Observations of High Frequency GWs observed in mesospheric airglow, and the implication to the GW imposed zonal stress and the residual circulation

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Introduction

• The background atmosphere and meridional circulation
• OH and mesospheric airglows, and altitude weighting functions, I’/I
• Directional statistics, and methods

[Globally, the meridional component is toward the summer pole, at OH emission altitudes]

• Momentum flux, methods of determination from airglow
• Freely propagating versus damped
• Momentum flux, statistical summary from a Brazilian study
• Summary
The Lower and Middle Atmosphere

Created by A. J. Gerrard, 10/99, based heavily on M. R. Schoeberl's depiction.
Atmosphere with Motion

Figure 12.2 Observed monthly and zonally averaged temperature (K) and zonal wind (m s⁻¹) for January. (Based on Fleming et al., 1990.)
Residual Meridional Circulation

Quasi monochromatic gravity waves—ever present

\( \lambda_x = 28 \text{ km} \)

\( C_g = 40 \text{ m/s} \)

\( C_i = 40 \text{ m/s} \)

\( \lambda_z = 28 \text{ km} \)

\( \sigma \sim \pm 10 \text{ km} \)
Dispersion Relationship

\[ m^2 = \frac{(N^2 - \omega^2)}{\left(\omega^2 - f^2\right)} k^2 - \frac{1}{4H^2} \]

Wave domain plot, intrinsic phase speed vs horizontal wavelength, versus vertical wavelength
Airglow Layers

![Diagram showing Airglow Layers](image)

**Table 1. Calculated Values of Centroid and Thickness (FWHM) for Undisturbed and Standard Deviation Profiles**

<table>
<thead>
<tr>
<th></th>
<th>Unperturbed Profile</th>
<th>Standard Deviation Profile</th>
<th>Variation</th>
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<tbody>
<tr>
<td></td>
<td>Centroid Height</td>
<td>FWHM</td>
<td>Centroid Height</td>
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<tr>
<td>O(1S)</td>
<td>97.3 (km)</td>
<td>9.3 (km)</td>
<td>94.3 (km)</td>
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<td>O_3(b)</td>
<td>95.0 (km)</td>
<td>9.4 (km)</td>
<td>92.1 (km)</td>
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<td>OH</td>
<td>89.9 (km)</td>
<td>10.9 (km)</td>
<td>86.8 (km)</td>
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Vargas et al. (2007)
GW Statistics

Propagation Direction

Momentum Flux vs. Prop. Direction

Maui, HI  Tang et al. (2005)

Cachoeira Paulista, BR  Vargas (2007), Phd Theses
# List of References

<table>
<thead>
<tr>
<th>Site</th>
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<th>GLon</th>
<th>Refs.</th>
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<td>74.7</td>
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<td>-</td>
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Meridional Propagation Direction
Northern Summer
Meridional Propagation Direction
Northern Summer
Meridional Propagation Direction
Northern Winter

- Resolute Bay
- Calgary
- Mill Stone Hill
- Esrange
- SOR
- Urbana
- Rikubetsu
- Shigaraki
- Maui
- Cariri
- Cachoeira
- ALO
- Rothera
- Halley
- Kototabang
- Tanjungsari
- Wyndhan
- Adelaide

Map showing the meridional propagation direction during the Northern Winter.
Meridional Propagation Direction

Northern Winter
Dissipation of GWs

Fritts (1984)
Dissipation of AGWs (Airglow)

Spatial Series

wave amplitude decreasing with altitude

Vargas et al. (2011), in preparation
Modeled MF Divergence
Dissipating AGWs

\[
\frac{\partial \overline{u}}{\partial t} = -\frac{1}{\overline{p}} \frac{\partial (\overline{\rho \langle u'w' \rangle})}{\partial z} \sim -\langle u'w' \rangle_{\text{top}} + \langle u'w' \rangle_{\text{bottom}}
\]

Vargas et al, (2007)
Measured Flux Divergence
Dissipating AGWs ($I'/I \geq 1\%$)

Flux Divergence OH-O($^1S$) Hourly Average
Cachoeira Paulista, BR
Southern Hemisphere

Vargas (2007), Phd Theses

Summary

• A globally distributed set of ground-based observations has been analyzed for the winter and summer directions of wave propagation.

• There is experimental evidence that wave forcing is globally significant and opposite to the summer-winter residual meridional flow, predominantly propagating toward the summer pole.

• AGW stress acting against the meridional flow imposes a deceleration which biases the magnitude of the meridional circulation (underestimates).
Residual Meridional Circulation Tracers Transport

H.-L. Liu (2007)

Tides and AGWs


Two-Day Wave
Figure 17.10 Radiative-equilibrium (a) temperature and (b) zonal wind in the middle atmosphere during solstice, as calculated in a radiative–convective–photochemical model. Thermal structure adapted from Fels (1985). Zonal wind calculated from thermal wind balance and from climatological motion at 20 km in Fig. 1.8.
Dissipation of AGWs (Lidar)

Na Lidar Scans @ São José dos Campos, BR

Damped AGW
Amplitude decreasing with altitude

Vargas et al. (2011), in preparation
Dissipation of AGWs (Lidar)

Phase quadrature between $T'$ and $w'$ is lost when AGW is dissipated.

Fig. 8. Time history of vertical wind and temperature for a high frequency wave on Dec. 7, 1999. (Bottom) 86 km and (Top) 94 km. Vertical wind and temperature have the same scale.

Swenson et al. (2003)