A Comparison of Arctic Cyclones between Periods of Low and High Forecast Skill of the Synoptic-Scale Flow over the Arctic

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Motivation

• Arctic cyclones (ACs) are synoptic-scale cyclones that originate within the Arctic or move into the Arctic from lower latitudes (e.g., Crawford and Serreze 2016)

• ACs may be associated with the poleward advection of warm, moist air, which can contribute to alterations of the synoptic-scale flow over the Arctic

• It is anticipated that relatively low forecast skill of the synoptic-scale flow over the Arctic may be attributed in part to forecast error growth accompanying alterations of the synoptic-scale flow induced by ACs
Purpose

• Investigate whether there are differences in the frequency, location, and intensity of ACs, and synoptic-scale flow patterns associated with ACs, between periods of low and high forecast skill of the synoptic-scale flow over the Arctic
Data and Methods: AC Identification

- Create a 2007–2017 AC climatology
- Obtain cyclone tracks from 1° ERA-Interim cyclone climatology prepared by Sprenger et al. (2017)
- ACs are deemed cyclones that last ≥ 2 d and spend at least some portion of their lifetimes in the Arctic (>70°N)
Utilize forecasts of 500-hPa geopotential height initialized at 0000 UTC during 2007–2017 and valid at day 5 from 11-member GEFS reforecast dataset v2 (Hamill et al. 2013)

Calculate area-averaged ensemble forecast spread of 500-hPa geopotential height over the Arctic (≥70°N)

Calculate area root mean square error (RMSE) of ensemble mean forecasts of 500-hPa geopotential height over the Arctic, using ERA-Interim (Dee et al. 2011) as verification
Calculate standardized anomaly of area-averaged ensemble spread ($\sigma_{\text{spread}}$) and of area RMSE ($\sigma_{\text{RMSE}}$) following Moore (2017).

Forecast days valid at day 5 associated with the top and bottom 10% of $\sigma_{\text{spread}}$ and $\sigma_{\text{RMSE}}$ are referred to as low and high skill days, respectively.

Time periods beginning five days prior to day 5 (i.e., day 0) through day 5 are referred to as low and high skill periods.

ACs that exist in the Arctic (>70°N) within the low and high skill periods are selected for further analysis.
Data and Methods: Forecast Skill Evaluation

$r^2 = 0.17$

 Scatter plot showing the relationship between $\sigma_{\text{spread}}$ and $\sigma_{\text{RMSE}}$ for different categories of skill days. The plot distinguishes between high skill days (blue), low skill days (red), and all other days (gray). The correlation coefficient $r^2$ is indicated as 0.17.
### Number and Frequency of ACs

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of days in period</th>
<th>Number of ACs in period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climo</td>
<td>4018</td>
<td>2549</td>
</tr>
<tr>
<td>Low skill</td>
<td>472</td>
<td>420</td>
</tr>
<tr>
<td>High skill</td>
<td>484</td>
<td>371</td>
</tr>
</tbody>
</table>

**Frequency of ACs (number of ACs day$^{-1}$)**

\[
\text{Frequency} = \frac{\text{number of ACs within period}}{\text{number of days within period}}
\]
Total number of ACs within 500 km of a grid point, divided by number of days in period (number of ACs day$^{-1}$)
AC Track Frequency

Climatology (N = 2549)

Total number of ACs within 500 km of a grid point, divided by number of days in period (number of ACs day\(^{-1}\))

Low skill (N = 420)
Total number of ACs within 500 km of a grid point, divided by number of days in period (number of ACs day$^{-1}$).
AC Track Frequency

Low skill (N = 420)

High skill (N = 371)

Total number of ACs within 500 km of a grid point, divided by number of days in period (number of ACs day$^{-1}$)
AC Track Frequency Differences

Low skill minus high skill

Difference in AC track density (number of ACs day$^{-1}$)
• Calculate standardized anomaly of minimum SLP every 6 h during lifetime of an AC and determine lowest standardized anomaly value during lifetime of AC
Intensity

Statistically significant differences in means between:

- low and high
- low and climo
- high and climo

Lowest standardized anomaly of SLP (σ) of ACs

- climo (N=2549)
- low (N=420)
- high (N=371)
Flow Amplitude

- Calculate absolute value of standardized anomaly of 500-hPa $v$-wind (hereafter $\sigma_v$) using ERA-Interim

- Calculate area average of $\sigma_v$ over the Arctic ($\geq 70^\circ$N) for low and high skill periods
Flow Amplitude

Low skill (avg. $\sigma_v = 1.14$)
0000 UTC 28 Aug 2016

High skill (avg. $\sigma_v = 0.45$)
0000 UTC 3 Sep 2011

500-hPa geopotential height (dam, black), wind (flags and barbs, m s$^{-1}$), and $\sigma_v$ (shading) from ERA-Interim
Flow Amplitude

Area average of $\sigma_v$ over the Arctic (≥70°N)

Hours relative to 0000 UTC of low and high skill days

- 1985–2017 climo median
- low-skill median
- high-skill median

**shading:**
- interquartile range
- statistically significant difference between low/high skill median and climo median

- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1.0
- 1.1

-24
-120
-96
-72
-48
-24
0
24

Climo median

Low-skill median

High-skill median

Black line represents the 1985–2017 climo median.

Red line represents the low-skill median.

Blue line represents the high-skill median.

Shading indicates the interquartile range.

The red points indicate a statistically significant difference between the low/high skill median and the climo median.
• Calculate standardized anomaly PW (hereafter $\sigma_{PW}$) using ERA-Interim

• Calculate area average of positive values of $\sigma_{PW}$ over the Arctic ($\geq 70^\circ$N) for low and high skill periods
Moisture

Low skill
0000 UTC 28 Aug 2016

High skill
0000 UTC 3 Sep 2011

700-hPa geopotential height (dam, black) and wind (flags and barbs, m s$^{-1}$), and PW (mm, shading) from ERA-Interim
Moisture

Low skill (avg. positive $\sigma_{PW} = 1.82$)
0000 UTC 28 Aug 2016

High skill (avg. positive $\sigma_{PW} = 0.63$)
0000 UTC 3 Sep 2011

700-hPa geopotential height (dam, black) and wind (flags and barbs, m s$^{-1}$), and $\sigma_{PW}$ (shading) from ERA-Interim
Moisture

Area average of positive values of $\sigma_{PW}$ over the Arctic ($\geq 70^\circ$N)

- 1985–2017 climo median
- low-skill median
- high-skill median

Shading:
- interquartile range
- statistically significant difference between low/high skill median and climo median
Summary

- Arctic cyclone frequency is higher for low skill periods compared to high skill periods.

- Arctic cyclones during low skill periods occur more frequently over eastern Eurasia, the northwestern North Pacific, and much of the Arctic Ocean relative to Arctic cyclones during high skill periods.

- Arctic cyclones during high skill periods occur more frequently over the northern North Atlantic, Norwegian and Barents Seas, and western Eurasia relative to Arctic cyclones during low skill periods.
Summary

• Arctic cyclones tend to be stronger during low skill periods compared to high skill periods

• There tends to be significantly amplified and deamplified synoptic-scale flow over the Arctic relative to climatology during low and high skill periods, respectively

• There tends to be significantly large and small amounts of moisture over the Arctic relative to climatology during low and high skill periods, respectively
• Arctic cyclones tend to be stronger during low skill periods compared to high skill periods

• There tends to be significantly amplified and deamplified synoptic-scale flow over the Arctic relative to climatology during low and high skill periods, respectively

• There tends to be significantly large and small amounts of moisture over the Arctic relative to climatology during low and high skill periods, respectively

Acknowledgments

Ben Moore
References


Extra Slides
Frequency of ACs by Season

Frequency of ACs (number of ACs day$^{-1}$) by season

Frequency = number of ACs within period / number of days within period
Number of Arctic Cyclones by Season

Number of ACs in climatology by season

Number of ACs in low and high skill periods by season

Low skill
High skill
Total number of ACs within 500 km of a grid point, divided by number of days in climatology during DJF (number of ACs day$^{-1}$)
AC Track Frequency (DJF)

Low skill (N = 107)

High skill (N = 70)

Total number of ACs within 500 km of a grid point, divided by number of days in period during DJF (number of ACs day$^{-1}$)
AC Track Frequency Differences (DJF)

Low skill minus high skill

Difference in AC track density during DJF (number of ACs day$^{-1}$)
AC Track Frequency (MAM)

Climatology (N = 609)

Total number of ACs within 500 km of a grid point, divided by number of days in climatology during MAM (number of ACs day\(^{-1}\))
AC Track Frequency (MAM)

Low skill (N = 82)

High skill (N = 108)

Total number of ACs within 500 km of a grid point, divided by number of days in period during MAM (number of ACs day$^{-1}$)
AC Track Frequency Differences (MAM)

Low skill minus high skill

Difference in AC track density during MAM (number of ACs day\(^{-1}\))
AC Track Frequency (JJA)

Climatology (N = 680)

Total number of ACs within 500 km of a grid point, divided by number of days in climatology during JJA (number of ACs day$^{-1}$)
AC Track Frequency (JJA)

Low skill (N = 125)

High skill (N = 94)

Total number of ACs within 500 km of a grid point, divided by number of days in period during JJA (number of ACs day$^{-1}$)
AC Track Frequency Differences (JJA)

Low skill minus high skill

Difference in AC track density during JJA (number of ACs day$^{-1}$)
Total number of ACs within 500 km of a grid point, divided by number of days in climatology during SON (number of ACs day$^{-1}$)
AC Track Frequency (SON)

Low skill (N = 106)

High skill (N = 99)

Total number of ACs within 500 km of a grid point, divided by number of days in period during SON (number of ACs day$^{-1}$)
AC Track Frequency Differences (SON)

Low skill minus high skill

Difference in AC track density during SON (number of ACs day$^{-1}$)
Preferred Longitudinal Corridors

Distribution of longitude of Arctic cyclones at first time in Arctic (>70°N; % per longitudinal bin)

- Climato (N=2549)
- Low (N=420)
- High (N=371)
Distribution of longitude of Arctic cyclones at first time in Arctic (>70°N; % per longitudinal bin) during DJF.

- Climatic distribution (N=592)
- Low activity (N=107)
- High activity (N=70)
Preferred Longitudinal Corridors (MAM)

Distribution of longitude of Arctic cyclones at first time in Arctic (>70°N; % per longitudinal bin) during MAM

climo (N=609)  low (N=82)  high (N=108)
Preferred Longitudinal Corridors (JJA)

Distribution of longitude of Arctic cyclones at first time in Arctic (>70°N; % per longitudinal bin) during JJA

- climo (N=680)
- low (N=125)
- high (N=94)
Preferred Longitudinal Corridors (SON)

Distribution of longitude of Arctic cyclones at first time in Arctic (>70°N; % per longitudinal bin) during SON

climo (N=668)   low (N=106)   high (N=99)
Lowest standardized anomaly of SLP ($\sigma$) of ACs by season

Statistically significant differences in means

DJF
- low (N = 107)
- high (N = 70)

MAM
- low (N = 82)
- high (N = 108)

JJA
- low (N = 125)
- high (N = 94)

SON
- low (N = 106)
- high (N = 99)
Intensification

• Calculate maximum 12-h deepening rate of cyclone following Sanders and Gyakum (1980) and Zhang et al. (2017)

\[
\text{12-h deepening rate at } t_0 \\
\text{(bergerons)} = - \left( \frac{SLP_{t+6h} - SLP_{t-6h}}{12} \right) \times \left[ \frac{\sin(60^\circ)}{\sin \left( \frac{\phi_{t+6h} + \phi_{t-6h}}{2} \right)} \right]
\]

where \( \phi = \text{latitude} \)
Intensification

Statistically significant differences in means between:

- low and high
- high and climo

Maximum 12-h deepening rate (bergerons) of ACs

- climo (N=2549)
- low (N=420)
- high (N=371)
Intensification

Maximum 12-h deepening rate (bergerons) of ACs by season

Statistically significant differences in means

DJF
MAM
JJA
SON

95%
75%
median
25%
5%

○ mean

Statistically significant differences in means
Statistically significant differences in means between:

- Climo (N=2549)
- Low (N=420)
- High (N=371)
Maximum SLP depth (hPa) of ACs by season

- **DJF (N=107)**: Low (N=82) and High (N=108)
- **MAM (N=99)**: Low (N=125) and High (N=94)
- **JJA (N=97)**: Low (N=106) and High (N=99)

Statistically significant differences in means

- **Intensity**
  - Mean
  - 95%
  - 75%
  - Median
  - 25%
  - 5%

- Low vs. High

- 75% and 95% confidence levels
Maximum Latitude

Maximum latitude (°N) of ACs

Statistically significant differences in means between:
- low and high
- low and climo
Maximum Latitude

Maximum latitude (°N) of ACs by season

DJF
- low (N=107)
- high (N=70)

MAM
- low (N=82)
- high (N=108)

JJA
- low (N=125)
- high (N=94)

SON
- low (N=106)
- high (N=99)

Statistically significant differences in means

95% 75% median 25% 5%

○ mean

Statistically significant differences in means

0 213 462

Maximum Latitude

80 90 77.5 75 72.5 70 82.5 85 87.5
Genesis Latitude

![Box plot of Genesis latitude (°N) of ACs]

- climo (N=2549)
- low (N=420)
- high (N=371)
Genesis Latitude

Genesis latitude (°N) of ACs by season

- **DJF**
  - Low: (N=107)
  - High: (N=70)

- **MAM**
  - Low: (N=82)
  - High: (N=108)

- **JJA**
  - Low: (N=125)
  - High: (N=94)

- **SON**
  - Low: (N=106)
  - High: (N=99)

**Statistically significant differences in means**

- Median
- Mean
- 25%
- 75%
- 95%
- 5%
Maximum 24-h Latitude Increase

Maximum 24-h latitude increase (°N) of ACs

Statistically significant differences in means between:

- low and high
Maximum 24-h Latitude Increase

Maximum 24-h Latitude Increase (°N) of ACs by season

DJF
low (N=107) high (N=70)

MAM
low (N=82) high (N=108)

JJA
low (N=125) high (N=94)

SON
low (N=106) high (N=99)

-5 -2.5 0 2.5 5 7.5 10 12.5 15

95% 75% median 25% 5%

○ mean ★ Statistically significant differences in means
Lifetime mean (N=2549) low (N=420) high (N=371)

Lifetime (days) of ACs

Statistically significant differences in means between:

- high and climo
Lifetime

Lifetime (days) of ACs by season

- **DJF**
  - Low: N = 107
  - High: N = 70
- **MAM**
  - Low: N = 82
  - High: N = 108
- **JJA**
  - Low: N = 125
  - High: N = 94
- **SON**
  - Low: N = 106
  - High: N = 99

- **Statistically significant differences in means**

- **Lifetime mean**
  - 4
  - 10
  - 2
  - 6
  - 8

- **75% median**

- **95%**

- **5%**

- **95%**

- **75%**

- **median**

- **25%**

- **5%**
AO Index of Days

Statistically significant differences in means between:

- high and climo
Flow Amplitude (65–75°N)

Area-weighted average of $\sigma_v$ over 65–70°N

- 1985–2017 climo median
- low-skill median
- high-skill median

Shading:
- interquartile range
- difference between low/high skill median and climo median

Hours relative to 0000 UTC of low and high skill days

-120, -96, -72, -48, -24, 0, 24
Moisture (65–75°N)

Area-weighted average of positive values of $\sigma_{PW}$ over 65–70°N

- 1985–2017 climo median
- low-skill median
- high-skill median

shading:
- interquartile range

statistically significant difference between low/high skill median and climo median

Hours relative to 0000 UTC of low and high skill days

-120 -96 -72 -48 -24 0 24

- 0.5 - 1.1
Meridional Moisture Flux (65–75°N)

Area-weighted average of positive values of 850-hPa $\sigma_{qv}$ over 65–75°N

- 1985–2017 climo median
- low-skill median
- high-skill median

shading:
- interquartile range
- statistically significant difference between low/high skill median and climo median
Worst Low Skill Day

GEFS Mean 5-d Forecast
valid 0000 UTC 3 Dec 2007

ERA Interim Analysis
valid 0000 UTC 3 Dec 2007

500-hPa geopotential height (dam, black)
Worst Low Skill Day

Avg. $\sigma_v = 1.34$
0000 UTC 3 Dec 2007

500-hPa geopotential height (dam, black), wind (flags and barbs, m s$^{-1}$), and $\sigma_v$ (shading)

Avg. $\sigma_{PW} = 2.89$
0000 UTC 3 Dec 2007

700-hPa geopotential height (dam, black), wind (flags and barbs, m s$^{-1}$), and positive values of $\sigma_{PW}$ (shading)
$\sigma_{\text{spread}} \text{ vs } \sigma_v$

$r^2 = 0.15$

- Red dots: Low skill days
- Blue dots: High skill days
- Gray dots: All other days
$\sigma_{\text{RMSE}}$ vs $\sigma_v$

$r^2 = 0.10$
$\sigma_{\text{spread}} \ vs \ \sigma_{\text{PW}}$

$r^2 = 0.09$

- High skill days
- Low skill days
- All other days
$\sigma_{\text{ACC}} \text{ vs } \sigma_{\text{spread}}$

$r^2 = 0.015$
$\sigma_{\text{ACC}} \text{ vs } \sigma_{\text{RMSE}}$

$r^2 = 0.35$