Response in Tropopause Polar Vortex Characteristics to Future Reductions in Sea Ice

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1. Introduction

SEA ICE is declining at an accelerating rate in the Arctic Ocean. As sea ice declines, it is important that the atmospheric response from changes in the Arctic surface boundary are understood. Greater amounts of heat and moisture have the potential to alter the unique conditions that enable Tropopause Polar Vortices (TPVs) to be maintained over the Arctic by reducing their radiative intensification mechanism. Since TPVs are important dynamical predecessors to surface cyclones, changes in their characteristics could be a key to understanding changes to surface low locations and intensity in the future.

2. What is a TPV?

A Tropopause Polar Vortex is defined as:

- A vortex occurring primarily in polar regions isolated from the jet stream.
- Based on the tropopause.
- Here we focus on cold core TPVs.

Using the 2 PVU surface as the dynamic tropopause, potential temperature can be used as a tracer of TPVs, given that PVU surfaces are material surfaces (adiabatically). Shown below are cross sections of the composite TPV from Cavallo and Hakim 2010[2]:

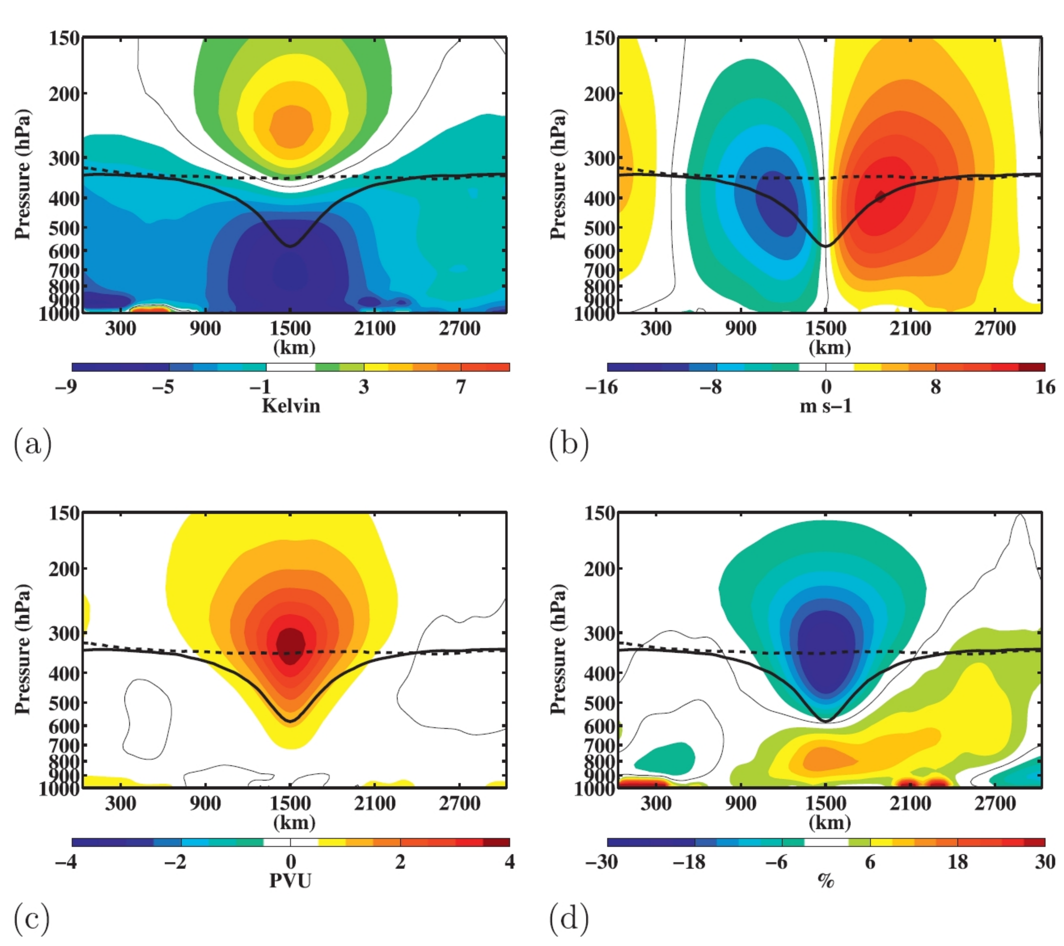

Figure 1: *TPV relative cross sections of anomalies in (a) temperature, (b) tangential wind, (c) Ertel Potential Vorticity (EPV), and (d) Relative Humidity.*

For this study, a vortex must be present for at least 2 days and spend at least 60% of its lifetime above 65 N in order to be considered a TPV.

3. Methodology

A high resolution ($\Delta x = 35\,km$) polar Weather Research and Forecast model (WRF) experiment was performed using two separate climatologies from the Community Atmospheric Model 3 (CAM3) to force the intial and boundary conditions: one with sea ice from a 1980-1999 CCSM ensemble ("20th century" conditions) and one with sea ice from a 2080-2099 CCSM ensemble ("21st century" conditions). This change in intial and boundary conditions due to sea ice is the only difference in start-up between the two model runs, allowing for a sensitivity experiment. Each simulation is run only during the months of November-February of each year for a total of 15 years. These months represent the greatest potential impact on the atmosphere because vertical air-sea gradients are largest. This implies that latent heating and radiative heating rates could change considerably and therefore could impact TPV characteristics.

A tracking algorthim developed by Dr. Greg Hakim is employed to gather location, lifetime, intensity, and well as other information about each TPV. Statistical analysis is performed on the results of this tracking algorithm.

4. Results

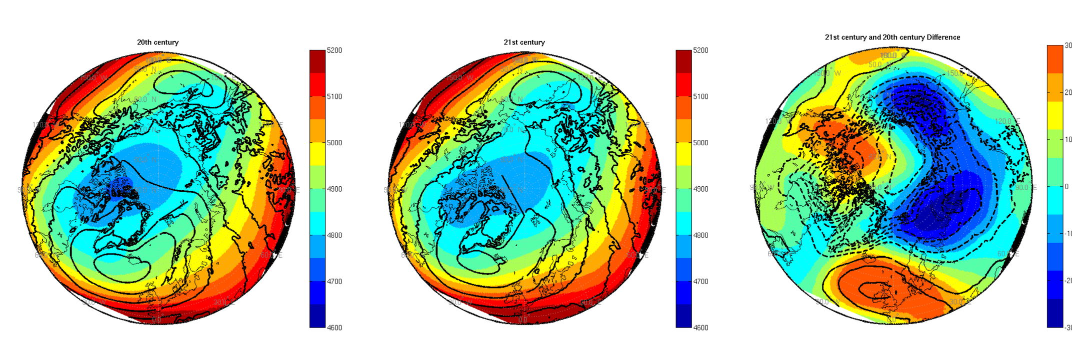

Figure 2: *500 hPa heights in filled contour with sea level pressure. SLP contours are at 5 hPa intervals in the 20th and 21st century. In the difference file, SLP contours are at 1 mb intervals with positive differences as solid lines, negative dashed.*

There is a large body of research which has demonstrated that sea ice loss is correlated with changing patterns, including poleward movement of a higher amplitude jetstream[4][3][1]. The results shown in Figure 2 are consistent with these findings. The 500 hPa pattern is more amplified, and in particular there is a large ridge over the North Atlantic and western North America. In the "21st" century, lower average sea level pressures are found over the Arctic. This is likely a combination of higher amplitude flow into the Arctic and enhanced low level baroclinicity along coast of the Arctic Ocean.

With changes in the large scale flow, it is important to understand the impact on TPVs in order to understand whether that could impact surface cyclones. The density plots below show that TPVs are generally move more poleward in the "21st" century. This is corroborated by the statistics, which show an increase in average latitude over TPV lifetime in the "21st" century versus the "20th". In addition to the poleward shift, TPV lifetimes and amplitudes are decreasing, while TPV radii remain the same. In order for the radiative mechanism to dominate in TPVs, heat and moisture must be limited, as is the case over ice and land. With sea ice loss, the radiative balances over the Arctic change, which we hypothesize could result in a net weakening of TPVs. In addition to the physical mechanisms, dynamical mechanisms may ultimately lead to a decrease in lifetimes through interactions with the jetstream.

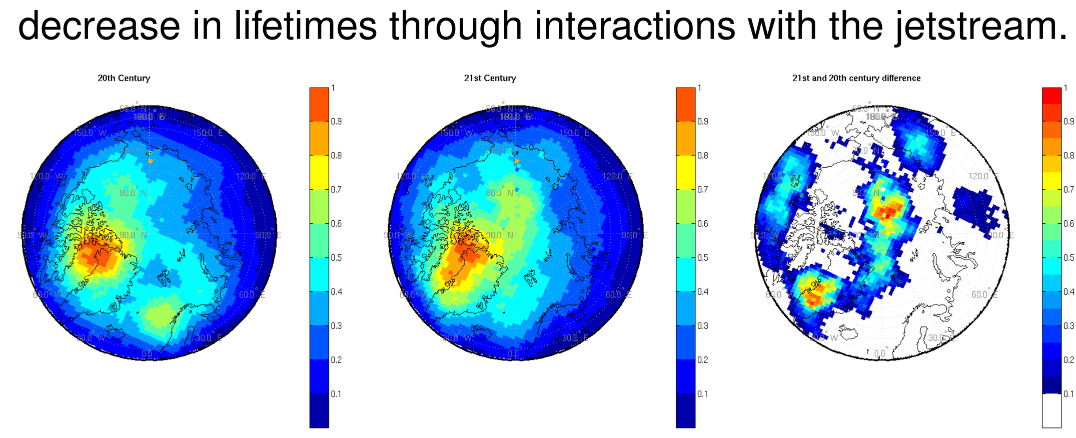

Figure 3: *Normalized density plots of all TPVs during model period.*

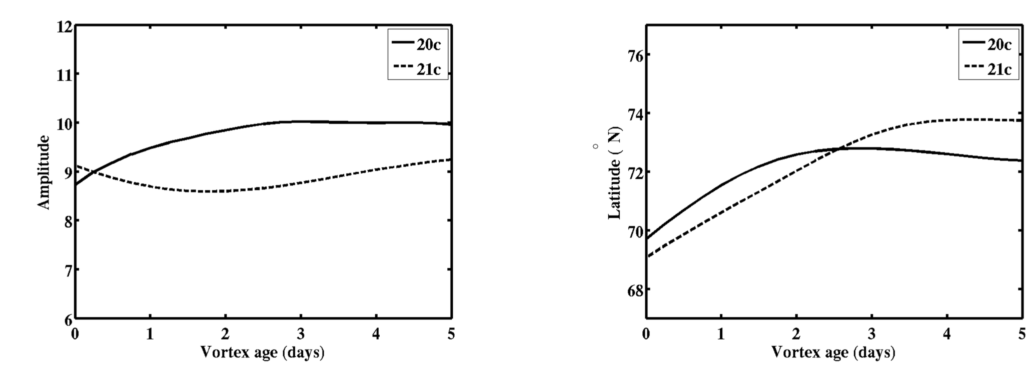

Figure 4: *From left to right: Potential temperature amplitude over vortex lifetime and average latitude over vortex lifetime. 20c solid, 21c dashed.*

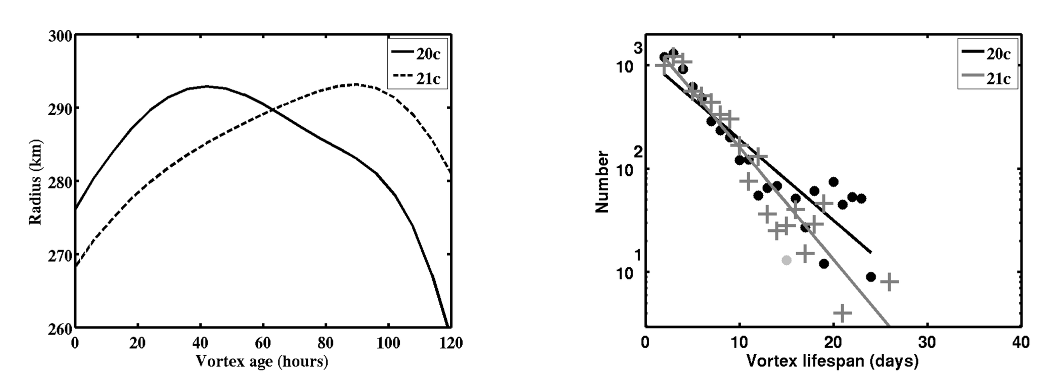

Figure 5: *From left to right: Vortex average radius over vortex lifetime and differences (20c solid, 21c dashed) in lifetimes for each model run.*

5. Conclusion and Future Research

If sea ice continues to decline, we expect considerable changes in TPV characteristics and locations. This could have implications on storm tracks given that TPVs are important for their formation.

Future work will include:

- When vortices are binned in a histogram format by potential temperature amplitude, a noticable decrease of high amplitude cyclones is seen in the "21st" century. Further work must be performed in order to determine the cause of this decrease, and whether or not this decrease could be used to explain the higher average amplitude seen in Figure 5.
- Calculation of the Arctic Oscillation and North Atlantic Oscillation to determine if significant differences exist between the two simulations.

6. Acknowledgements

We would like to thank Dr. Greg Hakim of the University of Washington for use of his tracking algorthim.

References

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