Unusually Deep Wintertime Cirrus Clouds Observed over the Alaskan Subarctic

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BACKGROUND. Unusually deep wintertime cirrus clouds at altitudes exceeding 13.0 km above mean sea level (MSL) were observed at Fairbanks, Alaska (64.86°N, 147.85°W, 0.300 km MSL), over a 12-h 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 subarctic on a day featuring barely 4 h of local sunlight. In any other context, they could have been confused for polar stratospheric clouds, which are a more common regional/seasonal occurrence approaching such 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 subarctic 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 subarctic. 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 highest and thus sequentially the last tropospheric 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 a positive or negative top-of-the-atmosphere forcing (i.e., heating or cooling; all other clouds induce a cooling sunlit 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 subarctic latitudes.

CLOUD OBSERVATIONS. Shown in Fig. 1 are level 1 normalized relative backscatter data (MHz km^2 μJ^{-1}) processed by the NASA Micro-Pulse Lidar Network (MPLNET) for 1–2 January 2017,

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DOI:10.1175/BAMS-D-17-0084.1

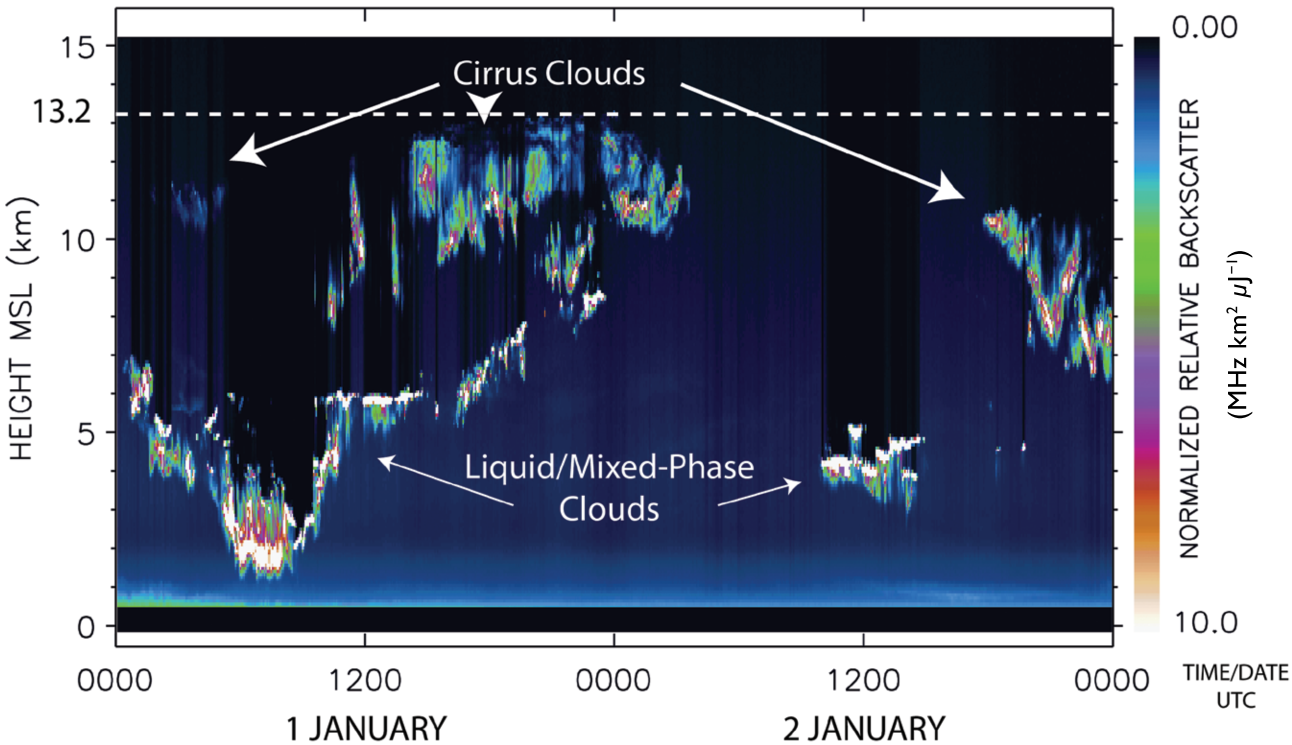

Fig. 1. NASA Micro-Pulse Lidar Network (MPLNET) level 1 normalized relative backscatter (MHz km^2 μJ^{-1}) measurements collected at Fairbanks on 1–2 Jan 2017. All heights are in kilometers MSL. Cirrus cloud-top heights reaching 13.2 km are depicted by dashed white line.

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 (UAF) campus. Intermittent low-level liquid water and mixed-phase clouds were observed throughout the first 12 h of 1 January. These clouds are easily distinguished by their relatively low base altitudes and high levels of signal attenuation beginning immediately above the apparent 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 translucent and transmissive. Cirrus clouds are more common at the very lowest optical depths, as well. Translucent cirrus were apparent near 0300 UTC 1 January between 10.0 and 11.0 km (this and all subsequent heights are MSL).

Beginning near 1200 UTC, breaks began occurring regularly in the liquid- and mixed-phase cloud deck near 6.0 km (note the diffuse ice virga streaks emanating below the denser, liquid-dominated cloud base in Fig. 1, which is a distinct lidar signature for mixed-phase clouds that are relatively common in/near the Arctic). 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 2 January, and the clouds had fully dissipated within the field of view by 0400 UTC. After a brief spell of liquid- and mixed-phase clouds observed near midday on 2 January, cirrus would reappear after 1800 UTC, now topped below 11.0 km. The period of unusually high-topped cirrus lasted approximately 12 h, 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 (colors) for 1–2 January 2017 derived

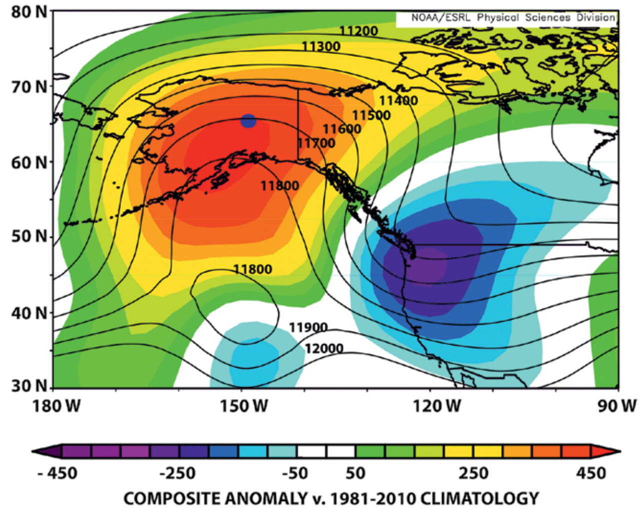

Fig. 2. NCEP–NCAR meteorological reanalysis composite-mean 200-hPa geopotential height (m; black contours) and corresponding climatological anomalies for 1–2 Jan 2017 over western North America. The MPLNET site at Fairbanks is denoted by the blue circle.

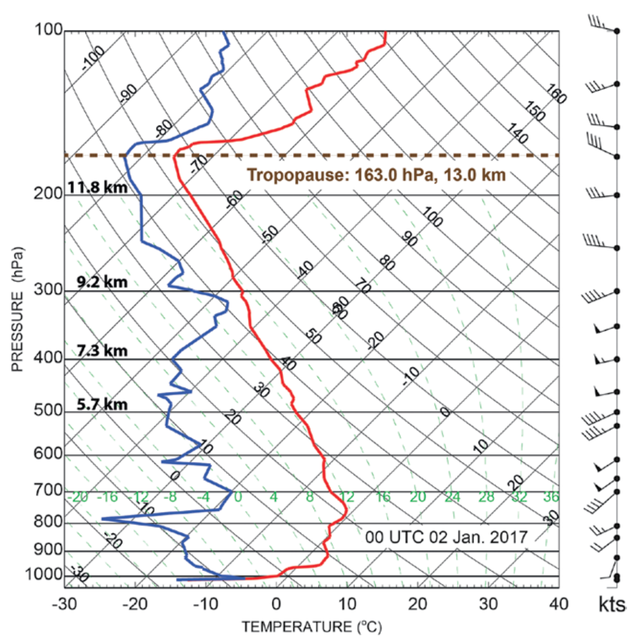

Fig. 3. Radiosonde profile of (left) temperature (red) and dewpoint (blue) and (right) wind speed and direction (1 kt = 0.51 m s^{-1}) collected at 0000 UTC 2 Jan 2017 at Fairbanks.

from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) meteorological reanalysis dataset for western North America (www.esrl.noaa.gov/psd/data/composites/day/). Split flow in the midlatitude westerlies beginning in advance of 180° 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 at least 400 m. The core of the 200-hPa ridge would stay positioned over the north-central Pacific Ocean along 150°W in the Gulf of Alaska. The ridge axis, however, would shift eastward on 3 January to along and east of the United States–Canada border, pushing even farther inland through western Canada on 4 January. Corresponding surface pressures were extremely high as the anticyclone ridge passed over the state, with a 1048-hPa maximum observed over the Wrangell–St. Elias National Park in the southeast portion of mainland Alaska at 0000 UTC 2 January (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 at this level were near −75°C (198 K). As suggested earlier, this sounding profile at upper levels was more typical of the subtropics and summertime midlatitudes, aside from the roughly 10°C surface inversion and a 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 underestimated.

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 to 380 K. Assuming that the ridge axis passed over the site between 1200 UTC 1 January and 0000 UTC 2 January, rapid isentropic ascent of air can then be seen over the 36–48-h period beginning 0000 UTC 31 December. 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 31 December along the 330-K isentrope, eventually capping out at 13.0 km near 0000 UTC 2 January.

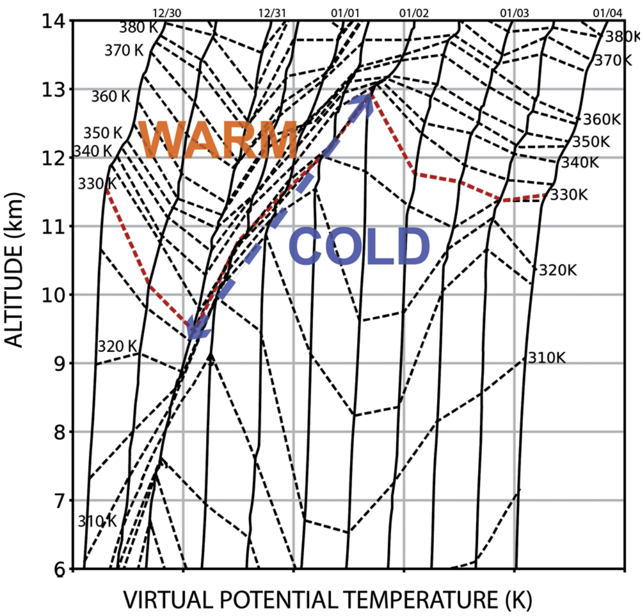

Fig. 4. Upper-tropospheric virtual potential temperature (solid; K) derived from successive radiosonde-based thermodynamic profiles collected at Fairbanks every 12 h between 0000 UTC 31 Dec 2016 and 0000 UTC 4 Jan 2017. Isentropes (dashed) are contoured between each profile with a 5-K interval. The 330-K isotherm is highlighted in red (see text).

After the ridge axis passed overhead, however, adiabatic subsidence took place immediately, consistent with cloud dissipation observed near 0400 UTC 2 January.

The colder and denser air driving the elevated front induced significant uplift, peaking at the tropopause itself at or above 13.0 km. The synoptic uplift apparently aided in the gradual deposition of water vapor on nascent haze particles. Figure 5 depicts an automated digital image of the cloud scene over Fairbanks from the 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 in the image. 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.

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 of the CALIOP level 2 cloud profile products from 2006 to 2015 (i.e., total cloud observations at 5-km resolution) over a 5° × 5° 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

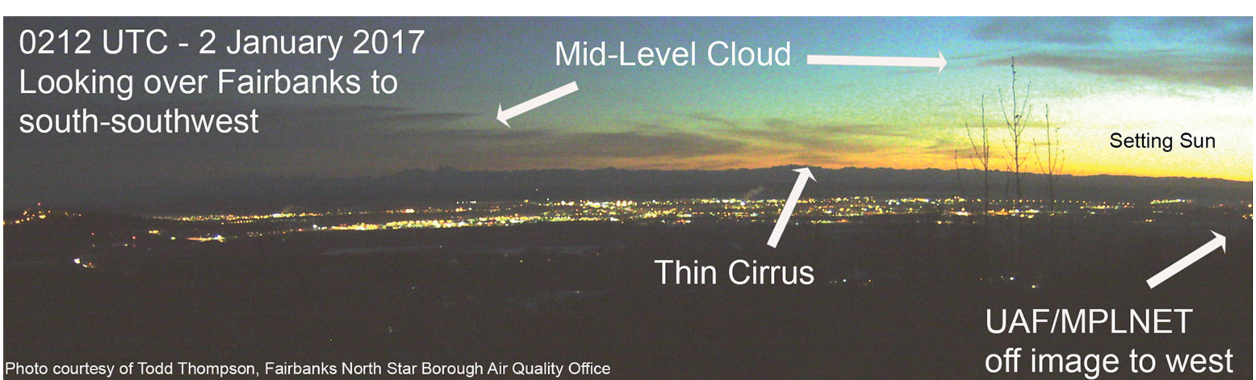

Fig. 5. Automated digital photo composite of the late afternoon sky over Fairbanks at 0212 UTC 2 Jan 2017. The camera is oriented toward the south-southwest looking over downtown in the Tanana Valley. The MPLNET site is off to the west of the image. (Photo credit to Todd Thompson of the Fairbanks North Star Borough Air Quality Office.)

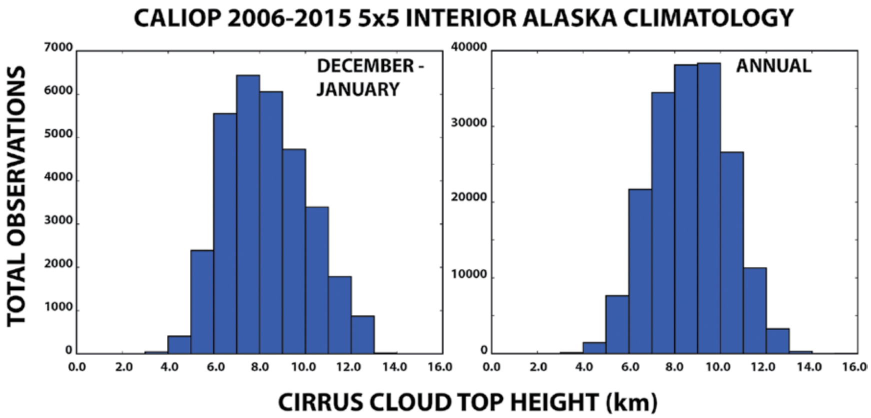

Fig. 6. Histograms in 1.0-km segments of observations for cirrus cloud-top height (km) derived from 2006–15 CALIOP level 2 5-km cloud profile datasets over a 5° × 5° region centered on Fairbanks (a) for Dec–Jan and (b) annually.

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 since 2006. 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 surprisingly significant number of cases do occur above 11.0 and 12.0 km. In December–January, the distribution is naturally shifted toward lower heights given the relatively colder regional air mass. Only a very limited number of observations have been collected at heights above 13.0 km over the last 10+ years, corresponding with only 10 distinct events overall and only 2 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 a corresponding sharp elevated frontal boundary passing over the central interior of Alaska. Split midlatitude westerly flow over the central Pacific led into the large-amplitude anticyclone centered over the Gulf of Alaska. The formation of such deep cirrus clouds is considered rare in the wintertime Alaskan subarctic, 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 at such heights during the subarctic 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 the fall and winter months approaching and exceeding 0°C have been occurring at increasingly alarming rates in recent years. How cirrus cloud properties and occurrence rates may 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 therefore 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.

ACKNOWLEDGMENTS. This work was conducted under the primary support of the Naval Research Laboratory Base Program (BE033-03-45-T008-17). Author JRC further acknowledges NASA Interagency Agreement NNG15JA17P on behalf of the NASA Micro-Pulse Lidar Network, which is supported by the NASA Radiation Sciences Program (H. Maring). Author JM recognizes the support of Dr. Jianglong Zhang and Office of Naval Research

Code 32 project N00014-16-1-2040 (Grant 11843919). Author GJF recognizes support from NSF-AGS Division of Atmospheric and Geospace Sciences (Grant 1443222). The authors collectively thank the NOAA/Earth Systems Research Laboratory for access to the NCEP–NCAR meteorological reanalysis dataset and online tools used to image the results of our queries. We also recognize the considerable career contributions of David O'C. Starr (NASA Goddard Space Flight Center) to the study of cirrus clouds and their role in climate, and who introduced author JRC to the magic of the isentropic surfaces plot depicted here as Fig. 4.

FOR FURTHER READING

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