An Examination of Low-Skill Arctic Cyclones During Summer

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Overview

- Identify periods of low and high forecast skill of the synoptic-scale flow over the Arctic and low-skill Arctic cyclones (ACs) occurring during these periods.

- Examine dynamical and thermodynamic quantities characterizing the Arctic environment and low-skill ACs during low-skill and high-skill periods.

- Conduct AC-centered composite analyses of intense low-skill ACs during low-skill periods to identify features and processes governing the evolution of these ACs.
Arctic forecast skill evaluation

• Utilize day-5 forecasts of 500-hPa geopotential height initialized at 0000 UTC during summers (June, July, and August) of 2007–2017 from 11-member 1° GEFS reforecast dataset v2 (Hamill et al. 2013).

• Calculate area-averaged root mean square error (RMSE) of 500-hPa geopotential height over the Arctic, using ERA-Interim as verification.

• Calculated standardized anomaly of area-averaged RMSE ($\sigma_{\text{RMSE}}$).
Arctic forecast skill evaluation

- Refer to forecast days valid at day 5 associated with the top and bottom 10% of $\sigma_{\text{RMSE}}$ as **low-skill days and high-skill days**, respectively.

- Refer to forecasts initialized 5 days prior to low-skill days and high-skill days as **low-skill forecasts and high-skill forecasts**, respectively.

- Refer to time periods through day 5 encompassed by low-skill forecasts and high-skill forecasts as **low-skill periods and high-skill periods**, respectively.
Quantities characterizing the Arctic environment

(a) Abs. value of stnd. anom. of 500-hPa v wind (σ)

(b) 850–600-hPa Eady growth rate (day⁻¹)

(c) Integrated vapor transport (IVT) (kg m⁻¹ s⁻¹)

(d) Negative 800–600-hPa ω (10⁻³ hPa s⁻¹)

(e) 350–250-hPa divergence (10⁻⁶ s⁻¹)

Legend

Distribution of quantities area-averaged over the Arctic (≥ 70°N)

- Low-skill mean
- High-skill mean
- Statistically significant difference with respect to climo at 95% confidence level
- 2007–2017 climo mean

Shading: Interquartile range

Data: 1° ERA-Interim
Identification of low-skill ACs

- Create a 2007–2017 summer (June, July, and August) AC climatology by obtaining cyclone tracks from 1° ERA-Interim cyclone climatology prepared by Sprenger et al. (2017).

- Deem cyclones that last ≥ 48 h and spend at least some portion of their lifetimes in the Arctic (> 70°N) as ACs.
Identification of low-skill ACs

• Track ACs in forecasts from GEFS reforecast dataset v2 by utilizing an objective sea level pressure (SLP)-based tracking algorithm (Crawford et al. 2020).

• Consider forecasts initialized 120 h prior to the time of lowest SLP of the ACs when located in the Arctic during low-skill and high-skill periods.

• Calculate 120-h intensity RMSE based on minimum SLP of the ACs at the aforementioned time of lowest SLP, using ERA-Interim as verification.

• Refer to ACs associated with the top 25% of 120-h intensity RMSE for low-skill and high-skill periods as low-skill ACs for these respective periods.
Identification of low-skill ACs

120-h Intensity RMSE (hPa)

Legend

Red: Low-skill ACs during low-skill periods (N = 58)

Blue: Low-skill ACs during high-skill periods (N = 39)

○ mean
★ min and max
Quantities characterizing low-skill ACs

(a) Min SLP (hPa)  
(b) Area-average abs. value of std. anom. of 500-hPa v wind (σ)  
(c) Area-average 850–600-hPa Eady growth rate (day⁻¹)  
(d) Area-average IVT (kg m⁻¹ s⁻¹)  
(e) Area-average negative 800–600-hPa ω (10⁻³ hPa s⁻¹)  
(f) Area-average 350–250-hPa divergence (10⁻⁶ s⁻¹)

Legend

Distribution of most extreme value of quantities characterizing ACs when the ACs are located in the Arctic for the following categories:

Gray: All ACs in 2007–2017 climatology (N = 730)  
Red: Low-skill ACs during low-skill periods (N = 58)  
Blue: Low-skill ACs during high-skill periods (N = 39)

Statistically significant difference with respect to climatology at 95% confidence level

Area-averaged quantities are calculated within 1000 km of AC center

Data: 1° ERA-Interim
AC-centered composites

- Composite top 25% strongest low-skill ACs during low-skill periods \((N = 14)\) at various lag times relative to the time of lowest SLP of the ACs when located in the Arctic using ERA5 \((0.25^\circ \times 0.25^\circ)\).
AC-centered composites

• Composite top 25% strongest low-skill ACs during low-skill periods ($N = 14$) at various lag times relative to the time of lowest SLP of the ACs when located in the Arctic using ERA5 ($0.25^\circ \times 0.25^\circ$).

• For each lag time:
  
  – Determine mean latitude and longitude of ACs.
AC-centered composites

- Composite top 25% strongest low-skill ACs during low-skill periods \((N = 14)\) at various lag times relative to the time of lowest SLP of the ACs when located in the Arctic using ERA5 \((0.25^\circ \times 0.25^\circ)\).

- For each lag time:
  - Determine mean latitude and longitude of ACs.
  - Rotate and project ERA5 grids to a 25×25 km EASE2 equal area grid such that the AC center lies on y-axis \((0^\circ\) longitude) of the EASE2 grid.

EASE2 Grid
AC-centered composites

- Composite top 25% strongest low-skill ACs during low-skill periods ($N = 14$) at various lag times relative to the time of lowest SLP of the ACs when located in the Arctic using ERA5 (0.25°×0.25°).

- For each lag time:
  - Determine mean latitude and longitude of ACs.
  - Rotate and project ERA5 grids to a 25×25 km EASE2 equal area grid such that the AC center lies on y-axis (0° longitude) of the EASE2 grid.

SLP (black) on 25x25 km EASE2 grid (grid points in red) valid 1200 UTC 6 Aug 2012
AC-centered composites

- Composite top 25% strongest low-skill ACs during low-skill periods \((N = 14)\) at various lag times relative to the time of lowest SLP of the ACs when located in the Arctic using ERA5 \((0.25° \times 0.25°)\).

- For each lag time:
  - Determine mean latitude and longitude of ACs.
  - Rotate and project ERA5 grids to a 25×25 km EASE2 equal area grid such that the AC center lies on y-axis (0° longitude) of the EASE2 grid.
  - Shift projected grids to mean latitude of ACs.

SLP (black) on 25x25 km EASE2 grid (grid points in red) valid 1200 UTC 6 Aug 2012
AC-centered composites

Grid before shifting to mean latitude

Grid after shifting to mean latitude
AC-centered composites

- Composite top 25% strongest low-skill ACs during low-skill periods ($N = 14$) at various lag times relative to the time of lowest SLP of the ACs when located in the Arctic using ERA5 (0.25°×0.25°).

- For each lag time:
  - Determine mean latitude and longitude of ACs.
  - Rotate and project ERA5 grids to a 25×25 km EASE2 equal area grid such that the AC center lies on y-axis (0° longitude) of the EASE2 grid.
  - Shift projected grids to mean latitude of ACs.
  - Rotate shifted grids to mean longitude of ACs.
AC-centered composites

Red lines show tracks of ACs during lag –48 h to lag 36 h, when valid.

Time series of minimum SLP (hPa) of ACs (red) and of mean minimum SLP (hPa) of ACs (black) during lag –48 h to lag 36 h, when valid.
(a) Lag = −48 h (N = 13)
(b) Lag = −36 h (N = 13)
(c) Lag = −24 h (N = 14)
(d) Lag = −12 h (N = 14)
(e) Lag = 0 h (N = 14)
(f) Lag = 12 h (N = 13)
(g) Lag = 24 h (N = 13)
(h) Lag = 36 h (N = 12)

18 21 24 27 30 33 36 39

300-hPa wind speed (m s\(^{-1}\))

Mean AC location

300-hPa wind speed (m s\(^{-1}\))

SLP (hPa)

1000–500-hPa thickness (dam)

Mean AC location
Lag = -48 h (N = 13)

Lag = -36 h (N = 13)

Lag = -24 h (N = 14)

Lag = -12 h (N = 14)

Lag = 0 h (N = 14)

Lag = 12 h (N = 13)

Lag = 24 h (N = 13)

Lag = 36 h (N = 12)

Mean AC location

200-km area-averaged 500-hPa relative vorticity ($10^{-5}$ s$^{-1}$)

500-hPa geopotential height (dam)

500-hPa wind (m s$^{-1}$)
(a) Lag = -48 h (N = 13)
(b) Lag = -36 h (N = 13)
(c) Lag = -24 h (N = 14)
(d) Lag = -12 h (N = 14)
(e) Lag = 0 h (N = 14)
(f) Lag = 12 h (N = 13)
(g) Lag = 24 h (N = 13)
(h) Lag = 36 h (N = 12)

Mean AC location

700-hPa geopotential height (dam)

Integrated vapor transport (IVT) (kg m$^{-1}$ s$^{-1}$)

- 100
- 125
- 150
- 175
- 200
- 250
- 300
- 350
- 400
- 450
- 500

IVT (kg m$^{-1}$ s$^{-1}$)

700-hPa geopotential height (dam)

Mean AC location
(a) Lag = -48 h (N = 13)
(b) Lag = -36 h (N = 13)
(c) Lag = -24 h (N = 14)
(d) Lag = -12 h (N = 14)
(e) Lag = 0 h (N = 14)
(f) Lag = 12 h (N = 13)
(g) Lag = 24 h (N = 13)
(h) Lag = 36 h (N = 12)

200-km area-averaged 350–250-hPa divergence (10^{-6} \text{s}^{-1})

Mean AC location

Negative values of 800–600-hPa \( \omega \) (every 1 \times 10^{-3} \text{ hPa s}^{-1})

350–250-hPa irrotational wind (m s^{-1})

350–250-hPa PV (PVU)
(a) Lag = $-48$ h ($N = 13$)
(b) Lag = $-36$ h ($N = 13$)
(c) Lag = $-24$ h ($N = 14$)
(d) Lag = $-12$ h ($N = 14$)
(e) Lag = $0$ h ($N = 14$)
(f) Lag = $12$ h ($N = 13$)
(g) Lag = $24$ h ($N = 13$)
(h) Lag = $36$ h ($N = 12$)

Mean AC location

850–600-hPa Eady growth rate (day$^{-1}$)
Summary

- The Arctic environment tends to be characterized by more amplified synoptic-scale flow, greater baroclinic growth, and potentially greater latent heating during low-skill periods compared to high-skill periods.

- Low-skill ACs tend to be stronger and embedded in a region of more amplified synoptic-scale flow, greater baroclinic growth, and potentially greater latent heating during low-skill periods compared to high-skill periods.

- Intense low-skill ACs during low-skill periods intensify downstream of a mid-to-upper-tropospheric vortex in a region of relatively strong lower-to-midtropospheric baroclinicity, lower-to-midtropospheric ascent, tropospheric-integrated vapor transport, and upper-tropospheric divergence.

- A combination of baroclinic processes and latent heating likely play important roles in the intensification of intense-low-skill ACs during low-skill periods.