Local Atmospheric Response to an Open-Ocean Polynya in a High-Resolution Climate Model

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Introduction

The Southern Ocean is known to occasionally feature **large areas of open water amid the winter ice pack, known as polynyas**. Most of these polynyas are coastal and kept ice-free by offshore winds. However, polynyas have also been observed in the open ocean. The most famous example is the Weddell Polynya that was observed in the mid-70s.

How open-ocean polynyas form is not well understood, nor are the impacts on the ocean or atmosphere. It is important to understand the impact of polynyas: i) a large-scale polynya may reappear in the Weddell Sea if conditions become favorable again; ii) many climate system models simulate open-ocean polynyas even for present-day forcing conditions; and iii) the Arctic may display open-ocean polynyas once it has transitioned to a regime of seasonal sea ice cover.

Here we study the impact of an open-ocean polynya on the atmosphere in a high-resolution coupled climate model [1].

The Model

We analyze output from a CESM1 simulation known as the high-resolution ASD run [2]. The ocean (POP2) and sea ice models (CICE4) are configured on an eddy-resolving (0.1°) grid, while the atmosphere (CAM5) has a 0.25° resolution (SE). The model was run under present-day (2000) conditions. A 14-yr spin-up phase was followed by 86 years of the main simulation. We analyze 3 years in which a persistent polynya is present, and 3 years without a polynya for comparison.

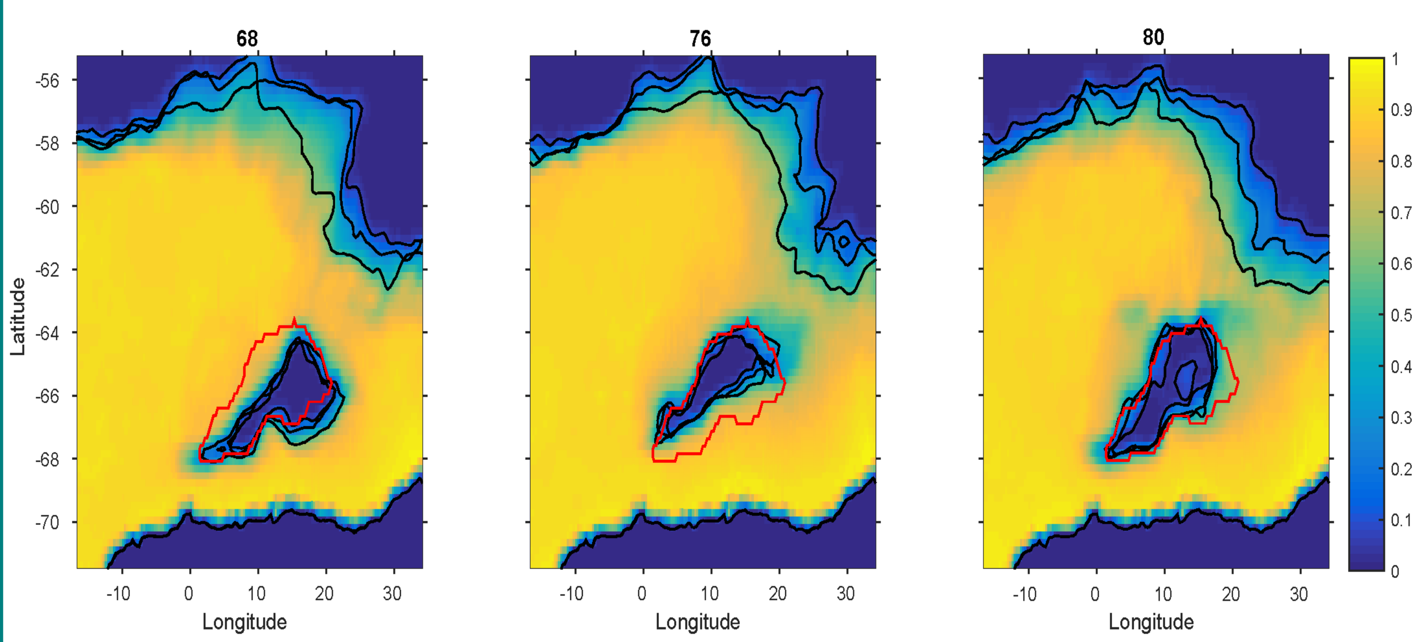

Figure 1: Sea ice fraction for the 3 polynya years, averaged over August-September-October (ASO). Black contours indicate the 15% limits of monthly-mean sea ice concentration, while the red contour indicates the canonical `polynya mask' used for non-polynya years.

References

. [1] Weijer et al. (2016): J. Clim, in press.

[2] R. J. Small et al. (2014). Journal of Advances in Modeling Earth Systems, 6(4), 1065-1094.

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Seasonal Evolution

The seasonal evolution of atmospheric variables is significantly different over polynyas (open ocean) compared to non-polynyas (sea ice). Expectedly, when ice fraction (ICEFRAC) stays low, surface temperature (TS) stays high, as does the atmospheric surface temperature (TBOT). Sensible (SHFLX) and latent (LHFLX) are high, leading to enhanced surface moisture (QBOT) and precipitation (PRECT). Net shortwave radiative budget at the top of the atmosphere (FSNT) is higher, due to enhanced adsorption.

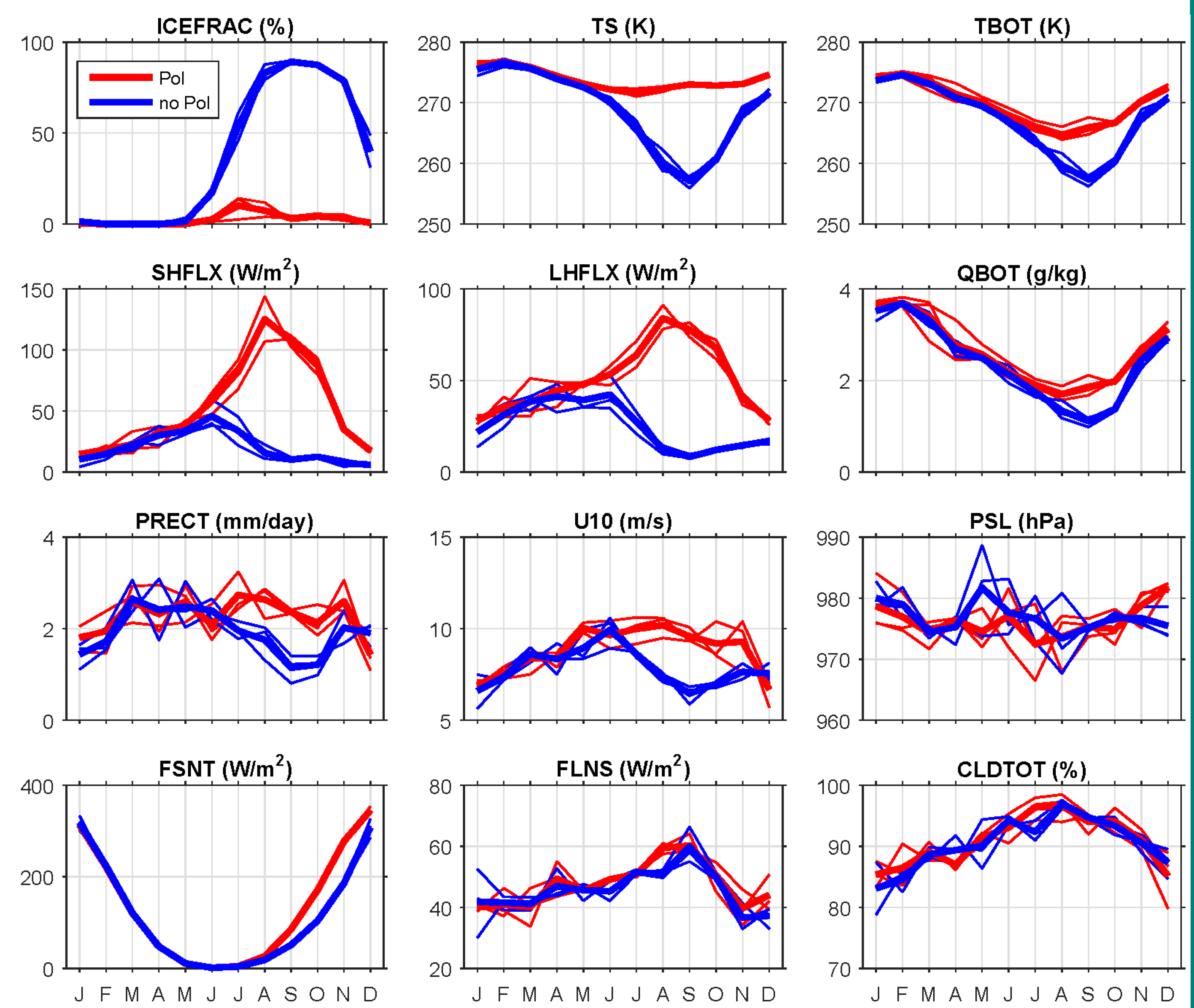

Figure 2: Seasonal evolution of several atmospheric quantities for polynya (red) and non-polynya (blue) years.

Surprisingly there is no impact on total cloud fraction (CLDTOT) and the longwave radiative budget at the surface (FLNS). Clouds over polynyas are optically much thicker than over sea ice; their enhanced contribution to the downward longwave radiative flux (FLDS) counteracts the stronger surface emissions.

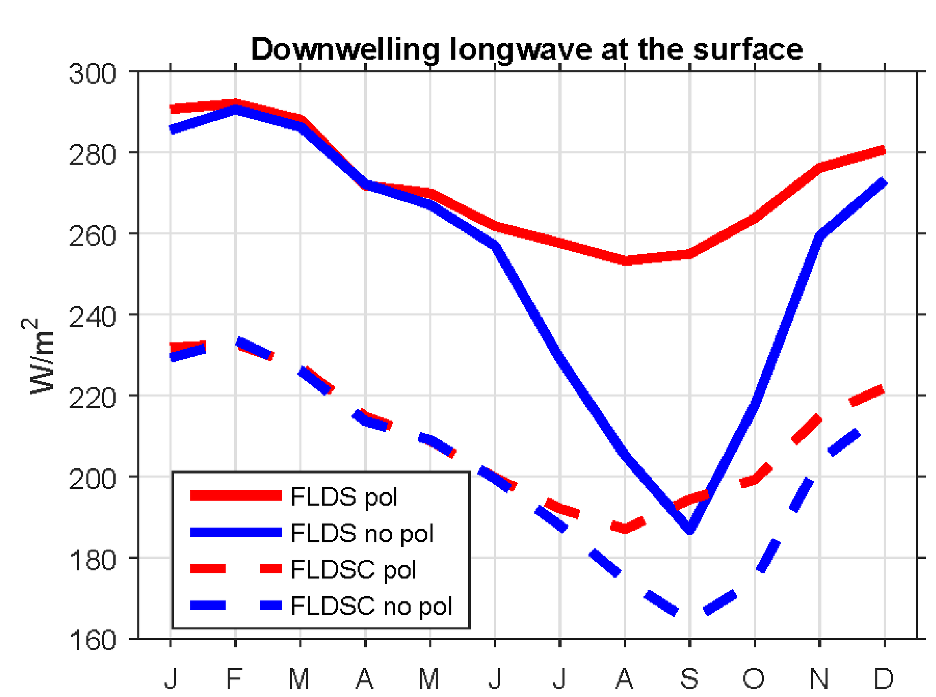

Figure 3: Downwelling longwave fluxes at the surface (FLDS) for polynya (red) and non-polynya (blue) years, and their clear-sky equivalents (FLDSC).

Vertical Structure

The polynyas also alter the vertical structure of the atmosphere. The cloud fraction (CLOUD) has a maximum at 900 hPa, associated with a maximum in updraft (-OMEGAT). Most importantly, the liquid (ICLDLWP) and ice (ICLDIWP) water paths are significantly higher, pointing at optical thicker clouds. For non-polynyas cloud fraction may be high (60%), but they are close to the surface and optically thin.

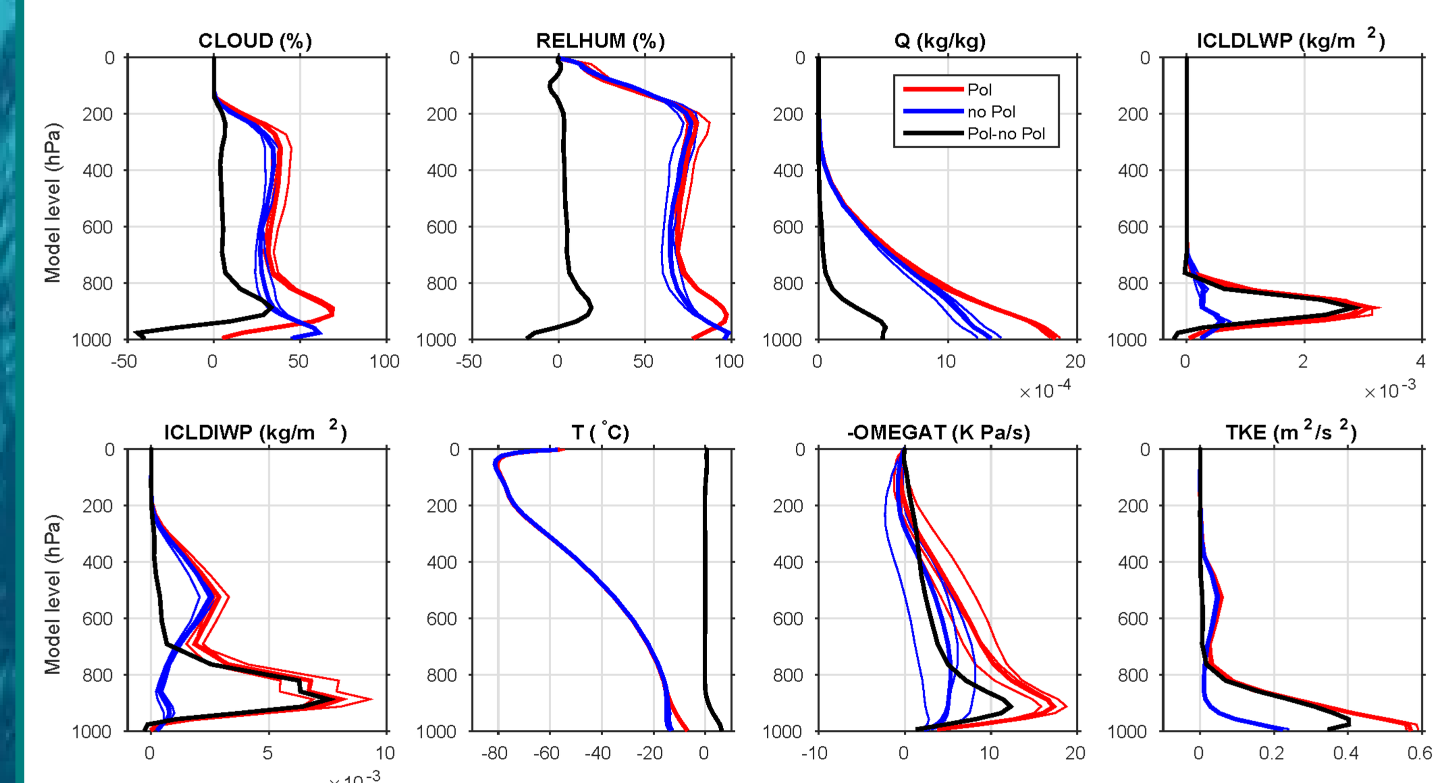

Figure 4: Vertical structure of several atmospheric quantities for polynya (red) and non-polynya (blue) years, and difference (black).

Directional Analysis

To study whether polynyas have an impact on synoptic variability, we made composites of daily-averaged variables based on wind-direction. A strong response is found for Northeasterly winds. A weak thermal low is found for southerly wind directions.

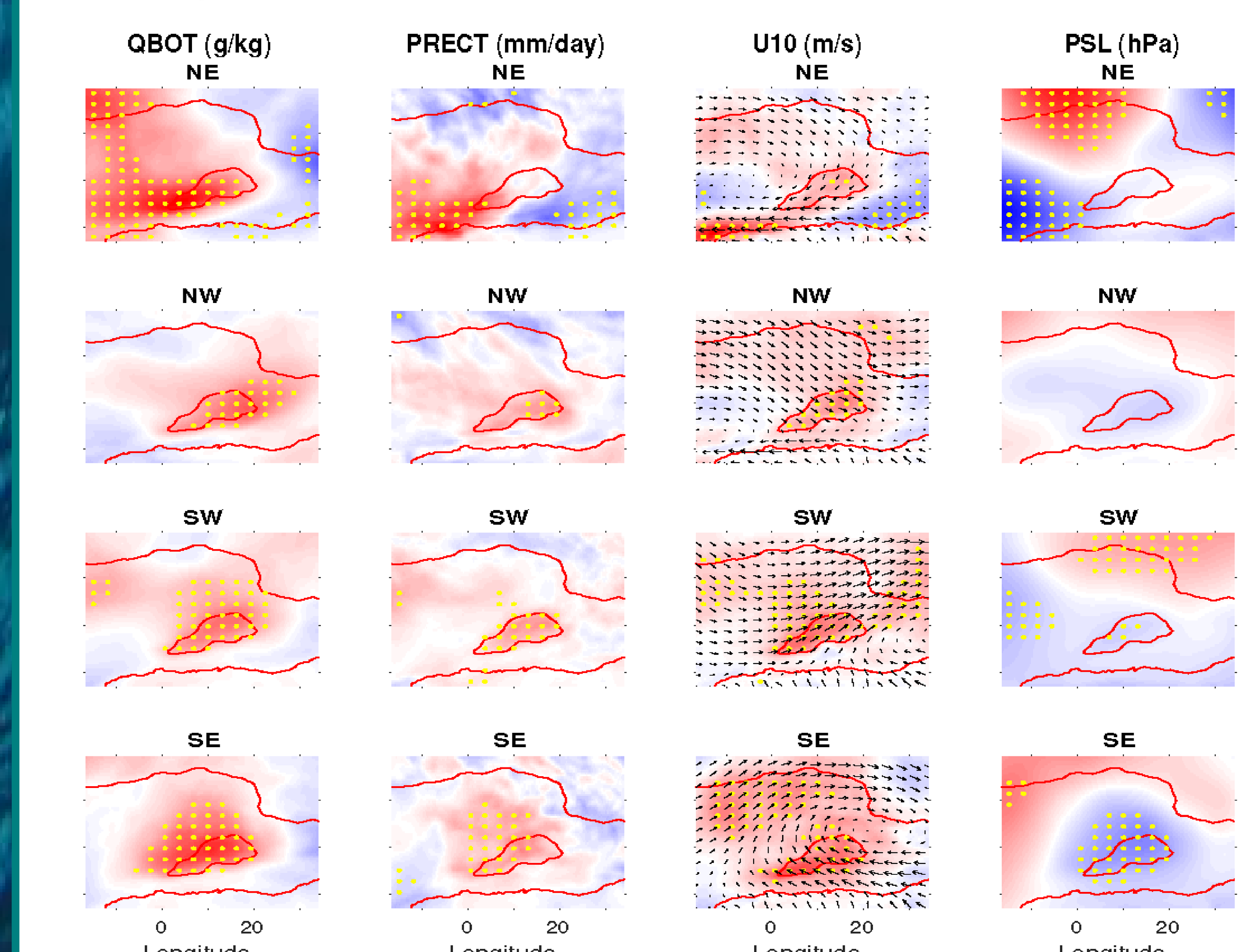

Figure 5: Daily-averaged variables composited according to wind direction; polynya minus non-polynya years. Difference in stippled regions are statistically significant. Red contours is 15% sea ice concentration, arrows indicate mean winds.