Medium Scale Traveling Ionospheric Disturbances (MSTIDs) – A Heliophsyics 2050 Roadmap

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Scientific Motivation

The formation and development of Medium Scale Traveling Ionospheric Disturbances (MSTIDs) is compelling because of the immediate practical implications for communications and geolocation. Additionally, the dynamics and interplay between the thermosphere and the ionosphere creating and resulting from these structures is still unresolved. MSTIDs are wave-like propagating disturbances in ionospheric plasma which have horizontal scales sizes of hundreds of km and periods of 30-60 minutes. Observations of these ionospheric structures were reported over 70 years ago [e.g., Munro, 1950], but the unpredictable nature of their occurrence and lack of global measurements, as well as the lack of measurements of the proposed drivers, have complicated efforts to understand how and why these features form in the ionosphere.

The most commonly observed type of MSTID (or AGW-TID), which are believed to be caused by Atmospheric Gravity Waves (AGWs), which may originate in the troposphere or from secondary sources in the mesosphere. A second type of MSTID has also been observed and is sometimes referred to as an "electrodynamic" MSTID (or Electrified-TID), as these structures are accompanied by large electric fields [Crowley and Rodrigues, 2012]. Typically, daytime MSTIDs are assumed to be AGW-TIDs [e.g., Frissell et al., 2016, and references therein], whereas nighttime MSTIDs are thought to be Electrified-TIDs in most cases. Nevertheless, AGW-TIDs can also occur in the nighttime. The primary differentiating characteristic between the two types of MSTIDs, however, is that Electrified-TID wavefronts align themselves from the northwest to the southeast and propagate southwestward towards the equator (in the northern hemisphere), as shown in Figure 1.

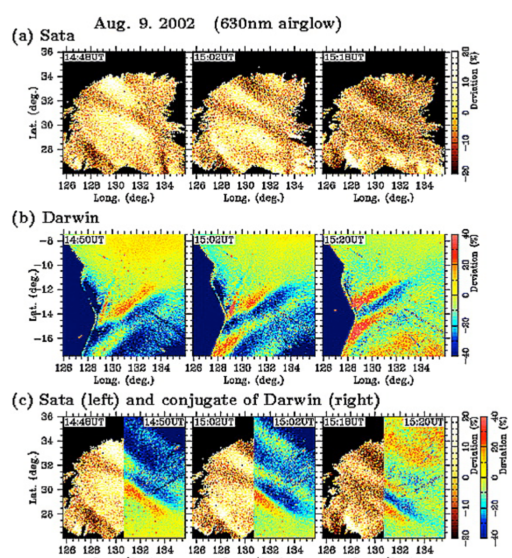

Figure 1: Simultaneous observations of an MSTID on conjugate field lines in both hemispheres [Otsuka et al., 2004]

AGW-TIDs, on the other hand, can propagate in any direction and the wavefronts do not align in a preferred direction (ie, equatorward). For example, AGW-TIDs propagating from a convective thunderstorm will appear in concentric rings from the storm [Azeem and Barlage, 2018]. While decades of research have made significant progress in the identification of MSTIDs, **many questions remain regarding the mechanisms responsible for their formation, the assumptions used in the mathematical description, and their impact on ionospheric electrodynamics**.

Open Questions

Recent observations and model studies complicate this proposed clear-cut distinction between AGW-TIDs and "Electrified-TIDs." Huba et al. [2015] examined AGW-TIDs generated by the Tohoku-Oki tsunami of 11 March 2011 and found that a conjugate effect can be generated from this acoustic source, indicating that AGW-TIDs can have an electrified component. Jonah et al. [2017] observed daytime MSTIDs over the Brazilian sector with a conjugate effect, also indicative of this electric component.

The Perkins instability is frequently cited as a potential mechanism for generating Electrified-TIDs [Kelley, 2011; Perkins, 1973]. Despite successful simulations, there are two major, unexplained issues with the assumption that the Perkins instability is responsible for Electrified-TID formation: the Perkins instability has a very low growth rate so the modes develop very slowly and simulations have not been able to produce structures that propagate in the observed direction [Duly et al., 2014]. **Two potential mechanisms that may play a role in enhancing the growth rate are Sporadic-E layers and neutral winds in the thermosphere** [e.g., Narayanan et al., 2018].

Given these gaps and the relative scarcity of observations, the following open questions have been identified:

1. What are the physical conditions required for an MSTID to exhibit conjugate behavior?
2. Are there observable local distinctions between MSTIDs driven by AGWs and electrodynamic effects?
3. What are the long term variations in MSTID activity?

Roadmap to 2050

Near term goals (2020–2025):

- Maximize use of existing measurements, including distributed ground-based instruments and CubeSat missions. Addresses 1.
- Deep dive into physics models to understand and separate mechanisms to identify future missions and campaigns. Addresses 1 and 2.

Mid-term goals (2025–2035):

- The Geospace Dynamics Constellation as outlined in the Science and Definition Team Report provides many of the required measurements, including plasma density and winds. During the development of this mission, the community needs to work together to identify how to expand and enhance complementary measurements (such as ground-based networks and CubeSat missions) to maximize the impact. Addresses 1 and 2.

Long-term goals (2035–2050):

- Continue to expand measurement networks based on the results. Addresses 3.

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