M-transform Program: A Manual

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OVERVIEW

These instructions describe how to use M-transform version1.2 function on IDL for airglow data analysis. This function is based on the *Matsuda et al*., 2014 method: *Matsuda, T. S., T. Nakamura, M. K. Ejiri, M. Tsutsumi, and K. Shiokawa (2014), New statistical analysis of the horizontal phase velocity distribution of gravity waves observed by airglow imaging, J. Geophys. Res. Atmos., 119, 9707–9718, doi:10.1002/2014JD021543*. Basically, this function needs an array of time series of pre-processed airglow data (*x,y,t*) as an input. The output is 2D phase velocity spectra (v_x, v_y). The wave parameters can be adjusted by setting the input keywords.

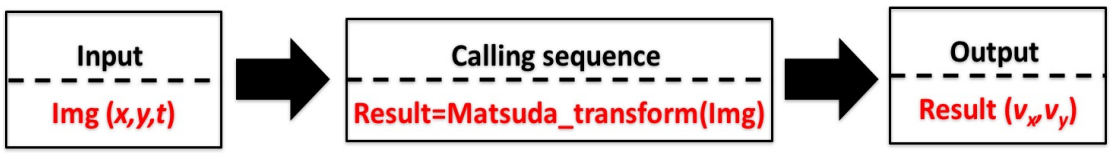


Figure 1. Flowchart of M-transform function.

HOW TO INSTALL

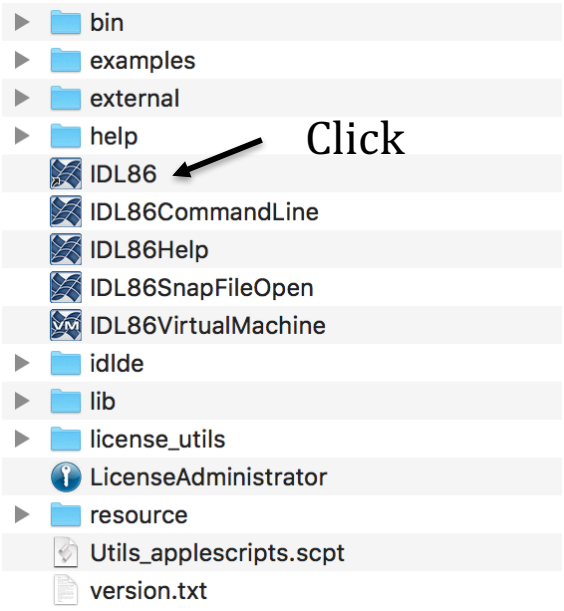
Table 1 shows the supporting operation system and IDL version to run this function.

Operating system	IDL version	RAM
Macintosh	≥ IDL 8.5	Min. 1GB
Windows	≥ IDL 8.5	Min. 1 GB

Followings are step by step on how to install the M-transform on your IDL machine both via workbench and command-line.

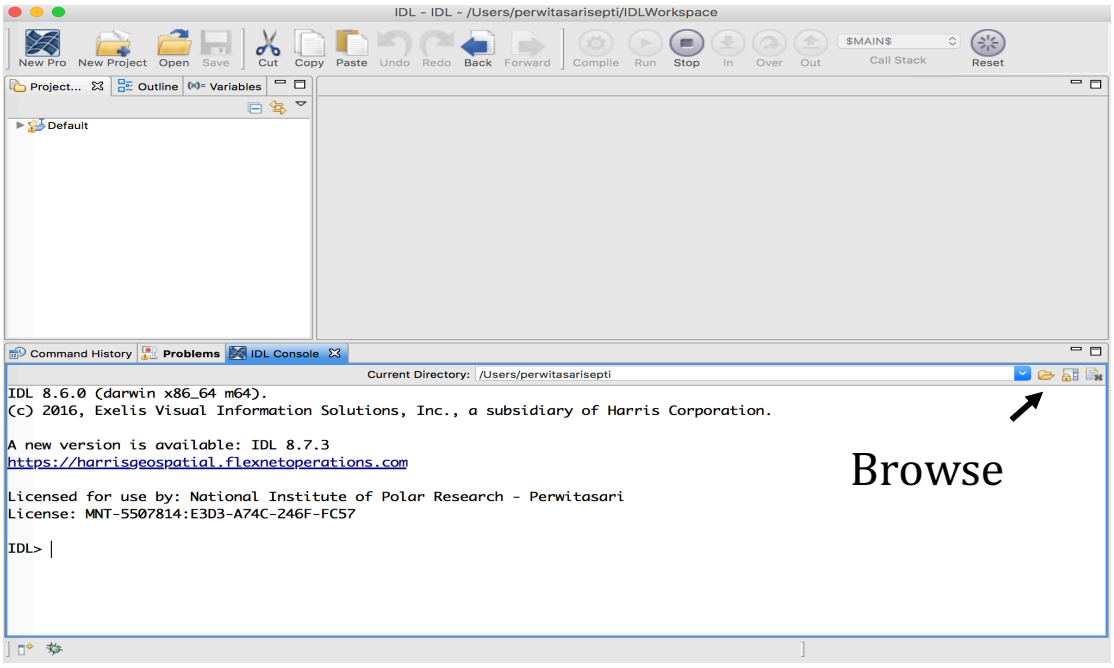
1. Via Workbench

a. Launch the IDL workbench by double-clicking the IDL icon in your IDL installation folder.

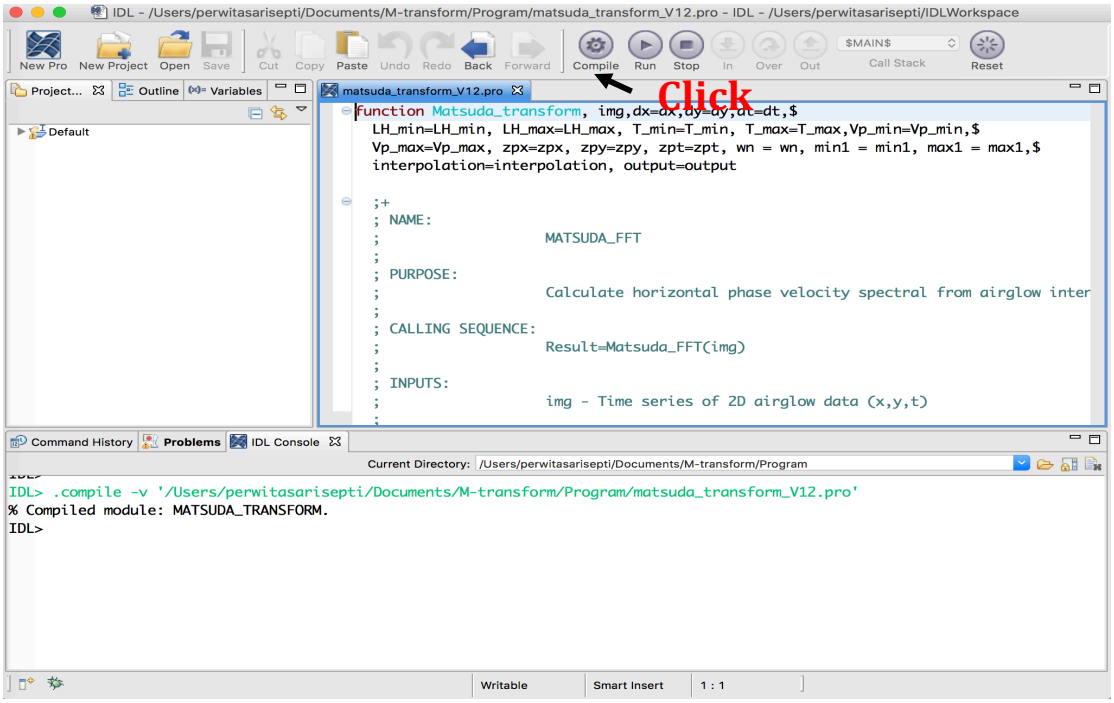


b. Set the current directory to your folder contained the 'matsuda_transform_V12.pro" by using "Browse" button on your IDL workbench or by typing the following command on the IDL console window.

```
IDL> CD, '/Users/perwitasarisepti/Documents/M-transform/Program/'
```



c. Click “Open File” button and choose “matsuda_transform_V12.pro” file from your folder and click “Compile” button.



d. If the compilation is successful, the following message will be prompted

```
% Compiled module: MATSUDA_TRANSFORM.
```

2. Via command-line

a. Make sure that the PATH for IDL environment has been set up properly. For a bash shell type the command bellow

```
open ~/.bash_profile
```

If it doesn't already exist, then insert following command

```
# Setting PATH for IDl 8.4
export $PATH="/Applications/exelis/idl84/bin/idl:$PATH"
```

b. Type *idl* at the X11 Terminal window shell prompt.

c. Set the current directory to the folder that contained the M-transform file by typing

```
IDL> CD, '/Users/perwitasarisepti/Documents/M-transform/Program/'
```

d. Enter the command line below to compile the file

```
IDL> .compile -v 'matsuda_transform_V12.pro'
```

e. If the compilation is successful, the following message will be prompted

```
% Compiled module: MATSUDA_TRANSFORM.
```

PROGRAM DESCRIPTION

Table 2 shows the summary of the M-transform description (see *Perwitasari et al.*, 2018 for more details).

Table 1. Description of M-transform function on IDL.

Program description	
Name	Matsuda_transform
Purpose	Calculate horizontal phase velocity spectra from airglow intensity image data using 3-D FFT
Calling sequence	Result=Matsuda_transform(Img)
Inputs	Img: time series of 2-D airglow data in geographic coordinates (x, y, t)
Input keywords	(a) dx, dy, dt: image resolution in x (m), y (m), and time (s) (b) LH_min, LH_max: minimum and maximum horizontal wavelength (m) to be processed (c) T_min, T_max: minimum and maximum wave period (s) to be processed (d) Vp_min, Vp_max: minimum and maximum horizontal phase speed ($m\,s^{-1}$) to be calculated (e) zpx, zpy, zpt: dimension of the zero-padded image size in x, y, and t to improve the intervals of k, l, and ω (f) min1, max1: minimum and maximum phase velocity spectra to be plotted (g) Interpolation: select interpolation method
Outputs	2-D phase velocity spectra (v_x, v_y)
Remarks	Requires equal sampling interval time resolution (dt)

The default values of input keywords are summarized in Table 3.

Input keywords	Default values
Image resolution (*dx, dy, dt*)	1000 m (*dx*,*dy*) and 60 s (*dt*)
Horizontal wavelength (*LH*)	5000≤ LH ≤100000 m
Wave Period (*T*)	480 ≤T ≤ 3600 s
Phase speed (*Vp*)	0 ≤ Vp ≤ 150 m/s
Zero padding size (zpx, zpy, zpt)	1024 (zpx, zpy), 256 (zpt)
Range of phase velocity spectra plot	-11.5 ≤ Vp ≤ -6.5

Restrictions of input keywords are listed in Table 4

Input Keywords	Cautions
Image Size (*nx,ny, nt*)	Pixel size in x and y should be equal (nx=ny)
Image resolutions (*dx, dy, dt*)	Resolution in x and y should be equal (dx=dy) and sampling interval should be fixed
Horizontal wavelength (*LH*)	LH_max>LH_min, 2*dx<LH<2*zpx*dx
Wave period (*T*)	T_max>T_min, 2*dt<T<2*zpt*dt
Zero padding (*zpx, zpy, zpt*)	nx<zpx,zpy, zpt<2048

By changing one of the input parameters, the other parameters will be automatically calculated accordingly:

1. Changing spatial image resolution (dx,dy), zero padding size input (zpx, zpy) will result in automatically changing the range of *k* and *l* as follows

   *sr(1,2)=(zpx/2-((zpx*dx)/LH_min)), zpy/2+((zpy*dx)/float(LH_min))*

   range_kl =sr(2)-sr(1)
2. Changing temporal image resolution (dt), wave period (T) and zero padding (zpt) will result in changing of period range as follow

   *tr(1,2)=(zpt/**2.**-zpt/(T_min/dt), zpt/**2.**-zpt/(T_max/dt))*

   range_t=tr(2)-tr(1)
3. Changing phase speed input will result in changing phase velocity range, please refer to line 227-272 on the program for the detail conversion.

Flowchart of how the M-transform works is shown in Figure 2. For detail explanation on pre-whitening, hanning filter etc please refer to *Matsuda et al*., 2014 and *Perwitasari et al.,* 2018.

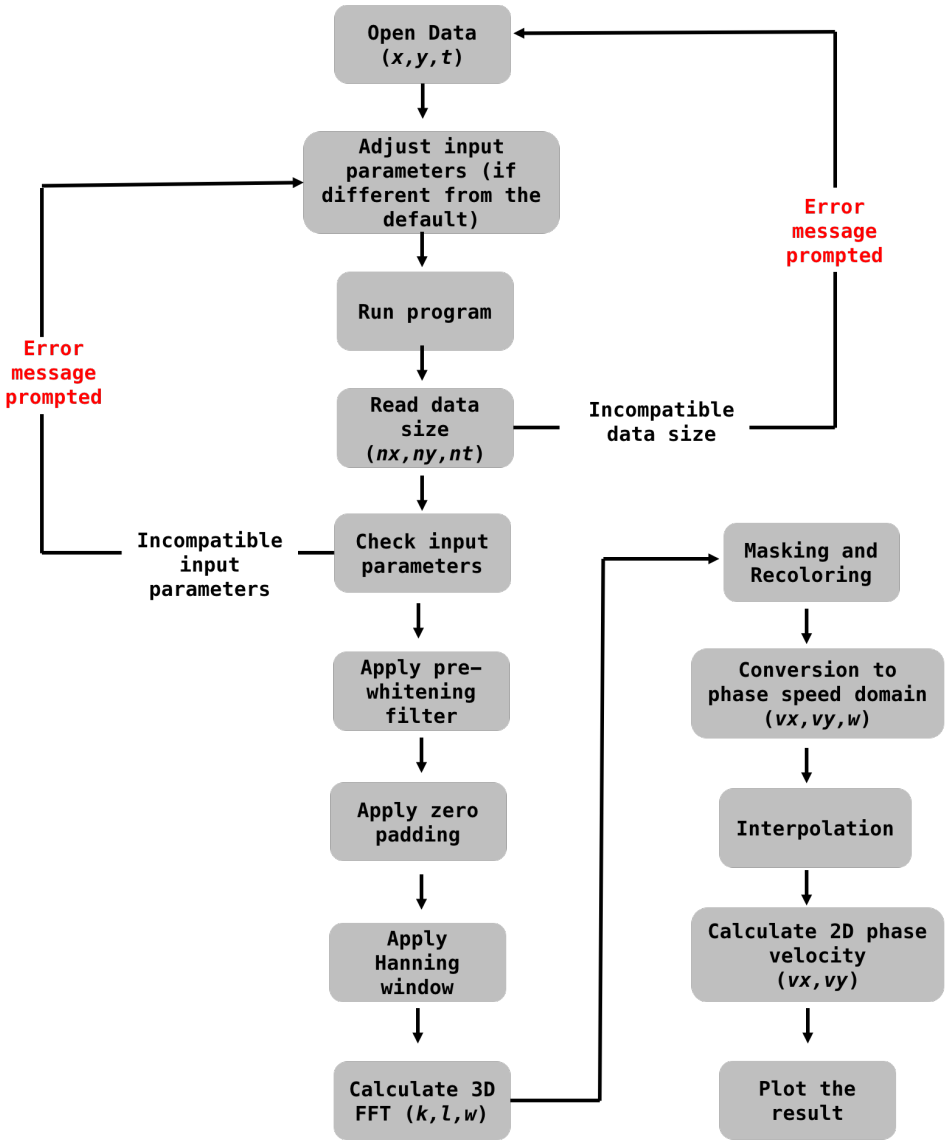


Figure 2. Flowchart on how the M-transform works within the function.

HOW TO USE

1. Data Preparation

a. Pre-process the airglow data through standard airglow data preprocessing data, e.g. star removal, projection onto geographical coordinate.

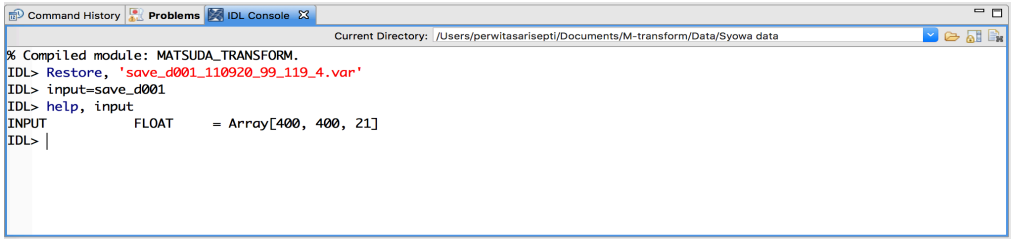
b. Make sure the data have fixed interval image pixels (*dx*, *dy*) and interval sampling (*dt*).

c. Normalized airglow intensity ($((I - \bar{I})/\bar{I}$) should be used for the input of this function.

d. In case of irregular time sampling interval, user should properly interpolate their data to fixed interval.

2. How to Run and Save

a. Load the 2D time sequence of airglow data to IDL. To restore the IDL sav file, type the following command. This example is airglow data with image size of 400x400 pixel (*nx* x *ny*) and 21 (*nt*) images



b. Load the M-transform function and compile it.

c. Specified the input keywords in the calling sequence if the intended wave parameters for the analysis are different from the default values. For example, if the sampling interval is 3 minutes instead of 1, adjust the input keyword as follow

```
IDL> Result=Matsuda_transform(input, dt=180)
```

d. After making sure that all the input keywords are correct, run the calling sequence by click “Enter” button.

e. The 2D phase velocity spectral plot will be automatically displayed as a result along with the 2D array of the spectral.

```
IDL> Result=Matsuda_transform(input, dt=180)
% Compiled module: HANNING.
Minimum PSD=      -22.0000
Maximum PSD=      -6.50954
     150       0     150
Plot end
% Time elapsed: 123.56989 seconds.
IDL> help, Result
RESULT          FLOAT     = Array[301, 301]
```

f. To save the array result as an IDL sav file and the plot, type the following commands

```
IDL> save, Result, filename='Result.sav'
IDL> saveimage, 'Result.jpg'
% Compiled module: SAVEIMAGE.
% Loaded DLM: TIFF.
Created Result.jpg in TIFF format
```

Figure 2 below shows the complete command to run the function and save the array and plot result to your local computer.

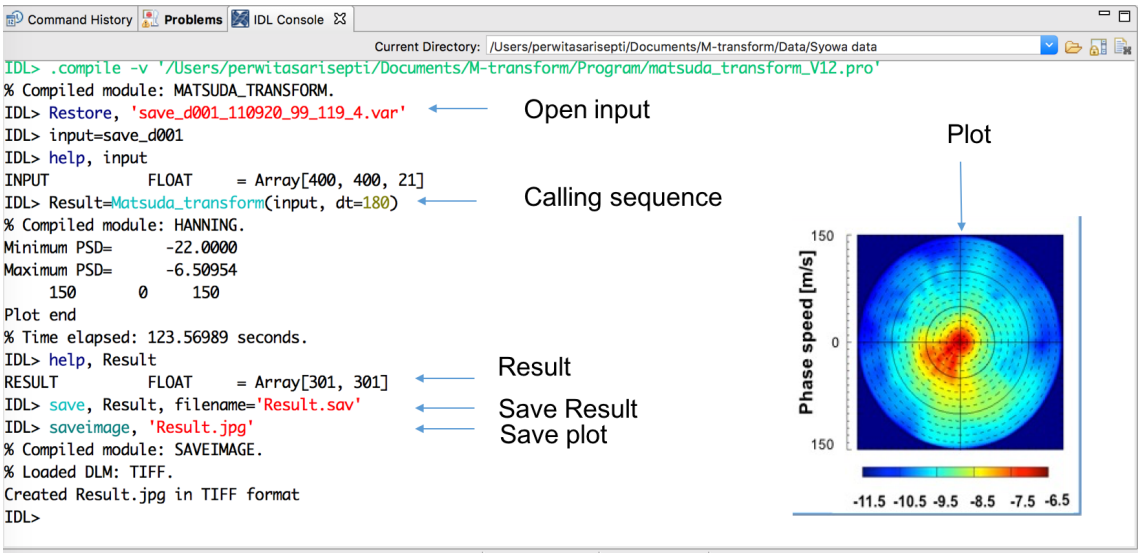


Figure 2. Complete command to run and save with plot displayed.

REFERENCE

Matsuda, T. S., T. Nakamura, M. K. Ejiri, M. Tsutsumi, and K. Shiokawa (2014), *New statistical analysis of the horizontal phase velocity distribution of gravity waves observed by airglow imaging*, J. Geophys. Res. Atmos., 119, 9707–9718, doi:10.1002/2014JD021543.

Perwitasari, S., Nakamura, T., Kogure, M., Tomikawa, Y., Ejiri, M. K., and Shiokawa, K. (2018), *Comparison of gravity wave propagation directions observed by mesospheric airglow imaging at three different latitudes using the M-transform*, Ann. Geophys., 36, 1597-1605, https://doi.org/10.5194/angeo-36-1597-2018.