Analysis of the Data from the Vessel Mounted Acoustic Doppler Current Profiler onboard RV Heincke

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April 2022

1 Introduction

The vessel mounted acoustic doppler current profiler data during the cruise HE597 were collected from an RDI Ocean Surveyor transducer which operates at a frequency of 150 kHz and from an RDI Workhorse Mariner transducer which operates at a frequency of 600 kHz mounted onto the keel of RV Heincke.

2 Cruise Overview

Between the start of the HE597 cruise on 20. April. 2022 at ∼04:00 UTC and the end of the cruise on 21. April. 2022, the Workhorse Mariner ADCP measured approximately 100 kilometres of real-time current velocity profiles of the waters along the vessel's course between the Port of Helgoland and the Port of Bremerhaven. During the cruise, current velocities and directions of up to a depth of 50 meters were measured accurately.

Figure 1: Research Vessel RV Heincke docked at the port in Helgoland

3 Analysis of Day 1 Data

3.1 Initial Measurements

The vmADCP is turned on at 06:30 UTC on 20.April.2022 when the vessel is docked at the port of Bremerhaven. The water at the port only reaches a depth of around 20 meters. The current velocities are relatively strong at these shallow depths and the 'u' component of the current velocity is $\sim$ -1.2 m/s which indicates southward flow. The 'v' component of the current velocity is $\sim$ +1.2 m/s which indicates a westward flow. The resultant direction of the current flow is southwestward.

3.2 Open Water Measurements

This trend continued to be observed along the course of the vessel until around 09:00 UTC when the vessel cleared out into open waters which can be observed in a steep increase in the water depth to $\sim$ 40 meters. Here the current velocities reverse their direction of flow from a southwestward flow to a northeastward flow ('u' component measures around +0.8 m/s and 'v' component measures around -1 m/s).

3.3 Mooring Search Period

From $\sim$ 11:00 UTC to 12:30 UTC, when the search for the test moorings was underway, the deeper parts of the water($\sim$ 40 meters) are relatively still as the u and v components range between +0.2 m/s to -0.2 m/s whereas the shallow waters exhibit a northeastward flow.

3.4 CTD Profile Period

At 13:27 UTC, when the first CTD profile was taken at Station 3, the shallow waters (up to 30meters) show a slight northwestward flow (magnitude of $\sim$ +0.5m/s). But at the deep water, the data has a lot of noise interference and therefore is unintelligible. The vessel returned to the port of Helgoland at approximately 04:00 UTC where the transducers were switched off.

4 Data Visualization and Analysis

4.1 Time Series Analysis

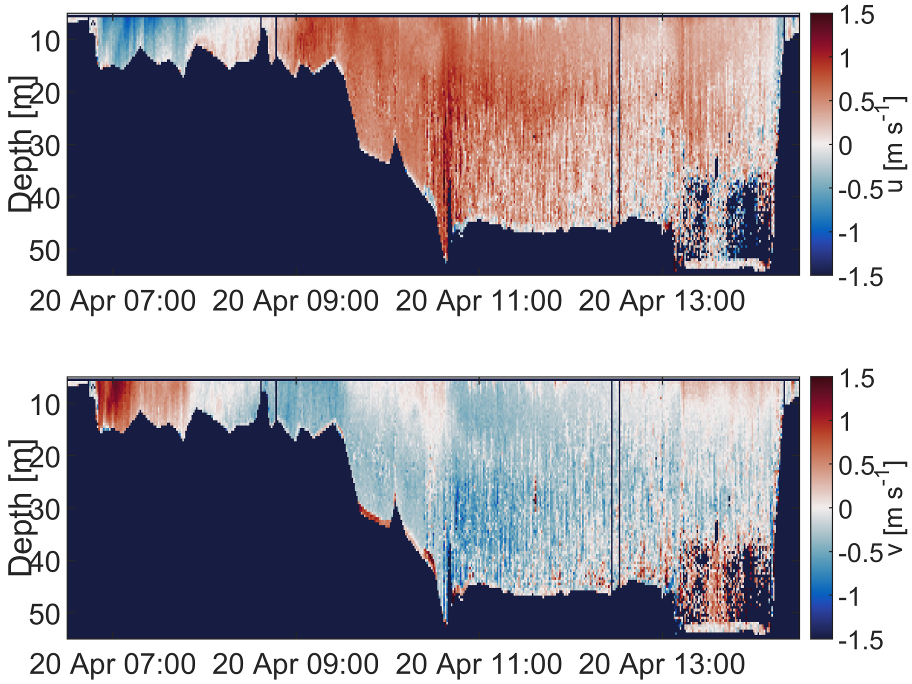

Figure 2: Time series of current velocities showing u and v components for Day 1

The time series plot (Figure 2) displays the evolution of current velocities throughout Day 1 of the cruise. The initial measurements at Bremerhaven port (06:30 UTC) showed particularly strong currents characteristic of the harbor area. A notable transition period was observed during the vessel's entry into open water at 09:00 UTC. The current velocities stabilized during the mooring search period between 11:00-12:30 UTC, showing minimal variation. Variable conditions were recorded during the CTD profiling at 13:27 UTC, with distinct patterns emerging in the shallow water layers.

5 Analysis of Day 2 Data

5.1 Morning Measurements

On the second day of the cruise, the transducers are turned on at around 06:00 UTC at the port of Helgoland. It is observed that the 'u' component of the current velocity measures at $\sim$ -1.3 m/s indicating a southward flow, whereas the 'v' component is approximately 0 m/s indicating a resultant flow of current in the southward direction.

5.2 Tidal Influence

Since the low tide at Helgoland on 21. April. 2022 was at 08:39 UTC, the southward flow of the current at the port of Helgoland can be reasoned as a result of the tide moving away from the port towards the south. We continue to observe this trend across the entire water column(up to 50 meters in depth) till around 07:00 UTC during which the CTD profile at Stations 4 and 5 were taken(06:18 UTC and 06:54 UTC respectively).

5.3 Mid-Morning Observations

From 07:00 UTC till around 09:00 UTC, when CTD profiles at Stations 6 and 7 were taken(07:41 UTC and 08:19 UTC respectively), the deeper waters ($\sim$40 meters in depth) show a slight eastward flow('u' component is ∼ 0 m/s and 'v' component is ∼ -0.5 m/s) whereas the shallow waters exhibit a slight southward flow('u' component ∼ -1 m/s and 'v' component ∼ 0 m/s).

5.4 Test Mooring Recovery Period

After the CTD profiling at Station 7, the vessel headed towards the site of the test moorings for a further attempt at recovery at 09:00 UTC. The current velocities during this period showed a marked shift towards the northeast, with the 'u' component measuring approximately +1.2 m/s and the 'v' component at -0.5 m/s. This pattern persisted throughout the recovery attempt and aligned closely with observations from similar locations during Day 1 of the cruise.

6 Detailed Current Pattern Analysis

6.1 Day 2 Current Patterns

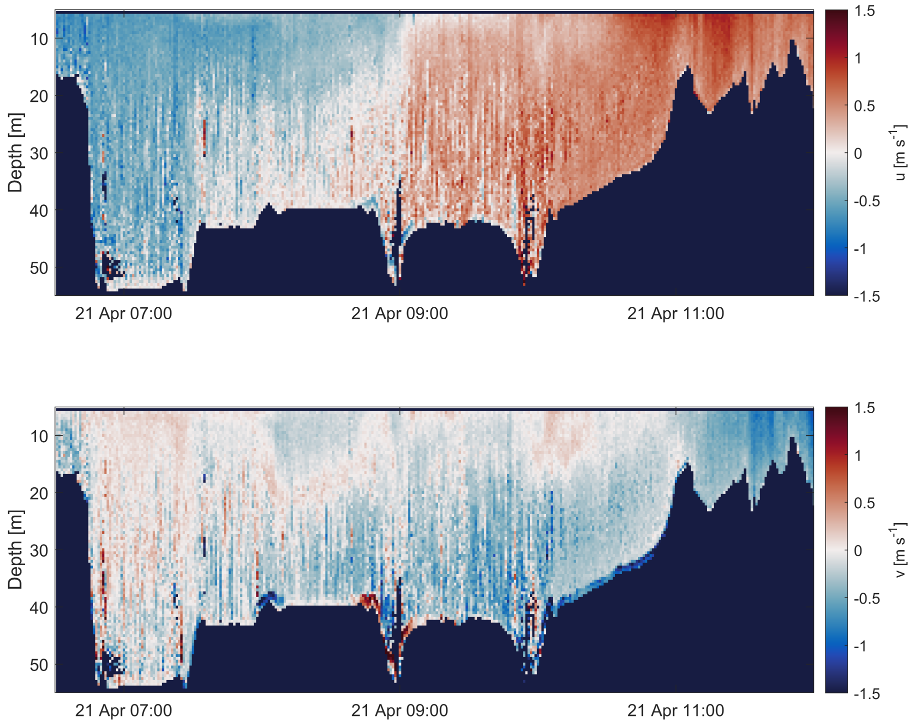

Figure 3: Day 2 current velocity patterns

Analysis of Day 2 current patterns (Figure 3) reveals several significant features. A pronounced tidal influence is evident at Helgoland port during the early morning hours (06:00-08:39 UTC), manifesting in strong directional flows. The water column exhibits clear stratification in current directions, with distinct patterns emerging at different depths. During mooring recovery operations, a consistent northeastern flow dominates the region. These patterns show remarkable consistency with observations from similar longitude ranges during Day 1, suggesting persistent regional circulation features.

6.2 Temporal Evolution of Current Patterns

The temporal evolution of current patterns shows distinct phases throughout Day 2. The early morning period is characterized by strong tidal influences, with current directions closely following the expected tidal flow patterns. Mid-morning observations reveal a more complex structure, with depth-dependent flow patterns becoming more pronounced. The afternoon period shows a transition to more uniform flow patterns, particularly in the deeper water columns.

7 Environmental Factors and Current Patterns

7.1 Tidal Influence Analysis

The influence of tidal cycles on current patterns is particularly evident in the Day 2 data. The morning measurements coinciding with the low tide at Helgoland (08:39 UTC) show a clear correlation between tidal phase and current direction. The southward flow observed at the port of Helgoland demonstrates the direct influence of tidal forcing on local current patterns. This tidal influence extends throughout the water column but shows varying degrees of impact at different depths.

7.2 Bathymetric Effects

The relationship between water depth and current patterns emerges as a significant factor in the observations. Shallow waters near coastal areas consistently show stronger current velocities and more variable directions. The transition to deeper waters is marked by more stable current patterns and generally lower velocities. These bathymetric effects are particularly pronounced in areas where depth changes rapidly, suggesting strong topographic control on local circulation patterns.

7.3 Spatial Variability

Analysis of spatial patterns reveals distinct regional characteristics in current behavior. The coastal areas near both Helgoland and Bremerhaven show unique current patterns that appear to be influenced by local geographic features. The open water regions display more consistent flow patterns, though still showing clear spatial structure in both velocity magnitude and direction.

8 Analysis of Current Velocities across CTD Stations

8.1 Station-wise Analysis

The analysis of current velocity direction at Station 5 (54.143 degrees North, 7.889 degrees East) reveals a complex flow pattern. The 'u' component of current velocity measures approximately -0.8 m/s, indicating a southward flow, while the 'v' component at approximately +0.2 m/s indicates a westward flow, resulting in a net southwestward flow. Similar flow patterns are observed at Stations 6 and 7, where both deep and shallow waters consistently exhibit southwestward flow characteristics.

8.2 CTD Station Profiles

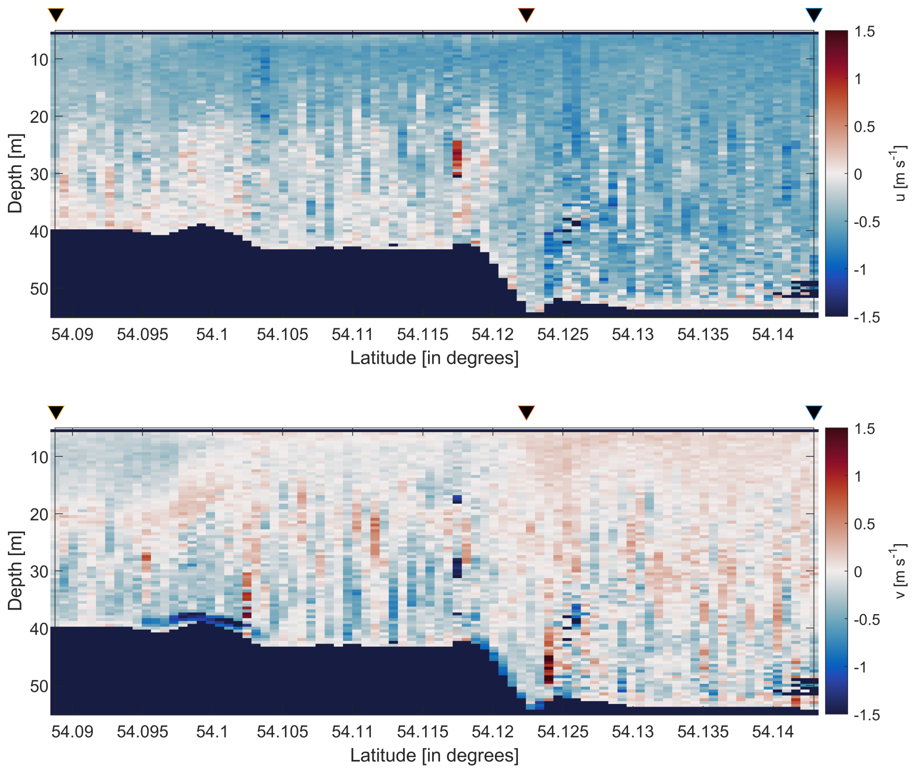

Figure 4: Current profiles at CTD Stations 5, 6, and 7

The CTD station current profiles (Figure 4) provide detailed insights into the vertical structure of water column dynamics. The profiles reveal distinct vertical structuring of currents at each station, with clear depth-dependent variations in current direction. A strong correlation emerges between water depth and current strength, with characteristic patterns developing at different depth ranges. The vertical structure shows consistent features across multiple stations, suggesting regional-scale influences on current patterns.

8.3 Mean Flow Analysis

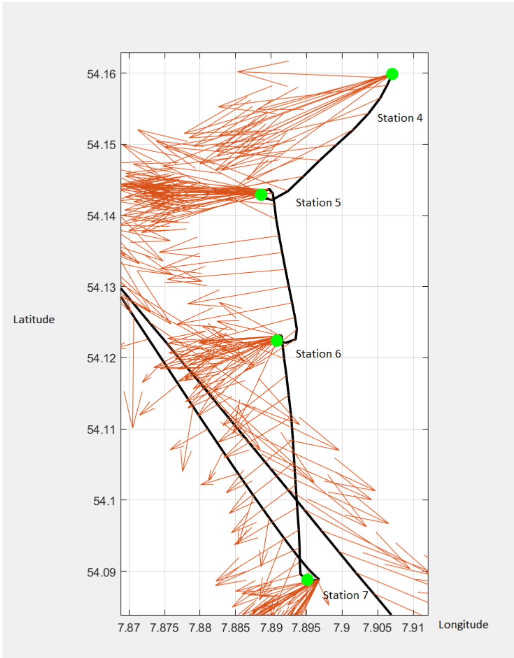

Figure 5: Mean flow quiver plot across CTD stations

Analysis of the mean flow patterns (Figure 5) reveals consistent current structures across the study area. The predominant southwestward flow at Stations 4-7 represents a persistent feature of the regional circulation. Between Stations 5 and 6, the flow exhibits a strong westward component, while the section between Stations 6 and 7 shows a return to southwestward flow. These patterns demonstrate remarkable spatial coherence across the study area, suggesting the influence of larger-scale oceanographic features.

8.4 Vertical Structure Analysis

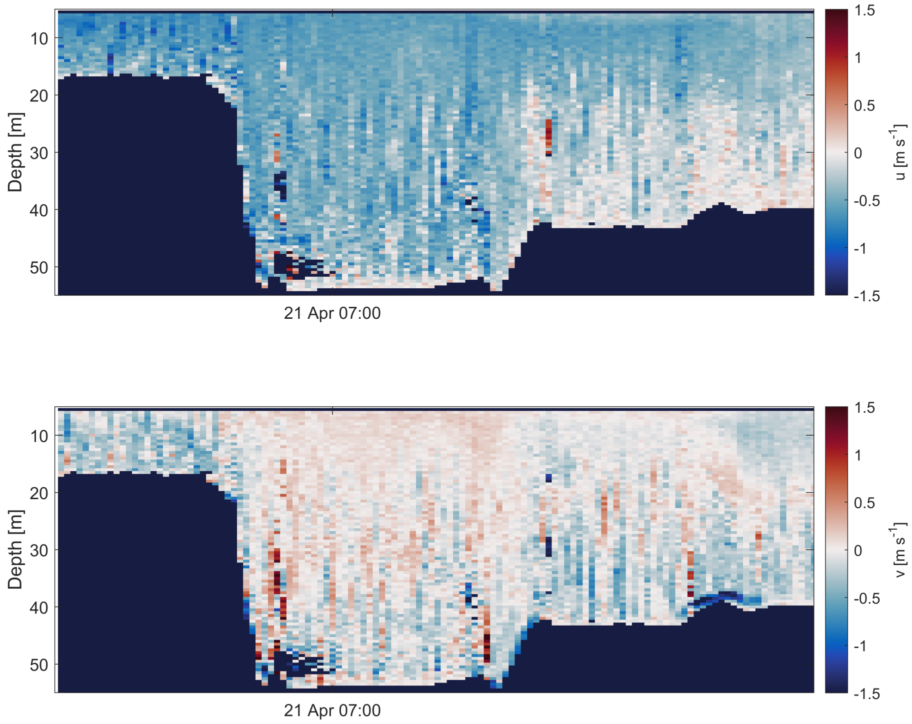

Figure 6: Depth-dependent current structure

The vertical structure analysis (Figure 6) provides critical insights into the depth-dependent nature of current patterns. The water column exhibits distinct layering of currents with depth, with surface layers (0-30m) showing different dynamic characteristics compared to deeper waters. The analysis reveals complex surface layer dynamics influenced by atmospheric and tidal forcing, while deeper waters (30-50m) demonstrate more stable flow patterns. Vertical shear patterns emerge as important features, particularly in regions of strong current gradients.

9 Discussion of Results

The comprehensive analysis of vmADCP data reveals intricate patterns of current behavior in the German Bight region. Through the combination of time series, vector plots, and vertical profiles, a detailed picture of current dynamics emerges for the cruise period.

9.1 Temporal Patterns

The temporal evolution of current patterns shows significant variations associated with different phases of vessel operation. Notable changes occur during port departure and arrival periods, reflecting the influence of coastal processes. The transition between shallow and deep water areas marks distinct shifts in current patterns. Tidal cycle phases emerge as dominant factors in current variability, particularly during CTD station operations where temporal changes can be observed at fixed locations.

9.2 Spatial Patterns

The spatial analysis reveals distinct regional current regimes throughout the study area. Bathymetry appears to play a crucial role in shaping flow patterns, with clear differences between shallow and deep regions. Coherent structures in current direction persist across similar depth ranges, suggesting strong topographic control. Location-specific current characteristics emerge, particularly near coastal features and in areas of rapidly changing bathymetry.

10 Conclusion

The vessel-mounted ADCP measurements during cruise HE597 (20-21 April 2022) have provided comprehensive insights into current patterns between the ports of Helgoland and Bremerhaven. The data collected from both the RDI Ocean Surveyor (150KHz) and RDI Workhorse Mariner (600KHz) transducers reveals several significant patterns in current behaviors.

10.1 Spatial Variations

The analysis reveals clear spatial variations in current directions throughout the study area. Near Bremerhaven, currents predominantly flow northwestward, while the Helgoland area and test mooring sites exhibit eastward flows. CTD Stations 4-7 consistently show southwestward flows, indicating a stable regional circulation pattern in this area.

10.2 Temporal Variations

Significant temporal variations in current patterns emerged across the two-day cruise period. Day 1 observations showed a clear transition from southwestward to northeastward flow as the vessel moved into open waters. Day 2 demonstrated strong tidal influence, particularly evident near Helgoland port during low tide (08:39 UTC), where pronounced southward flows were observed.

10.3 Depth-dependent Behaviors

The analysis reveals complex depth-dependent current behaviors throughout the study area. Shallow waters (up to 30 meters) consistently showed different flow patterns compared to deeper waters, suggesting strong vertical structuring of currents. Deeper waters (40-50 meters) exhibited more stable conditions, particularly during mooring search operations, indicating reduced influence of surface forcing at depth.

These measurements successfully captured both spatial and temporal variability of current patterns in the study area, providing a comprehensive dataset for understanding local hydrodynamics. The consistency of certain flow patterns observed across both days of the cruise, particularly in specific longitude ranges (7.9-8.0 degrees), suggests persistent regional circulation features that could be significant for local oceanographic processes and navigation planning.

The findings from this study contribute significantly to our understanding of the complex current systems in the German Bight region. The effectiveness of vessel-mounted ADCPs in capturing detailed current profiles across varying spatial and temporal scales has been clearly demonstrated, providing valuable data for both oceanographic research and practical maritime applications.

11 Appendix

11.1 A1

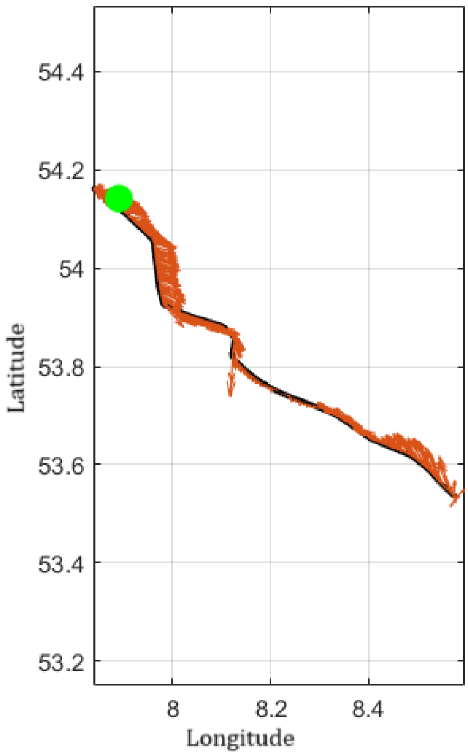

Figure 7: Quiver Plot of the Flow patterns across the stations on Day 1

11.2 A2

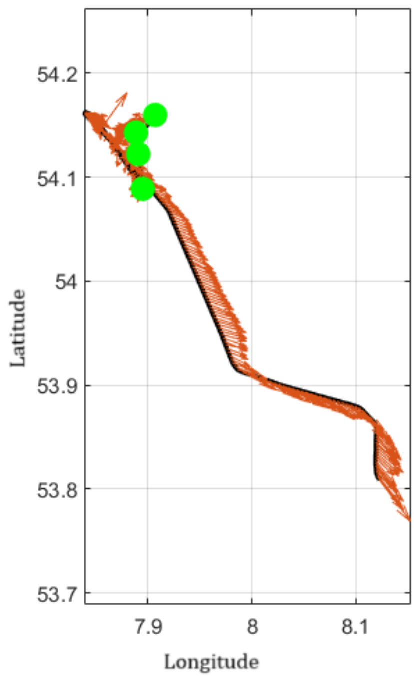

Figure 8: Quiver Plot of the Flow patterns across the stations on Day 2