NJIT New Jersey's Science & Technology University

Mesospheric Gravity Waves and Their Sources at the South Pole

Abstract

The sourcing locations and mechanisms for short period, long vertical wavelength upward-propagating gravity waves at high polar latitudes remain largely unknown. Using all-sky imager data from the Amundsen-Scott South Pole Station we determine the spatial and temporal characteristics of 94 observed small-scale waves in three austral winter months in 2003 and 2004. These data, together with background atmospheres from synoptic and/or climatological empirical models, are used to model gravity wave propagation from the polar mesosphere to each wave's source using a ray-tracing model. Our results provide a compelling case that a significant proportion of the observed waves are launched in several discrete layers in the troposphere and/or stratosphere. Analyses of synoptic geopotentials and temperatures indicate that wave formation is a result of baroclinic instability processes in the stratosphere and the interaction of planetary waves with the background wind fields in the tropopause. These results are significant for defining the influences of the polar vortex on the production of these small-scale, upward propagating gravity waves at the highest polar latitudes.

South Pole All-Sky Imager Instrumentation

Pictures of ASI-1, ASI-2 and Panchromatic camera (from left to right) taken in 2012. They are installed on the top of the elevated station of the South Pole Station, and have been in operation.

❑ All-sky imager-1 (ASI-1)

Optics	Fisheye
Camera	Hamamatsu C4880-72S
Interference filter	427.8nm, 557.7nm, 630.0nm, 589.0nm, 486.1nm
Typical exposure time	4 sec

❑ All-sky imager-2 (ASI-2)

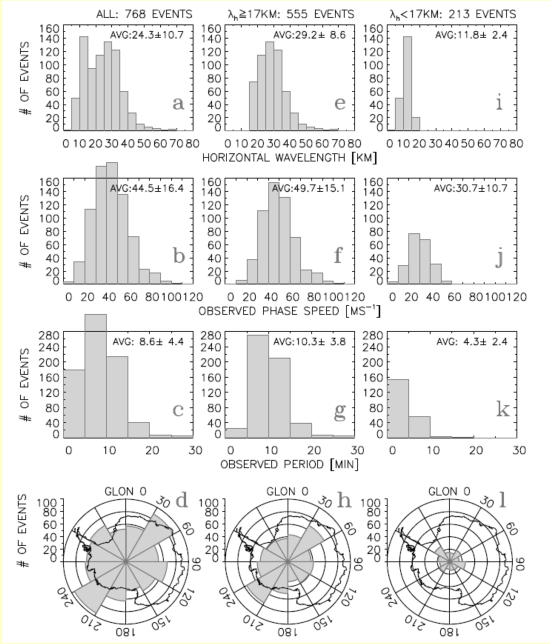
Optics	Fisheye
Camera	Hamamatsu C9100-13
Interference filter	481.3 nm, 486.1 nm, 671.0 nm, 845.1 nm
Typical exposure time	8 sec

❑ Panchromatic camera (Watec-1)

Optics	Fisheye
Camera	Watec WAT-120N+
Interference filter	None
Typical exposure time	0.5 sec

Prior Observations at SPA

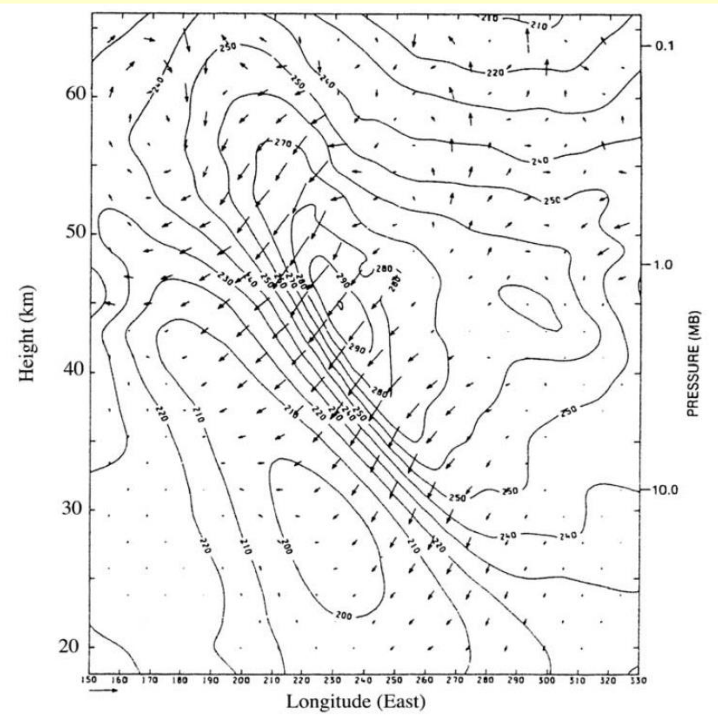
Suzuki et al. [2011] has looked at characteristics of waves in Na airglow from 2003-2005 over South Pole, Antarctica (SPA) using the same instrument. They present the first climatology of waves over SPA, and note a preferred propagation direction for observed waves. Their results are shown on the right, and are similar to wave characteristics seen from other locations. They were unable to determine a cause of this preference.



Gravity Wave Excitation by Baroclinic Instability

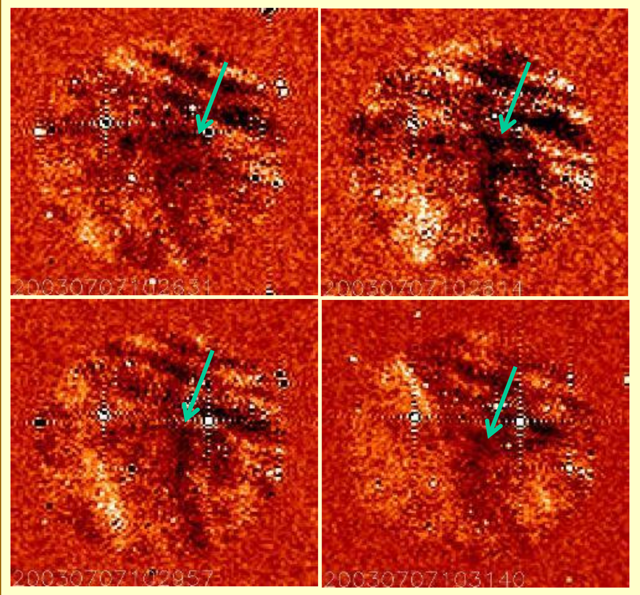
Geostrophic polar vortex winds disturbed by interaction with upwardly propagating planetary waves can result in ageostrophic flow and non-thermal vertical motion. This in turn causes downwelling and adiabatic compression/heating [Fairlie et al., 1990]

It is known from previous work [O'Sullivan and Dunkerton, 1995] that larger-scale intertia gravity waves can be excited as the vortex adjusts back to geostrophy. However, few observations exist tying smaller-scale acoustic-gravity waves to such sources.



Graphic from Fairlie et al. [1990]

South Pole ASI Gravity Wave Observations

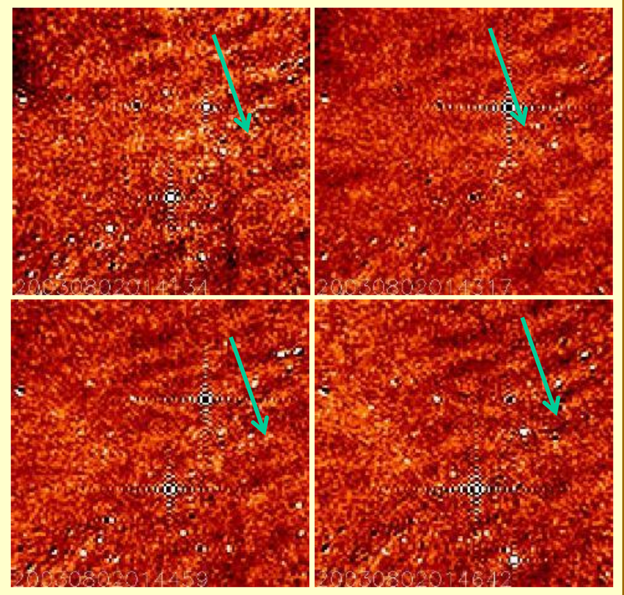


Observed at 1026UT July 7, 2003

Time-differenced, unwarped Sodium (589nm) all-sky images were inspected for the presence of gravity waves.

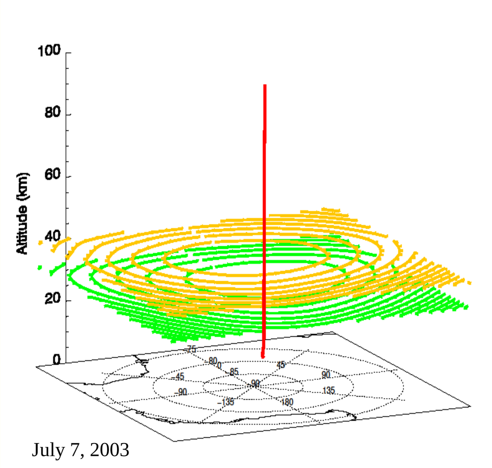
We developed a catalogue of 94 wave events over 38 days during June and August 2003, and August 2004.

The horizontal wavelengths, periods, and propagation angles were measured for all waves.

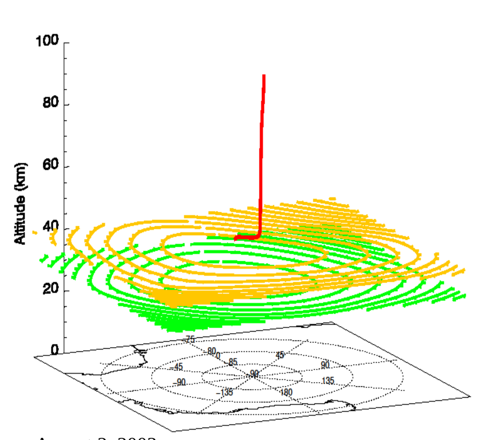


Observed at 141UT August 2, 2003

Investigation of Wave Sources via FOREGRATS



July 7, 2003



August 2, 2003

In order to investigate the sources of observed waves, we utilized the FOREGRATS (FORECasting of Gravity waves via Ray-tracing Algorithms with prescribed Tropospheric Sources) ray-tracing model. The model tracks the 1-d amplitude evolution and 3-d ray propagation of the wave, allowing us to determine the wave ray path through a supplied background atmosphere to its source. We reconstruct the background atmosphere by combining ECMWF Reanalysis below 50-km and MSISE-HWM between 50- and 100-km. A sample of results, corresponding to the gravity waves shown in all-sky images above, is shown on the left. The orange-yellow and green plots are representative maps of geopotential height at 30-km and 40-km indicative of the background conditions through which the wave is propagating and the red line is the wave ray path downward from 100-km.

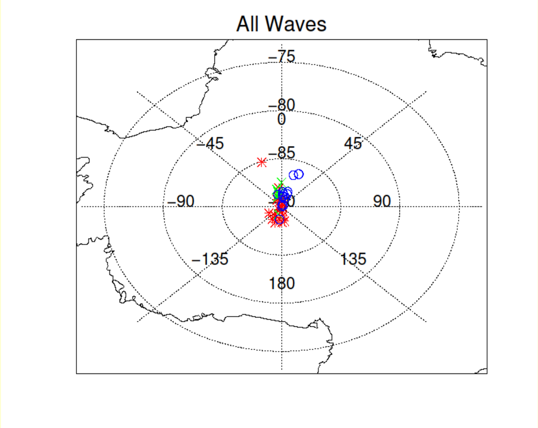
The wave observed on July 7, 2003 travels rapidly down to the ground, terminating ~2-km above the surface at -86.3°S.

The wave observed on August 2, 2003 by contrast terminates 38-km above the surface, at -85°S. From analysis of atmospheric conditions shown later, this wave seems to arise from baroclinic instability.

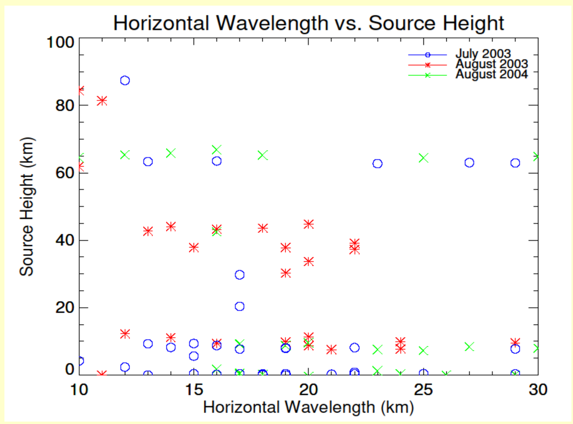
Ray-Tracing Results: Evidence of Discrete Wave-Forming Layers

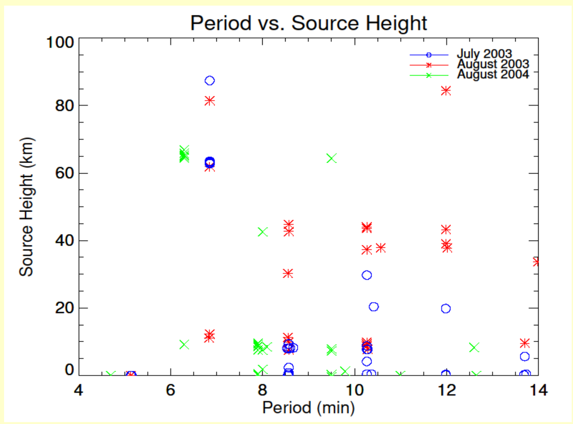
All 94 wave events were ray-traced using FOREGRATS, and a statistical analysis of the results is shown below. All but 6 of the waves originated within 2.5° latitude of SPA. 7 were found to be evanescent, indicating they are not in fact propagating gravity waves.

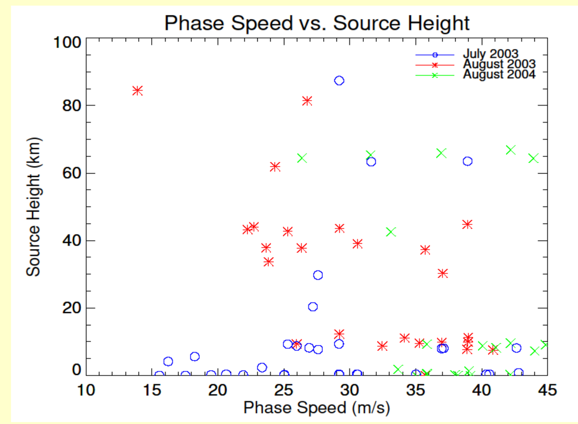
41 were traced to tropospheric sources. 16 waves originated above 50-km. As ECMWF extends only to 50-km we are unable to analyze these further at this time, though future analysis with SABER data may shed light on the conditions producing these waves. We noted no correlation between wave source height and the spatial and temporal characteristics of the waves. Of the 30 that remain, 15 originated in the tropopause, between 9-km and 15-km, and 15 in the stratosphere, between 15-km and 50-km.



Based on our results, waves appear to originate in several discrete layers, centered at 65-km, 40-km, the tropopause, and the surface.







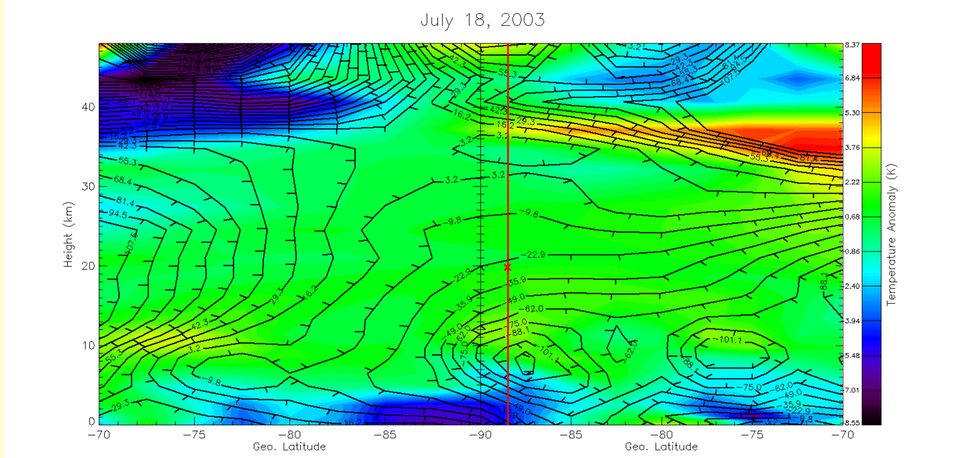
Investigation of Wave Sources via Geophysical Indices

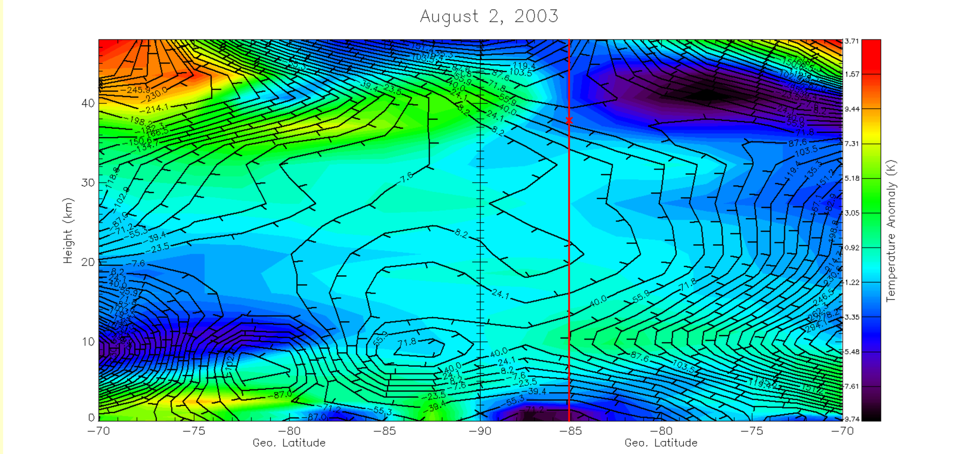
In order to determine possible sources of the observed waves, we analyzed 24-hour time-differenced geopotential heights and temperatures along the ray path. The results of several runs are shown on the right. Black contour lines are lines of constant geopotential height, with ticks pointing towards regions of lower geopotential height (which act as a proxy for isobars), and color contours represent 24-hour temperature variation, with red signifying an increase in temperature from the previous day, blue signifying a drop, and green relatively little change. The red vertical line denotes the latitude at which the wave ray terminated, and the red "x" signifies the actual source of the wave. In using a 24-hour time difference, we can look for significantly vertically tilted regions that would indicate displacement of the polar vortex (or in the tropopause, the background wind fields) that would produce baroclinic instabilities, and thus excite gravity waves.

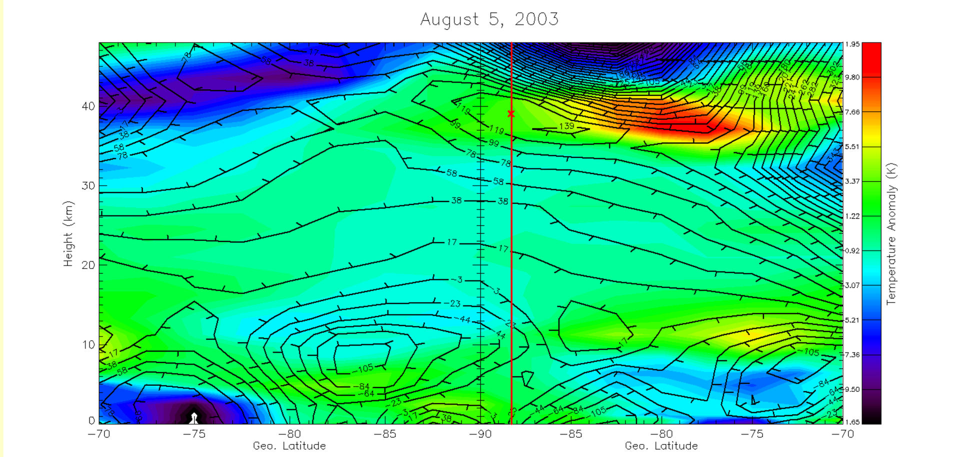
The plots from July 18, August 2, August 5, 2003 show waves forming in the stratosphere (at 20-km, 38-km, and 39-km) in regions where the differenced geopotential height maps are heavily tilted, indicating a disturbance of the polar vortex winds that has moved the polar vortex "off-balance".

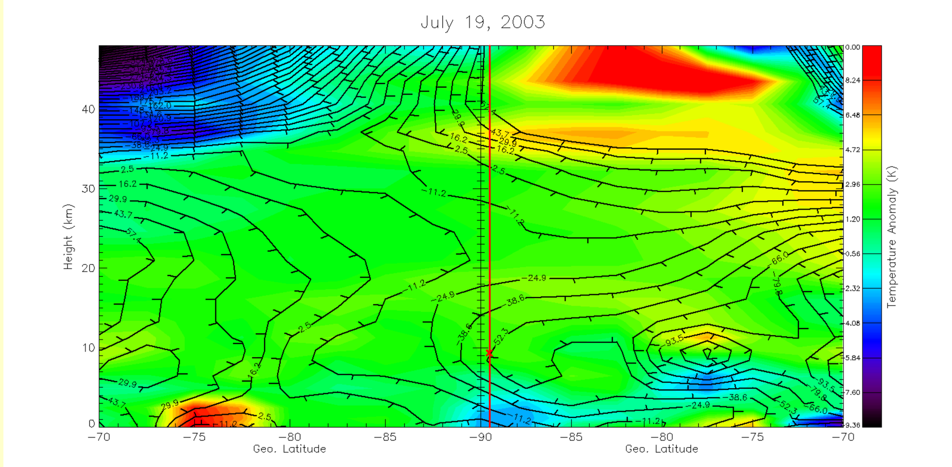
Plots from July 19, August 3, 2003 show waves forming in the tropopause (at 9-km, 12-km) in disturbed regions with a more gradual vertical tilt. The signature of a planetary wave is present in each case, which is the likely cause of the upward motion and vertical tilt that is generating these waves.

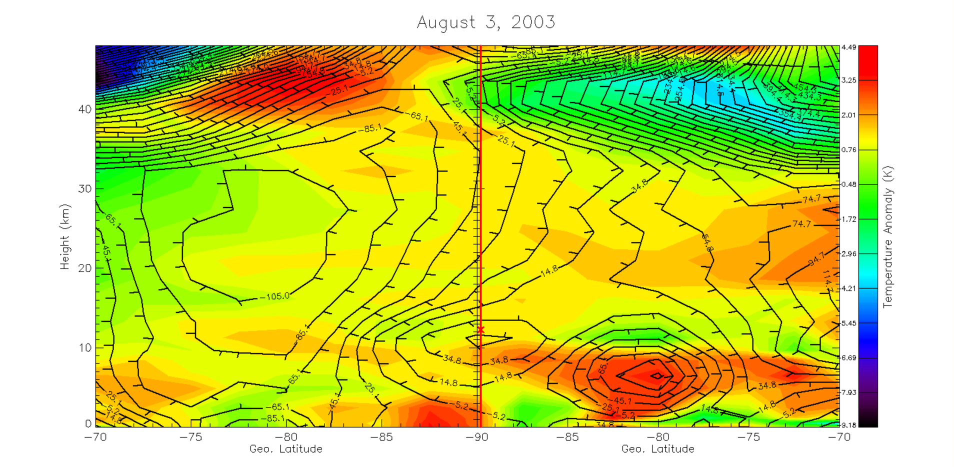
In each and every case, vertical tilt indicative of baroclinic instability is seen right where the waves form!











Conclusions

From these observations and analyses, we have demonstrated conclusive evidence of gravity wave generation by baroclinic instabilities both in the tropopause and the stratosphere. We note the apparent existence of discrete wave-forming layers, though our analysis does not indicate why this may be the case, or even whether this is a physical feature or a result of a limited sample set. To date, an investigation of this phenomenon at this scale has never before been carried out.

Some concerns still remain. Due to the limitation of using a climatological model at high altitudes, and the fact that we are looking at synoptic features forcing of gravity waves, we are unable to investigate wave sources above 50-km, despite evidence of wave forcing between 50- and 90-km occurring at roughly the same frequency as in the stratosphere. We would expect that these waves are driven by the same mechanism, as the polar vortex extends up into this region.

For further reference, see:

Mehta, D., A. J. Gerrard, Y. Ebihara, A. T. Weatherwax, and L. J. Lanzerotti (2016), Mesospheric gravity waves and their sources at the South Pole, *Atmos. Chem. and Phys.*, Atmos. Chem. Phys. Discussions, in review, http://www.atmos-chem-phys-discuss.net/acp-2016-52/

This study was supported by the National Science Foundation with grants PLR-1247975 and 942 PLR-1443507 to the New Jersey Institute of Technology. Access to SPA imager data can be obtained from http://www.antarcticgeospace.org

D. Mehta[1] (dm36@njit.edu), A. Gerrard[1], Y. Ebihara[2], A. Weatherwax[3], L. Lanzerotti[1]

1. New Jersey Institute of Technology-Center for Solar-Terrestrial Research, USA , 2. Research Institute for Sustainable Humanosphere, Kyoto University, Japan, 3. Merrimack College, USA.