Improving Understanding and Predictability of Arctic Cyclones Linked to Tropopause Polar Vortices

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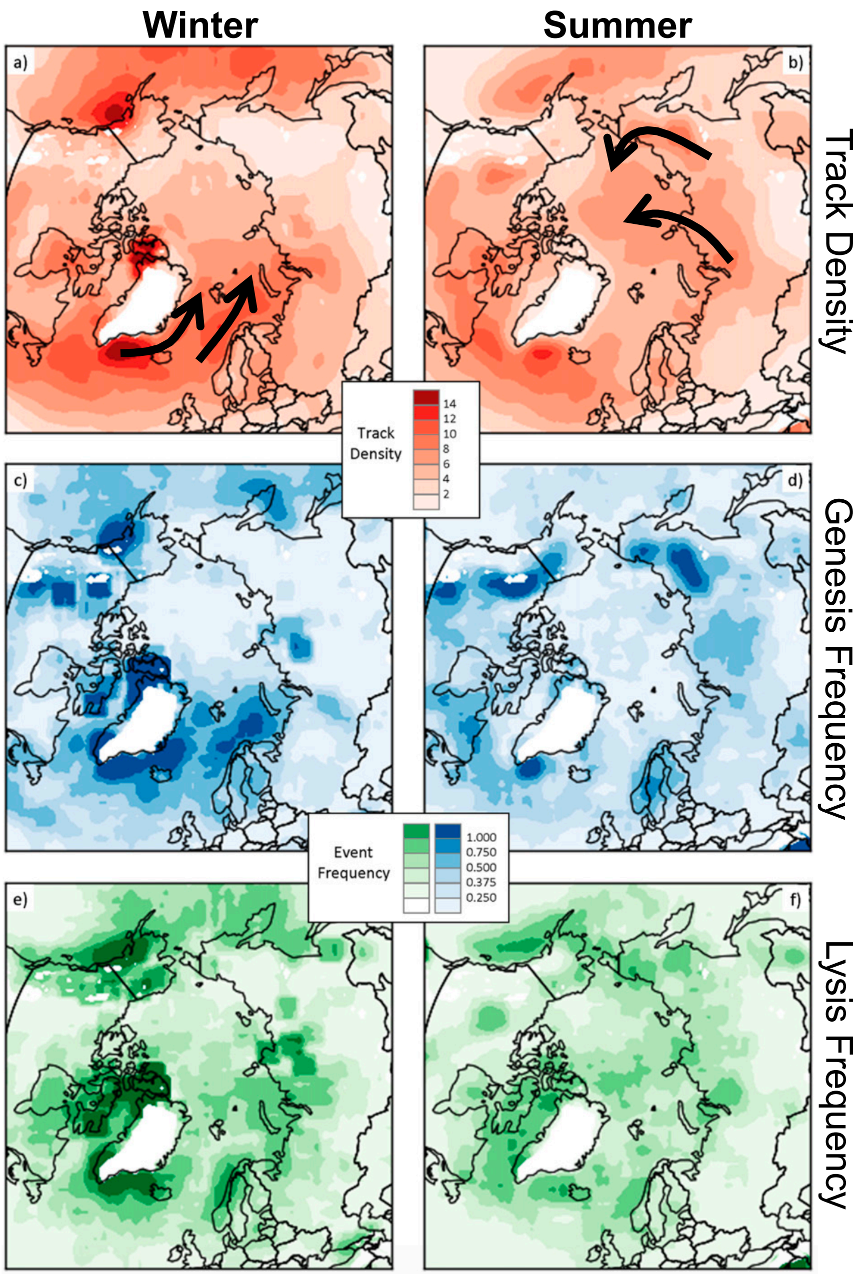
Motivation

- Tropopause polar vortices (TPVs) may act as precursors for the development of intense Arctic cyclones (e.g., Simmonds and Rudeva 2012)

- Arctic cyclones may be associated with strong surface winds and poleward advection of warm, moist air, contributing to Arctic sea-ice loss (e.g., Zhang et al. 2013)

- Predictability of Arctic cyclones has received limited attention in the literature

Background



- Arctic cyclones may originate within and outside of Arctic
- ~30–40% of Arctic cyclones originate within Arctic during both winter and Summer
- During winter, Arctic cyclones often originate from North Atlantic
- During summer, Arctic cyclones often originate from Eurasia

Figure 3 adapted from Crawford and Serreze (2016)

Background

- Highly-amplified flow may enable cyclones and associated intrusions of warm, moist air to enter the Arctic

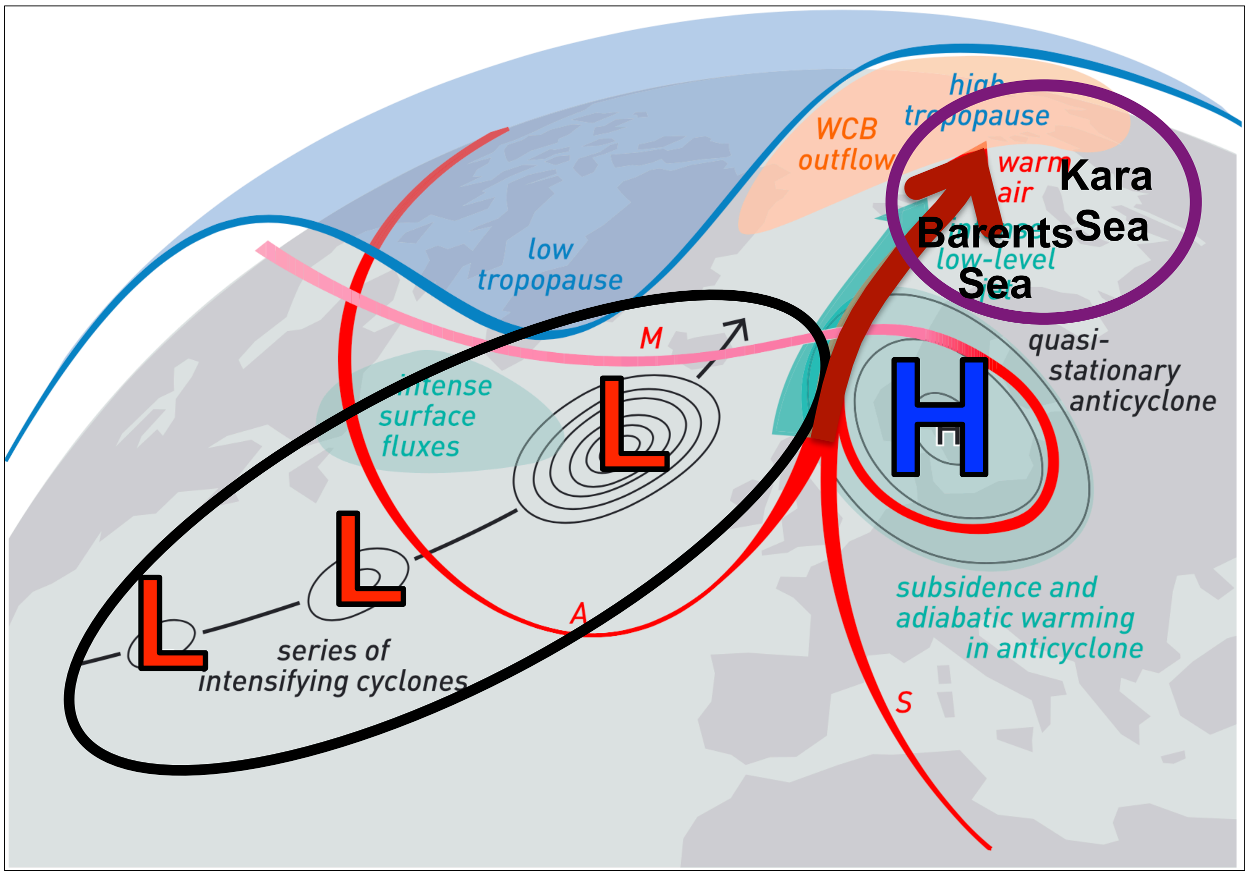


Figure 4 adapted from Binder et al. (2017)

- During late Dec 2015 and early Jan 2016, warm, moist air transported between series of cyclones and blocking anticyclone (Binder et al. 2017)
- More than 30 cm of sea ice thinning in the Barents and Kara Seas occurred during this event

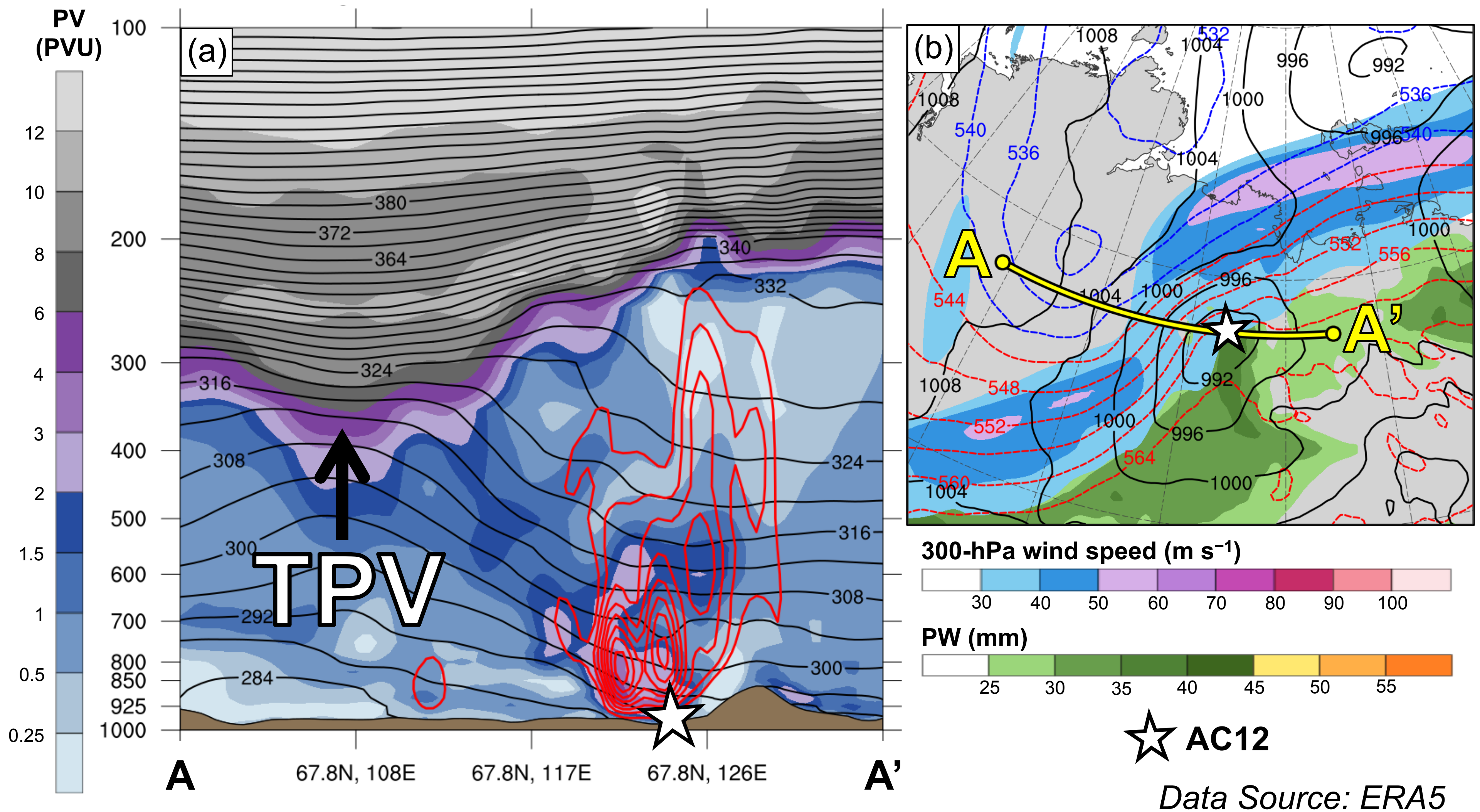
Background

- TPVs, baroclinic processes, and latent heating may play important roles in the evolution of Arctic cyclones

- Simmonds and Rudeva (2012), Yamazaki et al. (2015), and Tao et al. (2017) illustrate that a TPV and baroclinic processes play important roles in the evolution of the Great Arctic Cyclone of August 2012 (AC12)

Background

2100 UTC 3 Aug 2012



(a) θ (K, black) and ascent (red, every 5×10^{-3} hPa s^{-1});
(b) 1000–500-hPa thickness (dam, blue/red) and SLP (hPa, black)

Background

- Forecast skill over the Arctic may be lower than in middle latitudes (e.g., Sandu and Bauer 2018)

- Yamagami et al. (2018) examine medium-range forecast skill for 10 strong Arctic cyclones occurring during the summers of 2008–2016 using five operational ensemble predictions systems (EPSs)

  – Forecast skill of these Arctic cyclones is lower than that of midlatitude cyclones in the Northern Hemisphere

- Low Arctic forecast skill may be attributed in part to low forecast skill of Arctic cyclones

Research Questions

1) Are there differences in location and large-scale flow pattern in which Arctic cyclones occur between low and high Arctic forecast skill periods for each season?

    a) Are there preferred locations and large-scale flow patterns in which low-skill Arctic cyclones linked to TPVs occur for each season?

2) What factors govern the evolution of low-skill Arctic cyclones linked to TPVs?

3) What factors limit the forecast skill of low-skill Arctic cyclones linked to TPVs and lead to reduced Arctic forecast skill?

Research Plan: Hypothesis 1

1) Are there differences in location and large-scale flow pattern in which Arctic cyclones occur between low and high Arctic forecast skill periods for each season?

- **Hypothesis:** When compared to high Arctic forecast skill periods, low Arctic forecast skill periods are associated with:
  - More Arctic cyclones originating from outside of the Arctic during all seasons
  - More Arctic cyclones occurring when the large-scale flow is more amplified during all seasons

Research Plan: Hypothesis 1

- Arctic cyclones that originate outside of the Arctic may be associated with stronger intrusions of warm, moist air and greater latent heating
  - Larger forecast errors that may be associated with stronger intrusions and greater latent heating may contribute to larger forecast errors over the Arctic
- During highly amplified flow, a waveguide may extend from lower latitudes into Arctic
  - Forecast errors associated with Arctic cyclones may grow and propagate into the Arctic along waveguide

Research Plan: Hypothesis 1

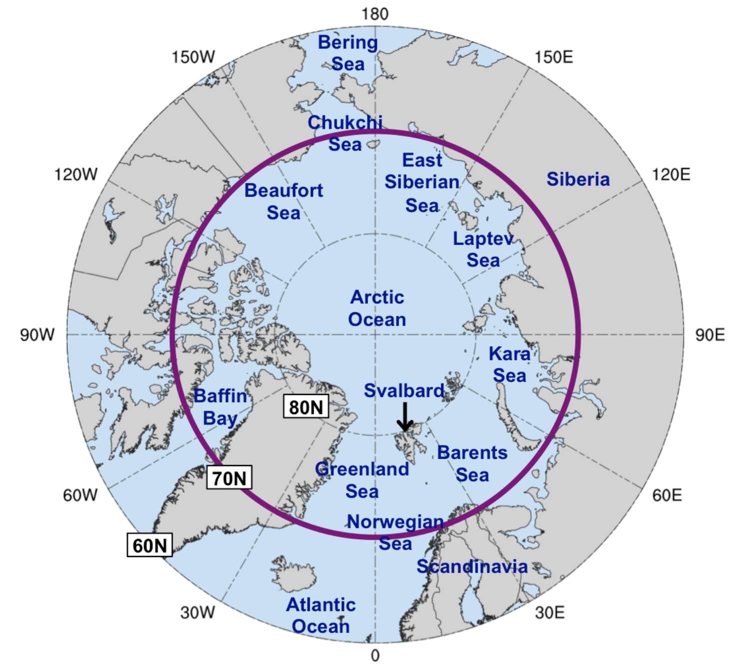
- Create climatology of Arctic cyclones
- Determine low and high Arctic forecast skill periods
- Compare the locations of Arctic cyclones and large-scale flow patterns during which Arctic cyclones are present between both periods for each season

Research Plan: Hypothesis 1

- Create a 2007–2017 Arctic cyclone climatology
- Obtain cyclone tracks from 1° ERA-Interim cyclone climatology prepared by Sprenger et al. (2017)

Research Plan: Hypothesis 1

- Evaluate Arctic forecast skill in terms of the area-averaged standardized anomaly of ensemble spread (σ_{anom}; e.g., Torn 2017) of 500-hPa geopotential height over the Arctic (>70°N)
  - Forecasts initialized at 0000 UTC and valid at day 5 from:
    - 11-member GEFS reforecast dataset v2 (Hamill et al 2013)
    - 51-member ECMWF EPS (Buizza et al. 2007)



Research Plan: Hypothesis 1

- Forecast days valid at day 5 associated with the top and bottom 5% of area-averaged σ_{anom} in both the GEFS and ECMWF EPS will be referred to as **low and high Arctic forecast skill days,** respectively

- Time periods beginning five days prior to day 5 (i.e., day 0) to day 5 will be referred to as **low and high Arctic forecast skill periods**

Research Plan: Hypothesis 1

- Compare the locations of Arctic cyclones between low and high Arctic forecast skill periods for each season

- Compare large-scale flow patterns during which Arctic cyclones are present between both periods for each season
  - Consider large-scale teleconnection indices (e.g., Arctic Oscillation and North Atlantic Oscillation)
  - Consider number and location of high-latitude atmospheric blocks using block climatology from Sprenger et al. (2017)

Research Plan: Hypothesis 1a

a) Are there preferred locations and large-scale flow patterns in which low-skill Arctic cyclones linked to TPVs occur each season?

- **Hypothesis:** Low-skill Arctic cyclones linked to TPVs preferably originate from outside of the Arctic during all seasons, and preferably occur when the large-scale flow is more amplified during all seasons.

Research Plan: Hypothesis 1a

- Calculate average ensemble spread of Arctic cyclone position and intensity during life cycle of Arctic cyclones occurring during low Arctic forecast skill periods using ECMWF EPS

- Consider Arctic cyclones within the upper quintile of average spread for either position or intensity to be **low-skill Arctic cyclones**

  – Determine those Arctic cyclones that are linked to TPVs

- Examine geographical distribution of, and large-scale flow pattern associated with, the low-skill Arctic cyclones linked to TPVs for each season

Research Plan: Hypothesis 2

2) What factors govern the evolution of low-skill Arctic cyclones linked to TPVs?

- **Hypothesis:** TPVs, baroclinic processes, and latent heating may play important roles in the evolution of low-skill Arctic cyclones linked to TPVs.

Research Plan: Hypothesis 2

- Analyze several illustrative low-skill Arctic cyclones linked to TPVs using ERA5 (Hersbach and Dee 2016)
  - Select cases to be representative of different regions, seasons, and cyclone evolutions

Research Plan: Hypothesis 2

- Examine TPVs and baroclinic processes
  - Consider forcing for ascent associated with TPVs and interactions between TPVs and baroclinic zones
  - Consider evolution of the potential temperature field and the Eady baroclinic growth rate parameter (e.g., Hoskins and Valdes 1990) at various levels
- Examine latent heating
  - Consider evolution of meridional moisture flux, lower-to-midtropospheric ascent, low-level PV, and upper-level divergence over and near Arctic cyclones

Research Plan: Hypothesis 3

3) What factors limit the forecast skill of low-skill Arctic cyclones linked to TPVs and lead to reduced Arctic forecast skill?

- **Hypothesis:** Forecast errors related to TPVs, baroclinic processes, and latent heating limit the forecast skill of low-skill Arctic cyclones linked to TPVs and reduce Arctic forecast skill.

Research Plan: Hypothesis 3

- Ensemble analysis and forecast tools (e.g., ensemble sensitivity analysis) will be utilized to diagnose factors limiting the forecast skill of the illustrative low-skill Arctic cyclones linked to TPVs that are analyzed in conjunction with hypothesis 2

Research Plan: Hypothesis 3

- Ensemble sensitivity analysis (e.g., Ancell and Hakim 2007; Torn and Hakim 2008) can be used to determine how sensitive a forecast metric of interest *J* is to a model state variable x_i at an earlier forecast lead time

$$\frac{\partial J}{\partial x_i} = \frac{cov(\mathbf{J}, \mathbf{x}_i)}{var(\mathbf{x}_i)}$$

- The forecast metric *J* may be the position of an Arctic cyclone and the model state variable x_i may be upper-level PV
  - Examine sensitivity of Arctic cyclone position to structure of the upper-level PV field associated with a TPV