MSTIDs observed with SuperDARN

E. S. Miller and E. R. Talaat

APL

Geospace and Earth Science Group
Johns Hopkins University Applied Physics Laboratory

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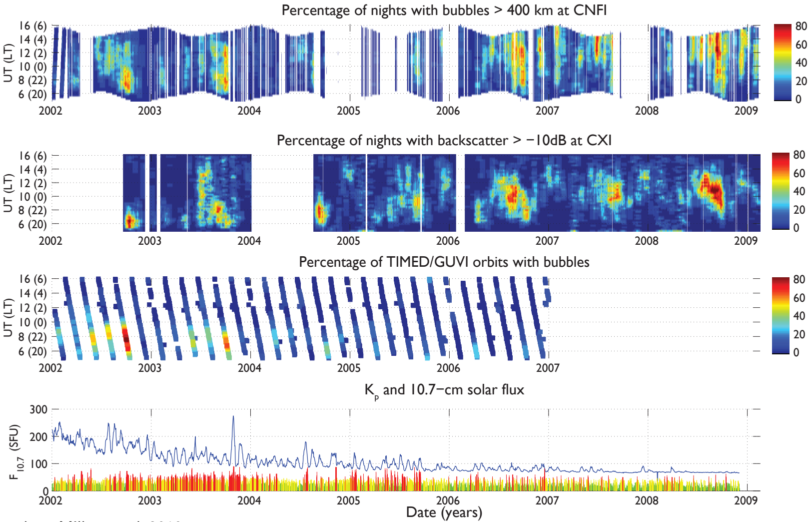
Outline

- 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



based on *Miller, et al*, 2010.

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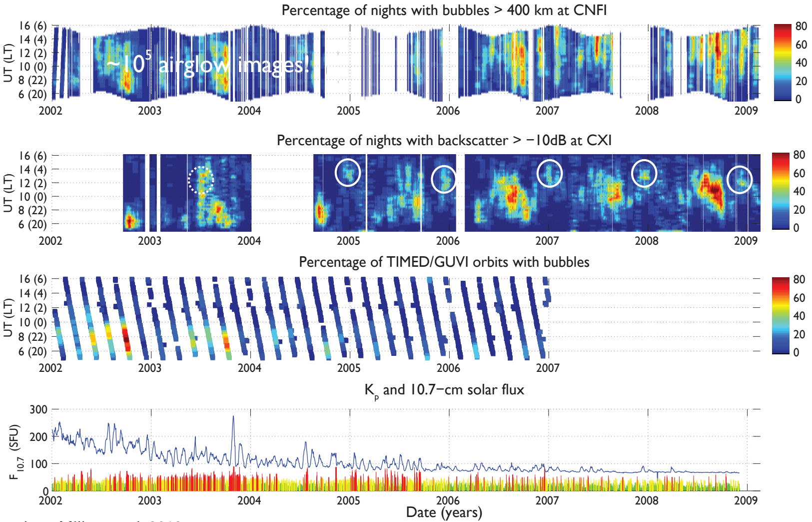

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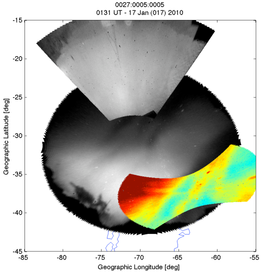
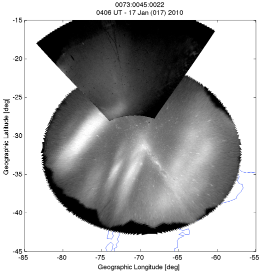
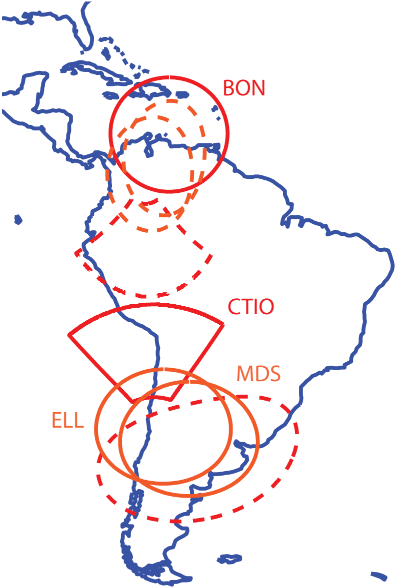
Conjugacy of MSTIDs

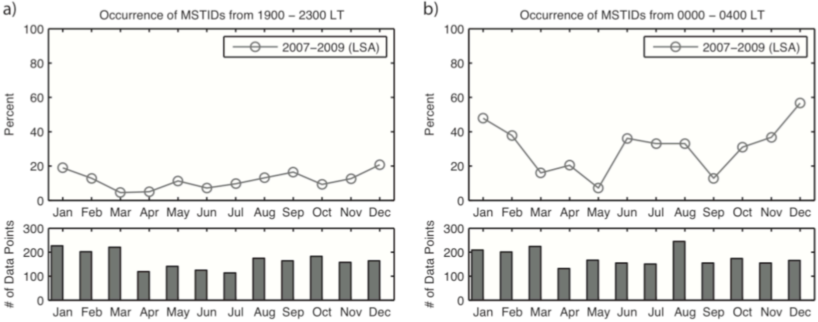




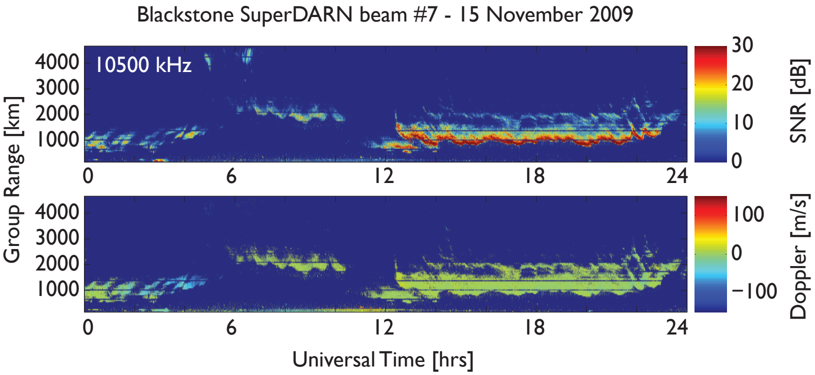


Climatology of low-latitude MSTIDs

- 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.



Ionospheric waves (TIDs)

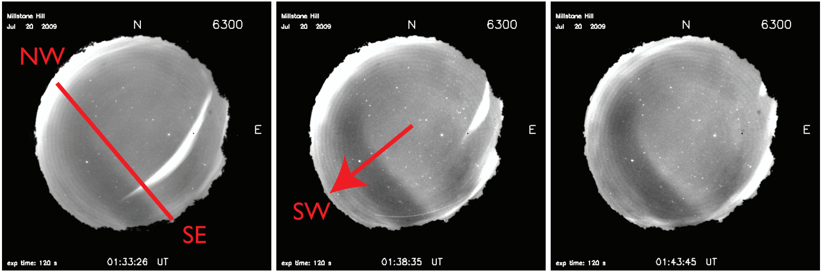


- Wavelike structures observed on HF links since early radio.
- Called "traveling ionospheric disturbances" (TIDs).
- Dedicated (e.g., CADI, TIDDBIT) stations/arrays deployed to study.

Ionospheric waves (TIDs)

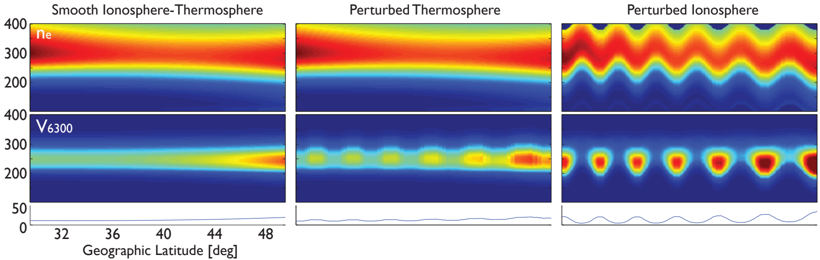
- Radio signature is change in skip distance/focusing due to variations in F region peak altitude and density.
- TIDs eventually classified into
  - Large-Scale (1000s of km wavelength, 100s of m/s velocity); typically associated with geomagnetic activity.
  - Medium-Scale (100s of km wavelength, 10s 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.

Airglow Bands — MSTIDs



- 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.

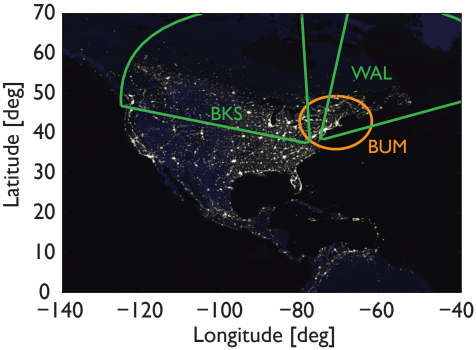
Airglow Bands — MSTIDs



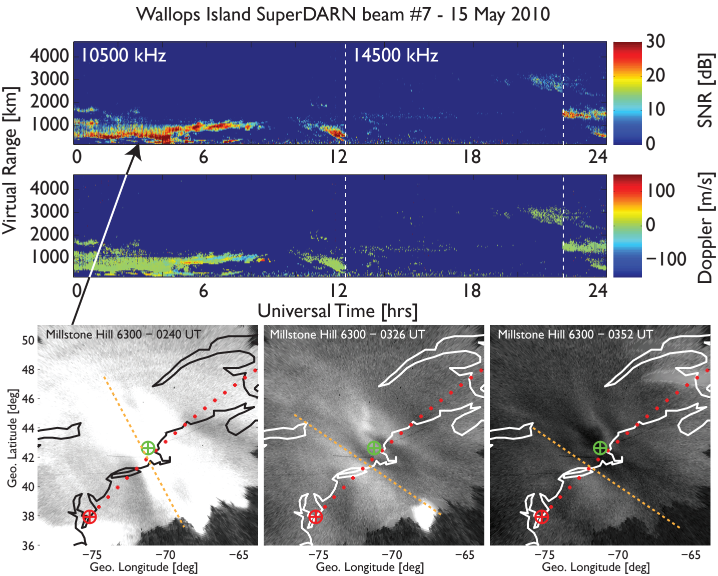
- Raised regions correspond to minimum airglow, lowered regions to maximum.
- Gravity waves alone unlikely to produce this structure $\rightarrow$ coupled to electrodynamics.
- But, is this the same as the radio TIDs?

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.

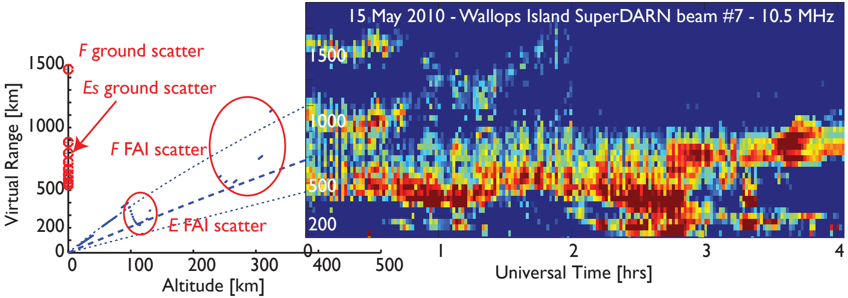


MSTIDs and SuperDARN



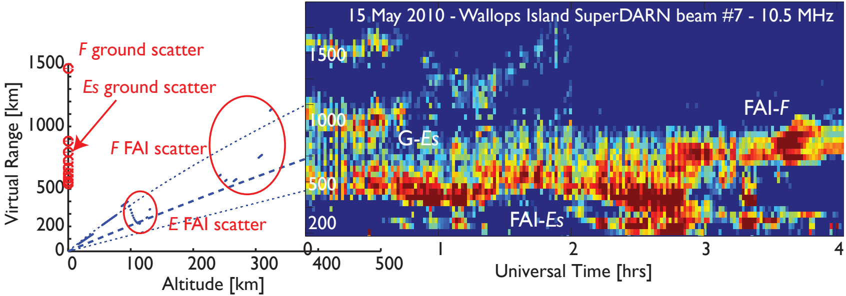
MSTIDs and SuperDARN

- 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.

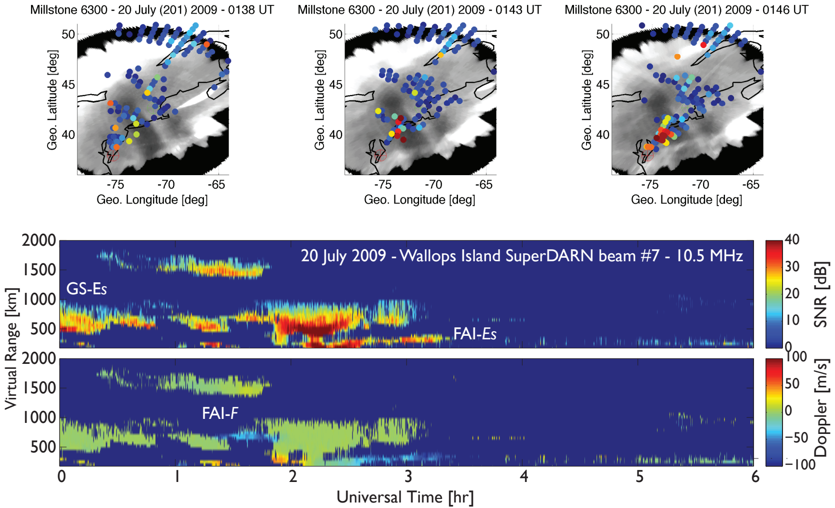


MSTIDs and SuperDARN

- 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?

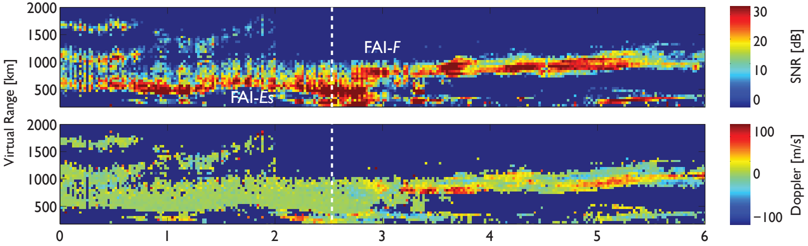


MSTIDs and SuperDARN



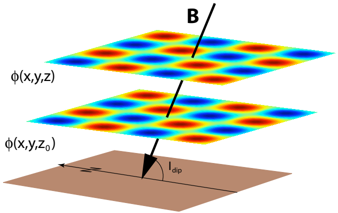
Evolution of $E_s \to$ FAI-$E_s \to$ FAI-F

- 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.

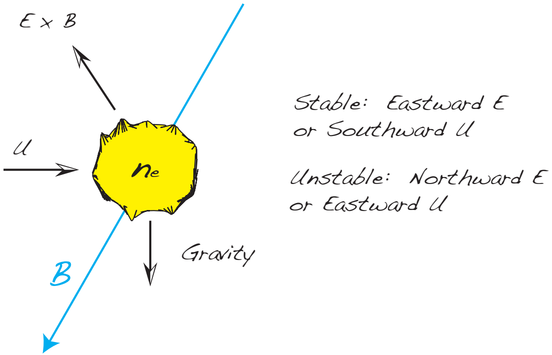


Theory of $E_s \rightarrow$ FAI-$E_s \rightarrow$ FAI-F

- Patchy E_s layers $\rightarrow$ $\mathbf{E}_p$ (polarization **E**-field).
- Meter-scale irregularities form between patches (sometimes called quasi-periodic echoes, QPE).
- $\mathbf{E}_p$ maps efficiently along geomagnetic field, **B**.
- $\mathbf{E}_p$ 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 → increases growth rate.
- Produces NW-SE aligned structure.
- Linear growth rate too small. Wrong propagation direction.

An Alternative Theory

- After *Kelley*, 2011.
- Wind-driven currents in gravity waves are cancelled by $\mathbf{E}_p \times \mathbf{B}$ currents in the preferred Perkins NW-SE (northern hemisphere) orientation.
  - Winds in gravity waves are parallel to the wave fronts.
  - $\mathbf{E}_p$ is parallel to the wavevector $\rightarrow \mathbf{E}_p \times \mathbf{B}$ is also parallel to $\mathbf{k}$.
- 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.