The Role of Ground-Based Observations in M-I Coupling Research

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Outline

- Some Definitions: Magnetosphere, etc.
- Space Weather
- Ionospheric Disturbances
  (M-I Coupling Effects)
- Class I Facilities
- DASI: Distributed Arrays
- Multi-Technique System Studies
Earth's Magnetosphere

- Bow shock
- Interplanetary magnetic field
- Cusp
- Magnetotail lobe
- Plasma mantle
- Plasma sheet boundary layer
- Cross-tail current
- Field-aligned current
- Ring current
- Convecting plasma
- Low-latitude boundary layer
- Dayside magnetopause current
- Magnetopause

Solar wind
Aurora: Energized Particles from Magnetosphere Enhance Ionospheric Conductivity within Auroral Oval
Weather in Earthspace

- Earth’s Magnetosphere – Ionosphere – Atmosphere form a **Coupled System**

- The **medium consists of magnetized plasmas** whose dynamics are controlled by electric fields and currents

- Distributed ground-based instruments and space-based imaging are providing **new perspectives and understanding**

- Severe Space Weather effects arise from **processes** which span these upper-atmosphere regions

- A **predictive capability is needed** to protect our assets in space
Space Weather Effects
Space Weather: Ionospheric Scintillation
(One Person’s Noise Is Another’s Data)

Scintillations disrupt signals important for communications/navigation systems.

Unstable plasma within the Earth’s ionosphere results in irregularities in refractive index.

Scintillations occur when radio waves pass through a turbulent ionosphere, reducing signal quality.
MIT Millstone Hill Incoherent Scatter Radar

Scanning Radar Probes Ionosphere and Space Weather Disturbances

Radio-Wave Remote Sensing
ISR Observes Storm Enhanced Density

log10 Density [10.25,12.25] (m$^{-3}$) SED February 6, 1986 17:45 UT

[Telemachus, JGR, 1993] Millstone Hill IS Radar
Radars Measure Ion Velocity and Map
Convection Electric Field \( (V \sim E \times B) \)

Electric Field Maps Between Ionosphere and Magnetosphere
Today's Weather: NEXRAD
Observations of Storm Front over N. America
Analysis & Understanding are Well Developed
Ground-Based Observations using GPS TEC

Image Space Weather Storm Fronts

[Foster et al. GRL 2002]
GPS samples the ionosphere and plasmasphere to ~20,000 km. Dual-frequency Faraday Rotation Observations give TEC (Total Electron Content).

TEC is a measure of integrated density in a 1 m$^2$ column.

1 TEC unit = $10^{16}$ electrons m$^{-2}$
Observations: GPS TEC

GPS TEC Map from 20-Nov-2003 15:00:00 to 20-Nov-2003 15:10:00

Log10(TEC)
Observations of the Plasmasphere
IMAGE EUV observations:
SED Plumes accompany Plasmasphere Erosion

2001/101/21:10
range: 5.32 RE  S/C latitude = 60.22

April 11, 2001
Footprint of Erosion Plume in the Ionosphere & Magnetosphere
CEDAR Class I Facilities

MIT Haystack Observatory

Millstone Hill Observatory

Firepond Optical Facility

Millstone Hill Radar
Modern Instruments (Radar/ Lidar: AMISR)
DASI Overview

- The NAS Solar and Space Physics Decadal Survey has recommended that the next major ground-based instrumentation initiative be the deployment of arrays of space science research instrumentation.

- DASI arrays will provide continuous real-time observations of Earthspace with the resolution needed to resolve mesoscale phenomena and their dynamic evolution.

- Ground-based arrays will address the need for observations to support the next generation of space weather data-assimilation models.

- The time is right for DASI: developing technology and IT systems support a new science capability.
Imaging Meso-Scale Phenomena with Distributed Observations
1. **Insufficient Observations**

   Observational space physics is data-starved, producing large gaps in our ability to both characterize and understand important phenomena. This is particularly true for Space Weather events, which often are fast-developing and dynamic, and extend well beyond the normal spatial coverage of our current sensor arrays.

2. **Geospace as a System**

   Geospace processes involve significant coupling across atmospheric layers and ‘altitude boundaries’, as well as coupling across multiple scale sizes from global (1000s km), to local (10s km), to micro-scale (meter-scale and smaller).

3. **Real-Time Observations**

   Elucidation of the fundamental coupling processes requires continuous real-time measurements from a distributed array of diverse instruments as well as physics-based data assimilation models.
Current Arrays: Limits on Global Coverage & Real-Time Access (e.g. GPS Receivers)

Issues:
Logistics & International Participation
Lowell Digisonde
October 15-16, 2002
Cachimbo
Auroral Processes: Distributed Imagers (Themis)
Thermosphere-Ionosphere Coupling

Optical Imagers View Atmospheric Waves
Distributed Instruments (HF Radar: SuperDARN)
20 Nov 2003 2030 UT log TEC [5,200] (TECu)

TEC Plume Mapped to Equatorial Plane
Ground-Based Imaging of Magnetosphere
SED Plumes generate strong SuperDARN HF Backscatter on April 11, 2001 (> 40 dB).
Ground-Based Observations: Polar Tongue of Ionization

Noon

20 Nov 2003
19:45:00 UT

Midnight
Intercepted Signals for Ionospheric Science

Multirole Coherent Software Radio Network

Multistatic Active and Passive Radar, Radio Scintillation Studies, RF monitoring

Cluster Computer Operational!

ISIS Array Node Assembly Has Started!

First Node Deployment to Greenbank Radio Observatory
Summer 2005; Deployment Supported by MIT Lincoln Lab
Multistatic Active Radar with MIT Millstone Hill Radar
140 Foot Telescope at Greenbank
DASI Report: Important Issues

- **Education**: Distributed instruments and R-T publicly-accessible data provide **extensive opportunities**.
- **State of the art IT systems** will be needed to realize the DASI architecture.
- **SYNERGY**: RT access to **different types of data** will enable new science arising from their **combination**.
- Instrument types and their Deployment should be **driven by the needs of the science**.
Magnetosphere
Ionosphere
Atmosphere
Coupling