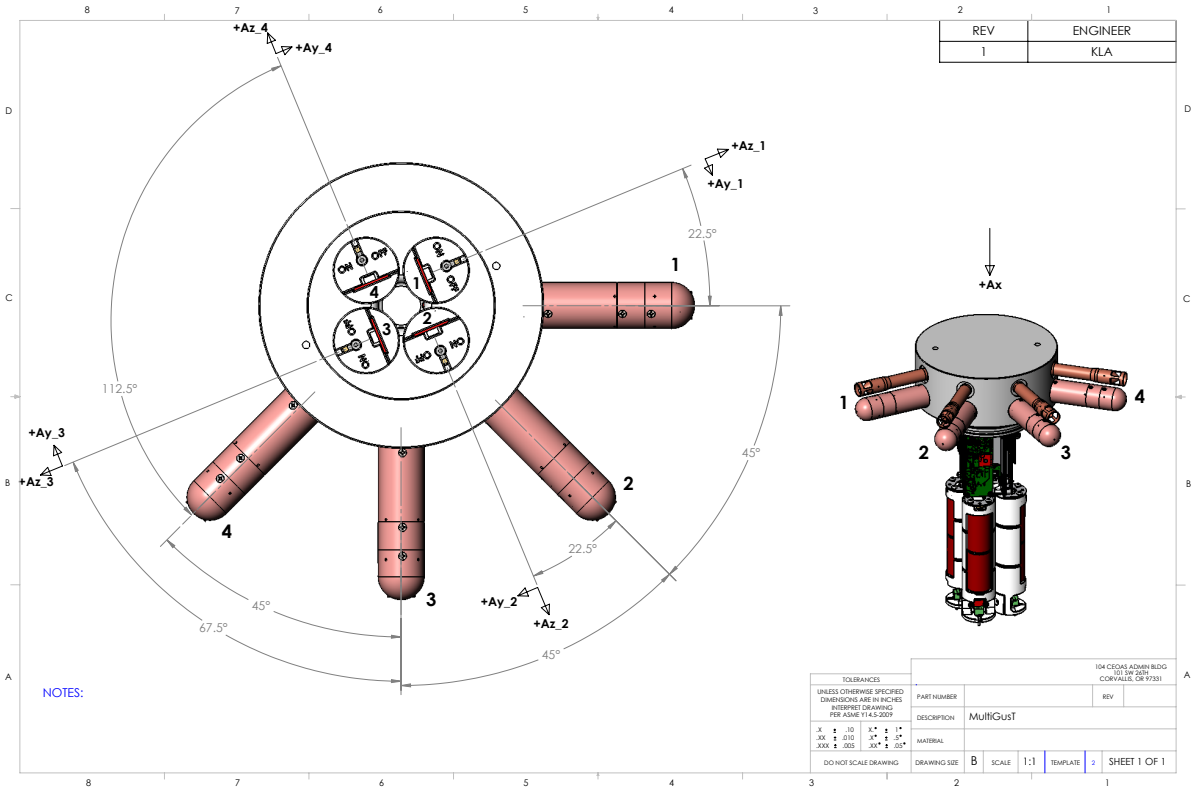
FIG. 2. Cross section of pitot-static tube showing details of the positioning of pitot-static and common mode differential pressure sensors. The cross sections ahead of the signal conditioning electronics are aligned with the dashed lines. The perspective is stylized to provide a clear view of components. (SOLIDWORKS drawing courtesy of Craig Van Appeldorn.)

D.3 gusT


+Ay
+Az
COMPASS
ORIENTATION
90°
0°
180°
270°
+Ax
+Az
- ROLL
+ ROLL
- PITCH
0° PITCH
+ PITCH
Oregon State University
College of Earth, Ocean, and Atmospheric Sciences
104 CEOAS ADMIN BLDG
101 SW 26TH
CORVALLIS, OR 97331
TOLERANCES
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES INTERPRET DRAWING PER ASME Y14.5-2009
DO NOT SCALE DRAWING
PART NUMBER
A10121
REV
DESCRIPTION
GUST
MATERIAL

DRAWING SIZE
B
SCALE
1:2
TEMPLATE
2
SHEET 1 OF 1

D.4 Multi gusT



Appendix E

Inferring K_T, J_q from χ

Osborn & Cox:

$$J_q^t = \frac{\langle \chi \rangle}{\langle \frac{\partial T}{\partial z} \rangle^2} \tag{E.1}$$

These angle brackets are interpreted as a time average for χpods and a depth-bin average for profilers like Chameleon.

The Osborn & Cox formulation is not well behaved when stratification is low. It gets worse in places with large salinity influence: large enough that $T_z < 0$ some of the time. In these cases, getting "reasonable" values for K_T and J_q^t requires masking out estimates when T_z is less than some ill-defined threshold.

Winters & D'Asaro:

$$J_q^t = \frac{\mathrm{d}z^*}{\mathrm{d}T} \langle \chi \rangle_{z^*} \tag{E.2}$$

z^* being the "reference" state — usually a fully sorted 3D scalar field, but this can be approximated by Thorpe sorting. The angle brackets represent averaging in "isoscalar" (isothermal) space. The Winters & D'Asaro formulation has the advantage that it can be well-defined for low gradients — thinking about distances between isoscalar surfaces. The idea is that the averaging occurs in a volume between two isothermal surfaces. The required gradient is then the average spacing between these two surfaces. Doing this requires treating the χpod as a profiler, being pumped by surface waves. We can keep track of the isotherms seen by the χpod in a chunk of data; and estimate the average distance between those isotherms. For dense enough sampling this average distance should converge to the distance between the isotherms in the fully sorted field (this is the necessary gradient). Note that the χpod densely samples approximately 1-2 metres of the water column. In low stratification, estimating the spacing requires high-resolution temperature measurements but that is exactly what the χpod! Consider a 1 minute chunk of data.

- Once χ has been estimated, we have $\chi \equiv \chi(t) \equiv \chi(T)$, T being temperature (1 second averages).

- We can divide the temperature time series into N quantiles, bin the χ estimates in these temperature bins and then average them to get $\langle\chi\rangle \equiv \chi(T_{\text{bins}})$. This is what Winters & D'Asaro (1996) call "isoscalar averaging" — every χ estimate made between 2 isothermal surfaces is averaged together.

Next, we need to determine the average distance between the isothermal surfaces T_{bins}.

- Each "up-" and "down-cast" in the minute is first individually Thorpe sorted.

- Find the location of the isotherms (T_{bins}) in the sorted profiles and difference them to get $\Delta z(T_{\text{bins}})$.

- Average in isothermal space $\langle\Delta z\rangle$; i.e. average every Δz measurement for each bin. $\langle\Delta z\rangle$ is the *average distance between the isotherms represented by the bin edges* T_{bins}

- $\langle\Delta z\rangle/\Delta T_{\text{bins}}$ is the necessary gradient for each bin.

- $$J_q^t = -\frac{1}{2}\frac{\langle\Delta z\rangle}{\Delta T_{\text{bins}}}\,\langle\chi\rangle \tag{E.3}$$

  We now have a J_q^t estimate for each temperature bin. Depth-average this value to get the *volume-average* J_q^t *in the volume sampled by the* χ*pod in the 60 second chunk of data*

- When salinity controls density, it is possible that $dT/dz < 0$ for extended periods of time. Thorpe sorting cannot preserve this sign (unless there are coincident measurements of salinity, in which case you would sort density). The only sensible thing to do is to determine the sign of the mean (or "large-scale") gradient from other sources such as nearby CTDs on the mooring.