Spatial Circulation Patterns Over Palmer Deep Canyon and the Effects on Adélie Penguin Foraging

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***Abstract*— Project CONVERGE, funded by the National Science Foundation Office of Polar Programs, is deploying a coordinated ocean observing network to better understand ecological connections along the Western Antarctic Peninsula (WAP). Partners from Rutgers University, the University of Alaska, Fairbanks (UAF), Oregon State University, the University of Delaware, and the Polar Oceans Research Group deployed a multiplatform-observing network that includes gliders, animal telemetry, active acoustics for zooplankton distributions, and CODAR High Frequency Radar (HFR). The three-site network was deployed in November of 2014 and provided hourly surface current maps through the following austral summer. This study targets data collected between January and February 2015. Here we focus on Palmer Deep eddy and the tidal currents as they transition from diurnal to semi-diurnal regimes throughout the study period. These data are helping us better understand the links between alternating tidal regimes and the foraging behavior of the local Adélie penguin populations. This analysis has further implications for future research as the region goes through dramatic climate change.**

Keywords - High Frequency Radar, Foraging ecology, Ocean Observing

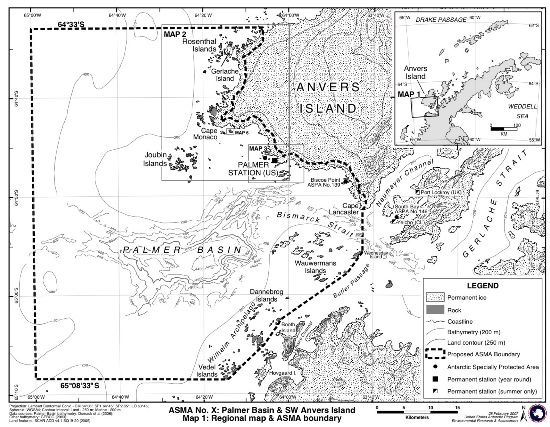

Figure 1: Project CONVERGE study area on the West Antarctic Peninsula.

I. INTRODUCTION

During the austral summer of 2014-2015, project CONVERGE deployed a multiplatform network to sample the Adélie penguin foraging hotspot associated with Palmer Deep, a submarine canyon located near Palmer Station, Anvers Island Antarctica. Local islands around this area have been occupied by Adélie penguins *(Pygoscelis adeliae)* for nearly 1000 years [1]. In this region in the Western Antarctic Peninsula (WAP), penguin foraging locations are highly variable over space and time [2], reflecting a patchy distribution of food resources. However, averaged over decades, they are spatially coherent with submarine canyons and

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nearshore deep bathymetry [3,4,5]. This suggests that the presence of the Palmer Deep canyon mediates and/or enhances the accessibility and predictability of the resource concentrating features affecting the trophic levels that have been supporting the Adélie penguin colonies over the millennium despite interannual variation in climate over the same time period. The focus of CONVERGE was to assess the impact of prey concentrating ocean tidal dynamics on Adélie penguin foraging behavior [6]. This coordinated research looks to better understand the links between the local oceanography and the Adélie foraging ecology associated specifically with the regime of the local mixed tide.

II. METHODS

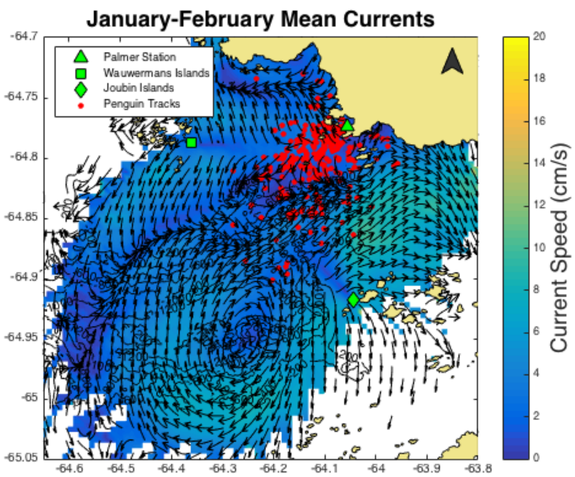
Surface current maps over the Adélie Penguin foraging grounds were used to study coincident surface current features and Penguin foraging locations. In order to minimize the risk and maximize the data return over Palmer Deep, a three-site High Frequency Radar (HFR) network was deployed. The first site deployed at Palmer Station was plugged into the power grid available through the station facilities. It transmitted at a frequency of 13 MHz with coverage that extended as far as 60 km offshore. The two 25 MHz sites deployed in the Joubin and Wauwermans Island chains relied on remote power systems that were constructed on site, lightered to shore via zodiac with help from the RVIB Lawrence M. Gould research vessel support in November 2014. The Remote Power Modules (RPMs) generated the required power for the HFRs through a combination of small-scale micro wind turbines and a photovoltaic array. These 25 and 13 MHz systems were gathering hourly data at a 0.5 kilometer resolution. Combining remotely sensed hourly surface current maps from this HFR network, autonomous underwater vehicles (glider AUVs) equipped with optics and echo-sounders for the detection of phytoplankton and Antarctic krill (*Euphausia superba*), and Adélie penguin satellite telemetry, we will map the distribution of phytoplankton-krill-penguin interactions in the context of the concentrating features captured by the surface current maps.

III. RESULTS

A. Mean Fields

The hourly maps provided by the HF radar network were averaged into monthly, and 2-month averages (January-February). The averages all highlight the influence of the deep canyon in the center of the data coverage (Figures 2a-d). In addition to the total mean based on data collected over the entire 2-month period, we identified times in which the local mixed tide was diurnal, semi-diurnal, and transitioning from one to the other. Additional mean plots are based on hourly data within these three categories. Several persistent circulation features of interest shift locations depending on the tidal regime. In the total January-February mean, there is a cyclonic eddy centered over the deepest parts of the canyon (1400m deep). This eddy sits between a mean flow into the Bismarck Straight in the NE corner of the coverage that reaches up to 12 cm/s and a weaker offshore flow to the west. During the diurnal period, the center of the eddy is pushed southeastward over shallower regions (200m deep) and the eddy borders northbound currents of 10 cm/s over the western portion of the canyon. These northbound currents push further east and accelerate to 14 cm/s at the entrance to the Bismarck straight. During semi-diurnal time periods, the Palmer Deep eddy is situated over the deepest part of the canyon (1400m deep) with a northeastward line of convergence with currents that accelerate to 17 cm/s entering the Bismarck Straight.

(a)



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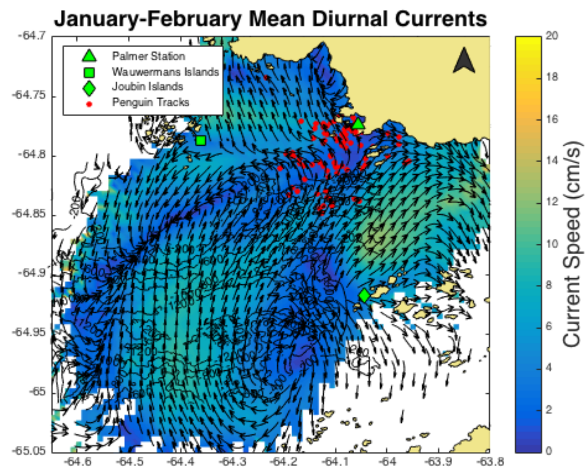

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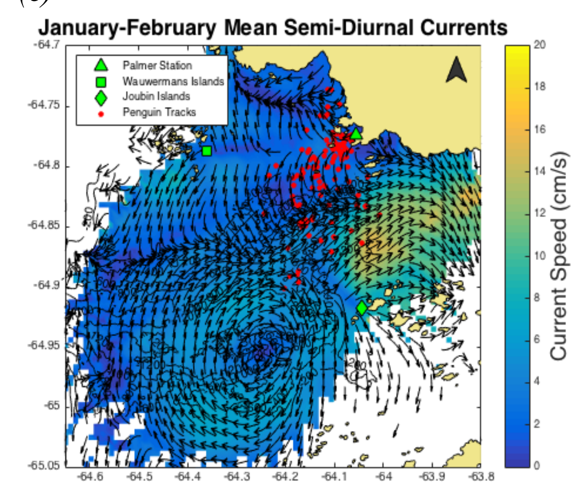

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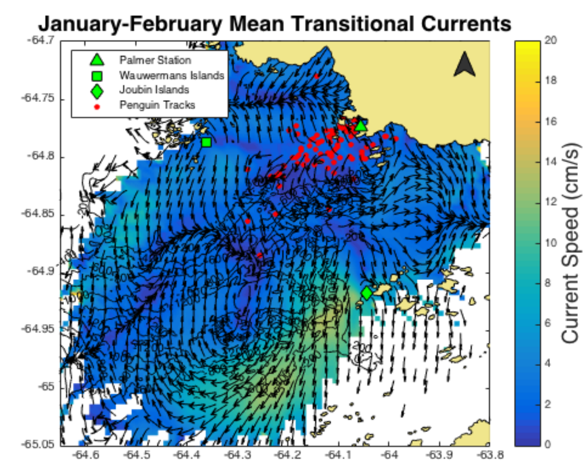


Figure 2: Mean plots illustrating the different tidal regimes. (a) Mean time plot (b) Diurnal mean time plot (c) Semi-diurnal mean time plot (d) Transitional mean time plot

During the transitional times between the semi-diurnal and diurnal tidal regimes, the strongest currents are located southeast of the center of the eddy, which is situated over the deepest part of the canyon, with current speeds up to 14 cm/s with comparatively weak current flows at 5 cm/s into the Bismarck Straight.

A common feature across all time mean plots is a line of convergence that occurs over the shallows, northwest of the canyon. In the total, semidiurnal, and transitional mean cases, this line of convergence begins over the deeper western portion of the canyon and stretches over the northern part of the canyon, where the depths are shallower, and heads northeastward in between the

Wauwermans Islands and Palmer Station into the Bismarck Straight. In the diurnal case the line of convergence begins in the northern-most portion of the canyon and heads southwest into the deeper western-part of Palmer Deep. This line of convergence, in all time averages, closely follows the bathymetry. The front associated with the observed convergent feature along the outermost western portion of the canyon steers the flow eastward (or southbound in the diurnal case) along the northern-part of Palmer Deep.

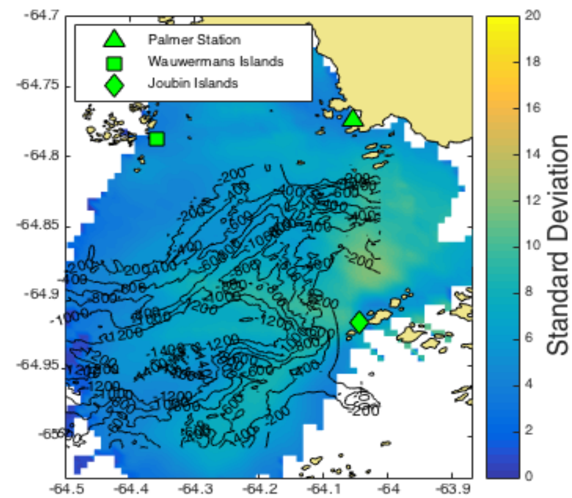
B. Adélie Foraging

Throughout all four mean fields, it is observed that the Adélie penguins are foraging relatively close to the colony in areas with weak mean currents and higher variability (Figures 2a-d and Figures 3a-b). Their foraging behaviors are associated near frontal regions that are correlated with the bathymetry of Palmer Deep and change depending on the tidal phase. This primary foraging location occurs in the same area, south of Palmer Station depending on the tidal regime. During the diurnal tidal period the frontal region drives the flow onshore consequently causing the penguins to forage closer to shore. During the semi-diurnal tidal regime the frontal region is further offshore; this coincides with penguin foraging further offshore, southwards and occasionally near the eddy. In the transitional tidal period, with a mean offshore flow is also offshore, the penguins can be seen foraging near a front closer to shore with a few outliers foraging near the eddy.

C. Adélie Foraging Ecology

Interactions between ocean currents, the canyon, and the lower trophic level organisms (phytoplankton and krill) are key to linking what has been observed between currents and penguins. During CONVERGE, gliders were used in concert with the HFR fields to sample the hydrography and phytoplankton distributions associated with convergent and divergent features. One glider equipped with lithium batteries sampled a line along the canyon

(a)



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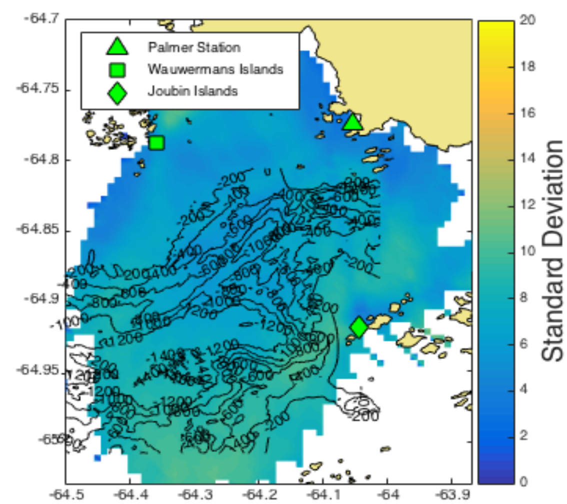

Figure 3: Standard deviations from the mean currents. (a) Standard deviation of the u-component from the mean (b) Standard deviation of the v-component from the mean

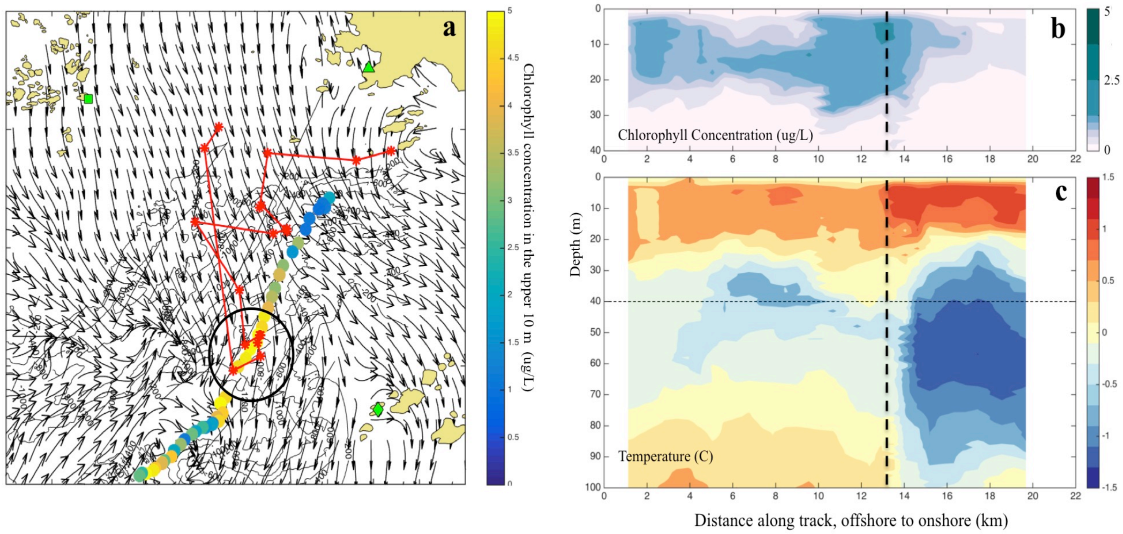

Figure 4: Glider section sampled through the surface current field shown as black vectors. (a) The color of the glider track depicts the observed chlorophyll concentration within the upper 10 m along the section. The concurrent penguin track is shown as red. (b) Vertical glider cross section of chlorophyll concentration within the upper 40 m of the water column. (c) Vertical glider cross section of temperature within the upper 100 m of the water column. The vertical line in panels b and c coincides with the data within the black circle in panel a.

axis from January 5, 2015 through February 26, 2015 (Figure 4).

This 56-day mission sampled throughout the entire foraging season of the local Adélie population. Over that time the glider mapped the hydrography, chlorophyll fluorescence and acoustics in the context of the observed surface currents and penguin foraging tracks highlighted in Figure 4a. On January 27, 2015 it sampled the same region targeted by a foraging penguin along the offshore edge of a coastal current (Figure 4). The circle in Figure 4a highlights the frontal region visited by the satellite tagged Adélie penguin, and the enhanced phytoplankton concentrations associated with a surface bloom (Figure 4b). The vertical sections of the glider highlight the strong hydrographic front associated with the feature identified by both the surface current map and penguin track. The concurrent measurements of the dynamic ocean properties coupled with ecological measures through the food web offer an unprecedented view of the Palmer Deep ecosystem.

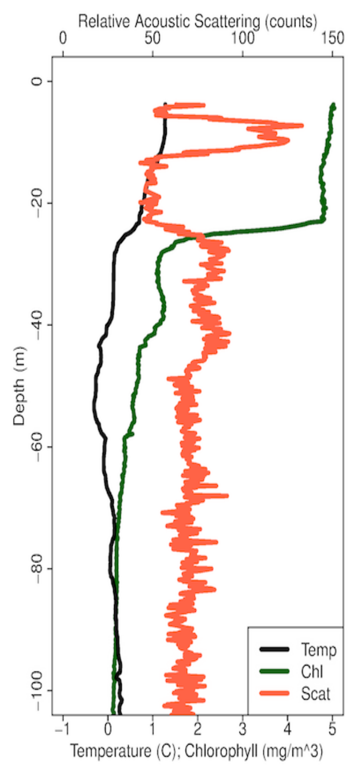

Figure 5: Vertical profile of temperature, chlorophyll concentration and relative acoustic scattering in the circled location in figure 4. The increased relative acoustic scattering from the ADCP on the glider suggests that krill are associated with the frontal region highlighted in figure 4, and related to phytoplankton concentrations.

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in Figure 4.

While the frequency (1 MHz) was not ideal for detecting krill, concurrent profiles of the acoustic return crossing the front suggest a surface peak that could be related to krill feeding on the observed bloom (Figure 5). This tight coupling from the physics through the food web as observed by the glider along this frontal region gives strong evidence for the critical role that krill distribution patterns must have on Adélie penguin foraging.

IV. DISCUSSION

The results of CONVERGE highlight the importance of the local ocean physics in the Palmer Deep region and the significant part that these oceanographic features play in sustaining a complex ecosystem. Since the Adélie penguins are flightless and must return to their nest to feed their chicks, they must nest is close proximity to marine regions where high prey concentrations are predictable over ecological time scales (decades to centuries; [3]). Therefore this implies that the Palmer Deep canyon is associated with resource concentrating features, including fronts and eddies that are influenced by smaller scale oceanographic dynamics such as the tidal periods. Since the West Antarctic Peninsula has undergone dramatic climate change, the last three decades in particular has resulted in a steady decline in the Adélie penguin population [7,8]. It is crucial to understand how the oceanographic features of the Palmer Deep canyon influence the trophic levels that are supporting the Adélie penguin colonies as this region is experiencing persistent warming. With the continuation of the multiplatform-observing network deployed by project CONVERGE; we will be able to better understand this intricate ecosystem.

VI. REFERENCES

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