New Lidar Data Processing Techniques for Improving the Detection Range and Accuracy of Atmospheric Gravity Wave Measurements

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Lidar observations pose one of the most feasible routes to introduce new, meaningful information into studies of atmospheric gravity waves (GW). The high-resolution and wide vertical-coverage that lidar offers cannot be matched using other remote sensing. As GW vertical energy coupling is an actively developing area of study, lidar measurements of gravity waves are necessary in developing these theories and keeping them grounded in observation. Lidar wave measurements of second-order parameters rely on detailed processing techniques to ensure that they represent only the wave energy and that they contain no bias due to noise. While inherent and induced mean-zero noise is typically eliminated when deriving first-order parameters, it induces a bias in second-order parameters like variance (which is used in calculating many parameters corresponding to atmospheric wave energy).

This study presents and compares three existing bias correction techniques as detailed in Jandreau and Chu (2022), establishing the details of their application and determining when each technique should be used. To demonstrate this, the errors and values of each are compared under multiple conditions, varying signal-to-noise (SNR) level and sample size. The three methods compared are the Variance Subtraction technique (Whiteway and Carswell, 1995), the Spectral Proportion technique (Chu et al., 2018), and the Interleaved Method (Gardner and Chu, 2020). The results of this test show that each technique has a set of conditions under which it is best applied, generally trading between accuracy and precision. Variance Subtraction only works when there is a very-high-SNR, regardless of sample size. Spectral proportion works best with a high-SNR, regardless of sample size. Interleaved performs the best when used under either low- or high-SNR as long as it is given a large enough sample size.

To demonstrate these techniques, 10+ years of Rayleigh and Fe metal lidar observations from McMurdo Station, Antarctica are transformed into measurements of GW energy parameters. These average measurements cover the entire year, with summer measurements from 30-50 km and winter measurements from 30-70 km and 80-100 km. By applying these techniques, the positively-biased variance at the top of the observational window is reduced by over an order-of-magnitude in the summer, and up to a factor of 2 in the winter. Without their use, the summer Rayleigh data could not be used to calculate these parameters, and winter Rayleigh data could not reach above 50 km. These monthly average energy measurements alongside shorter-term case studies allow the identification of scientifically meaningful seasonal and vertical trends in GW strength and energy dissipation.