The WVU Magnetometer

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1. Introduction

- Magnetic field measurements, $\mathbf{B}(\mathbf{x},t)$, are essential in determining the properties of local or distant geospace plasmas as well as their dynamics.

- A fluxgate (vector) magnetometer is the standard instrument for measuring the full vector field. Other types of magnetometers measure time variations of the field.

- Currently several hundred fluxgate magnetometers, as either individual instruments or parts of arrays, are deployed around the world, especially in high-latitude areas. Specially manufactured magnetometers are flown on spacecraft.
Magnetic Field: Sources and Variability

- Sources: External (ionospheric, magnetospheric) and internal (induced, ground) currents. Main current systems of interest are:
  - Ring current
  - Cross-tail current
  - Magnetopause current
  - Equatorial electrojet
  - High-latitude currents (electrojets, Birkeland/field-aligned, etc.)

- Amplitude:
  - Field intensity in N. America: ~0.5 μT (0.6 G).
  - Fluctuations: 1-200 nT
  - Desired resolution: <0.1 nT

- Temporal variability:
  - From <1 sec (waves)
  - to several years (solar cycle)

- Spatial coherence:
  - Regions of high correlation of sizes from 1 km to 1 R_E.
2. Space Science Objectives

- Local geomagnetic field measurement
- Integration with magnetometer array (MEASURE)
- High-latitude geomagnetic disturbances: convection and magnetospheric substorms
- Mid-latitude geomagnetic disturbances: magnetic storm development, radiation belt electron flux dynamics, and plasmaspheric density estimation
- Contribution to space weather forecasting
2a. Modeling the magnetospheric dynamics based on meridional-array measurements

- To distinguish between changes in amplitude versus proper motion of current systems, networks of magnetometers are needed.
- Meridional arrays are useful in monitoring spatial extent and proper motion of current systems.
- The main meridional array on the East Coast is UCLA/IGPP’s MEASURE (Magnetometers along the Eastern Atlantic Seaboard for Undergraduate Research and Education) longitudinal magnetometer array is the first permanent magnetometer chain developed to routinely measure the field line resonance (FLR) frequency at low to mid-latitudes.
- A magnetometer in northern West Virginia is a natural extension of the southern part of MEASURE.
2b. Complex magnetospheric dynamics

- The substorm: the basic storage-release global mechanism in Earth’s magnetosphere

- Considerable interest in understanding timing and spatial development of substorm over several decades

- Substorm location possible through magnetic-bay current wedge analysis
2c. Magnetospheric Field Modeling

- IMAGE magnetometer array.

- Magnetometers deployed over the LAT range of 58-79° (MLAT: 54-75°).

- The number of magnetometers has steadily grown over time, reaching 27 in recent years.

- The database currently spans 21 years of 10-sec three-component field measurements.

- Models of the geomagnetic field and its response to the solar wind have been developed from magnetometer measurements [Vassiliadis et al., 2002, 2007].
The Method of Virtual Magnetometers

- Method for developing a spatiotemporal model from meridional magnetometer array [Vassiliadis et al., 2002]

- Couple VM methodology to a nonlinear model for local $B_x$ and thereby obtain the local-field response to interplanetary activity.
Field Model: Real-time Operation and Verification

- Present model driven by geomagnetic indices (NASA/GSFC)
- Future versions of model to be driven by solar wind/IMF key parameters
- Observed vs. predicted fields compared for each array station.
- Example substorm event: Jan 1, 15:00 UT to Jan 2, 3:00 UT, 2003.
- Verification metrics: Correlation coefficient and nrms pred. error.
2d. Ultra-Low-Frequency Waves and Radiation Belt Electron Dynamics

- Radiation belt electron acceleration and transport remains one of the oldest and most important questions in space plasma research.
- The distribution of ULF wave power and its response to solar wind structures is key for understanding several fundamental acceleration mechanisms.

Figure 1. (a) Sketch of an electron drift path in a compressed dipole, with electric fields indicated for a toroidal oscillation in an $m = 2$ mode. (b) Radial drift velocity, radial electric field, and rate of change of energy seen by a resonant particle starting at local dawn.

[Elkington et al., 2003]

[Vassiliadis et al., 2007]
2e. Plasmaspheric Density Estimation: Cross-Phase Technique

- The cross-phase technique uses the measurements from two latitudinally spaced magnetometers to identify the local field line resonance (FLR) frequency at the station mid-point.

- The FLR frequency is inverted with 1-D model to infer density variations: magnetospheric at mid-latitudes and coupled M-I densities at low latitudes.
3. Education and Public Outreach

• At WVU:
  – Real-time magnetic field activity broadcast over WWW
  – Mention of experiment in selected physics and astronomy courses
  – Public lectures on interrelated space physics-astronomy topics in planetarium, other WVU venues

• At NRAO (suggested):
  – Geospace exhibit in visitor center
  – Brochure/handout
  – Collaboration with NRAO’s relevant ongoing EPO projects

• Outreach to secondary education:
  – Web-related classroom project
4. Synergistic Activities @WVU

• Lab plasma groups:
  – Emphasis on concepts common to lab and geospace plasmas:
    • Magnetic reconnection
    • Fluid and kinetic instabilities
    • Conserved quantities (magnetic helicity)
    • Self-organization

• Radioastronomy group:
  – Emphasis on common concepts:
    • Magnetospheric structure
    • Complex, multivariate dynamics
    • Development of data analytical and modeling tools
5. The instrument and its deployment

- Manufacturer: UCLA
- Sensor: Magnetometer in the THEMIS series
  - Ring core with toroidal drive winding
  - Mounting inside dual solenoid (sense/feedback coil)
  - High-stability 1% parts
  - 20-bit ADC
- Temperature control
  - Heater
  - Oil bath
  - Insulator
- Operations software written in LabView
  - Time domain window (two ranges)
  - Power spectrum (based on FT)
  - Dynamic spectrum
  - Temperature
- Data-collection computer (optionally provided)
  - 2 GHz, ~200MB/month, writable CD drive
- GPS receiver antenna (optionally provided)