Unusually Deep Wintertime Cirrus Clouds Observed over the Alaskan Sub-Arctic

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**Background.** Unusually deep wintertime cirrus clouds at altitudes exceeding 13.0 km above mean sea level (AMSL) were observed at Fairbanks, Alaska (64.86° N, 147.85° W, 0.300 km AMSL) over a twelve hour period, beginning near 1200 UTC 1 January 2017. Such elevated cirrus cloud heights are far more typical of warmer latitudes, and in many instances associated with convective outflow, as opposed to early winter over the sub-Arctic on a day featuring barely four hours of local sunlight. In any other context, they could have been confused for polar stratospheric clouds, which are a more common regional/seasonal occurrence at elevated heights. The mechanics of this unique event are documented, including the thermodynamic and synoptic environments that nurtured and sustained cloud formation. The impact of an unusually deep and broad anticyclone over the wintertime Alaskan sub-Arctic is described. Comparisons with climatological datasets illustrate how unusual these events are regionally and seasonally. The event proves a relatively uncharacteristic confluence of circulatory and dynamic features over the wintertime Alaskan sub-Arctic. Our goal is to document the occurrence of this event within the context of a growing understanding for how cirrus cloud incidence and their physical characteristics vary globally.

Cirrus clouds are unique within the earth-atmosphere system. Formed by the freezing of submicron haze particles in the upper troposphere, they are the last primary cloud mechanism contributing to the large scale exchange of the terrestrial water cycle. Accordingly, cirrus clouds are observed globally at all times of the year, exhibiting an instantaneous global occurrence rate near 40%. Radiatively, however, they are even more distinct. During daylight hours, cirrus are the only cloud genus that can induce either positive or negative top-of-the-atmosphere forcing (i.e., heating or cooling; all other clouds induce a negative sunlit cooling effect). Though diffuse compared with low-level liquid water clouds, their significance radiatively and thus within
climate, is borne out of their overwhelming relative occurrence rate. This emerging recognition makes understanding cirrus cloud occurrence and physical cloud properties an innovative and exciting element of current climate study. The observations described here contribute to this knowledge, and the apparent potential for anomalous wintertime radiative characteristics exhibited along sub-Arctic latitudes.

Cloud Observations. Shown in Fig. 1 are Level 1 normalized relative backscatter data (MHz·km²·uJ⁻¹) processed by the NASA Micro Pulse Lidar Network (MPLNET) for 1-2 January 2017, based on measurements collected with an eye-safe 532 nm single-channel elastic-backscatter lidar run autonomously atop the Geophysical Institute building on the west end of the University of Alaska Fairbanks campus. Intermittent low-level liquid water and mixed-phase clouds were observed throughout the first 12 hours of 1 January. These clouds are easily distinguished by their relatively low base altitudes and high levels of signal attenuation beginning immediately above cloud base. Lidars, much like the human eye, cannot resolve targets beyond a range-integrated optical depth approaching 3.0 (two-way path-integrated transmission rates approaching as low as 0.1%), and this limits the ability of lidars to fully profile such clouds containing any significant concentration of liquid water droplets. On the other hand, cirrus clouds, which consist solely of ice crystals, are far more likely to be transparent. Cirrus clouds are exponentially more frequent at the very lowest optical depths. Diffuse cirrus clouds were apparent early on the 1st near 0300 UTC between 10.0 and 11.0 km.

Beginning near 1200 UTC, breaks began occurring regularly in the mixed-phase cloud deck near 6.0 km (this and all subsequent heights are AMSL; note the diffuse ice virga streaks emanating below cloud base in Fig. 1, which are a distinct lidar signature for mixed-phase
clouds). These breaks allowed for the profiling of increasingly dense cirrus fallstreaks in the upper troposphere. Cloud top heights in these cirrus layers initially approached 12.0 km. By 1600 UTC, they approached 13.0 km, later exceeding this height by 2100 UTC. Cloud top heights then dropped relatively quickly after 0000 UTC on the 2nd, and the clouds had fully dissipated from the field-of-view by 0400 UTC. After a brief spell of liquid-phase clouds observed near midday on the 2nd, cirrus would reappear after 1800 UTC, now topped below 11.0 km. The period of unusually high-topped cirrus lasted approximately twelve hours, with distinct ascent and descent apparent in cloud structure on either temporal side of the event.

**Synoptic and Thermodynamic Environment.** Shown in Fig. 2 are composite mean 200 hPa geopotential height fields (m) and anomalies (shaded) for 1-2 January 2017 derived from the National Center for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) meteorological reanalysis dataset for western North America². Split flow in the midlatitude westerlies beginning in advance of 180° W led into a broad and high amplitude anticyclone centered along 150° W encompassing all of mainland Alaska and most of the Aleutian Islands. Fairbanks was positioned along the northern edge of the largest positive height anomalies, exceeding +400 m. The core of the 200 hPa ridge would stay positioned over the north-central Pacific along 150° W in the Gulf of Alaska. Its axis, however, would shift eastward on 3 January to along and east of the United States/Canada border, pushing even further inland through western Canada on the 4th. Corresponding surface pressures were extremely high as the anticyclone ridge passed over the state, with a 1048 hPa maximum observed over the

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² [https://www.esrl.noaa.gov/psd/data/composites/day/](https://www.esrl.noaa.gov/psd/data/composites/day/)
Wrangell-St. Elias National Park in the southeast portion of mainland Alaska at 0000 UTC on
the 2nd (not shown).

The 0000 UTC 2 January 2017 thermodynamic radiosonde profile recorded by the National
Weather Service (NWS) office at Fairbanks (Fig. 3) highlights a local tropopause height near
13.0 km MSL, measured a few hours after the highest cirrus cloud top heights were observed
(Fig. 1). Temperatures are this level were near -75° C (198 K). As suggested earlier, this
sounding profile at upper levels was more typical of the sub-tropics and summertime mid-
lattitudes, aside from the roughly 10° C surface inversion and stagnated cold air mass confined
within the local Tanana Valley. The 200 hPa height surface was measured at 11.8 km, or 0.1 km
higher than depicted in the reanalysis composite mean (Fig. 2). When considering the spatial
and temporal averaging inherent within global reanalysis products, it is likely that the
geopotential height anomalies depicted there are relatively low.

The influence of the strong anticyclone advancing over the region is further illustrated using
virtual potential temperature profiles for all NWS radiosondes launched between 0000 UTC 30
December 2016 and 0000 UTC 4 January 2017 (Fig. 4). Constant isentropic surfaces are
depicted within the successive profiles in 5 K intervals from 310 - 380 K. Assuming (safely) that
the ridge axis passed over the site between 1200 UTC on the 1st and 0000 UTC on the 2nd, rapid
isentropic ascent of air can then be seen over the 36-48 hr period beginning 0000 UTC on the
31st. This was likely the most significant contributing factor to the deep cirrus clouds observed.
As depicted, the upper tropospheric “frontal” boundary separating relatively warm and cold air
masses reached as low as 9.5 km on the 31st along the 330 K isentrope, eventually capping out
near/above 13.0 km at 0000 UTC on the 2nd. After the axis passed, however, adiabatic
subsidence occurred immediately, consistent with cloud dissipation observed near 0400 UTC on
the 2\textsuperscript{nd}.

The colder and denser air driving the elevated front induced significant uplift; the bulk of
which would peak at the tropopause itself at/above 13.0 km. This synoptic uplift no doubt aided
in the gradual deposition of water vapor on nascent haze particles, while gravity wave breaking
at the tropopause may have caused additional uplift resulting in sufficient atmospheric
conditioning for homogenous ice nucleation. This is speculative, however. The distinct
fallstreak nature of the clouds depicted in the lidar imagery suggests rapid crystal growth and
relatively large fall speeds. These properties are more traditionally observed from the large ice
crystals formed via heterogeneous freezing mechanisms, suggesting homogeneous nucleation
was perhaps not the preferred formation mechanism. Tropopause folding and/or locally-
enhanced stratospheric aerosol concentrations acting as ice nuclei were likely not significant
factors.

These points are reinforced in Fig. 5, which depicts an automated digital image of the cloud
scene over Fairbanks late afternoon locally on 1 January (0212 UTC 2 January). Though cirrus
clouds remained present over the MPLNET site at UAF, albeit at quickly lowering top heights,
only those clouds illuminated along the upper troposphere by the setting sun are distinguishable.
These clouds were situated south of Fairbanks nearing the Alaska Range, including Denali
National Park (~ 200 km south of the lidar site). The clouds appear reasonably dense, and again
could have been confused for lenticular polar stratospheric clouds. Still, fibrous elements are
also apparent, which again supports the likelihood of relatively large crystals and enhanced
fallstreak presence. Ultimately, though, the point is not necessarily to resolve such nucleation
pathways directly, as much as it is recognizing the correlative synoptic ingredients in place to
induce and sustain cirrus cloud formation in air advecting along and passing over/through the anticyclonic ridge axis.

**Climatological Significance.** As the MPLNET instrument has only been in place at Fairbanks since October 2016, climatological information on cirrus cloud occurrence is instead taken regionally from the satellite-based NASA Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP). Shown in Fig. 6 are histograms in 1.0 km segments of relative cirrus cloud occurrence measured by Version 3 CALIOP Level 2 Cloud Profile products from 2006-2015 (i.e., total cloud observations at 5-km resolution) over a 5°x5° sector centered on Fairbanks as a function of cloud top height both for December/January and annually. Cirrus were specifically distinguished in the CALIOP datasets as those clouds exhibiting top height temperatures colder than -37° C and warmer than -75° C. The former threshold corresponds with the approximate threshold for the homogeneous freezing of liquid water, which has been shown highly consistent for distinguishing cirrus clouds from autonomous lidar measurements. The latter is chosen conservatively to limit the influence of polar stratospheric clouds possible within the dataset.

Annually, a highly limited number of observations have been collected with CALIOP for cirrus cloud top heights exceeding 13.0 km. The bulk of the observations occur with cloud top heights between 8.0 and 10.0 km, consistent with reasonable expectation for such relatively cold latitudes, though a relatively significant number of cases (surprisingly?) do occur above 11.0 and 12.0 km. In December/January, the distribution is naturally shifted toward lower heights given the relatively colder endemic airmass regionally. Only a very limited number of observations have been collected at heights above 13.0 km, corresponding with only ten distinct events
annually and two during December and January. This implies that the clouds described here are sufficiently rare, though not completely unheard of.

**Summary and Perspective.** Lidar measurements of unusually deep cirrus clouds over Fairbanks, Alaska collected on New Year’s Day 2017 are described, with top heights exceeding 13.0 km. The synoptic and thermodynamic environment sustaining cloud formation featured an abnormally deep and broad anticyclone with corresponding sharp elevated frontal boundary passing over the central interior of Alaska. Split midlatitude westerly flow over the central Pacific gave way to the large amplitude anticyclone centered over the Gulf of Alaska. The formation of such deep cirrus clouds is considered rare in the wintertime Alaskan sub-Arctic, after comparison with climatological cloud properties derived regionally and seasonally from satellite lidar measurements. The synergy between active-based lidar profiling and operational radiosonde profiling of local thermodynamic properties at Fairbanks helps distinguish the tropospheric nature of the clouds, as compared with polar stratospheric clouds for which they could have been confused for at such heights during the sub-Arctic winter.

The remaining point to be made in the case analysis, then, relates to our understanding of how rare this event may or may not prove in the future. Polar meteorology, particularly around the Arctic, is experiencing significant change. Surface temperatures near the North Pole during fall and winter months approaching and exceeding $0^\circ$ C have been occurring at increasingly alarming rates in recent years. How cirrus clouds respond, however, is an equally compelling question to monitor in coming years compared with such newsworthy instances. Far from being insignificant contributors to climate, changes in basic cirrus cloud macrophysical and occurrence characteristics may in fact prove a bellwether to regional climate change, given their correlative
nature relative with local weather processes. The deployment of sufficient ground-based infrastructure is critical to monitoring cirrus, given the indefinite lifetime for CALIOP, the uncertainties surrounding follow-on satellite lidar missions and an inability to resolve all cirrus from radiometric imagers due to their translucent nature.

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FOR FURTHER READING


**FIGURE CAPTIONS**

**Figure 1.** NASA Micro Pulse Lidar Network Level 1 normalized relative backscatter (MHz·km²·uJ⁻¹) measurements collected at Fairbanks, Alaska on 1 January 2017. The MPLNET site at Fairbanks, Alaska is denoted by the blue circle. All heights in km above mean sea level (MSL). Cirrus cloud top heights reaching 13.2 km are depicted by dashed white line.

**Figure 2.** National Center for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) meteorological reanalysis composite mean 200 hPa geopotential height (m; black contours) and corresponding climatological anomalies for 1-2 January 2017 over western North America. The MPLNET site at Fairbanks, Alaska is denoted by the blue circle.

**Figure 3.** Radiosonde profile of temperature (red) and dewpoint (blue), including wind speed and direction (right side; kts) collected 0000 UTC at Fairbanks, Alaska on 2 January 2017.

**Figure 4.** Upper-tropospheric virtual potential temperature (solid; K) derived from successive radiosonde-based thermodynamic profiles collected at Fairbanks, Alaska every twelve hours between 0000 UTC 31 December 2016 and 0000 UTC 4 January 2017. Isentropes (dashed) are contoured between each profile in 5 K intervals.
Figure 5. Automated digital photo composite of the late afternoon cloud sky over Fairbanks at 0212 UTC 2 January 2017. The camera is oriented toward the south-southwest looking over downtown in the Tanana Valley. The MPLNET site is off to the west of the image. (Photo credit to Todd Thompson of the Fairbanks North Star Borough Air Quality Office).

Figure 6. Histograms in 1.0 km segments of observations for cirrus cloud top height (km) derived from 2006-2015 CALIOP Level 2 5-km Cloud Profile datasets over a 5°x5° region centered on Fairbanks, Alaska for (a) December-January and (b) annual.
FIGURE 1
NASA Micro Pulse Lidar Network (MPLNET) Level 1 normalized relative backscatter (MHz·km²·uJ⁻¹) measurements collected at Fairbanks, Alaska on 1-2 January 2017. All heights in km above mean sea level (MSL). Cirrus cloud top heights reaching 13.2 km are depicted by dashed white line.
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