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Analysis of Physical Oceanographic Data from Trinity Bay, May – August 2002

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Abstract

A cruise was carried out during May 2002 in Trinity Bay, a northward facing embayment of the Avalon peninsula, Newfoundland, to deploy oceanographic meters with which to collect data on the circulation and hydrography of Trinity Bay. Seventeen moorings were deployed to record current velocity, temperature, and salinity from May to August 2002. All the moorings included thermistors to measure water temperature. Eleven moorings used S4 and/or RCM current meters, while six used Acoustic Doppler Current Profilers (ADCP's). We present plots of the raw data, statistical analyses, and information on quality control processes. This work is a continuation of studies carried out in the same region in 2000 and 2001.

Acknowledgements

We thank the crew and captain of the CCGS Ann Harvey for their help in this oceanographic study. Funding for this project was provided from an NSERC Strategic Grant to B. deYoung, P. P. Pepin, P. Snelgrove and J. Helbig.

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Introduction

We are interested in the distribution and density of fish eggs and how to improve sampling of them for application to fisheries management. One key component of our work is to improve our knowledge of the physical circulation processes in Trinity Bay. To aid in reaching this goal, seventeen moorings were deployed in 2002 to provide data on the physical oceanography of the region. This work follows on from a similar program in 2001 (Tittensor *et al*., 2002) and a pilot study in the summer of 2000 (Schillinger *et al*., 2000).

The moorings were deployed from the 8th to the 10th of May 2002 (days 127-129) and retrieved on August the 28th (day 239) for a total residence time of around 110 days (all times in this report in GMT, days in Julian calendar with Jan 1st being day zero). The data that were gathered from these locations underwent quality control procedures and statistical analysis, and were then plotted. The results of this study are presented in the following pages. Moorings M1-M2, M4, M6-M9, M12-M13 and M16-M17 had RCM and/or S4 current meters along with thermistors. Moorings M3, M5, M10-M11 and M14-M15 had Acoustic Doppler Current Profilers (ADCP's) and thermistors attached. The locations of the moorings are shown in Figure 1, with further details in Table 1.

Data processing

RCM and S4 current meter data (including velocity, temperature and salinity) were checked first by visual observation and the removal of large peaks that were obviously artifacts, along with readings taken during descent into / ascent from position. Any missing data (just a few points at a time) within the time series were linearly interpolated from surrounding points. Velocity component data, salinity and temperature were then plotted. Current meter data that were curtailed early due to instrument malfunction are reported in Table 1. The S4 current meter at mooring M8 at a depth of 20 metres had a power failure and did not return any data, as did the RCM meter at a depth of 40 metres at M17. The S4 meter at 20 metres located at mooring M9 was examined in relation to other current meters, and by tidal analysis, and though a complete time-series existed it was discovered to be seriously flawed. Further investigation revealed that this was due to a 20° tilt in the angle of the instrument, and the data were discarded.

ADCP data followed a similar procedure with artifacts removed and interpolated where identified. The data were separated into 4 metre depth bins (with the lowest depth bin beginning at 6 metres above the depth of the instrument), and the backscatter examined in order to remove any depth bins that were giving spurious readings. Backscatter was corrected following standard techniques (Deines, 1999) utilising factory-set instrument characteristics as well as environmental factors such as the sound absorption coefficient and the speed of sound at each depth cell. These parameters, together with the slant range to each depth cell, were then used in the sonar equation to estimate the backscatter coefficient. Velocity was then decomposed into components, filtered using a 5^{th} order forward-and reverse Butterworth low pass digital filter with a cut-off of 30 hours (along with the backscatter) and plotted.

The mean and standard deviation of the currents at all moorings are recorded in Table 2. Mean current velocity data and standard deviation were also plotted for both 20 and 40 metres as vector arrow plots. Data from all instruments (ADCP's, S4's, RCM's and Vemco temperature meters) had a sampling period of 20 minutes. All instruments appeared to be within two meters of their target mooring depth (20, 40 or 75 metres). Table 1 presents our best estimates for the actual depths of instruments as deployed.

The raw temperature data were plotted as horizontal contour maps for depths of 20, 50 and 100 metres, interpolating for regions between the moorings. Data from each mooring were then processed using a 5^{th} order forward-and-reverse Butterworth low pass digital filter with a cut-off frequency of 30 hours in order to remove high-frequency variability. These filtered data were interpolated into 1 metre vertical depth bins, and isotherms plotted over the time-span of the moorings. Mean temperature profiles for the western, central, and eastern moorings were also plotted as time-series.

Wind data from a mooring located at 47° 57.53'N 53° 36.49'W were plotted as wind stress. The anenometer snapped off on day 187 so a full time series was not available.

Empirical Orthogonal Function (EOF) analysis was performed on filtered current velocity data in the spatial domain at 20 and 40 metres, using data from moorings that had a time-series from at least day 130 to day 215. At 20 metres, the M8 data from 40 metres was used in the analysis since this was the only data in the central western region. We rotated the eigenvectors in order to minimise the mean of the absolute complex angle.

Tidal analysis of data was undertaken following Pawlowicz *et al.* (2002), and the results tabulated and plotted as contours for selected tidal constituents. The tidal script output the amplitudes of the major and minor axes of the tidal ellipse. We then plotted and tabulated the geometric mean of these axes, in order to represent the amplitude of the velocities of the tidal constituents. The data revealed that mooring M9 (S4 at 20 metres) had aberrant data and led to the removal of this instrument from further analyses. It appears that the instrument became wrapped in the mooring line and sat at an angle of 20° to the vertical. There was no way to recover useful data from the instrument. It may be that the line also interfered with the sensors.

Hourly current meter data was compiled and interpolated at 20 metres to provide a vector field which could be used to advect passive tracers in particle tracking simulations. A 'mirror point' was introduced at M11 (at which location the ADCP instrument had a power failure) that contained exactly the same velocity field as the nearby M10; the width of the interpolated region would otherwise have been inordinately narrow. These simulations ran from day 130 to day 215, and were compiled into movies. Selected still frames from these movies are presented.

References

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Pawlowicz, R., Beardsley, B., and Lentz, S, 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. *Computers and geosciences.*

Schillinger, D. J., deYoung, B., and Foley, J., 2000. Physical and biological tow-yo data from Trinity Bay, July 2000. *Physics and Physical Oceanography data report 2000-4*. Department of Physics and Physical Oceanography, Memorial University of Newfoundland.

Tittensor, D. P., Naud, R., deYoung, B., and Foley, J., 2002. Analysis of physical oceanographic data from Trinity Bay, May – August 2001. *Physics and Physical Oceanography data report 2002-1*. Department of Physics & Physical Oceanography, Memorial University of Newfoundland.

Table 1: Location of 2002 Trinity Bay moorings. Moorings deployed between 8-10th May, and retrieved on 28th August 2002. Note: Vemco temperature meters sometimes continued to provide data when current meters were non-functional.

Mooring	Latitude (ºN)	Longitude (ºW)	Actual depth of current meters	Water depth	Start day, useful current meter data	End day, useful current meter data
M1	47 45.918	53 41.775	S4 – 20m RCM – 40m	190m	128	238
M2	47 43.485	53 35.045	S4 – 18m RCM – 38m	225m	128	206 (S4) 165 (RCM)
M3	47 47.525	53 36.172	ADCP – 76m	340m	128	239
M4	47 53.288	53 39.021	S4 – 20m RCM – 40m	181m	128 (S4) 129 (RCM)	237 (S4) 217 (RCM)
M5	47 52.158	53 34.691	ADCP – 75m	350m	129	239
M6	47 50.495	53 28.777	S4 – 20m S4 – 40m	126m	128	238
M7	47 55.113	53 31.749	S4 – 20m RCM – 40m	276m	128	239
M8	47 59.802	53 36.230	*S4 power failure* RCM – 40m	166m	129	221 (RCM)
M9	47 59.040	53 33.310	*S4 data flawed* RCM – 40m	114m	129	209 (RCM)
M10	47 57.674	53 27.190	ADCP – 75m	449m	128	239
M11	47 56.715	53 23.466	ADCP – 75m	400m	128	187
M12	48 01.831	53 27.682	S4 – 20m RCM – 40m	212m	128	239 (S4) 215 (RCM)
M13	48 06.565	53 27.764	S4 – 20m RCM – 40m	260m	128	221 (S4) 212 (RCM)
M14	48 04.572	53 23.310	ADCP – 74m	239m	128	239
M15	48 03.474	53 18.460	ADCP – 75m	300m	128	239
M16	48 11.096	53 19.600	S4 – 22m RCM – 42m	327m	127	238 (S4) 229 (RCM)
M17	48 07.713	53 13.274	S4 – 22m *RCM power failure*	334m	127	238

Table 2: Summary of current velocities from moorings.

Mooring	Depth (m)	Component	Mean (cm s^{-1})	Std. dev. (cm s^{-1})
M1	20	u	-1.55	4.61
		v	-1.61	7.30
	40	u	-0.62	2.83
		v	-2.18	4.45
M2	20	u	1.21	8.61
		v	-3.06	6.45
	40	u	0.45	3.69
		v	-0.46	3.34
M3	20	u	2.09	7.66
		v	-1.12	7.74
	40	u	-1.80	5.60
		v	-1.54	5.58
M4	20	u	-2.44	5.09
		v	-5.84	7.52
	40	u	-2.17	3.43
		v	-4.16	4.30
M5	20	u	0.64	7.80
		v	-1.43	7.16
	40	u	-0.39	6.36
		v	-2.73	5.86
M6	20	u	2.22	6.42
		v	3.57	9.76
	40	u	2.31	4.88
		v	4.05	7.19
M7	20	u	-0.37	7.16
		v	0.38	7.78
	40	u	-0.65	3.91
		v	-0.18	4.40
M8	40	u	6.80	3.48
		v	-3.27	4.48
M9	20	u	-1.43	3.65
		v	-0.90	4.02
M10	20	u	-1.24	7.28
		v	1.84	6.34
	40	u	-0.94	5.31
		v	1.63	4.92
M11	20	u	0.51	7.19
		v	1.75	9.00
	40	u	-0.55	5.82
		v	0.08	7.03

Table 2 (continued): Summary of current velocities from moorings.

		v	0.08	7.03
M12	20	u	1.29	7.53
		v	-2.59	7.74
	40	u	0.52	4.05
		v	-1.11	3.66
M13	20	u	-2.63	7.53
		v	-9.04	9.40
	40	u	-2.41	3.87
		v	-6.81	5.10
M14	20	u	3.59	7.73
		v	-1.99	6.71
	40	u	3.54	5.28
		v	-2.25	5.10
M15	20	u	6.66	8.45
		v	6.86	7.89
	40	u	4.65	5.61
		v	5.29	6.49
M16	20	u	-6.14	9.52
		v	2.17	10.06
	40	u	-4.49	4.67
		v	2.91	6.45
M17	20	u	-3.03	11.83
		v	6.56	8.83

Table 3: Amplitude (cm/s) of selected tidal constituents of the current at 20m.

	M1	M3	M4	M5	M6	M7	M10	M12	M13	M14	M15	M16	M17
MM	1.76	4.09	1.29	1.83	2.07	1.01	1.05	2.55	3.40	1.96	2.59	1.36	2.88
MSF	0.81	1.41	0.98	1.69	1.16	0.83	1.24	1.43	1.15	0.74	0.18	0.85	2.18
O1	0.24	0.11	0.05	0.54	0.29	0.24	0.15	0.24	0.25	0.07	0.66	0.17	0.40
K1	0.27	0.42	0.29	0.27	0.30	0.66	0.20	0.28	0.58	0.30	0.16	0.26	0.26
M2	0.10	0.20	0.21	0.19	0.34	0.04	0.47	1.17	0.46	0.75	0.60	0.36	1.00
S2	0.13	0.48	0.20	0.26	0.25	0.13	0.53	0.58	0.28	0.38	0.70	0.45	0.36
MK3	0.13	0.10	0.08	0.14	0.24	0.16	0.10	0.12	0.12	0.08	0.20	0.12	0.19

Table 4 (a & b): Phase (degrees relative to Greenwich) of selected tidal constituents of the current at 20m.

a)

	M1	M3	M4	M5	M6	M7	M10
MM	225.17	247.54	231.31	283.20	142.46	274.63	247.38
MSF	196.05	109.64	275.94	313.54	38.95	222.26	116.57
O1	133.19	286.92	19.67	68.13	71.00	104.71	186.71
K1	111.26	179.09	45.63	92.14	264.88	142.80	173.22
M2	156.60	146.81	153.83	238.17	163.42	188.73	157.16
S2	277.54	303.28	218.52	323.69	202.85	292.31	288.48
MK3	192.64	73.79	231.62	98.14	44.97	178.86	62.23

b)

	M12	M13	M14	M15	M16	M17
MM	277.46	262.55	299.76	153.65	56.40	195.36
MSF	174.73	333.81	178.76	67.41	170.50	193.42
O1	66.58	349.65	232.31	34.14	342.21	125.18
K1	18.54	137.74	12.42	109.89	123.11	258.04
M2	144.36	121.23	116.16	107.39	194.47	166.03
S2	292.60	309.69	61.33	256.62	278.16	299.93
MK3	208.93	195.45	109.01	85.20	18.08	335.80

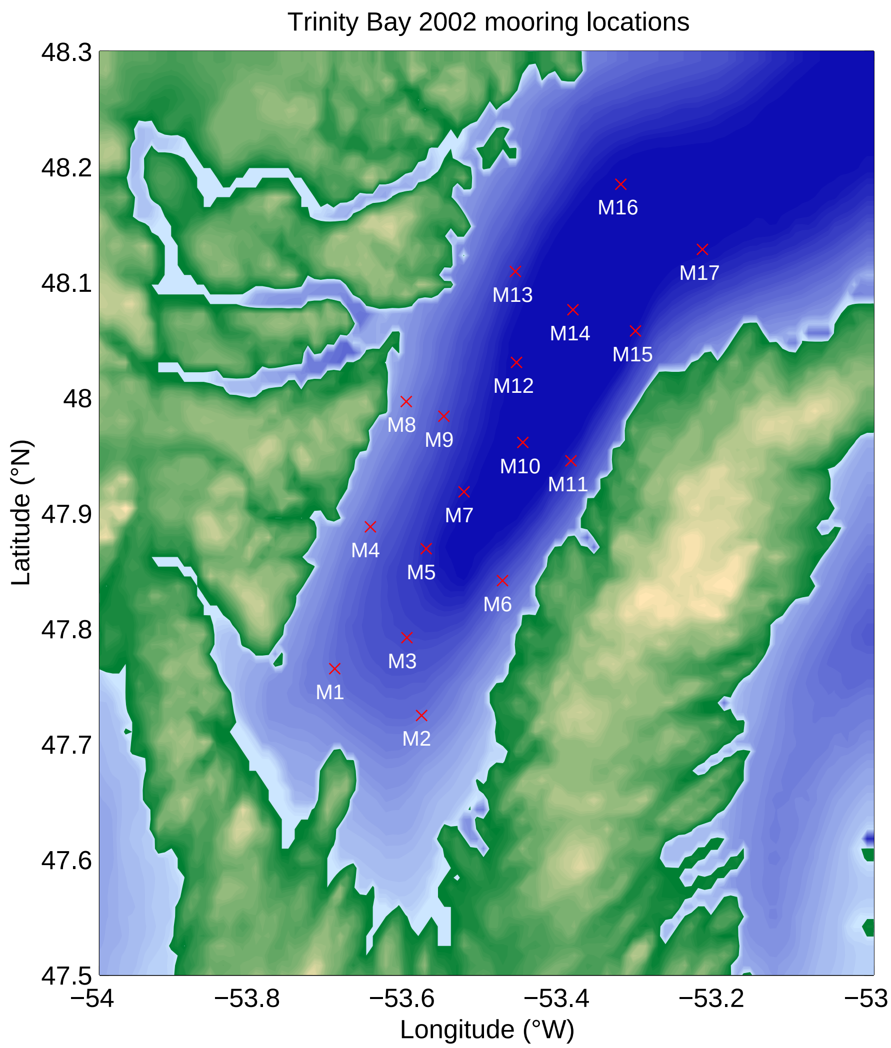

Figure 1: Mooring locations for the 2002 Trinity Bay cruise.

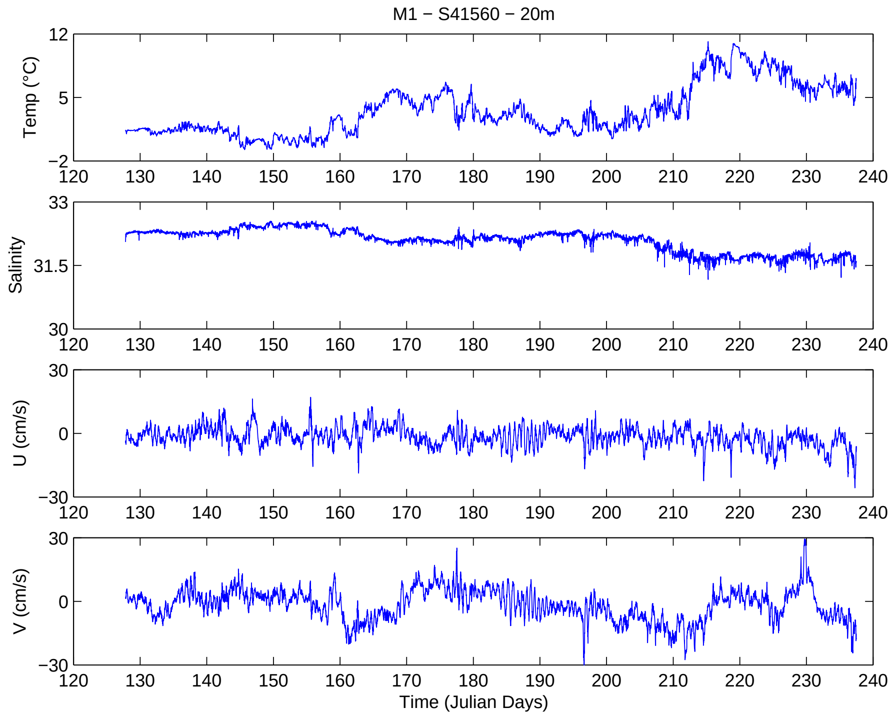

Figure 2: The temperature, salinity and component velocities at a depth of 20 metres, mooring M1.

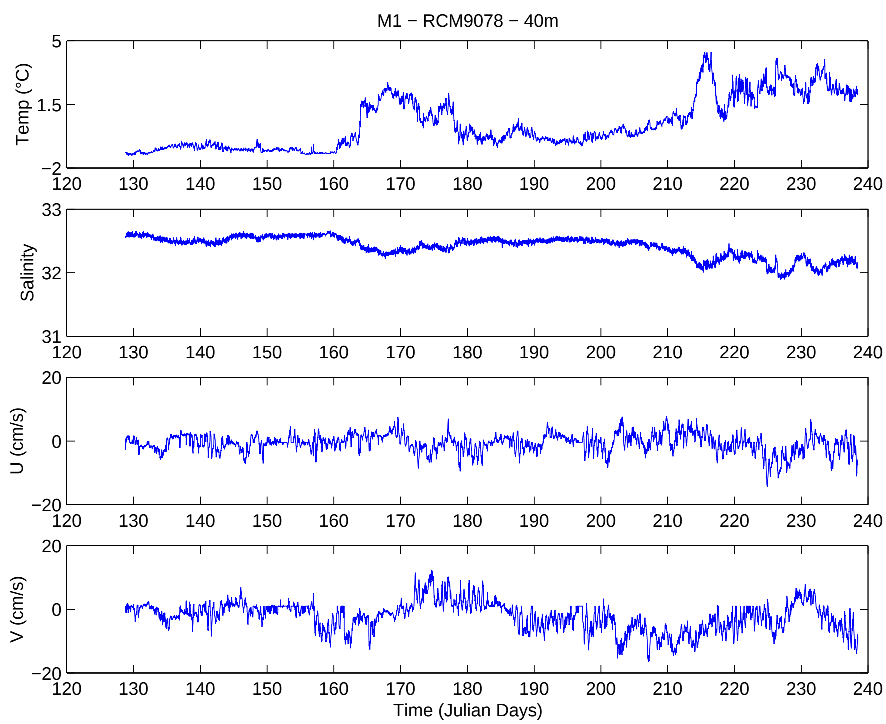

Figure 3: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M1.

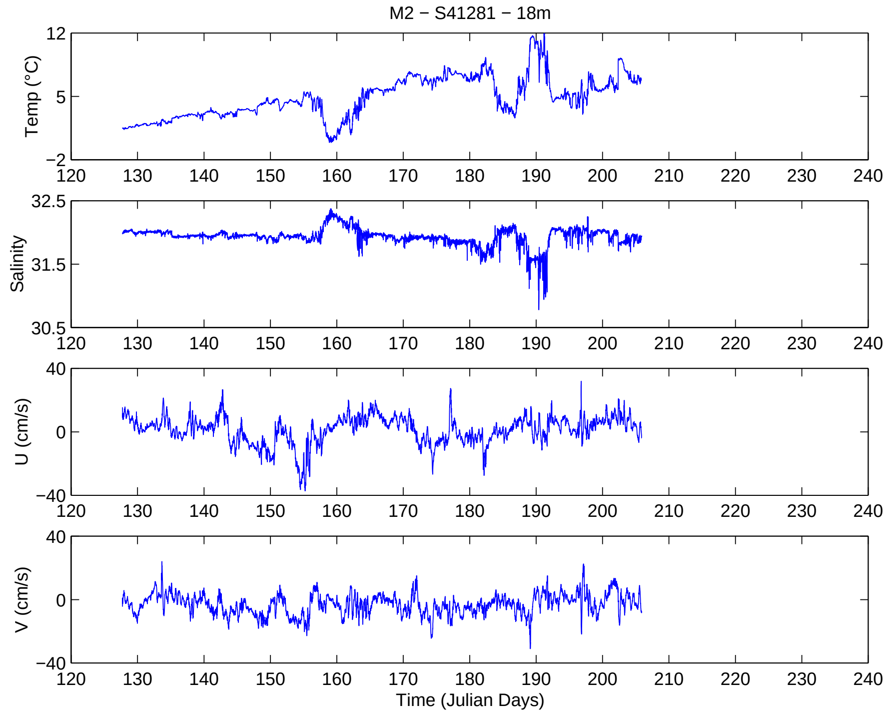

Figure 4: The temperature, salinity and component velocities at a depth of 18 metres, mooring M2.

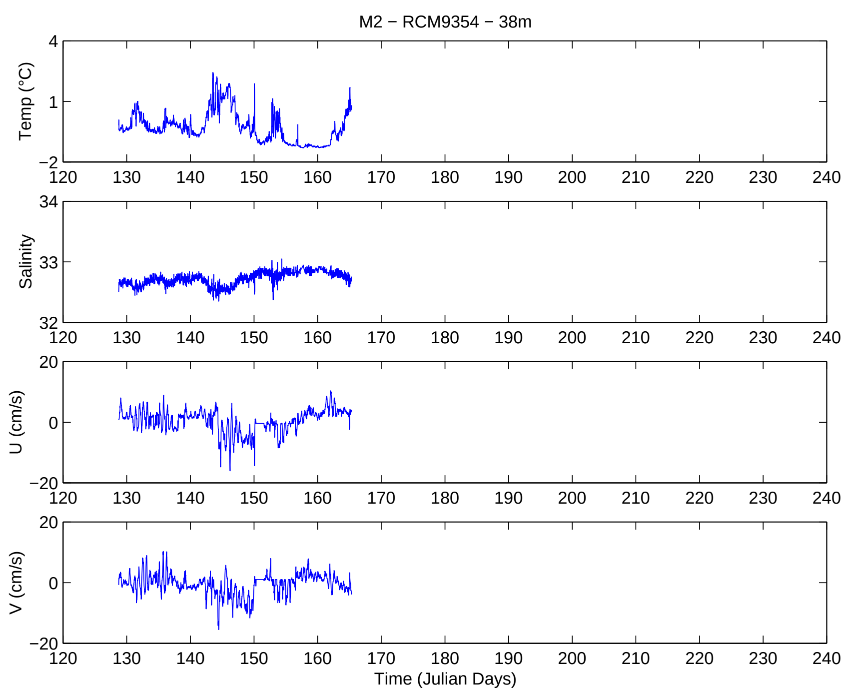

Figure 5: The temperature, salinity, and component velocities at a depth of 38 metres, mooring M2.

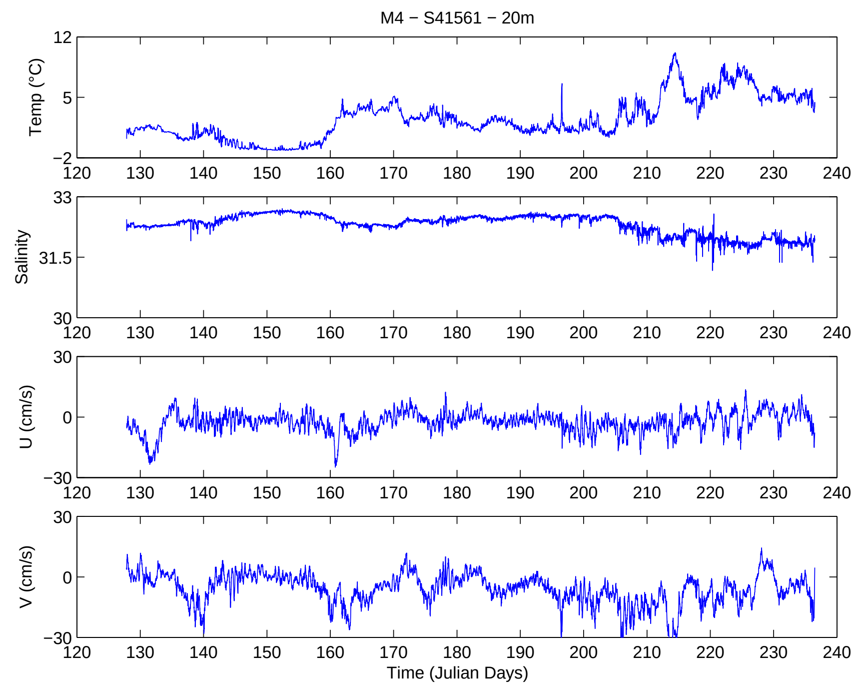

Figure 6: The temperature, salinity and component velocities at a depth of 20 metres, mooring M4.

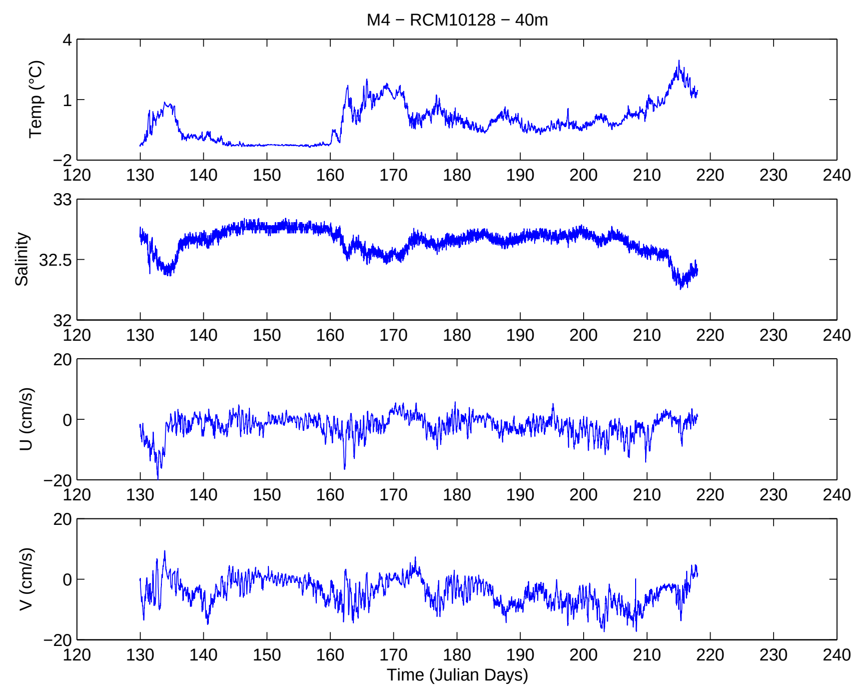

Figure 7: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M4.

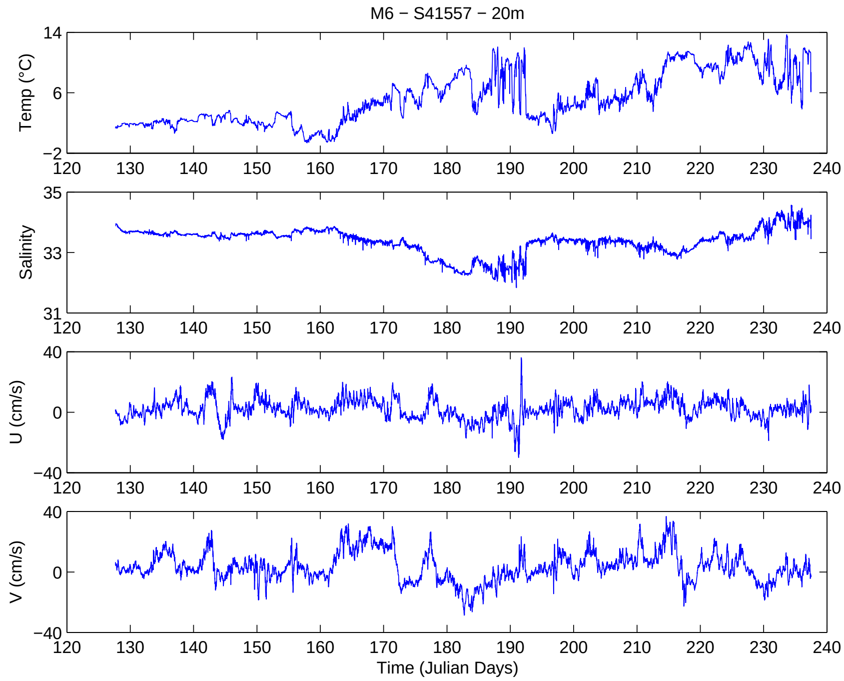

Figure 8: The temperature, salinity, and component velocities at a depth of 20 metres, mooring M6

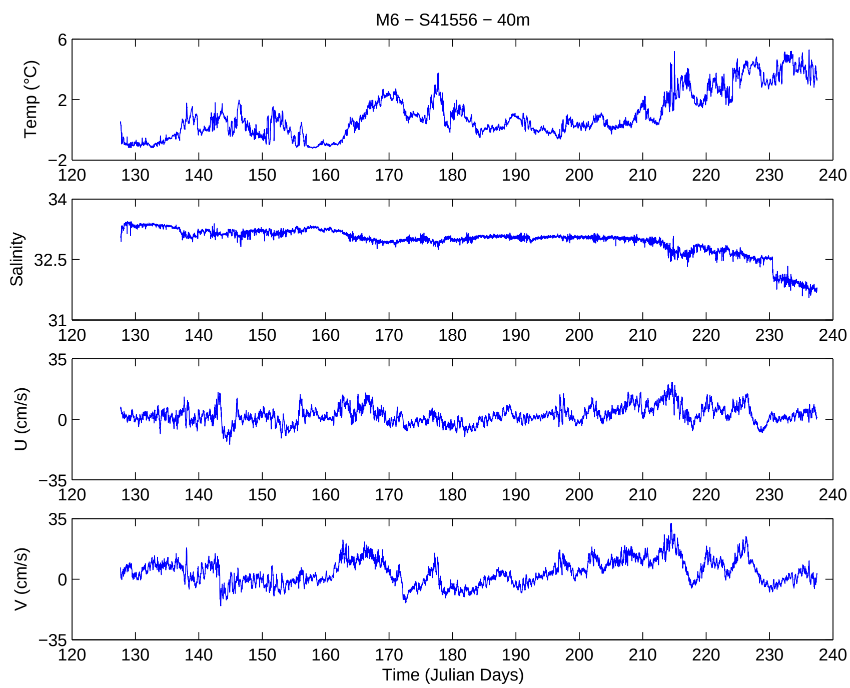

Figure 9: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M6.

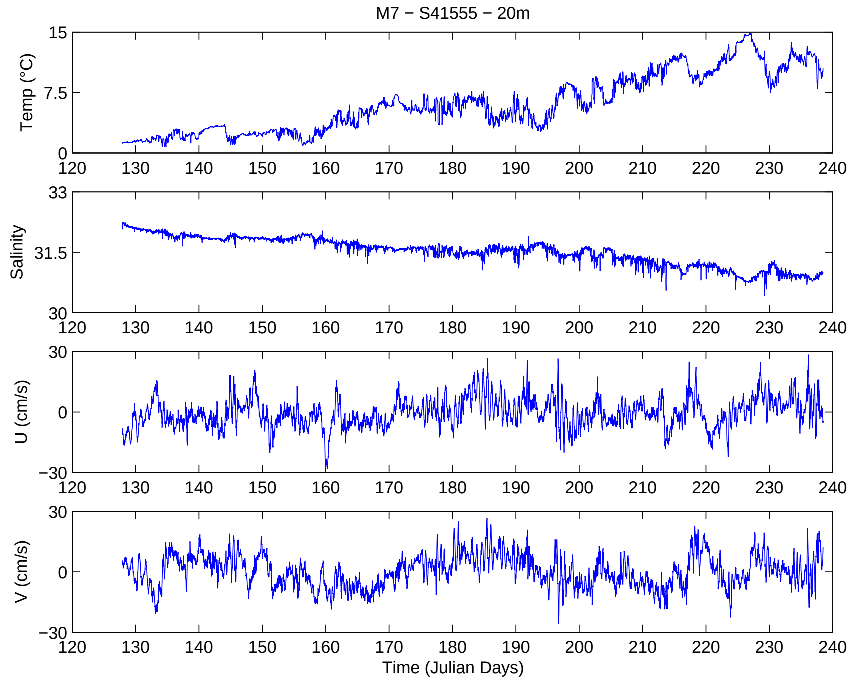

Figure 10: The temperature, salinity, and component velocities at a depth of 20 metres, mooring M7.

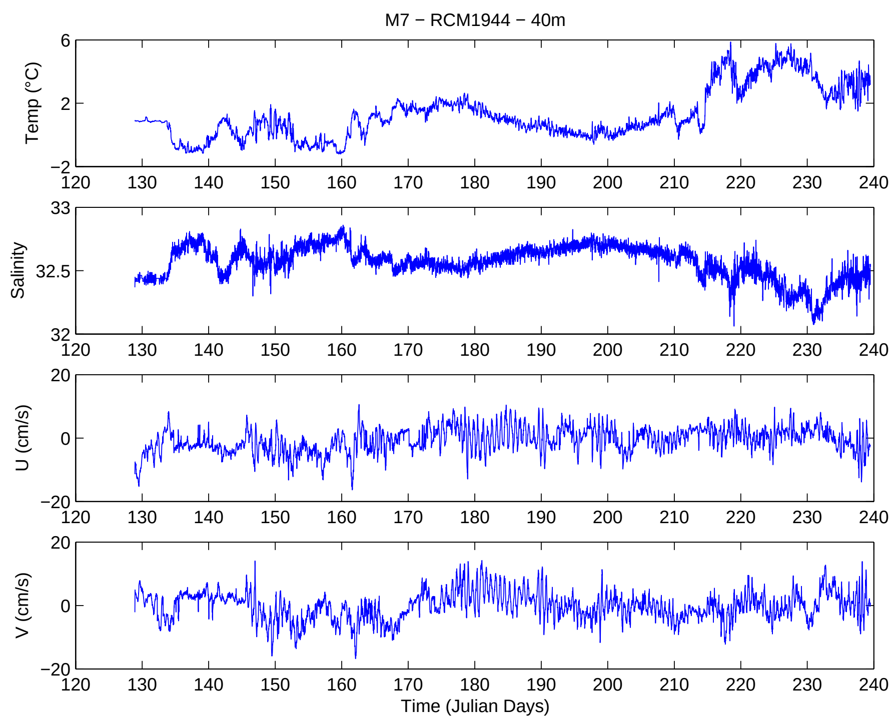

Figure 11: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M7.

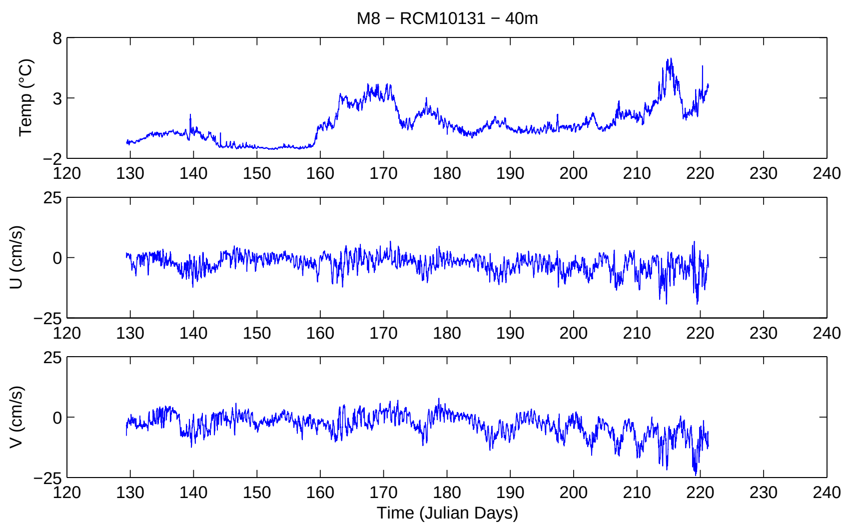

Figure 12: The temperature and component velocities at a depth of 40 metres, mooring M8.

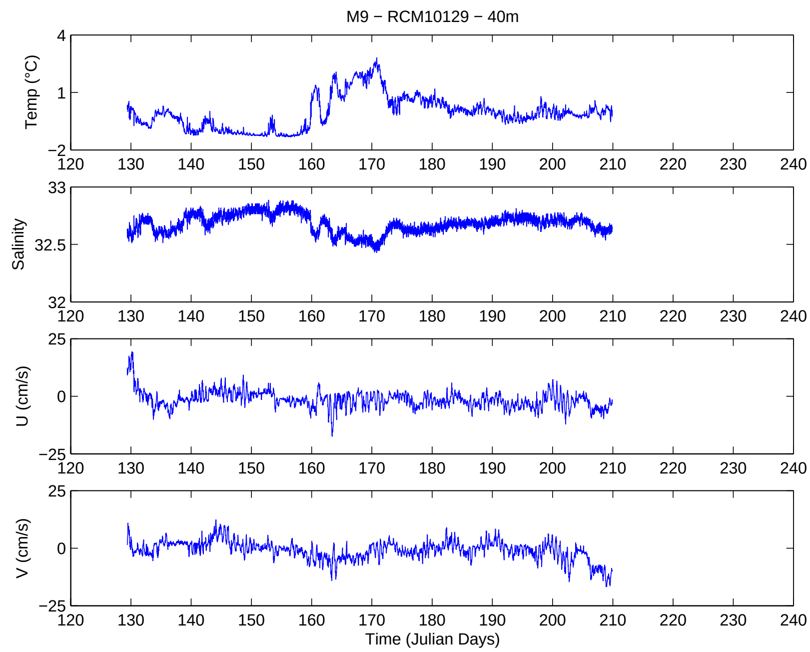

Figure 13: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M9.

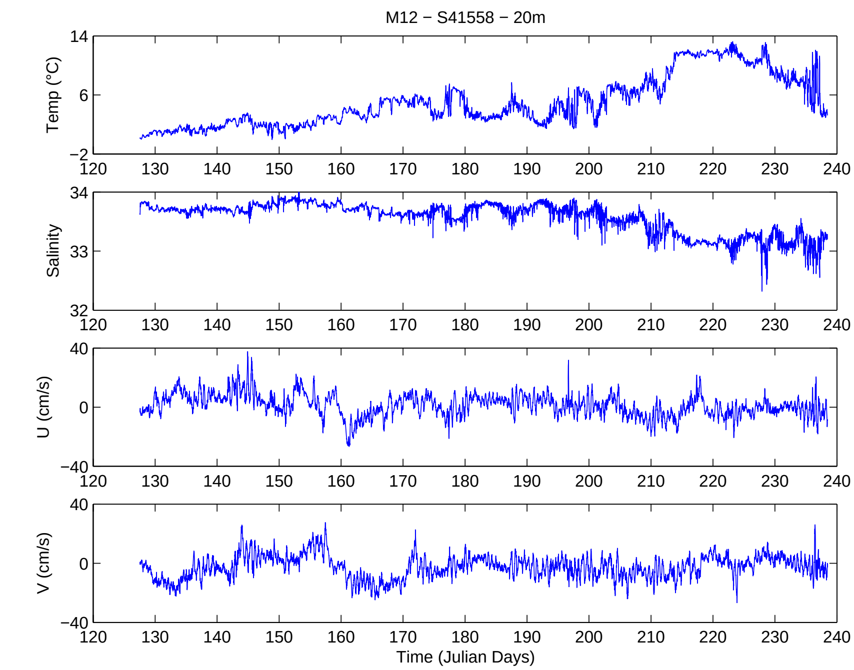

Figure 14: The temperature, salinity, and component velocities at a depth of 20 metres, mooring M12.

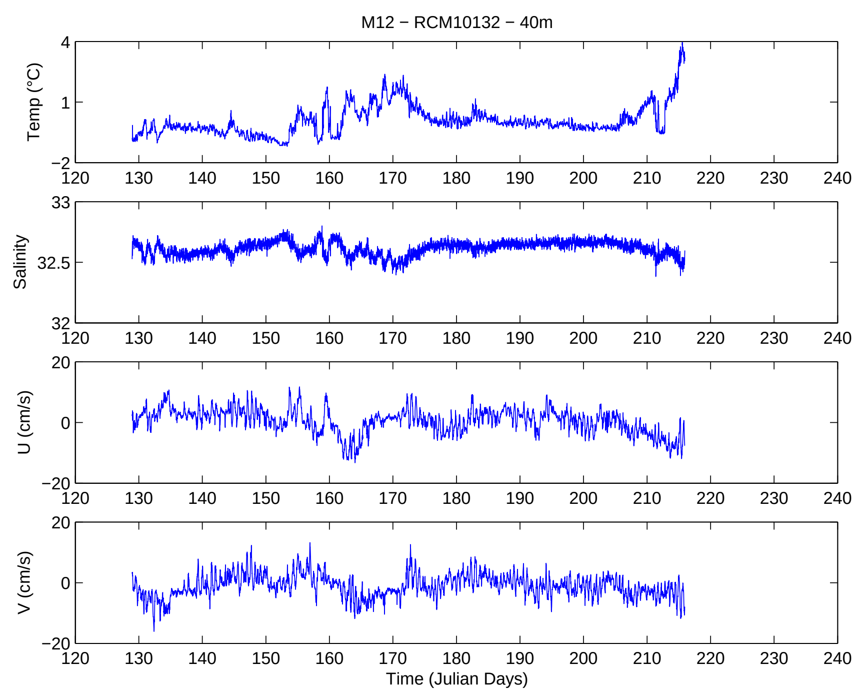

Figure 15: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M12.

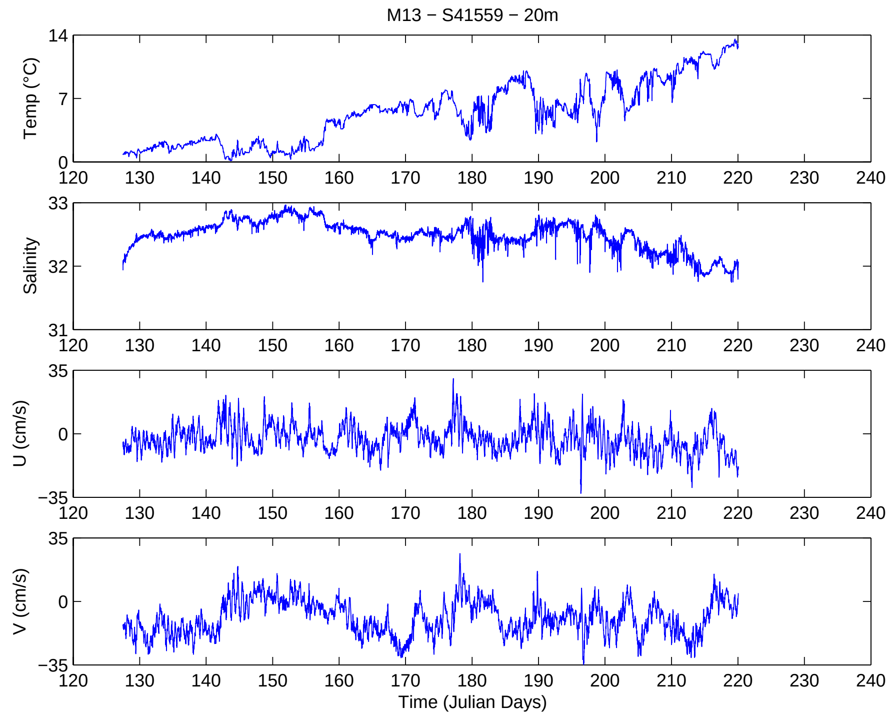

Figure 16: The temperature, salinity and component velocities at a depth of 20 metres, mooring M13.

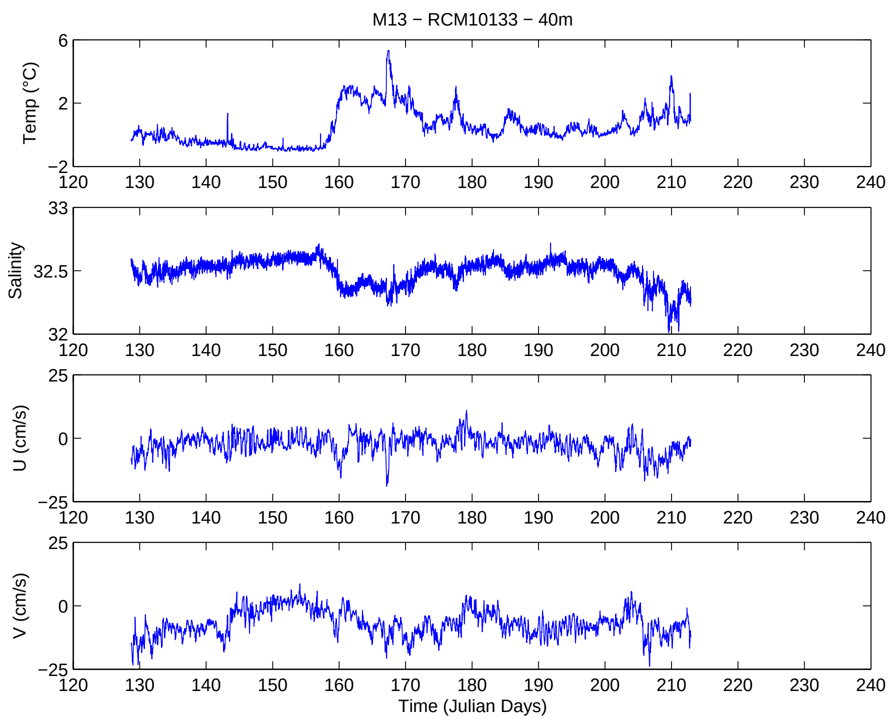

Figure 17: The temperature, salinity, and component velocities at a depth of 40 metres, mooring M13.

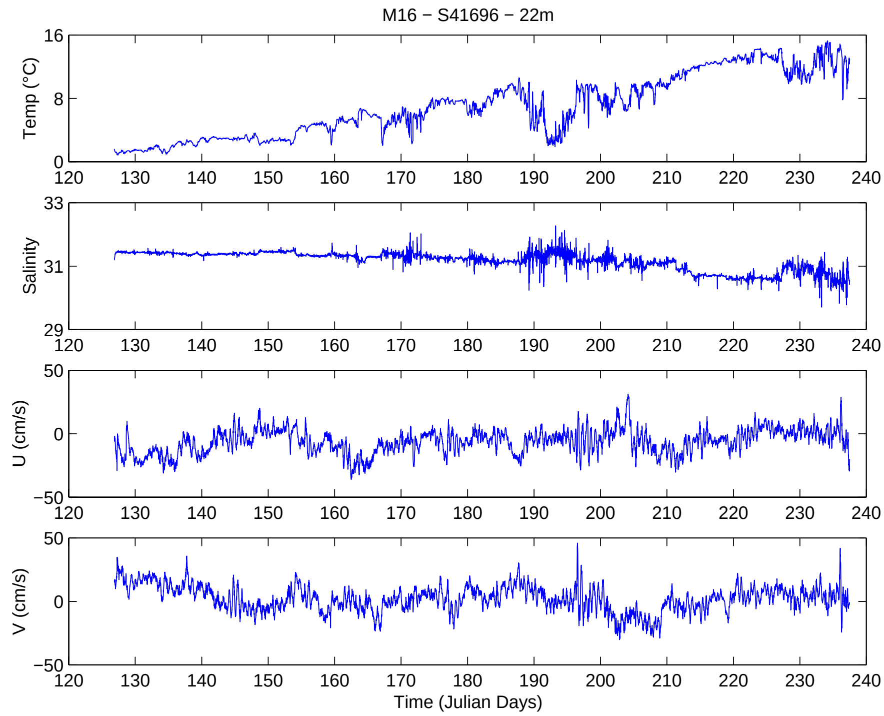

Figure 18: Temperature, salinity, and component velocities at a depth of 22 metres, mooring M16.

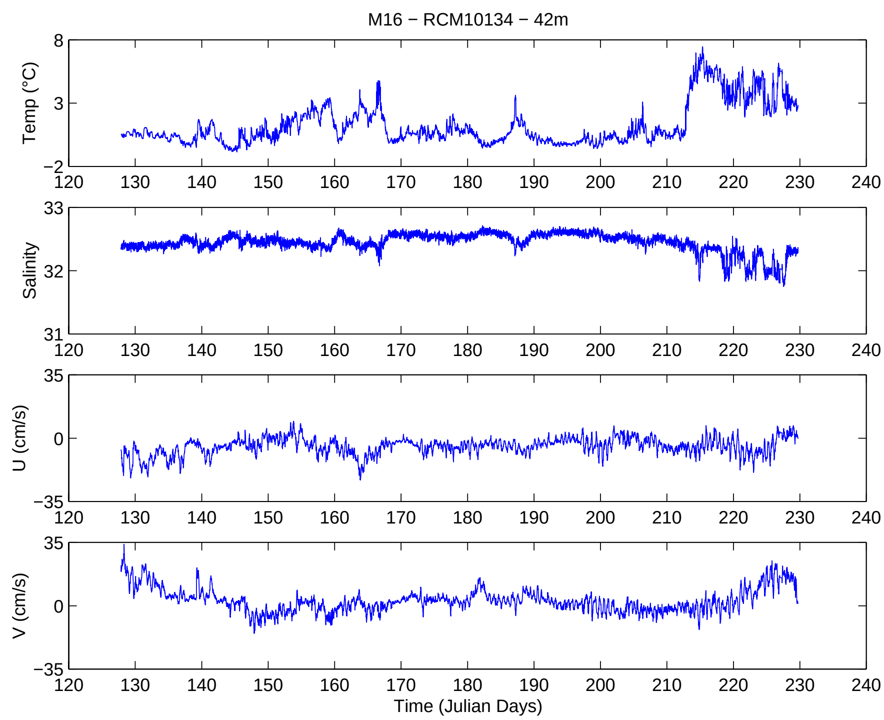

Figure 19: Temperature, salinity, and component velocities at a depth of 42 metres, mooring M16.

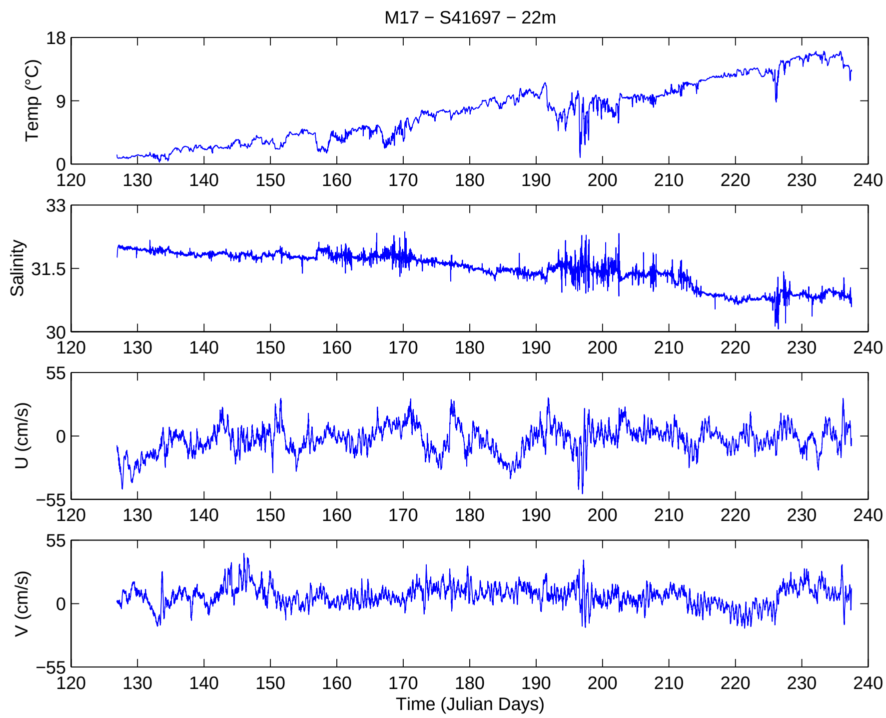

Figure 20: Temperature, salinity and component velocities at a depth of 22 metres, mooring M17.

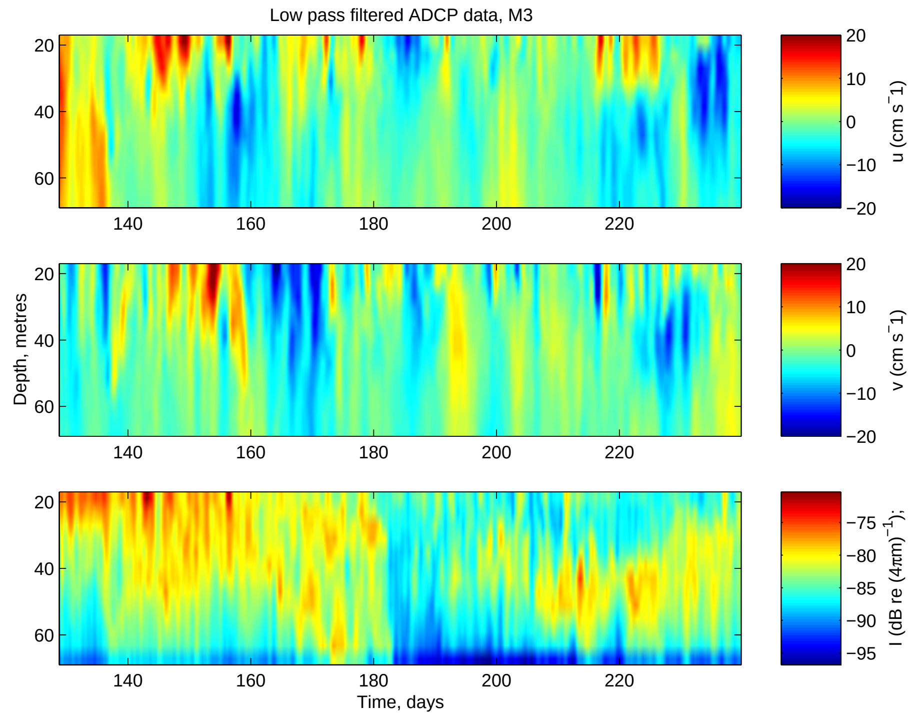

Figure 21: Low pass filtered ADCP data from mooring M3. Cutoff is 30 hours. Top: *u* speed (cm/s). Middle: *v* speed (cm/s). Bottom: backscatter intensity.

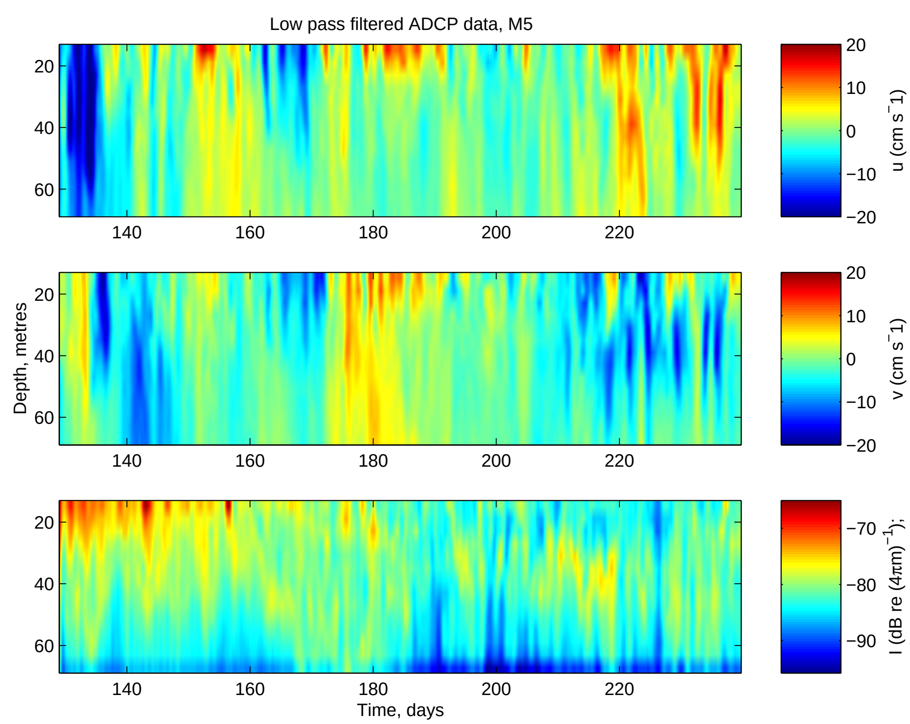

Figure 22: Low pass filtered ADCP data from mooring M5. Cutoff is 30 hours. Top: *u* speed (cm/s). Middle: *v* speed (cm/s). Bottom: backscatter intensity.

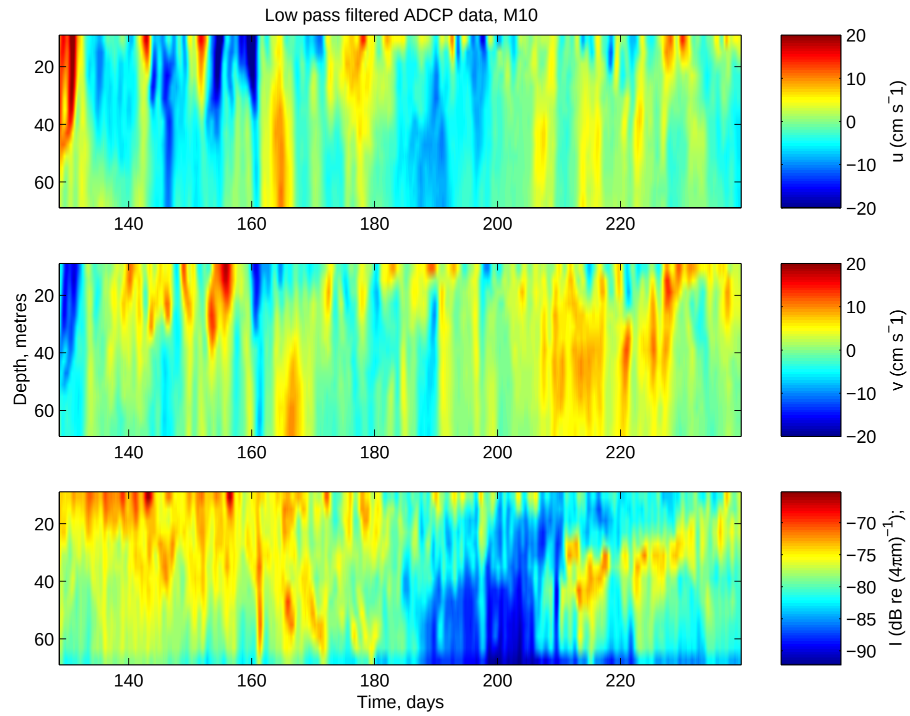

Figure 23: Low pass filtered ADCP data from mooring M10. Cutoff is 30 hours. Top: *u* speed (cm/s). Middle: *v* speed (cm/s). Bottom: backscatter intensity.

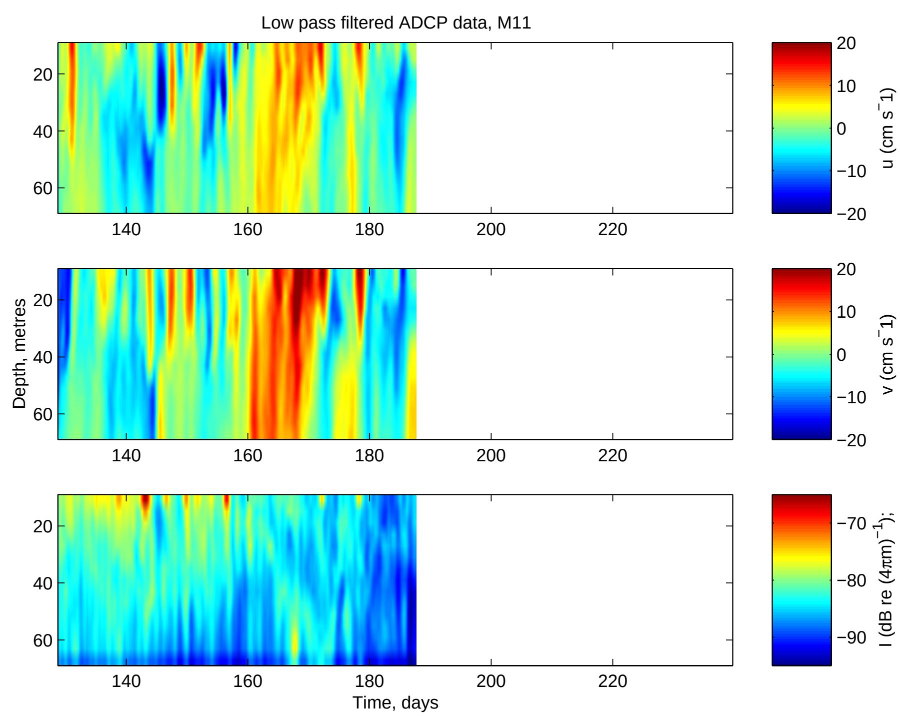

Figure 24: Low pass filtered ADCP data from mooring M11. Cutoff is 30 hours. Top: *u* speed (cm/s). Middle: *v* speed (cm/s). Bottom: backscatter intensity.

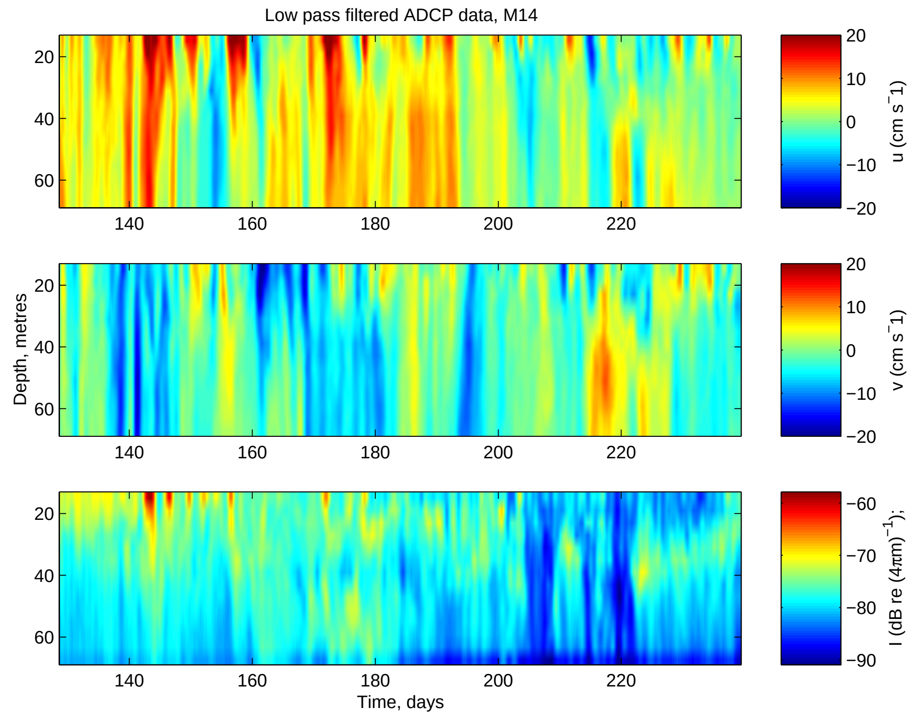

Figure 25: Low pass filtered ADCP data from mooring M14. Cutoff is 30 hours. Top: *u* speed (cm/s). Middle: *v* speed (cm/s). Bottom: backscatter intensity.

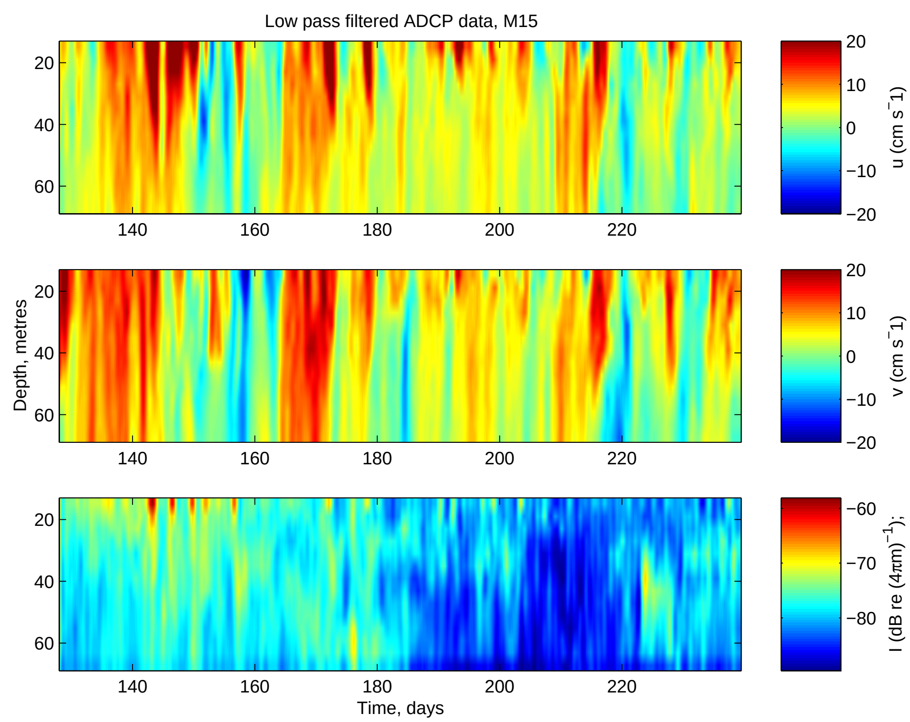

Figure 26: Low pass filtered ADCP data from mooring M15. Cutoff is 30 hours. Top: *u* speed (cm/s). Middle: *v* speed (cm/s). Bottom: backscatter intensity.

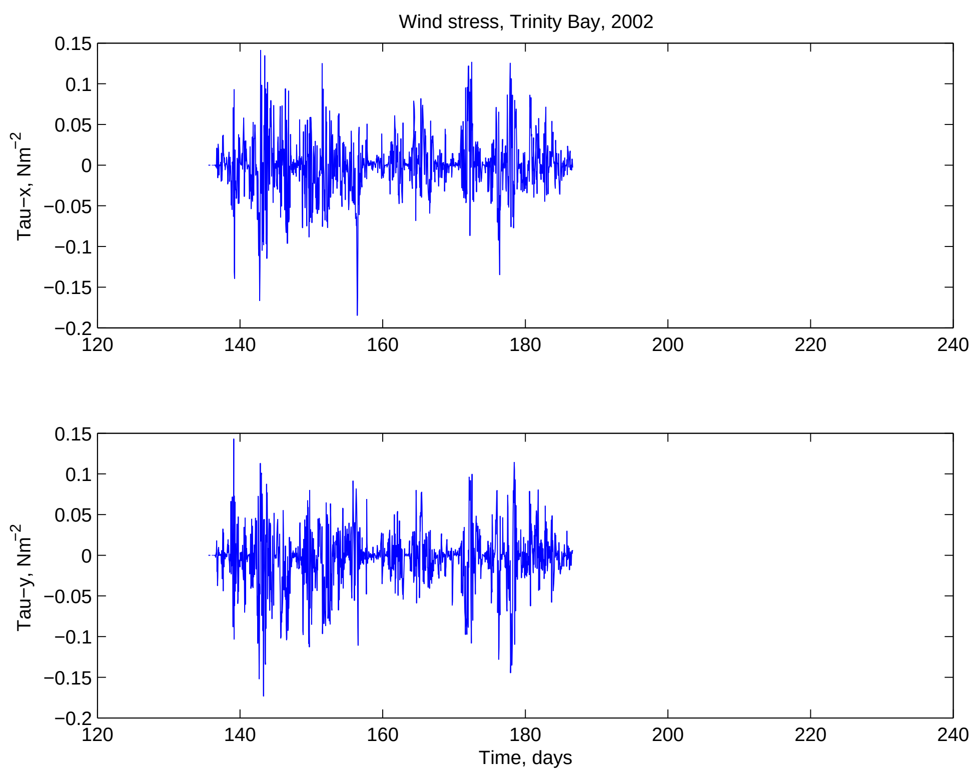

Figure 27: Wind stress, 2002, Trinity Bay, from an anenometer moored at 47° 57.53' N, 53° 36.49' W.

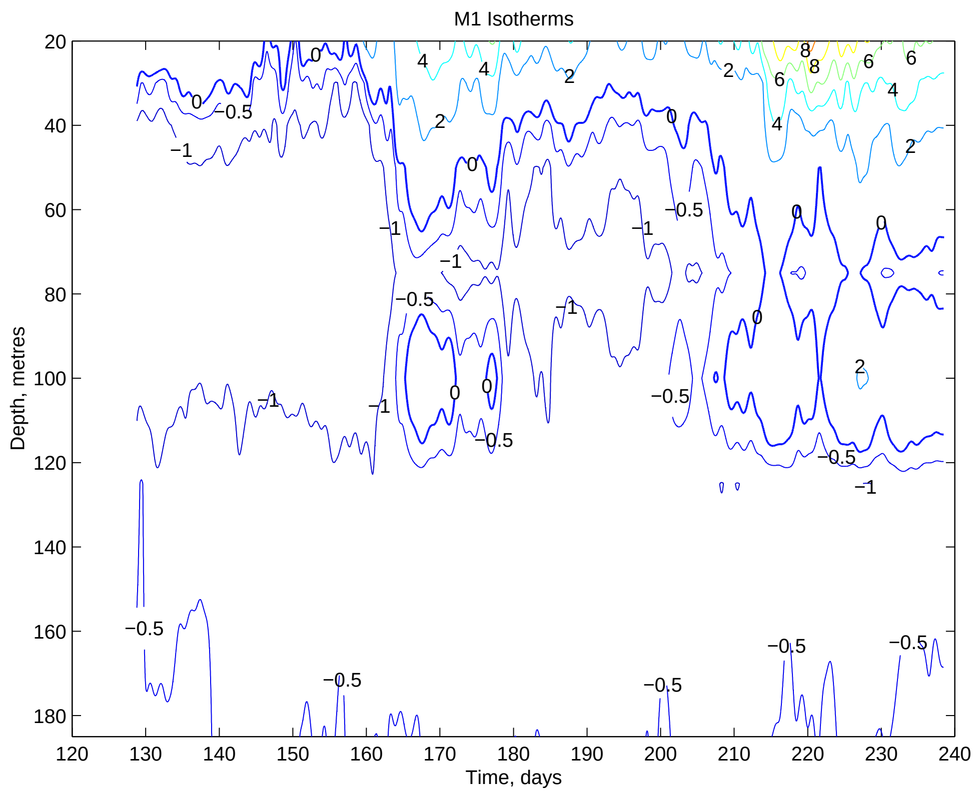

Figure 28: Isotherms at M1. From interpolated and filtered temperature data.

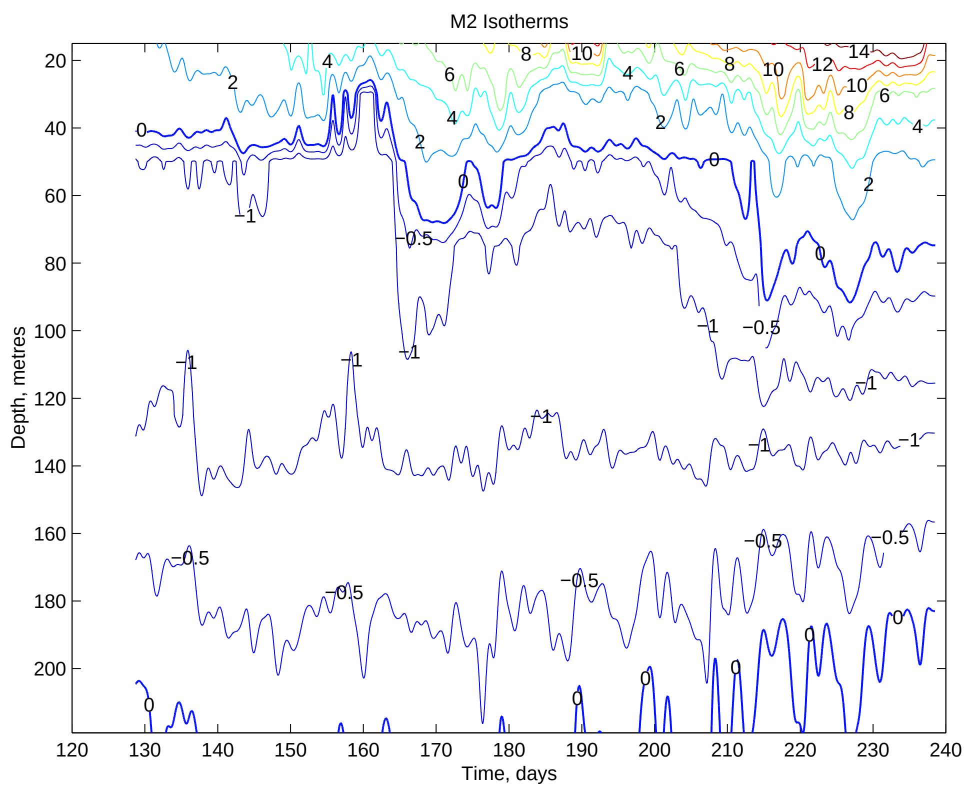

Figure 29: Isotherms at M2. From interpolated and filtered temperature data.

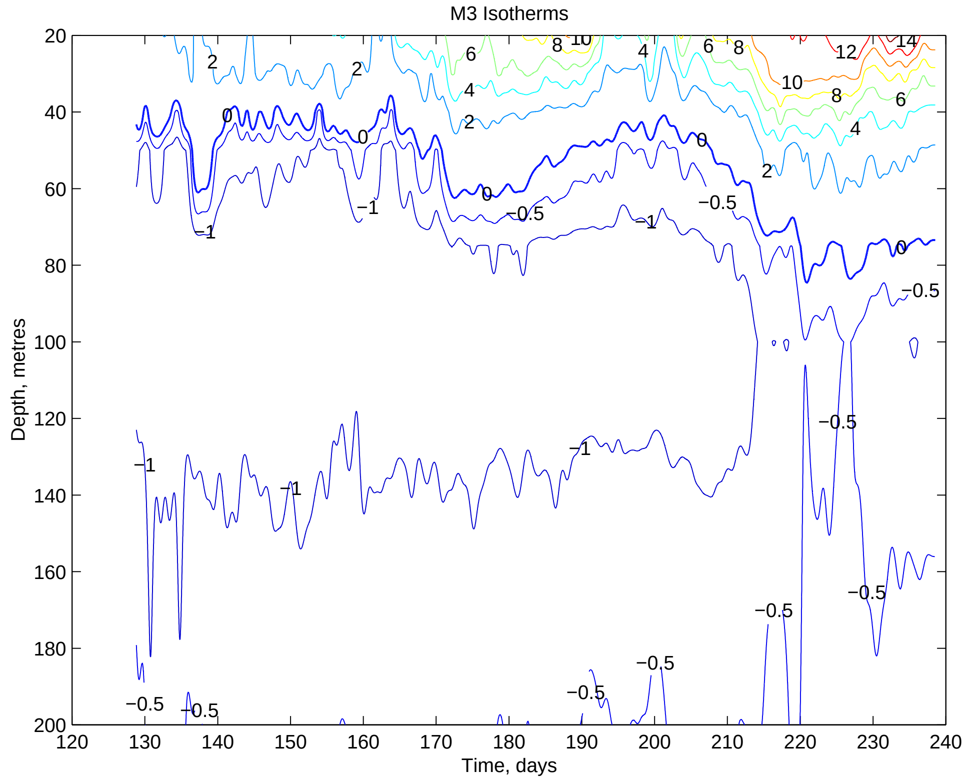

Figure 30: Isotherms at M3. From interpolated and filtered temperature data.

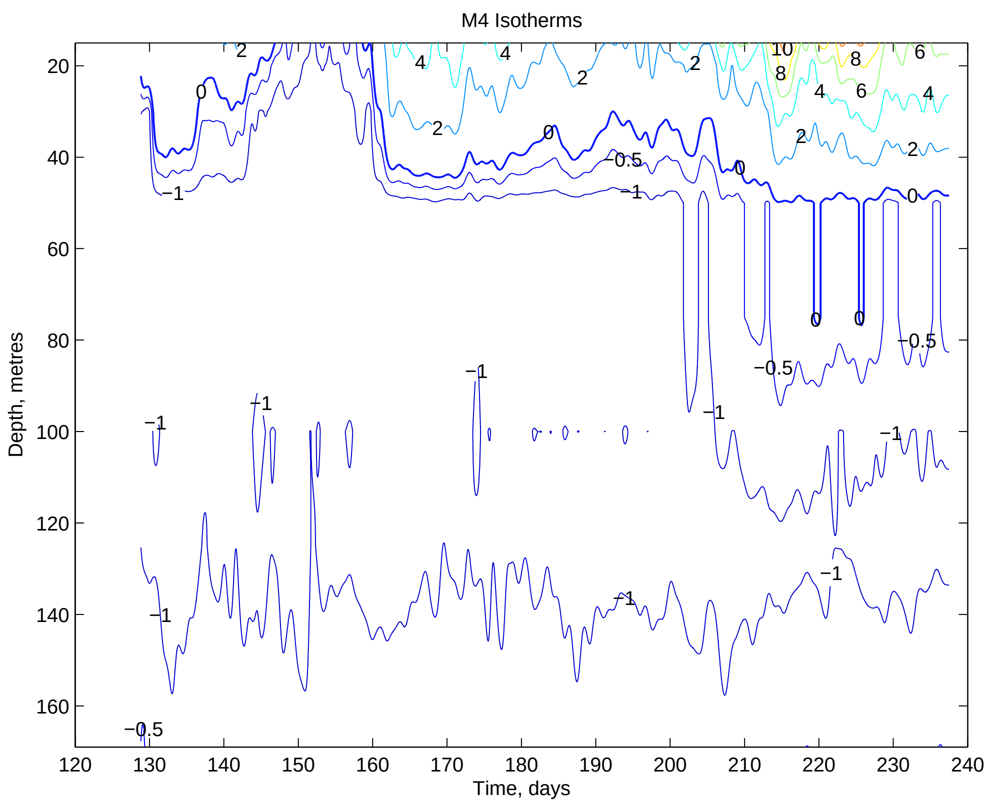

Figure 31: Isotherms at M4. From interpolated and filtered temperature data.

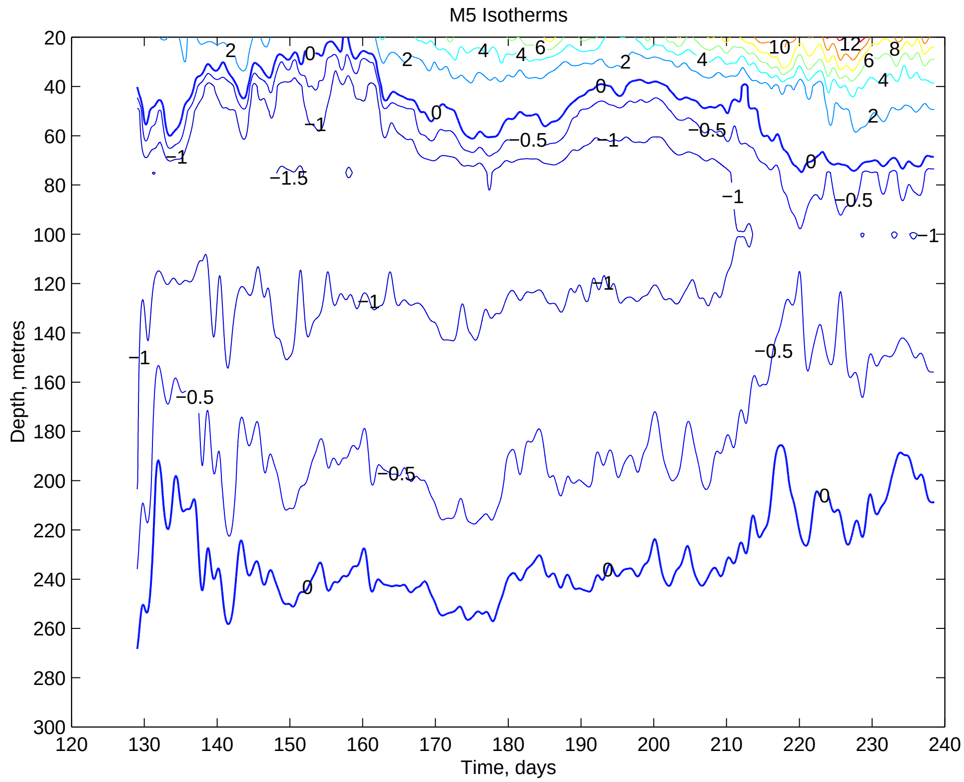

Figure 32: Isotherms at M5. From interpolated and filtered temperature data.

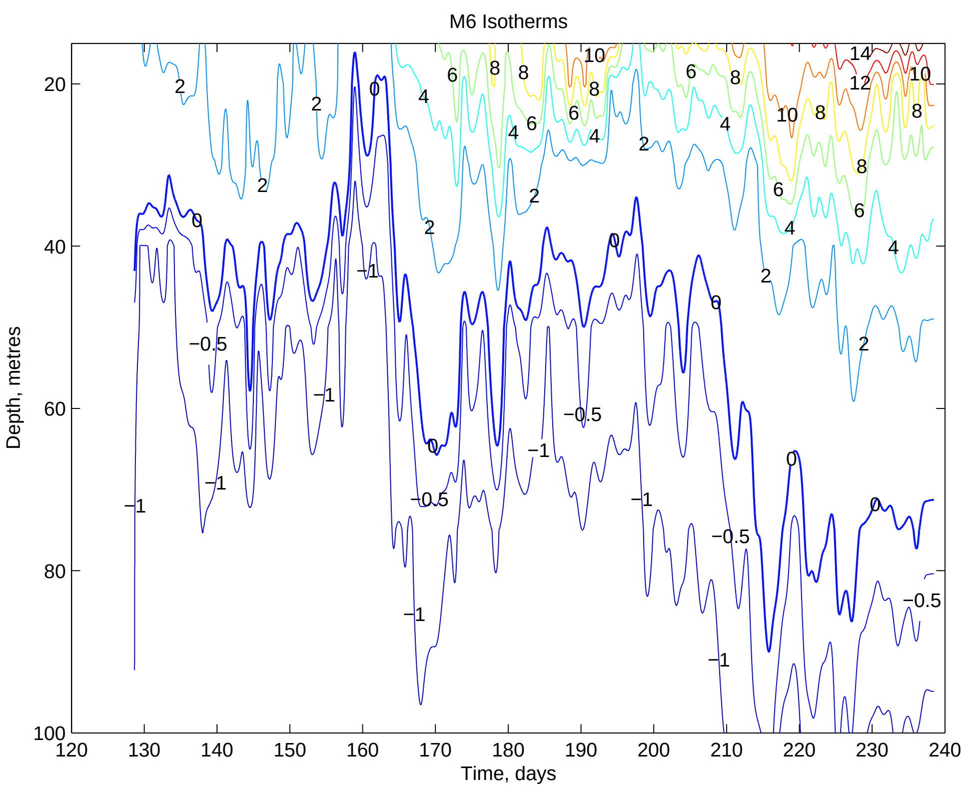

Figure 33: Isotherms at M6. From interpolated and filtered temperature data.

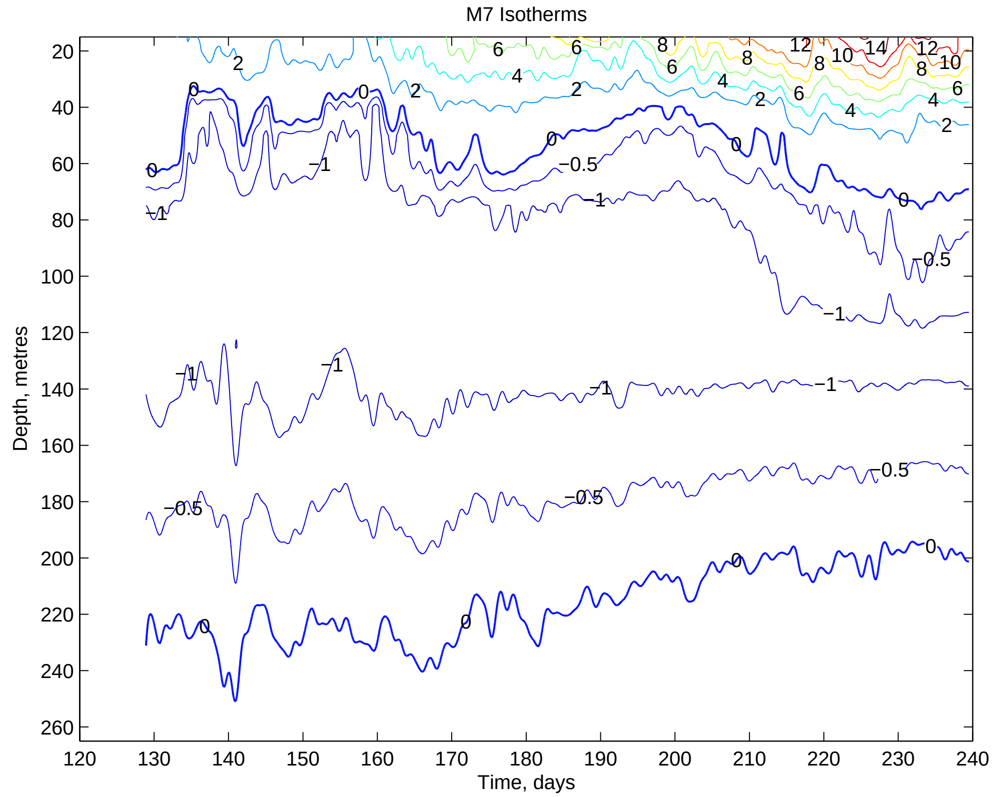

Figure 34: Isotherms at M7. From interpolated and filtered temperature data.

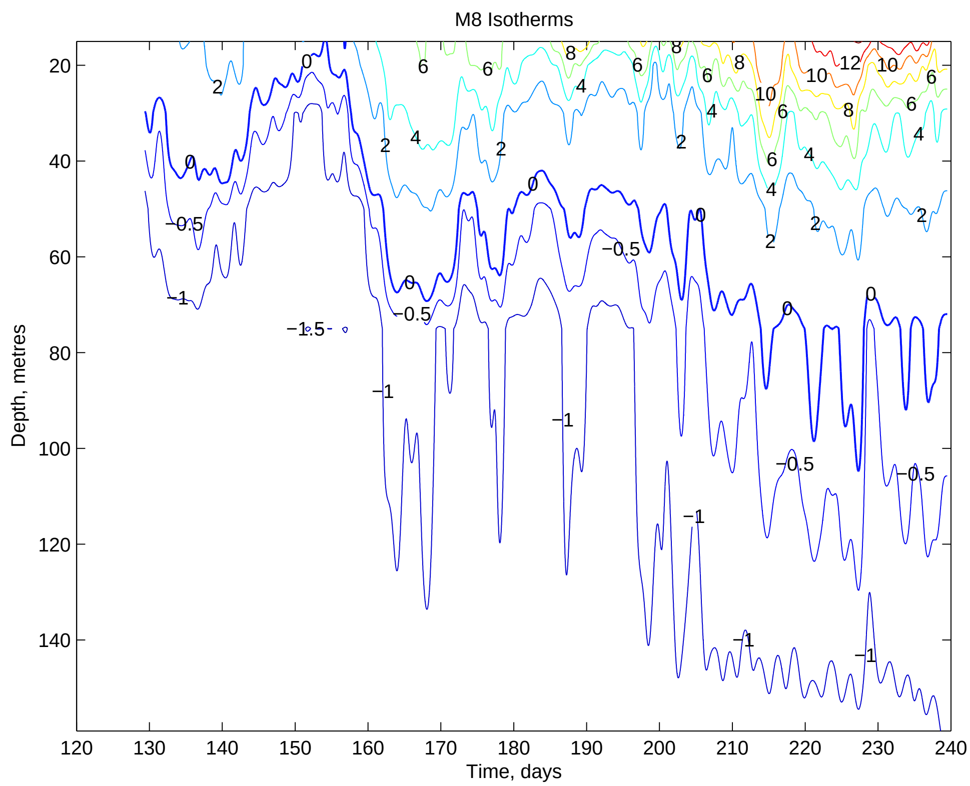

Figure 35: Isotherms at M8. From interpolated and filtered temperature data.

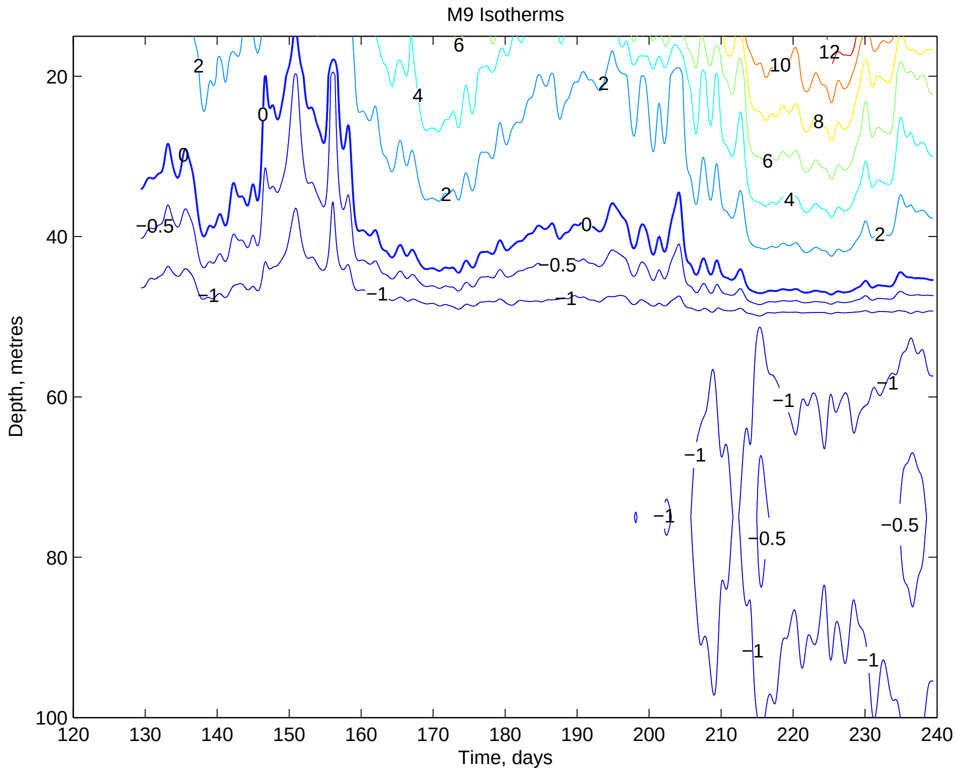

Figure 36: Isotherms at M9. From interpolated and filtered temperature data.

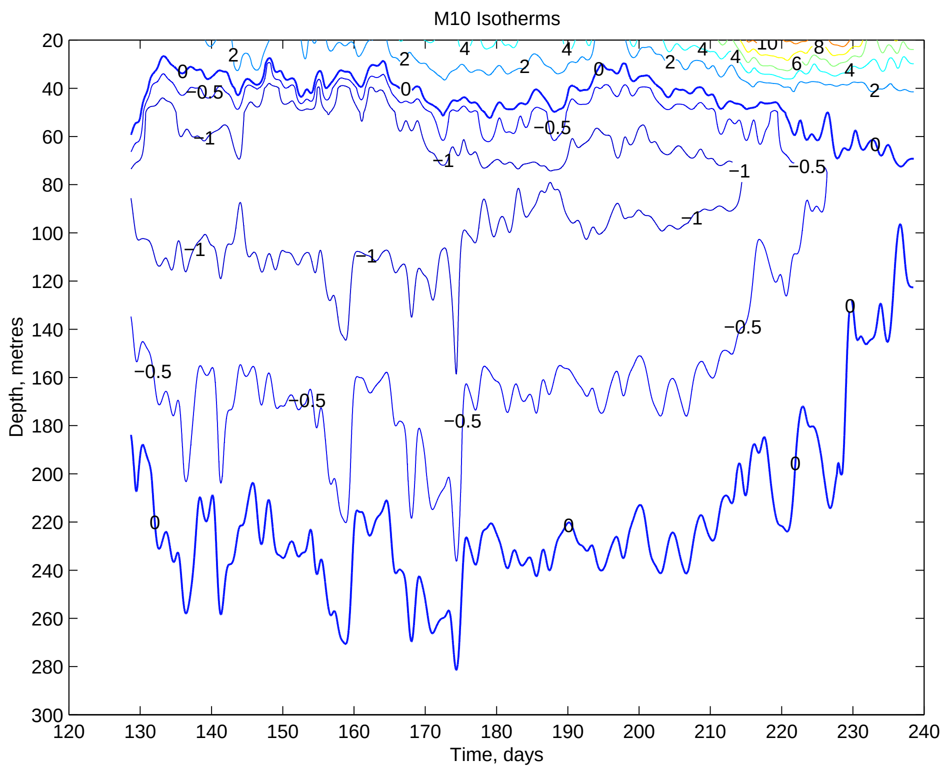

Figure 37: Isotherms at M10. From interpolated and filtered temperature data.

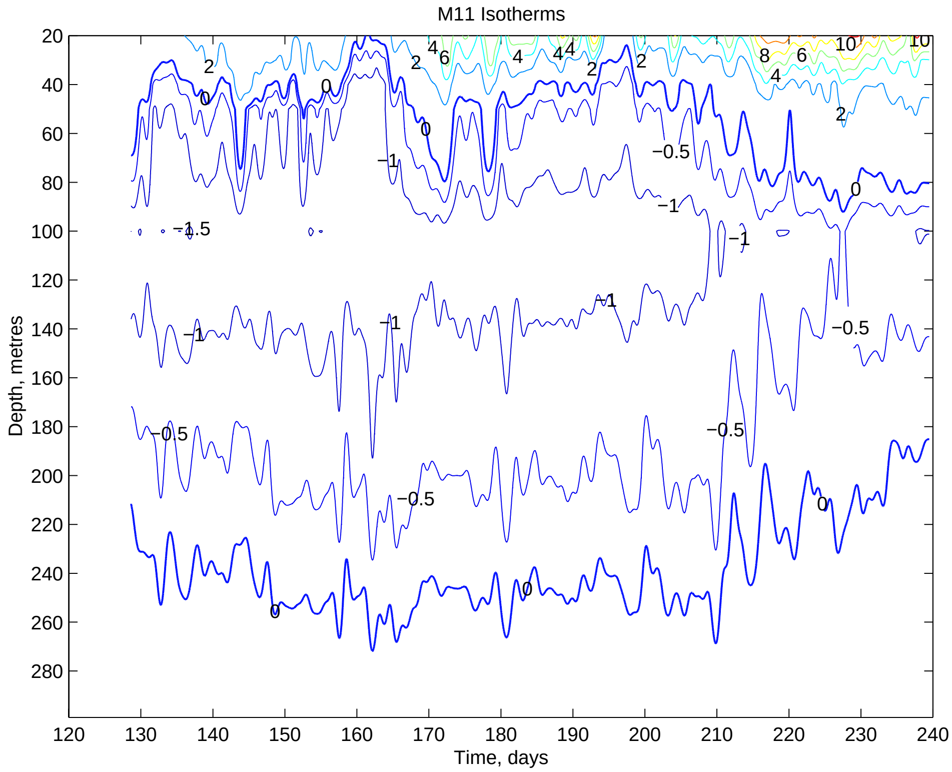

Figure 38: Isotherms at M11. From interpolated and filtered temperature data.

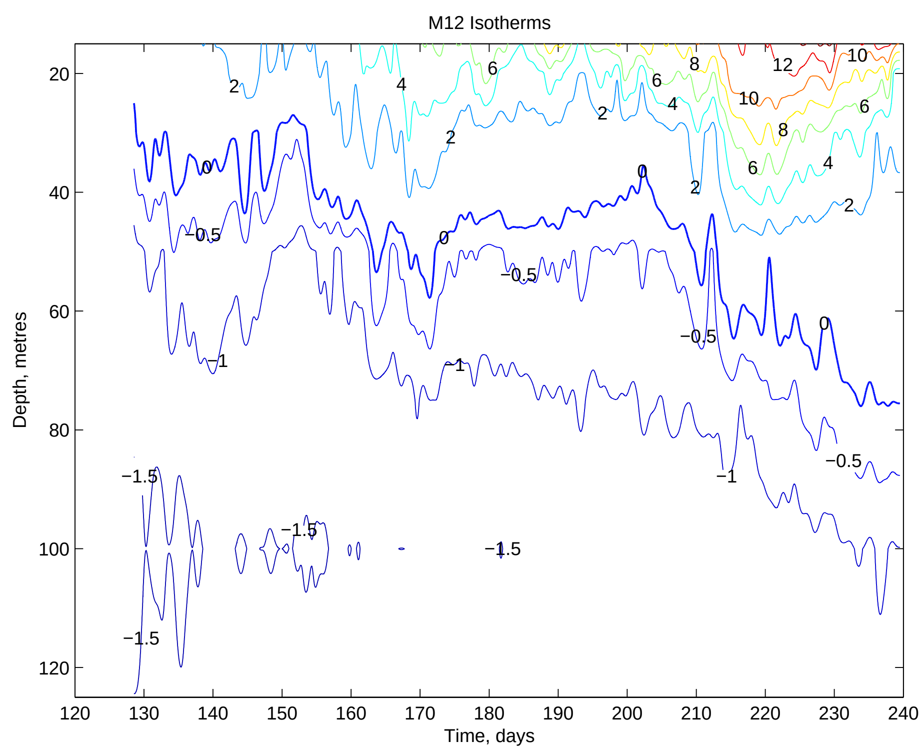

Figure 39: Isotherms at M12. From interpolated and filtered temperature data.

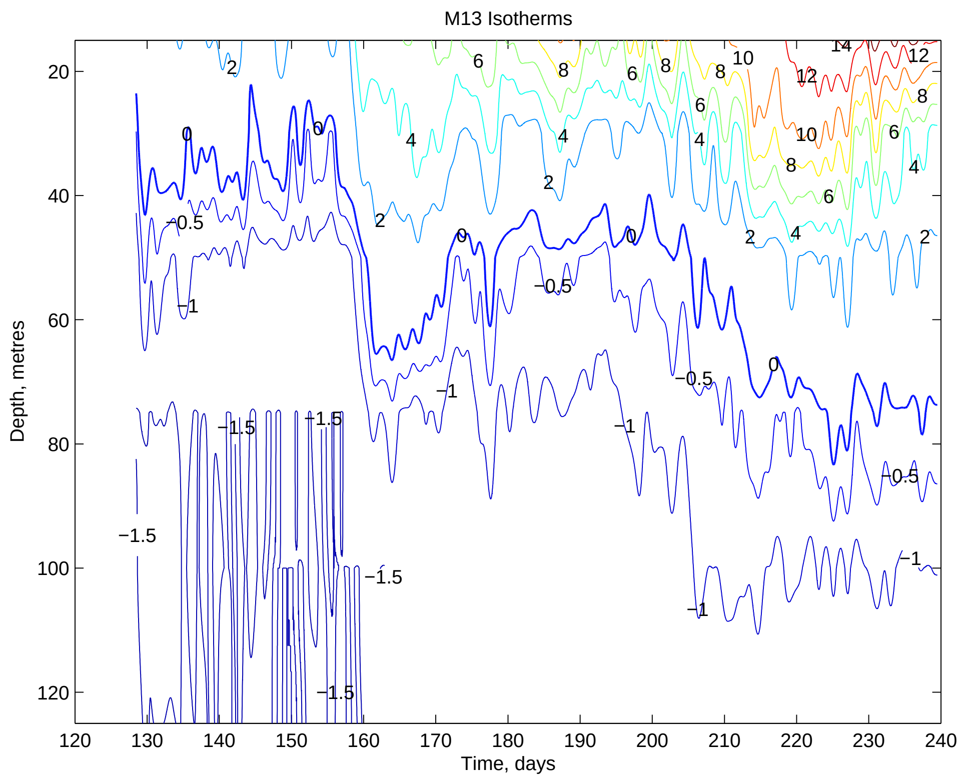

Figure 40: Isotherms at M13. From interpolated and filtered temperature data.

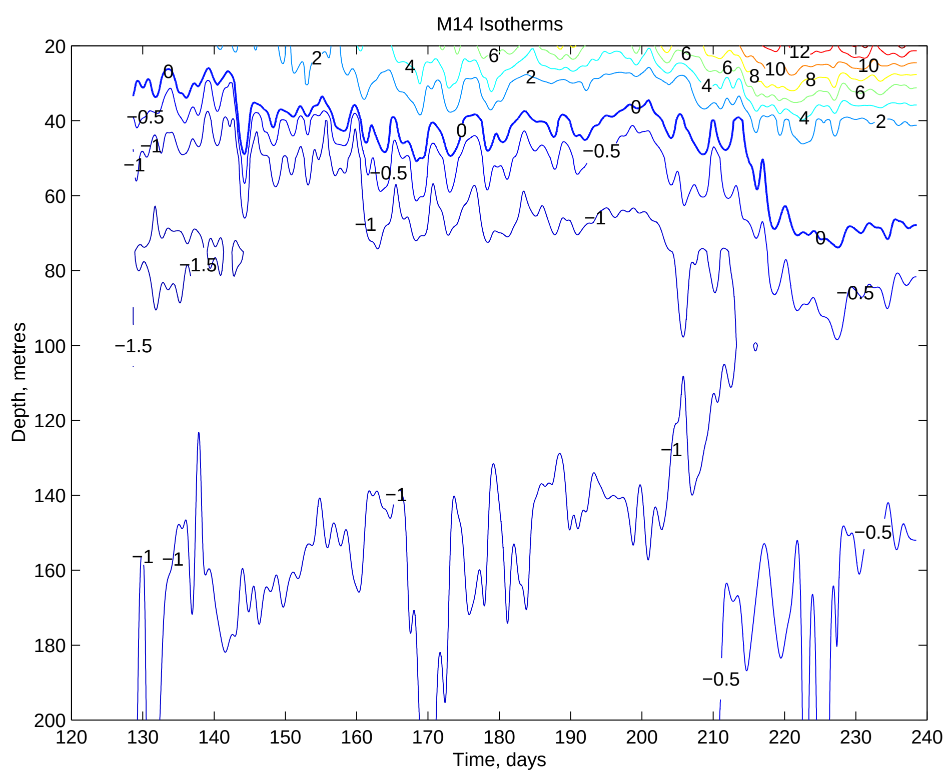

Figure 41: Isotherms at M14. From interpolated and filtered temperature data.

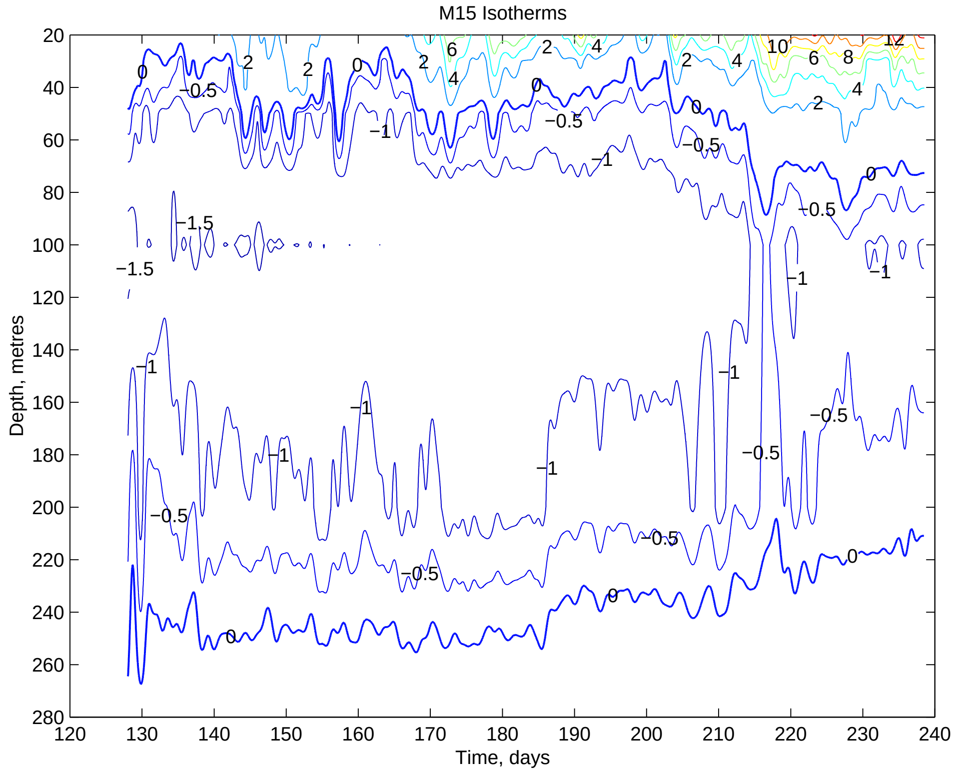

Figure 42: Isotherms at M15. From interpolated and filtered temperature data.

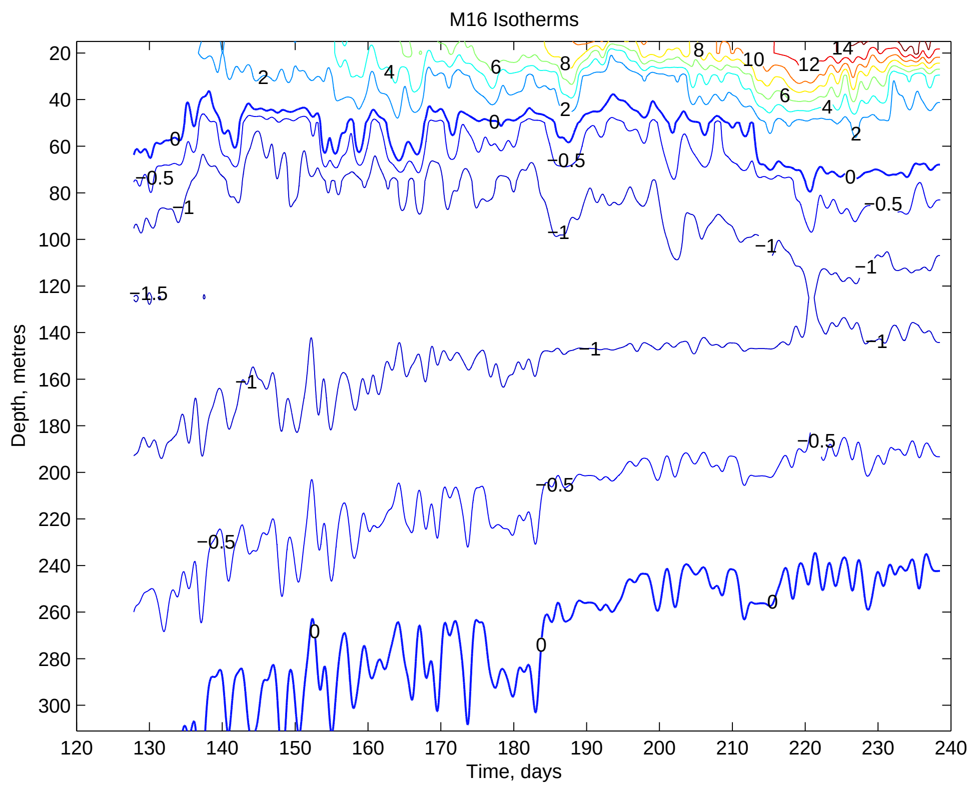

Figure 43: Isotherms at M16. From interpolated and filtered temperature data.

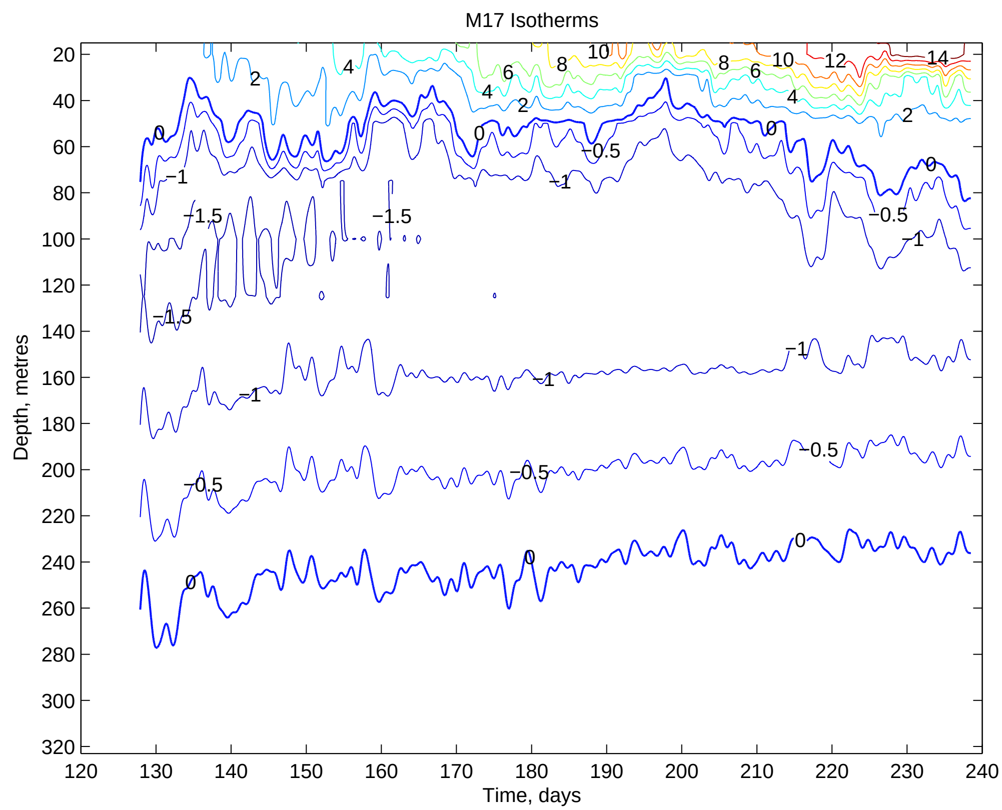

Figure 44: Isotherms at M17. From interpolated and filtered temperature data.

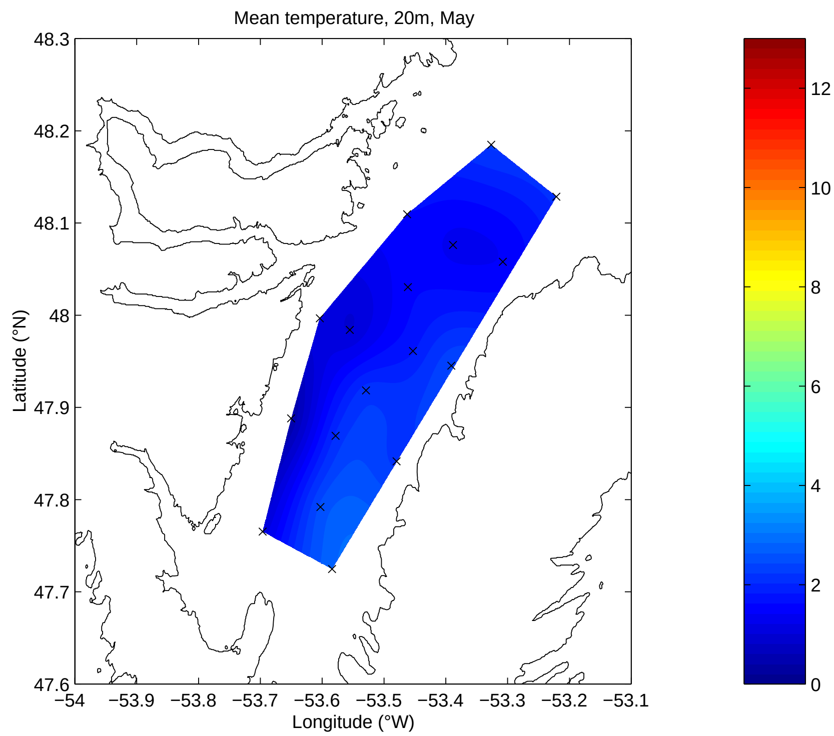

Figure 45: Mean temperature at 20m, May (data starts on May 9th).

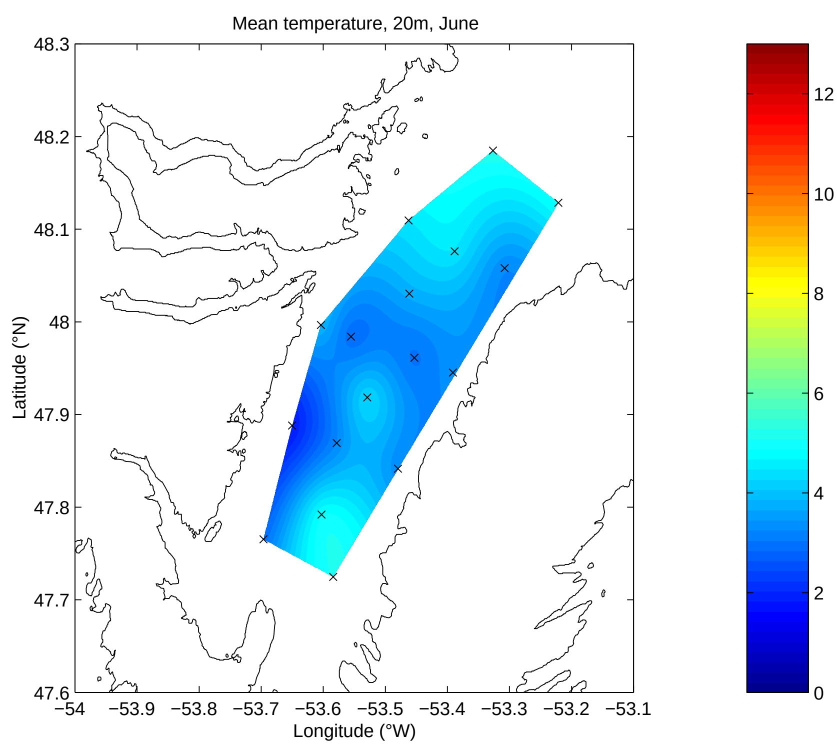

Figure 46: Mean temperature at 20m, June.

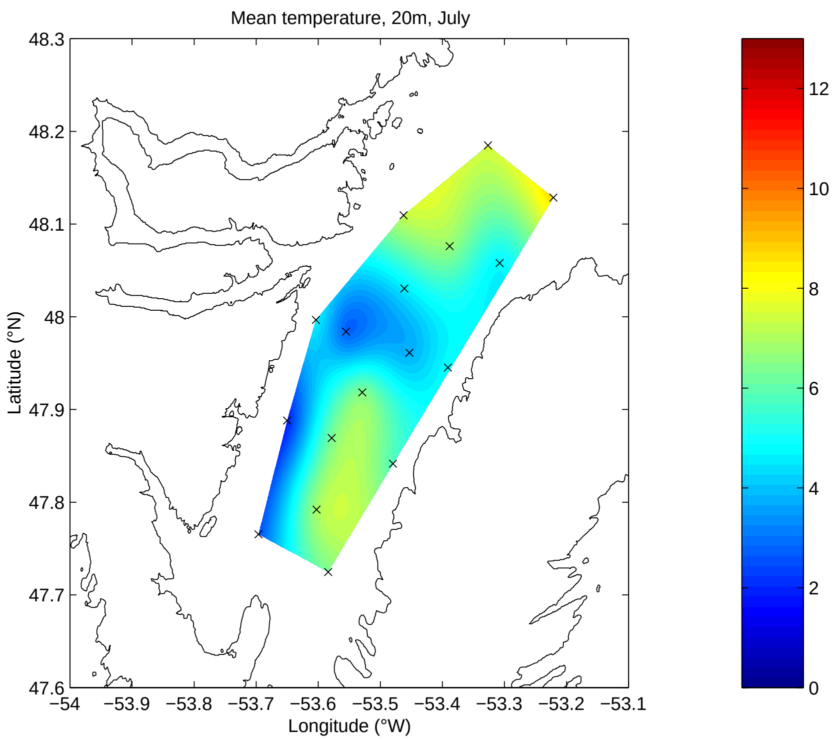

Figure 47: Mean temperature at 20m, July.

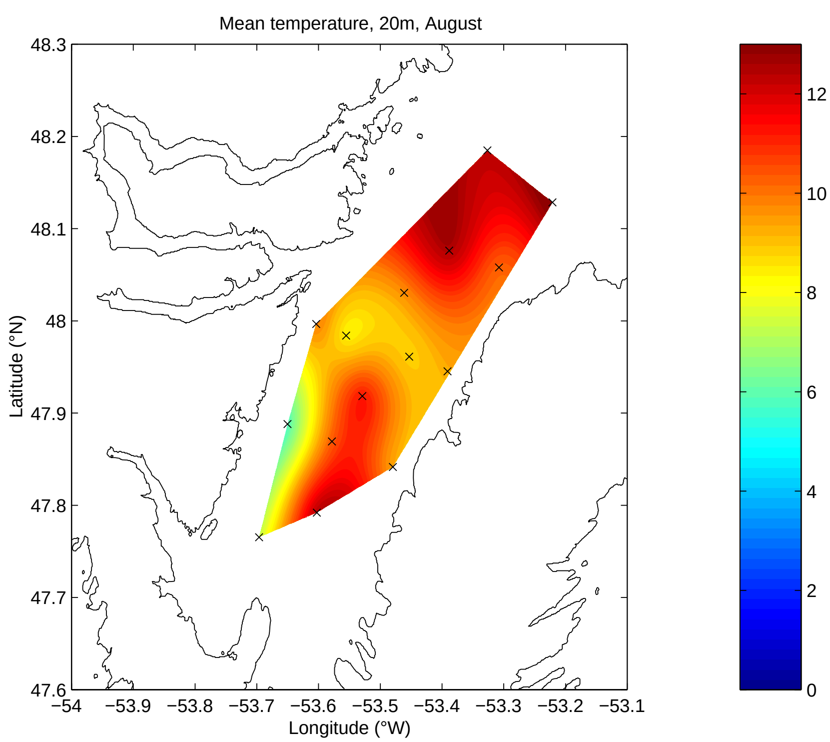

Figure 48: Mean temperature at 20m, August (data ends on August 28th).

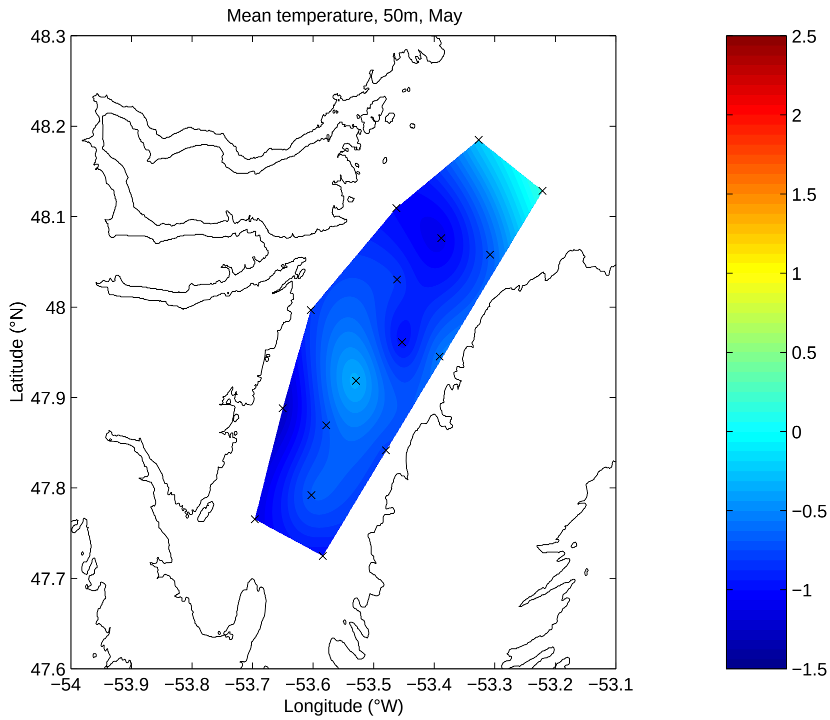

Figure 49: Mean temperature at 50m, May (data starts on May 8th).

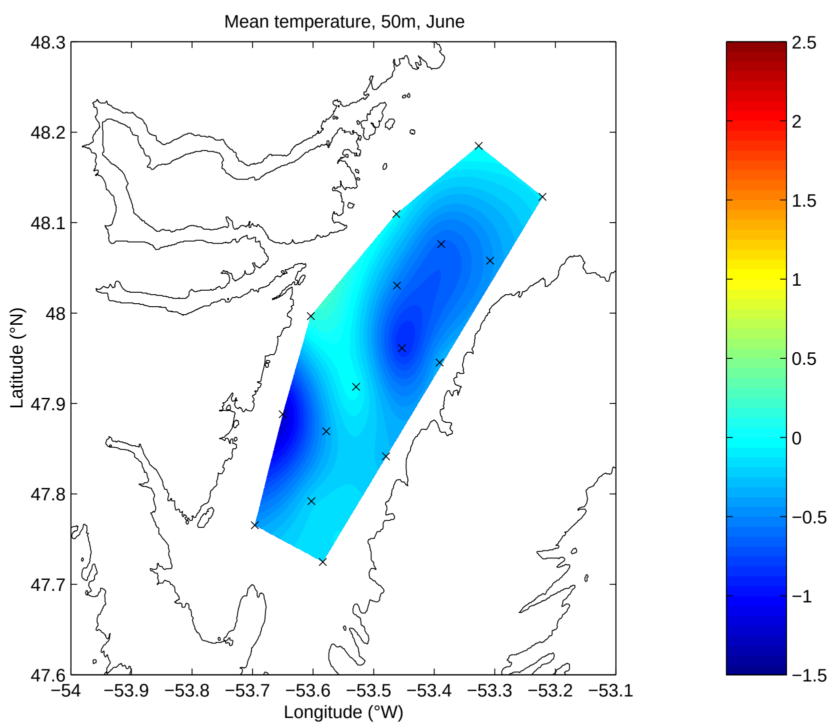

Figure 50: Mean temperature at 50m, June.

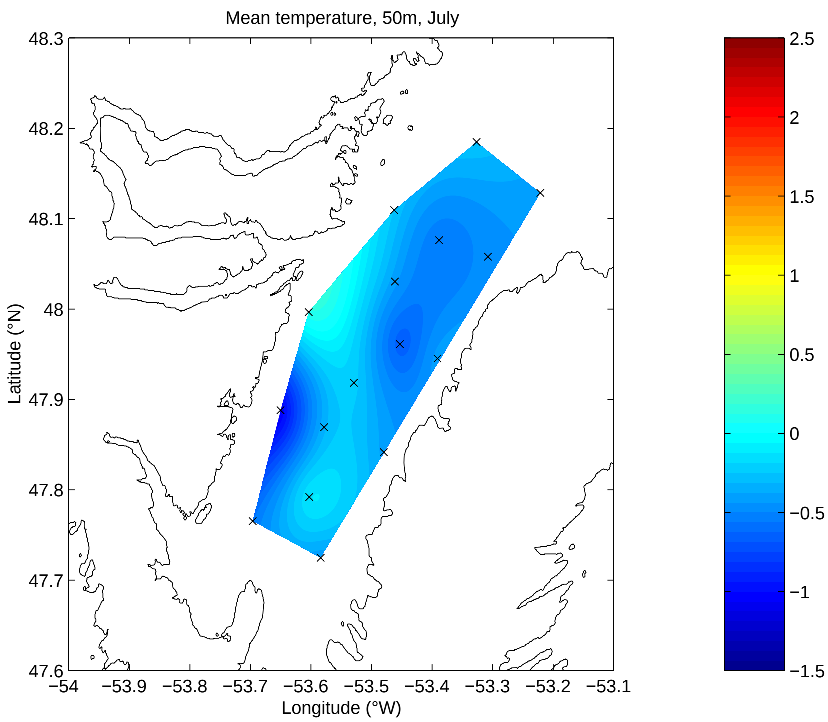

Figure 51: Mean temperature at 50m, July.

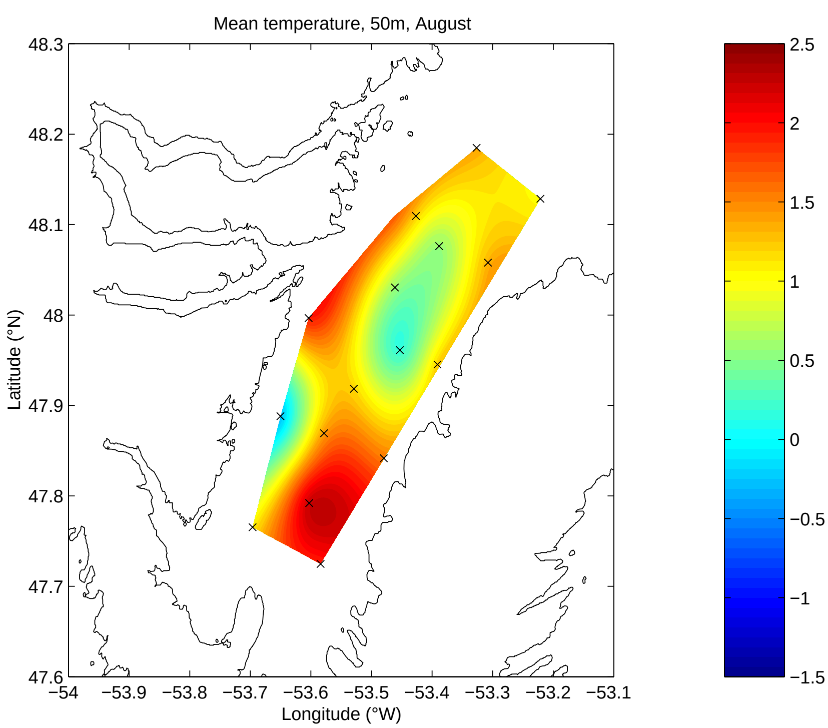

Figure 52: Mean temperature at 50m, August (data ends on August 28th).

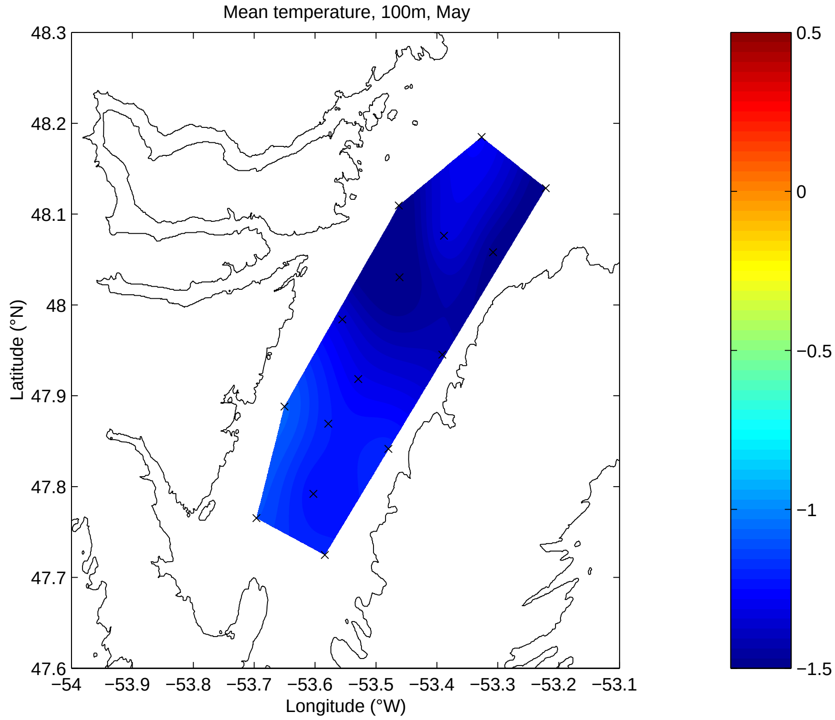

Figure 53: Mean temperature at 100m, May (data starts on May 8th).

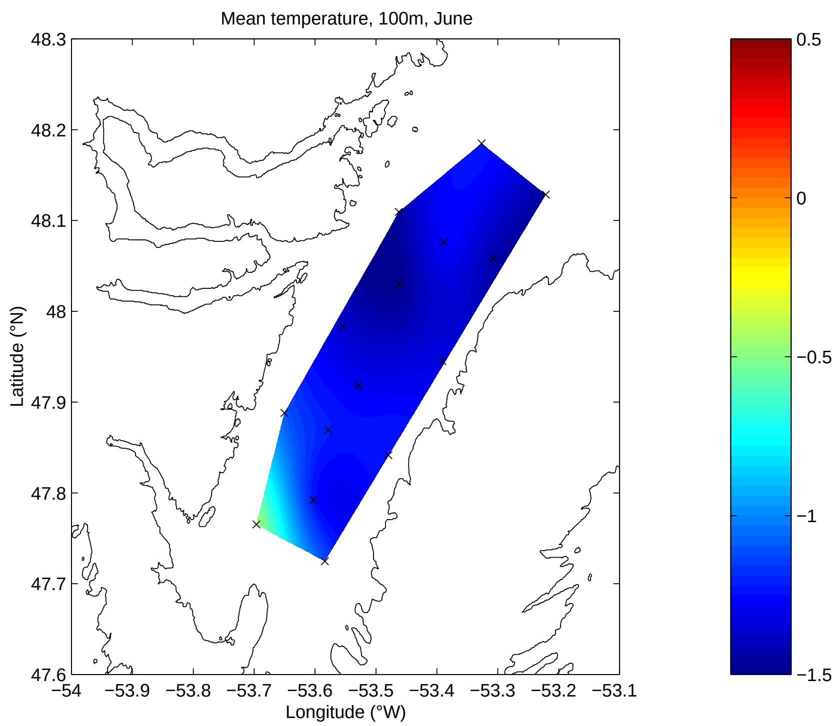

Figure 54: Mean temperature at 100m, June.

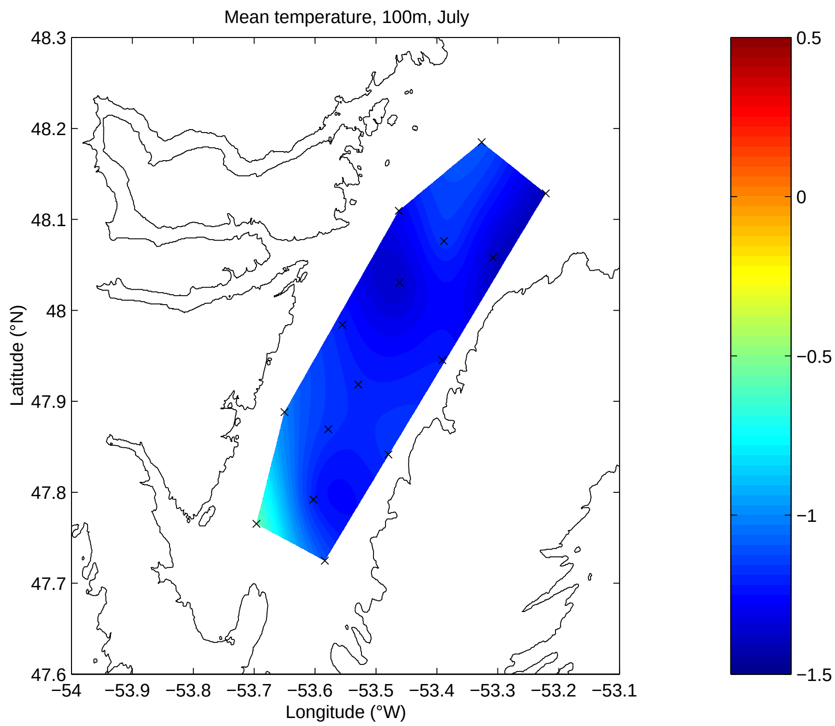

Figure 55: Mean temperature at 100m, July.

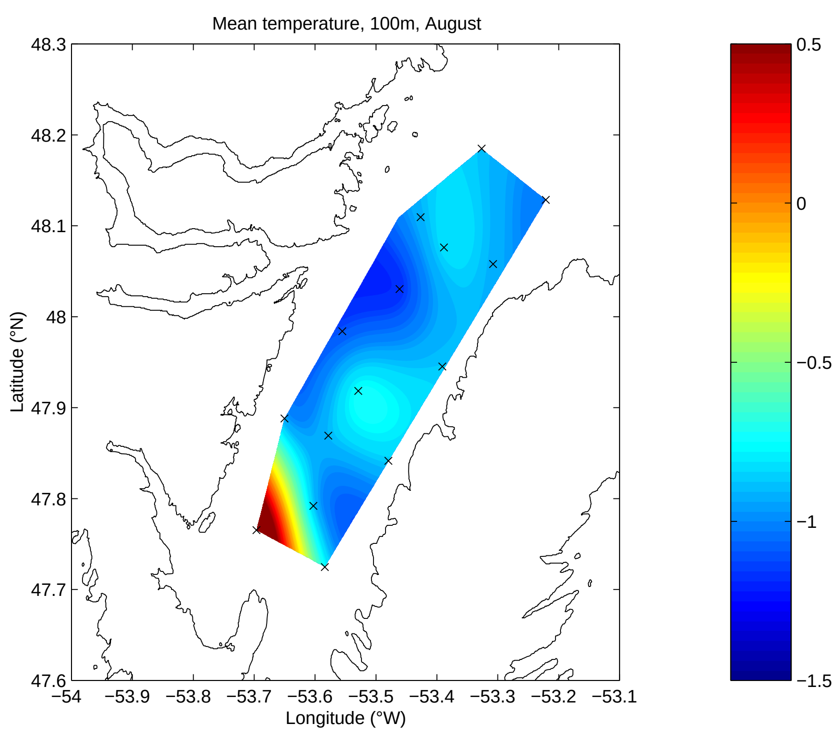

Figure 56: Mean temperature at 100m, August (data ends on August 28th).

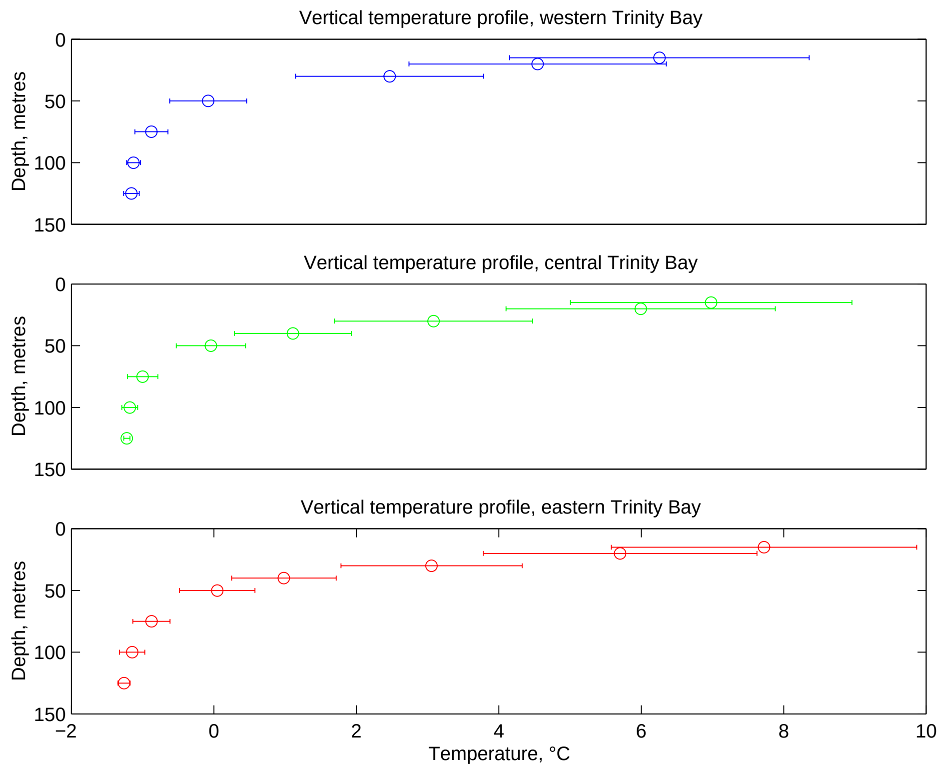

Figure 57: Vertical temperature profiles for western, central, and eastern Trinity Bay, to a maximum depth of 125 metres. Data from 8th May 2002 to 28th August 2002. Moorings making up each profile are as follows. Western: M1, M4, M8, M13, M16. Central: M3, M5, M7, M12, M14. Eastern: M2, M6, M11, M15, M17.

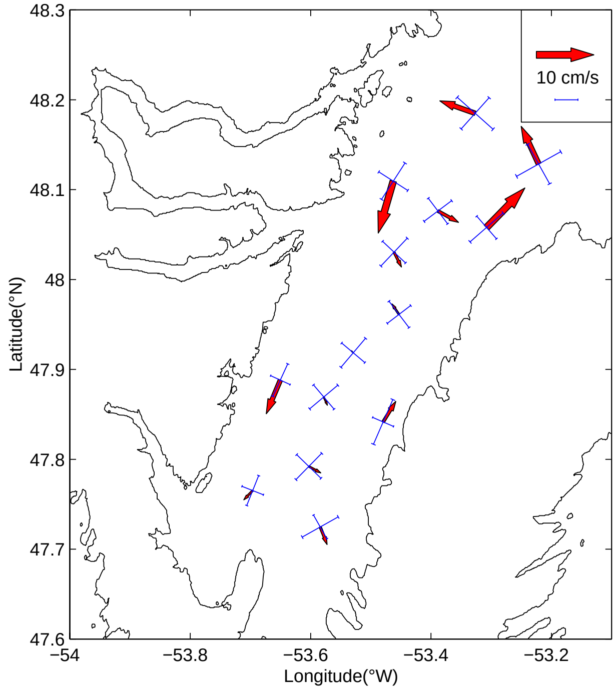

Figure 58: Mean currents, Trinity Bay, May – August 2002, at a depth of 20m. The solid axes represent standard deviation of the flow along the direction of maximum and minimum variance.

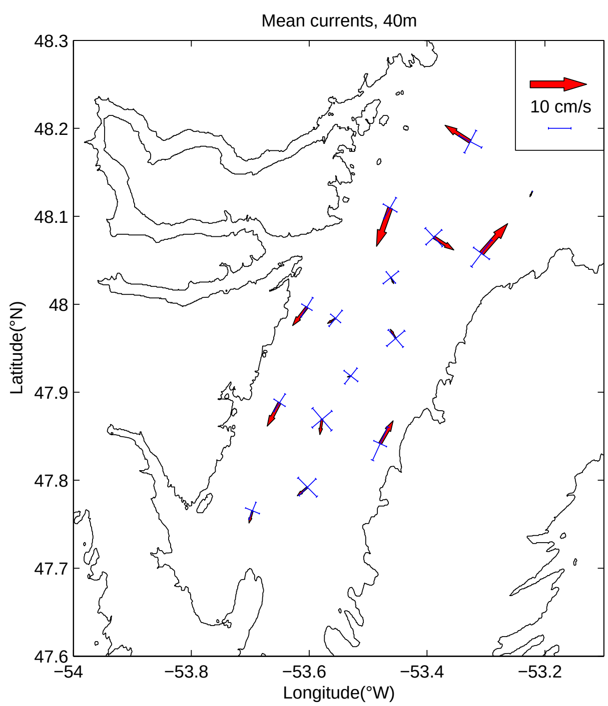

Figure 59: Mean currents, Trinity Bay, May – August 2002, at a depth of 40m. The solid axes represent standard deviation of the flow along the direction of maximum and minimum variance.

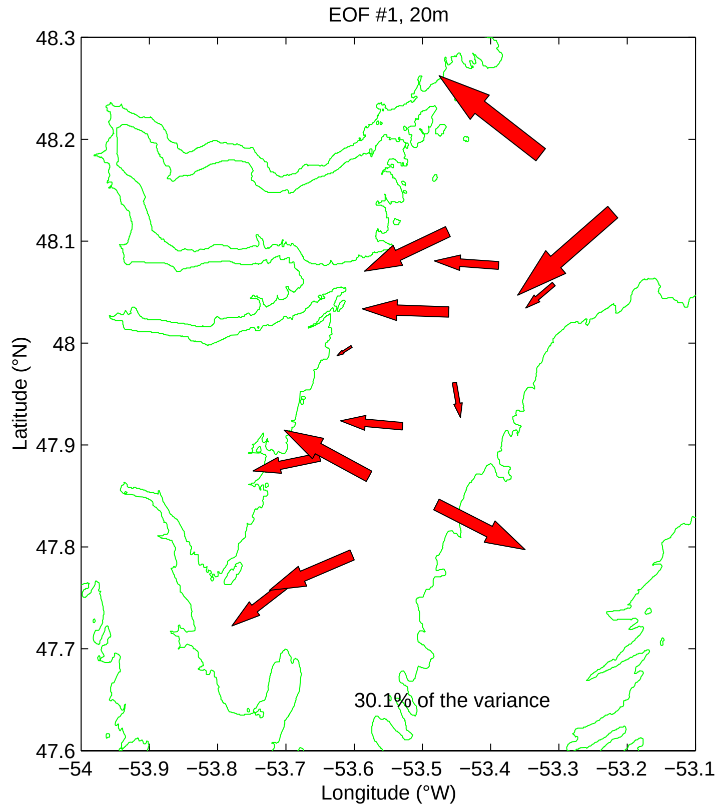

Figure 60: EOF number 1, 20 metres. Mooring M8 uses data from 40m.

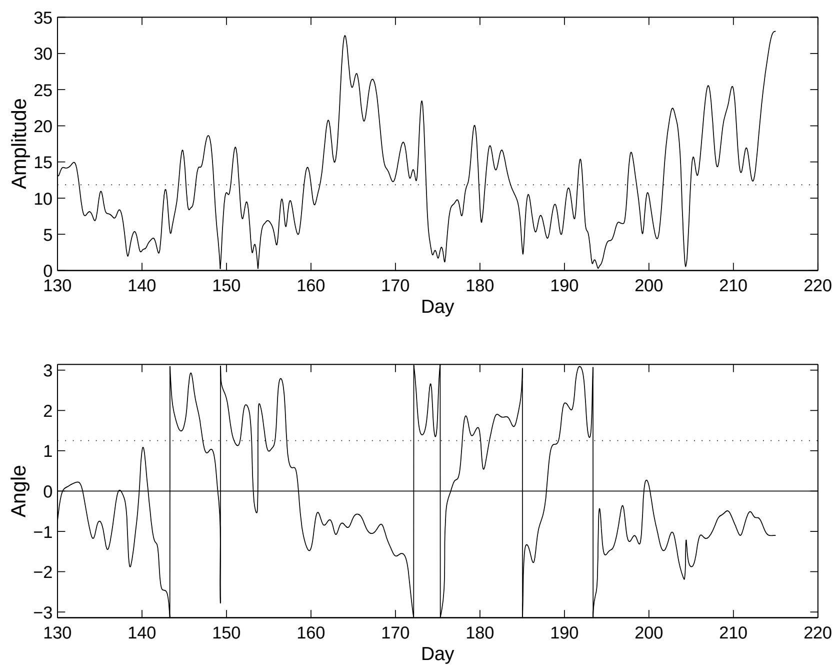

Figure 61: Time-series plot of the amplitude and angle (in radians) of the first eigenmode, 20 metres. The dotted line in the time-series indicates the mean of the absolute value.

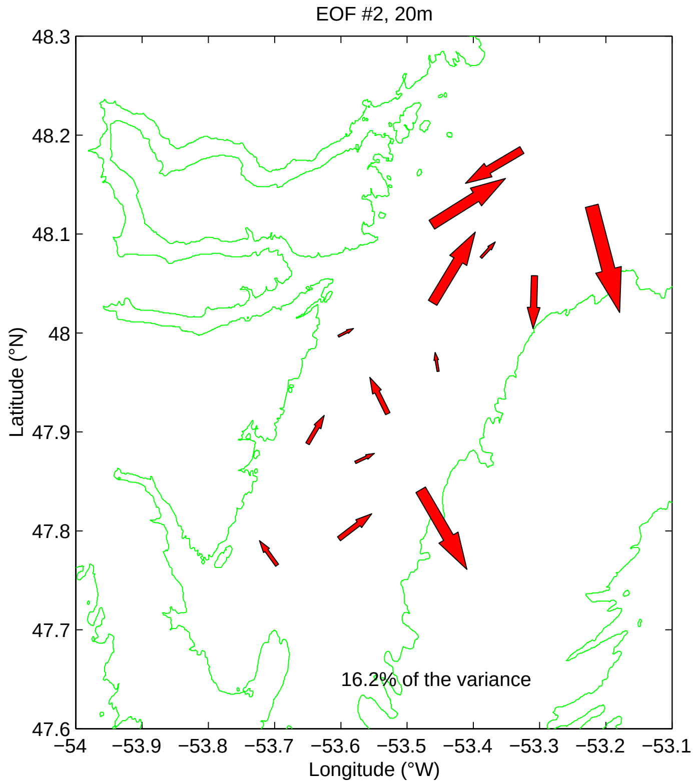

Figure 62: EOF number 2, 20 metres. Mooring M8 uses data from 40m.

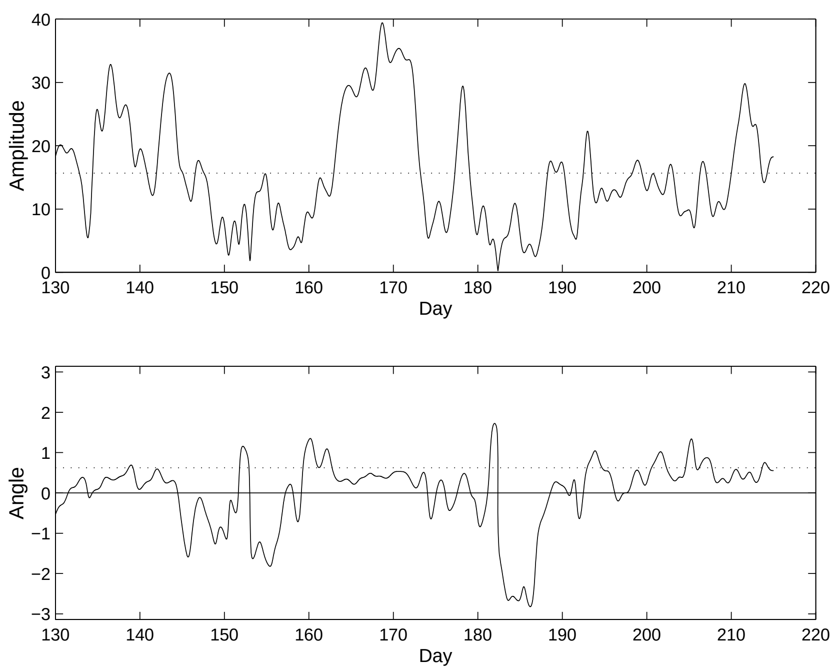

Figure 63: Time-series plot of the amplitude and angle (in radians) of the second eigenmode, 20 metres. The dotted line in the time-series indicates the mean of the absolute value.

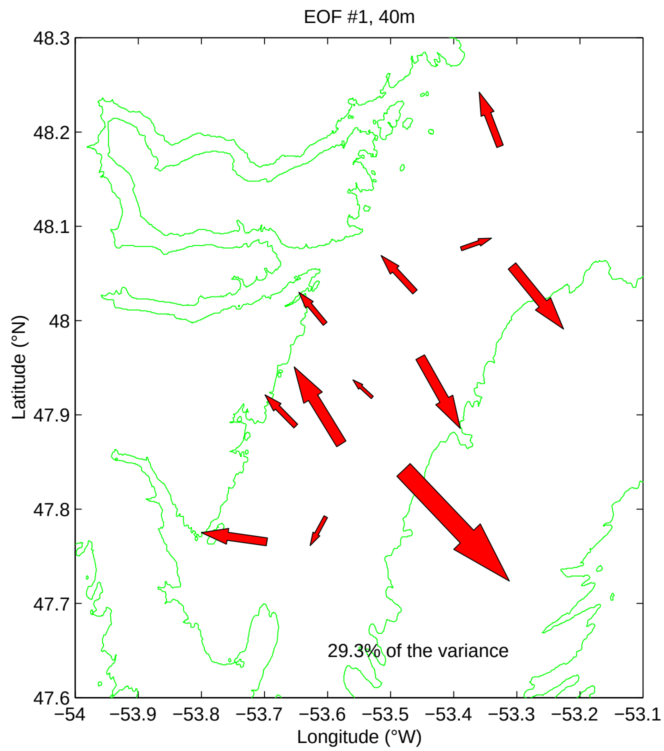

Figure 64: EOF number 1, 40 metres.

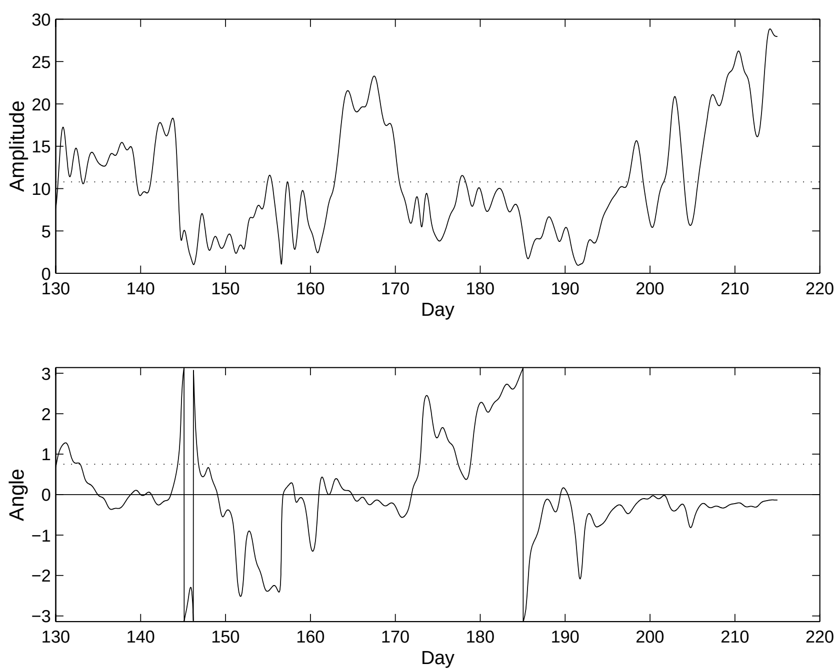

Figure 65: Time-series plot of the amplitude and angle (in radians) of the first eigenmode, 40 metres. The dotted line in the time-series indicates the mean of the absolute value.

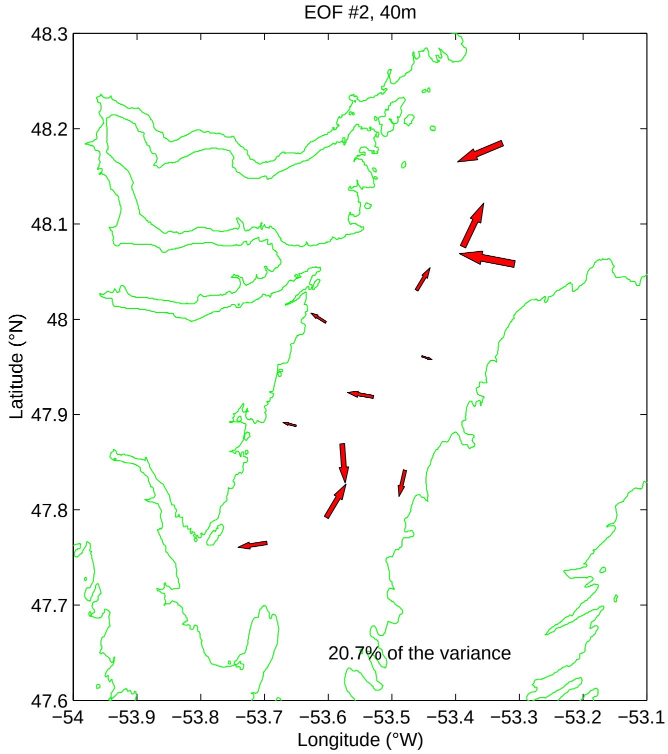

Figure 66: EOF number 2, 40 metres.

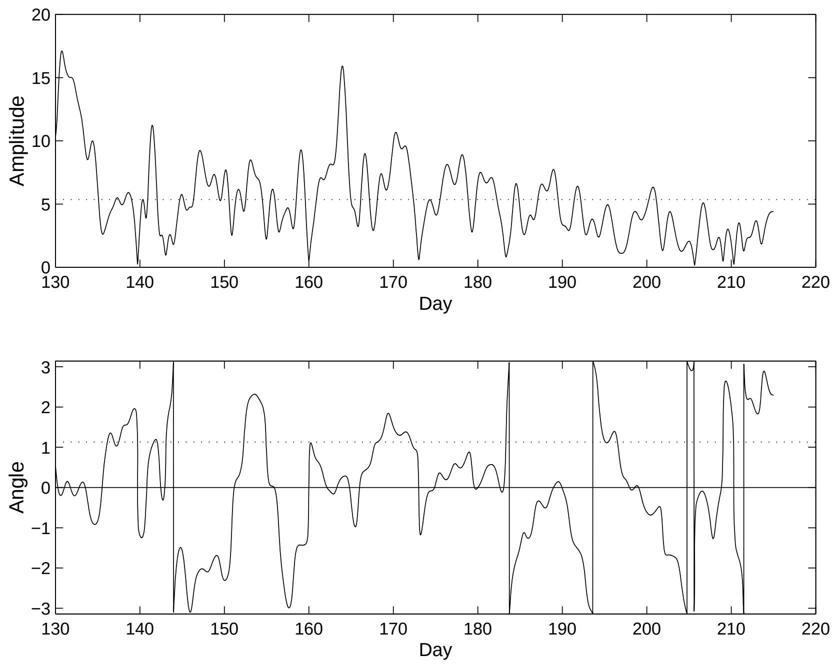

Figure 67: Time-series plot of the amplitude and angle (in radians) of the second eigenmode, 40 metres. The dotted line in the time-series indicates the mean of the absolute value.

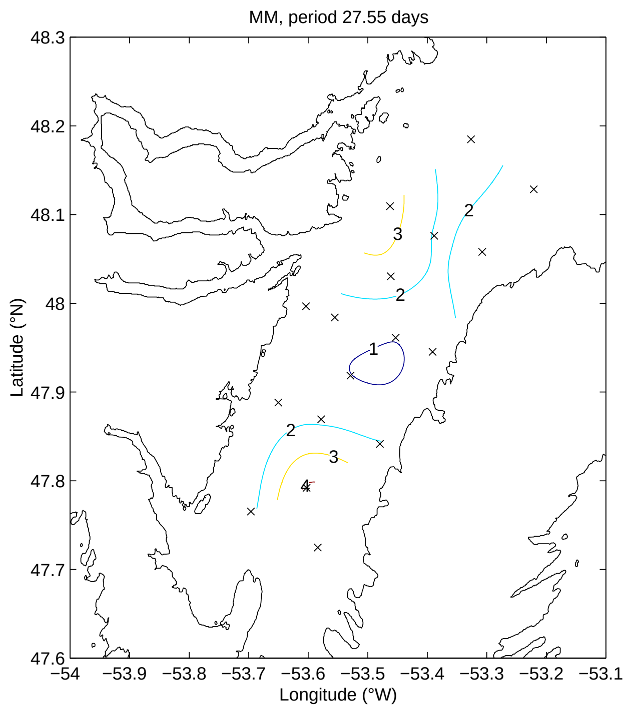

Figure 68: The interpolated MM constituent tidal velocity data at 20m (amplitude, cm/s).

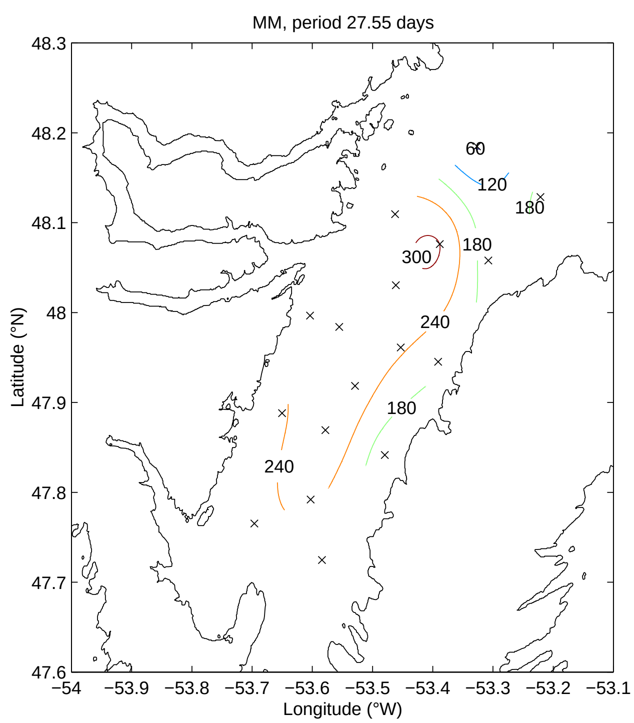

Figure 69: The interpolated MM constituent tidal velocity data at 20m (phase, degrees relative to Greenwich).

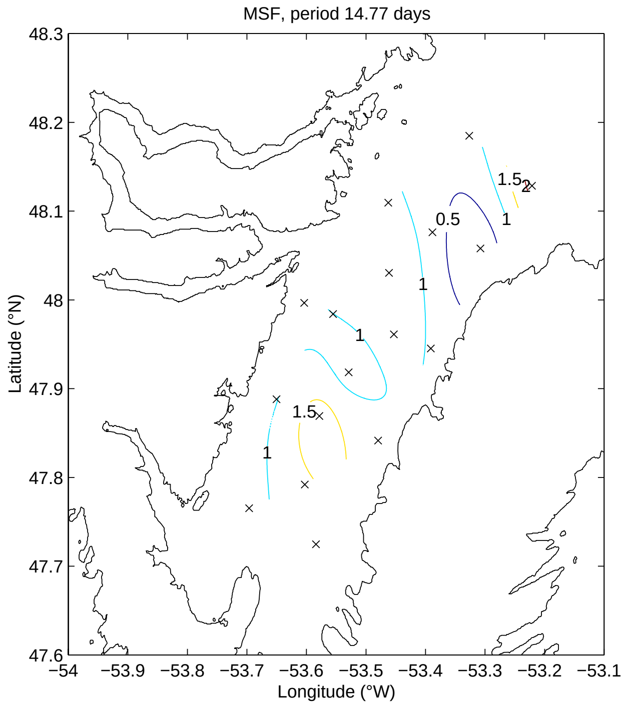

Figure 70: The interpolated MSF constituent tidal velocity data at 20m (amplitude, cm/s).

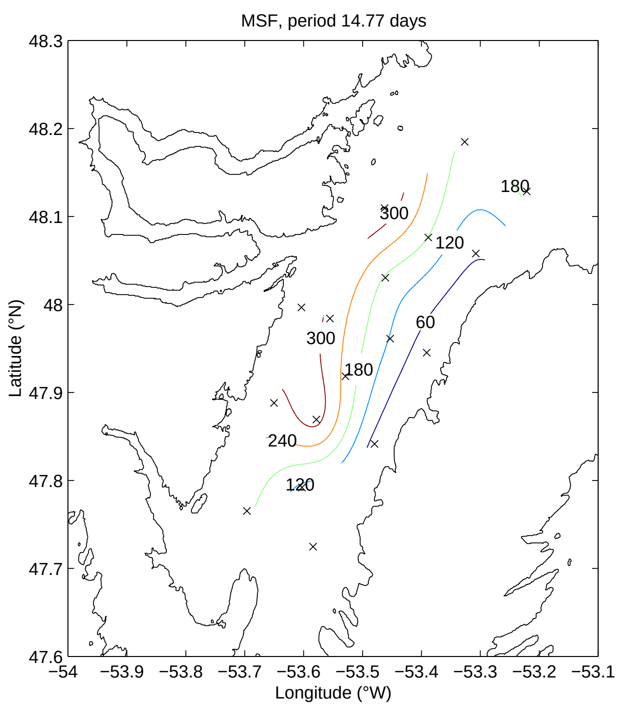

Figure 71: The interpolated MSF constituent tidal velocity data at 20m (phase, degrees relative to Greenwich).

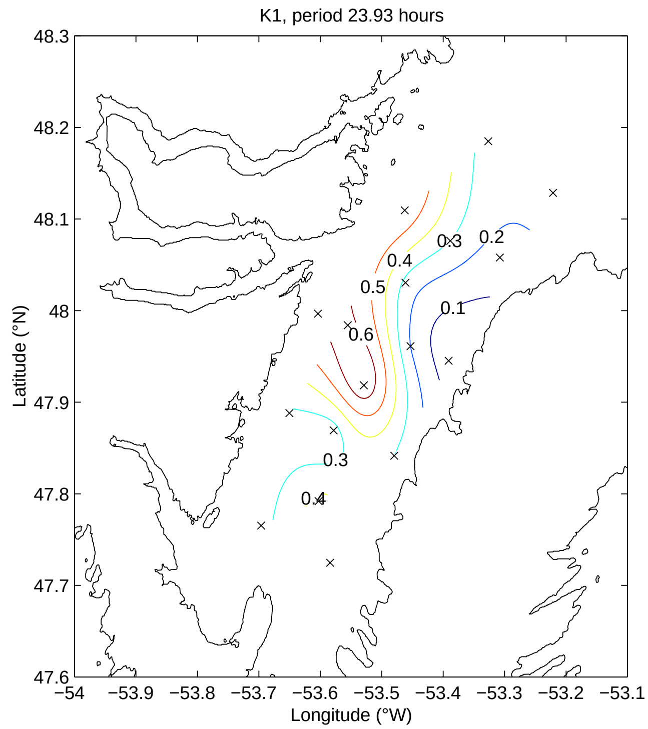

Figure 72: The interpolated K1 constituent tidal velocity data at 20m (amplitude, cm/s).

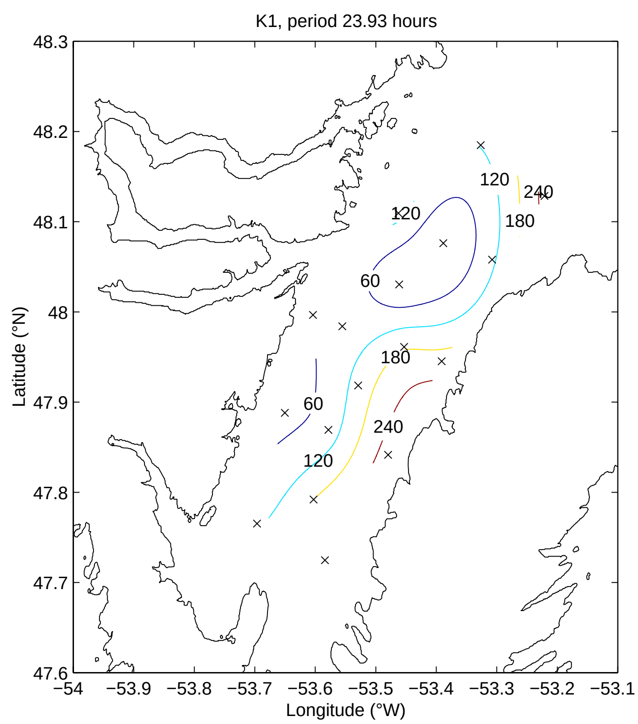

Figure 73: The interpolated K1 constituent tidal velocity data at 20m (phase, degrees relative to Greenwich).

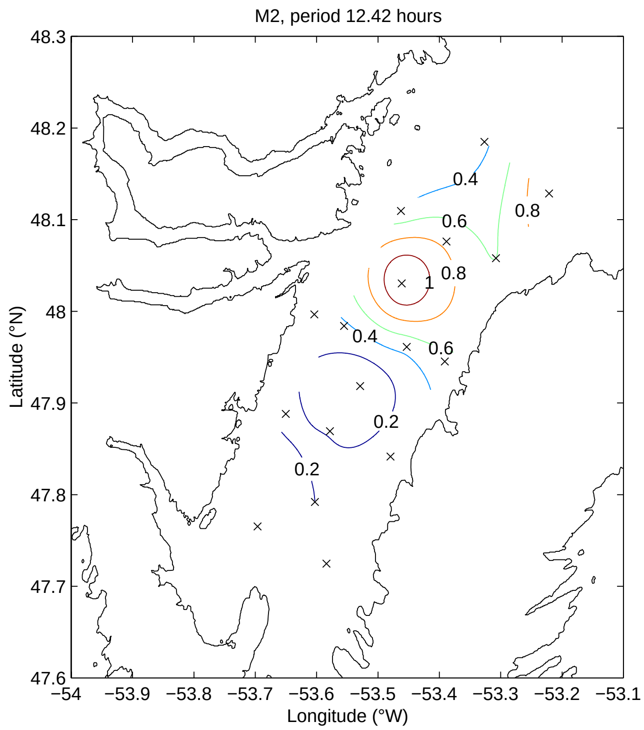

Figure 74: The interpolated M2 constituent tidal velocity data at 20m (amplitude, cm/s).

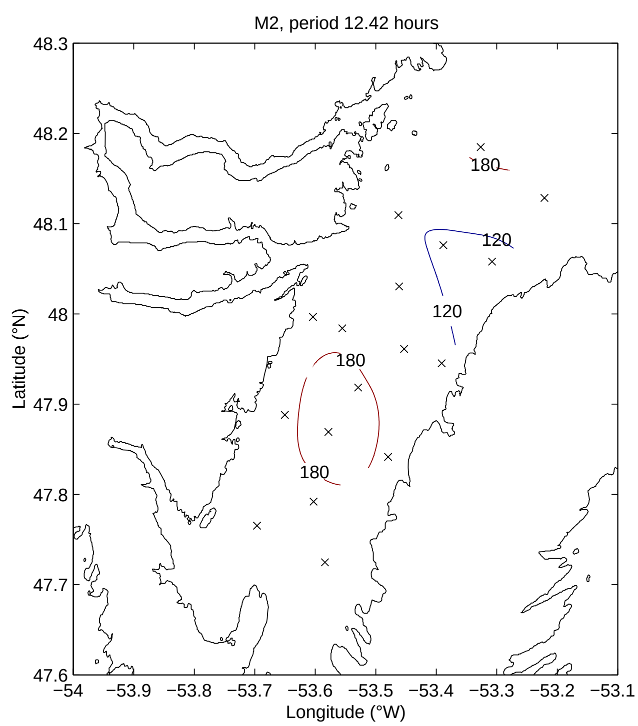

Figure 75: The interpolated M2 constituent tidal velocity data at 20m (phase, degrees relative to Greenwich).

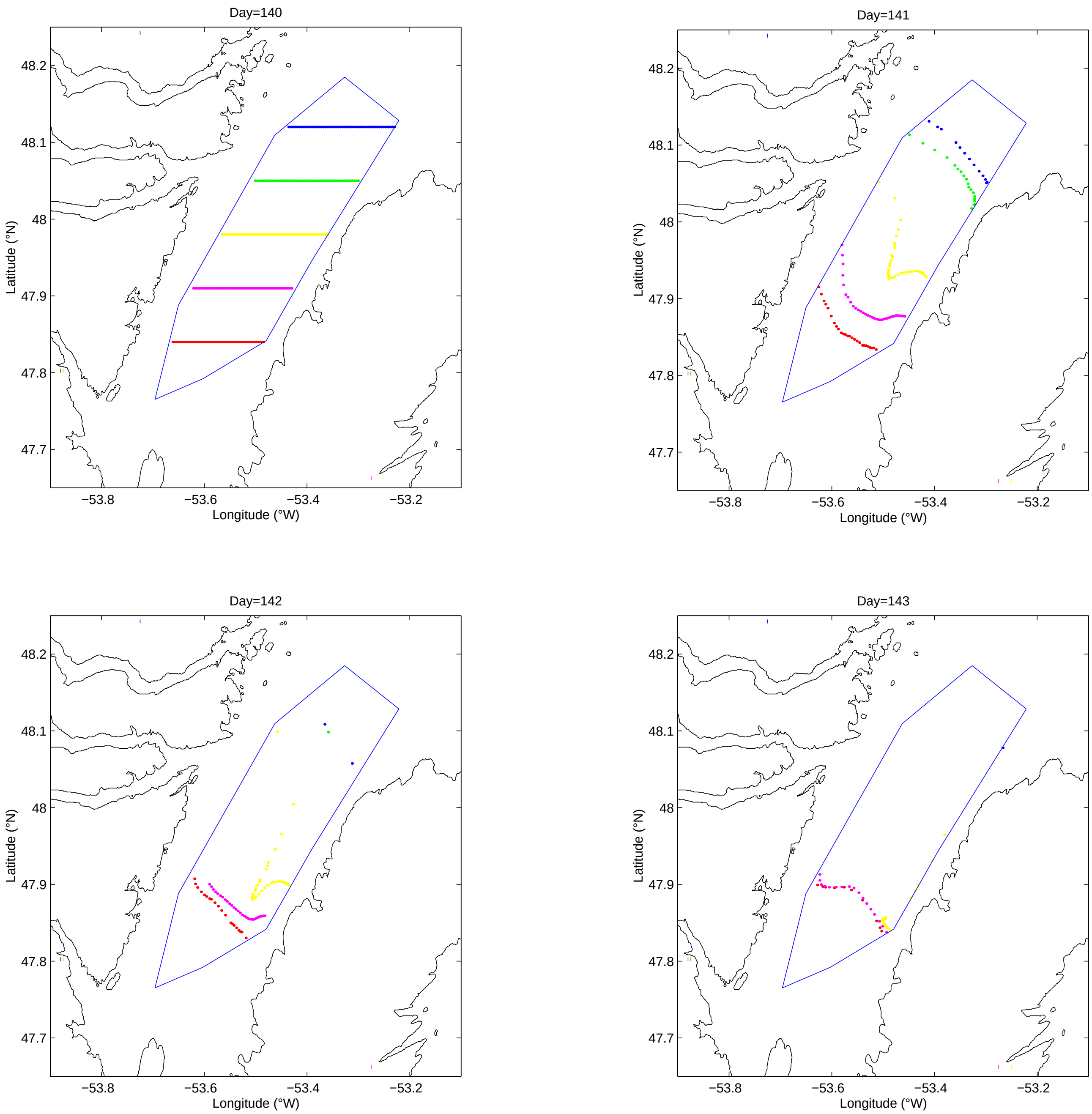

Figure 76: 5-day particle tracking run, beginning on day 140.

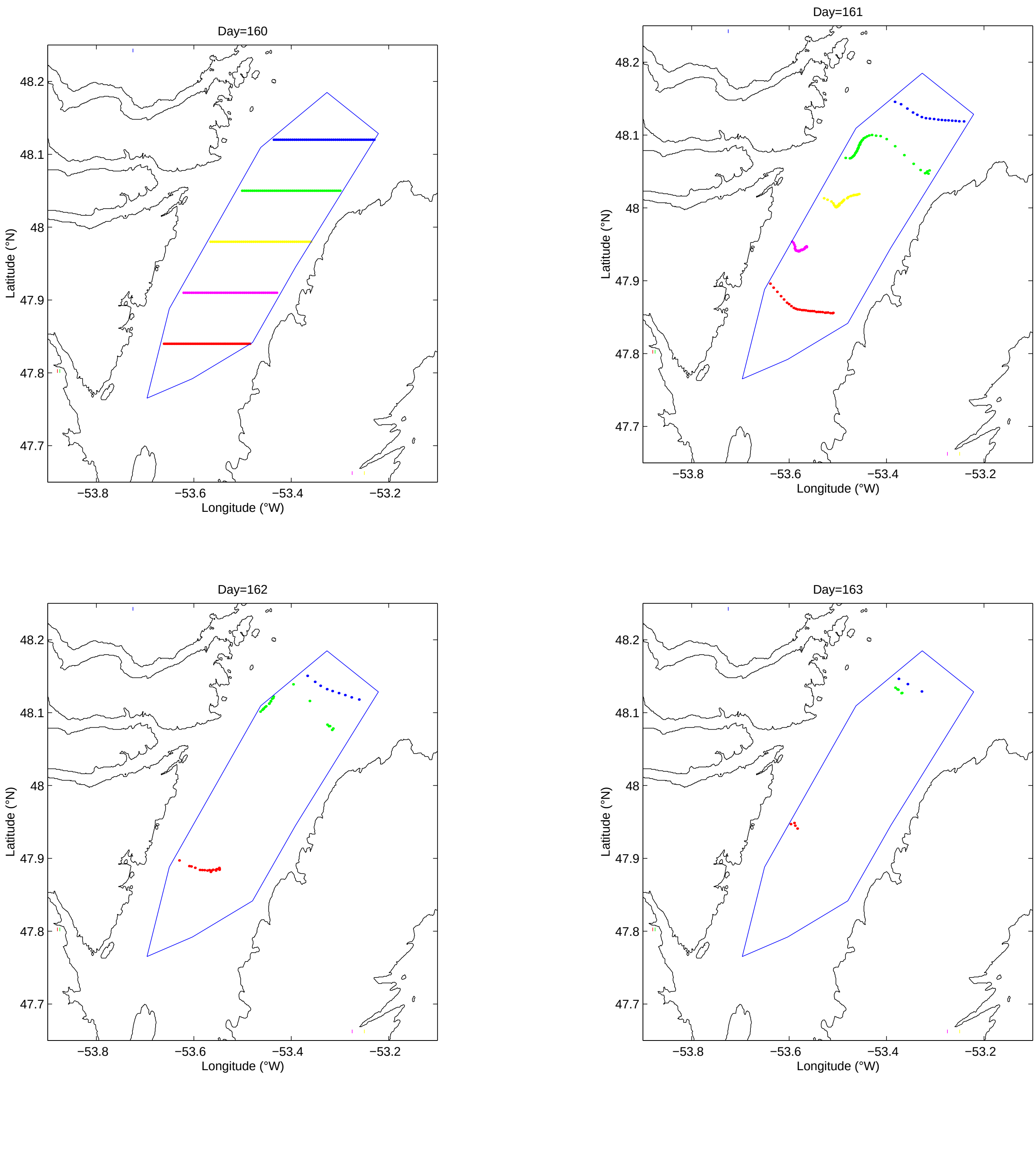

Figure 77: 5-day particle tracking run, beginning on day 160.

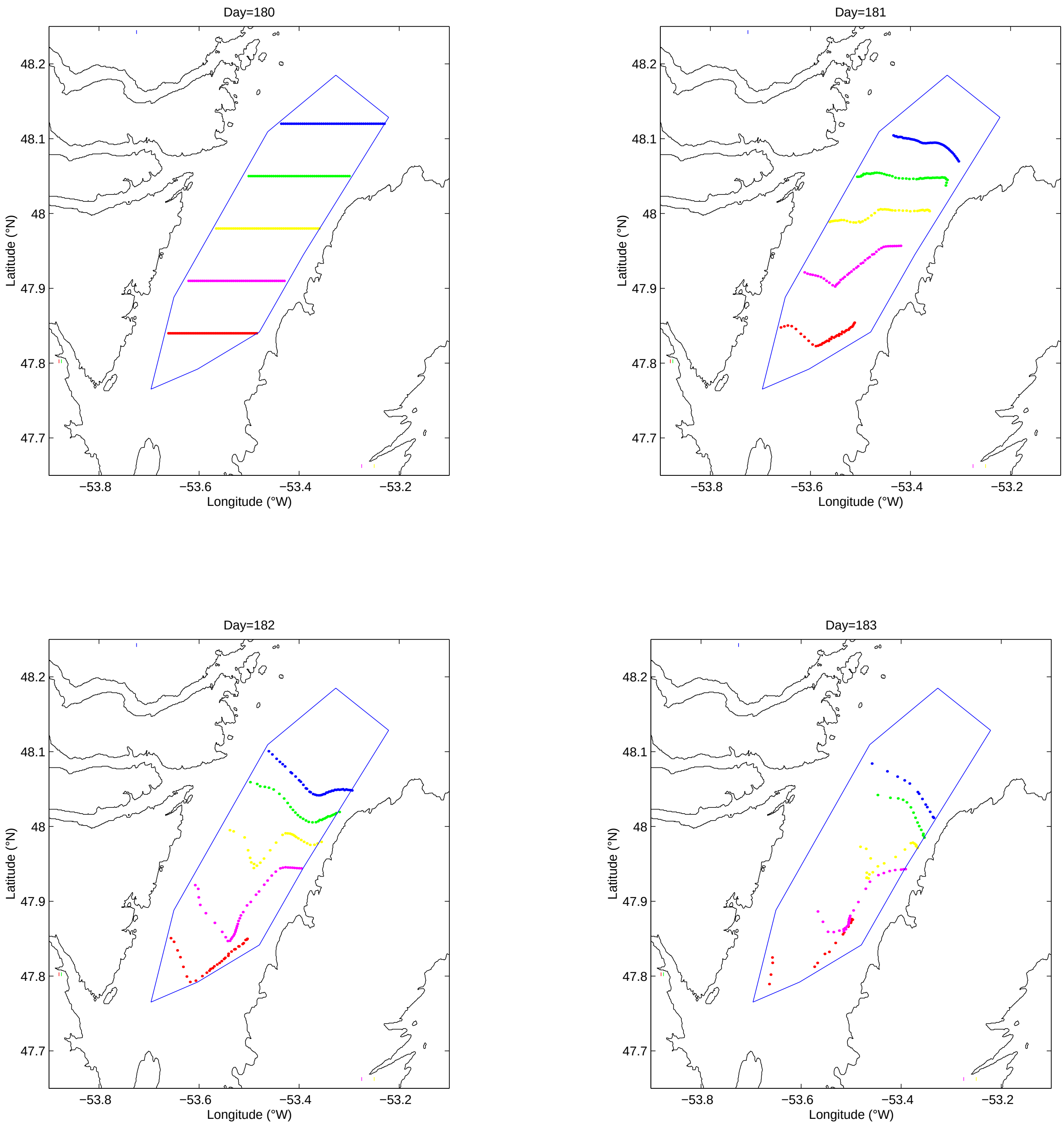

Figure 78: 5-day particle tracking run, beginning on day 180.