Tethered Satellites as an Enabling Platform for Operational Space Weather Monitoring Systems

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ABSTRACT – Tethered satellites offer the potential to be an important enabling technology to support operational space weather monitoring systems. Space weather "nowcasting" and forecasting models rely on assimilation of near-real-time (NRT) space environment data to provide warnings for storms events and deleterious effects on the global societal infrastructure. Typically, these models are initialized by a reanalysisthematic model to provide "most probable distributions" of environmental parameters as a function of time and space. The process of NRT data assimilation generally pulls the climate model closer toward the observed state (e.g., via Kalman smoothing) for nowcasting, and forecasting is achieved through a set of forward predictions that are driven by the assimilated NRT parameters. Many challenges are associated with the development of an operational system, from the top-level architecture (e.g., the required space weather observatories to meet the spatial and temporal requirements of these models) down to the individual instruments capable of making the NRT measurements. This study focuses on the latter challenge: we present some examples of how tethers (satellites from 100,000 to 20,000 km) are uniquely suited to address certain shortcomings in our ability to measure critical environmental parameters necessary to drive these space weather models. Examples include long baseline electric field measurements, magnetospheric ionospheric conductivity measurements, and the ability to separate temporal from spatial irregularities in environmental parameters. Tethered satellite functional requirements are presented for two examples of space environment observatories.

- The Near-Earth Space Environment varies over spatial and temporal scale sizes covering many orders of magnitude
- Cross-scale coupling between physics processes often plays an important role in the formation, evolution, and dissolution of each other
- Plasma waves and instabilities imply spatial-temporal complexity, which presents a challenge to separate temporal evolution from spatial propagation and deformation

Motivation

Unique Capabilities of Space Tethers

- Multipoint In Situ Measurements
  - Long Baseline (up to 20 km)
  - Electric field measurements
  - A more efficient VLF antenna for remote sensing (VLF probe of magnetosphere)
  - Fixed distance transmitter/receiver for radio wave probing of ionospheric layers between the two s/c (e.g., via Faraday rotation, phase shift irregularities indicating changes in TEC, etc.)
  - Fixed distance electron gun/imagers for probing ionospheric E region electric fields (e.g., if deployed downward by space plane at 110 m, can image auroral emissions stimulated by downward propagating beam to map near-electric fields)

- Systematic Multipoint Measurements of plasma density

The Science Question

What mechanisms are involved in control of $E_{||B}$?

The Space Tether Solution

Space tethers can make simultaneous multipoint electric field measurements with a fixed separation in distance

- Proven during TSS-1R
- Found asymmetries in density propagations within a large plasma bubble. Important for scintillation.

Example Technique Proven

Measurements to enable Science Closure: A low orbiting 1 km tethered cubesat would provide direct measurements of $E_{||B}$ to within 6 mV/m

Example 1: Auroral $E_{||B}$

Direct Measurements of $E_{||B}$ in auroral acceleration region

Example 2: Plasma Bubbles

Systematic Multipoint measurements of plasma density

Tethers for CubeSats

Enables CubeSats with miniature plasma and/or field sensors

ISS & CubeSat launches

NanoRack launches CubeSats via ISS

Tethered Sounding Rocket Sections

Enables unique observations of space environment (e.g., $E_{||B}$, plasma turbulence)