Response to Anonymous Referee #2

Thank you very much for your comments on the manuscript. Please find our responses to your comments below highlighted in red.

Anonymous Referee #2

General Comments

The manuscript details water vapor measurements made with a Spatial Heterodyne Spectrometer (SHS) from an ER-2 high altitude aircraft and compares retrieved water vapor densities with coincident radiosonde measurements. My overall impression of the manuscript is quite positive. It provides sufficient context and the detailed descriptions provided make it quite easy to follow. The agreement between the SHOW and the radiosonde water vapor densities is remarkable, particularly given the complexity of the L0 to L1 processing required in the analysis of the SHOW data. Given the quality of the manuscript, my specific and minor comments below are to be considered as advisory to the authors and not requiring another detailed review.

Specific Comments

The manuscript details a series of steps required to remove instrumental effects from the level-0 data. The most complex of these stems from the combination of aliasing due to the passband of the interference filter spanning the Littrow wavenumber and a vertical fringe frequency tilt of the interferometer. The result is a row-dependent spectral modulation seen near left edges of Figures 7c and 7d and require that a detailed instrument model be in integral part of the retrieval. Although it's implicit in the discussion, I think it is important to point out that the difficulties and uncertainties associated with correcting for this effect could be eliminated by using a filter with passband shifted slightly to the red that blocks all light at wavelengths on the opposite side of Littrow. To simplify the analysis is there a plan to replace the interference filter for future flights of the instrument?

You are correct. This effect can be eliminated by changing the filter. Indeed, after the first ER-2 demonstration flights we obtained the financial resources to procure a new filter that is shifted so the Littrow wavelength sits at the edge of the filter passband. This ensures that there is negligible aliasing from the opposite side of Littrow. The filter was procured and installed in the Spring of 2018. The new configuration has been characterized in the lab and shows no signs of the aliasing effect. Several lines of text have been added to Section 5 of the manuscript to explicitly point out that this effect is entirely avoidable by design.

There are numerous places in the processing where a fitted high-order polynomial is subtracted from the data in an effort to assess the noise from the residual. It would be helpful to indicate the order of the polynomial used. Clearly with a very high order polynomial fit, some of the noise will be fit and the noise in the residual will be underestimated while fitting with a polynomial of too low an order will result in signal in the residual. How was the decision as to the order of polynomial used made?

In most cases, the high order polynomial was of order 8. However, we did not do a detailed analysis of the impact of lower or higher orders. For most of the cases, we are just using this approach to obtain a first order approximation of the noise in the measurements to check that photon-noise is the primary measurement noise on an individual interferogram sample. The text has been edited to explicitly state the order of polynomial that was used.

Although not ultimately used in the analysis due to optical depth issues I found the description of the cloud artifacts evident in the lowest rows of Figure 12a and 12b somewhat lacking. If the entrance optics are anamorphic and aligned properly, they should completely defocus spatial information in the horizontal direction. Why then does the modulation in rows 0 to ~30 in Figure 12a tilted? Could this possibly be a fringe due to a spectral line very close to the Littrow wavenumber?

Thanks for pointing this out. After a second look at the images, it turns out that the primary effect is likely due to removal of the DC bias in the presence of nearly saturated pixels at the interferogram center burst. It is known that saturated pixels causes the pixels in the corresponding row to have non-ideal behavior. The manuscript has been edited to note that the cause of this effect is not completely clear; however, it is believed that the culprit is likely saturated pixels at the interferogram center burst combined with the DC bias removal. In any case, we do not use these rows in the retrieval and the effect does not appear in the rows above the cloud feature where the retrieval is performed.

It appears that amplitude spectra where used throughout in the analyses. If proper phase correction is performed the spectral information can be isolated to the real part of the Fourier Transform only thereby reducing the shot noise contribution from the imaginary part and reducing the shot noise contribution by roughly the square root of two. That said, I suspect that the dominant source of uncertainty is not shot noise so perhaps this improvement is not worth the substantial effort required.

Unfortunately, we could not perform a proper phase correction on the SHOW measurements due to the presence of aliasing in the system. We also did not have access to a tunable laser that could be used to perform this characterization. Such a characterization will be performed prior to the next SHOW measurement campaign using the new filter.

Connected to the previous comment, the error bars shown for the SHOW measurement in Figure 19 appear to be quite small. Do these error bars include the systematic effects associated with uncertainties in the retrieval or are they simply an indication of the photon shot noise component of the noise? It would most illuminating, if the systematic uncertainties could be quantified. In general, I would suggest making a clearer distinction between statistical sources of noise (photo, dark, CCD read noise, etc.) and systematic sources of uncertainty (errors in the uniformity correction, uncertainties in the retrieval parameters, etc.). In various places in the manuscript all of these effects are referred to as "noise".

The error bars shown in this figure only include measurement noise. The error bars do not include systematic effects associated with uncertainties in the retrieval. In our sensitivity study (Langille et al (2018)) we examined some the sensitivities of the retrieval assuming an ideal instrument configuration. In the current work, the primary source of uncertainty is our ability to accurately capture the systematics associated with aliasing. We have made edits to the manuscript to make a clearer distinction between the various sources of noise.

To understand the instrument, it would be helpful to add a short section and perhaps a figure describing the anamorphic optics that feed the interferometer and the optics between the interferometer and the detector.

The anamporphic optics and imaging configuration are discussed in detail in the design paper (Langille et al., 2017).

Technical Corrections

Section 5 second paragraph, second sentence: Missing "to"

Corrected in the manuscript
Section 6 third paragraph: N in the SNR equations should be defined

Corrected in the manuscript

Equation 4: Define Ij and σj.

Corrected in the manuscript

Section 7, second sentence: Figure 3 reference should be Figure 2

Corrected in the manuscript

Section 9.4, end of first paragraph: LightMachinery should be more completely referenced (e.g. LightMachinery, Inc., Ottawa, Ont).

Corrected in the manuscript

Figure 9a: The black background makes it very difficult to read

Unfortunately, this is the only version of the flight path that was made available by AFRC.