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Terrestrial atmospheric responses on Svalbard to the 20 March 2015 Arctic total solar eclipse under extreme conditions

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This article reports on the near-surface atmospheric response at the High Arctic site of Svalbard, latitude 78° N, as a result of abrupt changes in solar insolation during the 20 March 2015 equinox total solar eclipse and notifies the atmospheric science community of the availability of a rare dataset. Svalbard was central in the path of totality, and had completely clear skies. Measurements of shaded air temperature and atmospheric pressure show only weak, if any, responses to the reduced insolation. A minimum in the air temperature at 1.5 m above the ground occurred starting 2 min following the end of totality, though this drop was only slightly beyond the observed variability for the midday period. Eclipse-produced variations in surface pressure, if present, were less than 0.3 hPa.

This article is part of the themed issue 'Atmospheric effects of solar eclipses stimulated by the 2015 UK eclipse'.

1. Introduction

The path of the total solar eclipse of 20 March 2015 began in the North Atlantic south of Greenland and proceeded east of Iceland, including the Faroe Islands near the eastern edge of totality. It provided for solar and terrestrial observations under unusually extreme conditions [1,2], extending our measurements of the effect of solar eclipses on the terrestrial atmosphere [3].

The 408 km-wide umbra passed centrally over Svalbard, a Norwegian archipelago halfway between the north tip of European Norway and the North Pole, at a latitude of 78° N. The central line of the approximately 500 km-wide umbra crossed just east of Longyearbyen, the capital, on the island of Spitsbergen, latitude 78°13′28 N and longitude 15°38′40.3 E, which was 83% into the umbra. See figure 1 and mapping links at http://eclipses.info.

Sjöblom [4] had previously analysed the effect of a 93%-solar-diameter eclipse (93% eclipse magnitude) that occurred on 1 August 2008, months after the midnight Sun had begun, whereas our observations were made in mid-totality and only two weeks after the Sun had re-emerged for partial days after the extended sunless winter. During the partial phases of the eclipse, the temperature dropped by only 0.3–1.5°C. The insolation was about 10^4 times lower during our 2015 total solar eclipse than during the partial eclipse, because the solar corona is about 10^6 times fainter than the solar photosphere.

A zoomable map on which clicking on any location gives local circumstances is accessible [5,6].

2. Observational circumstances

In the study by Peñaloza-Murillo & Pasachoff [3], a framework was set up for analysing the temperature drop during the total solar eclipse of 2001, observed from Zambia in clear skies. In a current study, we are extending our analysis to cloudy skies as observed at the 2009 total solar eclipse observed from China. For the Svalbard total solar eclipse of 20 March 2015, the eclipse was observed in a completely clear sky.

As the altitude of the Sun at totality was 11° and the mountains at Longyearbyen were slightly higher than that, the observing site was about 1.5 km just off the road to the east, just far enough to have totality visible to the east side of the mountaintops. Unexpectedly, given past cloudiness statistics, the weather on eclipse day (figure 2) and on the preceding day was completely clear.

Totality lasted for 2 min 27 s, from 101043 UTC to 101310 UTC, with a peak at 101157 UTC (HHMMSS).

3. Results

A HOBO™ H21-002 data logger from Onset Computer Systems was used to obtain temperature and pressure measurements every 10 s at the back of Arctic Bay (a building, not a water feature) dogsled site about 1 km to the east of Longyearbyen a half kilometre short of our actual observing site. To measure the air temperature response to changes in indirect insolation, HOBO 12-bit Temperature Smart Sensors (S-TMB-M006) were placed and then left untouched at 0.5 m and 1.5 m above the ground, on horizontal wooden surfaces, both in constant shade (figure 3); a standard radiation shield was not available for use, though the area was shaded from direct insolation and exposed to breezes. Aside from the radiative shielding offered by the wooden post, no effort was made to shield the stainless steel sensors from additional radiative losses. Considering the consistency with published measurements of long-term conditions, we do not consider this to be a significant source of error [7,8]. Temperature measurements have an uncertainty of less than 0.5°C at a resolution of 0.08°C, with an intrinsic response time less than 3 min in the calm conditions.

An accompanying pair of HOBO Smart Barometric Pressure Sensors (S-BPB-CM50) recorded the atmospheric pressure at the same heights and locations as the temperature sensors. The goal was to measure relative changes in atmospheric pressure as a function of time. These pressure sensors were not calibrated or adjusted for sea level (Longyearbyen is listed as only 1 m.a.s.l. (http://dateandtime.info/citycoordinates.php?id=2729907)) and thus provide only

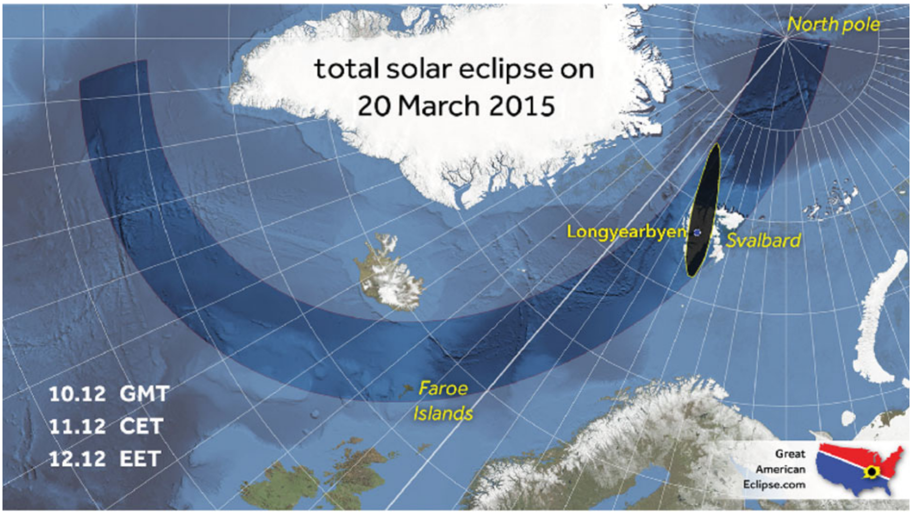

Figure 1. The eclipse path with the umbral position and shape (the black ellipse) during our observations (map by Michael Zeiler, eclipse-maps.com).

Figure 2. A wide-angle view showing our observing team and others on the ice east of Longyearbyen during totality, with the solar corona surrounding the lunar silhouette just to the left of the mountains; the umbral darkness is shown clearly (photo by Michael Zeiler, eclipse-maps.com).

relative pressure variations (figure 4). Systematic errors in pressure are less than 5 hPa (mbar) at a resolution of 0.1 hPa.

4. Discussion

The opportunity of observing and measuring atmospheric effects in a totally snowy and icy environment during a solar eclipse is a very rare opportunity. To our knowledge, only Kameda *et al*. [9], and to a lower extent Klekociuk [10], have performed meteorological measurements in such a difficult environment, during the total solar eclipse that occurred over Antarctica on 23 November 2003. According to these authors, that was the first total solar eclipse to be observed on the Antarctic ice sheet (Dome Fuji). At that time, the air temperature at 1.5 m above the snow surface and in the subsurface decreased by 3.0°C and 1.8°C, respectively. Estimated

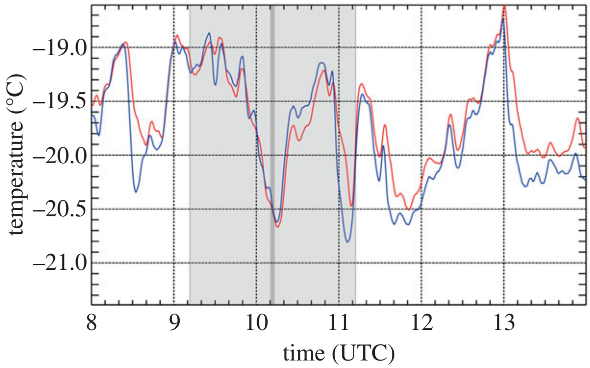

Figure 3. The temperature as a function of time on the day of the eclipse at a site 1 km east of Longyearbyen, Svalbard, with maximum eclipse at 1012 UTC = 1112 CET. The temperature was measured all day with two HOBO sensors, one at 0.5 m high (blue) and one at 1.5 m high (red), in continual shade of mountains at the back of the Arctic Bay headquarters. Data were taken at 10 s intervals, though the sensor had published response times of 2–3 min.

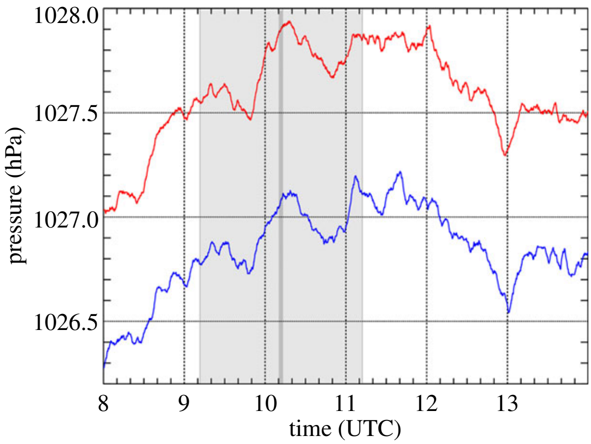

Figure 4. The atmospheric pressure, uncorrected for altitude, measured on eclipse day with two HOBO sensors, one 0.5 m high (blue) and one 1.5 m high (red), in continual shade of mountains at the back of the Arctic Bay headquarters; the small vertical separation is due to a lack of absolute calibration.

surface snow temperatures decreased by 4.6°C. Atmospheric pressure and wind direction did not change, but the wind speed possibly decreased by 0.3 m s^{-1} with decreasing air temperature, etc. Recently, a new chance to undertake a similar investigation under similar extreme environmental circumstances occurred with the total solar eclipse of 20 March 2015.

Both the temperature and pressure measurements indicated that a high-pressure airmass moved into the area between 0700 and 0800 UTC, bringing a slight increase in pressure and decrease in air temperature. This transition dominates the measurements on the day of the eclipse. Against this trend, the data loggers show correlated variations in the temperatures, probably attributable to eddy fluxes and wind shifts in the surface layer, with no obvious signal corresponding to the eclipse. In the 6 h period centred at the eclipse, the minimum temperature measured at 1.5 m was −20.7°C, which was about 2.25 s.d. below the mean of −19.6 ± 0.4°C for the same period. This occurred at 101510 UTC, i.e. 3 min after totality. The 0.5 m sensor recorded very similar temperatures, though with a slightly lesser mean temperature (−19.8°C) and a greater standard deviation (0.5°C). At the 0.5 m height, a second, slightly lower

minimum (−20.8°C) was recorded an hour later, but this occurred at a time of weaker correlation between the two sensors. Given the low solar angle, clear skies and the sensors' positions in the extended shade of the mountains, the lack of significant responses in the measured air temperatures is reasonable considering the diffuse radiation's relatively small contribution to the surface-heating rate.

The atmospheric pressure measurements showed coherent variations over the entire observing period. Though there was a local peak just following totality, the trend began prior to the eclipse; therefore, no obvious response could be attributed to the eclipse. If present, any eclipse-induced perturbation in atmospheric pressure was less than 0.3 hPa (mbar).

The results reported here are in good agreement with those of Maturilli & Ritter [11] (see their fig. 2c,e), whose temperature and pressure data were taken at their site about 70 km northwest of our site and adjacent to the Greenland Sea. Their measurements of insolation were not sufficiently sensitive to detect any level of irradiance during the 2 min of totality, when incoming radiation is about 10^{-6} that of the everyday Sun's from the solar photosphere [12]; they report $0\,\mathrm{W\,m^{-2}}$ insolation for the duration of totality and discuss the radiation and instrumental accuracy in their section 3.

Our team continues to make and plan temperature and pressure measurements at all future total and annular solar eclipses. Measurements from the 21/22 July 2009 total solar eclipse from China, the 11 July 2010 total eclipse from Easter Island, the 10 May 2013 annular eclipse in Tennant Creek, Australia, the total eclipse of 9 March 2016 and others remain to be studied. Extensive observations are planned for the American total eclipse of 21 August 2017.

Data accessibility. The raw data are available on request and will be posted at http://totalsolareclipse.org.

Authors' contributions. J.M.P. and A.L.C. carried out observations on site; J.M.P. drafted the paper; M.A.P.-M. contributed to planning and analysis; M.T.R. contributed to analysis and interpretation and critical revisions of the paper; all authors provided final approval of the paper.

Competing interests. The authors declare that they have no competing interests.

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