Exploring the Ripples of Earth’s Upper Atmosphere: Waves & Tides

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*Special Thanks to Dr. Federico Gasperini

Ask questions!
Exploring the Ripples of Earth’s Upper Atmosphere: Waves & Tides

Variability in the Thermosphere

Atmospheric Waves

Observation of Wave Field
Variability in the Thermosphere

- Absorption of Solar EUV Radiation

Sources:
- Courtesy of Dr. L. Frank, the University of Iowa
- Courtesy of the NCAR HAO and COMET

GOLD ASEN 6519 – Special Topics: Upper Atmospheres Prof. Jeff Thayer Fall 2012
Variability in the Thermosphere

SOURCES

- Absorption of Solar EUV Radiation
- Particle Precipitation
- Joule Heating

Particle Precipitation

Joule Heating

Magnetosphere-Ionosphere Current System

Pedersen currents

Hall currents

Courtesy of the NCAR HAO and COMET

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In the last decade evidence has shown that terrestrial weather significantly influences the ionosphere-thermosphere system.

**Sources**

- Absorption of Solar EUV Radiation
- Particle Precipitation
- Joule Heating
- Dissipation of Upward Propagating Waves
The primary mechanism through which energy and momentum are transferred from the lower atmosphere to the upper atmosphere and ionosphere is through the propagation of waves.
Atmospheric Waves

**Kelvin Waves**
- Propagate to thermosphere
- Time scale: 2-20 days
- \( \lambda_x \approx \) Earth’s circumference

**Rossby (Planetary) Waves**
- Do not easily propagate to thermosphere
- Time scale: 2 to >30 days
- \( \lambda_x \approx 1\text{-}1000 \text{ km} \)

**Thermal Tides**
- Time scale: 1/3 to 1 solar day
- \( \lambda_x \approx \) Earth’s circumference

**Gravity Waves**
- Propagate to thermosphere
- Time scale: min-hrs
- \( \lambda_x \approx 1 \text{ to } >100 \text{ km} \)
Atmospheric Waves

The focus is on **Thermal Tides** and **Gravity Waves**, waves responsible for coupling the lower atmosphere to the upper atmosphere and ionosphere.

**Kelvin Waves**

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**Gravity Waves**

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Atmospheric Waves

Thermal Tides

➢ The primary mechanism of excitation: periodic heating of the atmosphere by the Sun

\[
\sum_{s=-k}^{s=k} \sum_{n=1}^{N} A_{n,s}(z, \theta) \cos(n \Omega t + s \lambda - \phi_{n,s}(z, \theta))
\]

- \(z = \text{height}\)
- \(\theta = \text{latitude}\)
- \(\Omega n = \text{frequency}\)
- \(\Omega = \frac{2\pi}{24}\)
- \(t = \text{UT time}\)
- \(s = \text{zonal wavenumber (s>0 to west)}\)
- \(\lambda = \text{longitude}\)
- \(\Phi = \text{phase}\)
Atmospheric Waves

Thermal Tides

- The primary mechanism of excitation: periodic heating of the atmosphere by the Sun

\[
\sum_{s=-k}^{s=k} \sum_{n=1}^{N} A_{n,s}(z, \theta) \cos(n\Omega t + s\lambda - \phi_{n,s}(z, \theta))
\]

- Global waves observed in measurements like Temperature and Wind
- Waves with \( s = n \) are referred to as migrating tides, follow the apparent motion of the Sun
- Waves with \( s \neq n \) are referred to as non-migrating tides
The primary mechanism of excitation: periodic heating of the atmosphere by the Sun.

$$ \sum_{s=-k}^{s=+k} \sum_{n=1}^{N} A_{n,s}(z,\theta) \cos(n\Omega t + s\lambda - \phi_{n,s}(z,\theta)) $$

### Standard Nomenclature

- **$DWx$ ($DEx$)** to denote a westward- (eastward-) propagating diurnal tide with zonal wavenumber $x = s$
- For semidiurnal and terdiurnal tides $S$ and $T$ replaces $D$

#### Diurnal Eastward-propagating Tide with $s=3$, or $DE3$

- Major driver of the wave-4 structure in the ionosphere/thermosphere
- Excited in the tropical troposphere by latent heat release in deep convective clouds
- Large source of variability in the MLT (up to 30 K, or 20 m/s)

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**Atmospheric Waves**

**Thermal Tides**
The primary mechanism of excitation: periodic heating of the atmosphere by the Sun.

Atmospheric Waves
Thermal Tides

- The primary mechanism of excitation: periodic heating of the atmosphere by the Sun.
Atmospheric Waves

**Gravity Waves (GWs)**

- Gravity and Buoyancy are the restoring force for air parcels
- Local Waves
- Play an important role in coupling the lower atmosphere with the middle and upper atmosphere

Not to be confused with Gravitational Waves
Atmospheric Waves

Gravity Waves (GWs)

Atmospheric Waves

Nonlinear Wave Interactions

\[
\cos(\sigma_1 t + s_1 \lambda) \cdot \cos(\sigma_2 t + s_2 \lambda) \rightarrow \cos((\sigma_1 + \sigma_2) t + (s_1 + s_2) \lambda)
\]

Secondary Wave 1
\[
\cos((\sigma_1 + \sigma_2) t + (s_1 + s_2) \lambda)
\]

Secondary Wave 2
\[
\cos((\sigma_1 - \sigma_2) t + (s_1 - s_2) \lambda)
\]

Primary Wave 1
\[
\cos(\sigma_1 t + s_1 \lambda)
\]

Primary Wave 2
\[
\cos(\sigma_2 t + s_2 \lambda)
\]

Nonlinear Forcing Region
Observation of Wave Field

*Ground-based methods*

**Incoherent scatter radars**
- MLT temperatures and winds at 100-120 km, but only in intervals of 2 to 10 days

**Resonance lidars**
- Temperatures and winds both day and night, but not continuously

**MF and meteor radars**
- Winds between 80 and 100 km

**Passive optical methods**
- MLT temperatures and winds, but are restricted to nighttime

**Advantages**
1. Ability to distinguish waves over short time periods
2. Information on vertical structure

**Disadvantages**
1. Lack of information on the latitude-longitude structure
2. Inability to distinguish between global- and local-scale waves
Observation of Wave Field

Historical Side Note

Studying Thermal Tides with... Grenades

Review lecture - Rocket studies of atmospheric tides
Advantage

- **Latitude-longitude coverage** – The lower the inclination, the more rapid the orbit precesses with respect to the Sun (e.g., 120 days for $i = 70^\circ$)

Disadvantages

- **Sampling** – Due to inherent variability of atmospheric system within the 24-hour local time coverage

- **Aliasing** – Zonal mean and other longer-period waves can alias into the derived tidal field and be perceived as local time changes
Observation of Wave Field

Space-based methods

Advantage

- **Local Time coverage** – Observes waves as they develop and change in place, separating time and spatial variability

Disadvantages

- **Longitude Coverage** – Cannot observe far side of the Earth and complicates derivation of tides

Geostationary Satellites

*Constant Longitude*
Observation of Wave Field

*Initial GOLD Observations*
• Variability in the Thermosphere is due to both incoming energy from above (the Sun) and from below (atmospheric weather)

• Thermal Tides and Gravity Waves help connect the lower and upper atmosphere

• We use different observational techniques to sense waves and tides from the ground and space
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Questions?