Responses from authors to Reviewer 2's comments

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Title: Development of an in situ Acoustic Anemometer to Measure Wind in the Stratosphere for SENSOR

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Reviewer 2's comments:

The scope of this manuscript is to present the development and the performance of a sonic anemometer able to produce wind measurements in the stratosphere. While I think sensors technology is now mature to design experiments based on ultrasonic probes purposely developed for high altitude atmospheric observations, I have major concerns on the quality and the originality of the research proposed here.

Although the authors cite two recent articles presenting experiments that fully achieved the goal of performing science quality measurements in the stratosphere with acoustic anemometers, they do not reference them properly and instead they make such statements as "This is the first time that in-situ wind measurements were obtained during level flight at this altitude" (meaning above 20km), as reported in the abstract at lines 22-23.

This is misleading, as I will explain in the following, and the authors insist throughout the text on the fact that their measurements are (the first) being performed above 20km and during a balloon level flight, in order to differentiate their work from previous experiments based on this technology already performed in the stratosphere.

As a matter of fact, Banfield et al. 2016 and Maruca et al. 2017 (both cited in the maniscript) performed experiments in which sonic anemometers have been developed (and/or modified) and tested with positive outcomes on high altitude stratospheric balloons. In the case of Banfield et al. 2016 the probe operated up to ~ 33 km while the sonic anemometer of the TILDAE experiment by Maruca et al. 2017 operated up to around 19 km. These experiments (dated back in 2015 and 2016, respectively) have been successful attempts of employing sonic anemometers for stratospheric measurements and they both returned science quality data, as testified by the statistical analyses presented in the aforementioned manuscripts, including the computation of kinetic energy spectra (see Maruca et al. 2017).

Indeed, what is relevant for these type of the experiments is not the peak altitude at which a sonic anemometer returned some sort of signal, but the fact that ultrasonic probes have been able to produce reliable measurements in the stratosphere - meaning above the tropopause - and that these measurements could be used to perform rigorous scientific investigations. These goals have not been achieved by the experiment presented here, since the signals reported in the plots included in the manuscript clearly show that the probe needs further development and testing, and no analysis of the data *collected has been performed.*

On the sidebar, I would like to point out that the tropopause does not have the same altitude everywhere over the globe and it is lower at the poles, where the ultrasonic probe by Maruca et al. 2017 was operated. Thus the maximum operational altitude of 19 km reported in Maruca et al. 2017 is probably deeper in the stratosphere than the altitude of 20 km over the Da chaidan district (as reported in the present manuscript).

Even the evidence that the probe presented here has been tested during a level flight is rather weak, since Fig.7 shows a time series of only 300 seconds during which the altitude of the balloon was more or less constant. This time interval is really too short. However, following the narrative of the manuscript, this point should differentiate significantly the present work from Banfield et al. 2016 and Maruca et al. 2017, where ultrasonic anemometers operated only during the ascent phase of the the respective balloon flights.

For these reasons I cannot suggest the publication of this manuscript on AMT. Though, I strongly encourage the authors to pursue with the development of their acoustic anemometer and to re-propose this work corroborated by the analysis of the data collected, once its design will allow to perform science valuable measurements in the stratosphere.

Answers to the Reviewer 2's comments:

Thank you very much for your time and efforts reviewing this study. The answers that we have made based on the reviewer's comments are discussed below "point-by-point". Please kindly find the following responses (the comments are shown in italics and blue while answers in non-italics and red).

Q1:

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Thank you for your comment. Banfield et al. 2016 and Maruca et al. 2017 did a good job in developing and testing sonic anemometers on high altitude balloons. The focus of our work is, based on drawing experiences from their work, to take further improvements to the acoustic anemometer according to the atmospheric environment at the float flight altitude (~25km) of the balloon we used. Our anemometer had been tested in the experiment and obtained measurements during float flight. These are the major contribution of our work. A preliminary analysis of the data was also added according to your suggestions (please see answers to Q2).

In the TILDAE experiment by Maruca et al. 2017, the modified sonic anemometer can operate up to around 19km, above that altitude only fill values were returned due to "Almost assuredly, this was the result of the decrease in atmospheric pressure during the ascent". As to the balloon test by Banfield et al. 2016, they didn't show the wind measurements obtained from the sonic anemometer.

Above all, we had drawn the conclusion "This is the first time that in-situ wind measurements were obtained during level flight at this altitude".

We have added the following discussion on what efforts we had taken to accommodate our acoustic anemometer to the high-altitude atmosphere in our revised manuscript.

In our experiment, the high-altitude balloon were drifting at the altitude of about 25km, where the atmosphere had significant difference from terrestrial environment: low pressure of about 30hPa and low temperature with extremes approaching ~-70℃ during the balloon's ascent. In order to make sure our anemometer can operate at such an altitude, the characteristics of acoustic signals propagation attenuation in the atmosphere had been analyzed.

According to *Bass et al., 1990,* Bass et al., 1995 and *Sutherland and Bass, 2004*, when the sound wave propagates in the atmosphere, the signal attenuation caused by atmospheric absorption is mainly related to the acoustic frequency and atmospheric pressure, attenuation coefficients α in dB per meters (dB/m) can be expressed as follows:

$$\alpha = 8.686f^2\{1.84\times10^{-11}\left(\frac{p}{p_0}\right)^{-1}\left(\frac{T}{T_0}\right)^{1/2} + \left(\frac{T}{T_0}\right)^{-5/2}\times\left[0.01278\frac{e^{-2239.1/T}}{f_{r,o}+f^2/f_{r,o}}+0.1068\frac{e^{-3352/T}}{f_{r,N}+f^2/f_{r,N}}\right]\}$$

Where f is the acoustic frequency in Hz, p is the atmospheric pressure in Pa, p_0 is the reference atmospheric pressure in Pa, T is the atmospheric temperature in K, $T_0 = 293.15K$, is the reference atmospheric temperature, $f_{r,o}$, $f_{r,N}$ are the relaxation frequency of molecular oxygen and the relaxation frequency of molecular nitrogen, respectively:

$$f_{r,o} = \frac{p}{p_0}\left(24+4.04\times10^4 h\frac{0.02+h}{0.391+h}\right),$$

$$f_{r,N} = \frac{p}{p_0}\left(\frac{T_0}{T}\right)^{1/2}\left(9 + 280h\, exp\{-4.17\left[\frac{T_0}{T}^{1/3} - 1\right]\}\right),$$

Where h is the molar concentration of water vapor in percent.

According to the above formulas, figure 1 shows the variation of different frequencies of acoustic signals attenuation caused by atmospheric absorption with height at a distance of 0.2m from the acoustic source.

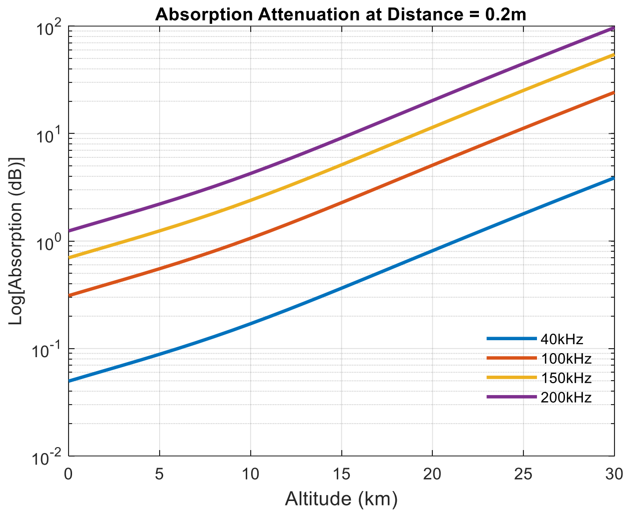

Figure 1 Atmospheric absorption attenuation of different frequencies of acoustic signals.

The atmospheric absorption attenuation of acoustic signal increases with the increase of acoustic frequency and with the decrease of atmospheric pressure that goes down exponentially with height. At the balloon level flight altitude of about 25km, the received signal intensity with acoustic frequency of 40kHz is at least 10dB higher than that of signals with frequencies of above 100kHz. Therefore, in our acoustic anemometer, the sensors with resonant frequency of 40kHz had been used to achieve higher Signal-to-Noise Ratio (SNR), which is the primary difference between the anemometer that we developed and the anemometers used by Banfield et al. 2016 and Maruca et al. 2017. Besides, an Automatic Gain Control (AGC) circuit is also used, different from terrestrial anemometers, to adjust its gain levels with altitude range to obtain better SNR.

In addition, to avoid the flow distortion from the gondola, the sensor bracket was not mounted outside of the gondola directly, but was through a boom with a length of 1.8m and an elevation angle of 45°. According to Lenoir et al., 2011, the perturbation from the gondola has little influence on the measurements.

Q2:

Indeed, what is relevant for these type of the experiments is not the peak altitude at which a sonic anemometer returned some sort of signal, but the fact that ultrasonic probes have been able to produce reliable measurements in the stratosphere - meaning above the tropopause - and that these measurements could be used to perform rigorous scientific investigations. These goals have not been achieved by the experiment presented here, since the signals reported in the plots included in the manuscript clearly show that the probe needs further development and testing, and no analysis of the data collected has been performed.

Thank you for your comment. We added a preliminary analysis of the data in the revised manuscript as follows.

The internal data sampling rate of the acoustic anemometer we developed is 10Hz. In order to improve the signal-to-noise ratio, the original sampled signal within 1s are accumulated, thus the data update rate we given in the manuscript is 1Hz (as shown in Fig. 7 and Fig. 8 in the manuscript). Here, we show the measurements above an altitude of 21km with update rates of 10Hz and 1Hz, respectively.

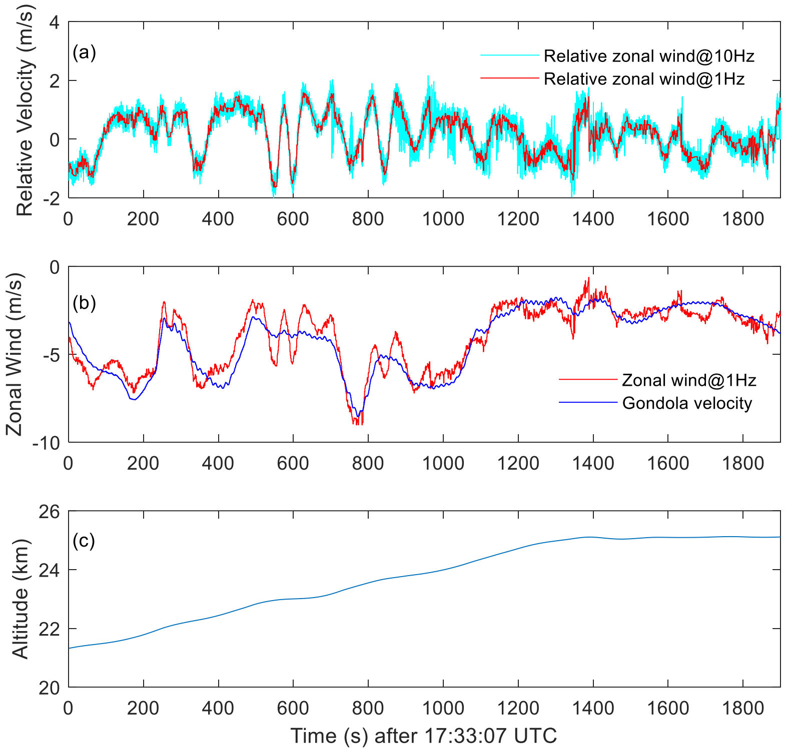

Figure 2 For a 1900-s period starting at 17:33:07 UTC: (a) relative zonal wind speed measured by the anemometer at update rates of 10Hz (cyan) and 1Hz (red), respectively, (b) comparison between zonal wind speed (red) and gondola zonal movement speed (blue), and (c) gondola altitude.

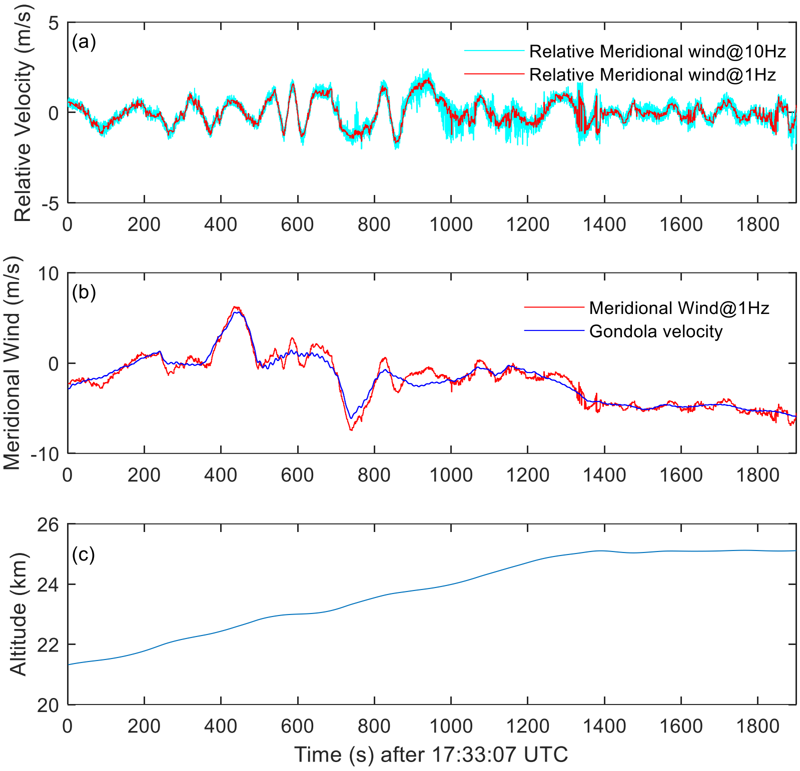

Figure 3 As in Fig.2, but for the meridional wind.

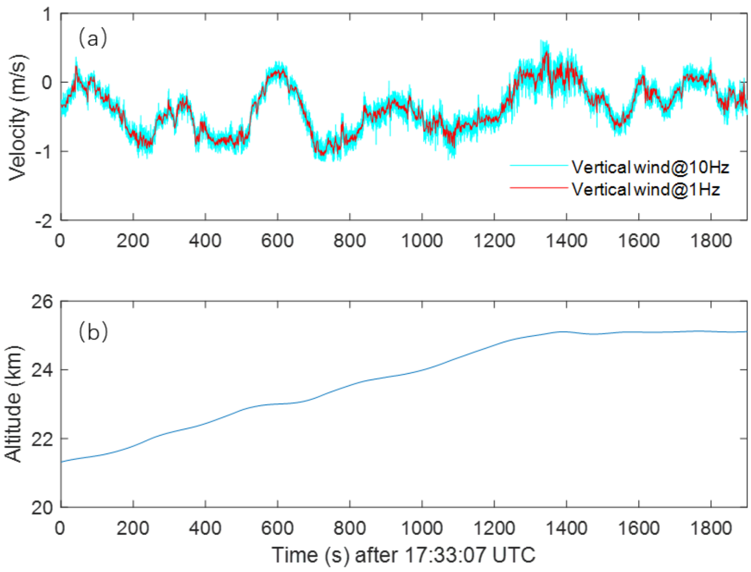

Figure 4 (a) vertical wind speed measured by the anemometer at update rates of 10Hz (cyan) and 1Hz (red), respectively, and (b) gondola altitude.

The power spectral density of the 10Hz measurements during the float flight period (from 1500s to 1900s) is evaluated using periodogram method (as shown in figure 5).

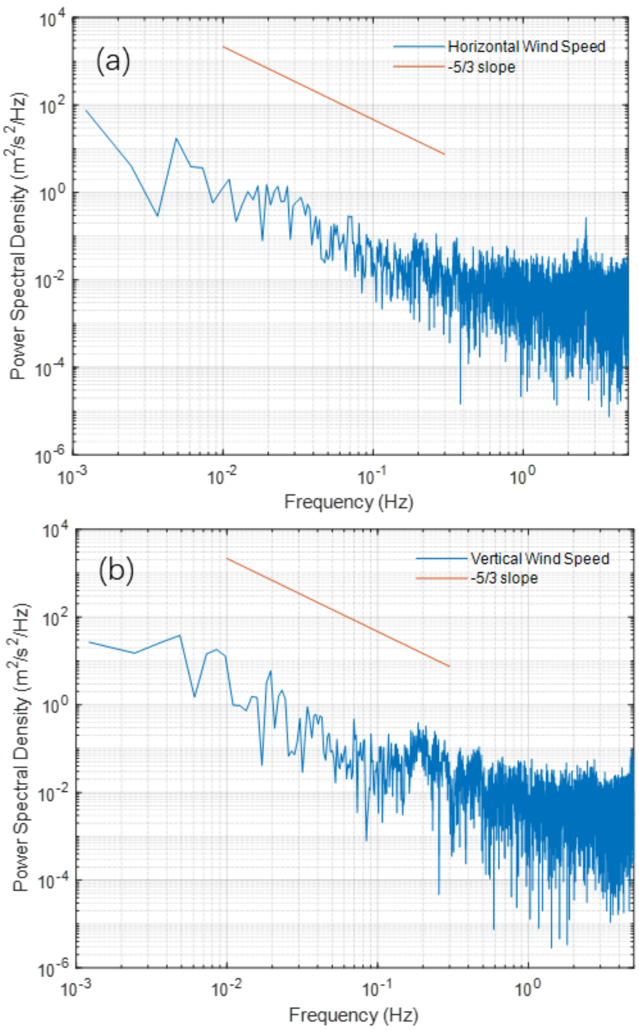

Figure 5 Spectral analysis of the 10Hz measurements during the float flight period (from 1500s to 1900s): (a) relative horizonal wind speed, and (b) vertical speed. The red line in each case indicates the theoretical spectral trend of -5/3.

According to Kolmogoroff's theory (Kolmogorov, 1941), turbulence spectra can be well accepted to have specific gradient characteristics: a -5/3 slope in the inertial sub-range. From the measured spectral shown in figure 3, a clear -5/3 slope decay at frequencies from 0.02 to 0.3Hz indicates that there were turbulence exist at the float flight altitude.

Q3:

On the sidebar, I would like to point out that the tropopause does not have the same altitude everywhere over the globe and it is lower at the poles, where the ultrasonic probe by Maruca et al. 2017 was operated. Thus the maximum operational altitude of 19 km reported in Maruca et al. 2017 is probably deeper in the stratosphere than the altitude of 20 km over the Da chaidan district (as reported in the present manuscript).

Thank you for your comment. The height of tropopause at the poles is lower than that in the middle latitude indeed. According to the above analysis (see answers to Q1), the attenuation of acoustic signal is mainly related to atmospheric pressure, which decreases exponentially with height. We have compared pressure data obtained from the radiosonde, launched by the Antarctic Meteorological Research Center (AMRC) on the same day as the experiment by Maruca et al. 2017 at 12:00 UTC, with that measured by our instrument (as shown in the figure below). The atmospheric pressure over Antarctica is slightly lower than that over Da chaidan district at the same altitude. At the maximum operational altitude of 19km over Antarctica reported in Maruca et al. 2017, the pressure is about 61.52 hPa, while the corresponding altitude over Da chaidan district is about 19.73 km at the same pressure. This may be the maximum operational altitude of the sonic anemometer by Maruca et al. 2017 over Da chaidan district, since the atmospheric pressure is the main cause of acoustic signal attenuation. In our experiment, the float altitude of the drifting balloon we used is about 25km, the pressure is about 30hPa, which is much lower than the altitude of 19.73km. Therefore, It is a technically demanding that the acoustic anemometer should work at this flight height. And we had taken measures (see answers to Q1) to ensure that the anemometer can operate at such a low-pressure environment. We think these are the major contribution of our work.

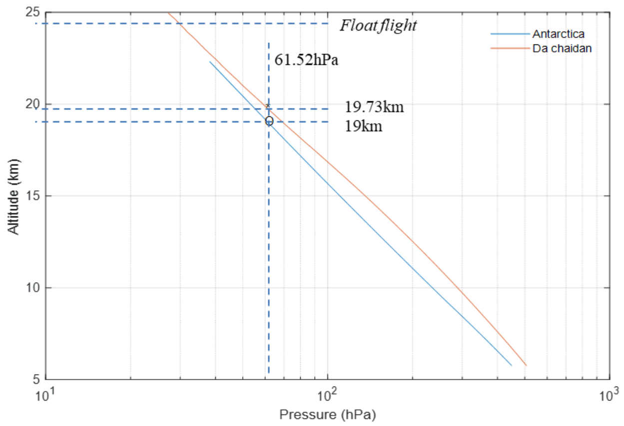

Figure 6 Pressure comparison: the blue line represents data obtained from the radiosonde launched by the Antarctic Meteorological Research Center (AMRC) on the same day as the experiment by Maruca et al. 2017 at 12:00 UTC, while the red line is the measurements from our instrument.

Q4:

Even the evidence that the probe presented here has been tested during a level flight is rather weak, since Fig.7 shows a time series of only 300 seconds during which the altitude of the balloon was more or less constant. This time interval is really too short. However, following the narrative of the manuscript, this point should differentiate significantly the present work from Banfield et al. 2016 and Maruca et al. 2017, where ultrasonic anemometers operated only during the ascent phase of the the respective balloon flights.

Thank you for your comment. We showed more our measurement data and presented a preliminary analysis of the data, please see our answers to Q2.

Q5:

For these reasons I cannot suggest the publication of this manuscript on AMT. Though, I strongly encourage the authors to pursue with the development of their acoustic anemometer and to re-propose this work corroborated by the analysis of the data collected, once its design will allow to perform science valuable measurements in the stratosphere.

Thank you for your comment and suggestions. We added a preliminary analysis of the data collected, please see our answers to Q2.

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