First look at the A-TWAIN 200-m mooring

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1 Data and processing

1.1 ADCPs

1.1.1 Data

Overview

	Dates	Δt	Δz	$\bar{\vert u \vert}$	$\bar{\theta}$	Source file
#1	16.09.12-17.09.13 *(366 d)*	20 min	4 m	2.0 cm s^{-1}	70.1°	*ATWAIN2012_200_adcp_at201_processed.mat*
#2	21.09.13-17.09.15 *(726 d)*	15 min	4 m	7.1 cm s^{-1}	51.1°	*ATWAIN2013_200_adcp_at201_processed.mat*
#3	19.09.15-19.09.17 *(730 d)*	20 min	8 m	10.2 cm s^{-1}	32.3°	*ATWAIN2015_200_adcp_at201_processed.mat*

Table 1: *Overview of the three deployments, including mean amplitude* $\bar{|u|}$ *and direction* $\bar{\theta}$ *of the depth-averaged current (originally intended to use to orient the* u *component along the principal flow direction).*

Data and noise characteristics

Noise characteristics differed somewhat between the three deployments. Velocity spectral shapes (Figure 1) from the different deployments diverge sharply towards the high-frequency end, with the second (2013-2015) deployment exhibiting the greatest amount of high-frequency noise.

Outside the HF band, for frequencies below $\sim$ (1 cyc)(6 hrs)$^{-1}$, the spectral shapes and amplitudes correspond well. Amplitudes at the semi-diurnal peaks are in very close agreement (Figure 2).

The three deployment records are well suited for direct intercomparison, except at time scales below about 6 hours, well below the long time scales in question here.

The difference in noise characteristics between the deployments is visible in full-resolution time series of currents from individual depths (Figure 3). The current amplitude and direction varies substantially between the deployments, however (Table 1, Figure 4).

Mean current profiles from the deplyments also differ markedly between the deployments. Differences and erroneous mean values near the edges can be attributed to problems near both edges of the depth range, but even after discarding suspect bins near the edges, it is clear that the mean structure is clearly different between the deployments (Figure 5). Standard deviation profiles are relatively similar between the deployments, however (Figure 6), consistent with the matching velocity spectra.

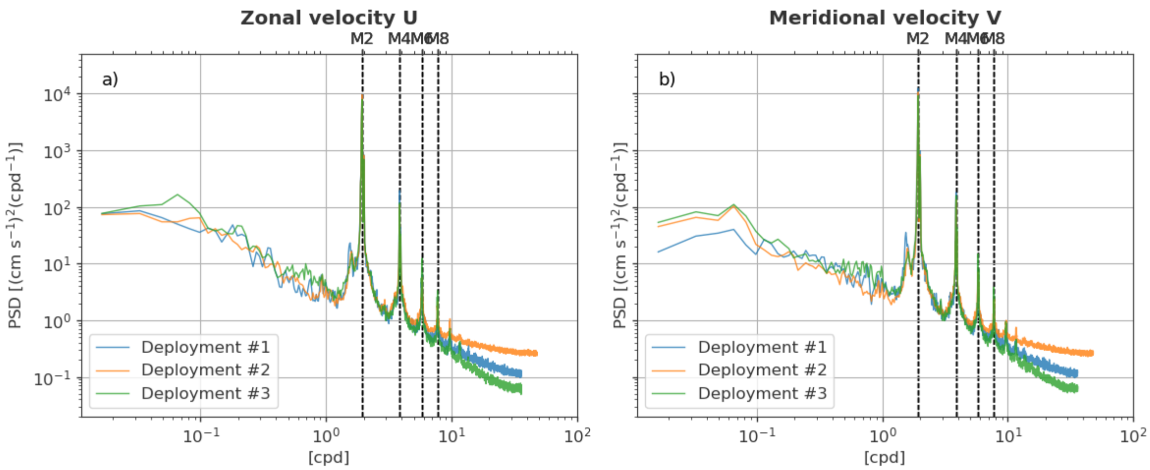

Figure 1: *Average spectra for the zonal (a) and meridional (b) velocity components. Computed for 61-day 50% overlapping windows (after applying a Hanning window to each).*

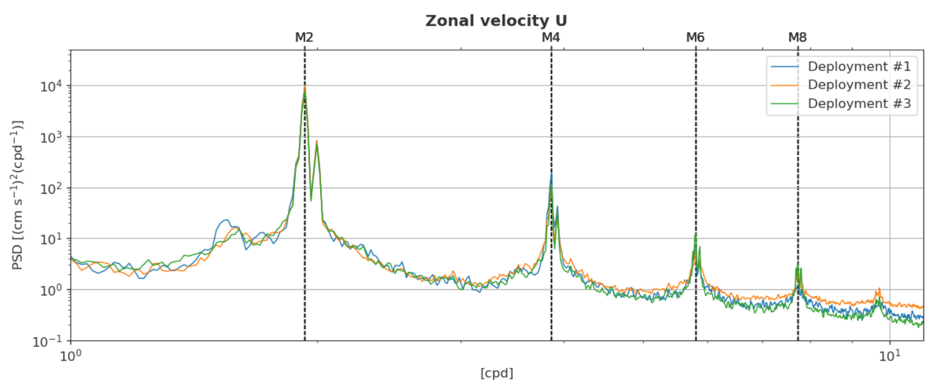

Figure 2: *Same as Figure 1a, but zoomed in on the tidal band.*

1.1.2 Processing

Note: *Can we really trust the return from nea the surface? Should e.g. the upper 10% be discarded a priori?*

Below follows a list of the initial processing steps taken.

1. Entire bins were discarded from each deployment record:
   - Bottom bins were discarded for all deployments.
   - All bins centered above the surface or at depths <5 m were discarded.
   - Bins where deployment average *pg4* (% good of 4-bin ensembles?) was below 92% were discarded.
2. All 148608 profiles of u and v from all three deployments were interpolated onto an even depth grid of spacing 1 m.
3. The time series from the three deployments were concatenated to a single time series `atwain/data/processed_mooring_data/combined_adcp.nc`.

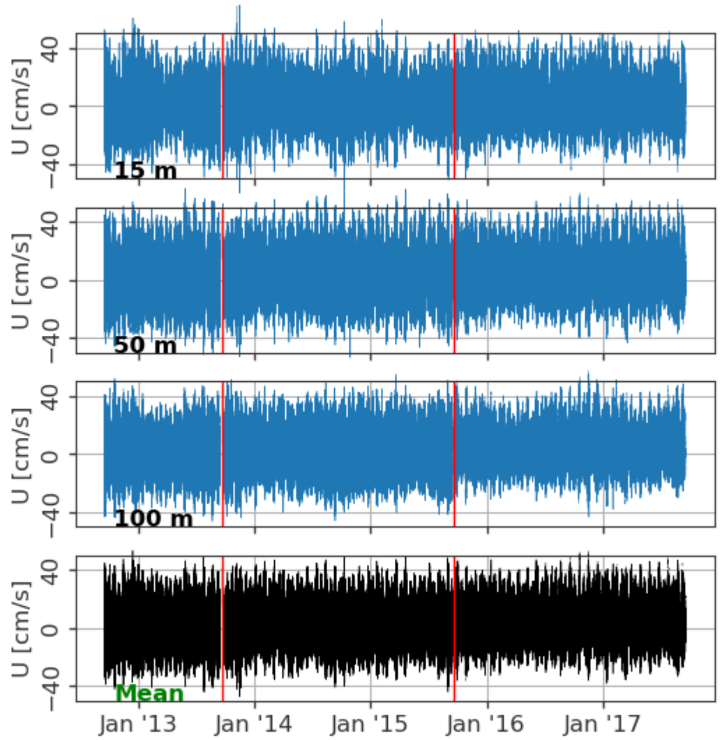

Figure 3: *Zonal velocity component in the joined time series at different depths (blue). The bottom panel shows the depth average (black). Mooring redeployment times shown as red vertical lines.*

4. 1-m bins where $\leq 15\%$ of measurements were invalid were discarded altogether from deployment 2 and 3 .
5. The time series from two latter deployments were concatenated to a single time series `atwain/data/processed_mooring_data/combined_adcp_2013_2017.nc`.
6. 1-m bins where $\leq 25\%$ of measurements were invalid were discarded altogether from deployment1.
7. The time series from two latter deployments were concatenated to a single time series `atwain/data/processed_mooring_data/combined_adcp_2012_2013.nc`.

Note that the above approach is very conservative, and likely discards many good data points near the edges. Is should serve the purpose of exploring the dataset well enough, but the ADCP data does need to be reprocessed at some later point.

Depth average currents were also computed for the along- and cross-current directions.

Script for combining the deployments into one file:
`atwain/code/processing_and_data/moorings/adcp/combine_currents.py`.

Resulting netcdf file with all 3 deployments joined:
`atwain/data/processed_mooring_data/combined_adcp.nc`

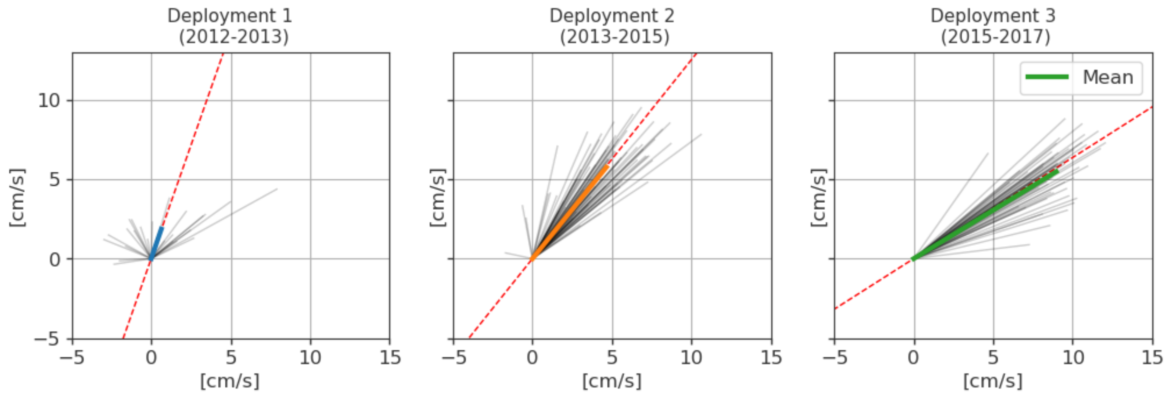

Figure 4: *Depth average velocity vectors for 14-day averaged intervals (black) and full, individual deployments (colored). Vectors have not rotated to the direction of predominent flow (predominant direction is shown in red).*

Script for last cleaning step and saving into individual files for deployments (1) and (2, 3):
`atwain/code/processing_and_data/moorings/adcp/final_clean_and_split_ncfiles.py`

Final, cleaned netcdf file for deployments 2 and 3:
`atwain/data/processed_mooring_data/combined_adcp_2013_2017.nc.nc`

Final, cleaned netcdf file for deployment 1 :
`atwain/data/processed_mooring_data/combined_adcp_2012_2013.nc`

Script for computing depth-average currents for 2013-2017:
`atwain/code/processing_and_data/moorings/adcp/make_depth_average_currents.py`

Pickled depth-average currents for 2013-2017:
`atwain/data/processed_mooring_data/depth_avg_currents_2013_2017.p`

Pickled depth-average currents for 2013-2017 (interpolated ontp even 15 min grid):
`atwain/data/processed_mooring_data/depth_avg_currents_2013_2017_int.p`

Various scripts for exploring the ADCP dataset and generating the plots below in:
`atwain/code/processing_and_data/moorings/adcps/*`.

1.2 Moored CTD sensors

1.2.1 Data

There were Seabird SBE 37 Microcat point CTD sensors mounted on the mooring during all three deployments (Table 2). All Microcat records also include conductivity and pressure. A sensor was also mounted at ~50 m during the first deployment, but this sensor failed.

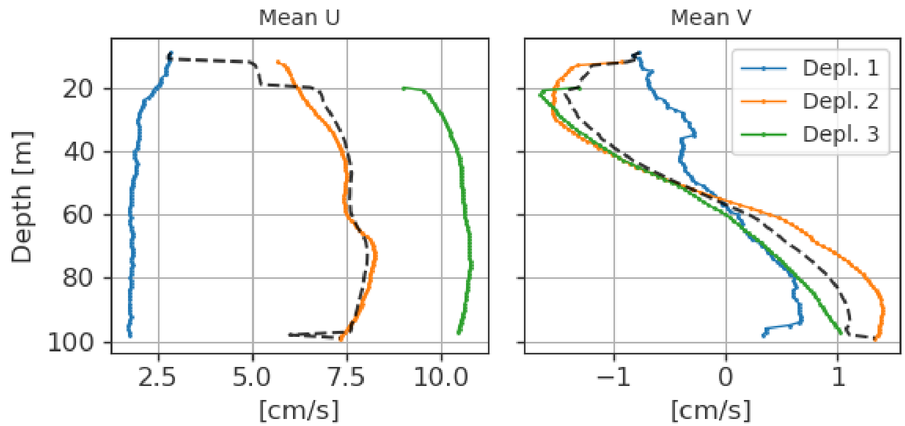

Figure 5: *Mean profiles of rotated velocity components (left) along and (right) across predominant flow direction. Blue: deployment 1, orange: deployment 2, green: deployment 3, black dashed: Full combined time series. mean profiles were computed after the processing detailed in Section 1.1.2. had been applied, but without applying the vector rotation; u and v here refer to the compass directions.*

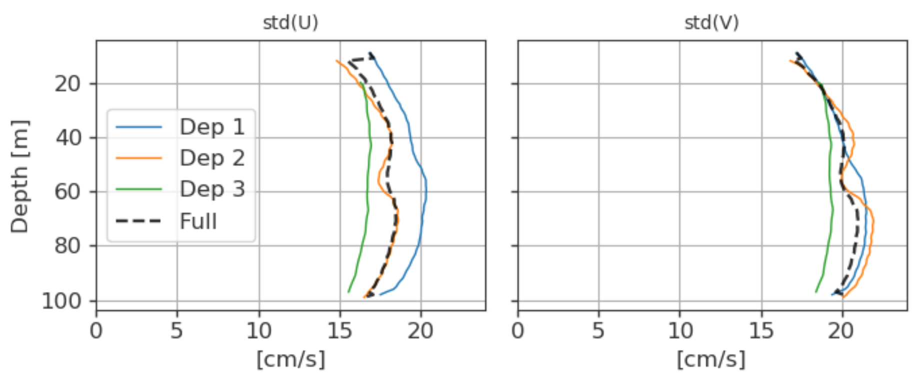

Figure 6: *STD profiles of rotated velocity components, see Figure 5.*

1.2.2 Processing

Processing details for the 2012-2013 CTD records are listed in `ATWAIN_datasets_overview.xlsx`. It looks like the data records were validated against CTD profiles and found to be in good agreement, and that no further processing was applied to the records which were output by the SeaBird software.

For the 2nd and 3rd deployments, CTD data has already been interpolated and combined with SST data to generate a pressure/depth time series.

Approximate CTD records from 105 db (50 db) were produced by joining the time series from the three (two) deployments - using the interpolated record for the two latter deployments. So not ideal, but good enough for exploring the dataset.

Heat content

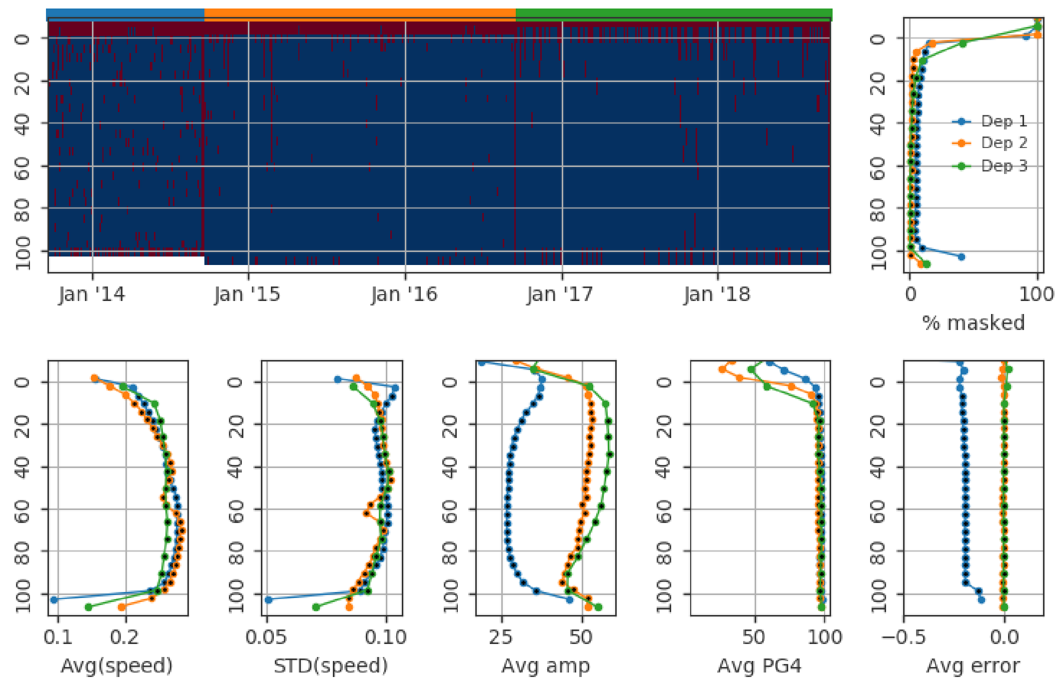

Figure 7: *Upper left: masked (invalid) values in the ADCP record as originally read. Upper right: Deployment bin average percentage masked. Bottom: Deployment bin average statistics for some relevant quantities. Black dots indicate bins remaining after step 1 in the list in Section 1.1.2.*

A rough calculation of depth integrated heat content Q (per unit area, J m^{-2}) was made, relative to the minimum observed temperature in the record, T_{min} =-2.46$°C$:

$$Q = c_p \int_{z0}^{z_1} \rho(T - T_{min})\, dz$$

where temperature had been transformed from a fixed pressure grid to a fixed depth one using the hydrostatic approximation. Since there isn't a surface salinity record, a fixed density ($\rho = \rho_0$=1028 kg m^{-3}) was assumed - this approach should eventually be improved.

Q, as well as the depth average temperature, was calculated for 0-100 m (overlapping approximately with the ADCP range), and for 55-100 m range (between the two CTD sensors and independent of SST).

Script for heat calculation (and concatenating into a single 2013-2017 time series):
atwain/code/processing_and_data/moorings/ctds/make_Q_prelim_2013_2017.py

Pickled bunch dictionary with time series of heat and average temperature (2013-2017):
atwain/data/processed_mooring_data/Q_prelim.p

Script for creating single CTD times series at 50 and 105db:
atwain/code/processing_and_data/moorings/ctds/make_combined_ctd_50db.py
atwain/code/processing_and_data/moorings/ctds/make_combined_ctd_105db.py

Pickled bunch dictionaries with CTD quantities at ~50 db (2013-2017) and ~105 db (2012-2017):

Deployment	Source file	Instrument	ID	Δt	Median pressure
1 *(2012-2013)*	*ATWAIN2012_ allcats_processed.mat*	Microcat	9294	15 min	105 db
		Microcat	9295	15 min	133 db
		Microcat	9296	15 min	182 db
2 *(2013-2015)*	*ATWAIN2013_Microcats_ interpolated_SST.mat*	Microcat	?	15 min	46 db
		Microcat	?	15 min	112 db
		Microcat	?	15 min	137 db
		Microcat	?	15 min	187 db
3 *(2015-2017)*	*ATWAIN2015_Microcats_ interpolated_SST.mat*	Microcat	9296	15 min	50 db
		Microcat	9294	15 min	130 db
		Microcat	9295	15 min	144 db
		Microcat	8763	15 min	927 db

Table 2: *Overview of moored CTD sensors on the 200 m A-TWAIN mooring.*

`atwain/data/processed_mooring_data/CTD_50db_combined.p`
`atwain/data/processed_mooring_data/CTD_105db_combined.p`

Generating some nice overview plots of T, S, $\Delta\rho$ and Q:
`atwain/code/processing_and_data/moorings/ctds/quick_data_plot_ctd.py`

1.3 Data products

1.3.1 Sea ice concentration

Daily sea ice concentration (SIC) was obtained from the Near-Real-Time DMSP SSM/I-SSMIS Daily Polar Gridded Sea Ice Concentrations (Maslanik, 1999) (25 km x 25 km grid, daily fields).

SIC at the mooring location was obtained by interpolation (*scipy.interpolate.griddata*) of the daily fields onto the mooring coordinates.

Remote opening and extraction of time series at A-TWAIN location from 2011:
`atwain/code/processing_and_data/sea_ice_concentration/get_SIC_DMSP.py`.

ATWAIN SIC time series, pickled:
`atwain/data/other/sea_ice_concentration/NSIDC_SIC_atwain_loc.p`

1.3.2 Sea ice drift

Sea ice drift estimates were obtained from the NSIDC Polar Pathfinder Daily 25 km EASE-Grid Sea Ice Motion Vectors product (Tschudi et al., 2019).

In order to estimate sea ice drift and fluxes above the A-TWAIN mooring, an area of 3$\times$3 points (75 km$\times$75 km) centered near the mooring location was selected (Figure 8). Average sea ice velocities were computed for this area, and sea-ice fluxes through the area boundaries were computed. The net flux into this area (units m^2s^{-1}) was used as a rough proxy for sea ice melt/formation above the mooring.

Annual netCDF PPD SIM files (downloaded from NASA Earthdata):
`atwain/data/other/sea_ice_drift/polar_pathfinder_daily/*nc.`

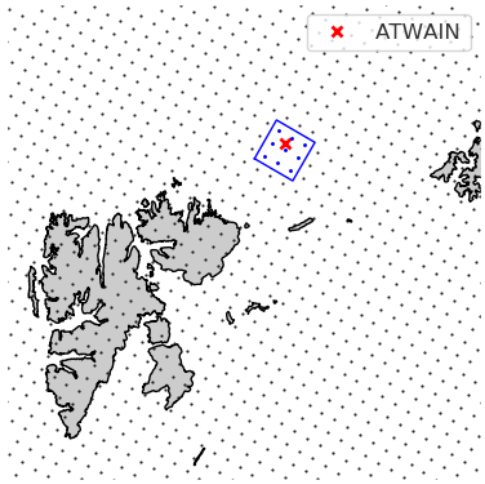

Figure 8: *Map showing PPD SIM grid points and the 3x3 point area (blue) used to estimate sea-ice fluxes above the A-TWAIN 200 m mooring. Red X shows the location of the A-TWAIN mooring.*

Script computing average quantities and fluxes in and out of the 3x3 grid area:
`atwain/code/processing_and_data/sea_ice_drift/extract_timeseries_pathfinder_25x25.py`.

Index slices defining this area in the data are pickled in:
`atwain/data/other/sea_ice_drift/polar_pathfinder_daily/slices_atwain_pathfinder25x25.p`.

Time series of sea ice fluxes and velocity are pickled in:
`atwain/data/other/sea_ice_drift/polar_pathfinder_daily/atwain_sea_ice_drift_timeseries.p`.

1.3.3 Sea surface temperature

Sea-surface temperature was obtained from the Optimum Interpolation Sea Surface Temperature product (OISST v2, available from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, at https://www.esrl.noaa.gov/psd/, Reynolds et al., 2007). SST at the mooring location was obtained by bilinear interpolation (*scipy.interpolate.interp2d*) of the daily fields onto the mooring coordinates, since *scipy.interpolate.RectSphereBivariateSpline* cannot deal with empty/masked values (land). The error compared to spherical should be negligible, but I may want to look into this at a later stage.

The SST time-series thus produced for the A-TWAIN mooring location is very close to, but clearly not identical to, the SST field in the combined moooring temperature *_sst.mat* files (Figure 9). This is despite that they come from the same data, and should be identical. I see two possible sources for this discrepancy.

1. Different interpolation schemes: my approach does not take into account the spherical domain, and therefore has errors - there should be very small, however..

2. Different ”A-TWAIN coordinate”: I’m using the deployment coordinates from the 2015 cruise report (*81°N 24.255’, 31°E 13.533’*) - these may not be appropriate for all three deployments. I’m not sure what coordinates were used in the *.mat* files.

I’ll keep using my extracted SST time series for now, but may want to return to this at a later stage.

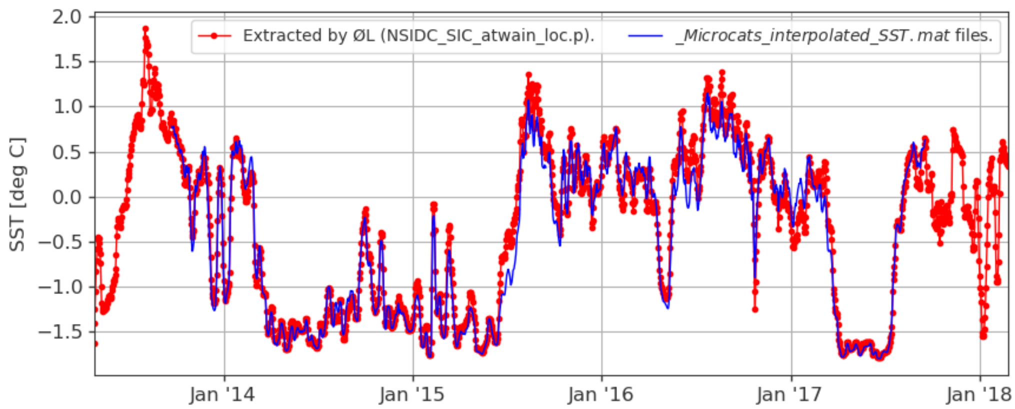

Figure 9: *Comparing SST extracted in ØL’s script to the preexisting SST time series (top bins in the _sst.mat files).*

OISST v2 download script:
`atwain/code/processind_and_data/sst/grab_oisst_v2_hires.py`.

OISST v2 generated time series, pickled:
`atwain/data/other/sst/sst_oisst_v2_hr.p`.

1.3.4 Atmospheric forcing

10-m winds and 2-m air temperature were obtained from the ERA-Interim reanalysis product (Dee et al., 2011). Data is available on a 0.75°×0.75° grid, yielding much higher zonal than meridional resolution at this latitude ($\Delta x \sim 0.16\Delta y$).

Surface wind stress $\vec{\tau}$ was computed from winds $\vec{U}$ using the conventional bulk formula (e.g. Gill, 1982), where $\vec{\tau}$ is proportional to $|\vec{U}|^2$ below 10 m s^{-1} and to $|\vec{U}|^3$ above (Large and Pond, 1981).

Wind stress curl ($(\nabla \times \vec{\tau}) \cdot \hat{k}$) was computed from first differences. This approach may have to be modified eventually, but I think the WS curl field looks smooth, and reasonably isotropic, and will stick with first differencing for now.

Quantities at the mooring location were obtained by bivariate spline interpolation for a rectangular mesh on a sphere (*scipy.interpolate.RectSphereBivariateSpline*) onto the mooring coordinates. May actually want to use the (techincally less appropriate) *interp2d* linear approach for consistency..

ERA Interim download script:
`atwain/data/other/wind/era_interim/dl_era_winds.py`.

Raw download netCDF file:
`atwain/data/other/wind/era_interim/era_interim_for_atwain.nc`

ERA Interim processing script:
`atwain/code/processing_and_data/wind/era_interim/compute_wscurl.py`.

Numpy converted ERA data for the area slice, and for the ATWAIN coordinate point (pickled):
`atwain/data/other/wind/era_interim/era_interim_for_atwain_area.p`
`atwain/data/other/wind/era_interim/era_interim_for_atwain_point.p`

1.4 Combining the time series

Time series of key variables from the CTD and ADCP records, as well as from the external datasets, were collected in a single file to facilitate intercomparison between the variables.

First, each relevant time series was interpolated onto the same grid (with spacing 1/97 days or 14.86 minutes). The time series was then smoothed with a 97-point boxcar filter, equivalent to a daily running average. Lastly, this time series was subsampled every 8 hours to produce the final time series.

Script for combining the time series:
`atwain/code/processing_and_data/combine_time_series.py`.

Resulting file (daily averaged quantities subsampled every 8 hours), pickled bunch:
`atwain/data/combined_timeseries.p`

2 Results

2.1 Currents

2.2 CTDs

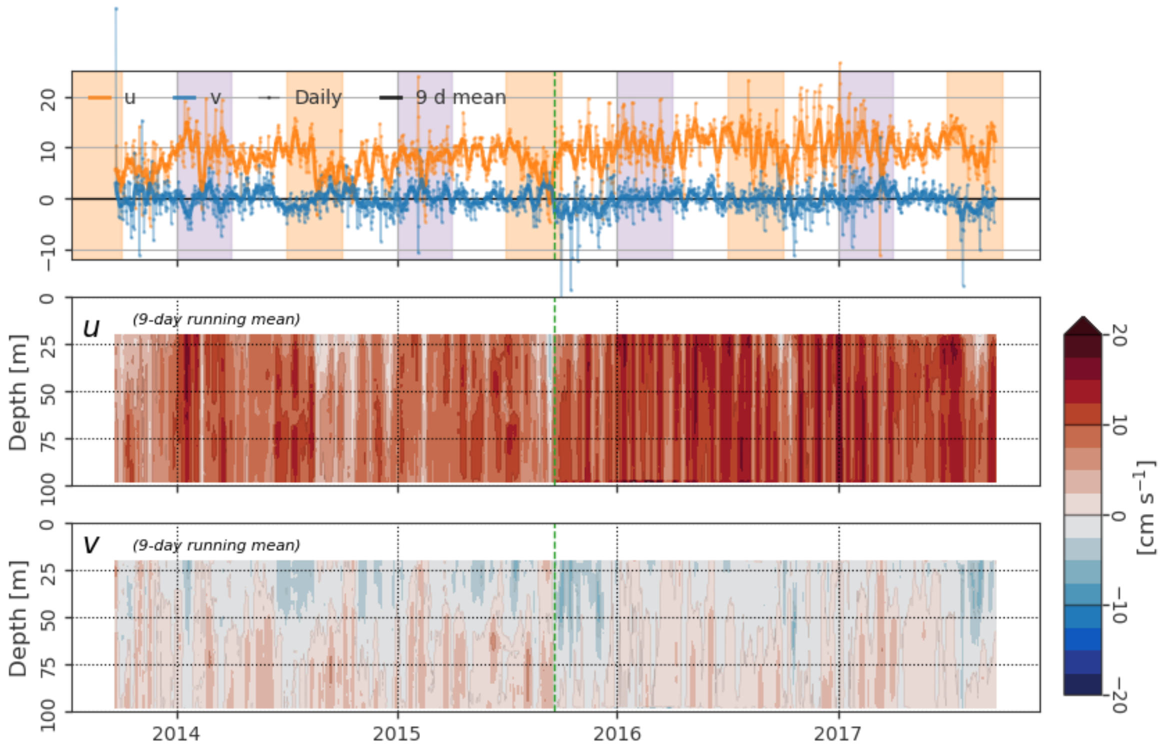

Figure 10: *ADCP currents (u and v correspond to along and across precominant flow direction). Upper panel: depth-averaged currents. Middle panel: u component. Bottom panel: v component. Green dashed line indicates when the mooring was serviced in 2015.*

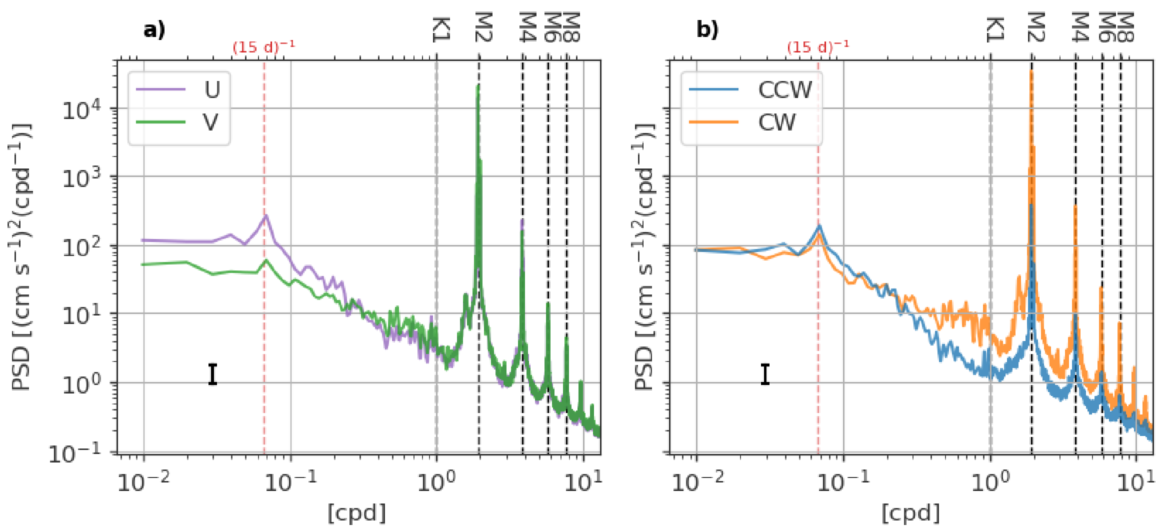

Figure 11: *Average frequency spectra for the 2013-2017 period. Separated by (a) vector component and (b) rotary component. Spectra computed for the 20-98 depth range. For each depth bin: PSD computed for 27 windows of length 101 days, and overlapping by 50%. Confidence interval calculated assuming that each window in time adds two degrees of freedom (a conservative approach).*

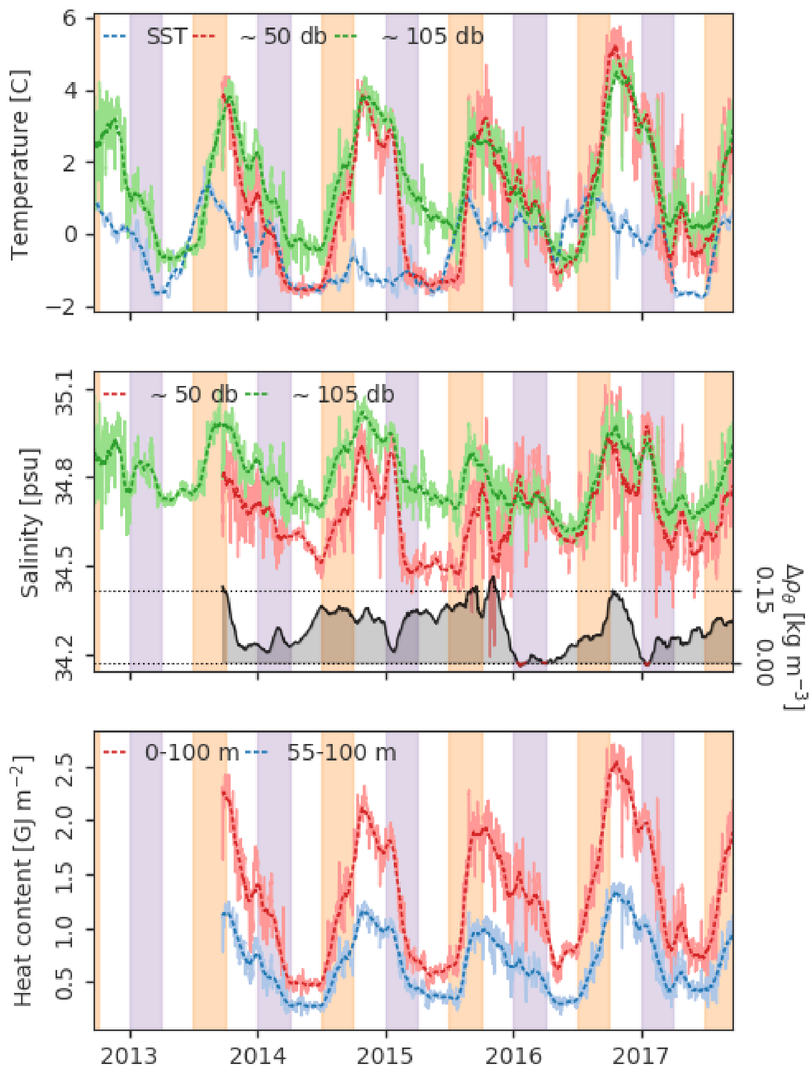

Figure 12: *Time series of temperature (upper), salinity (middle) and depth integrated heat content (bottom) from th ATWAIN 200m mooring. In addition, the secondary axis in the middle panel shows difference in potential density between the CTDs at ∼50 db and ∼105 db. Thin lines show daily averages, thick lines show 31-day running averages.*

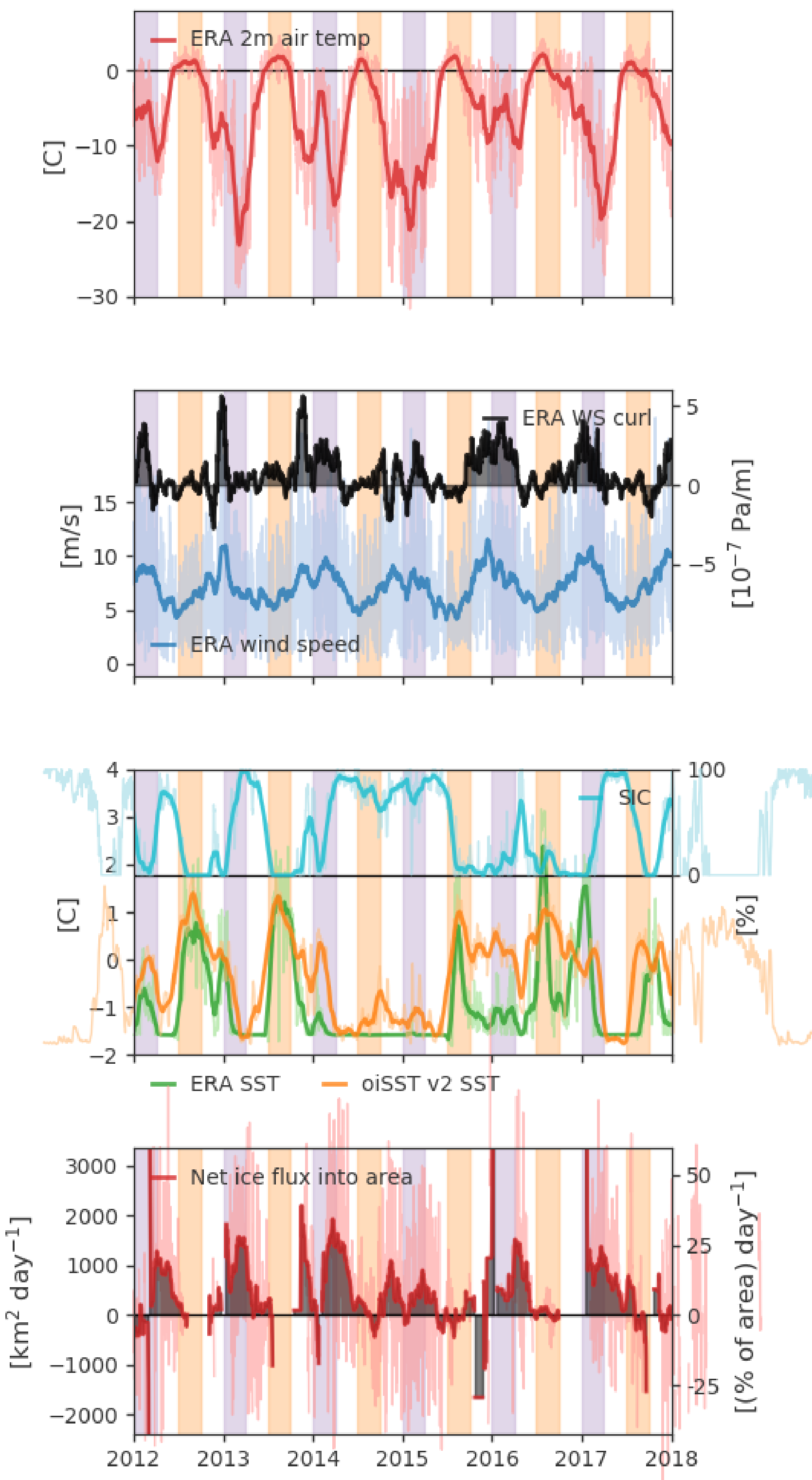

Figure 13: *Time series of various surface quantities computed from external data products. Thin lines show daily averages, thick lines show 31-day running averages.*

References

Dee, D.P., Uppala, S.M., Simmons, A.J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M.A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A.J., Haimberger, L., Healy, S.B., Hersbach, H., Hólm, E.V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A.P., Monge-Sanz, B.M., Morcrette, J.J., Park, B.K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.N., Vitart, F., 2011. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Quarterly Journal of the Royal Meteorological Society 137, 553–597. doi:10.1002/qj.828.

Gill, A.E., 1982. Atmosphere—Ocean Dynamics. Number 30 in International Geophysics Series. 1 ed., Elsevier.

Large, W.G., Pond, S., 1981. Open Ocean Momentum Flux Measurements in Moderate to Strong Winds. Journal of Physical Oceanography 11, 324–336. doi:10.1175/1520-0485(1981)011<0324:OOMFMI>2.0.CO;2.

Maslanik, J., 1999. Near Real-Time DMSP SSM/I Daily Polar Gridded Sea Ice Concentrations.

Reynolds, R.W., Smith, T.M., Liu, C., Chelton, D.B., Casey, K.S., Schlax, M.G., 2007. Daily High-Resolution-Blended Analyses for Sea Surface Temperature. Journal of Climate 20, 5473–5496. doi:10.1175/2007JCLI1824.1.

Tschudi, M., Meier, W.N., Stewart, J.S., Fowler, C., Maslanik, J., 2019. Polar Pathfinder Daily 25 km EASE-Grid Sea Ice Motion Vectors, Version 4. doi:10.5067/INAWUWO7QH7B.