https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

A near-sunset atmospheric sounding during the 14 October 2023 annular solar eclipse over Natal

Igo Paulino[1], Francisco Raimundo da Silva[2], Ana Roberta Paulino[3], and Gilvan Borba[4]

[1]Unidade Acadêmica de Física, Universidade Federal de Campina Grande, Campina Grande, PB, Brazil
[2]Laboratório de Variáveis Ambientais e Tropicais, Instituto Nacional de Pesquisas Espaciais, Natal, RN, Brazil
[3]Departamento de Física, Universidade Estadual da Paraíba, Campina Grande, PB, Brazil
[4]Departamento de Geofísica, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil

Correspondence: Igo Paulino (igo.paulino@df.ufcg.edu.br)

Abstract. Solar eclipses are transient atmospheric events that cause rapid localized reduction in solar radiation, which produces complex changes associate with the vertical coupling of the layers. This study investigates the vertical response of the neutral atmosphere to the 14 October 2023 annular solar eclipse over Natal, Brazil (5.79 ^{o}S, 35.2^o W). This event presented a unique configuration as the maximum obscuration of $\sim$ 88.5% occurred near sunset in a region of transition between land an ocean. A stratospheric balloon sounding launched immediately before the umbra reached Natal was used. The balloon collected atmospheric profiles (temperature, pressure, relative humidity, and ozone concentration) for over 1.45 hours, with the umbra passing over the balloon at $\sim$22.35 km altitude for 3 min and 36 s. Comparison with average October profiles and model data revealed significant vertical structures: (i) A notable cooling of 4-5 K was observed in the tropopause region (14 km altitude); (ii) Vertical fluctuations in temperature were enhanced, particularly above 14 km; (iii) atmospheric pressure decreased by 0.2-0.7 hPa above 12 km; (iv) ozone concentration showed strong vertical oscillation and an enhancement of up to 1 ppm above 20 km altitude; (v) relative humidity increased between 5 and 21 km altitude compared to control profiles. These observations of complex, small-scale fluctuations and clear responses in the vertical atmospheric field are consistent with previous reports and theoretical expectations of solar eclipse effects, confirming the importance of even an annular eclipse as a significant driver of localized atmospheric dynamics.

1 Introduction

Basically, three manifestations of solar eclipses can be observed on the Earth's surface: (i) partial eclipse, where the eclipse's penumbra crosses the surface; (ii) total eclipse, which occurs under the umbra (total eclipses occur when the Moon completely covers the Sun's disk); and (iii) Annular eclipse, which is similar to the total eclipse, but in this case, the Moon does not completely block the sunlight, producing a kind of "ring of fire." Under the umbra of a total eclipse, with the total obscuration of sunlight, there is a temporary artificial night. For the other two cases, only a reduction of sunlight can be perceived, but usually requires scientific instruments to observe it. Solar eclipses are rare events; to give an idea, from 2010 to 2019, only 18 solar eclipses occurred, and one-third of them were total eclipses. Furthermore, a good portion of the eclipse paths crosses the oceans.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

A solar eclipse is a very special phenomenon for atmospheric science because it can produce rapid changes in the entire neutral atmosphere and ionosphere. The local blocking of sunlight by the Moon casts a shadow in a column of the atmosphere, with a diameter of ∼270 km, which typically moves at a supersonic speed of ∼470 m/s. Thus, the duration of the obscuration is only a few minutes at any given point on Earth. The temporary absence of the Sun reduces the radiation (e.g., Zerefos et al., 2000), which, in turn, can reduce the temperature (e.g., Founda et al., 2007), increase the relative humidity (e.g., Tzanis et al., 2008), and diminish the atmospheric pressure on the surface (e.g., Pasken et al., 2023).

In the ionosphere, the blocking of sunlight, even for a brief period, is sufficient to reduce the ionization of the chemical constituents (e.g., Yang et al., 2025). This reduction produces secondary effects, such as bow waves (e.g., Zhang et al., 2017), which can also disturb the neutral wind in the thermosphere with propagating over long distances (e.g., Harding et al., 2018). This rapid change in the horizontal pressure gradient can generate waves at different levels of the atmosphere (e.g., McIntosh and ReVelle, 1984; Paulino et al., 2020). Other impacts of eclipses, such as effects on atmospheric electricity near the surface (e.g., Manohar et al., 1995) and the reduction in photovoltaic energy production (e.g., Madhavan and Venkat Ratnam, 2021) have also attracted the attention of the community, leading to a large volume of scientific literature being published on the subject. Therefore, the atmospheric response to solar eclipses remains a highly current topic of scientific investigation, with many theoretical and experimental/observational aspects still to be understood.

In particular, the thermodynamics of the atmosphere makes the vertical response quite complex, producing peculiar responses for each eclipse. Additionally, obtaining vertical soundings of the atmosphere during rapid events like these is a real experimental challenge. Satellite measurements have been used (e.g., Basha et al., 2025; Paulino et al., 2025), but their utility depends on the coincident passages of the satellite orbits across the eclipse path.

Another possibility is sounding the atmosphere, which is generally done using stratospheric balloons (e.g., Harrison et al., 2016; Das et al., 2023). However, this instrumentation has a limited coverage, typically from the surface up to stratospheric heights. In general, vertical structures and fluctuations in temperature, pressure, relative humidity, and ozone concentration have been reported, including different responses between the land and ocean (e.g., Basha et al., 2025).

Understanding how eclipses produce vertical structures in the atmosphere is a key point for advancing our knowledge of the coupling process of the atmospheric layers. The geographical location of Natal (5.79^{o}S, 35.2^{o}W), which is on the northeast coast of Brazil, combined with the dynamics of the October 14, 2023, annular solar eclipse, which crossed Natal near sunset, created a very peculiar configuration to investigate the behavior of the atmosphere under these conditions. Although this annular eclipse preserved 11.5% of the sunlight, many structures were found in the vertical field of the atmosphere, and salient aspects will be discussed.

2 Experiment and observation

2.1 Database

The data used in this work was obtained from soundings using stratospheric balloons. The soundings were conducted on 06,13, 14 and 18 October 2023. These measurements are part of the Southern Hemisphere Additional Ozonesondes (SHADOZ)

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

project, which has monitored ozone in the Southern hemisphere since 1998 ((Thompson et al., 2017; Witte et al., 2017, 2018)). The measurements include temperature, pressure, humidity, wind direction, speed, and ozone concentration (which is determined using an electrochemical cell) during the ascent of the balloons.

The electrochemical concentration cell (ECC) ozonesonde sensor consists of a nonreactive Teflon gas-sampling pump connected to a buffered potassium iodide solution in the cathode and a saturated potassium iodide solution in the anode. Thus, the iodine/iodide electrode reaction is used to obtain the ozone concentration ((Witte et al., 2017)). The data are recorded using telemetry with a transmission rate of typically 1 Hz. Assuming that the balloon ascends with a vertical speed of 5 m/s and that there is an interval of 20-30 s for the response of the electrochemical concentration cell, the estimated vertical resolution is about 100-150 m.

In the present work, a balloon was launched on 14 October 2023 (the eclipse day), when the region was under the influence of the eclipse penumbra. The flight extended for approximately 1.45 hours ($\sim$1.45 hour), covering the umbra's crossing over Natal until close to sunset. Moreover, a launch was performed on 13 October 2023, this was important to facilitate comparison of the eclipse day with the day before. Two other flights were also recorded in October 2023. The data collected in this month, excluding the data of the eclipse day, were used to average control profiles for the comparisons shown ahead.

Additionally, comparisons with the Naval Research Laboratory Mass Spectrometer Incoherent Scatter (NRLMSISE-00) model (Picone et al., 2002) were performed, using the numerical model as control profiles as well.

2.1.1 14 October 2023 sounding

Figure 1 shows the spatial and temporal evolution of the 14 October 2023 balloon sounding during the annular solar eclipse. The first step to understanding the dynamics involving these measurements was to convert the universal time (UTC) to solar local time (SLT), which depends on the latitude and longitude of the observation points. The same conversion was applied to the temporal evolution of the eclipse path.

The SLT is shown in Figure 1 as the colored lines, one for the central path of the eclipse and the other over the Natal region for the balloon path. Additionally, the extension of the umbra can be seen as light gray area in the left panel. It is possible to see that the sounding was completely within the eclipse umbra. The right panel shows the vertical evolution of the sounding as a function of latitude and longitude; the dashed blue line indicates the altitude where the eclipse crossed the balloon.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

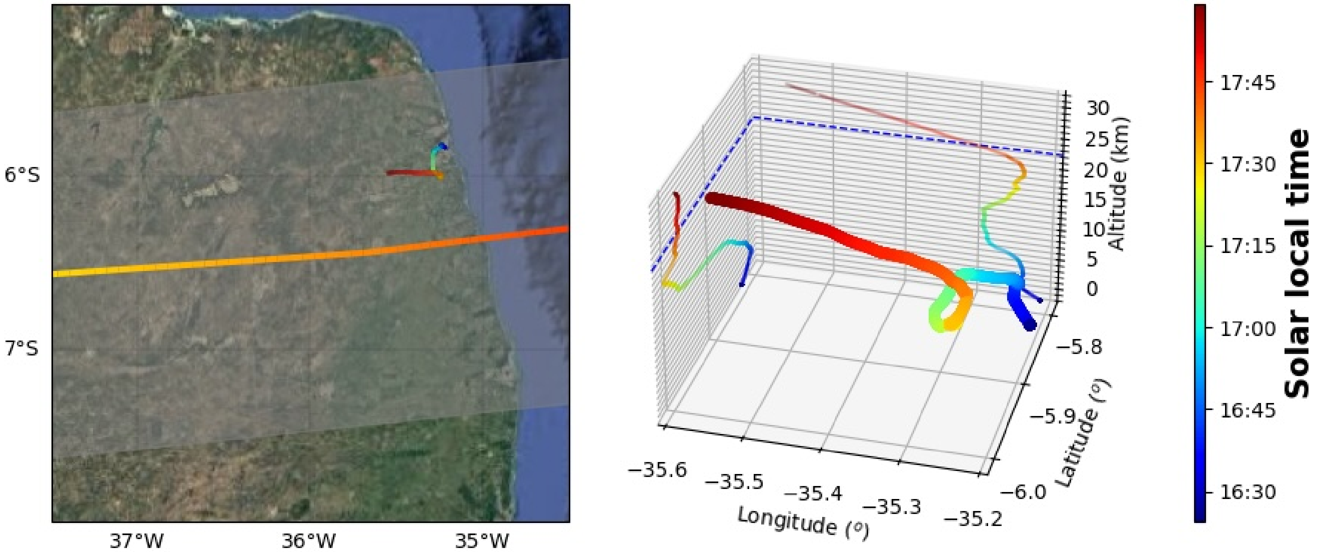

Figure 1. The spatial and temporal evolution of the sounding during the October 14, 2023, annular solar eclipse is presented. The left panel displays the coverage of the umbra region, with a central line whose color indicates the corresponding solar local time (SLT) in the color bar. The other colored line, overlaying the Natal region, shows the horizontal path of the balloon sounding and its color also represents the solar local time. On the right panel, one can see the vertical evolution of the balloon sounding. The dashed blue line indicates the exact time and altitude of the passage of the eclipse over the balloon. The left panel was done using Cartopy library (Met Office, 2010 - 2015)

The balloon was launched at 18:29:44 UTC, and the flight had a duration of 5,227 seconds, or ∼1.45 hours. The eclipse started at 15:03:50 UTC and ended at 20:55:16 UTC. The estimated time of the passage of the eclipse umbra over the balloon was 19:50:16 UTC. It is important to note that the duration of annularity was estimated at 3 minutes and 36 seconds. During this interval, the balloon took about 216 measurements and progressed vertically more than 1.4 km within the shadow of the umbra.

During this flight, it was possible to get several atmospheric parameters such as pressure, geopotential altitude, temperature, relative humidity, ozone pressure, ozone concentration, and wind speed and direction. It was a very particular experiment due to the eclipse itself, which was annular with an obscuration of around 88.5% over Natal, and the temporal window, which was very close to sunset.

3 Results and discussion

Figure 2 shows vertical temperature profiles for October 2023 measured by the balloon flights over Natal (colored lines) and a control profile estimated using the Naval Research Laboratory Mass Spectrometer and Incoherent Scatter model version 2.1 (light gray line). The average profile for October 2023 (dot-dashed olive line) includes the flights on 06, 13 ad 18 October 2023 and its standard deviation of the mean is represented by the shaded olive area. In addition, the vertical temperature profile

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

obtained on 13 October 2023 (one day before the eclipse) is shown by the dotted blue line.The profile on 14 October 2023 is represented by the solid red line.

In Figure 1, the altitudinal range of the Moon's shadow (umbra) passage is represented by the horizontal light gray area with the dashed black line at the center. Figure 1 also shows a small box emphasizing the range from 14 to 30 km altitude and displays the differences between the 14 October 2023 and MSIS profiles and between the 14 October 2023 and October average profiles.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

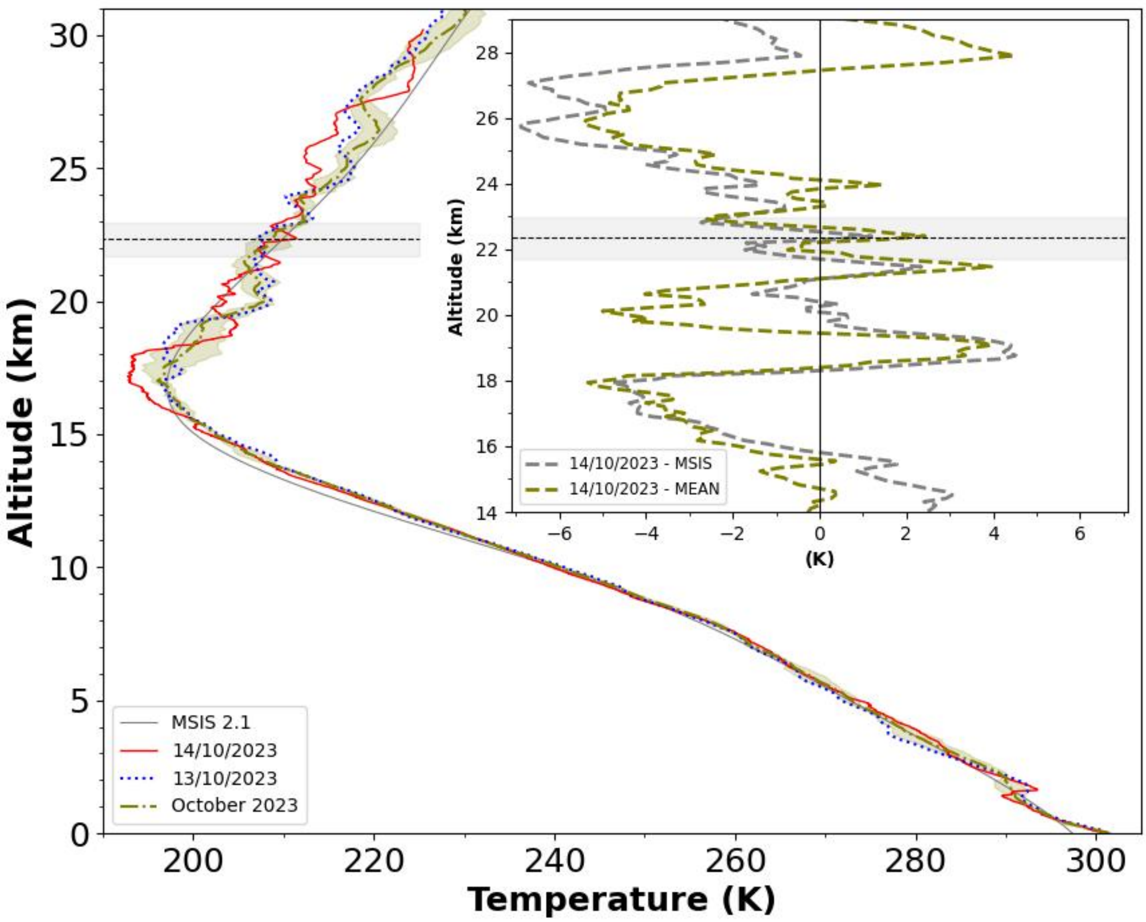

Figure 2. Vertical profiles of temperature collected by stratospheric balloons during October 2023 are compared with the MSIS model for 14 October 2023 (gray solid line). The average profiles for all flights that occurred during October are represented by the olive dot-dashed curve, and the shaded olive area represents the standard deviation of the mean. The profile collected on 13 October 2023 is represented by the dotted blue line, and the profile measured on 14 October 2023 is shown by the solid red line. The inset box in the chart shows the temperature difference between the 14 October 2023 profile and the MSIS model (dashed gray line) and the October average profile (dashed olive line). The light gray horizontal band with the black dashed line in the center represents the altitudinal range in which the eclipse umbra covered the balloon flight.

In the lower troposphere, up to 4-5 km altitude, there are some differences in the profiles when compared to the MSIS control profile. This is probably a response to tropospheric activity, which has strong day-to-day variability. From 5 to 13 km altitudes, the profiles are very close to each other. Above 14 km, in the upper troposphere and lower stratosphere, one can see that there

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

are very strong perturbations in the profiles, except in the MSIS model. Comparing the profile collected on 14 October 2023 to the others, there is a very clear cooling in the tropopause. This cooling reaches about 5 K when compared to the October mean profile, and more than 4 K in relation to the MSIS model. It is very important to mention that during that time, the measurements were under the effect of the eclipse penumbra, which started over Natal approximately when the balloon was launched.

Above the tropopause, perturbations in the temperature profiles were observed, almost always anti-correlated to the average measurements and the profile from the previous day. Although, in these altitude levels, i.e., in the lower stratosphere, primarily above 24 km altitude, the presence of perturbations in the temperature profiles, like those from 13 and 14 October 2023 is common. The oscillation observed in the 14 October 2023 profile is always anti-correlated to the oscillations in the profile from the previous day and the average profiles. Furthermore, the differences between the profile obtained on 14 October 2023 and the October average and MSIS profiles (small box chart) follow the same trend. This indicates that the temperature profile on 14 October 2023 was quite particular due to the effect of the eclipse passage.

Variations in the surface temperature are perhaps one of the most studied aspects during an eclipse. This is primarily because these measurements are easily conducted when the Moon's shadow crosses established meteorological stations on the Earth's surface or during temporary campaigns set up specifically for the event. With the reduction in solar irradiance, a drop in air temperature has been observed (e.g., Founda et al., 2007; Namboodiri et al., 2011).

In contrast, vertical profiles of temperature during the eclipse are more difficult to be investigated because they need a more specific experimental configuration. Nevertheless, some research has been conducted to study how the vertical temperature profiles respond to the passage of a local eclipse using satellites (e.g., Good, 2016; Paulino et al., 2025; Basha et al., 2025) and vertical soundings (e.g., Harrison et al., 2016; Das et al., 2023; Pasken et al., 2023). In general, vertical fluctuations and cooling in the tropopause have been observed, which is in agreement with the present results. In addition, variations in the tropopause altitude and differences between the land and ocean responses have been pointed out as well.

Figure 3 is similar to Figure 2, but displays the atmospheric pressure. The observed profiles are very close to each other, and it is very difficult to distinguish them in the chart. The small box on the upper left corner emphasizes the region from 9 to 29 km altitude, there it is possible to see that the pressure on 14 October 2023 was slightly lower than the average profile. The difference between the profiles decreases with altitude, reaching about -0.7 hPa near the tropopause, and then increases above this altitude, reaching -0.2 hPa around 29 km altitude.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

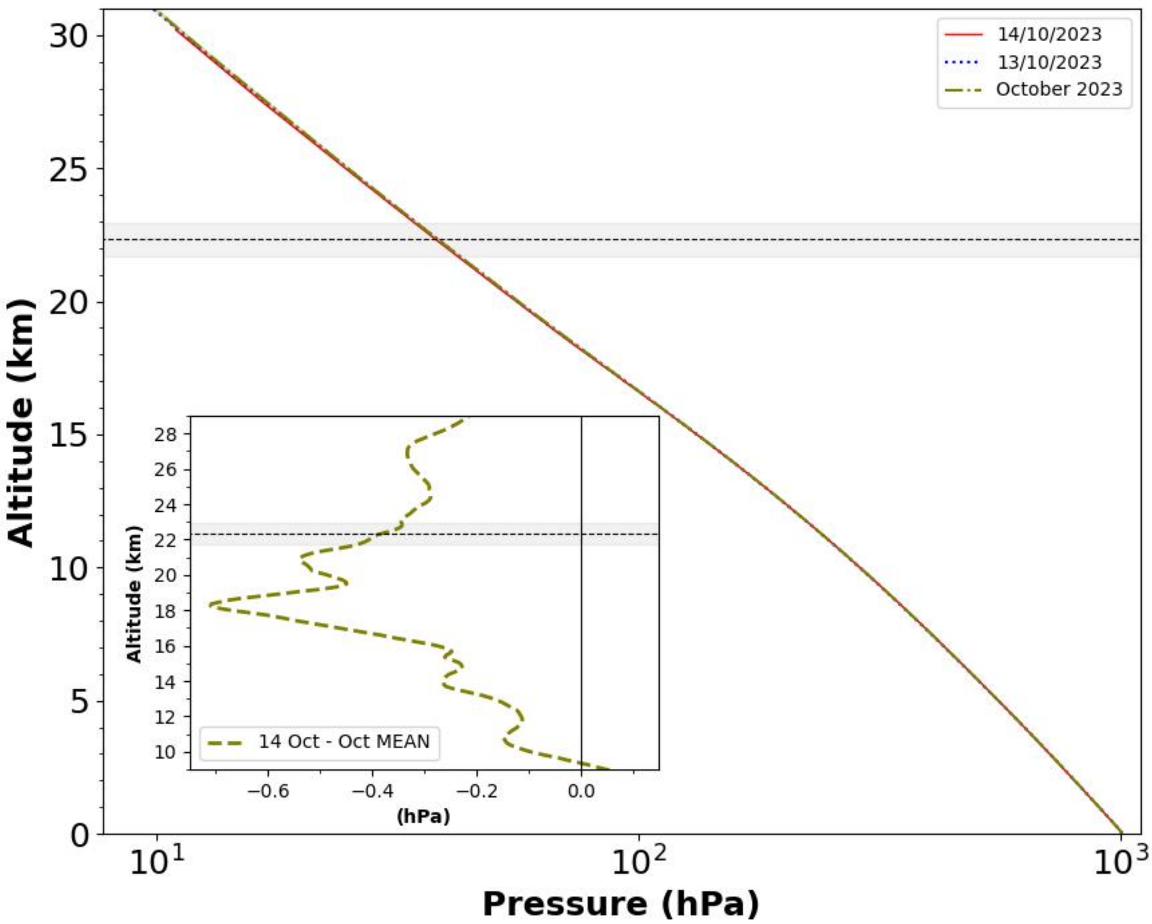

Figure 3. Same as Figure 2, but showing the atmospheric pressure.

Drop in atmospheric pressure during solar eclipses has been reported in previous observations. For example, Pasken et al. (2023) showed that the pressure reduced slightly during and after the passage of the 21 August 2017 solar eclipse in St. Louis, United States. The temperature gradient produced by the atmospheric cooling can induce pressure fluctuations with gravity waves as a prominent response Paulino et al. (2020).

Figure 4 shows the vertical profiles for the Ozone concentration, measured on 13 October 2023 (dotted blue line), 14 October 2023 (solid red line) and the average for October (dot-dashed olive line). The shaded olive area represents the standard deviation of the mean, calculated considering soundings on06, 13, and 18 October 2023. The Ozone concentration below 20 km altitude is very small, less than 1 part per million and the profiles have a lot of oscillation. In this case, the oscillations observed during

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

the eclipse are anti-correlated to the other profiles shown in Figure 4. This anti-correlation extends to the upper level as well. In addition, above the tropopause, the ozone concentration on 14 October 2023 was greater than what was observed on the other days, with an enhancement of ∼1 ppm above 28 km.

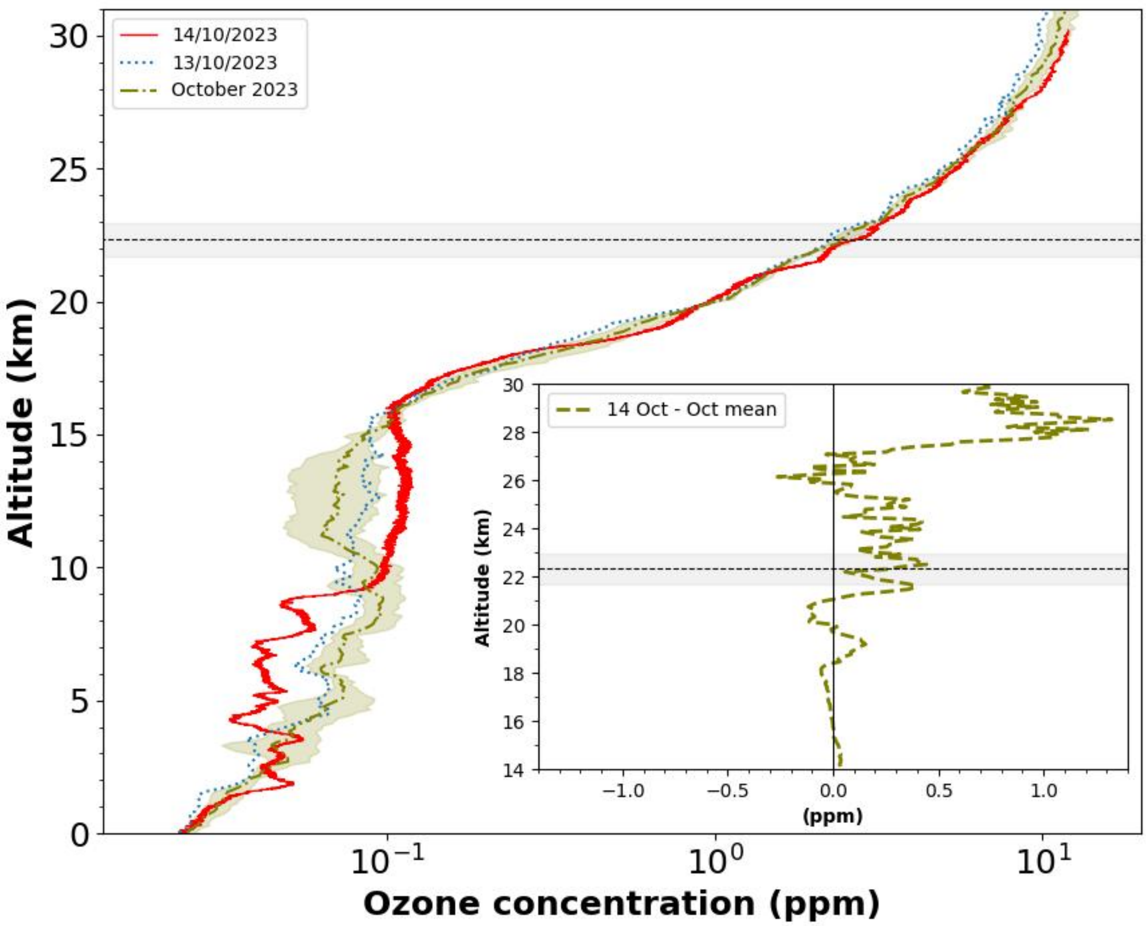

Figure 4. Same as Figure 2, but showing the Ozone concentration.

Earlier reports of the total Ozone concentration during solar eclipses reported an increase of ∼4% in the total Ozone column, as measured using Dobson spectrophotometers (Fournier d'Albe and Rasool, 1956; Stranz, 1961). Zerefos et al. (2000) showed a variation of 30 DU in the ozone concentration due to diffuse radiation, and Mateos et al. (2014) presented similar behavior observed during the 03 November 2013 solar eclipse over Spain.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

Theoretically, it is expected to have an increase in the Ozone concentration in the eclipsed column of the atmosphere due to ozone photochemistry. However, a theoretical study revised the enhancement of the Ozone concentration down to 1% (Hunt, 1965), and more recently, Bernhard et al. (2025) pointed out that the enhancement is too small to be measured confidently.

The present observations have shown very large fluctuations, but above an altitude of 21 km, which is just after the passage of the Moon's shadow, the concentration of Ozone is almost always higher than it was observed in October over Natal and can reach a few percent in the higher levels. Thus, the observations are consistent with the predictions and represent a very interesting result, since the measurements were done locally and do not have the limitations reported in other experiments. The enhancement in the ozone concentration observed in the present work is also supported by previous balloon launches; for instance, an increase of a few ppbv in the troposphere was reported during the 26 December 2019 solar eclipse over Gadanki (Akhil Raj and Ratnam, 2021).

Figure 5 shows the vertical profiles for relative humidity collected during October 2023 over Natal. The solid red line represents the measurements on the day of the eclipse. The dotted blue line represents the measurements one day before. The dot-dashed olive line represents the average for October 2023, using data collected on 06, 13 and 18 October 2023, where the shaded olive area represents the standard deviation of the mean. The day-to-day variability in the measurements is very clear for the relative humidity as well. The profile obtained on 14 October 2023 is very different from the other profiles, primarily above 5 km. From 5 to ∼21 km, the relative humidity was almost always higher on the eclipse day. Above 21 km altitude, which coincides with the passage of the umbra over the balloon, the relative humidity starts to decrease and becomes lower than the other measurements. Although the absolute values in these altitudes are very low (less than 1%), the curve shows a clear decrease that was not observed in the other profiles.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

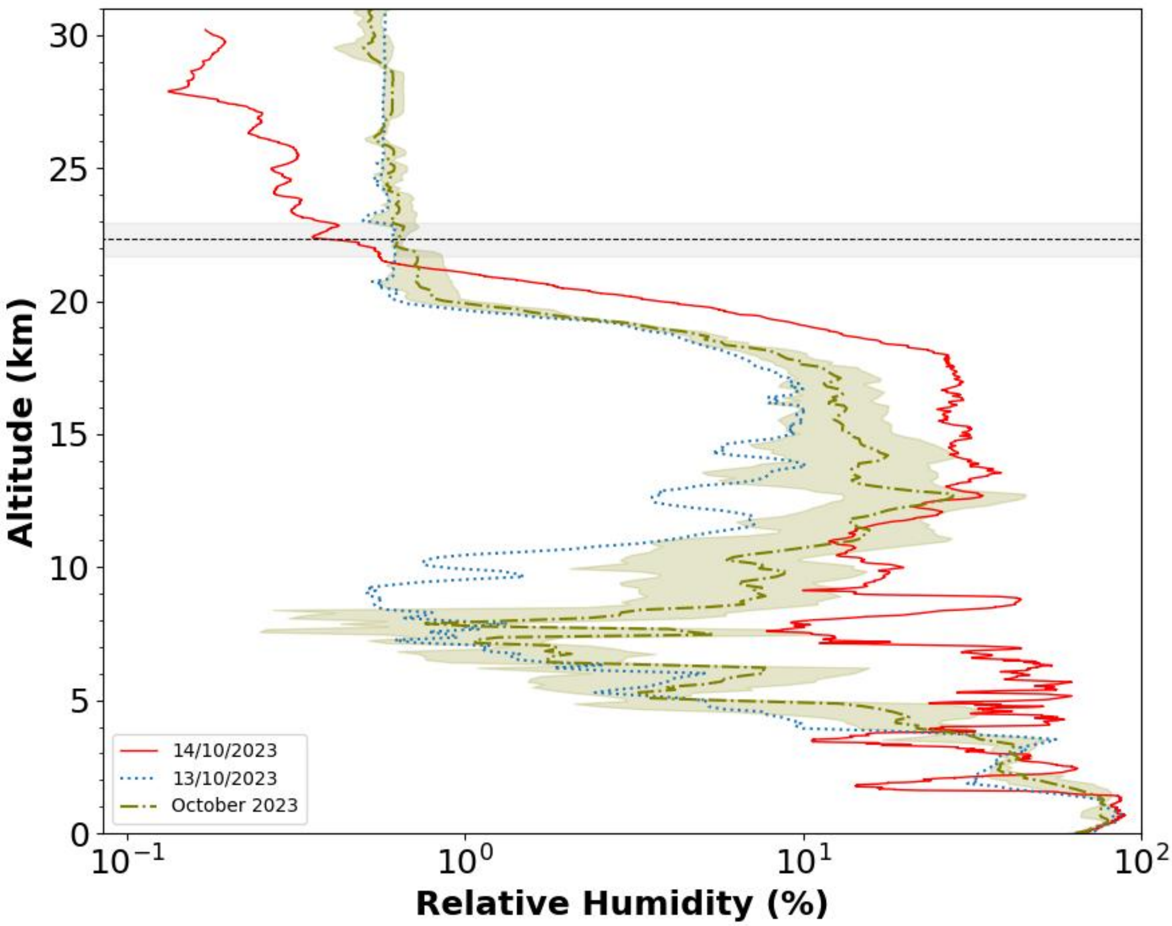

Figure 5. Vertical profiles of relativity humidity collected by stratospheric balloons during October 2023. The average profiles for all fights occurred during October are represented by the olive dot-dashed curve and the shadow olive area represent the standard deviation of the mean. The profile collect on 13 October 2023 is represented by the dotted blue line and the profile measured on 14 October 2023 is shown by the solid red line. T The light gray horizontal are with the black dashed live in the center represent the altitudinal range in which the umbra of eclipse cover the ballon flight.

Observations in eight Indian cities showed a considerable increase in relative humidity during the 21 June 2020 solar eclipse (Pratap et al., 2021). Furthermore, an increase in surface relative humidity was also reported by Tzanis et al. (2008) during the 19 March 2006 solar eclipse in Athens. During the eclipse of 12 November 1966, Funari and dos Santos (2018) also observed a reduction in relative humidity over Brazil. Basha et al. (2025) have also reported an increase in relative humidity over the

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

United States during the 08 April 2024 solar eclipse. In that work, they used data from the COSMIC-2 satellites over both the ocean and land. Consequently, it was possible to observe that there were also fluctuations in the vertical profiles.

During a solar eclipse, the blocking of sunlight is expected to cause an increase in relative humidity, primarily near the surface. This is because evaporation decreases, which subsequently makes the air more humid.

4 Conclusions

During the annular solar eclipse on October 14, 2023, a sounding of the atmosphere was conducted using a stratospheric balloon over Natal, Brazil. It was a very unique experiment due to the geographical configuration and the nature of the eclipse. The Moon's shadow, with a 'ring of fire', crossed Natal very close to sunset. The balloon was launched immediately after the penumbra reached Natal and collected atmospheric parameters such as temperature, pressure, relative humidity, and ozone concentration for more than 1.45 hours. The Moon's shadow crossed the balloon at approximately 19:50 UTC when the balloon was at an altitude of approximately 22.35 km. The eclipse duration was 3 minutes and 36 seconds, which allowed the sounding to collect 216 measurements while the umbra was present. The investigation showed that the atmosphere responds as complex structures and small fluctuations in the vertical profiles of the mentioned fields. More specifically, the following was observed:

- Some vertical fluctuations in the temperature profile were observed, with high amplitudes above 14 km. The tropopause experienced a cooling of 4-5 K when compared with the control and average measurements.;
- A drop in the pressure of 0.2-0.7 hPa was observed above 12 km altitude, with vertical variations along the altitudes.;
- The ozone concentration presented many vertical oscillations, and an increase above 20 km reaching 1 ppm was observed.;
- Between 5 and 21 km of altitude, the relative humidity increased compared with the control profiles. Above 21 km altitude, the relative humidity dropped, but at those levels, the values were very small.

All the experimental results are in agreement with previous observations and are consistent with the expected effects of the solar eclipse on the atmosphere. This confirms the importance of the annular solar eclipse as a transient event affecting the local structure and dynamics of the atmosphere.

Data availability. The data can be dowloaded at https://tropo.gsfc.nasa.gov/shadoz/Natal.html

Author contributions. IP and ARP - Data analysis and conception; FRS - Experimental conception and revision; GB - Scientific conception and revision

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

Competing interests. I. Paulino is member of the Annales Geophysicae Editorial Board.

Acknowledgements. This work has been supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, #309981/2023-9, #303115/2025-4 and #403980/2025-9).

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

References

Akhil Raj, S. and Ratnam, M. V.: Ozone vertical distribution during the solar eclipse of 26 December 2019 over Gadanki: Role of background dynamics, Atmospheric Pollution Research, 12, 101 116, https://doi.org/https://doi.org/10.1016/j.apr.2021.101116, 2021.

Basha, G., Ratnam, M. V., Jiang, J. H., and Pangaluru, K.: Investigating the Effects of the Solar Eclipse on the Atmosphere over Land and Oceanic Regions: Observations from Ground Stations and COSMIC2 Data, Atmosphere, 16, https://doi.org/10.3390/atmos16070872, 2025.

Bernhard, G. H., Janson, G. T., Simpson, S., Cordero, R. R., Sepúlveda Araya, E. I., Jorquera, J., Rayas, J. A., and Lind, R. N.: Does total column ozone change during a solar eclipse?, Atmospheric Chemistry and Physics, 25, 819–841, https://doi.org/10.5194/acp-25-819-2025, 2025.

Das, S. S., Kishore Kumar, K., Subrahmanyam, K. V., Venkat Ratnam, M., Suneeth, K. V., Sunilkumar, S. V., Sinha, P. R., Ghosh, A. K., Das, S. K., Sonwabne, S., Muralikrishna, U. V., Kolte, Y., Naja, M., Abhilash, S., Satheesan, K., Rakesh, V., Mahesh, P., Koushik, N., Satheesh Chandran, P. R., Girach, I. A., Namboodiri, K. V. S., Pandithurai, G., and Kirankumar, N. V. P.: Impact of Annular Solar Eclipse on the Trace Gases and Dynamics of the Lower and Middle Atmosphere: Results Inferred From an Integrated Campaign "Suryagrahan-2019", Earth and Space Science, 10, e2023EA003 044, https://doi.org/10.1029/2023EA003044, 2023.

Founda, D., Melas, D., Lykoudis, S., Lisaridis, I., Gerasopoulos, E., Kouvarakis, G., Petrakis, M., and Zerefos, C.: The effect of the total solar eclipse of 29 March 2006 on meteorological variables in Greece, Atmos. Chem. Phys., 7, 5543–5553, https://doi.org/10.5194/acp-7-5543-2007, 2007.

Fournier d'Albe, E. M. and Rasool, S. I.: Observations of atmospheric ozone during a total eclipse of the sun, Ann. de Geophys., 12, 72–74, 1956.

Funari, F. L. and dos Santos, P. M.: O eclipse total do sol ocorrido em 12 de novembro de 1966 em Bagé (RS), Brasil, e seus efeitos nos parâmetros meteorológicos, Revista do Instituto Geológico, 39, https://doi.org/10.33958/revig.v39i3.603, 2018.

Good, E.: Satellite observations of surface temperature during the March 2015 total solar eclipse, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374, 20150 219, https://doi.org/10.1098/rsta.2015.0219, 2016.

Harding, B. J., Drob, D. P., Buriti, R. A., and Makela, J. J.: Nightside Detection of a Large-Scale Thermospheric Wave Generated by a Solar Eclipse, Geophysical Research Letters, 45, 3366–3373, https://doi.org/https://doi.org/10.1002/2018GL077015, 2018.

Harrison, R. G., Marlton, G. J., Williams, P. D., and Nicoll, K. A.: Coordinated weather balloon solar radiation measurements during a solar eclipse, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374, 20150 221, https://doi.org/10.1098/rsta.2015.0221, 2016.

Hunt, B. G.: A theoretical study of the changes occurring in the ozonosphere during a total eclipse of the sun, Tellus, 17, 516–523, https://doi.org/10.3402/tellusa.v17i4.9158, 1965.

Madhavan, B. and Venkat Ratnam, M.: Impact of a solar eclipse on surface radiation and photovoltaic energy, Solar Energy, 223, 351–366, https://doi.org/https://doi.org/10.1016/j.solener.2021.05.062, 2021.

Manohar, G. K., Kandalgaonkar, S. S., and Kulkarni, M. K.: Impact of a total solar eclipse on surface atmospheric electricity, Journal of Geophysical Research: Atmospheres, 100, 20 805–20 814, https://doi.org/https://doi.org/10.1029/95JD01295, 1995.

Mateos, D., Antón, M., and Vaquero, J.: Influence of solar eclipse of November 3rd, 2013 on the total ozone column over Badajoz, Spain, Journal of Atmospheric and Solar-Terrestrial Physics, 112, 43–46, https://doi.org/https://doi.org/10.1016/j.jastp.2014.02.005, 2014.

McIntosh, B. A. and ReVelle, D. O.: Traveling atmospheric pressure waves measured during a solar eclipse, Journal of Geophysical Research: Atmospheres, 89, 4953–4962, https://doi.org/https://doi.org/10.1029/JD089iD03p04953, 1984.

Met Office: Cartopy: a cartographic python library with a Matplotlib interface, Exeter, Devon, https://scitools.org.uk/cartopy, 2010 - 2015.

Namboodiri, K. V. S., Dileep, P. K., Mammen, K., Ramkumar, G., Kumar, N., Sreenivasan, S., Kumar, B. S., and Manchanda, R. K.: Effects of annular solar eclipse of 15 January 2010 on meteorological parameters in the 0 to 65 km region over Thumba, India, Meteorologische Zeitschrift, 20, 635–647, https://doi.org/10.1127/0941-2948/2011/0253, 2011.

Pasken, R., Halverson, J., and Braunschweig, P.: Surface Mesonet and Upper Air Analysis of the 21 August 2017 Total Solar Eclipse, Atmosphere, 14, https://doi.org/10.3390/atmos14091412, 2023.

Paulino, A. R., Paulino, I., and Pereira, J. A.: Responses of the 14 October 2023 annular solar eclipse observed in satellite temperature profiles, EGUsphere, 2025, 1–14, https://doi.org/10.5194/egusphere-2025-3085, 2025.

Paulino, I., Figueiredo, C. A. O. B., Rodrigues, F. S., Buriti, R. A., Wrasse, C. M., Paulino, A. R., Barros, D., Takahashi, H., Batista, I. S., Medeiros, A. F., Batista, P. P., Abdu, M. A., de Paula, E. R., Denardini, C. M., Lima, L. M., Cueva, R. Y., and Makela, J. J.: Atmospheric Gravity Waves Observed in the Nightglow Following the 21 August 2017 Total Solar Eclipse, Geophysical Research Letters, 47, e2020GL088 924, https://doi.org/https://doi.org/10.1029/2020GL088924, 2020.

Picone, J. M., Hedin, A. E., Drob, D. P., and Aikin, A. C.: NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues, Journal of Geophysical Research: Space Physics, 107, SIA 15–1–SIA 15–16, https://doi.org/https://doi.org/10.1029/2002JA009430, 2002.

Pratap, V., Kumar, A., and Singh, A. K.: Overview of solar eclipse of 21st June 2020 and its impact on solar irradiance, surface ozone and different meteorological parameters over eight cities of India, Advances in Space Research, 68, 4039–4049, https://doi.org/https://doi.org/10.1016/j.asr.2021.08.014, 2021.

Stranz, D.: Ozone measurements during solar eclipse, Tellus, 13, 276–279, https://doi.org/10.3402/tellusa.v13i2.9448, 1961.

Thompson, A. M., Witte, J. C., Sterling, C., Jordan, A., Johnson, B. J., Oltmans, S. J., Fujiwara, M., Vömel, H., Allaart, M., Piters, A., Coetzee, G. J. R., Posny, F., Corrales, E., Diaz, J. A., Félix, C., Komala, N., Lai, N., Ahn Nguyen, H. T., Maata, M., Mani, F., Zainal, Z., Ogino, S.-y., Paredes, F., Penha, T. L. B., da Silva, F. R., Sallons-Mitro, S., Selkirk, H. B., Schmidlin, F. J., Stübi, R., and Thiongo, K.: First Reprocessing of Southern Hemisphere Additional Ozonesondes (SHADOZ) Ozone Profiles (1998–2016): 2. Comparisons With Satellites and Ground-Based Instruments, Journal of Geophysical Research: Atmospheres, 122, 13,000–13,025, https://doi.org/https://doi.org/10.1002/2017JD027406, 2017.

Tzanis, C., Varotsos, C., and Viras, L.: Impacts of the solar eclipse of 29 March 2006 on the surface ozone concentration, the solar ultraviolet radiation and the meteorological parameters at Athens, Greece, Atmospheric Chemistry and Physics, 8, 425–430, https://doi.org/10.5194/acp-8-425-2008, 2008.

Witte, J. C., Thompson, A. M., Smit, H. G. J., Fujiwara, M., Posny, F., Coetzee, G. J. R., Northam, E. T., Johnson, B. J., Sterling, C. W., Mohamad, M., Ogino, S.-Y., Jordan, A., and da Silva, F. R.: First reprocessing of Southern Hemisphere ADditional OZonesondes (SHADOZ) profile records (1998–2015): 1. Methodology and evaluation, Journal of Geophysical Research: Atmospheres, 122, 6611–6636, https://doi.org/https://doi.org/10.1002/2016JD026403, 2017.

Witte, J. C., Thompson, A. M., Smit, H. G. J., Vömel, H., Posny, F., and Stübi, R.: First Reprocessing of Southern Hemisphere ADditional OZonesondes Profile Records: 3. Uncertainty in Ozone Profile and Total Column, Journal of Geophysical Research: Atmospheres, 123, 3243–3268, https://doi.org/https://doi.org/10.1002/2017JD027791, 2018.

https://doi.org/10.5194/egusphere-2025-6194
Preprint. Discussion started: 12 January 2026

Yang, X., Chen, P., Yao, Y., and Wu, M.: Response of the ionosphere to the total solar eclipse in the United States on April 8, 2024, Advances in Space Research, 76, 5566–5580, https://doi.org/https://doi.org/10.1016/j.asr.2025.07.085, 2025.

Zerefos, C. S., Balis, D. S., Meleti, C., Bais, A. F., Tourpali, K., Kourtidis, K., Vanicek, K., Cappellani, F., Kaminski, U., Colombo, T., Stübi, R., Manea, L., Formenti, P., and Andreae, M. O.: Changes in surface solar UV irradiances and total ozone during the solar eclipse of August 11, 1999, Journal of Geophysical Research: Atmospheres, 105, 26 463–26 473, https://doi.org/https://doi.org/10.1029/2000JD900412, 2000.

Zhang, S.-R., Erickson, P. J., Goncharenko, L. P., Coster, A. J., Rideout, W., and Vierinen, J.: Ionospheric Bow Waves and Perturbations Induced by the 21 August 2017 Solar Eclipse, Geophysical Research Letters, 44, 12,067–12,073, https://doi.org/https://doi.org/10.1002/2017GL076054, 2017.