Responses to Editor and Reviewers

General Comments:

Dear Dr. Geeta Vichare!

Thank you for considering our manuscript for review in Annales Geophysicae. We have carefully revised the paper based on all the concerns raised by both reviewers.

The main updates in this version include using a robust database of soundings from Natal to build climatological profiles for temperature, pressure, ozone concentration and relative humidity. We also included ERA5 data to help with the comparisons. Another important addition is the inclusion of uncertainties for the ozone concentration and relative humidity measurements, which are now shown as error bars in Figures 4 and 5. Furthermore, we performed hypothesis tests to check the statistical significance of the observed changes for all discussed parameters. Finally, we carefully proofread the text to make the English more academic, while keeping it clear and easy to read.

The changes made to the text are highlighted in a separate file and our point-by-point responses to both referees are listed below.

Best regards,

The Authors.

Referee #1:

REFEREE: **"There are minor typing erros in the text that need to be corrected. But the content is suitable for publication."**

AUTHORS: We would like to express our gratitude to Referee #1 for the time and effort spent reviewing our manuscript. We are also very grateful for their kind comments and recommendation in favor of publication. We conducted a detailed revision of the text to correct the typos identified by the Referee #1. Those corrections were highlighted in the tracked changes file.

Referee #2:

REFEREE:**“This is an interesting observational study based on a rare balloon sounding during the 14 October 2023 annular solar eclipse over Natal, Brazil. The experimental configuration is valuable, especially because the eclipse occurred near sunset and the shadow crossed the balloon at stratospheric altitude. The reported temperature cooling near the tropopause, pressure decrease, ozone enhancement, and relative humidity changes are relevant and generally consistent with expected eclipse-related atmospheric responses. However, I think the causal interpretation should be more cautious. The control dataset is limited to only a few October 2023 soundings, and natural day-to-day variability, gravity waves, coastal dynamics, and background meteorological conditions may also explain part of the observed vertical structure. ”**

AUTHORS: We appreciate the time invested by Referee 1, as well as their relevant and constructive comments aimed at improving our manuscript. In this revised version, we did our best to address all of their concerns.

REFEREE:**“Include a more robust climatological comparison, if possible, using additional October SHADOZ soundings from multiple years at Natal.”**

AUTHORS: Thank you for the excellent suggestion. As suggested by Referee #2, we have incorporated climatological profiles for temperature, pressure, ozone concentration and relative humidity using data collected over Natal from 1999 to 2023, totaling 62 soundings. These profiles have been updated in the manuscript replacing the average for October 2023. It can be seen that the range of the standard deviation is much wider. As rightly pointed out by Referee #2, it is now possible to better observe the variability of the atmospheric fields, which allowed for a more accurate comparison between the profiles collected on the day of the eclipse and the climatological averages. Figures 1, 2, 3, and 4 below show the new versions of the comparisons, which have also been updated in the manuscript.

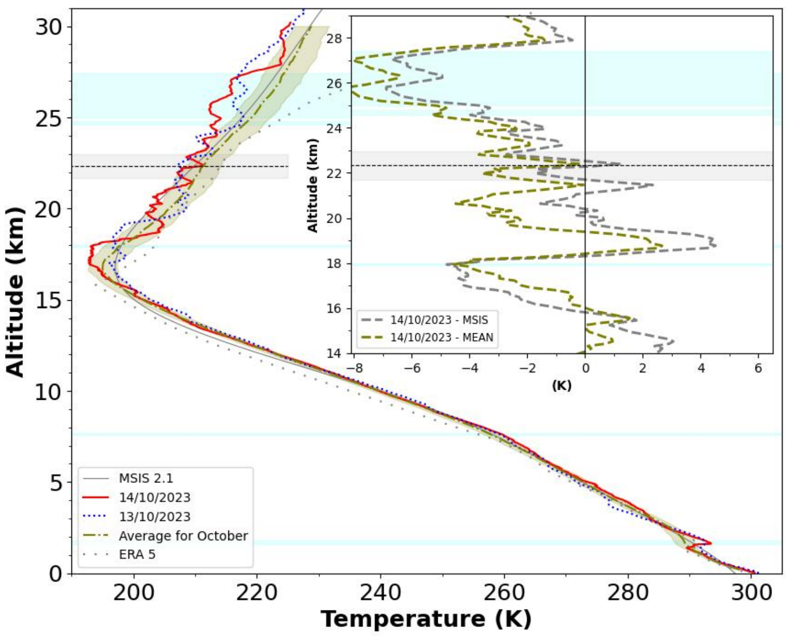

Figure 1: Vertical profiles of temperature obtained from stratospheric balloons, the MSIS model and the ERA5 reanalysis. The average profile for all flights conducted during October from 1999 to 2023 is represented by the olive dot-dashed curve, with the shaded olive area showing the standard deviation. 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 dotted gray line show the profile from the ERA5 reanalysis, while the NRLMSISE-00 model is shown by the solid gray line. The inset box in the chart displays the temperature difference between the 14 October 2023 profile and both the MSIS model (dashed gray line) and the climatological October average profile (dashed olive line). The light gray horizontal band with the black dashed line in the center represents the altitude range where the eclipse umbra crossed the path of the balloon. The horizontal cyan areas illustrate regions where statistically significant differences (at a 90% confidence level) were observed between the profile collected on 14 October 2023 and the climatological mean for October.

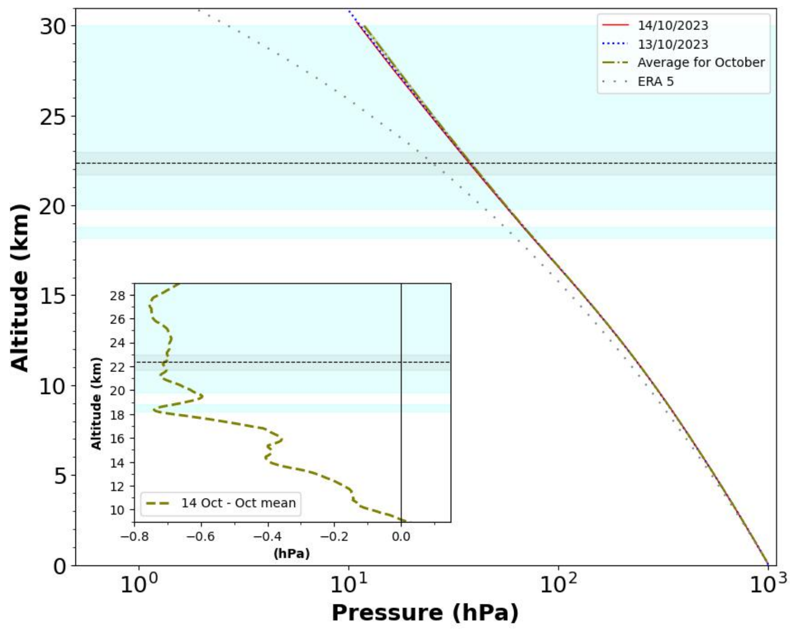

Figure 2: Same as Figure 1, but showing the atmospheric pressure.

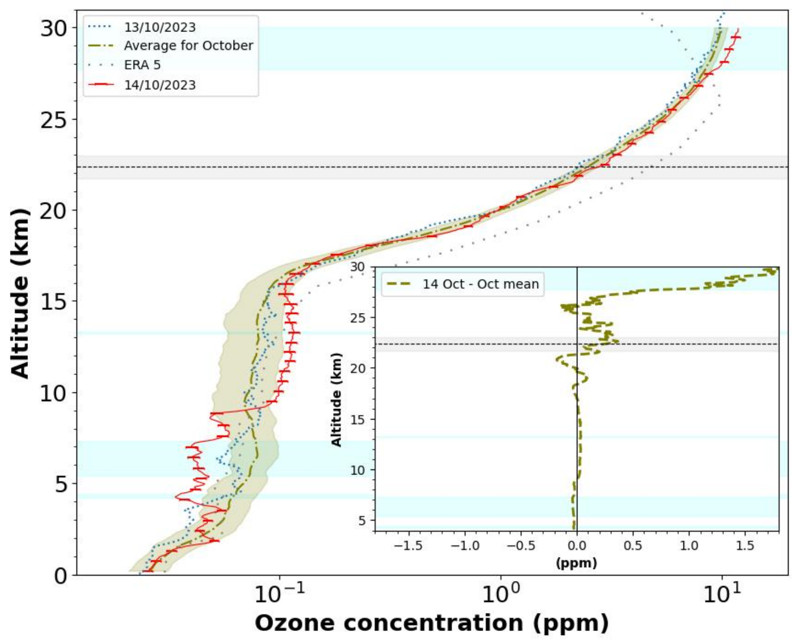

Figure 3: Same as Figure 1, but showing the Ozone concentration. Error bars represent the uncertainties in the ozone concentration.

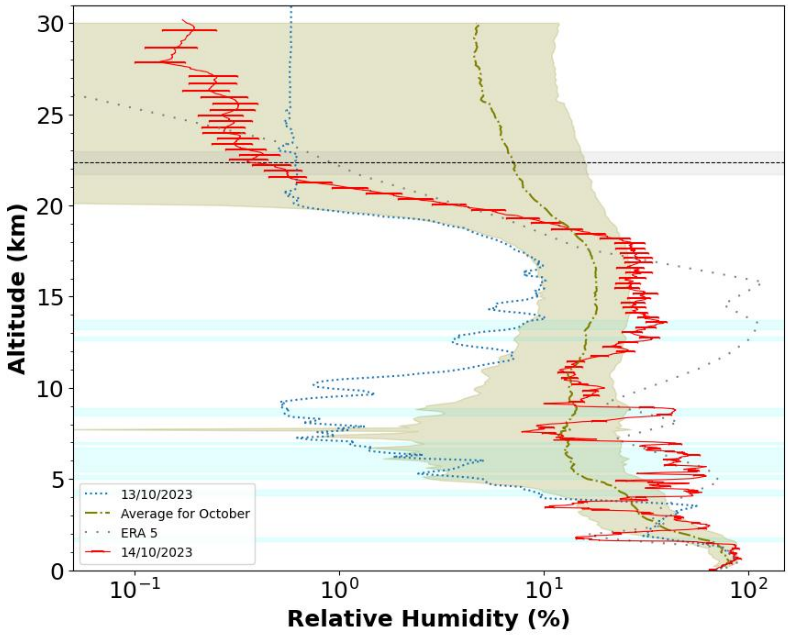

Figure 4: Same as Figure 1, but for relative humidity. The red error bars show an approximate estimation of the uncertainties.

REFEREE: **"Compare the observed profiles with reanalysis data, such as ERA5, to better characterize the background meteorological conditions on 14 October 2023."**

AUTHORS: We thank Referee #2 for the suggestion. The reanalysis profiles calculated by ERA5 have been added to Figures 1, 2, and 4 shown above. We observed some important similarities, such as a temperature inversion in the troposphere that was not predicted by the model. In contrast, ERA5 overestimated the temperature increase in the stratosphere and the pressure decrease. These points have been added to the manuscript.

REFEREE: **"Quantify the statistical significance of the temperature, ozone, humidity, and pressure anomalies relative to natural variability."**

AUTHORS: Thank you for another important suggestion from Referee #2. The statistical significance was quantified for the listed variables. To do this, we performed hypothesis tests to evaluate the changes (increases and decreases) observed in the profiles on 14 October 2023. For this analysis, we used 62 soundings from the SHADOZ project from 1999 to 2023, excluding the day of the eclipse. We used a 90% confidence interval. The statistically significant regions within this interval are shown in cyan in Figures 1, 2, 3, and 4 shown above. This information has now been included in the manuscript. The statistical significance was very useful to confirm the reliability of some results presented in the first version, as well as to minimize other points, such as the decrease in relative humidity in the stratosphere.

REFEREE: **"Provide a clearer uncertainty discussion for the ozone and relative humidity measurements, especially at higher altitudes where absolute humidity values are very small."**

AUTHORS: The uncertainties for ozone concentration and relative humidity were also added. These uncertainties were included as red error bars in Figures 3 and 4 shown above. The uncertainties for ozone concentration are provided in the SHADOZ data for the respective observation days. On the other hand, the uncertainties for relative humidity were estimated using the results from Miloshevich et al. (2009) for each altitude range.

Ozone column uncertainty estimates are provided for each sounding. Witte et al. (2018) describe in detail how ozone concentration uncertainties are determined. Basically, the uncertainty is calculated by combining instrumental errors and chemical variables. From the troposphere to the tropopause, where ozone concentrations are low, uncertainties come mostly from the sensor and variations in the background electric current. In contrast, in the stratosphere, where ozone concentrations are higher, uncertainties related to pump efficiency and stoichiometry become dominant. Combining and vertically integrating these factors along the profile results in a typical uncertainty of 5% to 6% for the total ozone column.

On the other hand, The error estimation for relative humidity measurements in SHADOZ launches involves applying empirical correction algorithms to raw radiosonde data to counteract solar radiation dry bias and sensor time-lag under extreme conditions (Miloshevich et al., 2009). Typical residual error is relatively low in the lower troposphere, ranging from ±3% to ±5%. However it becomes significative above the tropopause reaching ±10% to ±20% due to sensor exposition to temperatures below -40°C.

Those two paragraphs above were also included in the manuscript. Thank you very much for the suggestion. Using the uncertainties helps us discuss the changes in the profiles on 14 October 2024 with more confidence.

REFEREE:**“Moderate some of the causal language. Terms such as ”confirms” could be replaced by ”is consistent with” or ”supports the interpretation that,” unless stronger attribution analysis is added. Improve manuscript editing. There are several grammatical and typographical issues, for example ”relativity humidity,” ”fights” instead of ”flights,” and ”dowloaded.” Some figure captions also need revision for clarity.”**

AUTHORS: Thank you for your careful suggestions to improve the text. We have revised the language to address this concern from Referee #2.

REFEREE:**“Overall, this is a valuable observational study based on a rare dataset. I recommend publication after revision. The main issue is not the relevance of the observations, but the strength of the causal attribution to the eclipse. The manuscript would be more convincing if the attribution of the observed anomalies were presented with more caution and the comparison with background atmospheric variability were strengthened.”**

AUTHORS: We are once again grateful for the important suggestions of the Referee #2 and for the careful review process, which will greatly enhance the overall quality of our manuscript.