Atmospheric Gravity Waves in the Ionosphere and Thermosphere During the 2017 Solar Eclipse

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Eclipse-Induced Bow Waves

• Absence of heating source becomes a moving perturbation source. When the footprint moves supersonically, a bow-wave front is formed.

• GNSS network observed both bow-wave front and the trailing gravity waves.

[Chimonas, 1970]

[Eckermann et al., 2007]

[Zhang et al., 2017]
Global Ionosphere-Thermosphere Model (GITM)

**Features:**
- Self-consistent global circulation model for the upper atmosphere
- Non-hydrostatic solutions
- Flexible 3D grids

**Solar Eclipse Simulation:**
- **Time:** 13:30–23:30 UT, Aug 21, 2017
- **Global simulation** with resolutions of 2°x0.5° in geophysical longitude and latitude **0.3 of the scale height** between **100–600 km** altitude.
- Differences between control and eclipse runs are considered as consequential effects by eclipse.

[Image of solar eclipse simulation with title and scale height information]

Methodology

[Lin et al., 2017]
The obscuration factor is set to be 10% at totality.

EUV flux is assumed uniform across the solar disk, a simplified setup.

The ionosphere-thermosphere responses are extracted at 2 ground station locations: Missouri (MO), and Massachusetts (MA), at 5-sec cadence. The former station underwent totality and a partial eclipse of 60% at the latter station during the peak time.

Methodology

Lin et al., 2018

Marriott et al., 1971

Huba and Drob, 2017
Waves in the IT System

- **Electron density (right column):**
  - < 230 km: decrease peaks at totality
  - > 230 km: ~30 min delay in maximal decrease

- **Neutral density (left column):** Maximal decrease occurred ~30 min after totality started.

- IT responses at totality location show strong wave features.

- High-frequency waves are observable clearly in the neutral density profiles at the totality station because the sharp transition of the change rate of EUV obscuration factor.

[Lin et al., 2018]
Periodicity: Short-Period Waves

Strong waves < 20 min: resulting from the sharp gradient of the obscuration

>1 hr: Capturing the large-scale ‘cavity’ during the eclipse

Neutral Density

Electron Density

[Lin et al., 2018]
Wave Activities in Vertical Total Electron Content (VTEC)

- Savitzky-Golay (3-degree, 0-order) low-pass filter to separate the large-scale and small-scale structures.
- Longer-period waves (gravity waves) sustain hours after eclipse ended.
- Compared with measurements:
  - Bow-wave front
  - Trailing waves within the bow
  - Negative zone spans ~20° x 20°
Summary & Conclusions

• Lack of thermospheric heating is sufficient to induce bow waves.

• Strong high-frequency wave components \((T < 30 \text{ min})\) are observable in both I&T at the totality stations but absent from the partial-eclipse station.

• The supersonic moving shadow results in a bow-wave front and trailing gravity waves seen in VTEC. Large-scale variability has an elongated tail and small-scale variability reveal wave structures within a negative zone spanning \(~20^\circ \times 20^\circ\).

• Gravity waves sustain hours after eclipse ended.