Preliminary Analysis
MSc Ocean Physics, University of Victoria

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Contents

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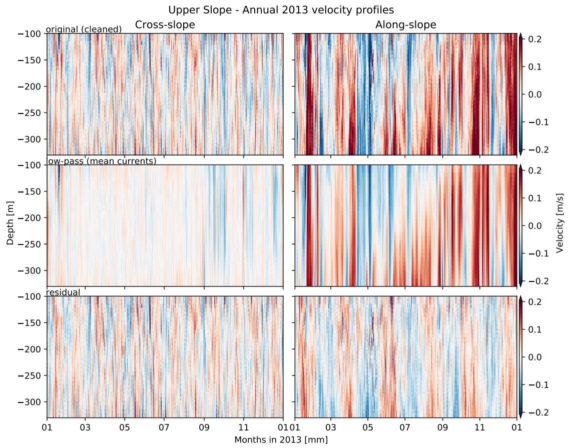
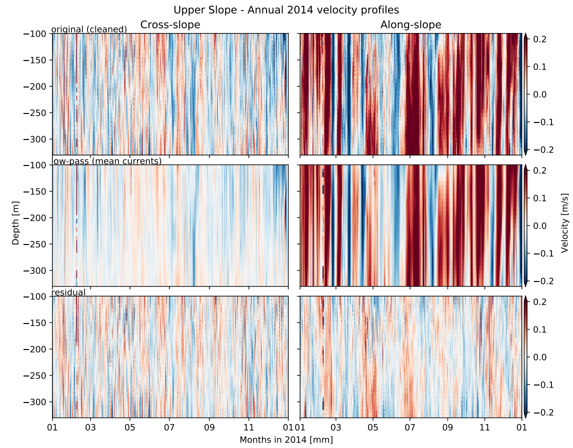
1 Upper Slope 75 kHz ADCP (-330 m to -100 m)

1.1 Annual velocities

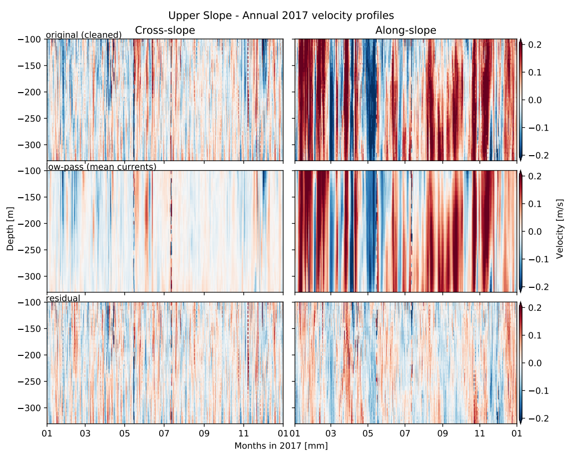
- There are similarities in mean currents to the A1 data (Thomson), as part of the Northeast Pacific Coastal Current. Annually, there is a general semi-annual switch in the direction of the mean currents; the winter and fall appear to be dominated by the California current moving towards the northwest, and in the spring and summer, the Alaska current moving to the southeast could indicate enhanced canyon upwelling (Allen). The spring switch seems to happen quite suddenly in May/June of each year, through depth, while the switch back is a more gradual process that starts deep almost immediately and takes about three months to reach the surface at the end of the summer. There may also be indications of the Vancouver Island Coastal Current, to be identified.
- Velocities are dominant in the along-slope direction, throughout the year, in contrast to the Axis ADCP.
- Residual data shows consistent tidal influence, and do not change much throughout the years.



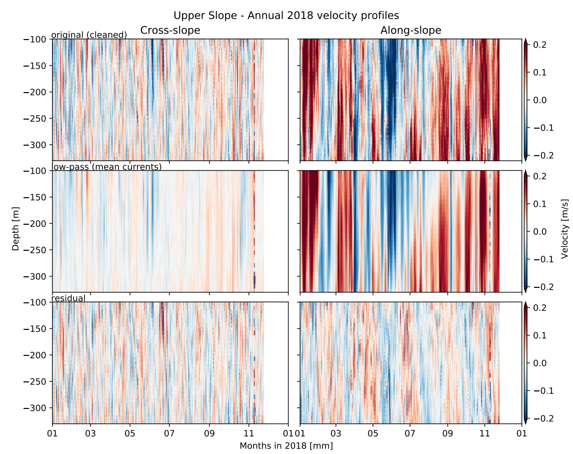
(a) 2013



(b) 2014



(c) 2017

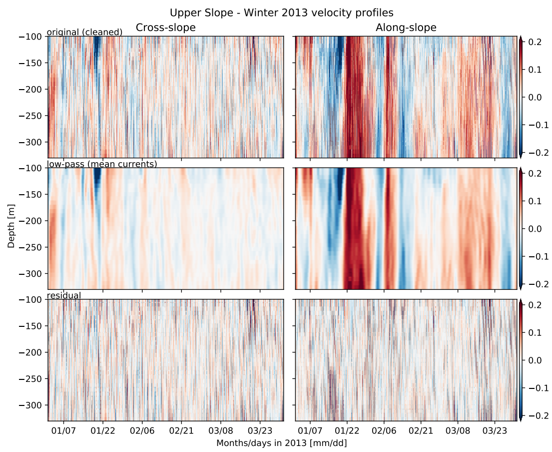


(d) 2018

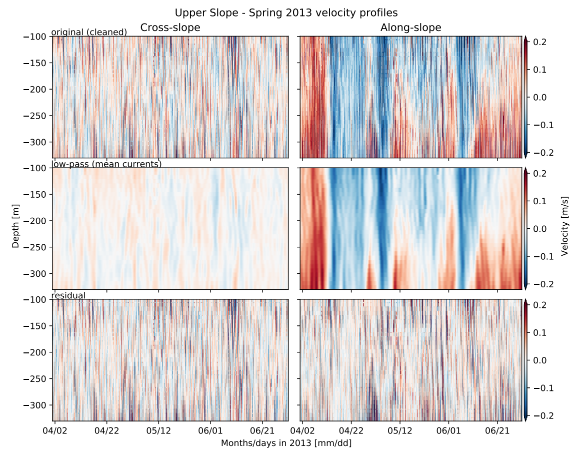
Figure 1: Comparative velocity data for Upper Slope 75 kHz ADCP, in 2013, 2014, 2017, and 2018. Velocities are displayed horizontally in cross- (left) and along-slope (right) directions, and vertically as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°.

1.2 Seasonal velocities

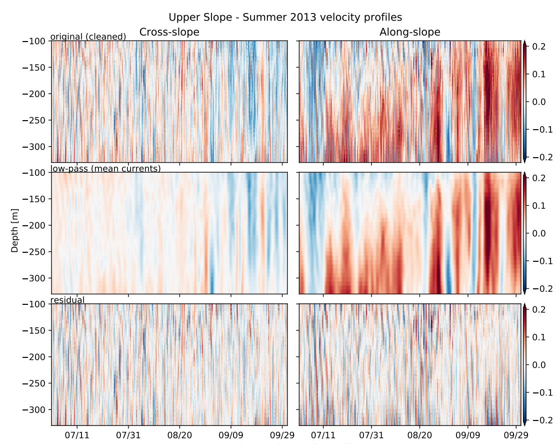
- Seasonally, there are apparent two week (an average estimate) pulses in mean current velocity data in the along-slope direction. There is a similar two week periodicity present in the spectrograms. This could be indicative of the spring/neap cycle. However, this periodicity does change seasonally, being somewhat slower (approaching a monthly switch) and more prominent in winter/fall, nearly entirely absent in the spring, and seemingly more sporadic or even weekly in the summer. This suggests some interaction with the more general semi-annual switching of mean currents, as described above.



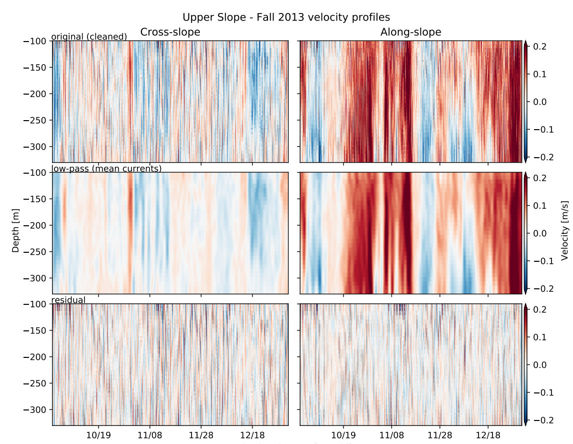
(a) Winter



(b) Spring



(c) Summer

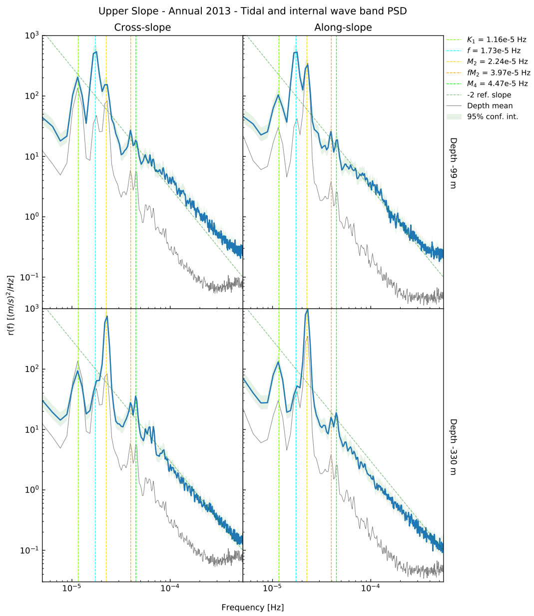


(d) Fall

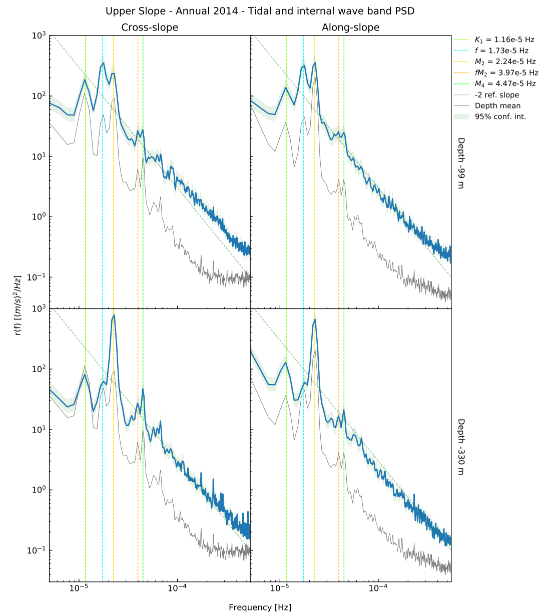
Figure 2: Seasonal velocity data for Upper Slope 75 kHz ADCP, in 2013. Shown, in order, are (a) winter, (b) spring, (c) summer, and (d) fall. For sub-figures, velocities are displayed horizontally in cross- (left) and along-slope (right), and vertically as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°

1.3 Annual PSD

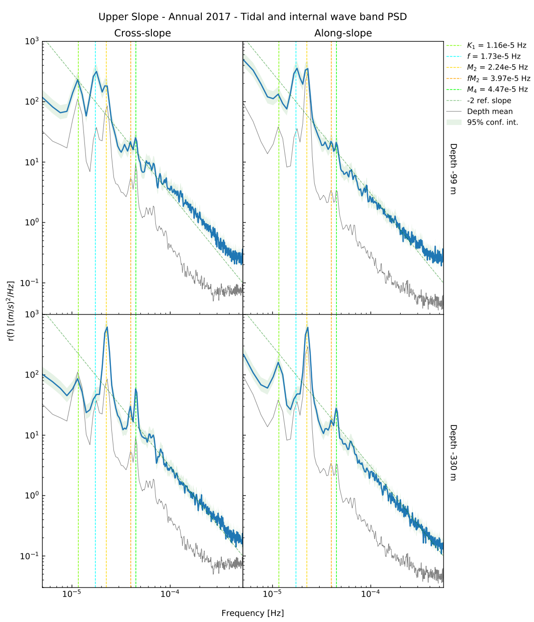
- Cross/Along-slope spectra have comparable variance and features at both depths, and through each observed year.
- f and M_2 dominate at upper depth, as expected for internal tides near canyon topography. f is weaker in deeper waters, and M_2 is stronger.
- There appear to be sum peaks for fM_2 and M_4, as discussed by Mihaly/Thomson. By their reasoning, this *could* indicate non-linear wave-wave interaction as a means of energy decay for internal waves, due to downward wind internal waves and upward topographic internal tides. They predict winter intensification (see Seasonal Spectra).
- Slope of continuum flattens out at higher frequencies, notable in the depth-average spectrum, and could be associated with an instrument 'noise floor' (to be determined).
- As an annual PSD, there are no notable high frequency peaks that could be associated with internal waves. A seasonal or monthly PSD would be more suitable for detecting these frequencies.
- GM spectrum has been omitted for revision, as it may be incorrect due to units of f and energy considerations (K and P versus total energy) during calculations. A -2 reference slope has been included in the meantime.



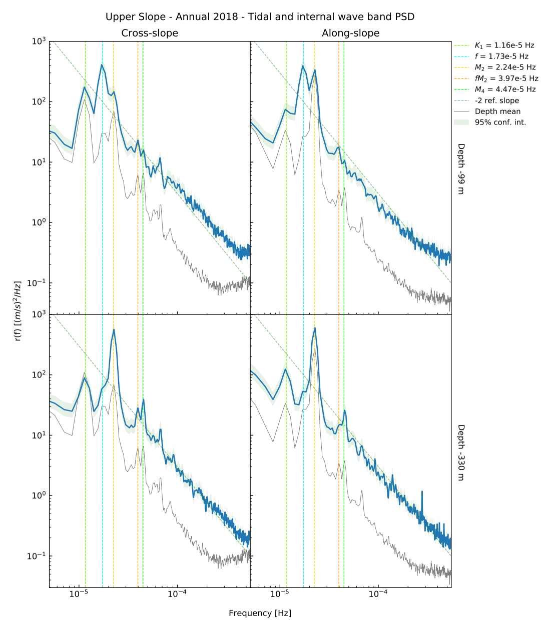
(a) 2013



(b) 2014



(c) 2017

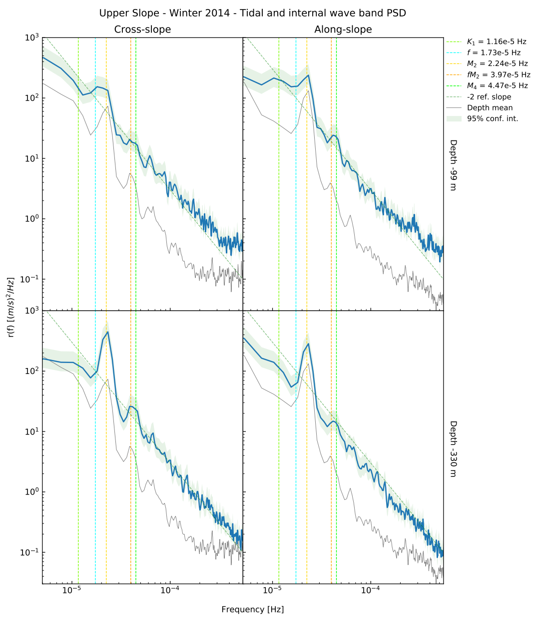


(d) 2018

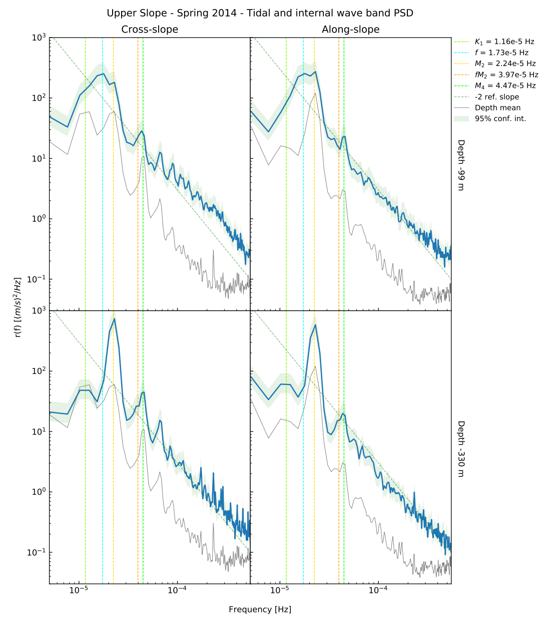
Figure 3: Comparative annual PSD data for Upper Slope 75 kHz ADCP, in 2013, 2014, 2017, and 2018. PSD are for the cross- (left) and along-slope (right) velocity data, at an upper depth of -99 m (top) and lower depth of -330 m (bottom). PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

1.4 Seasonal PSD

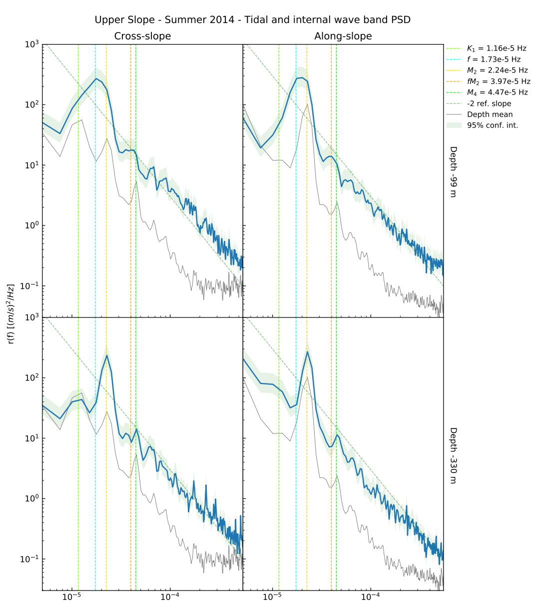
- At -99 m in winter, there is greater variance in the sub-K_1 frequency band than in other seasons.
- At -99 m in spring (and somewhat in summer), for cross-slope velocities there is a notable 'hump' in the continuum of frequencies greater than M_4. This could be an instrument error (see spectrograms for spring 2014).
- f and M_2 dominate at upper depth, as expected for internal tides near canyon topography. f is weaker in deeper waters, and M_2 is stronger.
- There appear to be sum peaks for fM_2 and M_4, as discussed by Mihaly/Thomson. By their reasoning, this *could* indicate non-linear wave-wave interaction as a means of energy decay for internal waves, due to downward wind internal waves and upward topographic internal tides. They predict winter intensification, but this does not seem to be present. In fact, the spring and fall see the greatest variance in these peaks, particularly in the cross-slope direction.
- Slope of continuum flattens out at higher frequencies, notable in the depth-average spectrum, and can likely be associated with an instrument 'noise floor' (to be determined).
- There are still no notable recurring high frequency peaks. A seasonal or monthly PSD would be more suitable for detecting these frequencies.
- GM spectrum has been omitted for revision, as it may be incorrect due to units of f and energy considerations (K and P versus total energy) during calculations. A -2 reference slope has been included in the meantime.



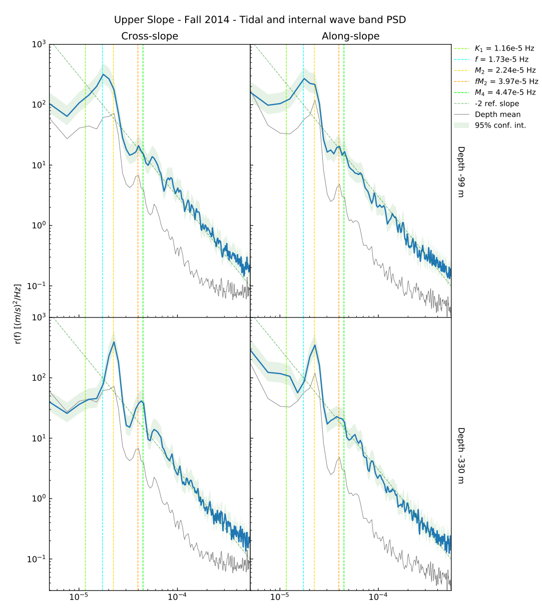
(a) Winter



(b) Spring



(c) Summer



(d) Fall

Figure 4: Seasonal PSD data for Upper Slope 75 kHz ADCP, in 2014. Individual PSD show the cross- (left) and along-slope (right) velocity data, at an upper depth of -99 m (top) and lower depth of -330 m (bottom). Seasonally, they are displayed in order as (a) winter, (b) spring, (c) summer, and (d) fall. PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

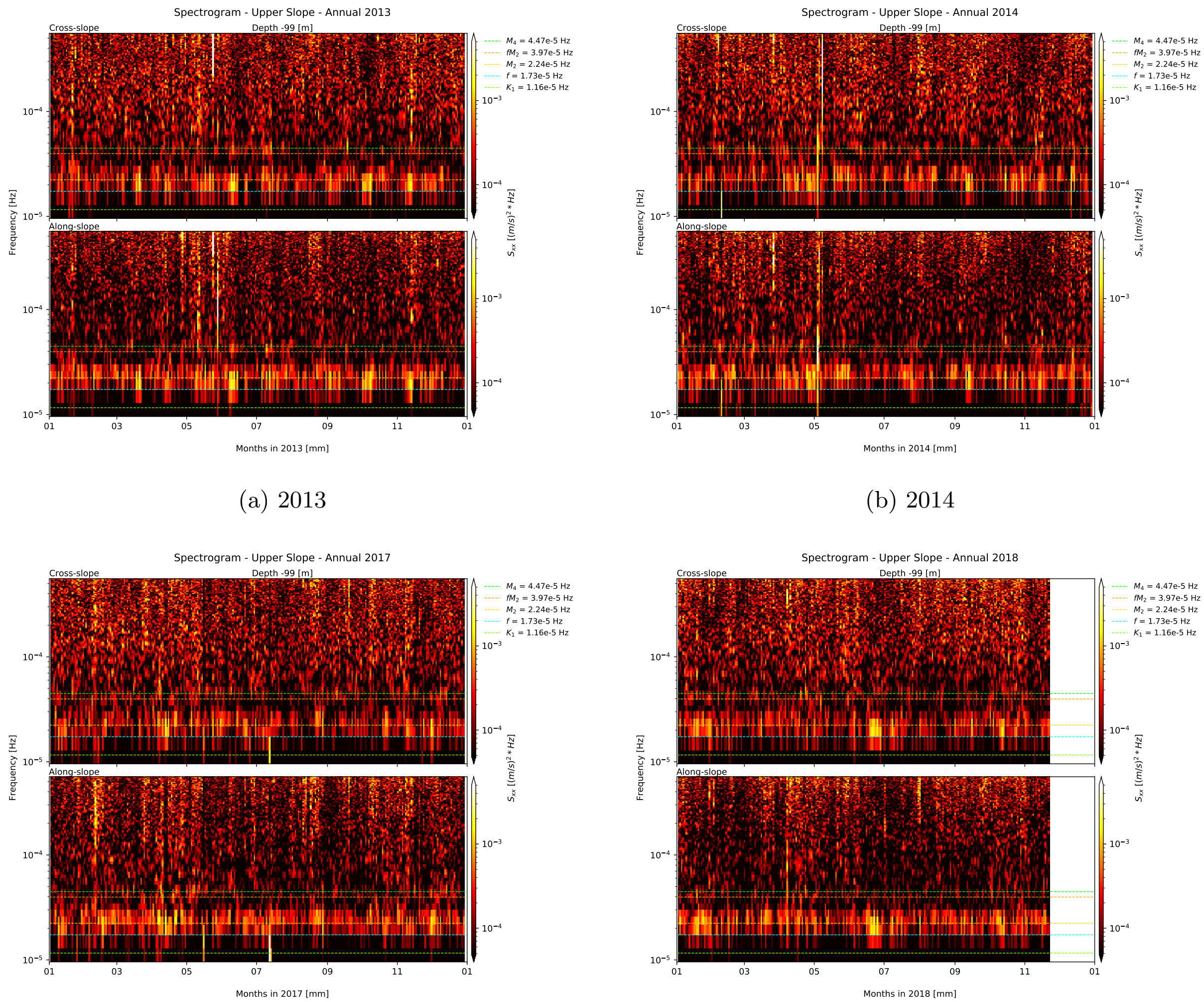
1.5 Spectrograms

-99 m

- Spectrograms at -99 m (Figure ??) indicate common pulses of annual activity in the internal wave band: notable activity through the winter/spring and fall, with diminished activity through the summer possibly due to the absence of winter storms.
- Though these pulses are more pronounced in the along-slope direction, there is more consistent activity at higher frequencies in the cross-slope direction, perhaps due to turbulent motion as water crosses from deep to shallow waters?
- There are also notable short-term events that are likely associated with passing storms, with time-scales of a few days to a week.
- Tidal frequencies are stronger at lower frequencies, in contrast to -330 m, and f seems to play a significant role. This will be further evaluated in PSD, below.
- Tidal frequency strength does not seem to follow any notable periodicity, but does seem to intensify in concert with internal wave band activity. This in contrast to -330 m.

-330 m

- Spectrograms at -330 m (Figure ??) also indicate common pulses of annual activity in the internal wave band: in this case, a large ($>$ one month) and strong pulse in $\sim$November, and smaller($<$ one month) pulses occasionally in $\sim$February and $\sim$May, the latter possibly coinciding with the major seasonal switch in mean currents. There is a notable lull in activity through the summer months, possibly due to the absence of winter storms.
- Though these pulses are more pronounced in the along-slope direction, there is more consistent activity at higher frequencies in the cross-slope direction, perhaps due to turbulent motion as water moves from deep to shallow?
- At this depth, there are fewer notable short-term events that would be likely attributed to passing storms.
- Tidal frequencies are stronger at higher frequencies (M2, fM2, M4), in contrast to -99 m, and f seems to play a weaker role as depth increases. This will be further evaluated in PSD, below.
- Tidal frequency strength does not seem to follow any notable periodicity, but does seem to intensify in concert with internal wave band activity. This in contrast to -330 m.



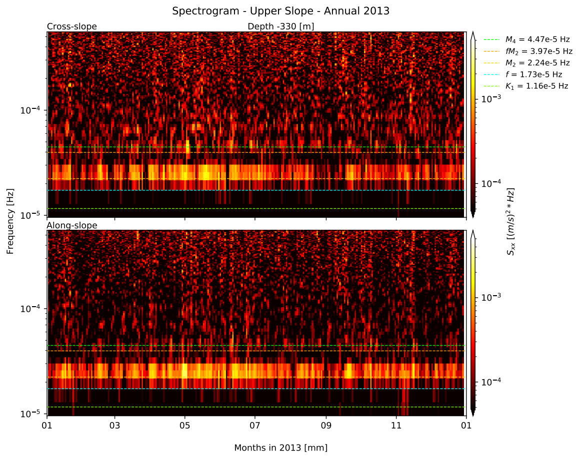
(a) 2013

(b) 2014

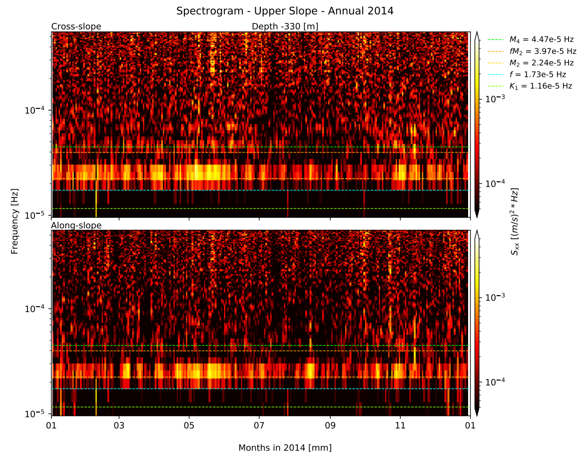
(c) 2017

(d) 2018

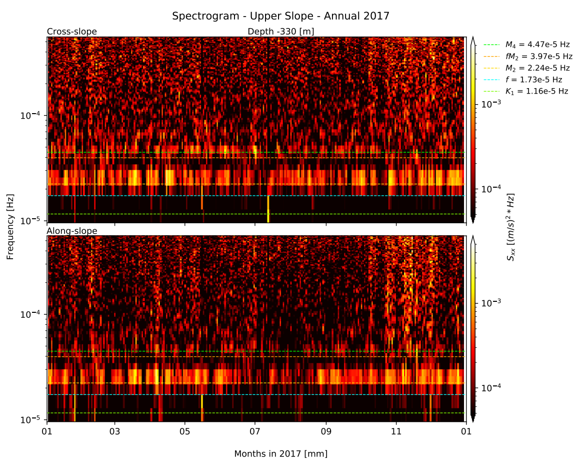
Figure 5: Whitened, comparative spectrogram data for Upper Slope 75 kHz ADCP, at -99 metres depth, in 2013, 2014, 2017, and 2018. Spectrograms are for the cross- (upper) and along-slope (lower) velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.



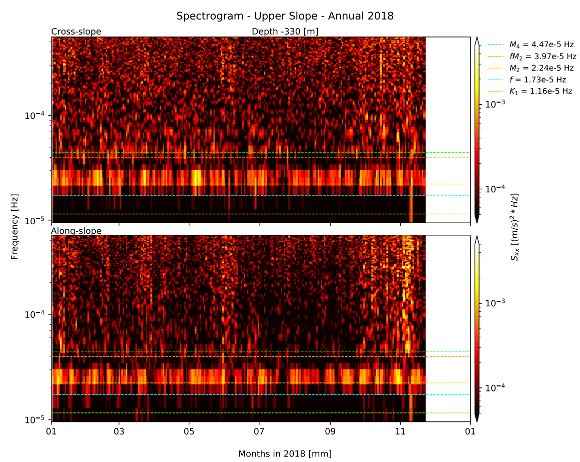
(a) 2013



(b) 2014



(c) 2017



(d) 2018

Figure 6: Whitened, comparative spectrogram data for Upper Slope 75 kHz ADCP, at -330 metres depth, in 2013, 2014, 2017, and 2018. Spectrograms are for the cross- (upper) and along-slope (lower) velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.

1.6 Vertical velocities

- Vertical velocity data is fairly consistent through the years and seasons, and has little to note beyond some seasonal variation that aligns with the horizontal observations already mentioned, and a resonance or harmonic effect near the surface that is possibly due to the presence of biological interference. However, very little delving has been done, and more analysis could be conducted.

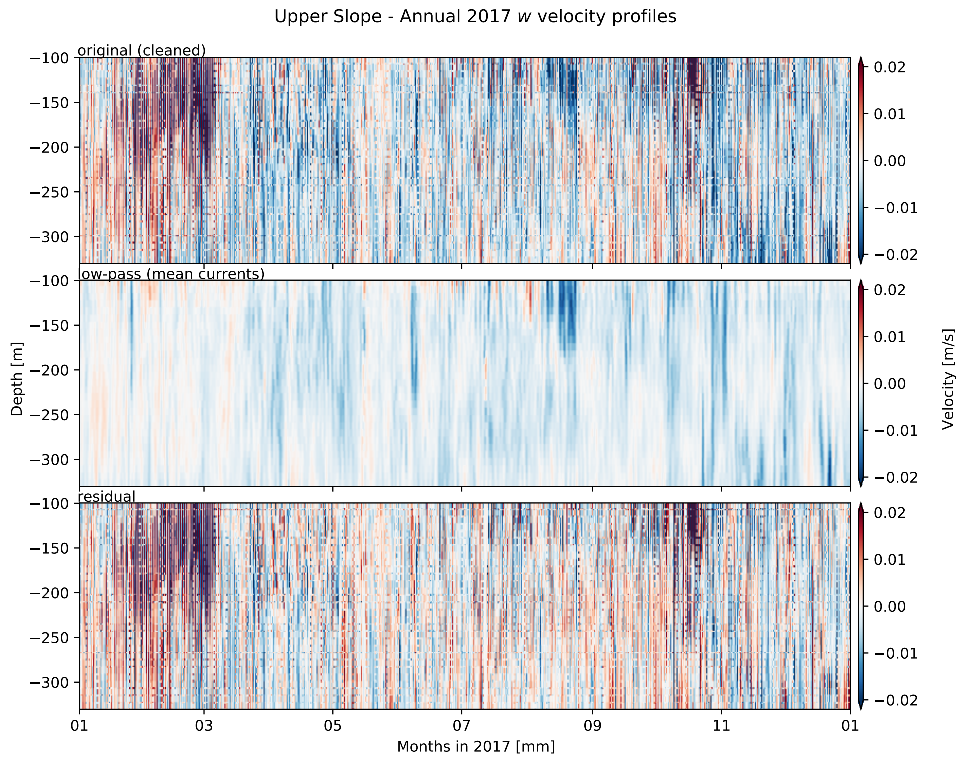


Figure 7: Annual w velocity data for Upper Slope 75 kHz ADCP, in 2013. Velocities are displayed as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°.

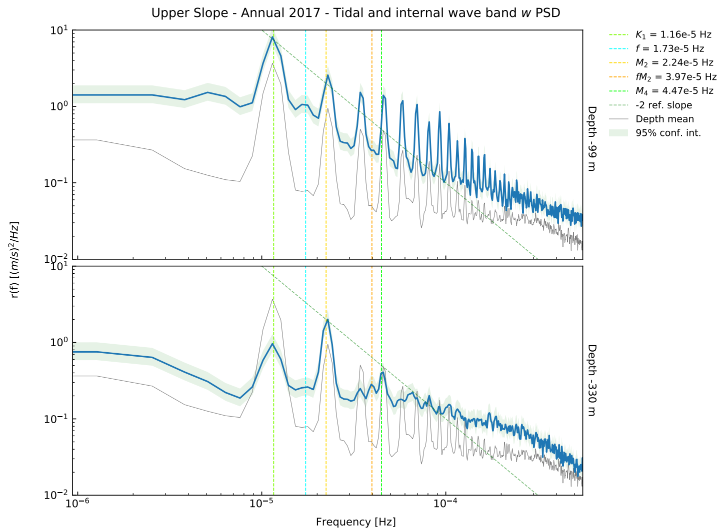


Figure 8: Annual PSD data for Upper Slope 75 kHz ADCP, in 2014. PSD are for the vertical velocity data, at an upper depth of -99 m (top) and lower depth of -330 m (bottom). PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

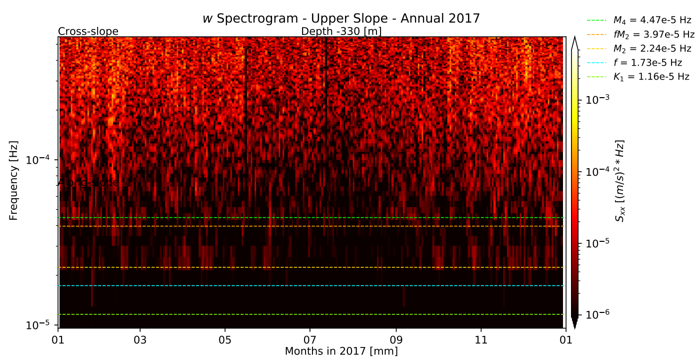


Figure 9: Whitened spectrogram data for Upper Slope 75 kHz ADCP, at -330 metres depth, in 2017. Spectrograms are for the vertical velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.

2 Axis 75 kHz ADCP (-900 m to -400 m)

2.1 Annual velocities

- There are significant gaps in the Axis 75 kHz data, with data from 2014 onward showing signs of poor quality. Analysis will be based off of 2013, and continued with Axis 55 kHz data for 2017 and 2018 in the next section.
- Mean current velocities are slightly dominant in the cross-slope direction, throughout the year, in contrast to the Upper Slope ADCP.
- There is less seasonality to the mean current velocity data than for the Upper Slope ADCP, though there is some strengthening to the cross-slope in spring and summer at upper depths.
- Cross-slope data shows consistent flow into the canyon (onshore) at lower depths, and flow out of the canyon (offshore) at higher depths. Represents circulation within the canyon.
- Along-slope data is fairly consistent towards the northwest throughout the year, with possible ∼weekly periodicity at higher depths.
- Residual data shows a consistent periodicity throughout the year, varying with depth.

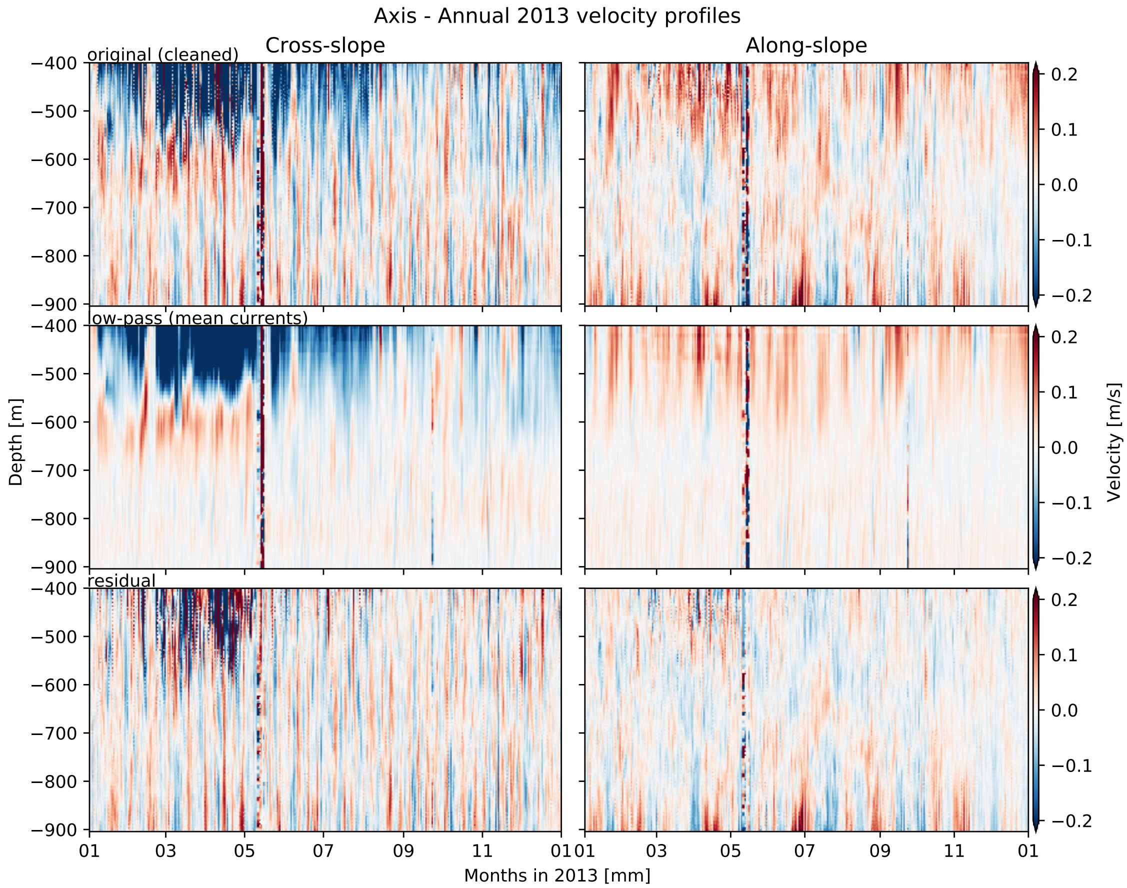
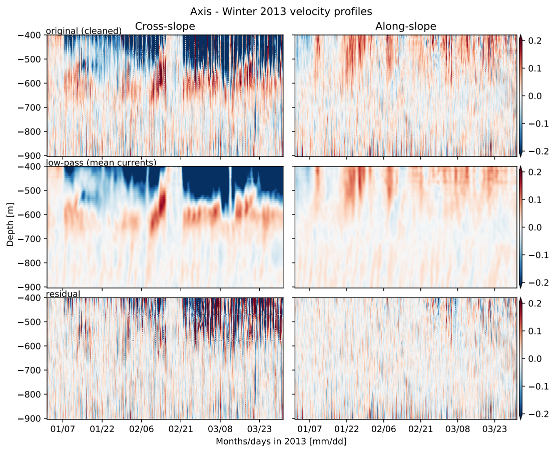


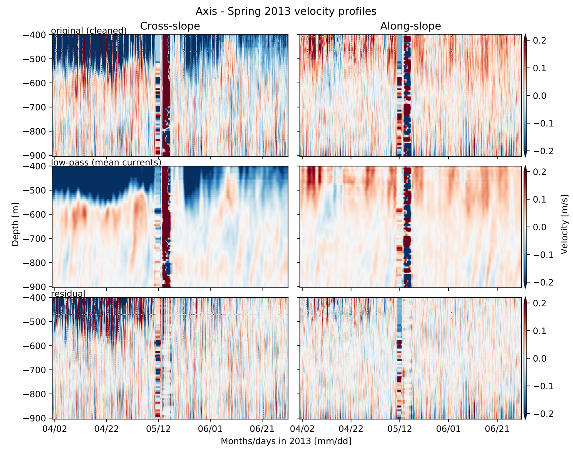
Figure 10: Velocity data for Axis 75 kHz ADCP, in 2013. Velocities are displayed horizontally in cross- (left) and along-slope (right) directions, and vertically as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°.

2.2 Seasonal velocities

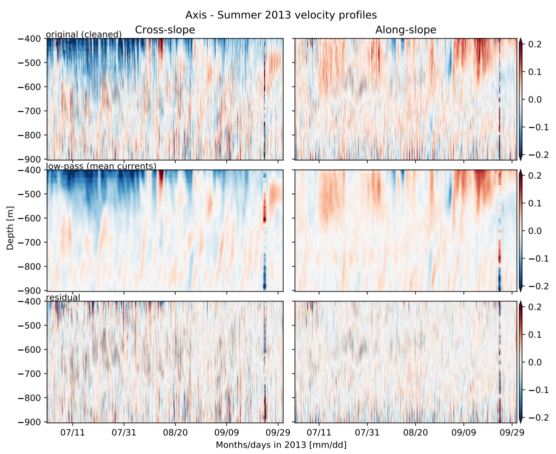
- Lower depth velocity data is fairly consistent in each season.
- Upper depth velocity data is fairly consistent for along-slope, but there is winter and spring intensification for cross-slope.



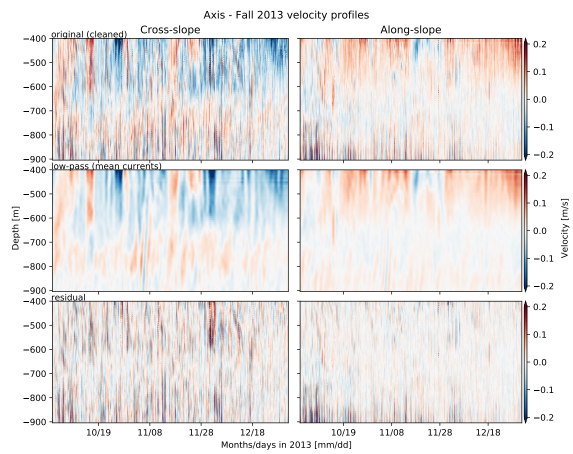
(a) Winter



(b) Spring



(c) Summer



(d) Fall

Figure 11: Seasonal velocity data for Axis 75 kHz ADCP, in 2013. Shown, in order, are (a) winter, (b) spring, (c) summer, and (d) fall. For sub-figures, velocities are displayed horizontally in cross- (left) and along-slope (right), and vertically as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, rotated to match the continental slope angle of approximately 30°.

2.3 Annual PSD

- There is greater variance in the cross-slope upper depth.
- There is a 'flattening' of the continuum slope at upper depths.
- Cross-slope upper depth shows high K_1 variance.
- Cross-slope lower depth shows high M_2 variance.
- Along-slope upper depth shows some M_2 variance.
- Along-slope lower depth show high K_1 and M_2 variance.
- There do not appear to be sum peaks for fM_2 and M_4, as in the Upper Slope ADCP.
- Slope of continuum flattens out at higher frequencies, notable in the depth-average spectrum, and could be associated with an instrument 'noise floor' (to be determined).
- There are three significant peaks at higher frequencies at upper depths, and this also shows up in early 2014. This should be compared to the 55 kHz Axis data in later years.
- GM spectrum has been omitted for revision, as it may be incorrect due to units of f and energy considerations (K and P versus total energy) during calculations. A -2 reference slope has been included in the meantime.

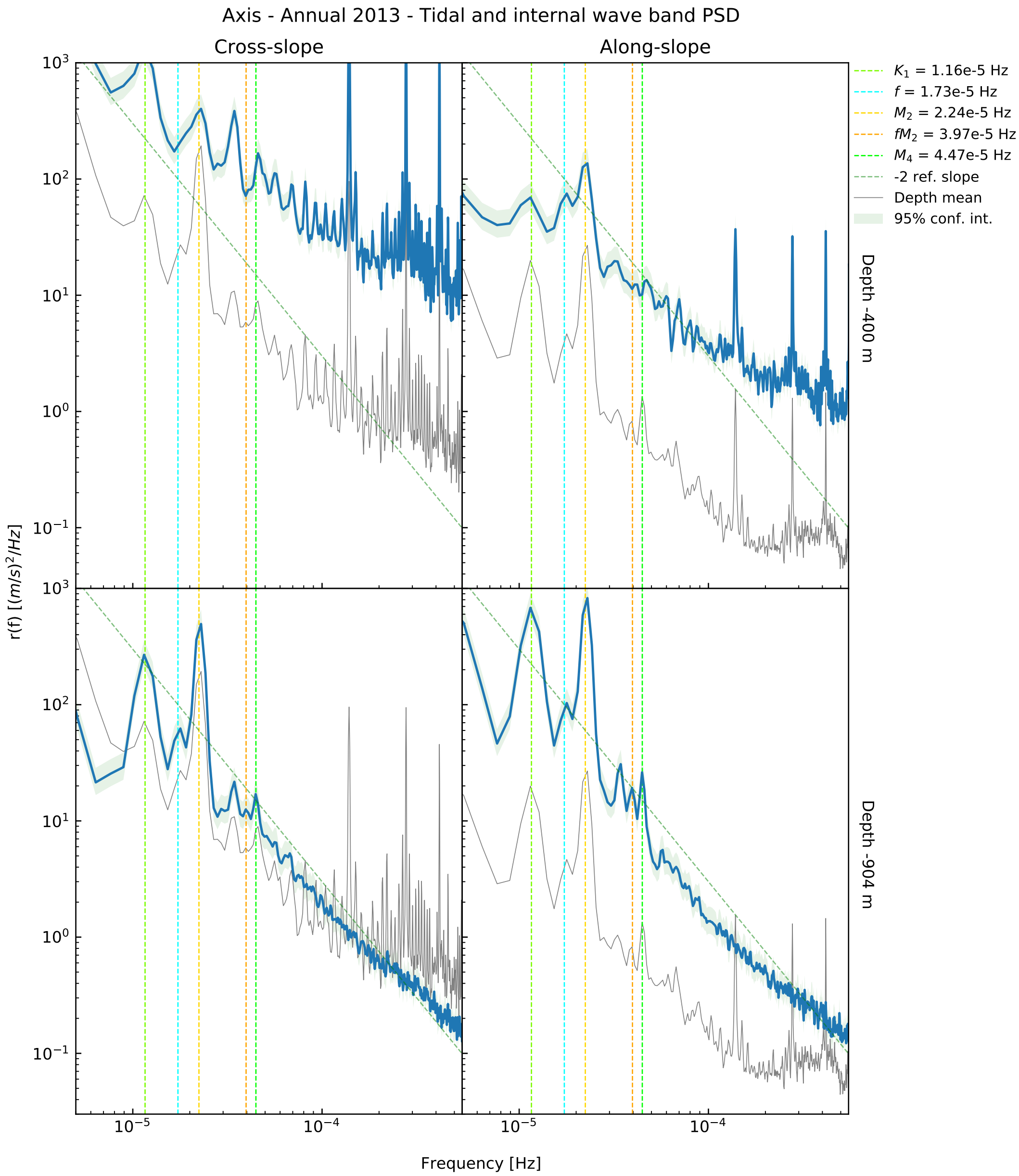
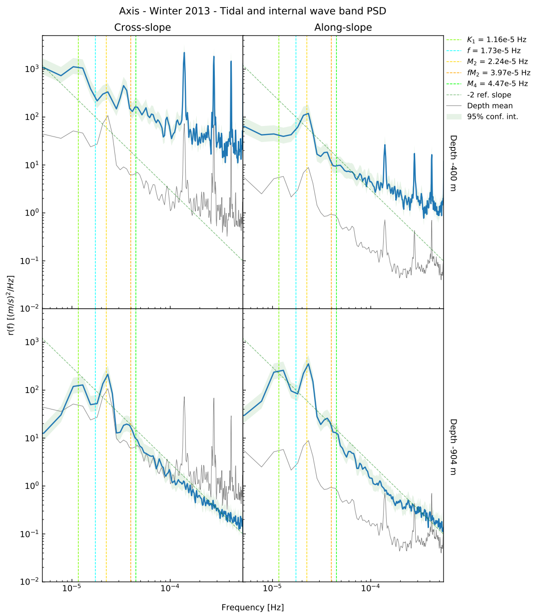


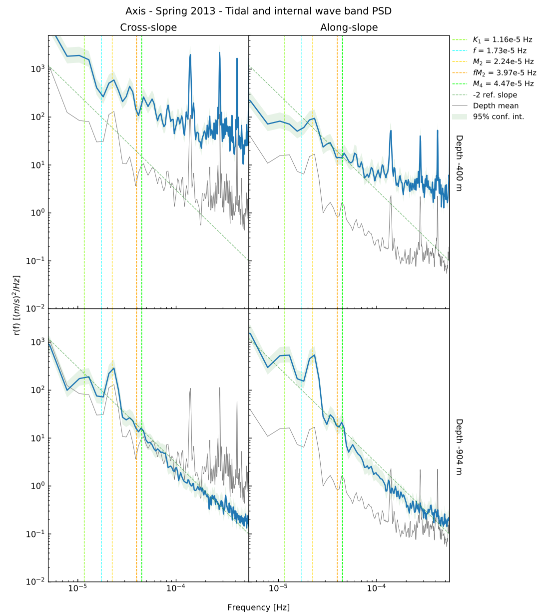
Figure 12: Comparative annual PSD data for Axis 75 kHz ADCP, in 2013. PSD are for the cross- (left) and along-slope (right) velocity data, at an upper depth of -99 m (top) and lower depth of -330 m (bottom). PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

2.4 Seasonal PSD

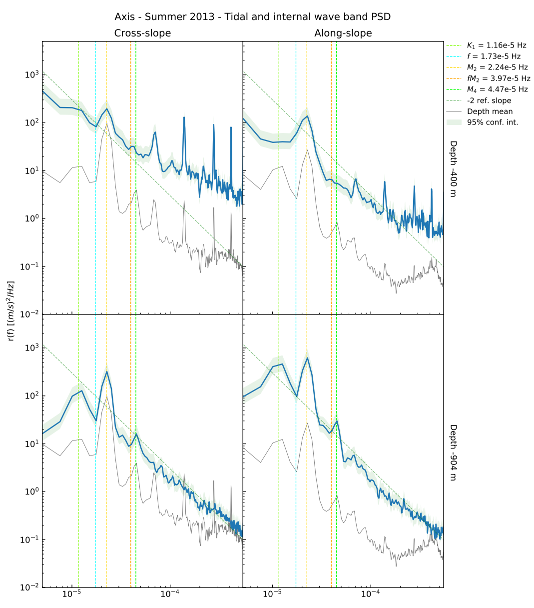
- There is greater variance in cross-slope upper depths.
- There is a 'flattening' of the continuum slope at upper depths.
- For cross-slope upper depth, there is greater variance in the winter and spring, and intensification of three high-frequency peaks.
- For cross-slope lower depth, there is little seasonal variation.
- For along-slope upper depth, there is little seasonal variation.
- For along-slope lower depth, there is an increase in the variance of low frequencies (less than K1) in the spring.
- M_2 seems to be the dominant tidal frequency, followed by K_1, in most cases besides upper depth cross-slope in winter and spring.
- There do not appear to be sum peaks for fM_2 and M_4, as for Upper Slope.
- Slope of the continuum flattens out for upper depths.
- GM spectrum has been omitted for revision, as it may be incorrect due to units of f and energy considerations (K and P versus total energy) during calculations. A -2 reference slope has been included in the meantime.



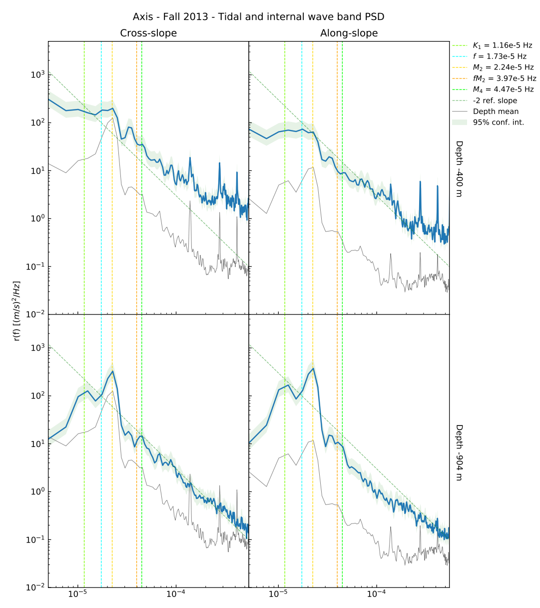
(a) Winter



(b) Spring



(c) Summer



(d) Fall

Figure 13: Seasonal PSD data for Axis 75 kHz ADCP, in 2013. Individual PSD show the cross- (left) and along-slope (right) velocity data, at an upper depth of -99 m (top) and lower depth of -330 m (bottom). Seasonally, they are displayed in order as (a) winter, (b) spring, (c) summer, and (d) fall. PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

2.5 Spectrograms

- Some frequency banding in the high frequencies corresponds with notable spikes in the PSD data, but are so consistent that they could be an instrument issue.
- The upper depth spectrogram shows plenty of activity, particularly in the cross-slope direction, with an apparent large pulse in the winter and spring.
- The lower depth spectrogram is more consistent over 2013, with few notable features, possibly due to the greater depth resulting in less seasonality due to storms, etc.

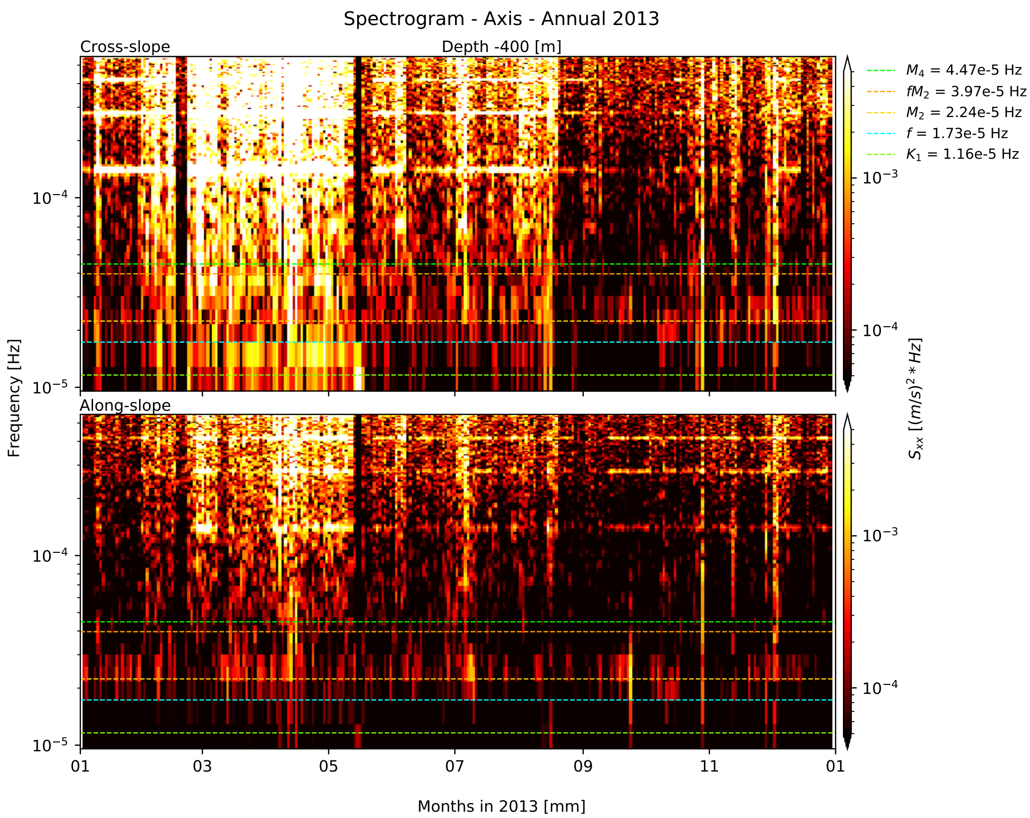


Figure 14: Whitened spectrogram data for Axis 75 kHz ADCP, at -400 metres depth, in 2013. Spectrograms are for the cross- (upper) and along-slope (lower) velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.

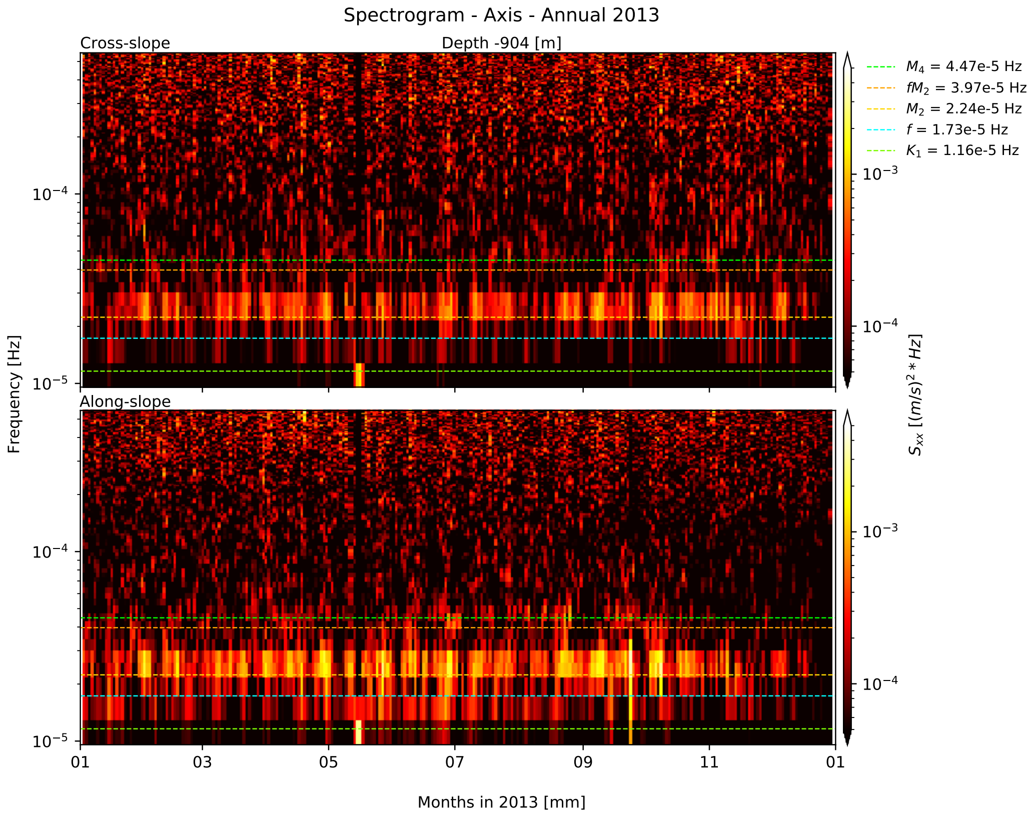


Figure 15: Whitened spectrogram data for Axis 75 kHz ADCP, at -904 metres depth, in 2013. Spectrograms are for the cross- (upper) and along-slope (lower) velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.

2.6 Vertical velocities

- Vertical mean current velocity data shows sinking water at upper depths in the winter and spring, and rising water at upper depths the rest of the year.
- Lower depths show mean currents as consistently sinking, though these velocity values are very small.

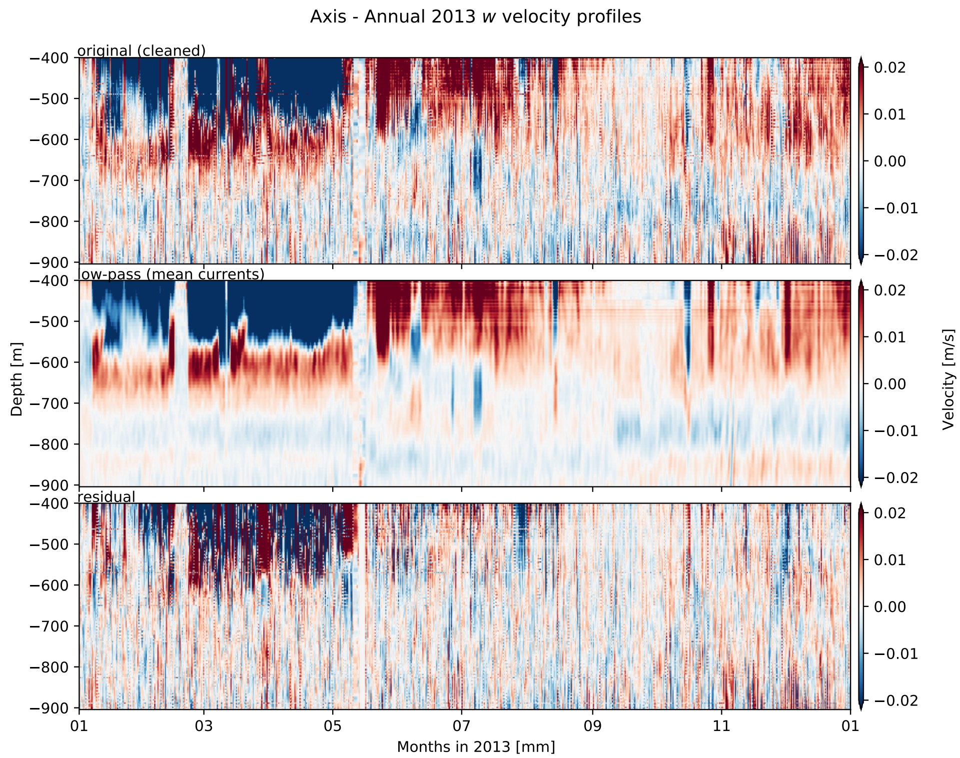


Figure 16: Annual w velocity data for Axis 75 kHz ADCP, in 2013. Velocities are displayed as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°.

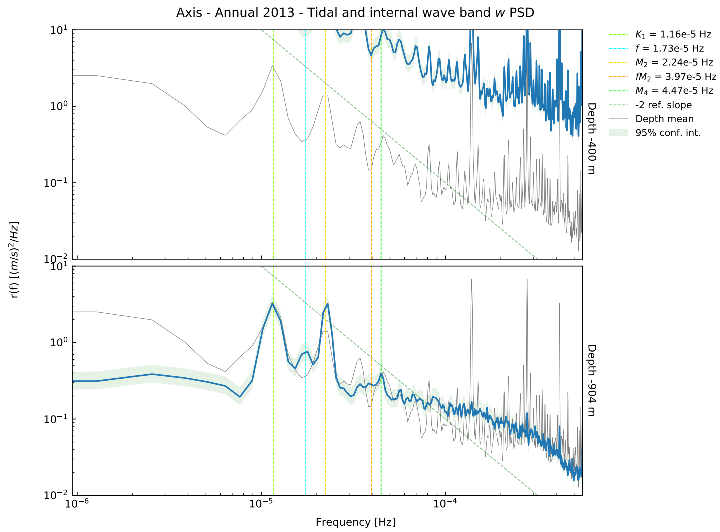


Figure 17: Annual PSD data for Axis 75 kHz ADCP, in 2013. PSD are for the vertical velocity data, at an upper depth of -400 m (top) and lower depth of -904 m (bottom). PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

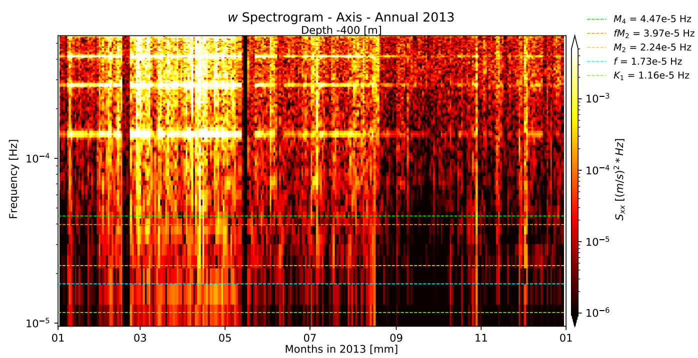


Figure 18: Whitened spectrogram data for Axis 75 kHz ADCP, at -400 metres depth, in 2013. Spectrograms are for the vertical velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.

3 Axis 55 kHz ADCP

3.1 Annual velocities

3.2 Seasonal velocities

3.3 Annual PSD

3.4 Seasonal PSD

3.5 Spectrograms

3.6 Vertical velocities

4 Upper Slope vs Axis

4.1 Annual velocities

4.2 Seasonal velocities

4.3 Annual PSD

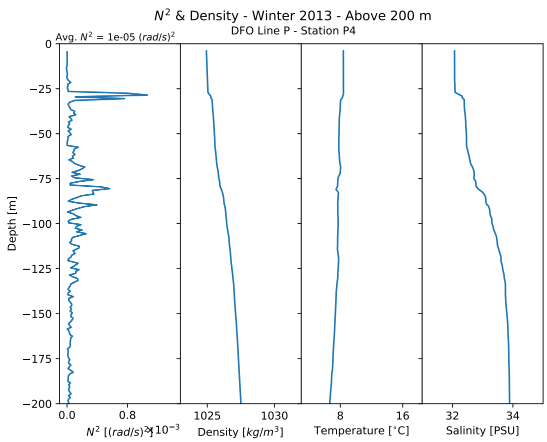
4.4 Seasonal PSD

4.5 Spectrograms

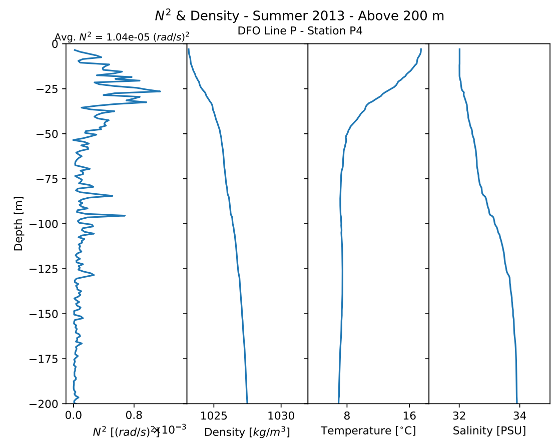
4.6 Vertical velocities

5 Buoyancy and CTD

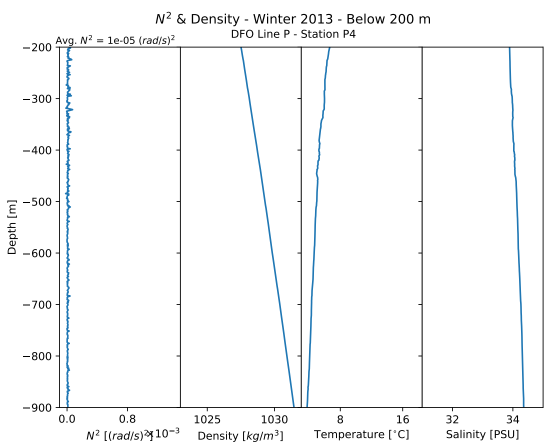
- In the upper 200 m, there is only slight variation to the N^2, density, temperature, and salinity profiles, with greater variation in the summer months (depth and slope of the pycnocline).
- Below 200 m there is even less variation, indicating that internal tides don't change much; lower depth N^2 is fairly static around 1.1e-5 Hz, which gives an N value of around 3.3e-3 Hz.
- Since the data does not show much above 200 m, no WKB scaling is necessary.



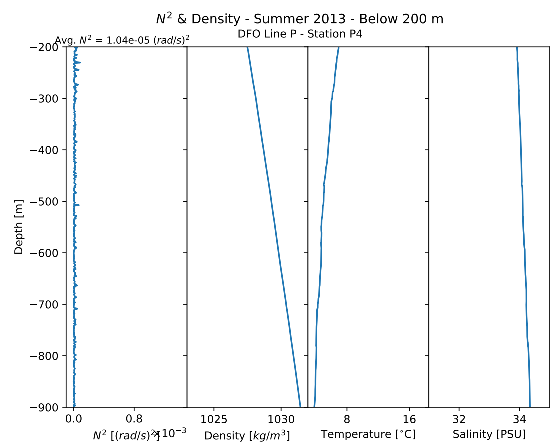
(a) Upper Winter



(b) Upper Summer



(c) Lower Winter



(d) Lower Summer

Figure 19: Seasonal N^2 and CTD data for Station P4 of Line P, collected by the DFO in 2013. The top row are upper depth plots (above -200 m), and the bottom row lower depth plots (below -200 m). Each plot shows N^2, density, temperature, and salinity, in order.