Supporting Information for "Climatology of High-frequency Gravity Waves Observed by an Airglow Imager at Andes Lidar Observatory"

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A sample of image sequences that only contain OH images is shown in Figure S1(a). Two time-differenced (TD) images ($TD_1 = I_2 - I_1$, $TD_2 = I_3 - I_2$) are obtained from three continuous OH images (I_1, I_2, I_3). In this case, a gravity wave detected from TD_1 and TD_2 is considered to have lasted the duration of three images, i.e., 3 min. From 25 Aug 2011, the imager captured OH and OI airglow images alternately with 1-min and 1.5-min integration times, respectively. The sample of image sequences of this configuration is shown in Figure S1(b). There is one OI image between two closest OH images. In this case, a gravity wave should last at least 6 min to be detected in this set of three OH

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images. Because of this difference, the number of identified gravity waves at different observation configurations are not comparable.

The TD method was implemented by taking the difference of two consecutive images. This method is equivalent to a high-pass filter and emphasizes the high-frequency gravity waves in latter wave extraction. The magnitudes of frequency response of TD method can be described by the following equation:

$$G(w) = \left|1 - e^{i\omega}\right|, \tag{1}$$

of which ω is the angular frequency from 0 to 2π, corresponding to the linear frequency from 0 to $1/\Delta t$. Δt is the interval between two consecutive OH images, which could be 1 min or 2.5 min as shown in Figures S1(a) and S1(b). In Figure S2, the frequency response shows that the TD method augments the amplitude of waves with relatively short periods and dramatically suppresses the amplitude of waves with long and extremely short periods, which may make them less likely to be detected. When Δt=1 min, the period range of strengthened amplitudes is narrow and near the periods of 2–7 min. When Δt= 2.5 min, this period range is boarder and extends to 15 min. Firstly, the TD method itself may distort the probability distribution of gravity wave parameters. Secondly, the differences of interval may also cause some discrepancies in the statistical results.

The discussions above about the frequency response of TD method do not consider the gravity wave intrinsic amplitudes frequency spectrum. Theoretical (Gardner & Liu, 2014) and observational (Guo et al., 2017) studies have shown that the power frequency spectrum is approximately proportional to $\hat{\omega}^{-p}$ for gravity waves of the period range of 5 min to 6 hr, where p is typically around 2. Gravity waves with longer period tend to be associated with larger amplitudes. The apparent wave amplitudes after applying

TD method are calculated by multiplying the gravity wave frequency spectrum estimated from lidar measurements (Guo et al., 2017) by the frequency response of TD method. As shown in Figure S3, the apparent wave amplitudes increase with period and reach a constant level above certain period. From the perspective of wave detection, the TD method attenuates the amplitude of gravity waves of longer period, thus make them less likely to overwhelm the gravity waves of shorter periods. The estimation above provides some insights into the potential influences of TD method on extracted wave information. The effects of TD method depend on the integration time of images and should be used with caution. When results from different sites or configurations are compared, this factor should be taken into account. In this study, we choose to skip one OH image in the processing procedures for the period that only OH images were captured. In Figures S2 and S3, the frequency responses of the TD method and apparent wave amplitude for 2-min and 2.5-min intervals show less differences. In this study, a large mount of waves are identified in both configurations. The retrieved wave characters are nearly identical between the two configurations, thus they are combined and discussed together.

References

Gardner, C. S., & Liu, A. Z. (2014). Measuring eddy heat, constituent, and momentum fluxes with high-resolution Na and Fe Doppler lidars. *Journal of Geophysical Research: Atmospheres*, *119*(17), 10583–10603. Retrieved from `http://dx.doi.org/10.1002/2013JD021074` doi: 10.1002/2013JD021074

Guo, Y., Liu, A. Z., & Gardner, C. S. (2017). First Na lidar measurements of turbulence heat flux, thermal diffusivity, and energy dissipation rate in the mesopause region. *Geophysical Research Letters*, *44*(11), 5782–5790. (2017GL073807) doi: 10.1002/

61 2017GL073807

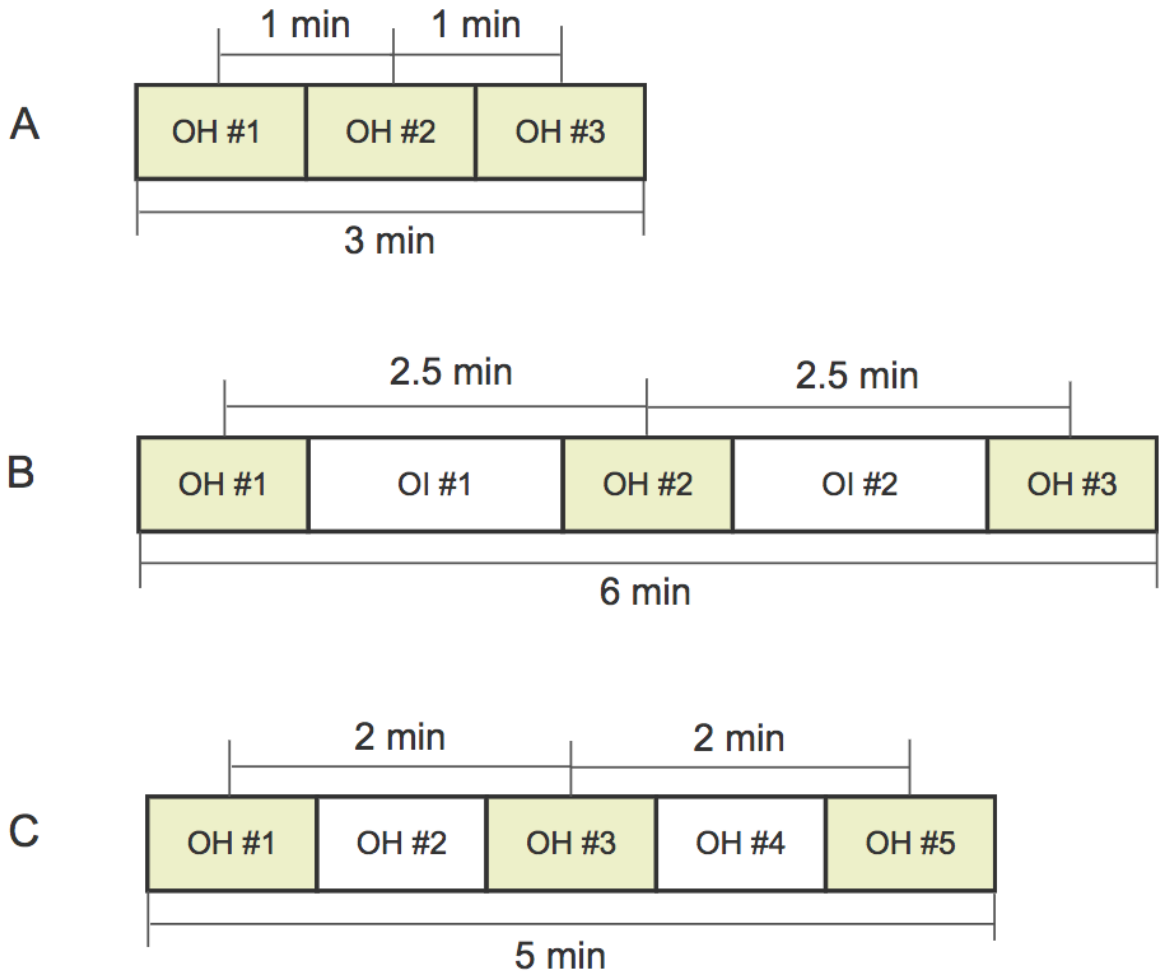

Figure S1. Temporal sequences of OH and OI airglow images. Each block represents a OH or OI image. The width of OI images is wider showing the integration time for OI airglow images is 1.5 min while 1 min for OH airlow images. The shadowed OH images are a set of three images selected for TD method.

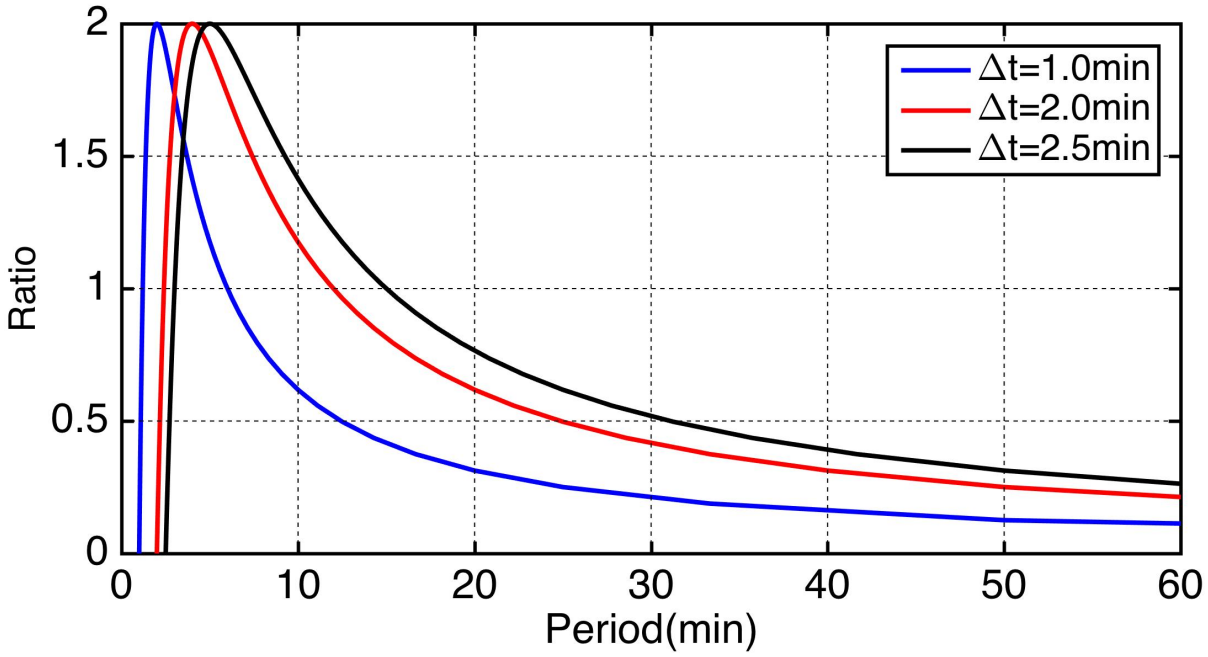

Figure S2. Frequency response of the TD method for different minimum interval of OH airglow images.

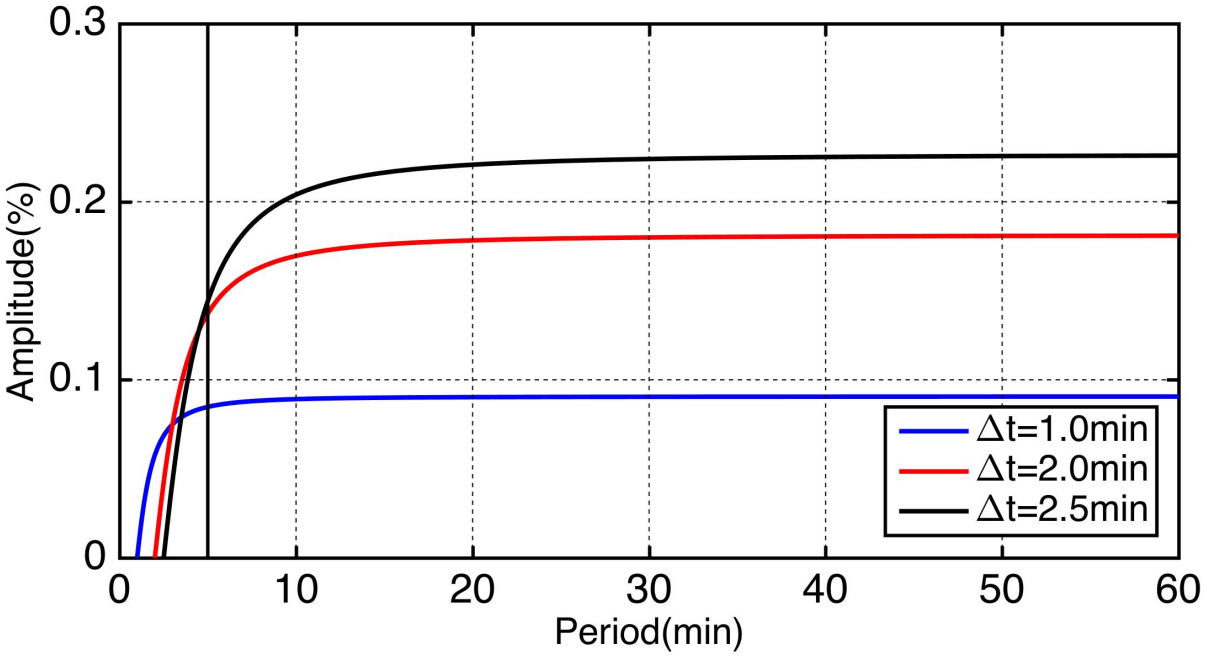

Figure S3. Relative wave amplitude of applying TD method on the gravity waves with a theoretical spectrum of $\hat{\omega}^{-2}$.