Port Valdez Weather Buoy Analysis 2019 - 2022

Report by:

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Contents

List of acronyms

CO-OPS	Center for Operational Oceanographic Products and Services (NOAA)
FAA	Federal Aviation Administration
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PWS	Prince William Sound
PWSRCAC	Prince William Sound Regional Citizens' Advisory Council
PVD	Progressive Vector Diagram
QA/QC	Quality Assurance / Quality Control
VDZA2	NOAA tide station in Valdez Harbor
VMT	Valdez Marine Terminal
WMO	World Meteorological Organization

Executive summary

This report summarizes three years of meteorological and oceanographic measurements made by two buoys deployed in Port Valdez, one adjacent to the Valdez Marine Terminal (VMT) and one near the Valdez Duck Flats. Time series at each of the buoys were analyzed for seasonal, intra-, and interannual patterns. Air and water temperatures, and solar radiation all showed a cyclical seasonal progression typical to subarctic regions, with minima in February and maxima in August. Relative humidity was high, as befits a coastal region with a large amount of annual precipitation, and tended to follow temperature trends. Air pressure, driven by large-scale atmospheric circulations, was similar between the two sites. Winds were primarily from the east in autumn and winter, again driven by the large-scale atmospheric patterns that create a low-pressure system over the Gulf of Alaska during that time. In late spring and summer, daily westerly sea breezes were common. A 114-year-long temperature climatology was constructed for the Valdez region, which showed a steady and persistent warming trend. Over the time period that the buoys have been deployed, winters have been warmer than average, and summers cooler than average. Surface currents tend to be higher at the VMT than at the Duck Flats, given their locations (along the middle of the Port versus at the head). Visual representations of surface current vectors showed that summer sea breezes consistently influenced surface currents, although the current directions were different between the two buoys. Tidal oscillations were more prevalent during calmer periods, and current directions were much more variable in autumn and winter.

Introduction

The Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) operates two weather buoys in Port Valdez, one offshore of the Valdez Marine Terminal (VMT) at Jackson Point that was deployed in May 2019, and one adjacent to the Valdez Duck Flats that was deployed in September 2019 (fig. 1). Both buoys have been uploading meteorological and oceanographic observations on an hourly basis (with some interruptions due to hardware/software failures and service visits) since their deployment.

Standard equipment on each buoy includes an anemometer, relative humidity sensor, three temperature thermistors (one dedicated for air temperature, a secondary included in the relative humidity sensor, and one to measure sea surface temperature mounted ~1 meter (m) below the waterline), barometer, radiometer, Acoustic Doppler Current Meter (for surface currents), and a wave sensor (only on the VMT buoy at present). An onboard electric compass is used to measure the buoy heading to adjust direction measurements (wind, waves, and current) to true north. The measured parameters of interest, their units, and recording period are listed in table 1.

Table 1: Meteorological and oceanographic parameters collected by the buoys.

Parameter	Instrument Make/Model	Units	Recording period
Wind speed	RM Young 05103-L	m/s	6 minutes
Wind gust speed	RM Young 05103-L	m/s	6 minutes
Wind direction	RM Young 05103-L	Deg. True	6 minutes
Air temperature	Campbell Scientific 109	°C	15 minutes
Relative humidity	Campbell Scientific HC2S	%	15 minutes
Barometric pressure	Setra CS100-QD	mbar	15 minutes
Solar Radiation	Hukseflux LP02	W/m^2	15 minutes
Current speed	Nortek Aquadopp 2 MHz	m/s	20 minutes
Current direction	Nortek Aquadopp 2 MHz	Deg. True	20 minutes
Significant wave height	Axys TriAXYS	m	Hourly
Maximum wave height	Axys TriAXYS	m	Hourly
Wave period	Axys TriAXYS	s	Hourly
Wave direction	Axys TriAXYS	Deg. True	Hourly

The high frequency of sampling by the buoys has already created a large archive of observations, slightly over 1.5 million primary observations at each buoy, plus a large amount of associated metadata and numerous derived parameters. The purpose of this report is to provide an analysis of some of the seasonal and higher frequency patterns found in the data.

This report is structured around the different data types produced by the buoys. Following discussion with PWSRCAC staff and committee members, the primary averaging period to be used was decided to be monthly. In some cases, higher frequencies have been used where appropriate to provide a higher level of detail. Given the very broad backgrounds of the many PWSRCAC stakeholders, technical jargon has been avoided where possible to provide a plain language interpretation for that large and diverse audience; where necessary, definitions of technical terms are provided. Rather than the usual methods/results/discussion format featured in the scientific literature, a more narrative structure has been adopted, and explanations of methods, highlighting of the results, and discussion of them have been done all at the same time for the many different data collected. The metric units used by the buoys have also been mostly converted to imperial units. Graphical presentations of the data have been used as much as possible and a tabular compilation of monthly averages at both buoys has also been included in appendices.

Data operations, notes, and quality assurance/quality control (QA/QC)

All data was downloaded directly from the buoy data server. Each time series was examined with automated and manual methods for anomalous spikes. Relative humidity values prior to January 2020 at the VMT were removed (the sensor was damaged) and occasional bad water temperature observations at the buoys (<28°F) were removed. On or about March 11, 2020, the VMT buoy had a power issue which tripped the main fuse from the battery, which resulted in intermittent daytime-only data (when the solar panels produced enough voltage to power up the data logger) until the buoy was repaired on April 29, 2020.

A primer on the visualization of vector data

Meteorological and oceanographic data are either scalar observations (magnitude only, e.g., temperature) or vector observations (magnitude and direction, e.g., winds). Scalar data may be visualized with a standard x-y plot that should be familiar to most. Vector data, having two components, is more complicated to visualize and average. A vector may be visualized as an arrow, with the direction indicated by the direction the arrow is pointed, and the magnitude indicated by the length of the arrow (fig. 2A). When doing mathematical operations on a vector, vectors are usually broken up into components that correspond to the dimensions of the vector. The red and blue arrows in figure 2A indicate those two components for the two-dimensional vector shown: there is a horizontal component and a vertical component. Those components are usually designated as 'u' and 'v' in the technical literature, and in the context of meteorological data are referred to as the zonal (i.e., "east-west") and meridional (i.e., "north-south") components. In this context positive numbers mean one direction and negative numbers mean the opposite. For example, on the east-west axis in figure 2, a positive number is eastward and a negative number is westward. Figures showing vector components in this report have annotations and/or compass roses indicating the east/west and north/south directions to aid the reader.

Averaging of vector observations is usually done on the components and then may be visualized in a number of ways. The two methods used in this report are roses and quiver plots. A rose is a good way to summarize a large number of observations and may be thought of as something similar to a bar chart, but arranged in a circle to indicate directions. An example of a rose plot is shown in figure 2B, which represents all the wind observations made by the VMT buoy in the month of June 2020. The wind directions (the direction the wind is blowing from) are broken up into 10° "bins" that are shown by the bars. The length of the bars is proportional to the frequency of winds blowing from that direction and the colors indicate bins of wind speeds, which are shown on the color scale to the right. Figure 2B shows us that most of the winds in June 2020 were primarily in the east-west direction. The median wind direction (i.e., the most frequent, shown by the longest bar) was just south of westerly. The four largest bars showing westerly to southwesterly winds can be summed up on the circular scale and shows that something like half (50%) of winds were in those westerly to southwesterly directions. The color scale shows that the strongest winds were westerlies, with a small proportion blowing 15-20 knots (green bars), slightly more blowing 10-15 knots (cyan bars) and more still blowing 5-10 knots (light blue bars). One can also see that easterly winds were generally weak, being mostly 0-5 knots (dark blue bars). In this report, rose plots are used only for the most recent year of data (2022), because showing multiple years results in very small roses or multi-page figures that become difficult to interpret.

Quiver plots allow examining finer scale patterns that would be impractical with rose plots and show a vector as an arrow or a line. An example quiver plot is shown in figure 2C, again using wind data from June 2020 at the VMT buoy, but with daily average wind speed and direction shown. Each arrow in the plot is the daily average wind velocity, with the angle of the stick showing the direction of the wind vector and the length of the stick indicating the wind speed. The axis is scaled such that the length of the stick is proportional to the ticks on the bottom axis. Because the winds, waves, and currents in Port Valdez are primarily oriented in the east-west direction, the plots were produced with time shown vertically. Arrowheads are shown in the example plot, but are not shown in the rest of the plots in this report because they show a great deal more data and the arrowheads tend to add clutter and make the plots more difficult to read. Quiver plots are more data-dense, and the entire time series from each buoy is shown (instead of the most recent year) to give a sense of the entire time series collected so far.

Surface current observations at the buoys are the sum of several different components, including tides, winds, and the large-scale circulation in the Port driven by freshwater inputs and Coriolis forces; prior reports have tried to remove the influence of tides, and examined how those components are correlated with current velocities (Campbell, 2021; Campbell 2022). The periodicity of the tides makes vector averaging methods such as roses and quiver plots uninformative (e.g a current that runs at one knot to the east on a rising tide and one knot to the west on the falling tide will have an average velocity of zero), and the volume of the data makes it difficult to display. One simple way of following a vector time series is the use of Progressive Vector Diagram (PVD). This is a plot where successive vectors are plotted on top of each other, with the tail of each vector plotted on to the head of the one preceding it. This produces a “track” this is some ways similar to the track produced by a surface drifter, if one assumes an isotropic (“the same in all directions”) flow field. In practice, Port Valdez does not have an isotropic flow field, so the paths shown in the PVDs in this report should be considered more as a way to look at how flow directions change over time.

An example of a PVD is shown in figure 3, which displays 12 hours of current observations made every 15 minutes. In that plot the first observation is denoted by a green dot, and the last a red dot, and the first observation is placed at the origin (i.e. the zero point on both axes). The plot shows how the current vectors shift back and forth during a tidal cycle, along a more or less southwest to northeast axis, and also show an overall transport towards the west. In the plot the vectors have been scaled to represent the distance that the current would have travelled in the 15-minute observation, to give a sense of the magnitude of the current. In the example of figure 3 the net current (the difference between the green and red dots) was about 1.5 km to the west.

Meteorologists and oceanographers use different conventions when speaking of directions: meteorologists speak of the direction that winds are coming from (e.g., a northerly wind is coming from the north), while oceanographers speak of the direction water is traveling to (e.g., an eastward current is travelling to the east). This convention has been adhered to in this report for the rose plots, but has not for the quiver plots, because the quiver plots are a direct representation of the vector in question (the average movement of the air or water). This is why the rose in figure 2B has bars pointing to the left ("winds from"), while the quiver plot in figure 2C has vectors pointing to the right ("direction air is moving to"). In the text of this report both "from" and "to" notation is used depending on the convention (meteorological vs oceanographic) to distinguish between the conventions.

Results and discussion

Air and sea surface temperature

Monthly air and water temperatures at both buoys showed the typical sinusoidal seasonal cycle expected in a subarctic environment (figs. 4, 5), with maxima in August and minima in February and considerable day-to-day departures from monthly means. Air temperatures tended to be slightly higher at the VMT buoy (fig. 4) than at the Duck Flats buoy (fig. 5), which may indicate a slightly more terrestrial influence at the Duck Flats buoy (e.g., downsloping winds from the Valdez Glacier Valley, discussed in the winds section below). Water temperatures were also slightly cooler at the Duck Flats, likely reflecting potential source waters from the Lowe River and Valdez Glacier Stream which can be expected to be cooler than seawater given the presence of year-round ice in their watersheds.

Relative humidity

Both of the relative humidity sensors failed in early 2022. Those sensors were the last of a supply that came with the buoys when they were donated to PWSRCAC, and their performance has been underwhelming, with several other sections of the data record removed for quality reasons. Newer sensors that the supplier advertises as more robust were acquired in 2022 and installed on the buoys during the spring 2023 service. Considering the time series as a whole, it can be said that relative humidity was variable at both sites (figs. 4, 5). Much of the time relative humidity was quite high, greater than 70%, as expected in the coastal climate both buoys are measuring. Relative humidity was highest in August and lowest in March, following the temperature cycle.

Barometric pressure

Air pressure was very similar between both sites, as would be expected because air pressure is largely driven by large scale atmospheric circulations (figs. 4, 5). There was a weak seasonal cycle in air pressure, with some differences notable among years. Following a period of relatively low air pressures, air pressure in late summer 2019 was quite high and likely driven by a large-scale atmospheric ridge that set up over the north Gulf Coast that year (Amaya et al., 2020). A similar pattern set up in 2020. Air pressure during the summer months of 2021 and 2022 tended to be higher than in 2020 and appears to have been similar to 2019. Pressure was more variable in the autumn months, with the onset of so-called “Equinox weather” which tends to feature large cyclonic circulations driven by the Aleutian Low, which usually sets up in the Gulf of Alaska in autumn and winter and determines the storm tracks to the region (Rodionov et al., 2007).

Solar radiation

As to be expected given the latitude of the sites, solar radiation was strongly seasonal, peaking in June and lowest during the winter months (figs. 4, 5). Both buoys are shaded by the mountains fringing Port Valdez during the late autumn and winter months, which has created some power issues (both buoys are powered by solar panels), particularly at the VMT location. The intermittent values in March and April 2020 (collected only during days when the solar panel energized the logger) resulted in spuriously large averages for those months because only daytime values were collected, those data were omitted from the averaging.

Wind speed and direction, wind gusts

Winds are summarized as monthly wind roses for 2022 in figures 6 and 7, and (again, following meteorological convention) are shown as the direction the wind is blowing from (i.e., an east wind blows from the east). The anemometers on the buoys are very sensitive and usually move slightly in all but the calmest conditions. They are also subject to freezing up after heavy snow and rain events followed by freezing temperatures. This manifests as a zero wind speed from exactly true north (vector multiplication on the 0 wind speed results in a direction of 0 as well) and can be seen on the wind roses as a spike in observations at the 0° band only. Those spikes may be used as an indicator of the frequency of calms during summer months and freeze-up events in winter. Freeze ups were quite frequent in January through March 2022, comprising >30% of all observations, and several calm periods occurred in July through September.

Both the roses and the quiver plots (figs. 6-9) show that most winds were easterly during autumn and winter, and transitioned to westerlies from May until August at both buoys. The strongest winds were easterlies, during the autumn and winter months, likely driven by outflow winds caused by the large-scale atmospheric features that set up in autumn/winter (the Aleutian Low offshore and high pressure over the interior). The summer westerlies are a daily sea breeze caused by localized heating and cooling that is familiar to mariners in the region (Lethcoe and Lethcoe, 2009). During the day, the sun heats the land faster than the ocean, creating upward convection and low air pressure over land; this draws air in from the ocean and creates a landward breeze (from the west in Port Valdez). At night, the land cools faster than the ocean, creating convection in the opposite direction. To illustrate this, hourly average winds in the east-west direction at the VMT buoy are depicted in figure 10 (patterns were identical at the Duck Flats buoy). Westerly winds are depicted with a green color scale and easterly winds are depicted with a blue color scale. The figure shows that the “westerly season” in Port Valdez begins in late April or early May, and extends into August. During the westerly season, winds on most days were easterly from midnight until approximately 10 a.m., then switched to westerlies into the afternoon and evening. There were occasional short episodes where the westerlies were disrupted by summer storms with strong easterly winds (fig. 8).

The roses and quiver plots also show that wind directions were not completely symmetrical, as there was a northerly component as well, regardless of if the winds were primarily from the east or west. That slight northerly tendency may have been caused by topographic steering of the winds by the steep terrain of Port Valdez, with westerly winds blowing out of Shoup Bay to the northwest. The northeastern direction of easterly winds may indicate that winds from Valdez Glacier Valley tend to predominate over those of the Lowe River Valley at the Duck Flats location.

Following the World Meteorological Organization (WMO) standard, the buoys also recorded a running 3-second average wind speed and reported the maximum of that 3-second average in each 6-minute wind recording period as the wind gust speed. The wind gust time series at the buoys in 2022 (fig. 11) followed the same pattern as sustained winds, with maximums during the winter months and elevated gusts during the summer westerly season. Summer gust speeds were in the 10-knot range and 25-knot gusts occurred during autumn and winter storms.

Wave height and direction

Wave observations have also been summarized as roses (fig. 12) and quiver plots (fig. 13) at the VMT buoy. No wave measurements have been made at the Duck Flats buoy since 2020. Wind makes waves and the wave observations reflect the wind observations, with most waves, and the largest waves, from the east at the VMT buoy during the winter months and from the west in spring and summer.

The largest maximum wave height observed in the time series was an observation of just under nine feet in December 2022 (fig. 14) and similar wave heights were recorded in early and late 2021. Maximum summertime wave heights were between one and three feet and wave heights were slightly higher during winter storms.

Sea surface temperature climatology

Although the buoys have a fairly short time series, to put the buoy observations into a climatological context it is possible to convert observations into anomalies (i.e., departures from the long-term average) using observations from nearby stations, with the assumption that they are reasonably similar. There is a National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services (NOAA CO-OPS) weather and water level station in Valdez harbor, named VDZA2, which has a record of water temperatures that goes back to 2008. An average annual temperature cycle based on weekly averages was created from the VDZA2 time series (fig. 15) to use as a long-term average.

Water temperatures at the buoy may then be averaged by each week and subtracted from the weekly averages at VDZA2 to produce an anomaly plot (fig. 16), which depicts the departure of observations from the long-term average seasonal cycle (only the VMT buoy is shown because patterns are essentially identical at the Duck Flats buoy). The anomaly plot shows that relative to the 2008-2020 average, surface waters were much warmer than average in the early summers of both 2019 and 2020 at the VMT buoy but tended to be cooler than average in autumn in both years. This matches with larger-scale oceanographic patterns seen elsewhere, including a Gulf of Alaska wide marine heat wave in 2019 (Amaya *et al.* 2020) and warm surface waters observed in Prince William Sound (PWS) in 2020 (Campbell, *unpubl. obs*). A La Niña event began in late 2020, and continued through 2022 (NOAA CPC 2022). La Niña events are usually correlated with cooler surface temperatures in the North Pacific (Papineau, 2001; Newman et al., 2016), but PWS tends to lag the Gulf of Alaska by about a year in terms of temperature responses (Campbell, 2018). Near surface water temperatures in Port Valdez tended towards cooler than average through much of 2022, with consistently warmer than average water temperatures May through July.

Air temperature climatology

Although the water temperature record is comparatively short, a longer climatology is available for monthly average air temperatures in Valdez that was compiled by the Berkeley Earth database (http://berkeleyearth.org/). The Berkeley Earth time series spans from 1908 to 2013, using data from several National Weather Service (NWS) and Federal Aviation Administration (FAA) weather stations that have existed in the Valdez area over the years. The Berkeley Earth time series overlaps the VDZA2 time series (2008 – 2013), which may be used to compare the two records to look for overlaps. Similarly, the buoy record from the VMT buoy runs from 2019 to present day concurrently with VDZA2, and the two records may also be compared for overlaps (fig. 17). Again, only the VMT buoy will be used for this analysis because the temperatures recorded at the VMT and Duck flats are very similar. Those comparisons show a very tight relationship between the time series, but with significant offsets and slopes. Although the two data sets showed the same pattern, there were slight differences in the temperatures that they estimated: The Berkeley Earth time series was cooler than the VDZA2 time series, while average temperatures at the VMT buoy tended to be slightly warmer than at VDZA2.

With the assumption that the offsets apply to the entire time series, they may be applied to correct the VDZA2 and Berkeley Earth air temperature time series to be consistent with the VMT time series, using the equations shown in figure 17. The complete time series of air temperature anomalies from 1908 to 2021 (fig. 18) shows a consistent warming trend of just under a half a degree Fahrenheit per decade over the last 114 years, an overall increase in average temperatures of ~5 degrees. This is consistent with trends observed elsewhere in the region (e.g., Campbell, 2018).

Beyond the overall trend, there is an interesting pattern in more recent years towards warmer than average winters and cooler than average summers that is apparent when looking at the 2019-2022 period of the VMT buoy record (fig. 19), but the pattern appears to go back to at least 2014 (fig. 18). Interestingly 2014 was the year of a basin-wide marine heat wave, colloquially known as "The Blob" (Bond et al., 2015) caused by changes in atmospheric patterns (an atmospheric ridge) that resulted in less winter mixing of heat out of the ocean. The pattern observed in Port Valdez may reflect a reverberation of those large-scale ocean-atmospheric patterns, with perhaps local effects mixed in. In general the northern Gulf of Alaska is warming (Danielson et al., 2022), but the northern coast of the Gulf of Alaska is also losing ice mass at among the fastest rates in the world (Doumbia et al., 2020), which has been observed to cause a near-surface cooling trend in northwestern Prince William Sound (Campbell, 2018). The warmer winters may represent that overall warming trend, while cooler summers may reflect a similar cooling caused by the meltwaters that predominate discharges in the summer months.

Surface currents

Surface currents at the VMT buoy were as high as 1.5 knots and considerably smaller at the Duck Flats buoy (fig. 19), which is not surprising given the different locations. The Duck Flats buoy is deployed in shallow water near the head of Port Valdez (where motions will be more vertical), while the VMT buoy is deployed in deeper water over a steeply sloped bottom mid-Port, where tidal currents will be stronger as the tides slosh back and forth.

When examining the "tracks" produced by the PVD at the VMT (fig. 21) and Duck Flats (fig. 22) on the same scales (i.e. each plot in each figure has exactly the same scaling so are directly comparable), several patterns emerge. At the VMT in May, June, July, and part of August surface currents were predominantly to the northeast. Those months are also the time of peak of the sea breezes (fig. 10), suggesting that wind-driven currents predominate at that time.

At the Duck Flats at the same time (excepting May), surface currents were primarily northwesterly. Those patterns are likely because the Duck Flats buoy is very close inshore at the head of the Port (fig. 1) where currents will be constrained by the shoreline and topographically steered even during westerly winds. Those patterns would also be enhanced by the freshwater entering the head of the Port from the Lowe River and Valdez Glacier Stream (fig. 23), which ramps up in May is at its peak through the summer months, and declines in September/October. Freshwater entering the ocean will tend to be deflected to the right under Coriolis force, and sets up a counterclockwise circulation in the Port (Gay, 2018) which would manifest as a northwesterly current at the site of the Duck Flats. The continued strong northwesterly transport into September at the Duck Flats (when discharge was still high) but not the VMT ("upstream" of the head of the Port) supports this idea.

In the autumn/winter months, the PVD at the VMT (fig. 21) show easterly transport prevailing in the surface currents. To look more closely at the details that are difficult to discern in the equally scaled plots in figures 21 and 22, the PVD may be rescaled to allow the scaling of each plot to vary based on the data for just that month (i.e. "zooming" in to each month). At the VMT (fig. 24) one can see tidal oscillations that are occasionally disrupted by periods with more consistent directional transport. Those likely correspond to the equinox storms observed in the wind records (e.g. fig. 8). Months with relatively light winds (e.g. September) also show more oscillations, indicating that tidal motions tended to predominate at those times.

At the Duck Flats (fig. 25), tidal oscillations were more pronounced in the winter (January – March) and show much more complex motions, which is perhaps due to a more complicated interaction between winds, tides and discharge. Freshwater inputs at the head can also create eddies that can cause current directions to change considerably as they pass. Current directions essentially covered the entire compass rose in January – March and again in October – December (fig. 25). The weaker currents at the Duck Flats may also represent more "noise" caused by slack in the mooring system: The Duck Flats mooring has a rather large scope, and part of the signal will be the buoy moving around on its mooring, and part of the signal will be from when the buoy is taut on its mooring and water is moving past it. By comparison the VMT buoy mooring has much less scope for movement and will tend to have less related variability. Note also that there were subtle differences in wind directions during those periods (fig. 9) that would also lead to variability in surface currents.

The surface current vector plots shown here highlights the complexity of the surface currents in Port Valdez; the PVD plots show how winds, tidal variations, and discharge interact in complicated ways, and a simple visualization such as done here cannot tease apart the various influences easily. Surface currents in Prince William Sound often manifest as a "Spirograph" type pattern, where tidal ellipses are superimposed over mean flows (Okkonen and Belanger, 2008), and that appears to be the case in Port Valdez as well. A better description of current variability can be accomplished with a more dynamical approach where the various components are explicitly modelled (e.g. see Wang et al., 2012); that kind of effort would require a much more considerable time commitment than devoted to this report (e.g. When the PWS Science Center engaged a physical oceanographer to develop a model for PWS it involved a full time researcher working for two years).

Conclusions

The analysis done here shows the patterns one would expect of meteorological and oceanographic observations in a subarctic region with a large tidal range. The main observations may be summarized as follows:

- Air and water temperatures, and solar radiation followed a seasonal sinusoid with maxima in August and minima in February. Temperatures were slightly cooler at the Duck Flats buoy than at the VMT buoy.
- Relative humidity was high at both sites and followed the seasonal temperature pattern.
- Air pressure was similar between both sites and driven by large-scale atmospheric circulations.
- Winds were mostly from the east in autumn and winter, with maximum gusts on order of 25 knots, and transitioned to weak easterly and stronger westerly sea breezes during the summer months.
- Wave directions tended to match wind directions. The highest waves were observed during autumn/winter storms and were of considerable size, just under nine feet tall; spring/summer sea breeze generated waves were one to three feet.
- A temperature climatology was constructed that shows a persistent warming pattern over the past 114 years.
- In recent years (2019 onward), winters have been warmer than average while summers have been cooler than average, which may be combination of the overall regional warming, with localized cooling due to ice melt.
- Surface currents in Port Valdez are complex and result from the interplay of winds, tides, and freshwater inputs. At the VMT, surface currents were northeasterly during summer sea breezes, and were northwesterly at the Duck flats. Tidal oscillations were visible during calmer periods, and surface current directions were very variable during autumn and winter.

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Figures

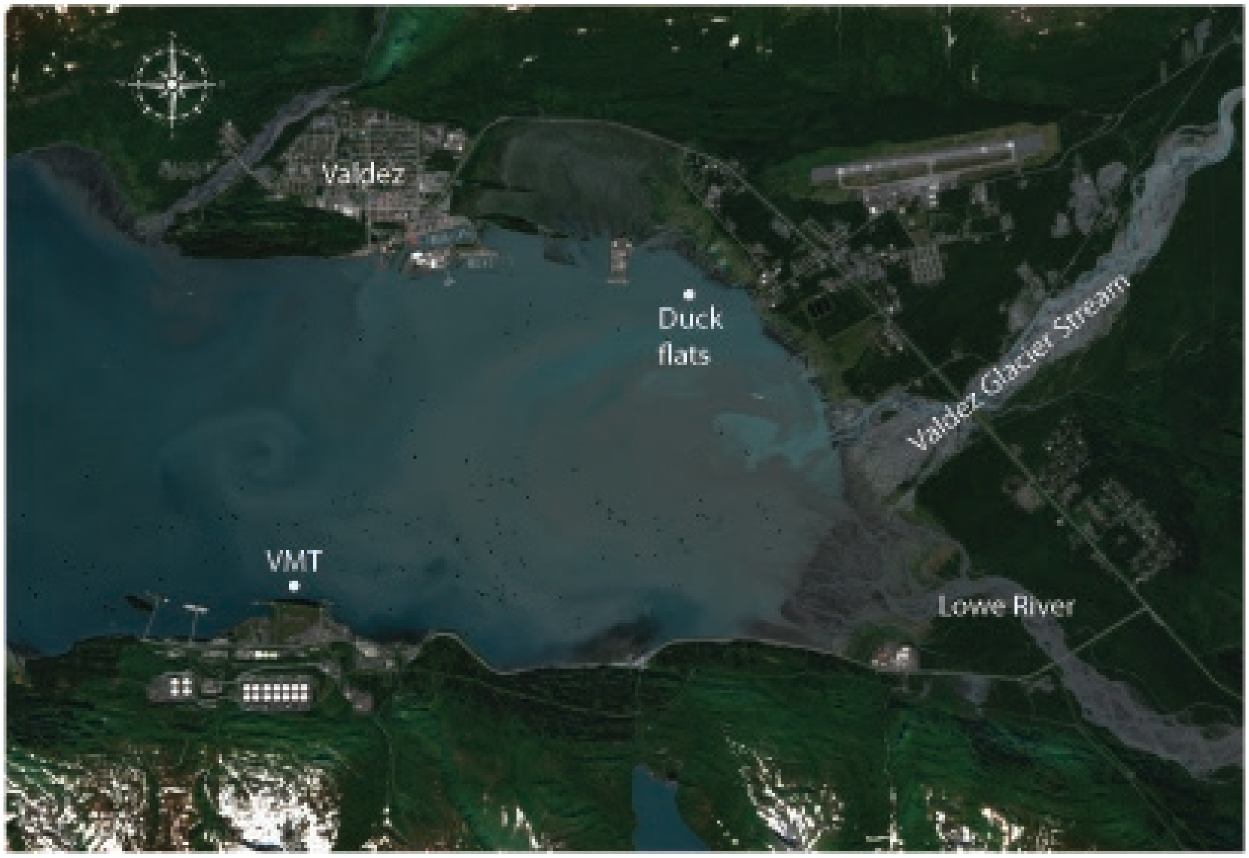

Figure 1: Sentinel 2 satellite image of Port Valdez (taken June 22, 2022) showing the location of the two buoys and other geographic locations mentioned in the report.

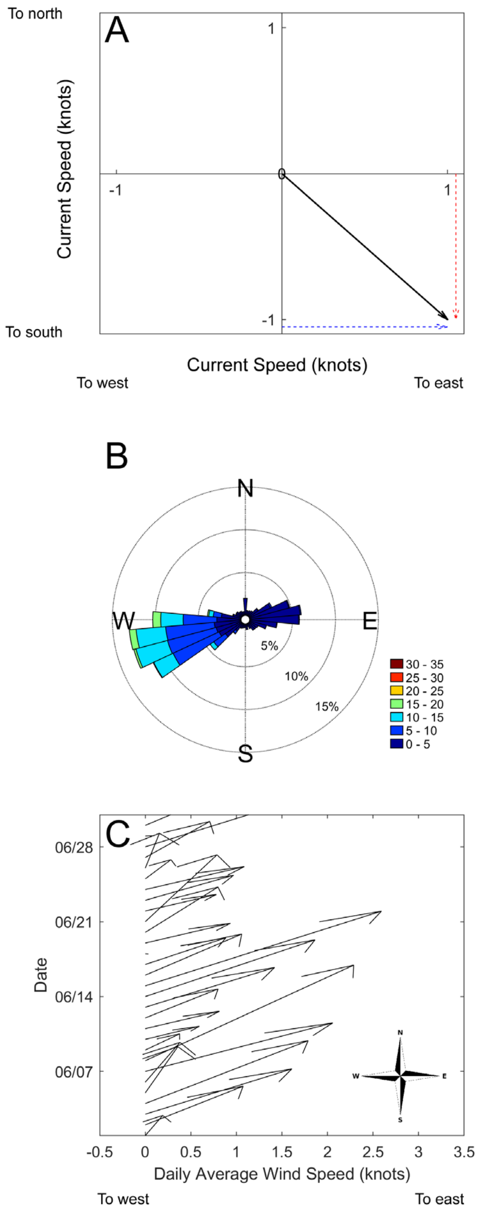

Figure 2: Examples of the visualization of vector data. Panel A: An example of a vector observation, for example a 1-knot current to the southeast. The vector may be broken up into two components, an east-west component (blue arrow) and a north-south component (red arrow). Panel B: An example wind rose summarizing wind observations made in June 2020. The bars indicate 10° bands of wind directions (direction from), the lengths of the bars indicate frequency (how often winds in each band were observed), and the color encodes wind speeds. Panel C: An example of a quiver plot, showing daily average wind vectors (direction in which the air is traveling) for June 2020. The angle of the arrow indicates the direction on the compass rose, and the length of the arrow indicates average wind speed, scaled to match the bottom axis.

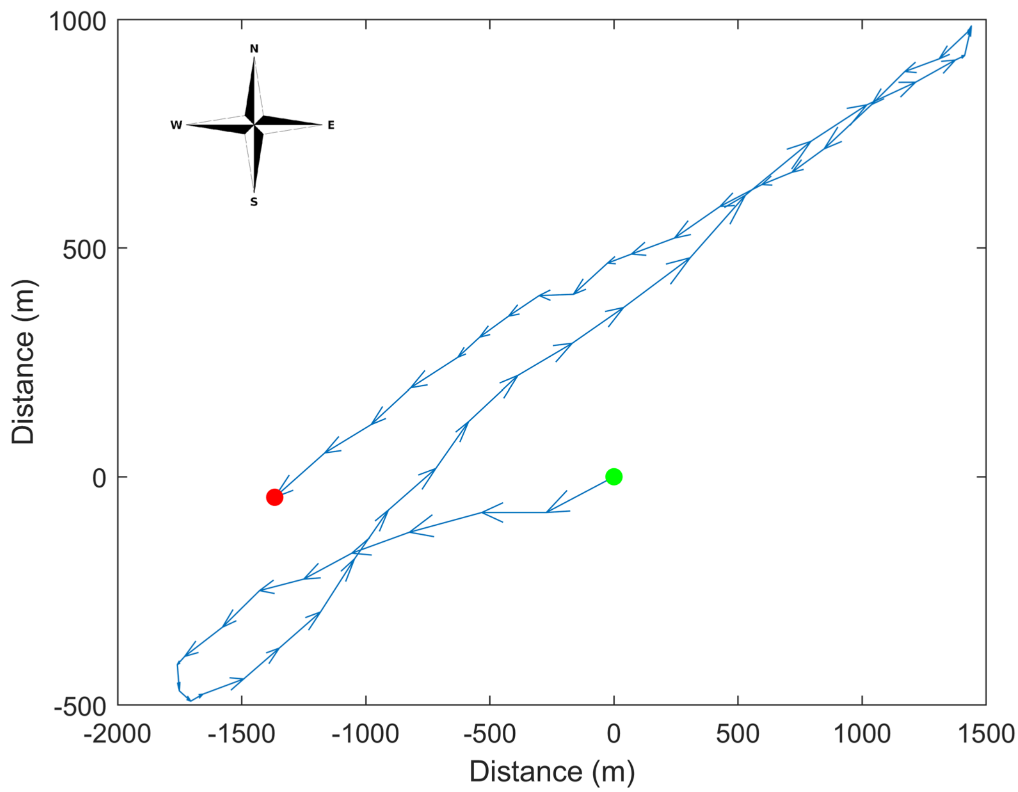

Figure 3: An example of a Progressive Vector Diagram, using 12 hours of surface current observations from the VMT buoy. The green dot indicates the start of the time series, and the red dot indicates the end. The vector has been scaled to show the distance and direction travelled during each 15-minute period (assuming a constant current velocity). In this example the tide was ebbing at the start of the period, reached low tide, then changed direction as the tide began to flood. The direction of the currents changed again after high tide. The distance between the green start dot and the red end dot indicates the overall transport over the 12-hour period (~1500 meters to the east).

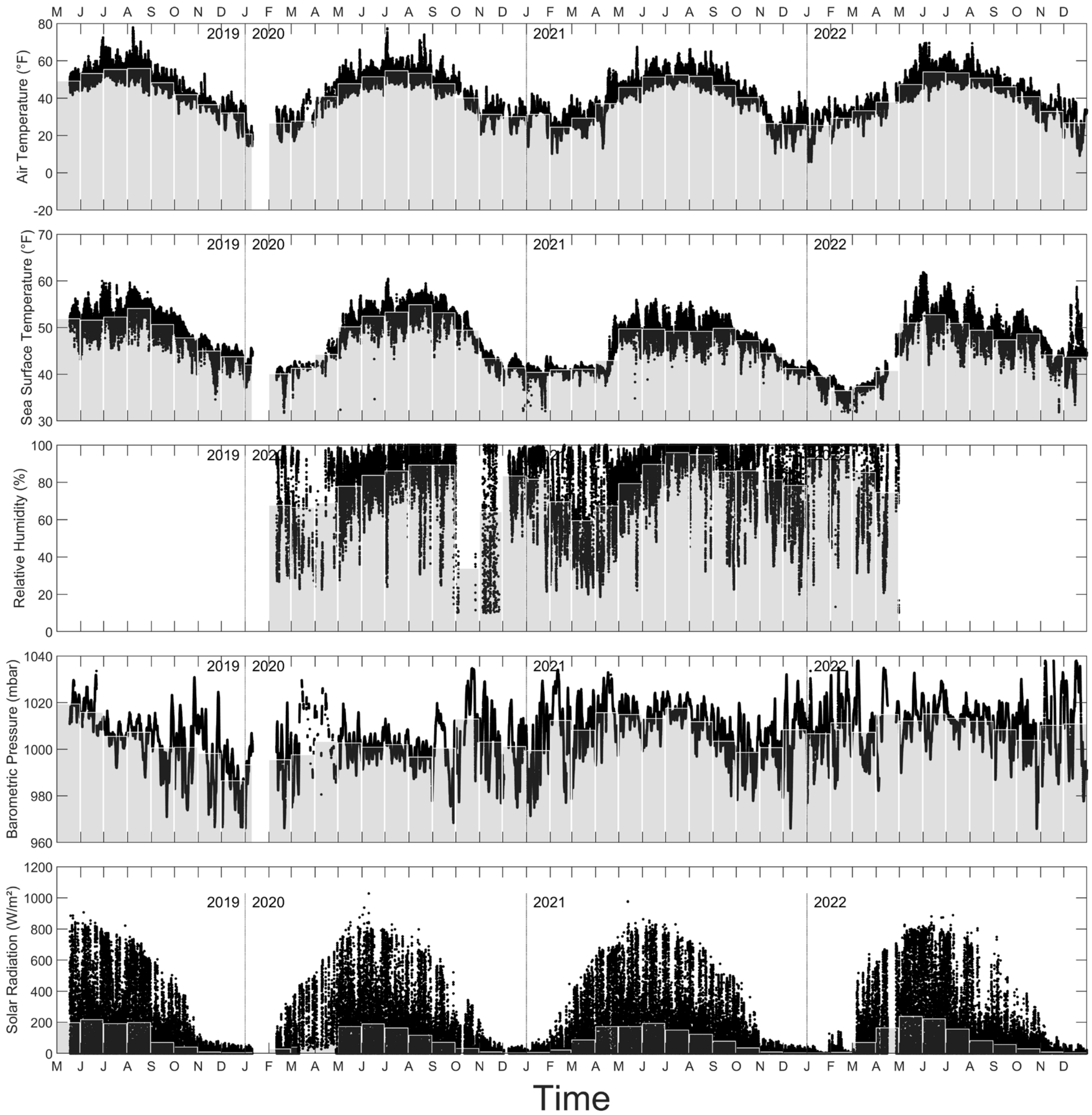

Figure 4: Scalar observations at the VMT buoy, including air (top panel) and water (2nd panel) temperatures, relative humidity (3rd panel), barometric pressure (4th panel), and solar radiation (bottom panel). Black dots are observations, bars indicate monthly averages.

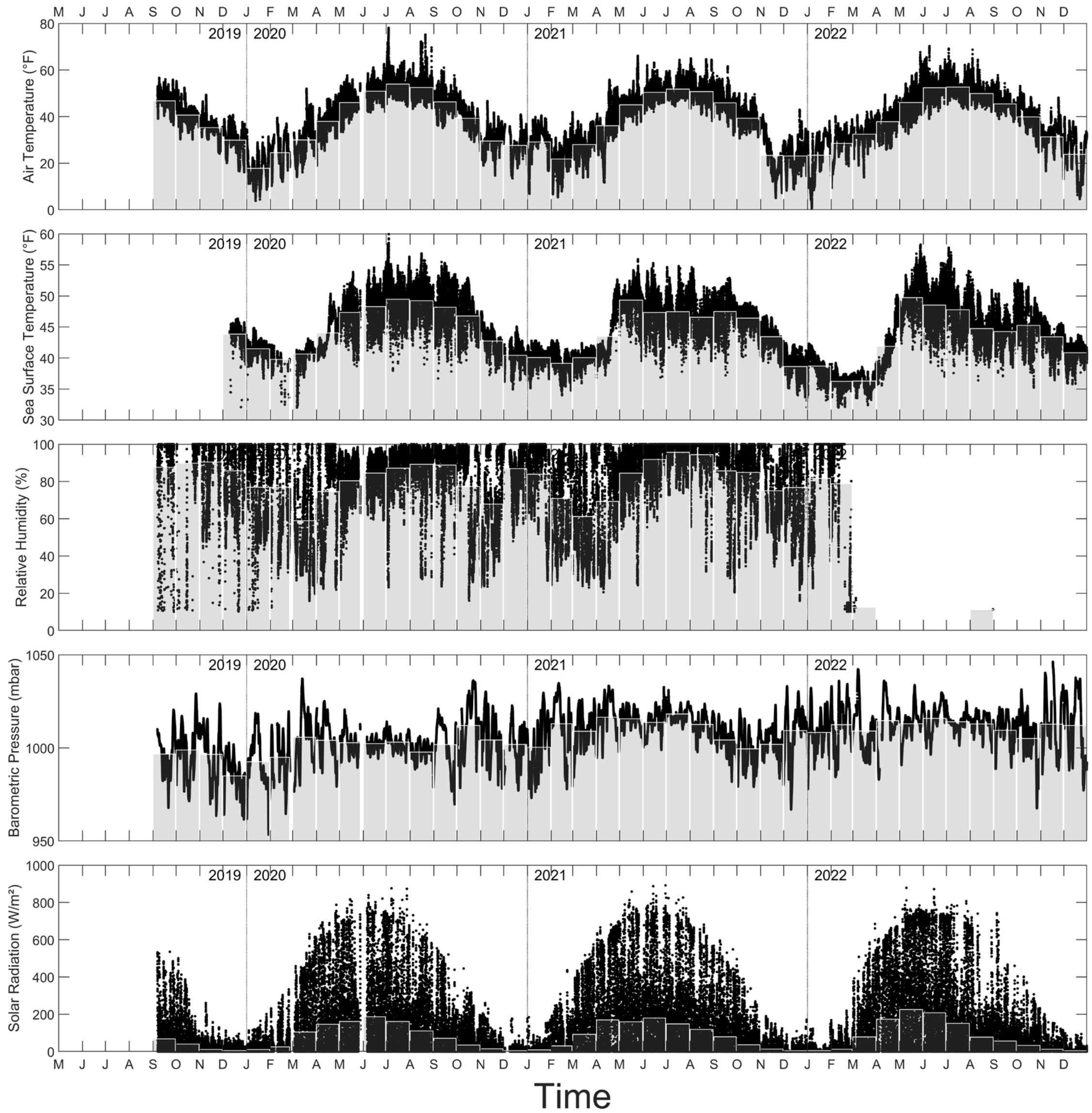

Figure 5: Scalar observations at the Duck Flats buoy, including air (top panel) and water (2nd panel) temperatures, relative humidity (3rd panel), barometric pressure (4th panel), and solar radiation (bottom panel). Black dots are observations, bars indicate monthly averages.

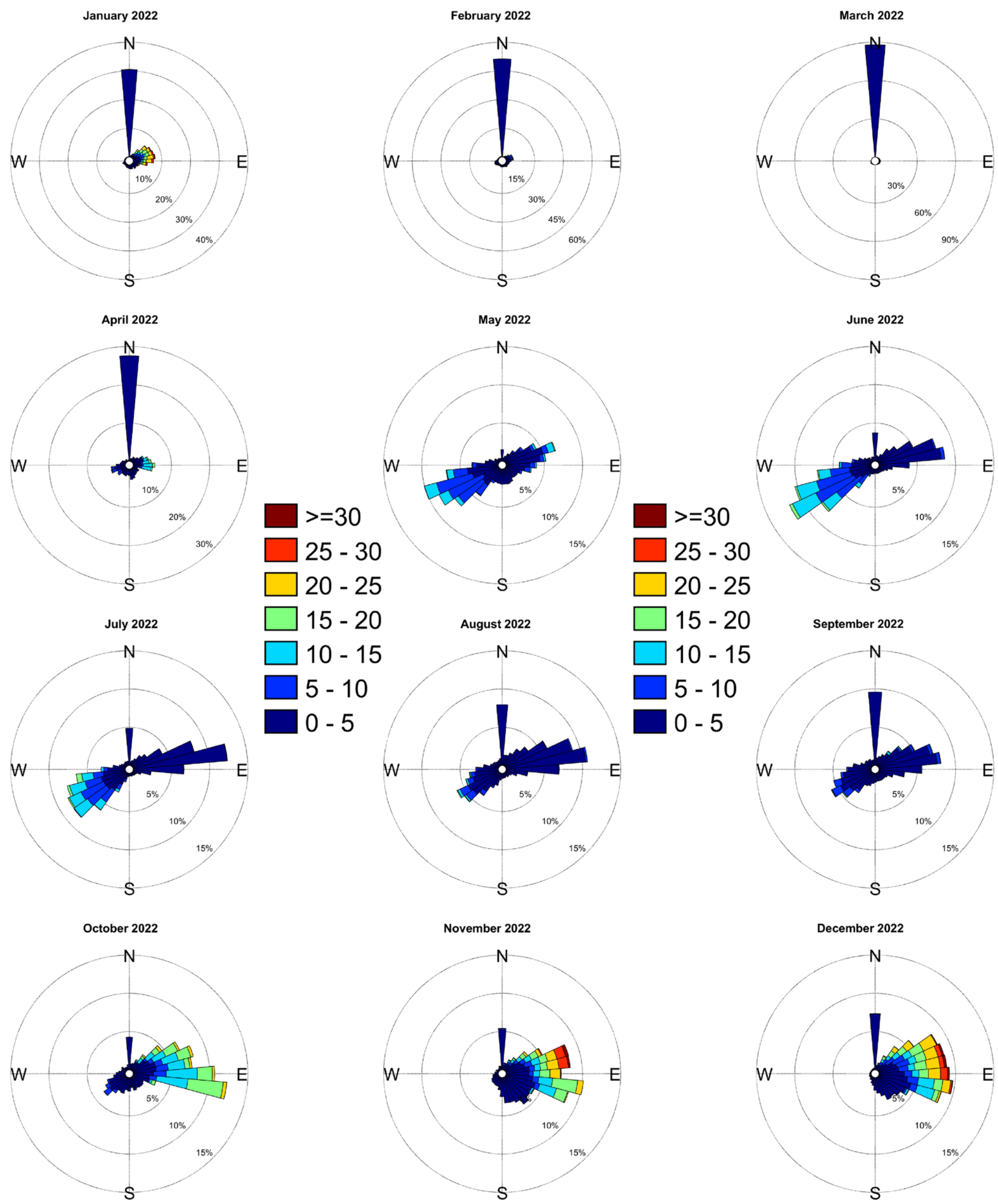

Figure 6: Monthly wind roses at the VMT buoy. Bars indicate the direction from and the color scale indicates wind velocities. Color scale is equivalent among the figures (i.e., all the figures are directly comparable). When the wind equals zero (caused by very calm periods, or when the anemometer ices up), vector multiplication results in the direction also recording as zero (i.e. due north).

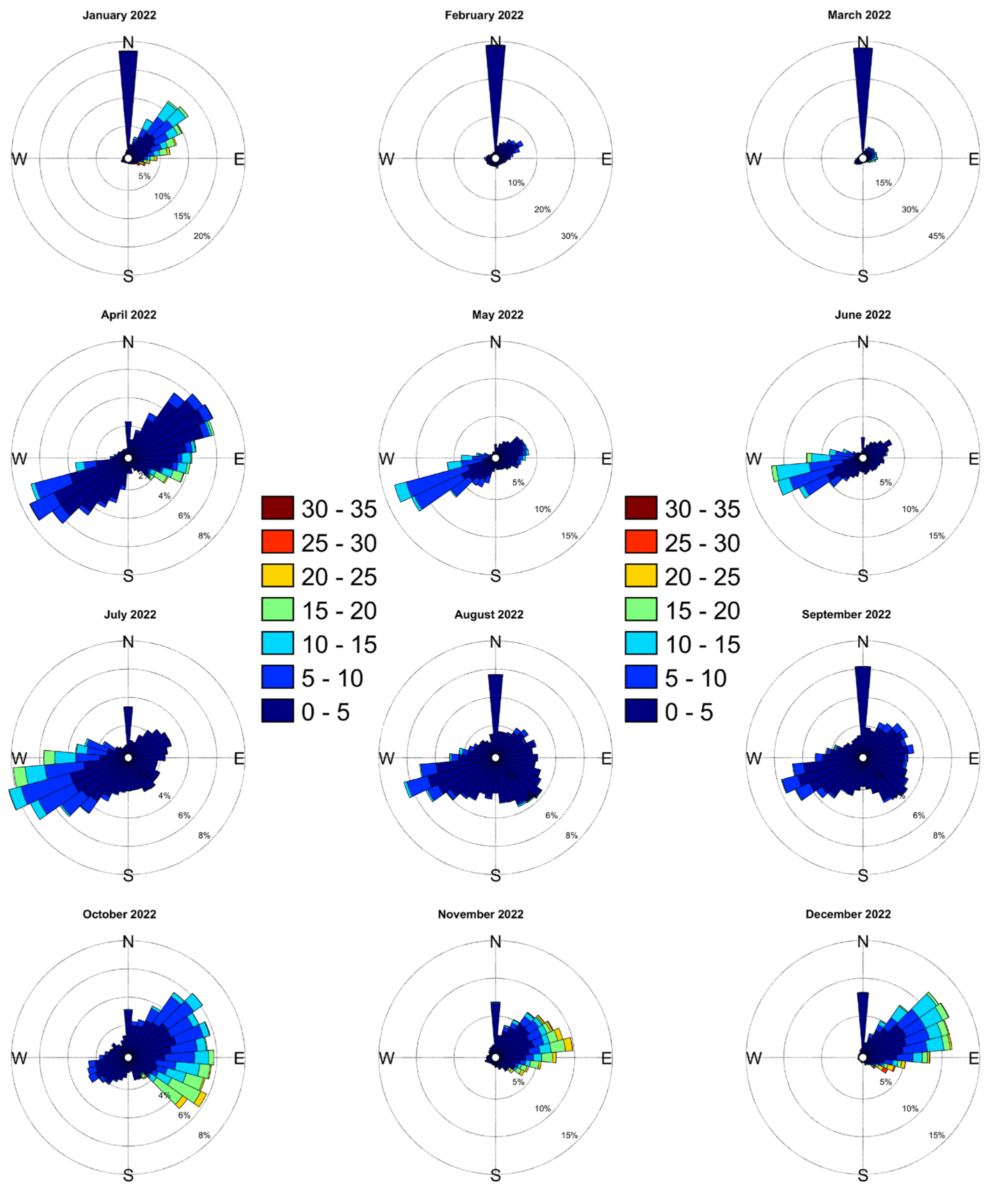

Figure 7: Monthly wind roses at the Duck Flats buoy. Bars indicate the direction from and the color scale indicates wind velocities. Color scale is equivalent among the figures (i.e., all the figures are directly comparable). When the wind equals zero (caused by very calm periods, or when the anemometer ices up), vector multiplication results in the direction also recording as zero (i.e. due north).

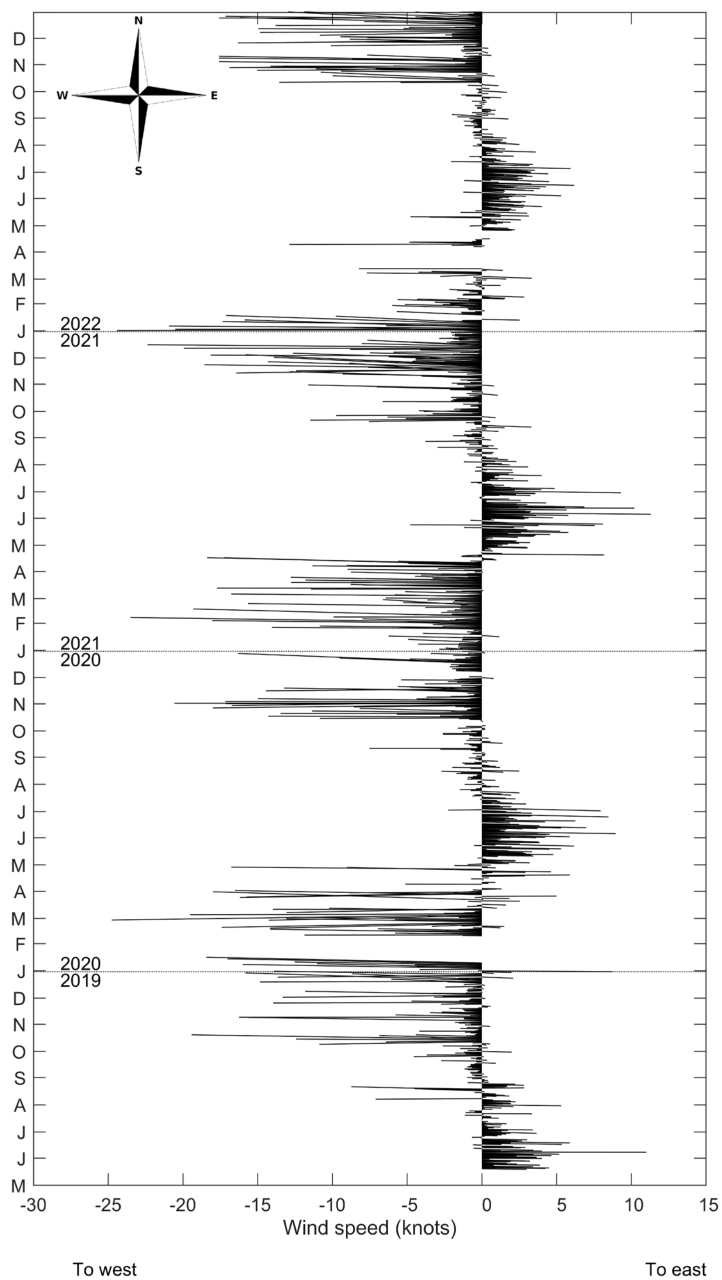

Figure 8: Quiver plot of average daily wind vectors at the VMT buoy. The length of each stick indicates wind speed and the angle indicates the direction from.

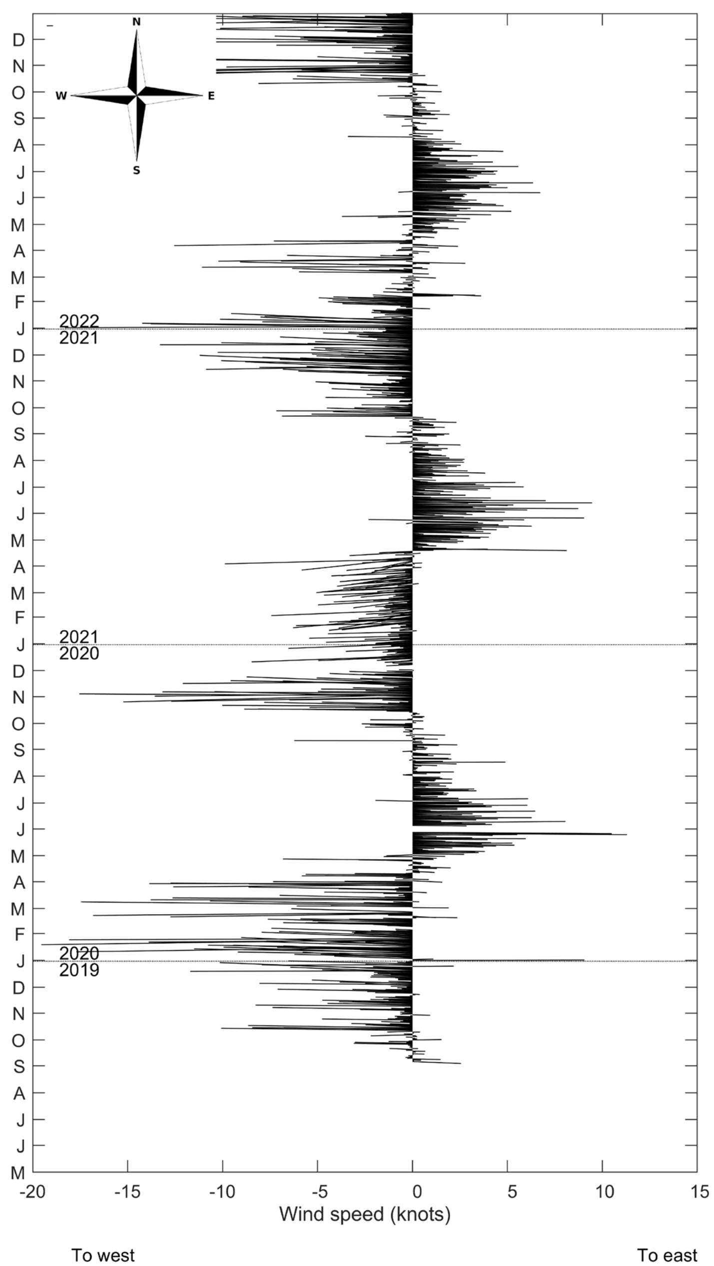

Figure 9: Quiver plot of average daily wind vectors at the Duck Flats buoy. The length of each stick indicates wind speed and the angle indicates the direction from.

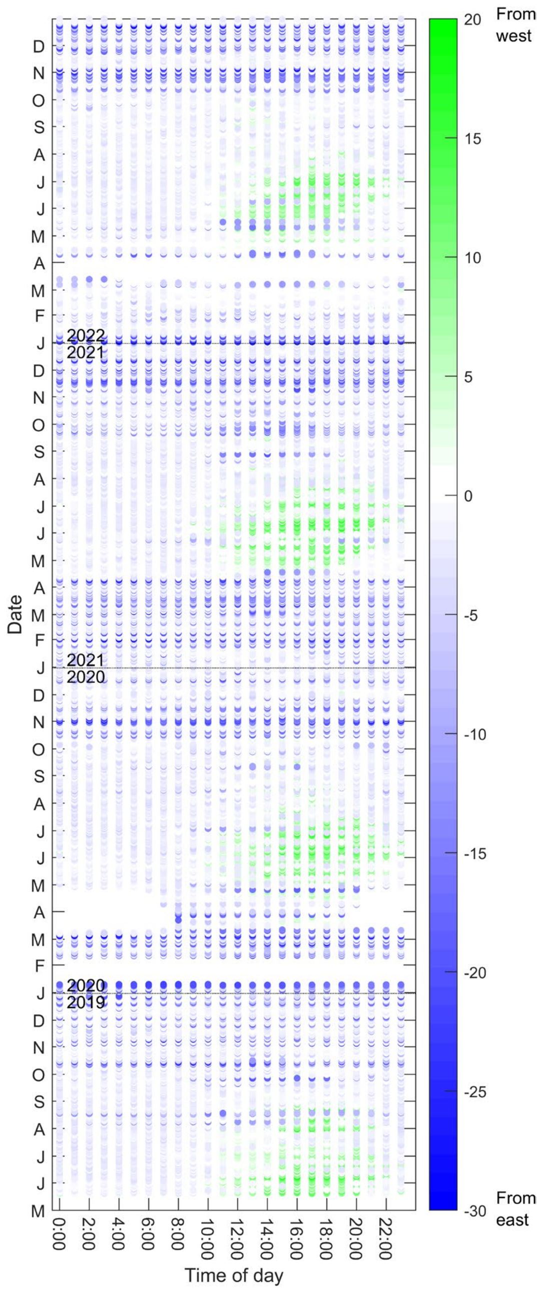

Figure 10: Daily east-west winds at the VMT buoy. Only the east-west component of the winds are shown; green colors scale with the strength of westerly winds, and blue colors scale with the strength of easterly winds.

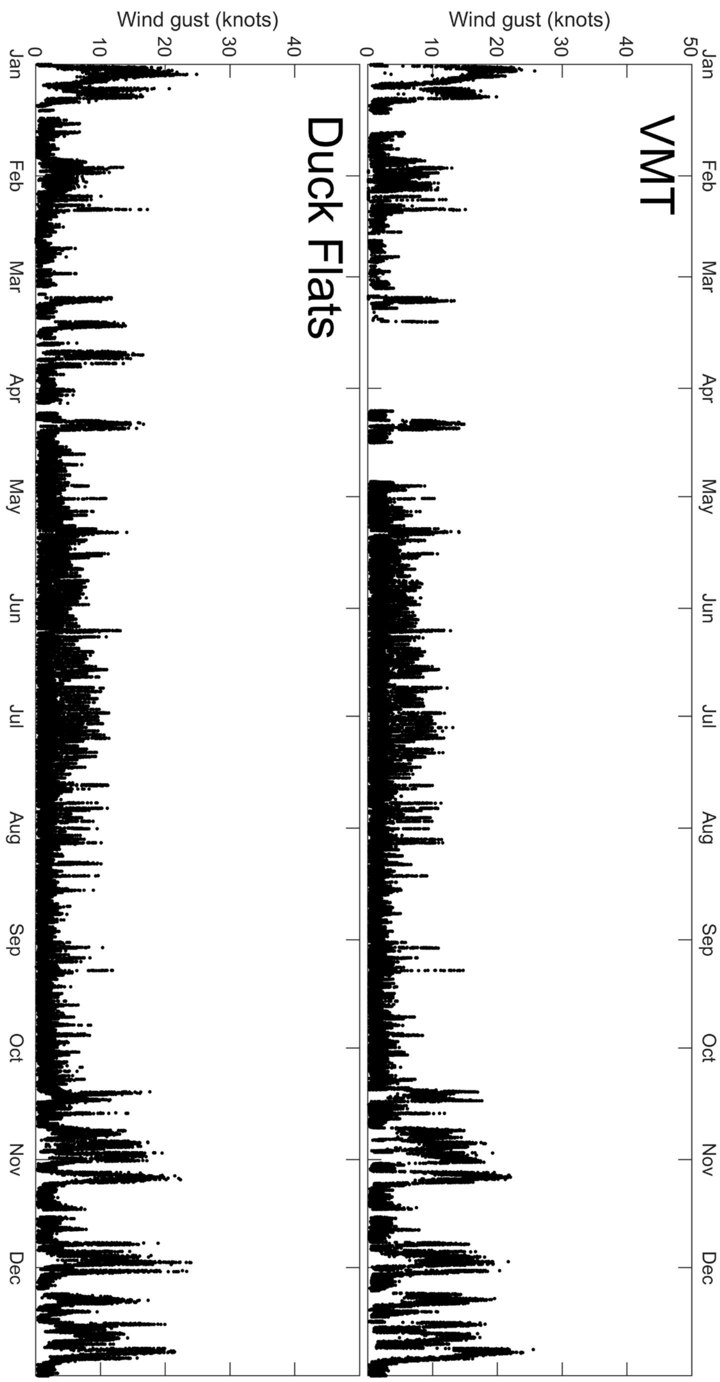

Figure 11: Wind gust time series at the VMT (top panel) and Duck Flats (bottom panel).

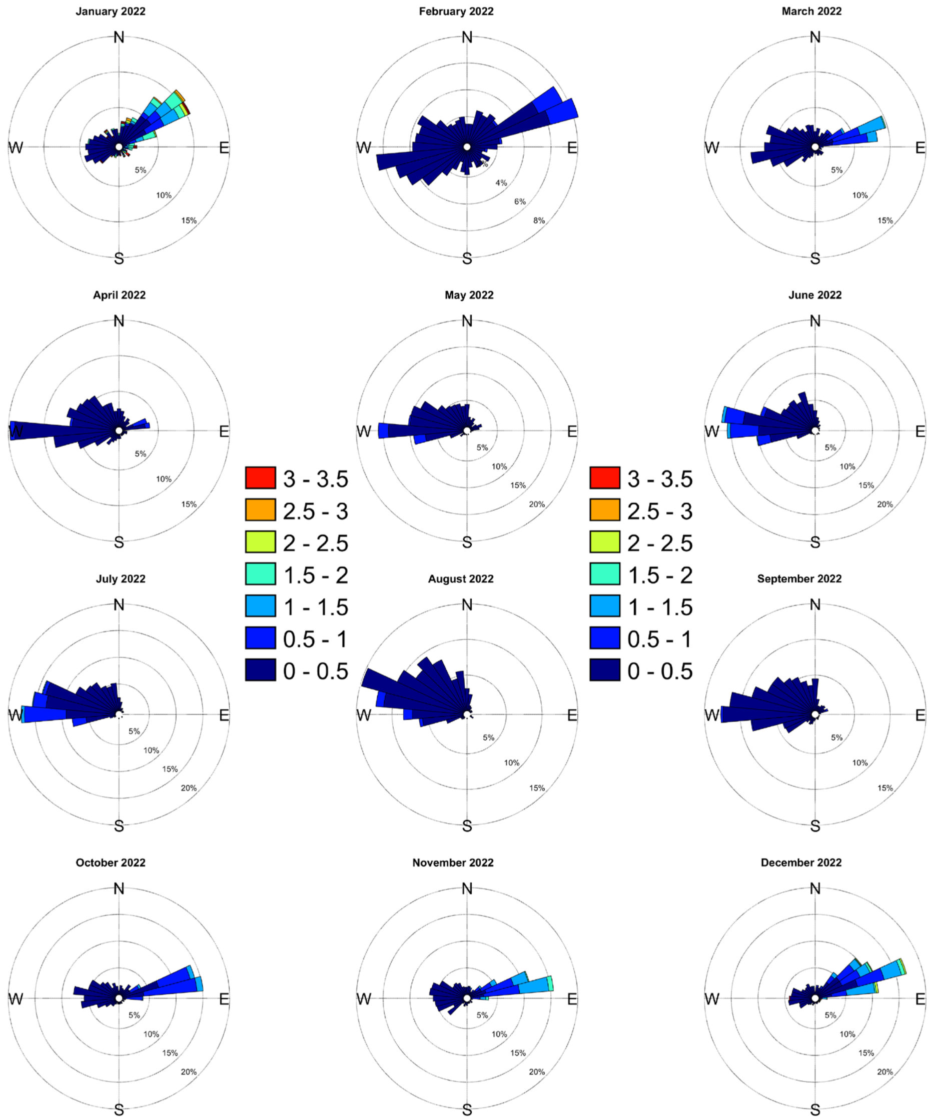

Figure 12: Monthly wave roses (feet) at the VMT buoy. Bars indicate the direction to and the color scale indicates significant wave heights. Color scale is equivalent among the figures (i.e., all the figures are directly comparable).

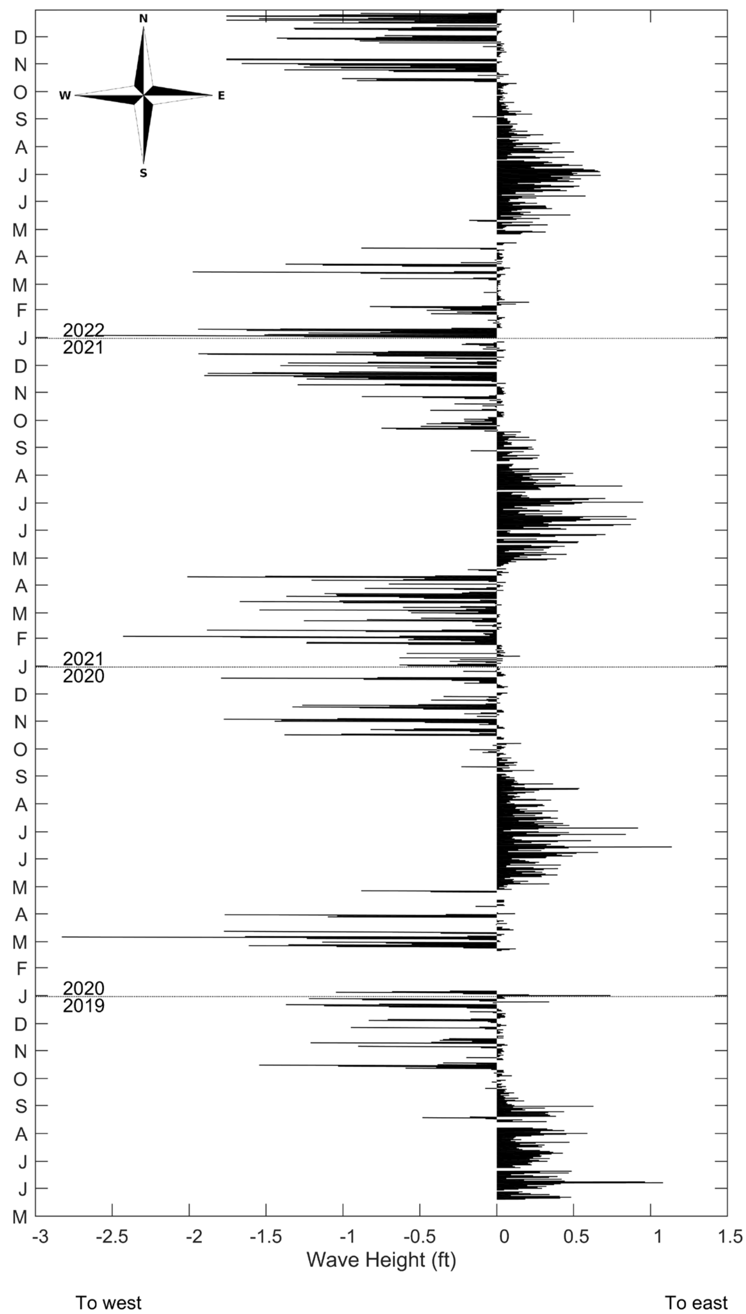

Figure 13: Quiver plot of average daily wave vectors (direction and height in feet) at the VMT buoy. The length of each stick indicates wave height and the angle indicates the direction the waves are travelling in.

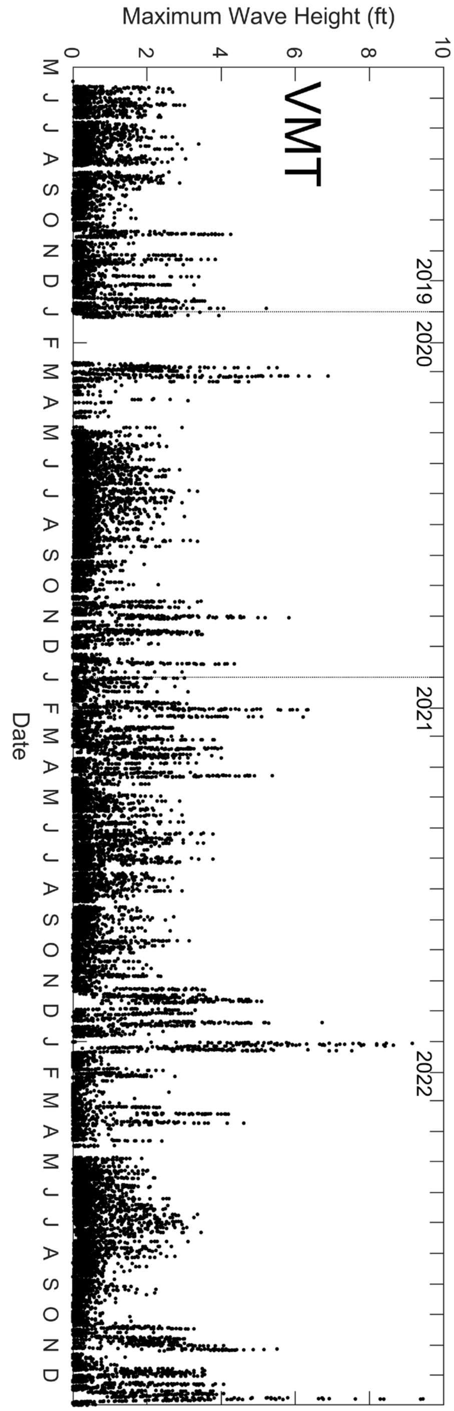

Figure 14: Time series of maximum wave heights observed at the VMT buoy.

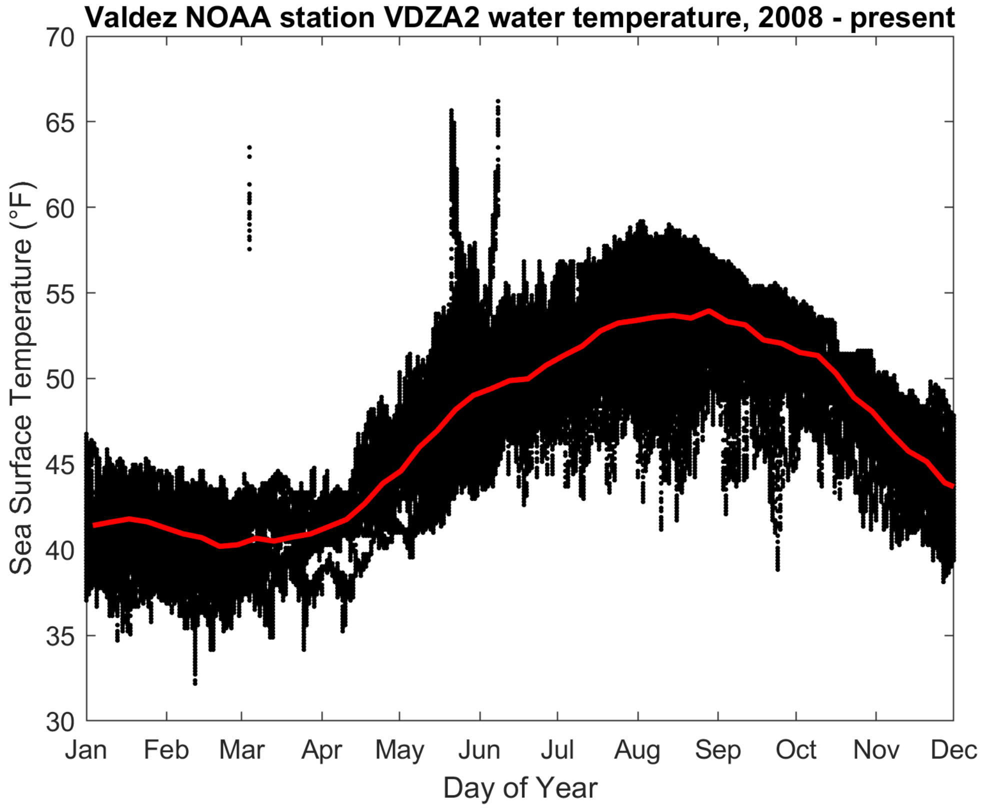

Figure 15: Annual average temperature cycle at the NOAA tide station VDZA2 in Valdez harbor. Air temperature data was overlaid from all years (2009-present) by day of year. Dots indicate observations and the red line indicates the weekly average.

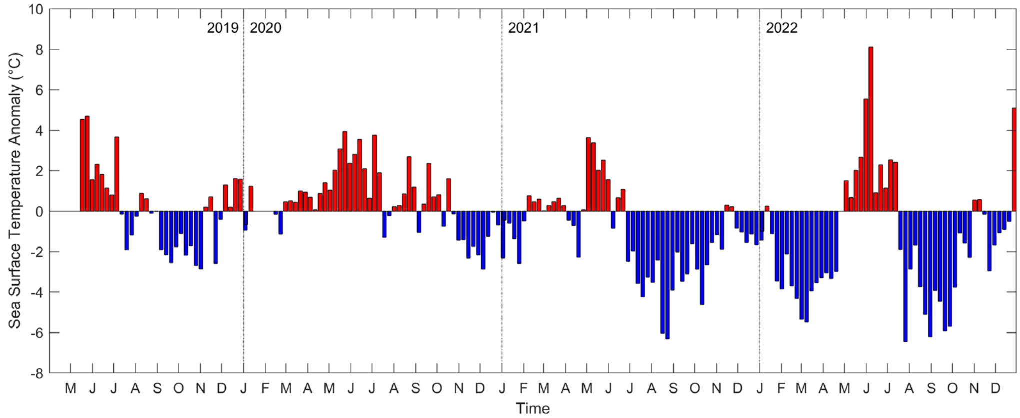

Figure 16: Weekly sea surface temperature anomalies at the VMT buoy. Anomalies are the departure of weekly average temperatures from the weekly average at the VDZA2 tide station.

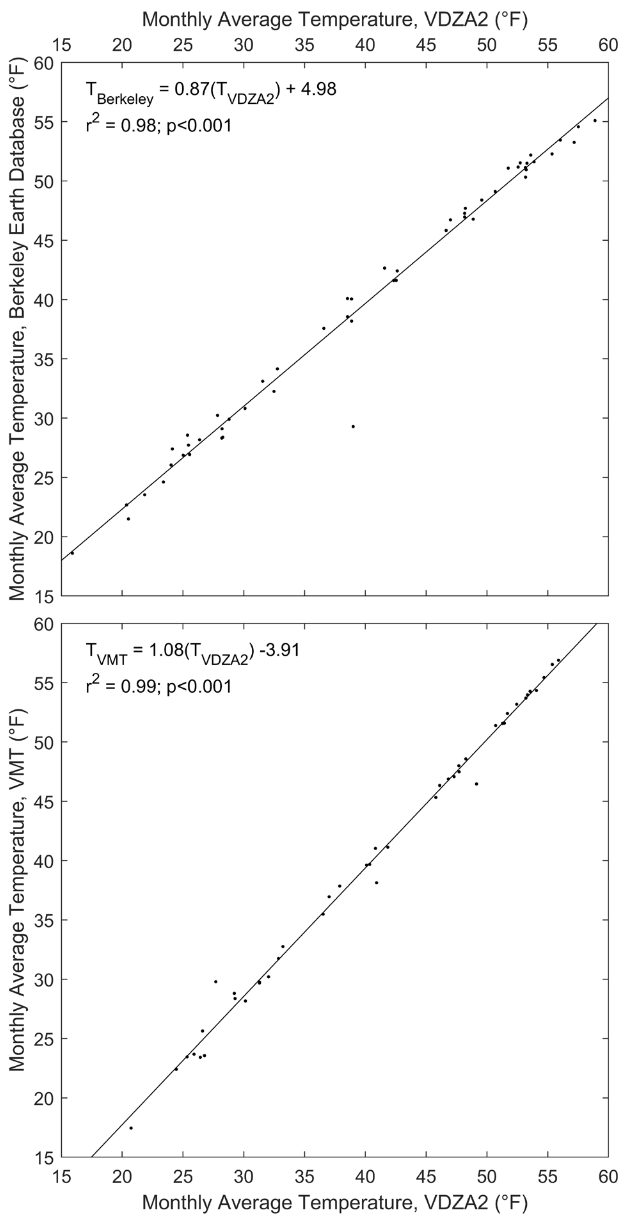

Figure 17: Top panel: Comparison of monthly average air temperature estimates from the Berkeley Earth database and monthly average temperatures calculated at the VDZA2 station at months where the two time series overlapped. Bottom panel: Comparison of average temperatures calculated at the VMT buoy and VDZA2 where the two time series overlapped. The regression lines were fit by least squares.

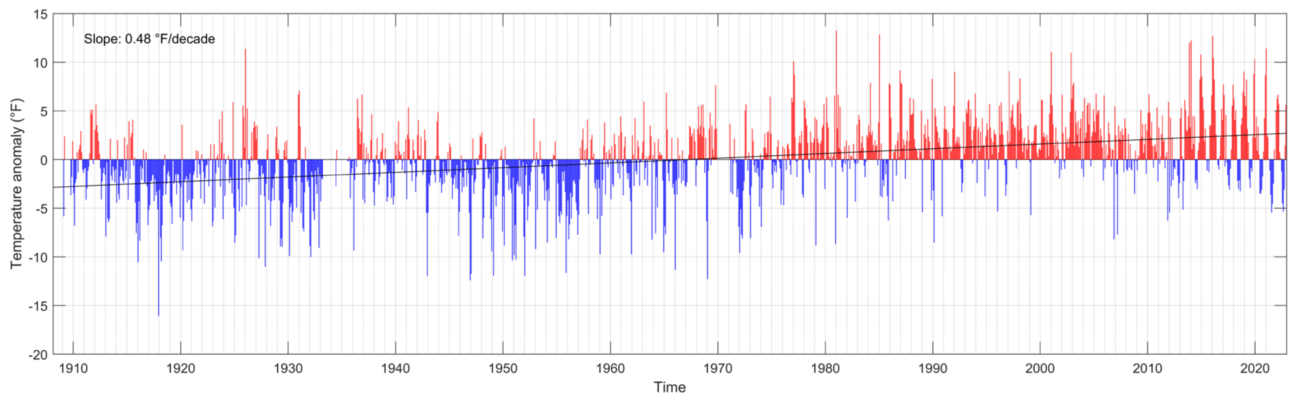

Figure 18: Air temperature anomalies from the combined Berkeley Earth database, VDZA2, and VMT monthly temperature estimates, 1908 - 2022.

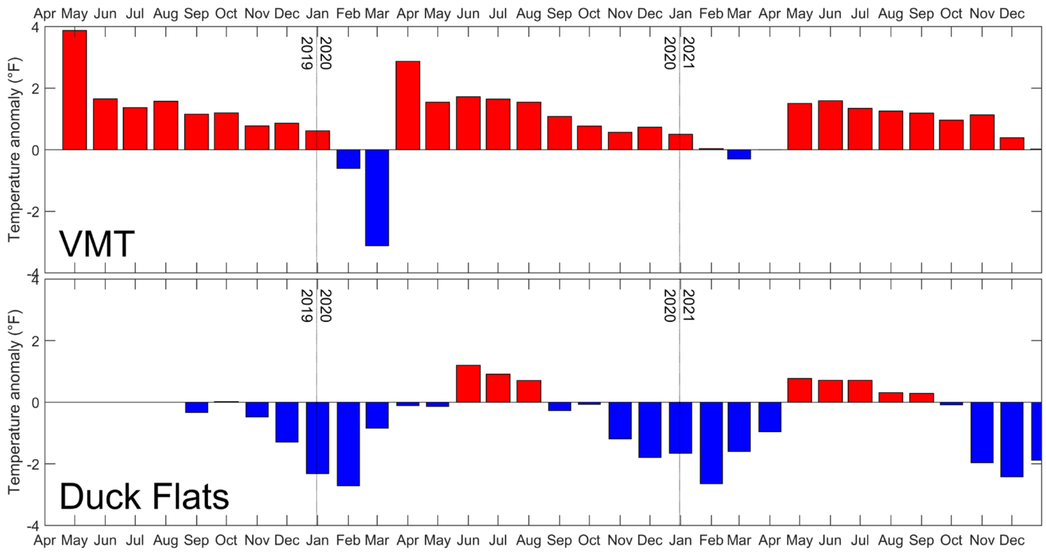

Figure 19: Monthly average air temperature anomalies at the VMT. This is the same data as in figure 18, but scaled to the time period the VMT buoy has been deployed.

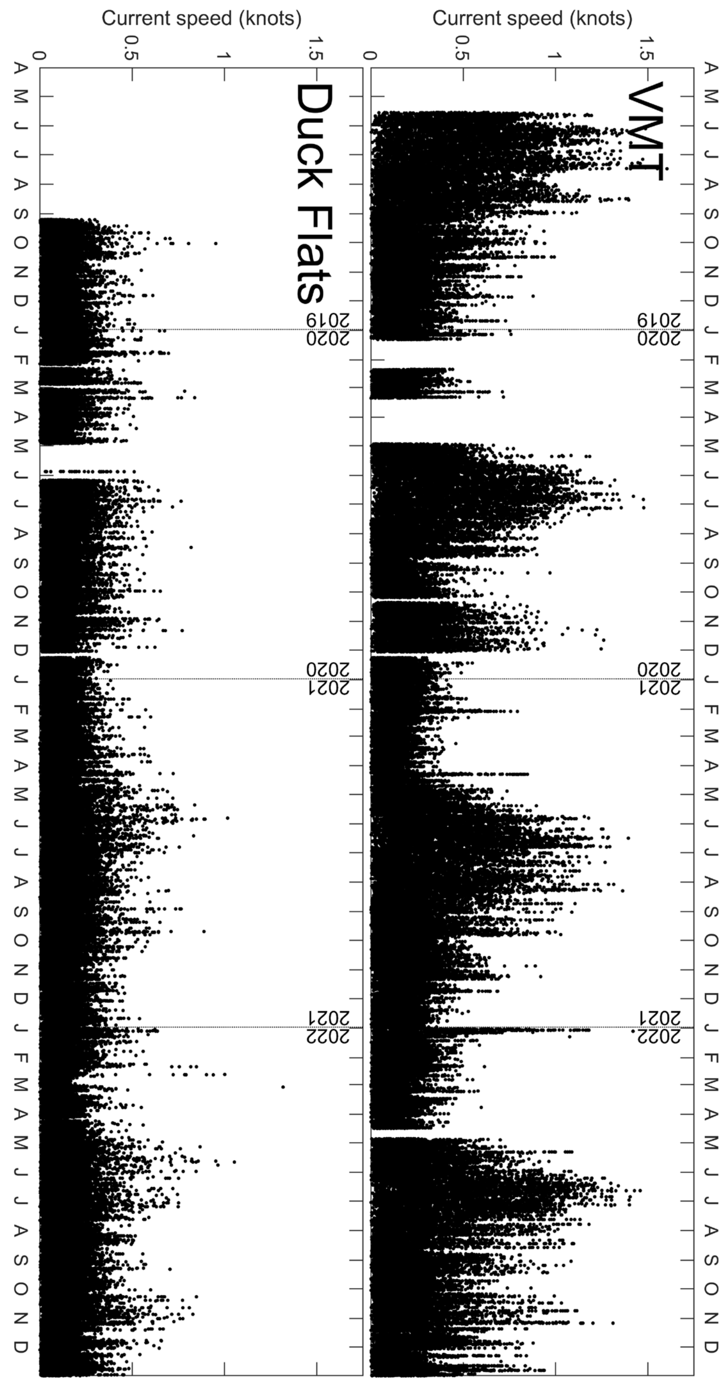

Figure 20: Current speed time series at the VMT (top panel) and Duck Flats (bottom panel).

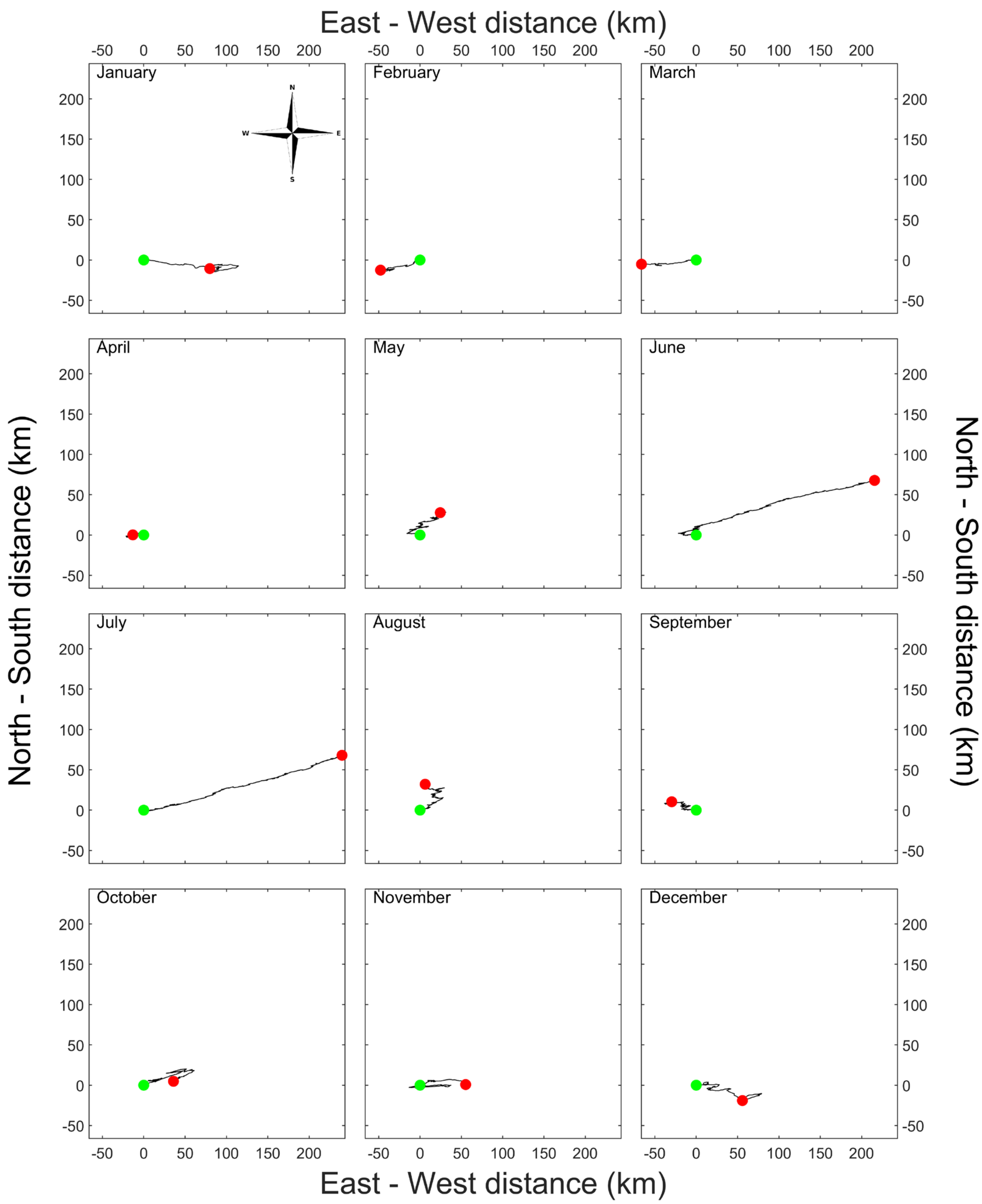

Figure 21: Monthly PVD of surface currents at the VMT buoy. All axes are scaled to be the same to make each vector track comparable. The bottom axis indicates direction east-west, with westerly directions negative and easterly ones positive, the side axis indicates direction north-south, with southerly directions negative.

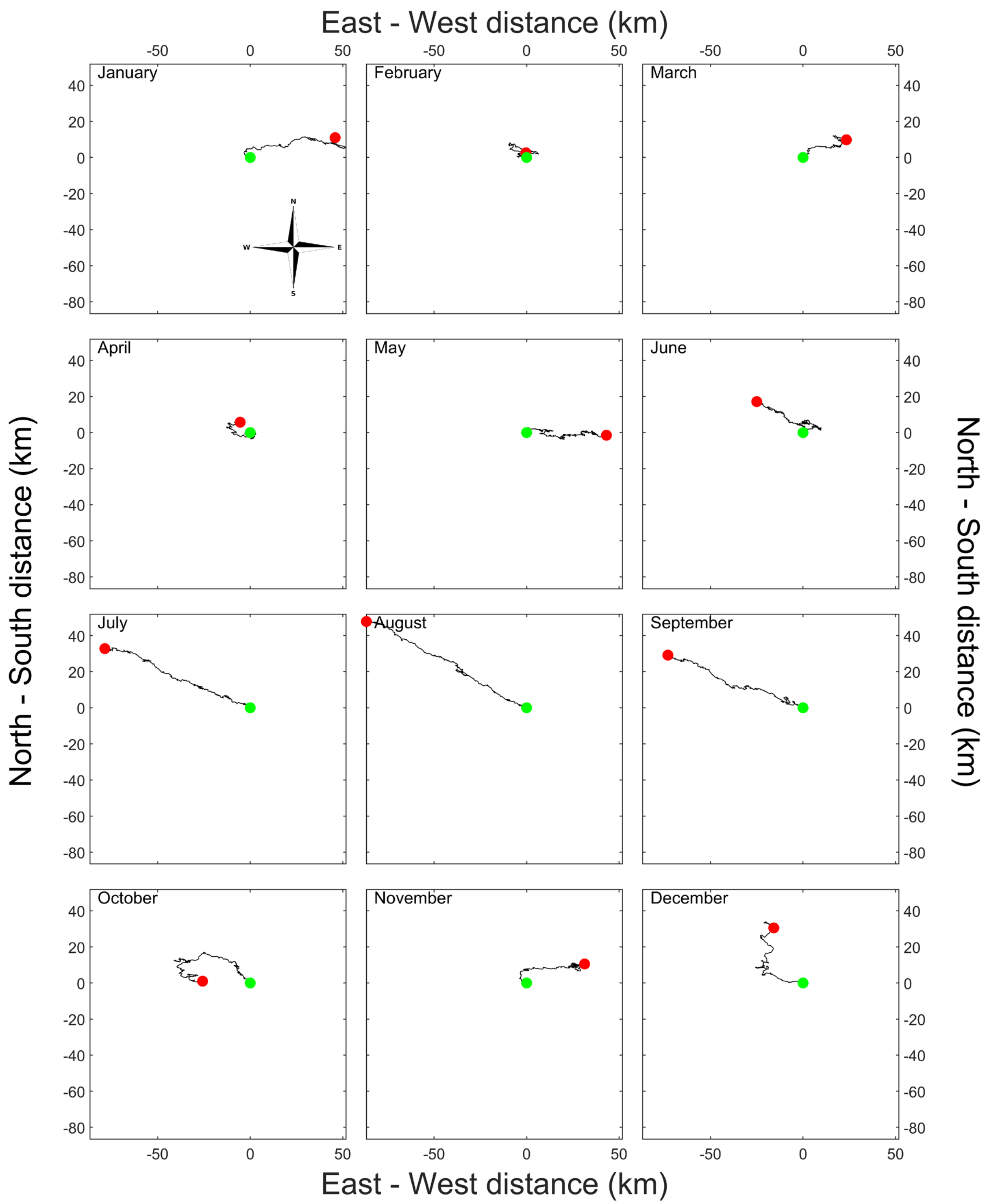

Figure 22: Monthly PVD of surface currents at the Duck Flats buoy. All axes are scaled to be the same to make each vector track comparable, and are equivalent to the axis scaling in figure 21.

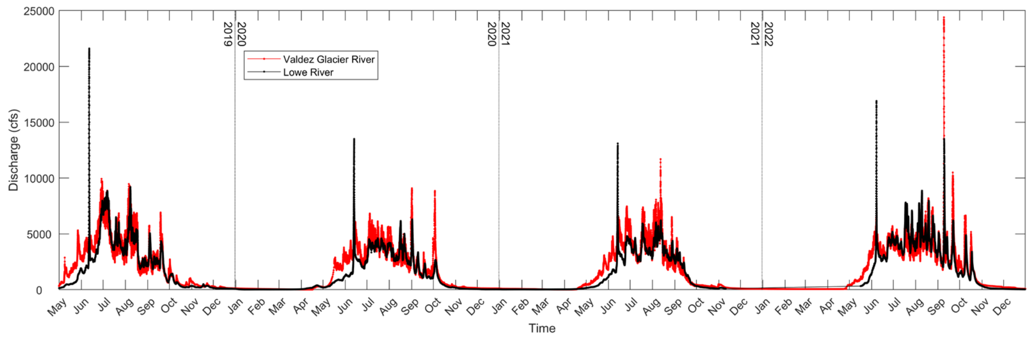

Figure 23: Hydrograph of discharge at the Lowe River (USGS station 15226620) and Valdez Glacier Stream (USGS station 15227090). Discharge data was downloaded from waterdata.usgs.gov.

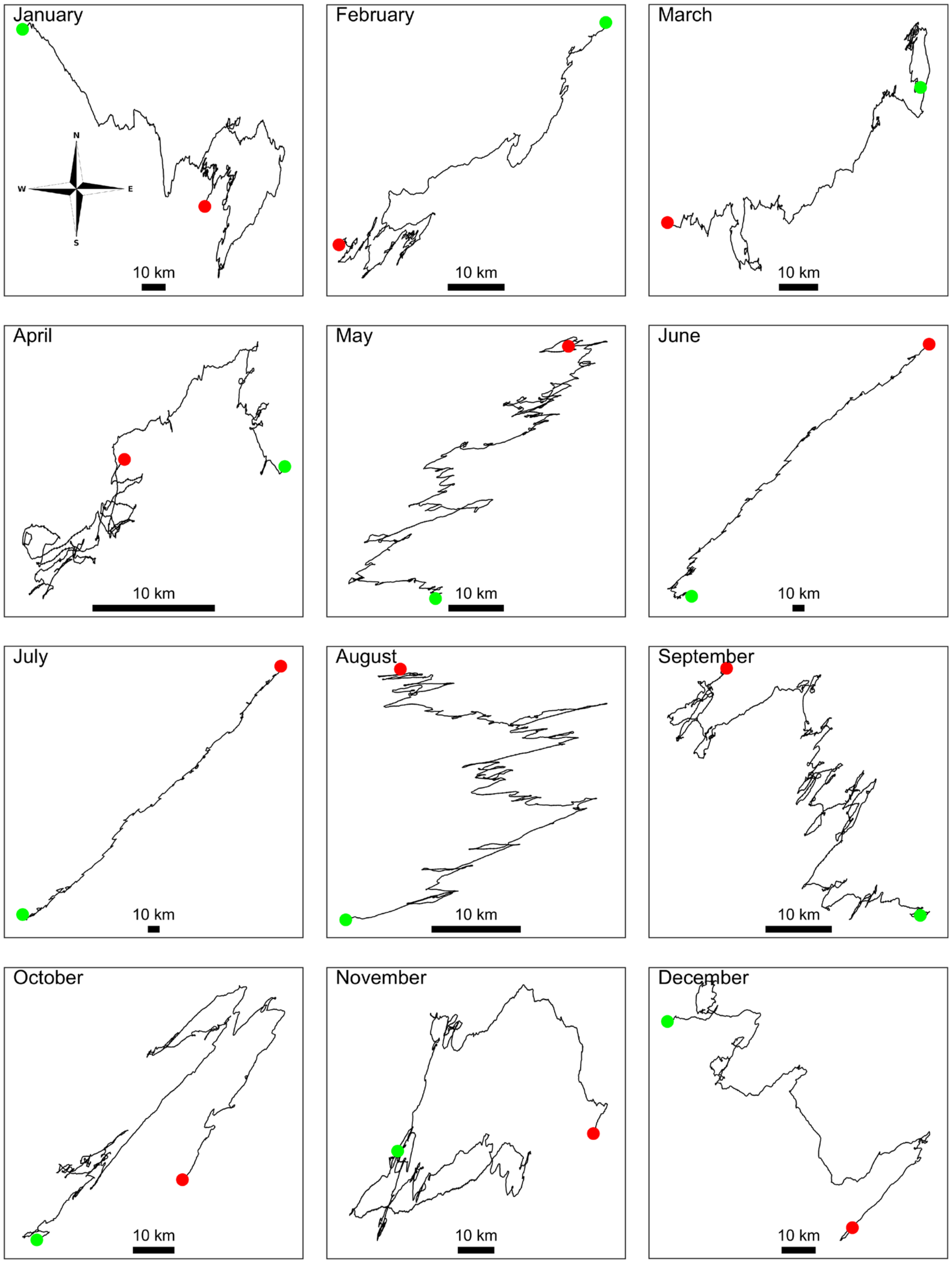

Figure 24: Monthly PVD of surface currents at the VMT buoy. All plots are the same data as figure 21, but the axes have been rescaled for each month to the limits of the data for that month. Each plot has been given a 10 km scale bar to give an impression of the scaling.

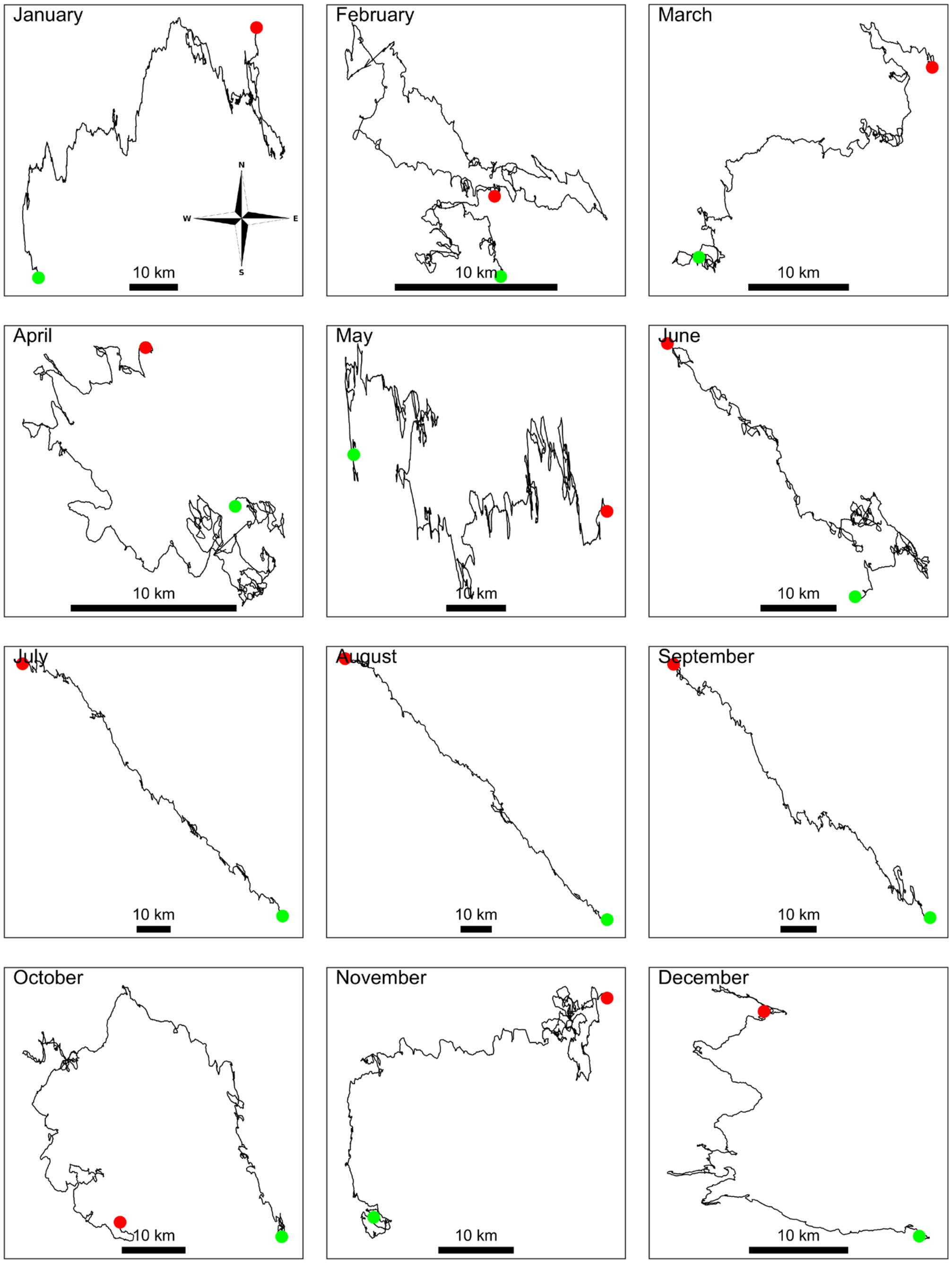

Figure 25: Monthly PVD of surface currents at the Duck Flats buoy. Scaling has been done as described in figure 24.

Appendix 1: Table of averages and minimum/maximum values at the VMT buoy, by month.

Month	Air Temperature (°F)	Water Temperature (°F)	Relative Humidity (%)	Barometric Pressure (%)	Solar Radiation (W/m²)	Wind Speed (knots)	Wind Gust (knots)	Significant Wave Height (ft)	Max. Wave Height (ft)	Current Speed (knots)
January	28.44 5.77 - 44.31	41.35 32.10 - 57.13	87.29 21.51 - 100.00	1000.31 966.18 - 1033.57	4.42 0.00 - 146.88	5.21 0.00 - 31.49	9.08 0.00 – 31.49	0.43 0.00 - 3.87	0.76 0.00 - 7.20	0.17 0.00 – 1.42
February	27.25 10.24 - 41.53	39.90 31.75 - 54.97	78.56 13.28 - 100.00	1007.20 966.15 - 1037.45	12.49 0.00 - 446.49	4.55 0.00 - 34.77	7.73 0.00 – 34.77	0.38 0.00 - 3.58	0.69 0.00 - 6.34	0.14 0.00 - 0.80
March	30.74 -6.92 - 47.48	41.74 31.90 - 65.46	71.30 20.02 - 100.00	1007.41 965.13 - 1037.95	82.93 0.00 - 637.42	5.41 0.00 - 34.77	8.33 0.00 – 34.77	0.56 0.00 - 3.78	0.99 0.00 - 6.88	0.13 0.00 - 0.72
April	37.29 10.47 - 55.80	42.63 34.59 - 52.48	69.89 10.23 - 100.00	1011.64 980.56 - 1034.88	162.83 0.00 - 746.60	4.00 0.00 - 30.25	6.62 0.00 – 30.25	0.29 0.00 - 3.14	0.55 0.00 - 5.38	0.14 0.00 - 0.85
May	47.22 36.80 - 68.67	50.50 32.38 - 61.09	78.63 22.19 - 100.00	1011.16 988.68 - 1032.79	194.46 0.00 - 976.98	4.07 0.00 - 19.46	7.70 0.00 – 19.46	0.26 0.00 - 1.79	0.51 0.00 - 2.98	0.31 0.00 - 1.20
June	52.50 38.65 - 72.50	51.61 34.67 - 61.84	86.67 48.10 - 100.00	1011.23 991.38 - 1033.57	205.24 0.00 - 1027.90	4.75 0.00 - 19.98	8.83 0.00 – 19.98	0.37 0.00 - 2.18	0.69 0.03 - 3.78	0.48 0.00 - 1.49
July	54.01 44.69 - 77.36	51.42 41.57 - 60.44	91.47 24.08 - 100.00	1009.59 990.72 - 1024.78	165.15 0.00 - 888.57	3.60 0.00 - 21.23	7.30 0.00 – 21.23	0.33 0.00 - 2.21	0.63 0.03 - 3.78	0.37 0.00 - 1.61
August	52.90 41.47 - 77.86	51.87 42.14 - 59.65	92.08 30.71 - 100.00	1007.03 977.82 - 1022.69	129.73 0.00 - 803.72	3.14 0.00 - 22.66	7.32 0.00 – 22.66	0.25 0.00 - 2.08	0.47 0.00 - 3.36	0.28 0.00 - 1.40
September	47.22 35.94 - 62.37	50.26 40.26 - 57.07	87.59 14.78 - 100.00	1003.19 968.33 - 1023.27	69.11 0.00 - 748.44	2.78 0.00 - 22.98	6.52 0.00 – 22.98	0.14 0.00 - 1.76	0.28 0.00 - 3.14	0.20 0.00 - 1.09
October	40.81 27.09 - 55.35	48.21 38.99 - 53.85	85.27 10.22 - 100.00	1003.67 965.79 - 1034.70	34.17 0.00 - 480.61	4.80 0.00 - 28.59	9.74 0.00 – 28.59	0.29 0.00 - 2.59	0.53 0.00 - 4.51	0.22 0.00 - 1.12
November	31.85 10.38 - 53.08	44.26 31.87 - 49.28	77.04 10.01 - 100.00	1002.87 966.61 - 1037.97	8.59 0.00 - 192.75	6.62 0.00 - 33.98	11.80 0.00 – 33.98	0.52 0.00 - 3.23	0.92 0.00 - 5.82	0.23 0.00 - 1.31
December	28.64 9.14 - 43.48	42.55 32.16 - 58.69	80.53 19.97 - 100.00	1001.69 965.98 - 1037.98	3.63 0.00 - 65.93	5.94 0.00 - 36.25	10.97 0.00 – 36.25	0.50 0.00 - 3.74	0.87 0.00 - 6.91	0.16 0.00 - 0.94

Appendix 2: Table of averages and minimum/maximum values at the Duck Flats buoy, by month.

Month	Air Temperature (°F)	Water Temperature (°F)	Relative Humidity (%)	Barometric Pressure (%)	Solar Radiation (W/m^2)	Wind Speed (knots)	Wind Gust (knots)	Significant Wave Height (ft)	Max. Wave Height (ft)	Current Speed (knots)
January	25.14 0.54 - 42.56	39.81 33.20 - 44.83	81.02 10.86 - 100.00	1001.17 953.29 - 1041.23	7.52 0.00 - 235.13	5.50 0.00 - 31.94	8.96 0.00 – 48.26	0.50 0.00 - 2.69	0.90 0.00 - 4.99	0.12 0.00 - 0.70
February	25.68 5.36 - 41.92	37.82 32.01 - 42.88	75.13 10.12 - 100.00	1007.57 964.57 - 1039.02	23.79 0.00 - 436.39	4.08 0.00 - 28.61	6.61 0.00 – 33.47	0.29 0.00 - 2.14	0.52 0.00 - 3.71	0.12 0.00 – 1
March	30.42 13.73 - 51.96	39.23 32.02 - 43.13	60.01 10.14 - 100.00	1009.17 966.27 - 1042.24	91.38 0.00 - 684.60	5.52 0.00 - 31.10	8.95 0.00 – 42.86	0.22 0.00 - 1.73	0.41 0.00 - 3.07	0.12 0.00 - 1.32
April	37.02 11.71 - 55.80	42.82 35.60 - 52.63	71.96 20.59 - 100.00	1010.61 979.17 - 1036.05	160.28 0.00 - 787.33	4.10 0.00 - 28.38	6.54 0.00 – 32.33	0.09 0.00 - 1.06	0.18 0.00 - 1.70	0.12 0.00 – 0.72
May	45.69 32.64 - 67.64	48.89 38.69 - 58.28	82.64 24.36 - 100.00	1010.95 989.29 - 1033.70	183.29 0.00 - 878.27	4.61 0.00 - 23.97	7.15 0.00 – 27.31	0.37 0.03 - 1.34	0.68 0.06 - 2.18	0.15 0.00 - 1.06
June	51.26 39.04 - 70.29	48.04 36.88 - 56.30	88.47 55.49 - 100.00	1011.07 994.11 - 1032.61	191.54 0.00 - 891.69	4.72 0.00 - 23.83	6.93 0.00 – 25.85	NA	NA	0.16 0.00 - 0.83
July	52.81 43.08 - 78.12	48.23 37.58 - 59.95	91.42 23.19 - 100.00	1011.80 991.91 - 1030.98	153.12 0.00 - 875.80	3.62 0.00 - 22.12	5.50 0.00 – 22.04	NA	NA	0.15 0.00 - 0.75
August	51.01 38.17 - 75.22	46.80 36.40 - 56.84	91.83 11.13 - 100.00	1007.88 978.77 - 1023.76	101.88 0.00 - 739.87	2.69 0.00 - 25.42	4.07 0.00 – 26.47	NA	NA	0.14 0.00 - 0.82
September	46.09 31.99 - 61.57	46.64 36.72 - 55.45	87.31 10.09 - 100.00	1003.36 967.75 - 1021.83	68.34 0.00 - 742.45	2.79 0.00 - 21.67	4.43 0.00 – 32.33	0.06 0.00 - 0.51	0.11 0.00 - 1.15	0.14 0.00 - 0.89
October	39.78 24.68 - 55.20	46.15 35.24 - 52.92	82.37 10.84 - 100.00	1003.84 967.44 - 1036.23	35.67 0.00 - 500.47	4.09 0.00 - 25.31	6.63 0.00 – 37.90	0.11 0.00 - 1.47	0.20 0.00 - 2.56	0.13 0.00 - 0.95
November	29.95 5.05 - 49.33	43.19 36.44 - 47.50	77.83 13.65 - 100.00	1003.71 963.49 - 1046.23	12.51 0.00 - 260.51	5.58 0.00 - 30.98	8.61 0.00 – 46.53	0.07 0.00 - 0.86	0.14 0.00 - 1.73	0.13 0.00 – 0.78
December	26.01 4.62 - 42.92	40.65 32.07 - 46.36	82.85 10.22 - 100.00	1002.04 961.57 - 1037.75	4.29 0.00 - 176.74	4.81 0.00 - 29.25	8.09 0.00 – 45.27	0.13 0.00 - 1.66	0.25 0.00 - 3.10	0.12 0.00 - 0.65