Investigating potential wet bias in the Purple Crow Lidar water vapor measurements

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ABSTRACT

The Purple Crow Lidar is a large aperture lidar, capable of retrieving water vapor into the stratosphere. A comparison with the ALVICE lidar in 2012 showed water vapor measurements were consistently larger than those of ALVICE in the lower stratosphere, prompting an investigation of the system. Processing approaches and additional instrumental corrections are considered.

1 INTRODUCTION

Water vapor plays a fundamental role in Earth's radiative budget, as well as in atmospheric chemistry and circulation. Its role is paramount in the coupling of the Upper Troposphere and Lower Stratosphere (UTLS), where small changes in water content can have a great effect on global-scale processes.

Located near London, Canada, the Purple Crow Lidar (PCL) measures atmospheric temperatures and water vapor using a frequency doubled Nd:YAG laser at 532 nm in 1000 mJ pulses at a 30 Hz repetition rate. Water vapor content is calculated using Raman backscatter returns from molecular nitrogen (at 607 nm) and water vapor (at 660 nm). Nitrogen counts are detected with a Licel transient recorder which is capable of analog and photon counting (PC) detection modes, while water vapor uses a Stanford Research Systems multi-channel scaler/averager and only uses photon counting. The incorporation of a liquid Mercury mirror allows for a large aperture telescope (2.65 m diameter),

which can detect water vapor into the lower stratosphere.

A validation campaign with the ALVICE lidar was carried out in 2012, showing a relative wet bias in PCL's water vapor measurements in the lower stratosphere [1]. This investigation intends to determine if the wet bias is due to environmental, instrumental, or algorithmic issues.

Water vapor measurements from lidar are calculated via the volume mixing ratio, which can be written as [2]:

$$w_v = \frac{M_W}{M_{air}} \frac{n_N}{n_{air}} \frac{\sigma_N}{\sigma_W} \frac{\xi_N}{\xi_W} \frac{\Gamma_N}{\Gamma_W} \frac{N_W}{N_N} \qquad (1)$$

where M is molecular weight, n is number density, σ is the backscatter cross section, ξ is instrument efficiency, Γ is the atmospheric transmission function, and N are the processed counts. The subscripts N and W indicate quantities related to the molecular nitrogen and water vapor channels respectively. Calculation of the processed counts includes applying a dead time correction to the PC counts [3], subtracting the background, and then merging with the analog counts [4].

2 METHODOLOGY

In this section, we discuss additional corrections considered in the calculation of processed counts and the water vapor mixing ratio.

2.1 Altitude offset

Differences between the analog and PC data acquisition cause an altitude offset in the raw count data. The offset is determined by sending a function generator pulse through the detectors and shifting the analog and PC count arrays so that the pulses line up. This test was carried out by summer research student Sean Hartery, finding a 68.1 m nitrogen channel offset.

2.1.1 Warm up correction

Identified in [5], the Licel transient recorder underestimates count rates until the system has warmed up. For the PCL nitrogen channel, this warm up time is about 40 minutes (Figure 1). If data acquisition has begun before the unit has warmed up, a correction can be applied.
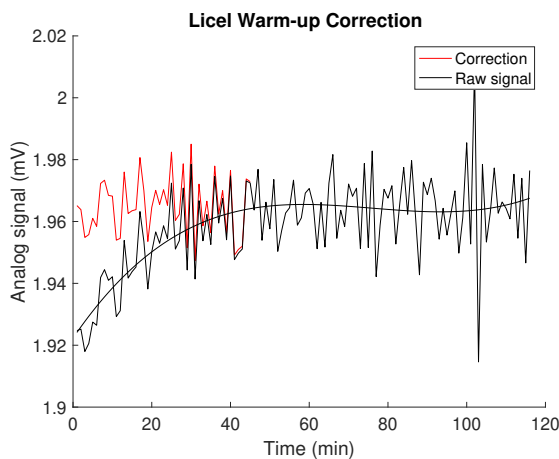

Figure 1: Warm up correction for the nitrogen analog counts.

2.2 Temperature dependence correction

The Raman cross section spectrum varies with temperatures found at different altitudes, resulting in signal loss if narrowband filters are used. The correction factor is calculated using an approach similar to the method discussed in [7], which requires knowledge of the temperature-dependent Raman cross sections and interference filters for nitrogen and water vapor returns (Figure 2).
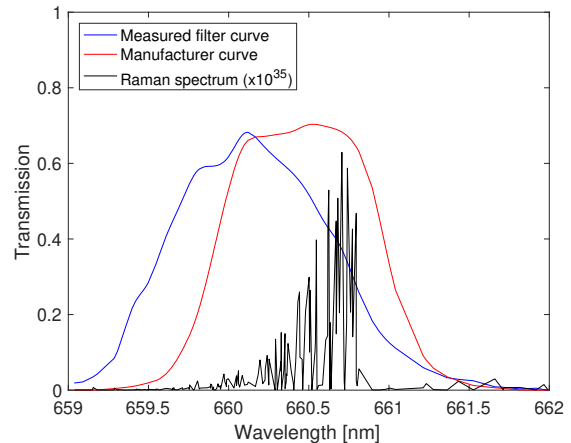

Figure 2: Interference filter for the water vapor channel and the water vapor Raman cross section at $20°C$. Note how the measured filter transmission varies from the manufacturer's specifications.

3 RESULTS

Figure 3 shows how the additional corrections mentioned in the Methodology section affect the overall water vapor mixing ratio. The 'warm up' correction has little overall effect, increasing the mixing ratio by only 0.03% when applied. The altitude offset correction is dominant in the lowermost region of the retrieval, where the analog counts are important, but is not a major consideration in the PC-dominated UTLS region. The temperature dependence correction has the largest contribution to the mixing ratio in the UTLS region, increasing the value by 10.9% at 14 km.

4 CONCLUSIONS

Although the corrections discussed here do affect the retrieval to varying degrees, none account for the lower stratospheric wet bias observed during the validation with the ALVICE lidar. A thorough characterization of the back-
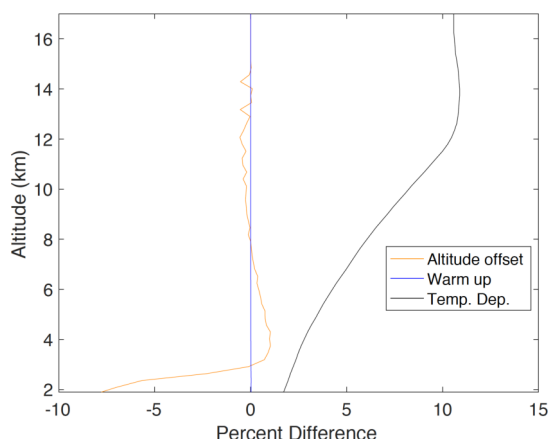
Figure 3: Percent differences between the original and corrected water vapor volume mixing ratio profiles.

ground is still required, as well as consideration of additional parameters, including differential overlap. Instrumental or environmental fluorescence may also contribute the observed wet bias, and should be tested for. However, since PCL operates in the visible region, it is not as susceptible to fluorescence as UV lidars.

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