Sea Ice and Ocean Response to a Strong Mid-Winter Cyclone in the Arctic Ocean

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Abstract

Sea ice mediates the exchange of momentum, heat, and moisture between the atmosphere and the ocean. Cyclones produce strong gradients in the wind field, imparting stress into the ice and causing the ice to deform. In turn, increased sea ice drift speeds and rapid changes in drift direction during the passage of a cyclone may result in enhanced momentum flux into the upper ocean. During the year-long MOSAiC expedition, an array of drifting buoys was deployed surrounding the R/V Polarstern, enabling the characterization of sea ice motion and deformation across a range of spatial scales. In addition, autonomous sensors at a subset of sites measured the atmospheric and oceanic structure and vertical fluxes. Here, we examine a strong cyclone that impacted the MOSAiC site during January and February, 2020, while the MOSAiC site was near the North Pole.

The cyclone track intersected the MOSAiC buoy array, providing an opportunity to examine spatial variability in sea ice motion during the storm in unprecedented detail. A key feature of the storm was the formation of a low-level jet (LLJ), first in the warm sector of the storm, then growing to eventually encircle the central low. The highest rates of ice motion and deformation coincide with effects of LLJ transitions. Analysis of deformation using the Green’s theorem approach indicates divergence and cyclonic vorticity as the LLJ enters the region, and convergence and anticyclonic vorticity as the LLJ leaves; maximum shear strain rate is enhanced throughout the LLJ’s passage. While the vorticity signal is particularly clear, floe structure and internal ice stresses result in high spatial variability in the magnitude of divergence and shear strain rates, especially at smaller scales. Increased current speed and shear in the upper layer of the ocean during the passage of the LLJ resulted from ice drag forcing the ocean mixed layer current. The results suggest an important role for cyclone-forced ocean mixing in pack ice during the Arctic winter.

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INTRODUCTION

Sea ice mediates the exchange of momentum, heat, and moisture between the atmosphere and the ocean. Cyclones produce strong wind gradients, imparting stress into the ice and causing deformation. In turn, increased sea ice drift speeds and rapid changes in drift direction during cyclone passage increases the momentum flux into the upper ocean. Spatial and temporal scales of mesoscale processes within a cyclone, including the development of fronts and low-level jets (LLJs) as well as the translation speed of the system, affect the stresses experienced by the ice at the surface. Motion of ice relative to the underlying ocean, in turn, results in stresses at the ice-ocean interface. In this study, we examine the sea ice and ocean response to a strong cyclone that impacted the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) site during January and February, 2020 using an array of autonomous sensors comprising the MOSAiC Distributed Network (DN). The kinematic sea ice response to the storm shows close correspondence with the evolution of a strong LLJ. We show that the net ice movement is dependent on its position relative to the cyclone track. We discuss the spatial patterns of deformation at small and larger scales. Finally, we discuss implications for Arctic coupled model development.

DATA

The MOSAiC observatory and surrounding DN were deployed in remnant first and second year ice north of the Laptev Sea at the beginning of the freeze-up season in 2019. Details of the deployment and equipment are available in a series of overview publications (Nicolaus et al. 2022, Rabe et al. 2022, Rabe et al. 2023, Schupe et al. 2022).

Central Observatory (CO) – 4x daily radiosondes
- Meteorological tower (Cox et al., 2023)
- Autonomous Ocean Flux Buoy (AOFB, Stanton et al. 2012)
- L-sites
- Autonomous Surface Flux Stations (ASFSs, Cox et al., 2023)
- AOFBs

P-sites
- 57 GPS buoys
- Network of positions allows measurement of velocity and velocity gradients

ERAS reanalysis (Hersbach et al. 2020)
- Radiosondes and subset of P-site met observations assimilated

SYNOPSIS SETTING

2020-01-31 00:00 – 2020-01-31 24:00: Sea ice drift speed. Colors as in Figure 1. Vertical lines mark the times shown in Figure 3: (a) 1/31 01:00, (b) 01:00 – 03:00, (c) 03:00 – 05:00, (d) 05:00 – 07:00, (e) 07:00 – 09:00, (f) 09:00 – 11:00, (g) 11:00 – 13:00, (h) 13:00 – 15:00, (i) 15:00 – 17:00, (j) 17:00 – 19:00, (k) 19:00 – 21:00, (l) 21:00 – 23:00, (m) 23:00 – 01:00

2020-01-31 00:00 – 2020-01-31 24:00: Local drift speed maxima trace passage of the storm

2020-02-01 00:00 – 2020-02-02 00:00: Secondary increase in drift speed at 16Z produced by strong inertial oscillation

2020-02-01 00:00 – 2020-02-02 00:00: Gradual clockwise path to the right, counterclockwise to the left

SUMMARY

We present detailed observations of coupled air-ice-ocean variability from an intense mid-winter cyclone over central Arctic pack ice. The observations show the spatial structure of air-ice-ocean interaction with unprecedented detail. We show that the development of a low-level jet is a key component for timing, scale, and intensity of the sea ice kinematic response. The horizontal structure of the cyclone wind fields produces a spatial gradient in sea ice motion, resulting in deformation of the ice pack, with a clear dependence on the stage of cyclone development and the location of the storm track. The sharp changes in air-ice stresses produced by the LLJ set off inertial ringing in the ocean, prolonging the sea ice deformation.

The results reinforce the notion that cyclone processes are a key feature of the coupled Arctic air-ocean system. In particular, models with insufficient ice-ocean coupling are likely to underestimate the deformation produced by cyclone passage. A major motivation for this work was to identify key processes for model validation. A companion study (Solomon et al., in prep) examines this event in detail using forecast runs of the Coupled Arctic Forecast System Model and the ECMWF Integrated Forecast System. Moving forward, we will examine the role of cyclone evolution and location in sea ice deformation across the full MOSAiC year.