A New Imaging Capability for Mesospheric Gravity Wave Research

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Imaging Atmospheric Gravity Waves: The Pioneers

INTERNAL ATMOSPHERIC GRAVITY WAVES AT IONOSPHERIC HEIGHTS

C. O. Hines

ABSTRACT

Irregularities and irregular motions in the upper atmosphere have been detected and studied by a variety of techniques during recent years, but their proper interpretation has yet to be established. It is possible that observational data may be interpreted in terms of a mechanism, namely, internal atmospheric gravity waves, which a spectrum of waves is generated at low altitudes and propagated upwards. The propagational effects of modulation, and dissipation act to change their frequency and increasing height, and to produce different types of waves at higher altitudes. These changes, coupled with an observed periodicity, lead to the various characteristics revealed by the wave formation. The generation of abnormal waves locally seems possible, and it seems able to account for unusual atmospheric phenomena.

Hines, 1960

Peterson and Kieffaber, 1973

Moreels and Hersé, 1977

Panoramic Image

A 10-min exposure of the southwest sky on December 22, 1972, from 15 km west of Albuquerque (1,800 m).
Ex: Imaging Discoveries and Capabilities

- **Circular gravity waves**
  Taylor et al., 1984

- **All-sky imaging**
  Swenson et al., 1995

- **Mesospheric bores**
  Taylor et al., 1995

- **Gravity wave breaking**
  Yamada et al., 2001

- **OH rotational temperature mapping**
  2013
Evolution of Airglow Imagers

- **Video cameras, 1980s**
- **All-sky multi-wavelength imagers, 1990s**
- **New Advanced Mesospheric Temperature Mapper (AMTM):**
  - Gravity wave intensity and rotational temperature perturbations and phase relationship
  - Infrared (1.5-1.65 μm) OH (3,1) bands measurements
  - Precision ~1 K in <30 sec.
  - High latitude capability: emission lines avoid aurora
AMTM Observations at ALOMAR, Norway (69.3°N)

Courtesy K. Bekkelund
OH (3,1) Rotational Temperature Movie:
(ALOMAR, Norway (69°N) Dec 16-17, 2011)

Fine structure in temperature, amplitudes: ~ few-several K
Using “Auroral” Keogram Technique to Study Larger Scale Waves

Uses a sequence of temperature maps

Two Keograms: summarizing N-S and E-W wave activity vs. time.
Keogram: Summary of Wave Activity
ALOMAR - Dec 16-17 2011 (16 hours)

OH (3,1) relative band intensity

OH (3,1) rotational temperature

Movie
Gravity Wave Breaking Event and Rapid Dissipation, ALOMAR, Nov 27-28, 2010

1 image/5 min (data rate 1 image/30 sec)

Note: 11 km wave shedding and GW dissipation within 15 mins
New Evidence of GW Self-Acceleration?

2D direct numerical simulations of a GW “self-acceleration” (SA) event exhibiting “SA” instability

2D and 3D GW instabilities in a 3D direct numerical simulation of a GW “self-acceleration” (SA) event shown with contours of vorticity magnitude and exhibiting “SA” instability

Fritts et al., 2013
Systematic increase in observed GW phase speed at OH layer (~87 km)

Uniform, then slowly decreasing GW intrinsic phase speed
Large Mean Wind Acceleration in the MLT in the Direction of GW Propagation

Event duration 20:15-20:55 UT
Initial Development of an Apparent 2D Instability at Smaller Spatial Scales Parallel to GW
Subsequent Development of 3D-Like Instabilities and Small-Scale Turbulence
Summary: GW Self-Acceleration

1) Large mean wind acceleration in the MLT in the direction of GW propagation
2) Corresponding increase in observed GW phase speed at the OH layer altitude (~87 km)
3) Uniform, then slowly decreasing, GW intrinsic phase speed
4) Initial development of an apparent 2D instability at smaller spatial scales in the plane of the GW
5) Subsequent 3D instabilities and turbulence at smaller scales.

Fritts et al., 2013
Challenging the Models!
Wave Interactions and Instability Development - (5 hours) June, 2012, USU
Stay tuned
Gravity Wave Breaking - Jun 06th, 2013
Logan UT (41.7°N)

\[ P_1(2) \text{ line of the OH (3,1) emission} \]

- Exposure time 10s
- 1 image every 30 s
GW Breaking Details - Logan, Jun 6th, 2013

5 to 10 km instability structures
Gravity Wave Breaking Model

Fritts et al., 2009: Spanwise and vertical 3D views (left and right) of vortex structures (yellow/red is high vorticity) at 10 buoyancy periods ($T_b$) in a DNS of GW breaking. Initial instabilities lie along the GW propagation.

GW breaking observed in the P1(2) line of the OH (3,1) band from Logan, UT, on June 6th, 2013
Advanced Mesospheric Temperature Mapper (AMTM) for High-Latitude Research

- Novel instrument: uses NIR (0.9-1.65 mm) InGaAs detector coupled to a specially developed large format (120° FOV) fast (f/1) telecentric optics
- One system operated at Amundsen-Scott South Pole Station since the 2010 Austral winter
- Second AMTM fully operational at ALOMAR, Norway, since Jan 2011
OH Temperature Mapping Over Utah using Keograms
AMTM measurements since January 2011

ALOMAR, Norway (69°N)
Gravity Wave Breaking Event and Rapid Dissipation, ALOMAR, Nov 27-28, 2010

250 km

1 image/5 min (data rate 1 image/30 sec)

200 km

Note: 11 km wave shedding and dissipation within 20 mins
Evolution of the Airglow Imagers

- Video camera (1980s)
- All-sky multi-wavelength imager (1993)
- Mesospheric Temperature Mapper (1997)
- IR all-sky imager (2009)
- Advanced Mesospheric Temperature Mapper (2010)
USU Imaging Research at South Pole

- New Advanced Mesospheric Temperature Mapper (AMTM):
- Gravity wave intensity and temperature perturbations and phase relationship
- Infrared (1.5-1.65 μm) OH (3,1) and (4,2) bands measurements
- Precision ~1 K in <30 sec.
- Emission lines avoid auroral contamination
Evolution of a GW Undergoing Self-Acceleration and Instability