Analyzing Interactions Between Atmospheric Waves

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**RESEARCH OBJECTIVES**

1. Understand the mechanics behind solar thermal tides
2. Explore the nature of waves in a model of the atmosphere
3. Determine the extent of non-linear wave-wave interactions present in the model
4. Demonstrate the complexity that is introduced by non-linear wave interactions

**ORIGINS OF ATMOSPHERIC WAVES**

- Terrestrial weather affects weather in the upper atmosphere
- Thermal tides excited in the lower atmosphere propagate to higher altitudes
- Linear and non-linear interactions produce secondary waves
- Planetary waves influence space weather, which can affect:
  - Communications, guidance, and navigation systems
  - Satellite orbits
  - Re-entry of spacecraft and orbital debris
- Waves on other planets can be modeled similarly

**MATHEMATICAL METHODS**

- Least Squares Fitting
- Spectral Analysis

**MODELING ATMOSPHERIC WAVES**

Atmospheric waves are periodic, and are thus modeled with Sine and Cosine equations.

- Solar thermal tides are referenced by their period, direction of propagation, and zonal wave number
  - Ex. DW1: 24-hour period, propagates to the west, zonal wave number of 1
- The below equation represents an atmospheric wave:
  \[ A \cdot \cos(\omega t + \delta_\Omega \lambda - \phi) \]
- Two-dimensional least squares fitting generates the coefficients
  - Temperature data is fit to the above equation

**RESULTS**

Interactions between primary waves and secondary waves are called sidebands, and are identified using 2-D spectra of wave amplitude.

Sidebands are identified by the following formula:

\[ \cos(\delta t \tau + m\lambda) \cdot \cos(\Omega t + \lambda) = \cos((\Omega + \delta\Omega) t + (s + m)\lambda) + \cos((\Omega - \delta\Omega) t + (s - m)\lambda) \]

Modulation of a Primary Wave

First, prominent primary waves are identified:

Then, sideband calculations are performed to determine which sidebands are present. The inter-dependence of the three waves below demonstrates that the wave interact non-linearly.

**DATA**

- Temperature and wind data is taken from the Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model
  - Developed by High-Altitude Observatory at the National Center for Atmospheric Research
  - MERRA (Modern-Era Retrospective Analysis for Research and Applications)
- 3-D time-dependent model of the Earth’s upper atmosphere
- Analyzing data from April 2009

**CONCLUSIONS**

- The nonlinear interactions between primary waves add complexity to the atmospheric profile
- The primary waves to continue studying for April 2009 are DW1, DW2, DE3, and UFKW
- Further research is necessary to fully understand the impact of non-linear wave-wave interactions

**FURTHER RESEARCH**

- Complete identification of wave-wave interactions
  - Determine the latitude vs. height structures of all primary waves and sidebands in the model
  - Classify all waves as primary or secondary
- Evaluate the spatial-temporal complexity produced by the non-linear wave-wave interactions

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