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Horizontal phase speed distribution of gravity waves observed in mesospheric temperature maps

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ABSTRACT

The goal of the current work is to develop a method suitable for analyzing the horizontal phase speeds of atmospheric gravity waves from an extensive amount of gravity wave data obtained by the USU Advanced Mesospheric Temperature Mapper (AMTM) from Logan, Utah and South Pole, Antarctica. AMTM is a novel infrared digital imaging system that measures selected emission lines in the mesospheric OH (3,1) band to create intensity and temperature maps of the mesosphere. This analysis builds on the recent work by Matsuda et al., (2014) using all-sky (180° field-of-view) intensity data to investigate the gravity waves horizontal phase speed distribution. In our analyses we applied this technique to process spectra from temperature maps using instruments located on USU campus in Logan UT and at the South Pole Station. Their field-of-view is 120°. The ground-based remote sensing temperature measurements have been obtained using the nighttime hydroxyl (OH) emission, which originates at an altitude of ~87 km. The results are compared to intensity data and later to conventional event analysis in which the phase fronts are traced manually.

Advanced Mesospheric Temperature Mapper

- The Advanced Mesospheric Temperature Mapper is a ground-based infrared imaging system that measures selected emission lines in the mesospheric Hydroxyl (OH) in order to create **intensity** and **temperature** maps at ~87 km. It provides high spectral sensitivity over a large 120° field of view which covers ~ 160×128 km^2 area of the mesosphere (Figure 1).

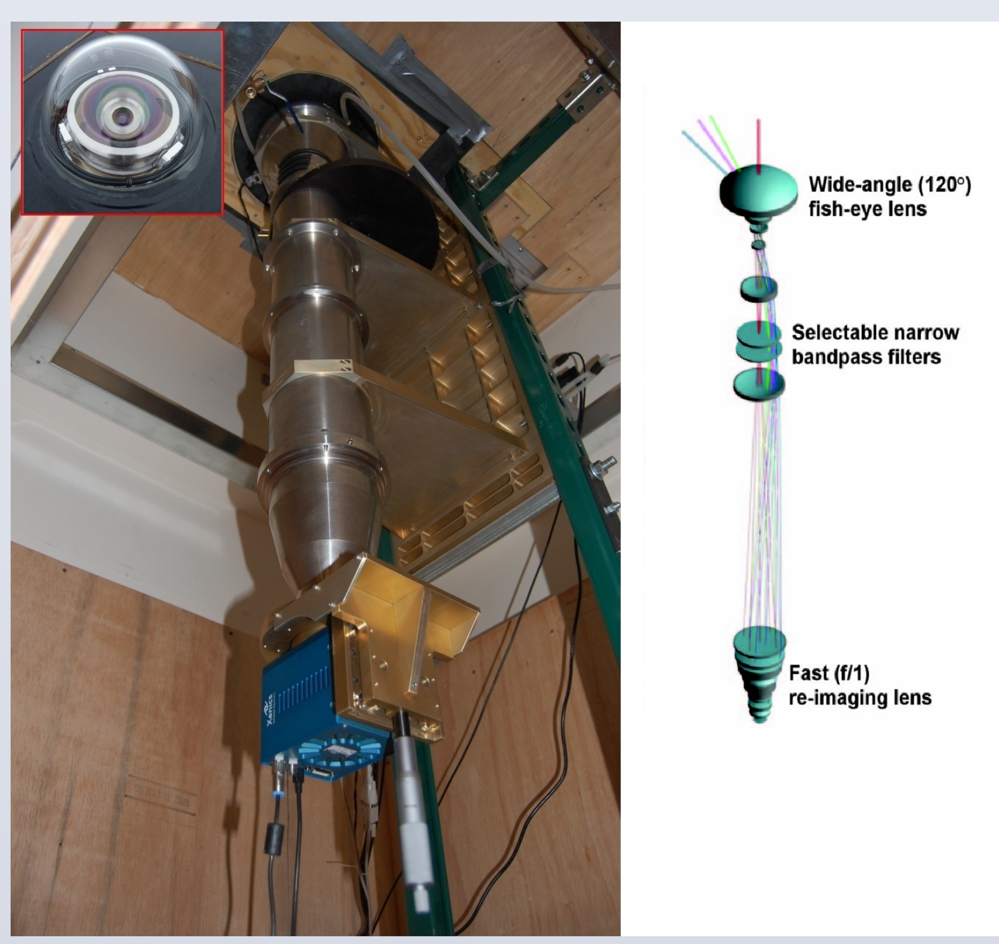

Figure 1. (Left) AMTM camera operated in Logan observatory (41.8° N) and Amundsen-Scott South Pole Station (90° S). (Right) Solid sketch design of AMTM system and ray paths for different angle of view.

- The wavelike structures in this emission are well-known from previous observations and theory to be caused by the passage of atmospheric gravity waves through the emitting layers. Gravity waves can significantly modify the emission profile of the OH bands. Therefore, we can horizontally monitor and measure the gravity waves in the upper atmosphere using AMTM image data.
- The horizontal wave parameters like wavelength, phase speed, period and propagation direction are measured directly with standard 3-D Fast Fourier Transform (FFT) analysis of images. The horizontal parameters are normally provided by airglow imagers which usually only measure the brightness of different mesosphere atmosphere emissions (OH, Na, O_2, and OI) corresponding to the mean altitudes of the associated emissive layers (~87, ~90, ~94, and ~96 km, respectively).

Image Pre-Processing

- AMTM provides high spectral sensitivity and high resolution temperature, but the image format is not immediately suitable for standard 2-D spectral analysis technique.

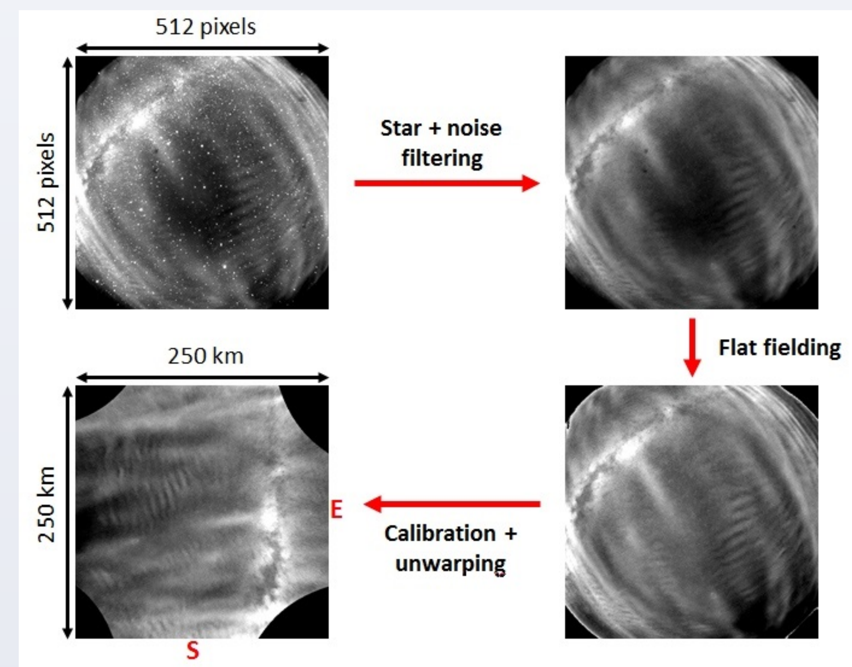

Figure 2. An example all-sky image illustrating pre-processing the raw images before analyzing them.

- To evaluate the images, we first **remove stars** from the each raw image and then the dark counts and offset values. The images are **flat fielded** and normalized to intensity or temperature perturbation ($\partial I/\bar{I}$). Finally they are **calibrated** and **unwarped** to a linear grid to only contain information about the gravity waves (Garcia et al., 1997). The pre-processed series of images are the inputs of our analysis program which calculates the 3-D FFT and provides the waves frequency and wavenumber ($\omega, \vec{k}$).

Gravity Waves Analyses

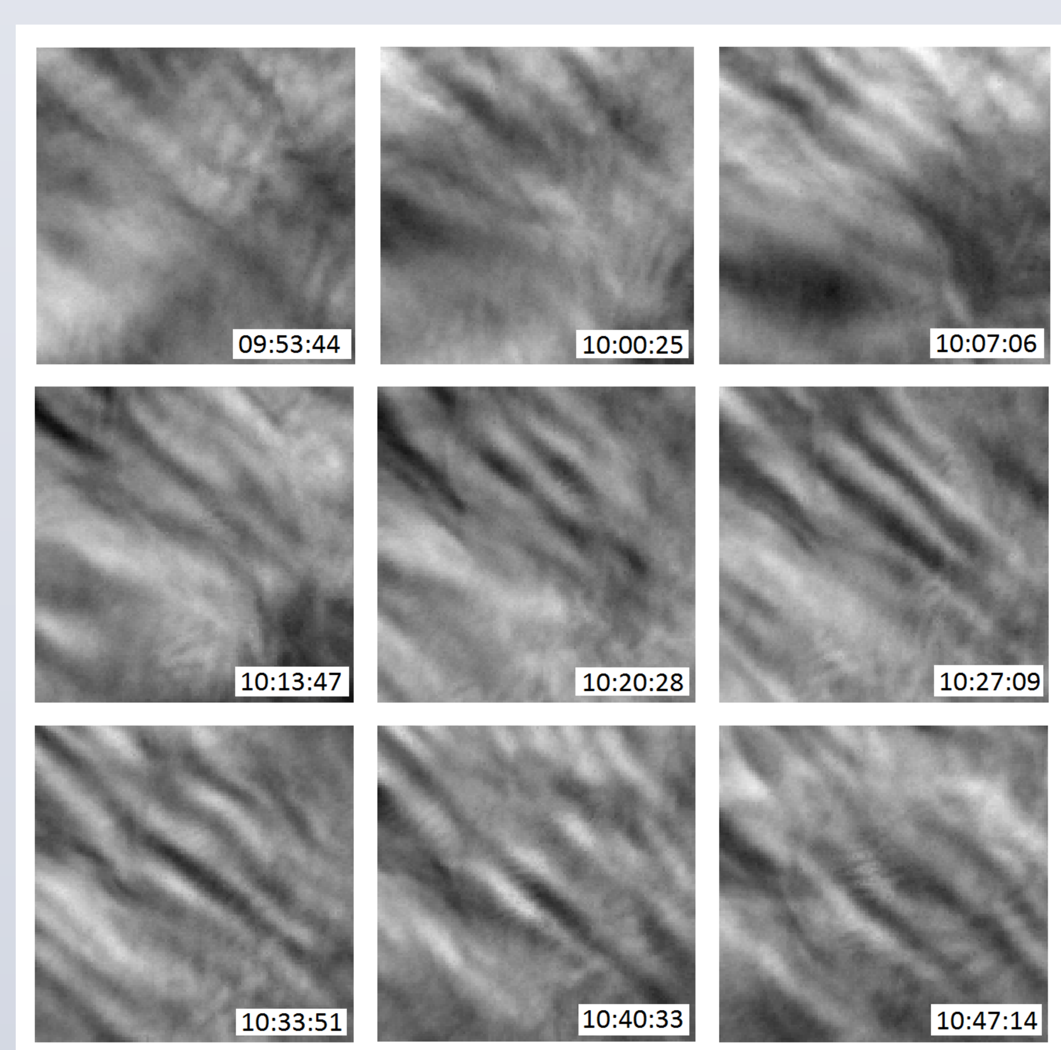

Figure 3. Pre-processed AMTM images at different times on May 31, 2013. Data from Logan, UT.

- Gravity waves are known to be important drivers of mesoscale fluctuations throughout atmosphere (Hines, 1960). They **couple** momentum and energy upward from their source into middle and upper atmosphere without material transport (Fritts and Alexander, 2003). Energy is transported by group velocity $\partial\omega/\partial\bar{k}$ which is perpendicular to $\bar{k}$ and only high frequency, long vertical wavelength components penetrate to the highest altitudes (Mowbray and Rarity, 1967). However, due to wave growth in upper atmosphere, large amplitude waves can break and influence mean circulation (Nappo, 2013). The most important wavelengths involved in this transfer are from 5 and 100 km.

Results

- To investigate the features of gravity waves motions, Matsuda et al. developed a new statistical method using all-sky intensity data to analyze the horizontal parameter of gravity waves for extensive amount of images with a **much broader** range of data-collecting times. In our analyses we applied this technique to process spectra from temperature maps with 120° field of view obtained from Logan, UT and South Pole, Antarctica.
- The only interested range of wavelengths (5-100 km) and periods (8-60 min) are selected and converted to average power spectrum to get horizontal distribution of gravity-waves phase-speed (<150 m/s). The following image shows the horizontal phase speed all over the night on May 30, 2013 for ~ 11 hr.

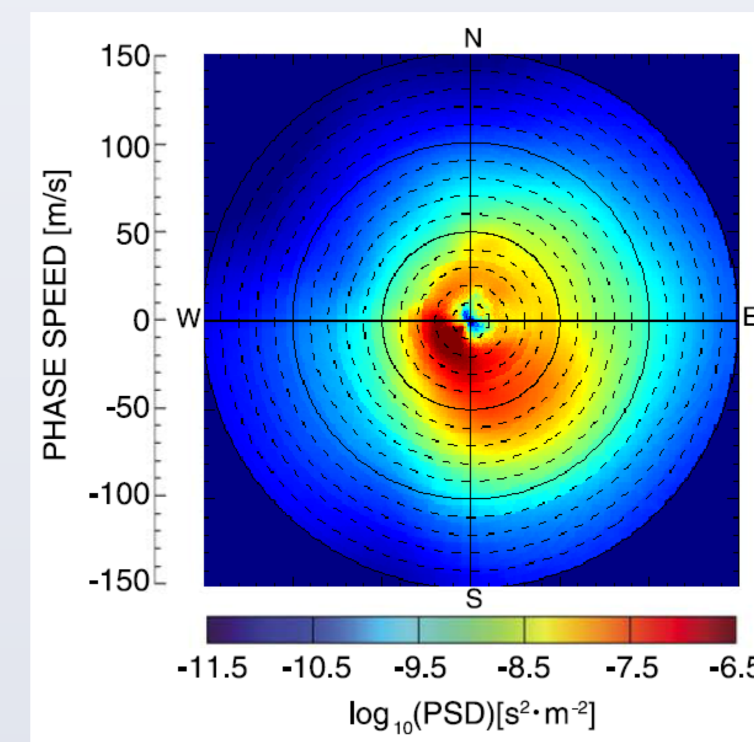

Figure 4. The horizontal phase speed over the whole night on May 31, 2013 from Logan, UT.

- The following figures shows the horizontal phase speed each for 130 pre-processed temperature images (total 1170 images and 1 image captured every 33.5 seconds). It shows that a gravity wave with average speed of ~50 m/s was initially going towards the southeast and disappeared after 11UT, then a perpendicular smaller gravity wave event, with a phase speed of ~25 m/s, propagated towards the southwest. However, later the waves distributed randomly and finally the initial larger waves came back.

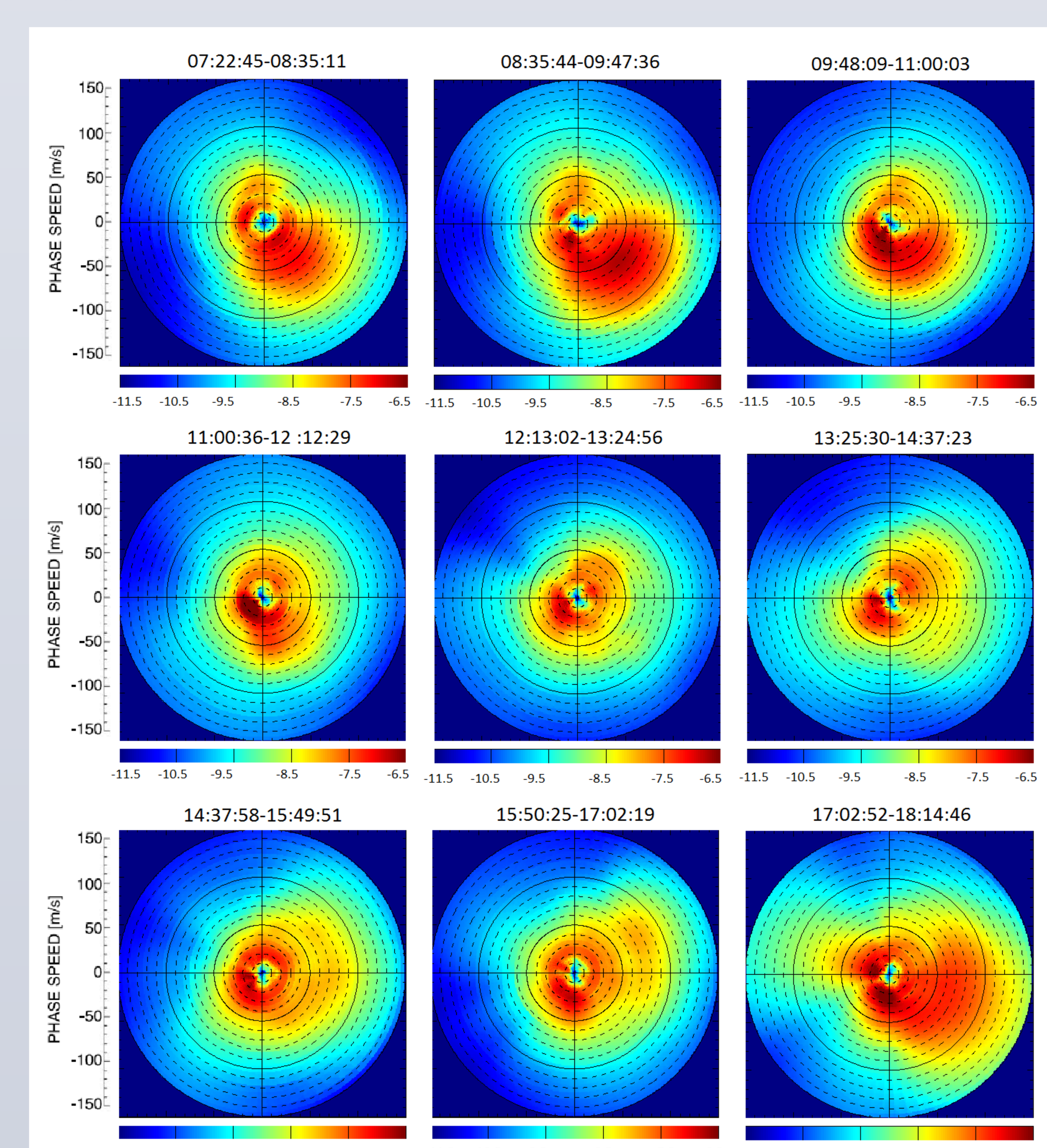

Figure 5. Horizontal phase speed spectrum for different times from 07:22:45-18:14:46 on May 31, 2013 Logan, UT. Each spectrum analyses 130 preprocessed images.

Conclusion and future work

- We have analyzed AMTM temperature data from Logan, UT and South Pole, Antarctica to investigate phase speed distribution of mesospheric gravity waves.
- Applying Matsuda et al. method, we have obtained the spectra corresponding to the gravity waves propagating over Logan, UT. The results were compared to intensity data and later to conventional event analysis in which the phase fronts are traced manually. This task was done when we were developing our IDL program to check the accuracy of the work.
- Example result shows two main directions of propagations during the night of May 31, 2013, due to two small-scale gravity waves (5-100 km) traveling in different directions. Applying this method to big number of temperature maps from different sites can improve our understanding about gravity waves dynamics in middle and upper atmosphere region (global model).
- The limit for the current work is the program runs for clear-sky and aurora-free images. And we have used simple dispersion relation with no background wind given in Nappo, 2012 in order to 3-D FFT spectra to phase speed.
- The future work will be to investigate the seasonal directionality of gravity waves propagation over a mid-latitude site (Logan) and an high-latitude site (South Pole).
- The energy transported by the gravity waves can also be assessed by this method and compared between the different sites/latitudes.

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