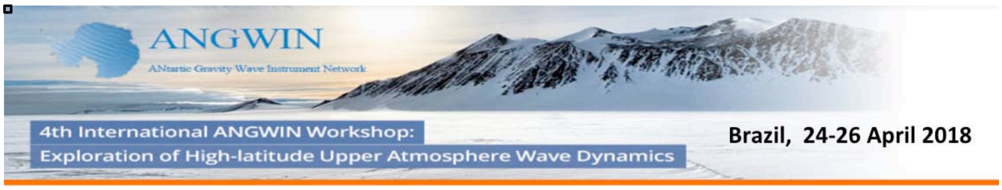

Development of a Phase Velocity Spectral Analysis Software Package (M-Transform) for Airglow Imaging Data

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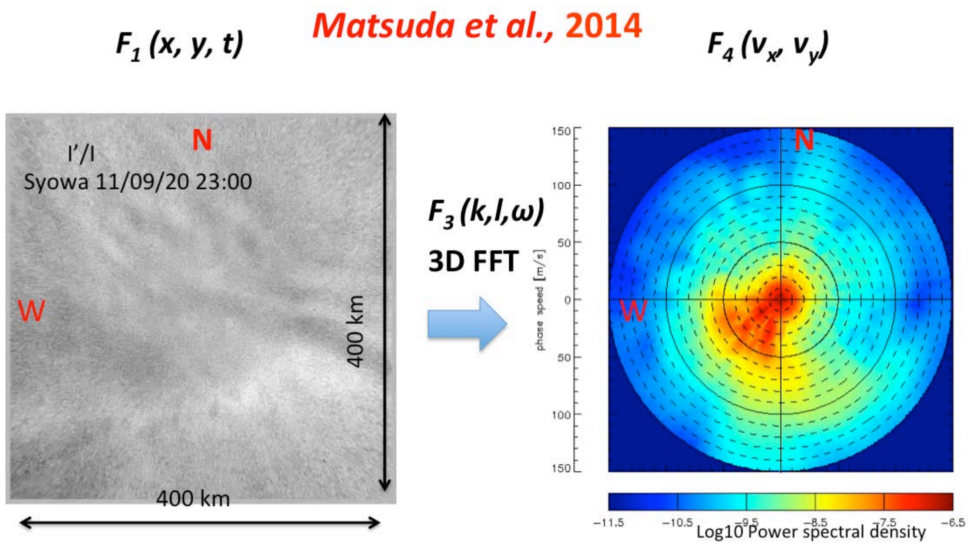
The topic of this talk is the development of a simple and user-friendly software for airglow data spectral analysis. The previous presentation by Hosik Kam is one of the examples of the use of this software package. In this talk, I will explain in detail how the program works, how to use it and how the performance of this program by running several simulations using actual and test data.

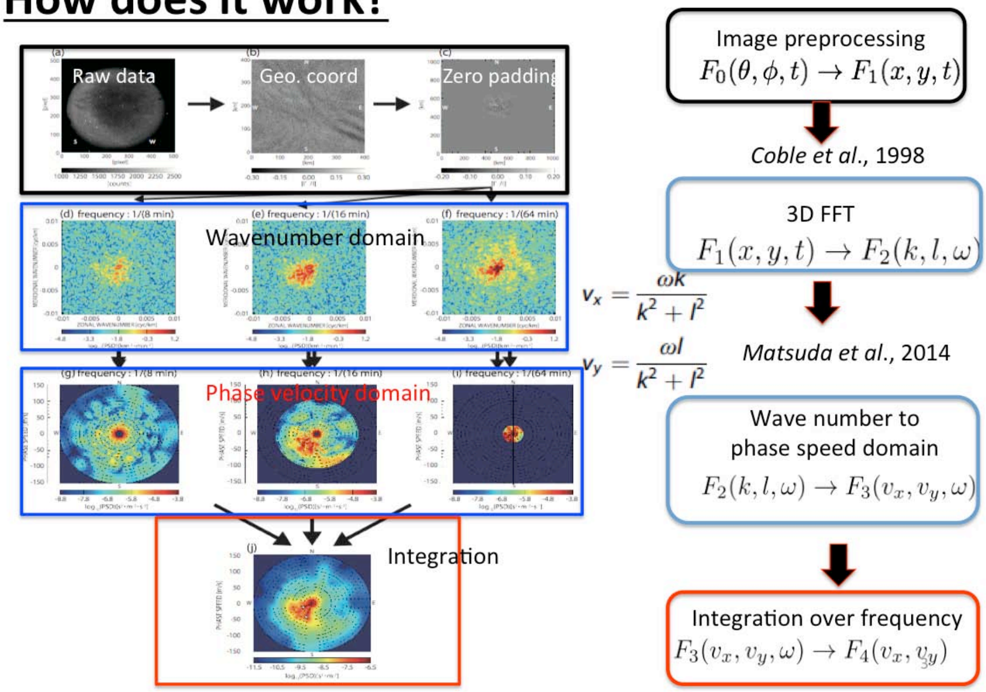
Matsuda Transform (M-Transform)



Transform airglow intensity data to power spectrum in horizontal phase velocity domain.

I will start with the introduction of M-Transform. M-tranform is a 3D FFT program to analyze airglow data based on method developed by *Matsuda et al.*, 2014. In a simple word, this method transforms the airglow intensity data to power spectrum in horizontal phase velocity domain. So how does it work?

How does it work?



This method requires time series of 2D preprocessed images (*x, y, t*), which includes common airglow image preprocessing, such as: star removal, correction of Van Rijhin effect and projection into geographical coordinate. We then apply the 2D pre-whitening, 2D Hanning window and zero padding before calculating the 3D FFT (*Coble et al*., 1998). *Matsuda et al*., 2014 new method transforms the the PSD in wave number domain to phase velocity domain by using this equation: (read above). Finally, we integrate the phase velocity spectrum over frequency and resulted in 2D phase velocity spectrum as seen in the last panel above.

Summary of M-Transform

+ Transform airglow intensity data to phase velocity domain.

+ Handle huge amount of data

+ Cut time consumption and man power to analyze huge amount of airglow data.

- However, the original program needs several sub-routines to run, which is not user-friendly.

Purpose

- Develop a simple and user-friendly function based on Matsuda et al, 2014 method on IDL.
- Encourage AGWs research groups to use it to analyze their data and produce result in a uniform format (phase velocity domain).
- In this manner, it's easier to compare AGWs phase velocity and energy distribution between different latitudes.

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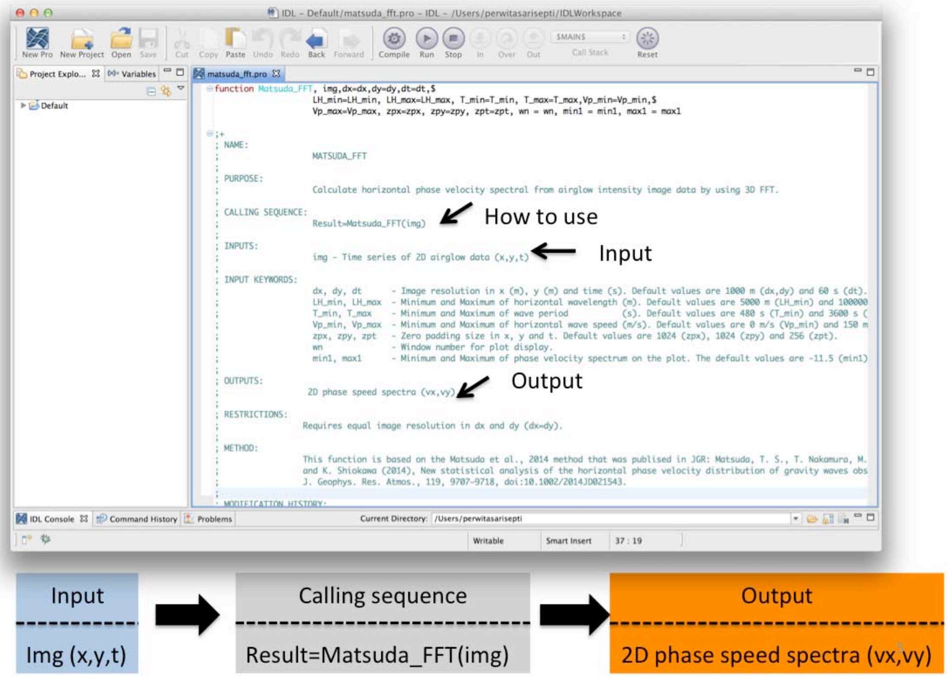
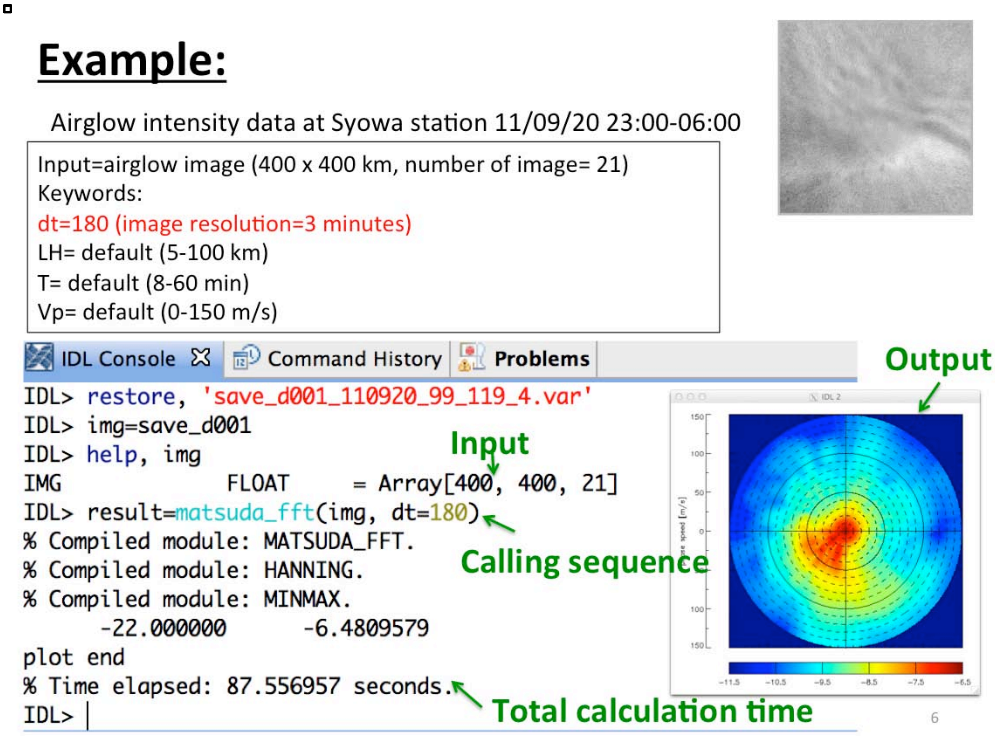
As a summary: M-Transform method transforms airglow intensity data to phase velocity domain. This method can handle huge amount of data, therefore it cuts time consumption and man power to analyze huge amount of airglow data. However, the original program needs several sub-routines, which is not user-friendly. Therefore, our main purpose is to develop a simple and user-friendly function based on *Matsuda et al*, 2014 method. We would like to encourage AGWs research groups to use it to analyze their data and produce result in a uniform format (phase velocity domain). In this manner, it's easier to compare the AGWs phase velocity and energy distribution between different latitudes.

M-Transform Function



In this slide, I'll explain our new function. This program is called Matsuda-FFT, for obvious reason. Basically, this function only needs an array of time series of pre-processed airglow data (*x,y,t*) as input. The calling sequence is just simply **Result=Matsuda_fft(img)**. The output is 2D phase velocity spectra. The wave parameters can be adjusted by setting the input parameters. The input keywords include: *dx,dy, dt* which are the image resolution, default values are etc (please read above). One restriction of this program is that it requires equal image resolution in *dx* and *dy*, or in other word, the image pixel should be a square.



This is an example on how to use the program. This was airglow data over Syowa station on 20 September 2011 (*Matsuda et al.*, 2014). The input is image with dimension of [400, 400, 21]. Since the image time resolution is 3 minutes, we set the input keyword as *dt*=180 s. The wave parameters are default values. The IDL console shows the input, calling sequence and total calculation time. The output can be seen as a plot in the right bottom panel. The horizontal axis is the *vx*, vertical axis is *vy* and the color bar shows the PSD in log scale. The phase speed spectrum shows the dominant propagation in the southwestward direction which agrees with the wave propagation seen in the movie above.

Performance Analysis

We examine the performance of this function by running several simulations:

1. Changing the input keywords:

a) Zero padding size: Zpx (512, 1024, 2048), Zpt (64, 128, 256, 512).

b). Wave parameters: *LH*(horizontal wavelength) (5-20 km, 20-100 km, 5-100 km), τ (wave period) (8-20 min, 20-60 min, 8-60 min).

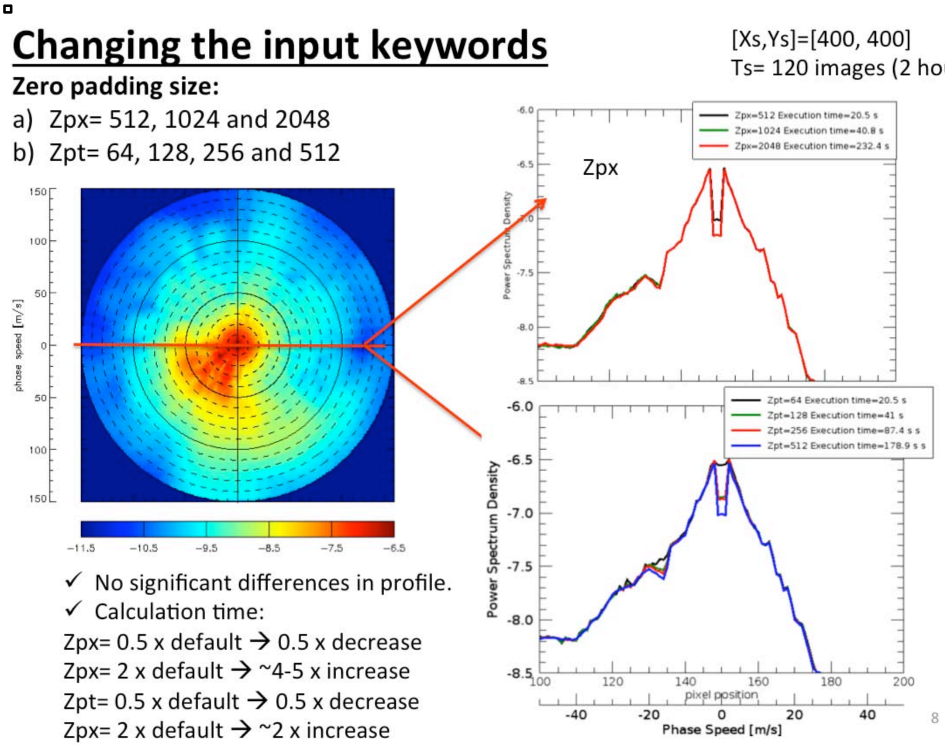
2. Changing the wave packet size (*X*) and wave duration (*T*) using test data

a) Case 1: *c* constant (40 m/s), τ and *LH* vary (τ=8, 15, 30 min)

b) Case 2: *c* constant, *X* varies (FWHM=50, 100, 200 km)

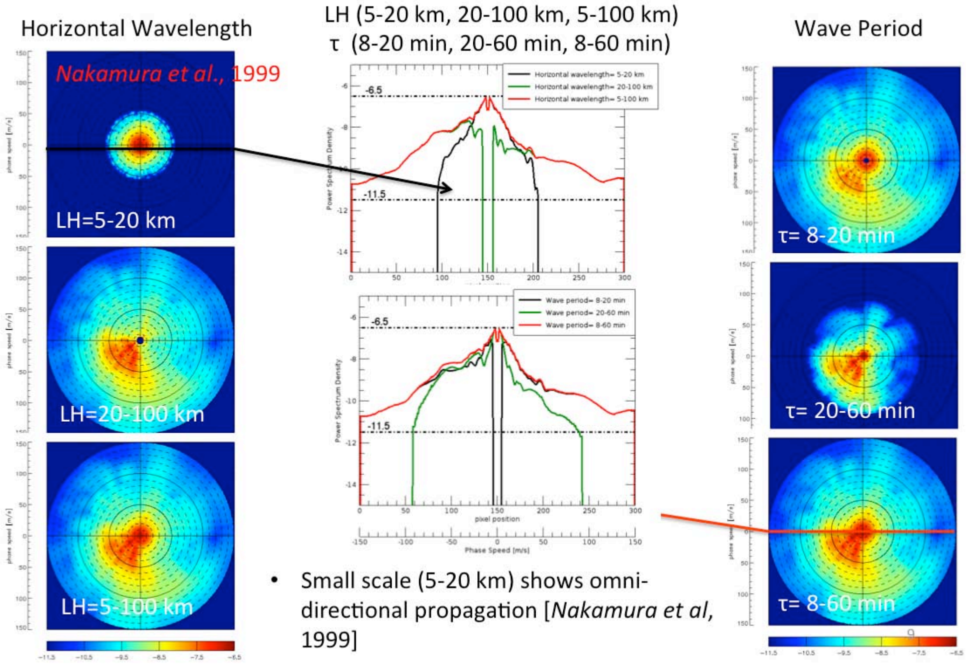
c) Case 3: *c* constant (40 m/s), *T* varies (30, 60, 120 min)

We examine the performance of this function by running several simulations: First, we check whether the program works correctly or not by changing the input keywords. Here we changed the size of zero padding in space and time domain. We tried several Zpx (512, 1024 and 2048), zpt (64, 128, 256, 512). We also change the wave paramenters, we analized how the spectrum for independent scale: Horizontal wavelength: (5-20 km, 20-100 km, 5-100 km) and period (8-20 min, 20-60 min, 8-60 min) behaves. By using some test data (a simple sinusoidal wave) we will show how the spectrum changing when we change the wave parameters, wave packet size*(X*) and duration (*T*). The first case is test wave with constant speed (40 m/s) and different wave period (8, 15, 30 min) and horizontal wavelength. In second case we applied Gaussian shape wave-packet with different FWHM (50, 100, 200 km) and for the 3^{rd} case, we changed the wave packet duration (30, 60, 120 min).

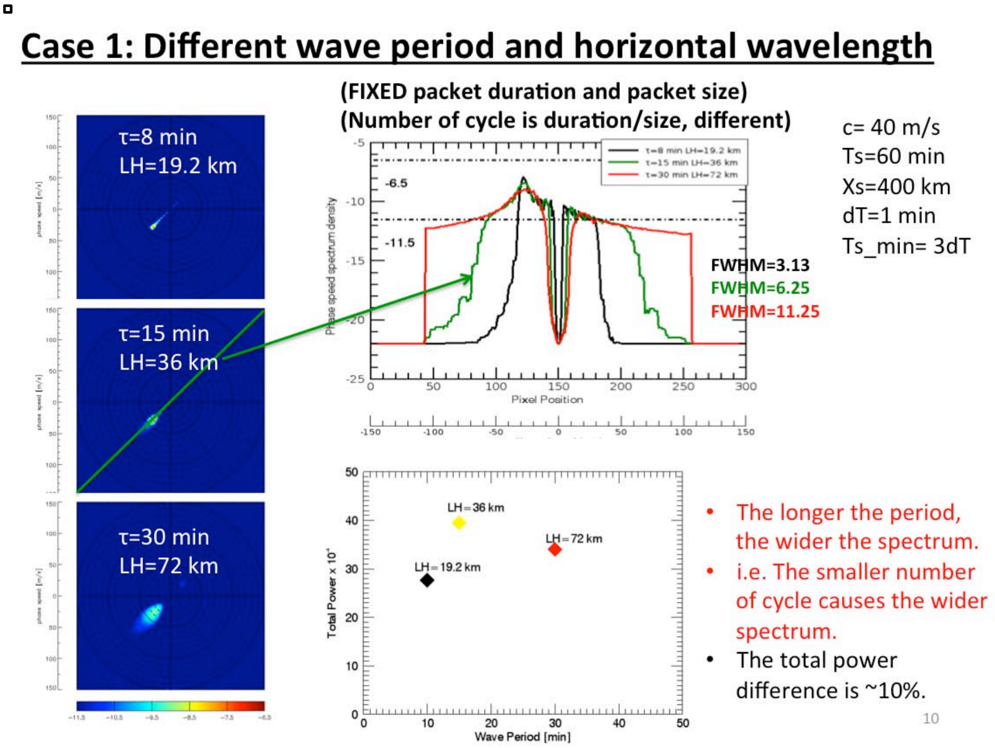


This is the result from changing the size of zero padding in space and time domain. We took 1D profile along the horizontal direction. The top graph shows the profile for different zpx (512, 1024 and 2048) and the calculation time. There is no significant changing in the profile when we apply different zpx. However, by changing the zpx size the calculation time is also changing. For example, by applying 512 zpx size, the calculation time for 120 images (2 hours) down to ½ compared to default size (1024). Accordingly, by increasing the size of zpx to double of default, the calculation time increases to 5 **times**. Similar result can also be seen when changing the zpt, the profile doesn't change significantly but it changes the calculation time. Therefore, user can determine which size of zero padding they would like to use according to their purpose.

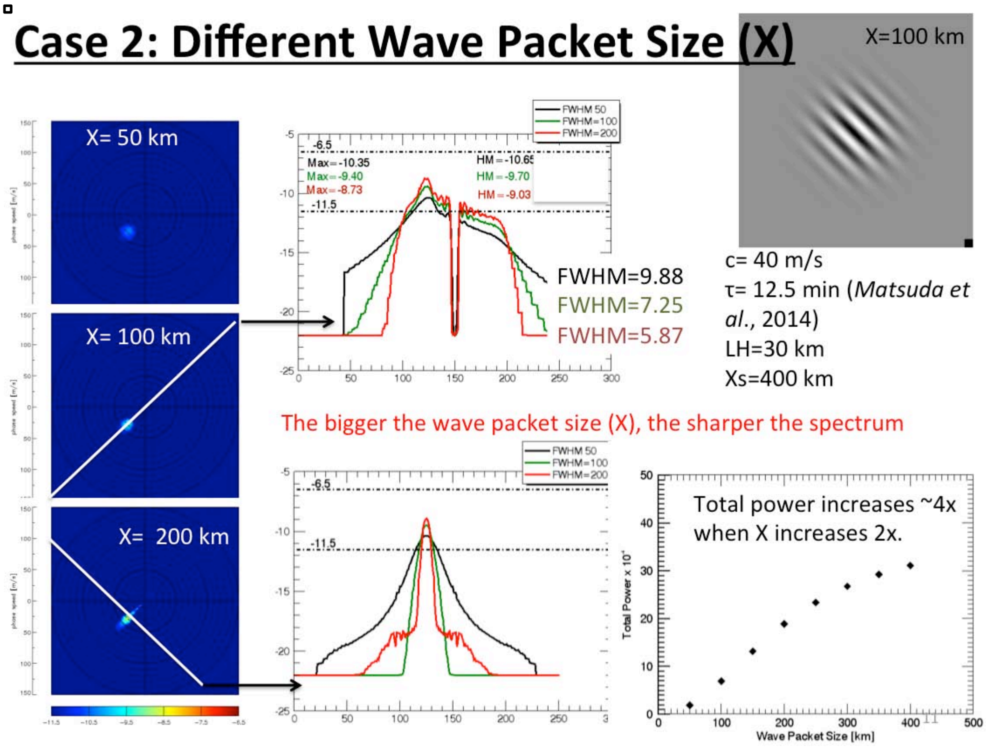
Changing the input keywords



These are the results of phase speed spectrum by changing the LH and tau. We found one interesting result, as shown in the top left corner panel, that smaller scale, close to ripple (5-20 km), the spectrum shows omni-directional propagation. This result agrees with the result reported by *Nakamura et al.*, 1999. However, when we changed wave period, directionality did not change significantly. This suggests both shorter period and longer period waves propagated into the same direction. The graphs in the center show the 1D horizontal profile of each wave and period categories.

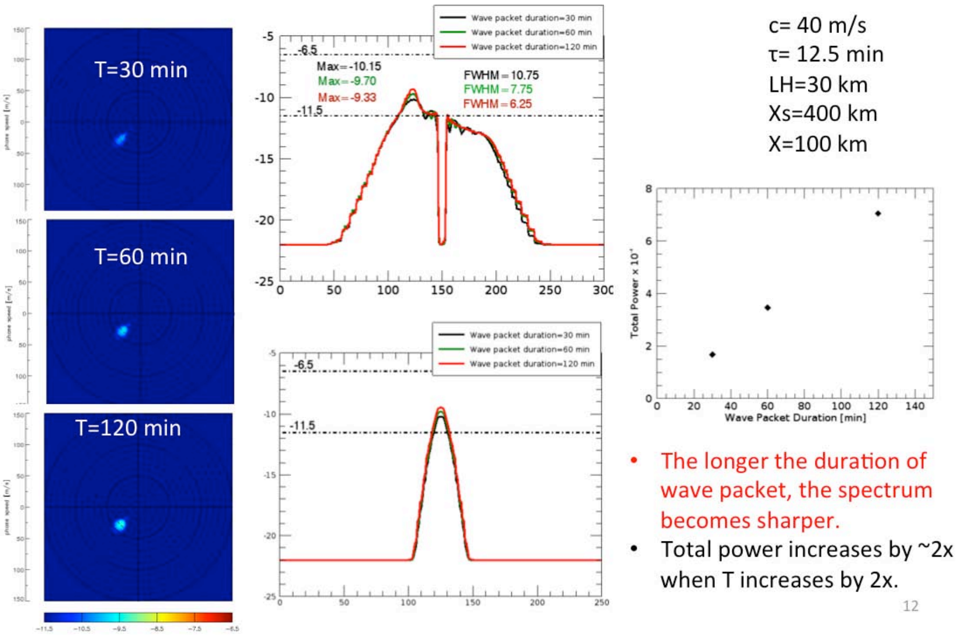


Next, by using a simple sinusoidal wave as a test data, we change the wave parameters to show how the phase speed spectrum behaves. In this simulation, the phase speed is constant (40 m/s), and packet size and duration are also fixed. We changed the wave period (8, 15, 30 mins). The horizontal wavelengths changed accordingly. The left panel shows the phase speed spectrums, we can see that the longer the wave period, it causes the spectrum to become wider. This is because the packet size and duration is fixed, but they are different if measured by number of cycles. If the duration or packet size, counted by number of cycles is small, then spectrum becomes broader. The upper panel graph shows the 1d diagonal profile for each periods. The FWHMs for each profile are shown above. The lower panel graph shows the total power of the spectrum. It shows the difference is ~10%.



For the second case, we applied a gaussian window to the test wave to create different wave packet size (50, 100, 200 km). The left panel shows the spectrum from each packet size. When the wave packet size becomes bigger, the spectrum become sharper. The top panel shows the diagonal profile of each wave packet and lower panel shows the transverse profile. It shows that the bigger the wave packet size, the sharper and narrower the spectrum. The right bottom corner is the total power as a function of wave packet size. It shows that the total power is expected to increase by ~4 times when the wave packet increases by 2 times.

Case 3: Different Wave Packet Duration (T)



For the 3rd case, we changed the duration of the wave packet (30, 60, 120 min) with a fixed image length (120 min). The left panel shows the phase speed spectrum. It shows that the longer the duration of wave packet, the spectrum becomes sharper. Right panel shows the total power is proportional to the packet length.

Summary

- We have developed a user-friendly function based on Matsuda et al., 2014 3D FFT method for airglow data to use on IDL.
- This function can calculate big amount of data with reasonable execution time.
- Several simulations have been done to examine the performance analysis of this new function.
- If you are interested in using this function, please feel free to contact us.