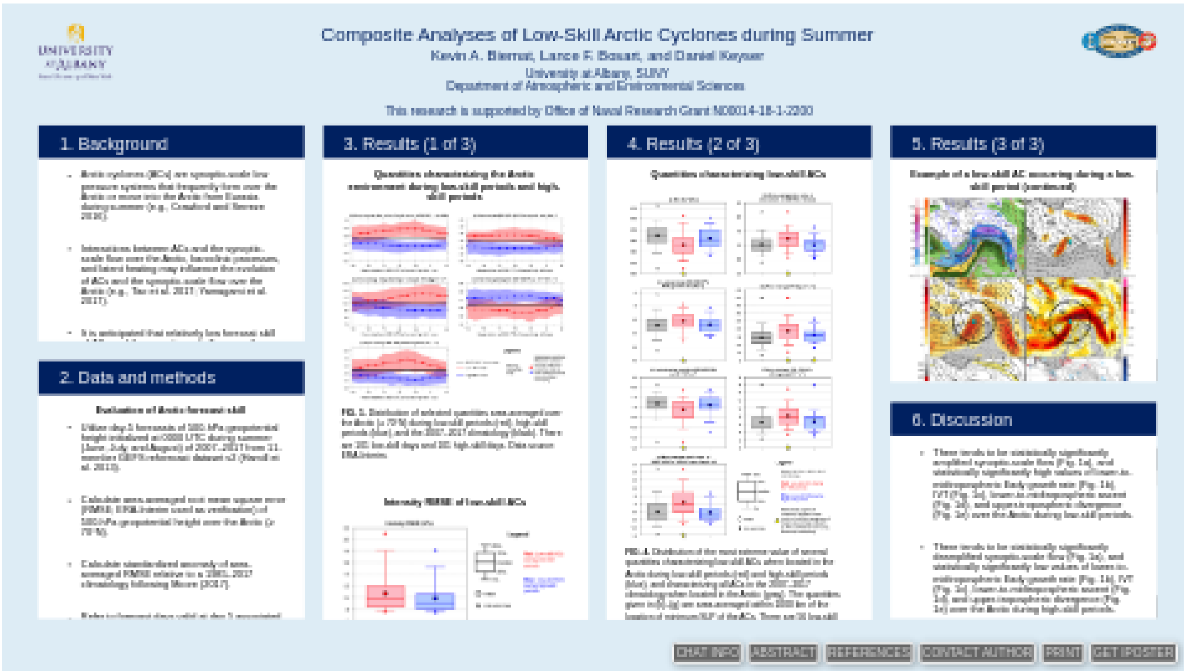
Composite Analyses of Low-Skill Arctic Cyclones during Summer



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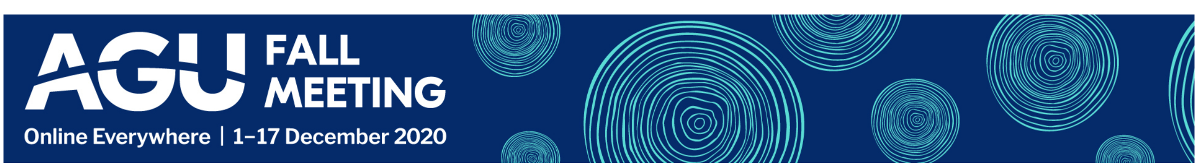

1. BACKGROUND

- Arctic cyclones (ACs) are synoptic-scale low pressure systems that frequently form over the Arctic or move into the Arctic from Eurasia during summer (e.g., Crawford and Serreze 2016).

- Interactions between ACs and the synoptic-scale flow over the Arctic, baroclinic processes, and latent heating may influence the evolution of ACs and the synoptic-scale flow over the Arctic (e.g., Tao et al. 2017; Yamagami et al. 2017).

- It is anticipated that relatively low forecast skill of ACs and the synoptic-scale flow over the Arctic may be attributed in part to forecast error growth accompanying interactions between ACs and the synoptic-scale flow over the Arctic, baroclinic processes, and latent heating.

- The purpose of this study is to examine dynamical and thermodynamic quantities characterizing the Arctic environment and low-skill ACs during periods of low and high forecast skill of the synoptic-scale flow over the Arctic.

2. DATA AND METHODS

Evaluation of Arctic forecast skill

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

- Calculate area-averaged root mean square error (RMSE; ERA-Interim used as verification) of 500-hPa geopotential height over the Arctic (≥ 70°N).

- Calculate standardized anomaly of area-averaged RMSE relative to a 1985–2017 climatology following Moore (2017).

- Refer to forecast days valid at day 5 associated with the top and bottom 10% of aforementioned standardized anomaly as low-skill days and high-skill days, respectively.

- Refer to forecasts initialized five 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.

Identification of low-skill ACs

- Create a 2007–2017 summer AC climatology by obtaining cyclone tracks from 1° ERA-Interim (Dee et al. 2011) cyclone climatology prepared by Sprenger et al. (2017).

- Require ACs to last ≥ 2 days and spend at least some portion of their lifetimes in the Arctic (> 70°N).

- Select ACs that exist in the Arctic during low-skill periods and high-skill periods for analysis.

- Track ACs in forecasts from GEFS reforecast dataset v2 initialized 120 h prior to time of lowest sea level pressure (SLP) of ACs when located in the Arctic during low-skill periods and high-skill periods using an objective cyclone tracking algorithm (Crawford et al. 2020).

- Calculate 120-h intensity RMSE (ERA-Interim used as verification) based on minimum SLP of ACs at aforementioned time of lowest SLP.

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

3. RESULTS (1 OF 3)

Quantities characterizing the Arctic environment during low-skill periods and high-skill periods

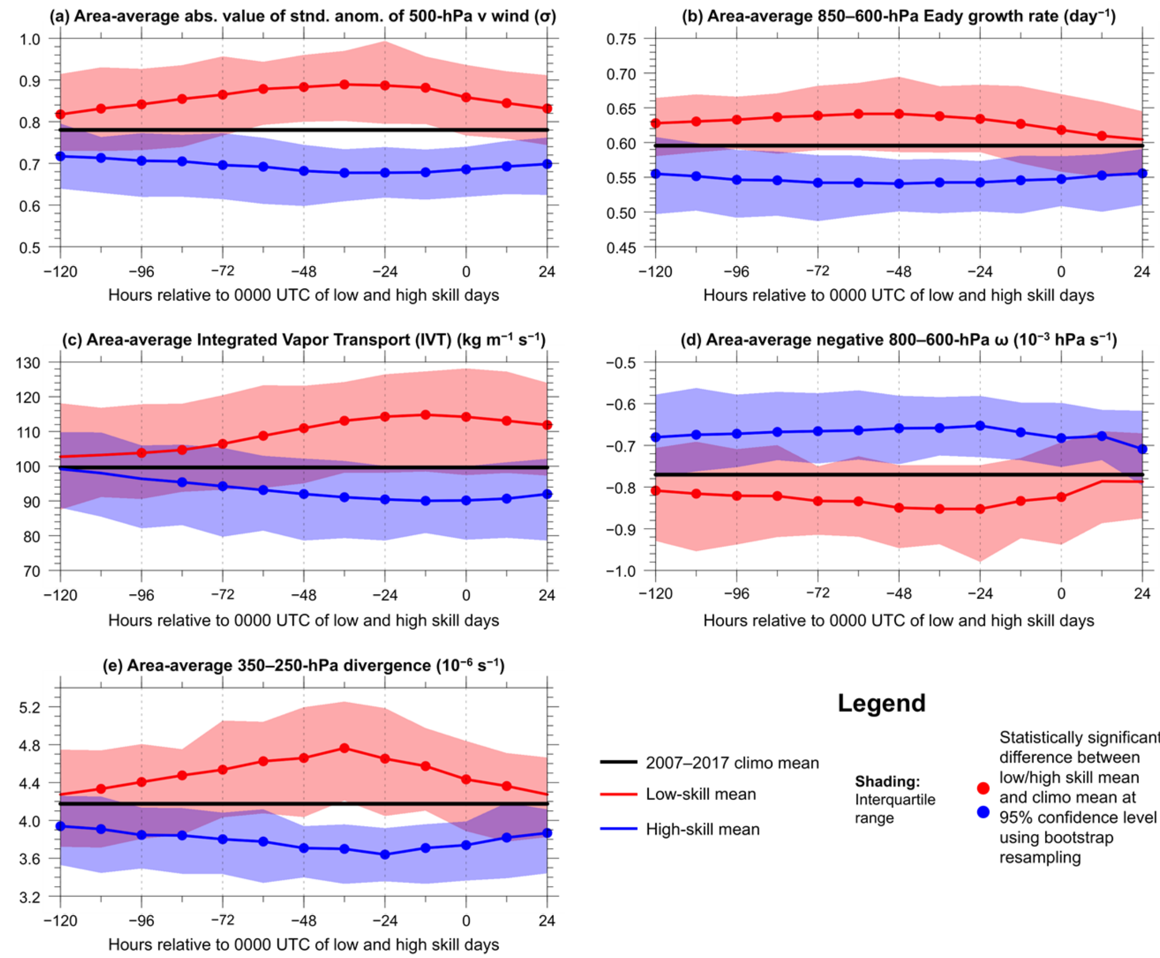

FIG. 1. Distribution of selected quantities area-averaged over the Arctic (≥ 70°N) during low-skill periods (red), high-skill periods (blue), and the 2007–2017 climatology (black). There are 101 low-skill days and 101 high-skill days. Data source: ERA-Interim.

Intensity RMSE of low-skill ACs

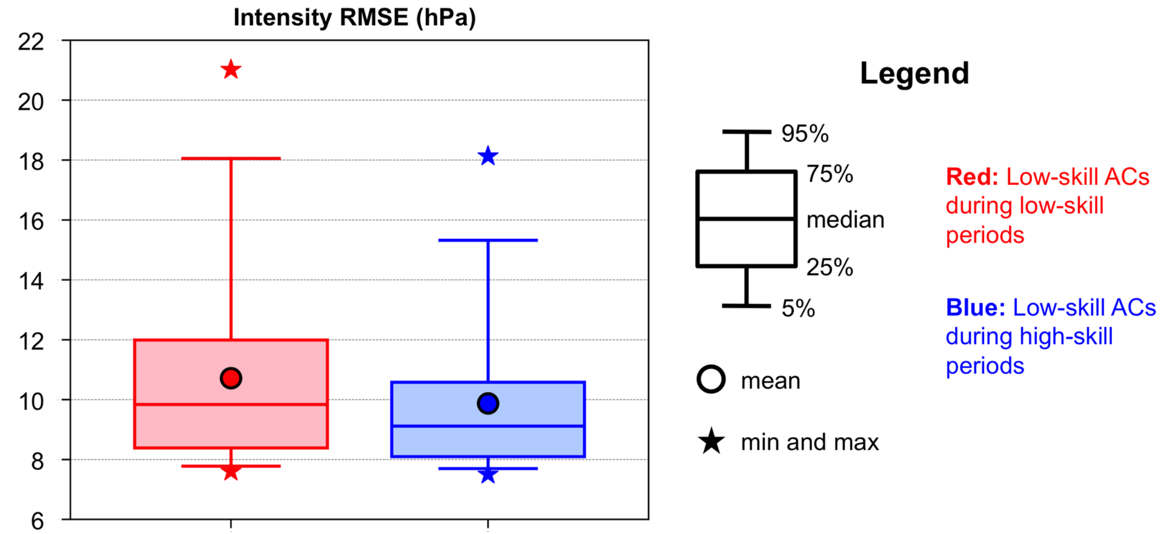

FIG. 2. Distribution of 120-h intensity RMSE (hPa) of low-skill ACs during low-skill periods (red) and high-skill periods (blue). There are 56 low-skill ACs during low-skill periods and 39 low-skill ACs during high skill period.

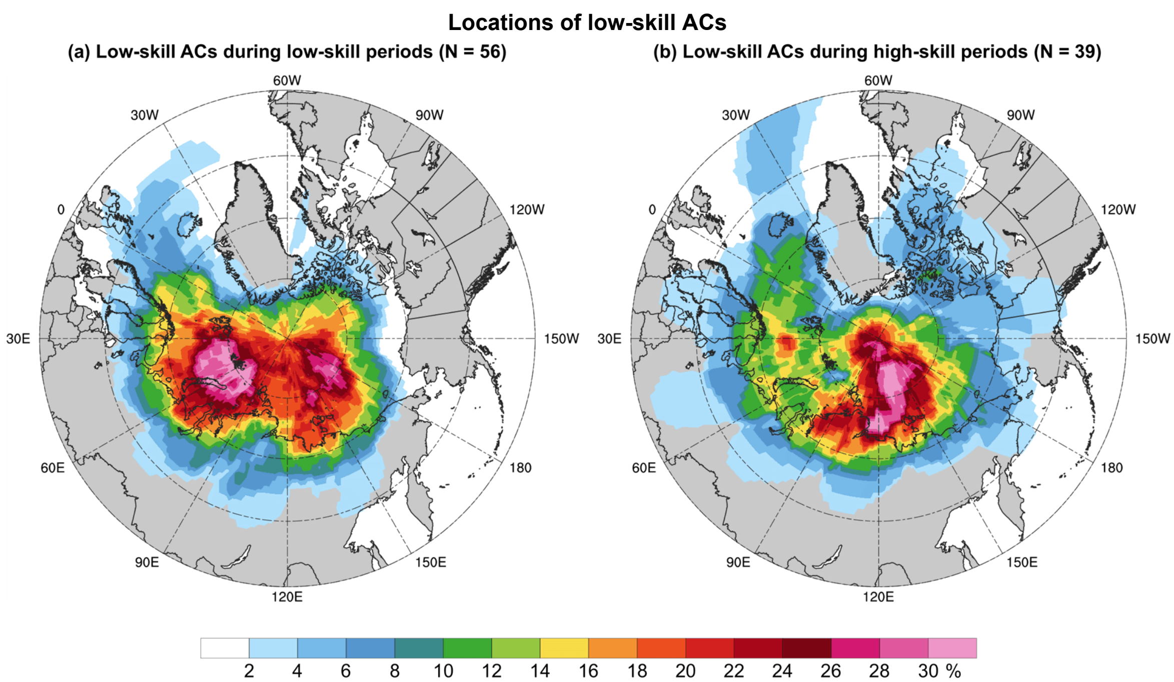

FIG. 3. Track frequency of low-skill ACs during (a) low-skill periods and (b) high-skill periods, shaded according to the percentage of the low-skill ACs for which a given grid point (using a 0.5° grid) is located within 500 km of the low-skill ACs at any time during (a) low-skill periods and (b) high-skill periods, respectively.

4. RESULTS (2 OF 3)

Quantities characterizing low-skill ACs

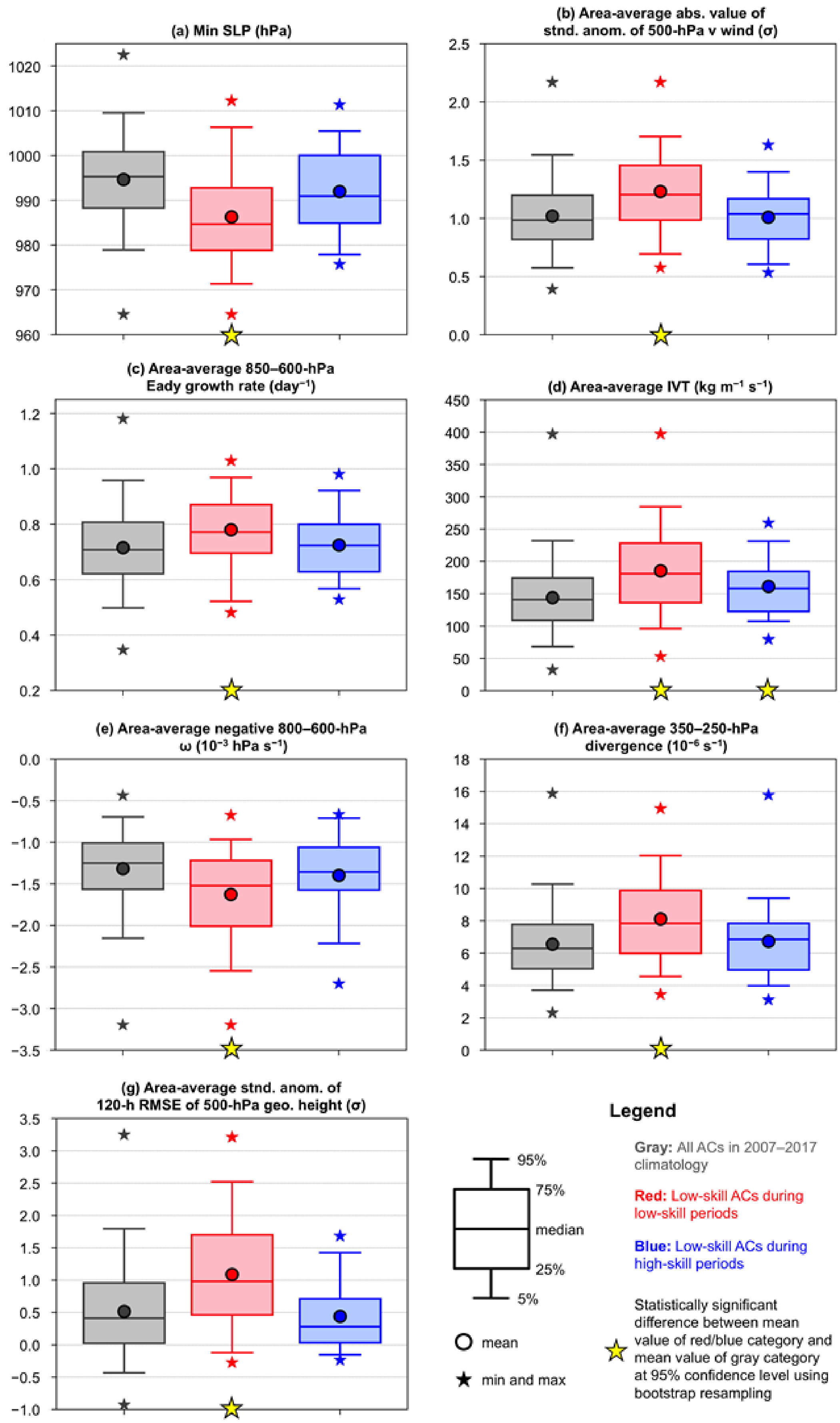

FIG. 4. Distribution of the most extreme value of several quantities characterizing low-skill ACs when located in the Arctic during low-skill periods (red) and high-skill periods (blue), and characterizing all ACs in the 2007–2017 climatology when located in the Arctic (gray). The quantities given in (b)–(g) are area-averaged within 1000 km of the location of minimum SLP of the ACs. There are 56 low-skill ACs during low-skill periods, 39 low-skill ACs during high-skill periods, and 730 ACs in the 2007–2017 climatology. Data sources: (a)–(f) ERA-Interim and (g) GEFS reforecast dataset v2.

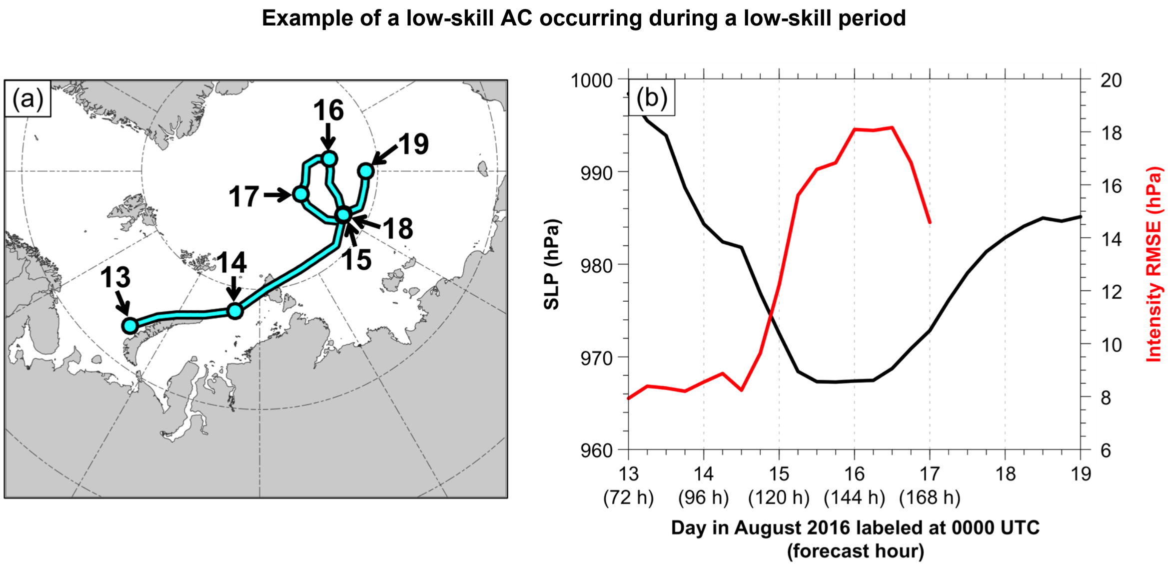

FIG. 5. (a) Track of an example low-skill AC occurring during a low-skill period. The AC occurs during 13–19 Aug 2016 and the low-skill period occurs during 10–15 Aug 2016. Dots show the 0000 UTC positions of the AC and numbers represent dates corresponding to the 0000 UTC positions. (b) Minimum SLP of the low-skill AC during 13–19 Aug 2016 (black) and intensity RMSE of the low-skill AC for forecasts initialized at 0000 UTC 10 Aug 2016 and valid during 13–17 Aug 2016 (forecast hours 72–168) (red). Data sources: ERA-Interim (track and intensity) and GEFS reforecast dataset v2 (intensity RMSE).

5. RESULTS (3 OF 3)

Example of a low-skill AC occurring during a low-skill period (continued)

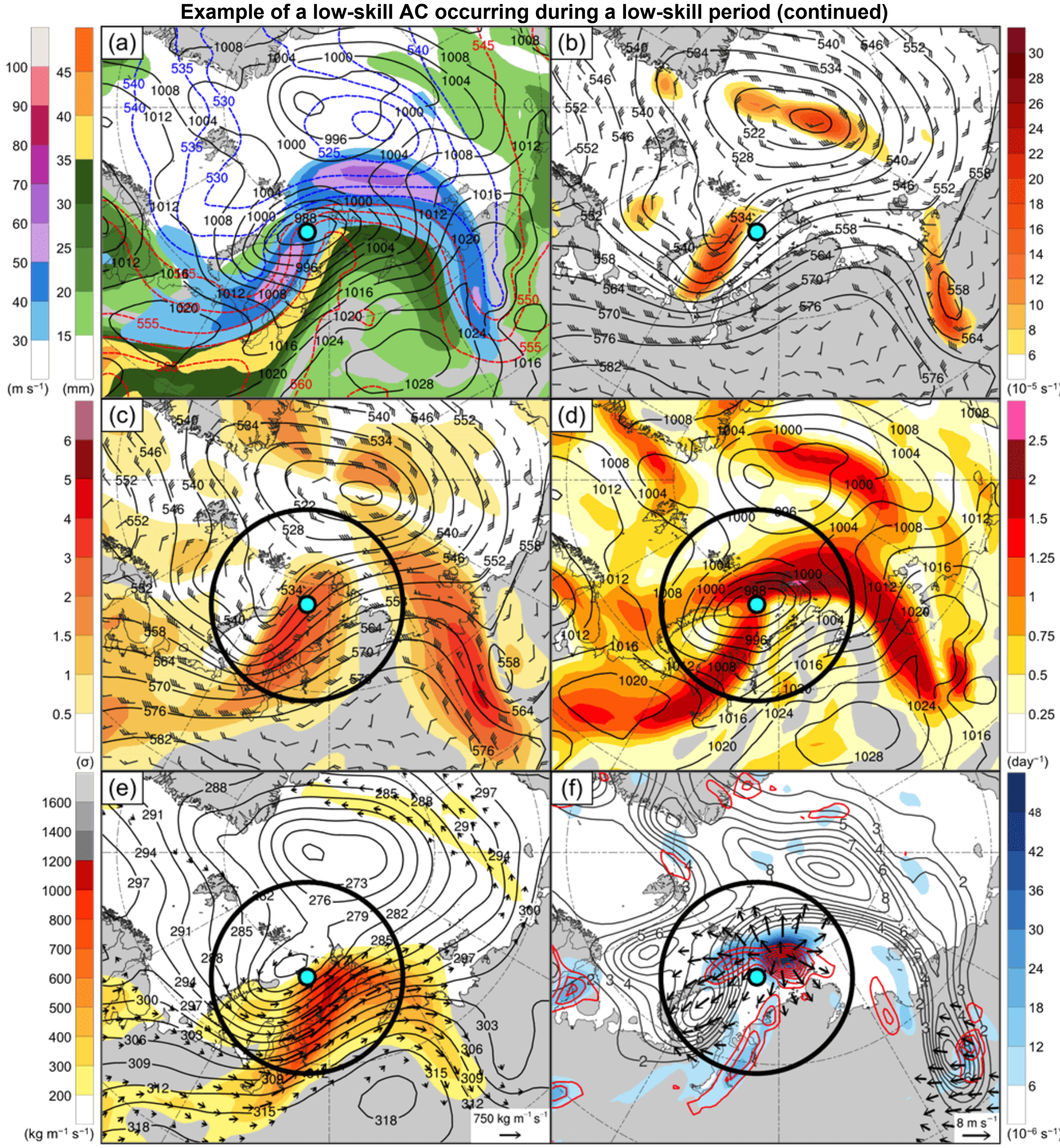

FIG. 6. ERA-Interim analyses valid at 0000 UTC 14 Aug 2016. The cyan dot shows the location of the example low-skill AC at this time and the 1000-km radius black circle surrounding the location of the AC shows where the area-averaged quantities given in Table 1 are calculated.

(a) 300-hPa wind speed [m s^(−1), shaded], precipitable water (mm, shaded), 1000–500-hPa thickness (dam, dashed red and blue), and SLP (hPa, black).

(b) 500-hPa relative vorticity [10^(−5) s^(−1), shaded], geopotential height (dam, black), and wind [m s^(−1), flags and barbs].

(c) Absolute value of standardized anomaly of 500-hPa v wind (σ, shaded), and 500-hPa geopotential height (dam, black) and wind [m s^(−1), flags and barbs].

(d) 850–600-hPa Eady growth rate [day^(−1), shaded] and SLP (hPa, black).

(e) IVT [kg m^(−1) s^(−1), shaded and vectors] and 700-hPa geopotential height (dam, black).

(f) Negative 800–600-hPa ω [red contours every 2 x 10^(−3) hPa s^(−1)], and 350–250-hPa divergence [10^(−6) s^(−1), shaded], irrotational wind [m s^(−1), vectors], and potential vorticity (PVU, gray).

TABLE 1. Same quantities as in Fig. 4 characterizing the example low-skill AC. The value of these quantities at 0000 UTC 14 Aug 2016 and the most extreme value of these quantities when the AC is located in the Arctic during the low-skill period (13–15 Aug 2016) are given. The area-averaged quantities are calculated within 1000 km of the location of minimum SLP of the AC (e.g., within the black circle shown in Figs. 6c–f for 0000 UTC 14 Aug 2016).

	Value at 0000 UTC 14 Aug 2016	**Most extreme value (compare to red category in Fig. 4)**
Min SLP (hPa)	984.4	967.3
Area-average abs. value of stnd. anom. of 500-hPa v wind (σ)	1.01	1.60
Area-average 850–600-hPa Eady growth rate (day^{-1})	0.85	0.92
Area-average IVT ($kg\ m^{-1}\ s^{-1}$)	314.0	323.0
Area-average negative 800–600-hPa ω (10^{-3} $hPa\ s^{-1}$)	−2.41	−2.58
Area-average 350–250-hPa divergence (10^{-6} s^{-1})	12.0	12.0
Area-average stnd. anom. of 120-h RMSE of 500-hPa geo. height (σ)	0.79	1.86

6. DISCUSSION

- There tends to be statistically significantly amplified synoptic-scale flow (Fig. 1a), and statistically significantly high values of lower-to-midtropospheric Eady growth rate (Fig. 1b), IVT (Fig. 1c), lower-to-midtropospheric ascent (Fig. 1d), and upper-tropospheric divergence (Fig. 1e) over the Arctic during low-skill periods.

- There tends to be statistically significantly deamplified synoptic-scale flow (Fig. 1a), and statistically significantly low values of lower-to-midtropospheric Eady growth rate (Fig. 1b), IVT (Fig. 1c), lower-to-midtropospheric ascent (Fig. 1d), and upper-tropospheric divergence (Fig. 1e) over the Arctic during high-skill periods.

- 120-h intensity RMSE tends to be higher for low-skill ACs during low-skill periods compared to low-skill ACs during high-skill periods, though some low-skill ACs during low-skill periods have similar values of 120-h intensity RMSE as some low-skill ACs during high-skill periods (Fig. 2).

- There are high track frequencies of low-skill ACs between 120°E and 180°E over the Arctic during both low-skill periods and high-skill periods, and between 30°E and 90°E over the Arctic only during low-skill periods (Figs. 3a,b).

- Low-skill ACs during low-skill periods tend to be stronger (Fig. 4a), and embedded within a region of more amplified synoptic-scale flow (Fig. 4b), higher values of lower-to-midtropospheric Eady growth rate (Fig. 4c), higher values of IVT (Fig. 4d), higher values of lower-to-midtropospheric ascent (Fig. 4e), higher values of upper-tropospheric divergence (Fig. 4f), and lower forecast skill of the synoptic-scale flow (Fig. 4g) compared to low-skill ACs during high-skill periods.

- Statistically significantly high values of IVT (Fig. 4d), lower-to-midtropospheric ascent (Fig. 4e), and upper-tropospheric divergence (Fig. 4f) surrounding low-skill ACs during low-skill periods suggest that there may be anomalously high values of latent heating surrounding these ACs.

- The aforementioned latent heating and statistically significantly high values of lower-to-midtropospheric Eady growth rate surrounding low-skill ACs during low-skill periods (Fig. 4c) likely contribute to these ACs being statistically significantly strong (Fig. 4a).

- Forecast error growth that may accompany 1) the interaction of low-skill ACs during low-skill periods with the synoptic-scale flow, 2) baroclinic processes (related to Eady growth rate), and 3) latent heating may contribute to the low forecast skill of these ACs and to the statistically significantly low forecast skill of the synoptic-scale flow surrounding these ACs (Fig. 4g).

- An example low-skill AC occurring during a low-skill period in August 2016 intensifies rapidly as it moves from the Barents Sea towards the central Arctic (Figs. 5a,b), across the regions of high track frequency of low-skill ACs during low-skill periods (Fig. 3a).

- As the example low-skill AC intensifies, the intensity RMSE increases (Fig. 5b), with the 120-h intensity RMSE being 12.2 hPa, which is slightly above the 75th percentile of 120-h intensity RMSE for low-skill ACs during low-skill periods (Fig. 2).

- The example low-skill AC intensifies in a region of strong baroclinicity (Fig. 6a) downstream of a midtropospheric vorticity maximum (Fig. 6b) as the AC interacts with moderately amplified synoptic-scale flow (Fig. 6c; Table 1).

- Relatively high lower-to-midtropospheric Eady growth rates associated with the strong baroclinicity (Fig. 6d; Table 1), midtropospheric forcing for ascent (suggested by Fig. 6b), upper-tropospheric jet coupling (Fig. 6a), and relatively high values of IVT (Fig. 6e; Table 1) likely support the relatively high values of lower-to-midtropospheric ascent and upper-tropospheric divergence in the vicinity of the example low-skill AC (Fig. 6f; Table 1) and the concomitant intensification of the AC.

- The relatively high values of IVT, lower-to-midtropospheric ascent, and upper-tropospheric divergence in the vicinity of the example low-skill AC suggest that latent heating likely occurs in the vicinity of the AC and likely supports the intensification of the AC.

- Forecast error growth that may accompany 1) the interaction of the example low-skill AC with the synoptic-scale flow, 2) baroclinic processes, and 3) latent heating may contribute to the low forecast skill of the AC and to the low forecast skill of the synoptic-scale flow surrounding the AC (Table 1).

- The most extreme values of the quantities characterizing the example low-skill AC given in Table 1 are high with respect to the corresponding distributions for low-skill ACs during low-skill periods given in Fig. 4.

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ABSTRACT

Arctic cyclones (ACs) are synoptic-scale low pressure systems that frequently form over the Arctic or move into the Arctic from Eurasia during summer. Interactions between ACs and the synoptic-scale flow over the Arctic may be associated with alterations to the evolution of ACs and the synoptic-scale flow over the Arctic. It is anticipated that relatively low forecast skill of ACs and the synoptic-scale flow over the Arctic may be attributed in part to forecast error growth accompanying interactions between ACs and the synoptic-scale flow over the Arctic and the associated alterations to the evolution of ACs and the synoptic-scale flow over the Arctic. The purpose of this study is to examine various features and processes governing the evolution of ACs that are characterized by low forecast skill and that occur during periods of low forecast skill of the synoptic-scale flow over the Arctic during summer.

Forecast skill of the synoptic-scale flow over the Arctic is evaluated by calculating a standardized anomaly of area-averaged root mean square error (RMSE) of day-5 forecasts of 500-hPa geopotential height over the Arctic during summer (June–August) for the 2007–2017 period in the 11-member NOAA GEFS reforecast dataset version 2. Periods characterized by exceptionally high values of standardized anomaly of area-averaged RMSE are referred to as low-skill periods. ACs occurring during low-skill periods are identified using an ERA-Interim AC climatology. Forecast skill of ACs occurring during low-skill periods is evaluated by calculating the RMSE of the intensity and position of the ACs for forecasts in the GEFS reforecast dataset v2 that are of 1–7 day forecast lead time and valid at the time of the lowest sea level pressure of the ACs when located in the Arctic during low-skill periods. ACs characterized by relatively high values of RMSE of AC intensity and position are referred to as low-skill ACs. Composite analyses will be performed using the ERA5 on selected categories of low-skill ACs in order to examine various features (e.g., upper-tropospheric troughs and vortices, lower-tropospheric baroclinic zones, and warm conveyor belts) and processes (e.g., baroclinic processes, surface boundary processes, and latent heating) governing the evolution of low-skill ACs occurring during low-skill periods.

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