MSTIDs observed with SuperDARN

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• MSTIDs at low latitudes — How I cast my lot with the motley crew.
• MSTIDs at high latitudes.
• AGWs and MSTIDs observed with SuperDARN.
• Outstanding Science Questions
Equatorial Irregularities at Hawaii

Percentage of nights with bubbles > 400 km at CNFI

Percentage of nights with backscatter > -10dB at CXI

Percentage of TIMED/GUVI orbits with bubbles

Kp and 10.7-cm solar flux

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Climatology of low-latitude MSTIDs

- Climatology from Haleakala, HI, 2007–2009 (after Makela and Miller, 2010).
- Preference for solstices (shared with $E_s$, not shown).
- Associated with VHF backscatter (FAI) and bubble formation.
• Wavelike structures observed on HF links since early radio.
• Called “traveling ionospheric disturbances” (TIDs).
• Dedicated (e.g., CADI, TIDDBIT) stations/arrays deployed to study.
Ionospheric waves (TIDs)

- Radio signature is change in skip distance/focusing due to variations in $F$ region peak altitude and density.
- TIDs eventually classified into
  - Large-Scale (1000s of km wavelength, 100s of m/s velocity); typically associated with geomagnetic activity.
  - Medium-Scale (100s of km wavelength, 10s to 100s of m/s velocity); ubiquitous.
- No particular preference for azimuth or season at higher latitudes.
- Widely attributed to acoustic-gravity waves generated in the auroral zone.
• Dark bands and wave structures observed in 1990s by Mendillo and others.

• Coordinated observations with Arecibo UHF radar indicated height perturbation in $F$-region (cf Behnke, 1979).

• Aligned NW-SE (northern hemisphere), propagate SW.
- Raised regions correspond to minimum airglow, lowered regions to maximum.
- Gravity waves alone unlikely to produce this structure \(\rightarrow\) coupled to electrodynamics.
- But, is this the same as the radio TIDs?
MSTIDs and SuperDARN

- Identify MSTIDs in Boston U.’s airglow images from Millstone Hill, MA ("BUM" on map).
- Examine SuperDARN data from Wallops Island, VA, ("WAL") during same time period.
MSTIDs and SuperDARN

Wallops Island SuperDARN beam #7 - 15 May 2010

Universal Time [hrs]

10500 kHz 14500 kHz

Millstone Hill 6300 - 0240 UT

Doppler [m/s]

SNR [dB]

Virtual Range [km]

0 6 12 18 24

1000 2000 3000 4000

−100 0 100

Geo. Longitude [deg]

−75 −70 −65

Geo. Latitude [deg]

−75 −70 −65

−75 −70 −65

−75 −70 −65
MSTIDs and SuperDARN

- Employ 2.5D HF raytrace similar to well-known Jones-Stephenson code.
- Parabolic ionosphere parameterized by Millstone Hill ionosonde.
- Geomagnetic field from IGRF-11.
- Creates a key to identifying backscatter signatures.
MSTIDs and SuperDARN

- Triple-hop sporadic-\(E\) (G-\(E_s\)) ground scatter 0000–0045 UT.
- Field-aligned irregularity (FAI) scatter from locations where \(\mathbf{k} \perp \mathbf{B}\).
- How to differentiate between FAI-\(F\) and G-\(E_s\)?
MSTIDs and SuperDARN

20 July 2009 - Wallops Island SuperDARN beam #7 - 10.5 MHz

GS-Es
FAI-Fs
FAI-Es

Virtual Range [km]

Universal Time [hr]

SNR [dB]

Doppler [m/s]
Evolution of $E_s \rightarrow FAI-E_s \rightarrow FAI-F$

- 15 May 2010 Wallops Island example again.
- FAI has non-zero Doppler velocity (not 100%, but true for geometry).
- $FAI-E_s$ appears 0040–0120, 0200–0300 UT.
- $FAI-F$ appears out of $FAI-E_s$ around 0230 UT: same time that band structure appears in airglow.
Theory of $E_s \rightarrow FAI-E_s \rightarrow FAI-F$

- Patchy $E_s$ layers $\rightarrow E_p$ (polarization $E$-field).
- Meter-scale irregularities form between patches (sometimes called quasi-periodic echoes, QPE).
- $E_p$ maps efficiently along geomagnetic field, $B$.
- $E_p$ causes $F$ region to become unstable as described by Perkins.
The Perkins Instability

- After *Perkins*, 1973. Updated by *Cosgrove and Tsunoda* to include $E_s$ layer coupling $\rightarrow$ increases growth rate.
- Produces NW-SE aligned structure.
- Linear growth rate too small. Wrong propagation direction.
• After Kelley, 2011.
• Wind-driven currents in gravity waves are cancelled by $E_p \times B$ currents in the preferred Perkins NW-SE (northern hemisphere) orientation.
  • Winds in gravity waves are parallel to the wave fronts.
  • $E_p$ is parallel to the wavevector $\rightarrow E_p \times B$ is also parallel to $k$.
• That is, there is no net current to cause Joule heating that will dissipate the wave’s energy.
MSTID vs MSTAD

- **MSTAD**: traveling *atmospheric* disturbance
  - Acoustic-gravity wave.
  - Period of 1s to 10s of minutes.
  - Ubiquitous at high-/mid-latitudes. No seasonality has been established.

- **MSTID**: traveling *ionospheric* disturbance
  - Mid-latitude, nighttime phenomenon.
  - Electrified (appear in opposite hemispheres). Propagate westward and toward the equator.
  - Frequently concurrent to sporadic-\(E\) layers.
  - Strongly seasonal (share solstice peaks with \(E_s\) layers).
  - Also observed at very low (equatorial) latitudes during deep solar minimum.
  - Origin unknown.
Future Directions

- Understand role of $E_s$ layers in initiating MSTIDs.
  - Standard SuperDARN may not work for this.
  - Arecibo ISR with heater and imagers might help image $E_s$ layers (Bernhardt).
- Get more all-sky imagers collocated with SuperDARN radars $\rightarrow$ sky conditions.
- Explore MSTID signatures in spacecraft optical data
  - DMSP/SSUSI and TIMED/GUVI UV (Comberiate)
  - DMSP/SSUSI visible (Miller, unreported)
- Investigate whether Kelley’s theory holds (better than Perkins’) at very low latitudes.