WP1: Strategy and Capabilities

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A Word on Terminology

- **TID warning**
  - prediction of an upcoming disturbance 2+ hours in advance, based on (1) monitoring of the helio- and geospace activity and intelligent-system (IS) models of the anticipated global response of the ionosphere or (2) statistical expectations of the regional MSTID occurrence;
- **TID alert**
  - forecast of an upcoming or ongoing disturbance with less than the 2-hour horizon, based on objective *TID-in-progress* detections and a short-term forecast of its trajectory of travel and wave dissipation rate;
- **TID report**
  - backcast of TID for end-users to *re-analyze* their previous data with a better specification of the ionosphere.

A Word on Terminology

TID Type	T, min	Λ, km	ΔNe/Ne	Vp, m/s	Underlying phenomena
Large scale (LS)	>60	600-1200+	60-80%	400-10,000	Aurora brightening during geostorms
Medium scale (MS)	20-60	50-600	5-30%	100-300	Lower atmospheric and surface forcing, including tropospheric weather events (typhoons, tornados); also tsunami
Acoustic shock wave	1-10	200-600	1-5	800-2,000	Natural and anthropogenic impulsive hazardous events such as earthquakes, volcanic eruptions, explosions, or rocket launches
Intermediate scale (IS)	1-10	1-50	1-20%	-	Spread-F
Small scale (SS)	1-10	0.1-1	1-5%	-	Scintillation of satnav UHF signal

General T-FORS Challenges

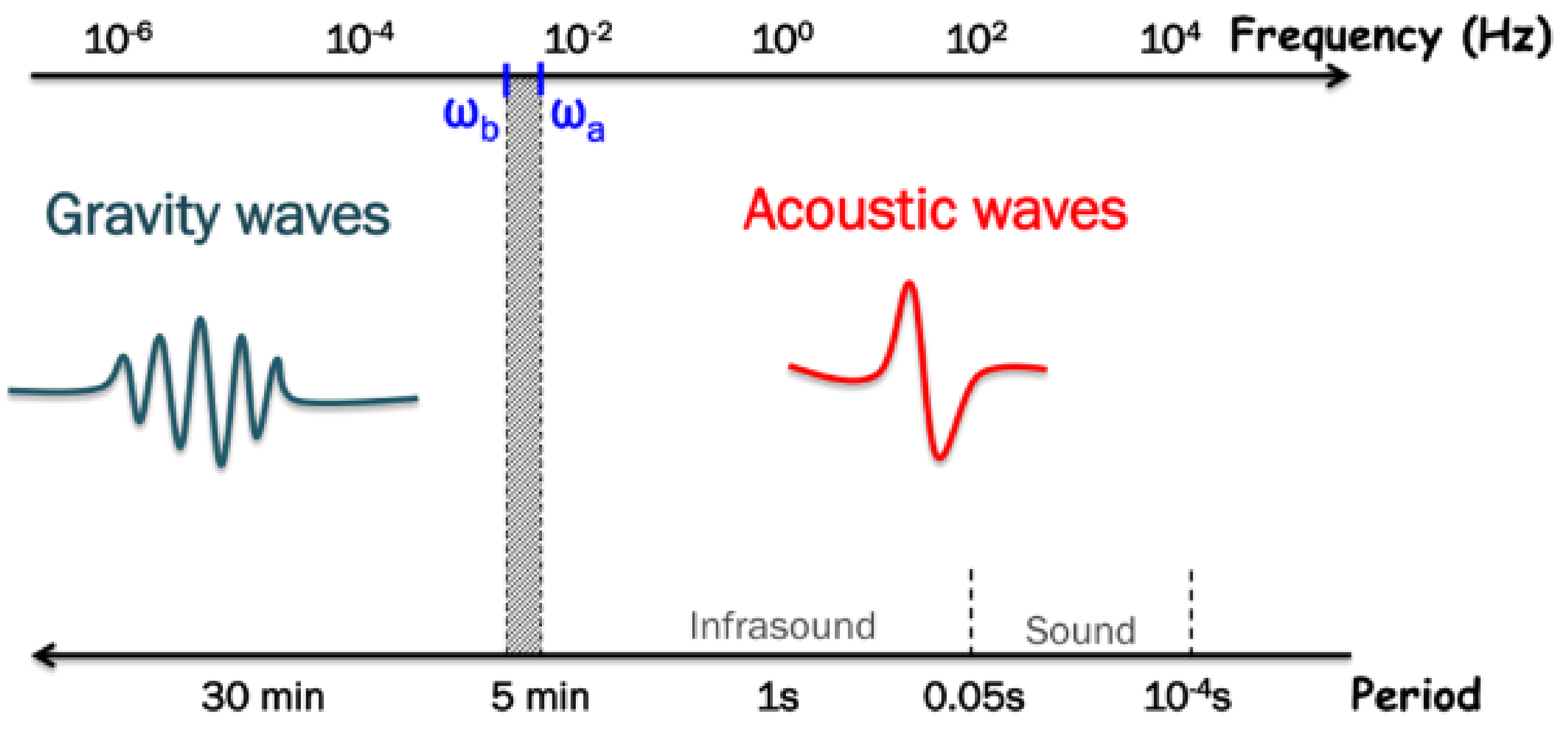


Figure 1. Frequency and period ranges for acoustic and gravity waves. The frequency ω_a is commonly called "the acoustic cutoff frequency" indicating that acoustic waves with $\omega > \omega_a$ propagate through the atmosphere. The frequency ω_b is the Brunt-Väissälä frequency (or buoyancy frequency). Waves with frequencies below the ω_b are the gravity waves. In the lower atmosphere, the acoustic cutoff frequency is typically 3.3 mHz, and ω_b is 2.9 mHz. Waves with frequencies $\omega_b < \omega < \omega_a$ (shaded rectangle) are called evanescent waves and can only propagate horizontally.

after Astafyeva [2019]

- Hines[1960] : IAGW as a single TID generation mechanism
  - Two AQW branches, depending on the wave period
  - Earthquake: acoustic wave
  - Tsunami: gravity wave
- **Known problem: AGW dynamics is different from TIDs**
  - AGWs are better understood but more difficult to sense remotely
  - AtmoSense program (US): use the neutral lower atmosphere, not ionosphere to backtrack AGWs to their sources
    - Vector Aero-seismometer on balloons

General T-FORS Challenges: forecast

Large-scale TIDs

- Multi-link chain of events that lead to TID generation
  - Most common: brightening of auroral oval during geostorms

TID Propagation may not be isotropic

Medium-scale TIDs

- Many sources and physical mechanisms for TID generation
- Because of AGW-TID presumed relationship, this translates to
  - Specifying AGW -> TID generation
  - Travel of AGW from the source
    - Horizontal
    - Vertical to the ionospheric heights
  - Identify AGW source site
  - Forecast seeding event at the source

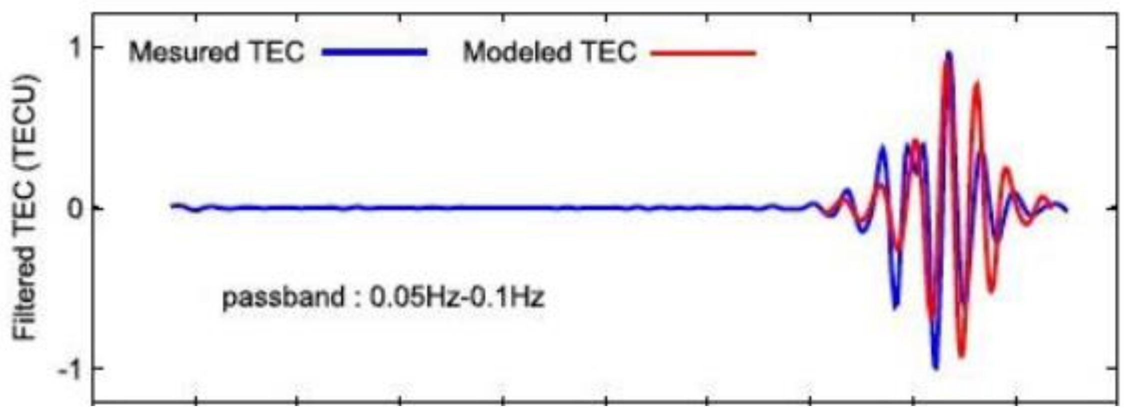
General T-FORS Challenges: Nowcast

- Vast spaces: difficult to get good spatial coverage of sensor data
  - Only fragmented/sporadic sensing available
- “Ionospheric weather service”: transition to operations is hard
  - Fully automatic, “glass-room” operations
  - No “person-in-the-loop” capability
    - All intelligent data interpretation must be automated
    - Data noise problem… conditioning is required
  - Near Real-time demand
    - Problem: latency from data collection to TID specification
      - sometimes time window of 1 wave period is needed to catch it

TID Nowcast Tools

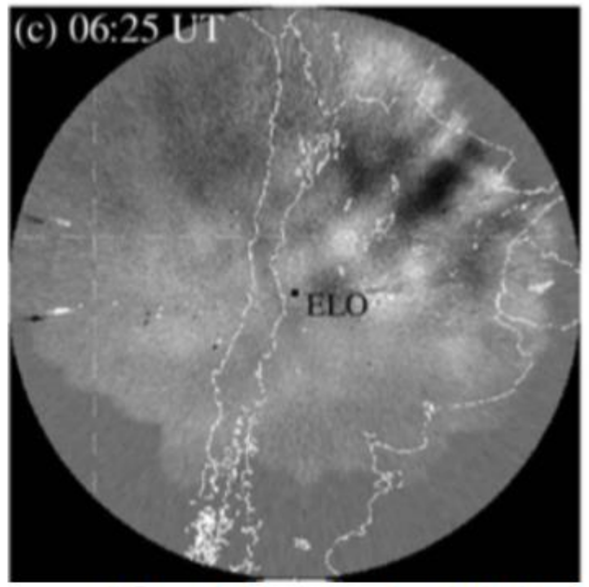
IN TIME DOMAIN

- Wave is seen as a variation in time
  - Can be combined with triangulation to sense the direction of travel

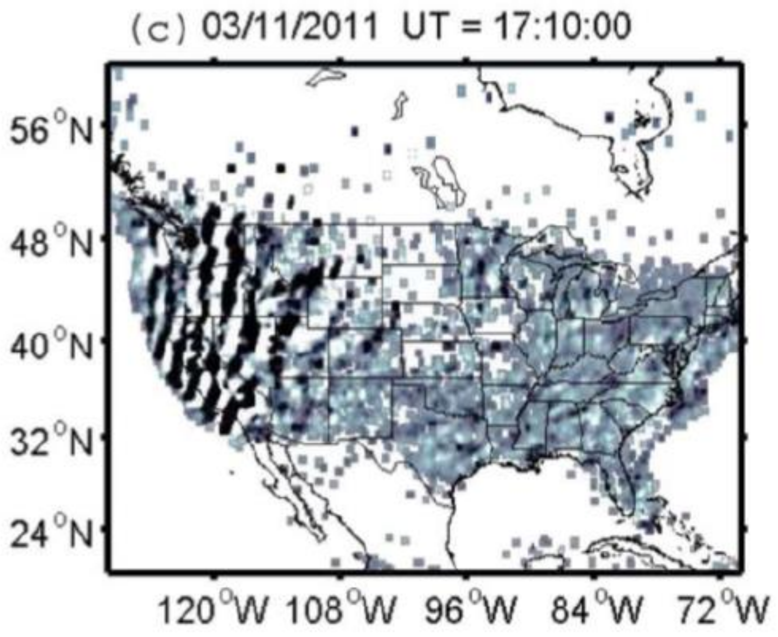


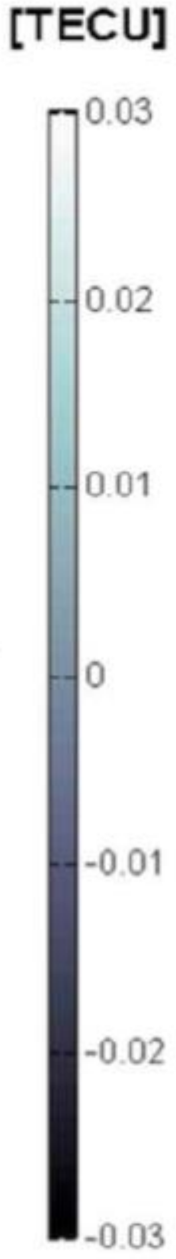
IN SPACE DOMAIN

- Wave is seen as a variation in space
  - Frame-to-frame for the direction of trave



[Smith et al. 2015]





[Crowley et al. 2016]

T-FORS Sensor Toolbox

- Detection in time
  - Ionosonde networks
    - HF-Int method: variation of MUF(3000), triangulation -- LSTID
    - HF-TID method: based on FAS and Digisonde-to-Digisonde links – LSTID, some MSTID
    - MSTID and SSTID signatures in ionograms (model training and comparisons only)
    - Detrended isodensity contours
  - CDSS (Doppler radar)
    - MSTID and SSTID (infrasound) in multi-node short-range networks, with triangulation
  - GNSS
    - Detrending of TEC requires time window for analysis
  - LOFAR
    - SSTID
  - Ground barometers for AGW/MSTID detection

T-FORS Sensor Toolbox

- Detection in space
  - GNSS Networks
    - Maps/animations/keograms/hodocrones of detrended TEC (dTEC) – a rich dataset!
    - Includes SPIRE
  - All-sky Cameras
    - Nighttime only for comparisons
  - Swarm (2015-2022)
    - For comparisons and model training
  - Ground backscatter radar (GBSR)
    - monitoring skip distance

Forecast of TID propagation

- Once detected and characterized, TID can be promoted in time
  - Horizontal phase velocity and travel azimuth are needed
    - These can be provided automatically
  - Several research questions about TID propagation are left unanswered
    - Waveguide GW vs free-form “hopping” AW propagation
    - AGWs are isotropic and TIDs are not
    - Wavelength increases with the distance traveled
    - Cutoff of propagation can be observed

Azeem et al. [2017]
Huang et al. [2019]
Fedorenko et al. [2013]

TID short- and long-term Warnings

- General impression is “not much is available”
  - DLR: statistical index A_{TID} for mid-latitudes (solar wind drivers)
    - Borries et al. JASTP [2023]

Helio- and Geospace Activity

- Important to know the context of detected TIDs
  - TID may be the least of the upcoming problems
    - Scintillation and loss of lock
    - D-region absorption
    - Plasma losses and MUF depression
    - Significant plasma restructuring in the vertical dimension
- A suite of helio- and geospace indicators are available
  - e.g., ESWD repository
- Custom models and indices
  - SWIF

Thank you for your attention!

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