Development of Space Weather Monitoring System & Statistical Study of GPS Scintillations

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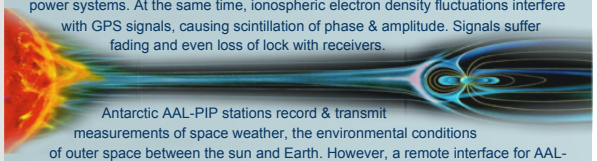
Abstract

Autonomous Adaptive Low-Power Instrument Platforms (AAL-PIP), containing several space weather instruments, were recently deployed in Antarctica. Among the instrumentation on the platforms are magnetometers for measuring magnetic activity and Connected Autonomous Space Environment Sensor (CASES) Global Positioning System (GPS) software-defined receivers for measuring ionospheric scintillation, the diffraction of signal due to electron density in the ionosphere. In order to adequately keep track of the measurement data & the platform, a remote user interface is necessary. In this project, we develop a Graphical User Interface (GUI) that displays daily magnetic activity and GPS scintillation events, as well as housekeeping data to monitor system health. Then, we conduct a statistical study to reveal a correlation between the disturbances in the ionosphere and GPS signal fading. In this study, we find general patterns of the relationship in the recorded data from 24 January 2012 through 7 May 2012 utilizing different sets of data from the AAL-PIP system and reputed solar storm indices.

Background & Motivation

The sun emits a continuous flow of charged plasma particles that permeates through the solar system in a 'solar wind'. Its interaction with Earth causes fluctuations in the magnetic field flux & ionospheric electron densities. Magnetic field fluctuations create phenomena like Auroras & Geomagnetically Induced Current (GIC), which damages power systems. At the same time, ionospheric electron density fluctuations interfere with GPS signals, causing scintillation of phase & amplitude. Signals suffer fading and even loss of lock with receivers.



Antarctic AAL-PIP stations record & transmit measurements of space weather, the environmental conditions of outer space between the sun and Earth. However, a remote interface for AAL-PIP is needed in order to analyze the recorded data. Our goal was to create a monitor system displaying space weather data & AAL-PIP system health, & to study recorded data to explore the solar-storm/GPS-scintillation relationship.

Illustration: NASA

What is AAL-PIP?

Autonomous Adaptive Low-Power Instrument Platform (**AAL-PIP**) is magnetometer/GPS-receiver platform that withstands extreme weather. Currently, 6 platforms operate in the Antarctic Region.

AAL-PIP INSTRUMENTATION

Fluxgate Magnetometer (FGM)
- Measures 3-axes of the DC and AC magnetic field
- DC – static magnetic field due to Earth's internal field
- AC – magnetic activity from external sources (i.e. solar wind)
- Sampling rate of 1 samples/sec

Search Coil Magnetometer (SCM)
- Measures 2-axis of change in magnetic flux over time
- Voltage is drawn across the coil as field undergoes change
- Sensitivity of direction provides details of magnetic field vectors.
- Sampling rate of 10 samples/sec

CASES GPS Receiver
- Dual frequency GPS receiver that measures phase & amplitude scintillations of L1C/A & L2C signals in ionosphere
- Cognitive engine triggers low rate (~1Hz) or high rate (~50-100Hz) data collection based on scintillation activity
- Software defined radio technology provides ability to make updates, switch to power saving modes & collect data remotely.

Statistical Analysis of GPS Scintillation

- GPS scintillation is distortion of GPS signal caused by the diffraction produced as it passes through interference of the ionospheric electron density.
- In polar regions, scintillation is most observed in signal phase (σ_ϕ).
- GPS data from AAL-PIP System 4 in Antarctica (72 days between Jan 24 & May 7 2012).

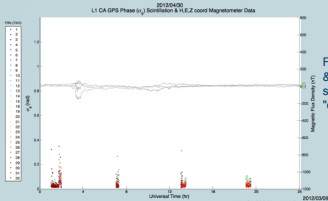


Fig 1. Magnetic activity & Low Rate GPS phase scintillation during a "quiet" non-storm day.

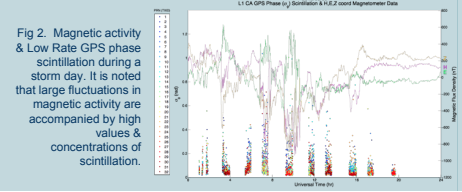


Fig 2. Magnetic activity & Low Rate GPS phase scintillation during a storm day. It is noted that large fluctuations in magnetic activity are accompanied by high values & concentrations of scintillation.

- Findings from comparisons of low rate scintillation with magnetic activity, like Fig 1 (quiet day) & Fig 2 (storm day), indicate a strong correlation between the two

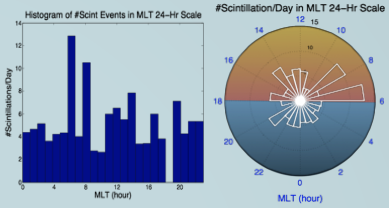


Fig 3 & Fig 4. Cumulative number of scintillations per hour (Magnetic Local Time) during high rate data collection of the whole time period (Jan 24 - May 07).

- Magnetic Local Time (MLT) is a time-zone system based on true geomagnetic coordinates.
- 3.6 hour offset from Universal Time at South Pole.
- By plotting cumulative number of scintillations that occurred each hour in 24-hour MLT scale, as in Fig 3 & 4, found hours of day in which most scintillations were recorded during high rate collection.

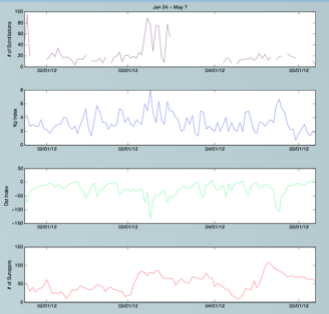


Fig 5. Comparison of daily number of scintillations with daily max Kp & Dst storm indices, as well as number of sunspots

- Kp & Dst are reputed storm indexes whose scales derived from global geomagnetic readings.
- Number of sunspots is a phenomena that is closely related to the sun's magnetic activity.
- Fig 5 displays the relationship of scintillation with Kp, Dst, and sunspots over the period of time, indicating a strong correlation between all.

Development of AAL-PIP Monitoring System

- Development of a new usable interface to track Virginia Tech remote stations in Antarctica, from a server at Michigan University.
- New scientific data is downloaded & displayed on screen daily, along with housekeeping data.

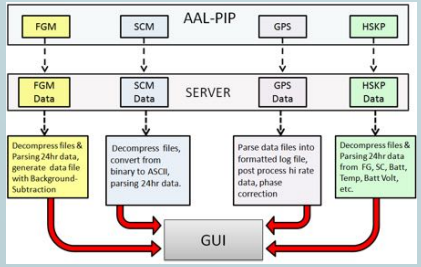


Fig 6. Block Diagram Overview of the data handling from Fluxgate Magnetometer (FGM), Search Coil Magnetometer (SCM), GPS, and Housekeeping (HSKP) to the Graphic User Interface (GUI).

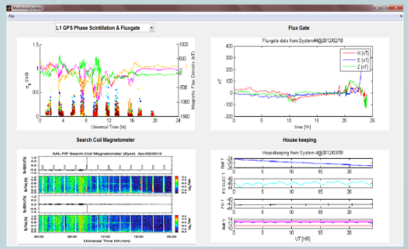


Fig 7. Window of the Graphical User Interface. It displays data from GPS, the Fluxgate, the Search coil and Housekeeping.

- Usability in all ranges mainly to analyze daily events in GPS scintillation and magnetic activity.
- The Interface was developed using MATLAB
- The GUI contains a separate section for each instrument: the GPS CASES, Fluxgate, and Search Coil, as well as Housekeeping to keep track of AAL-PIP system health

Conclusion

We have developed an AAL-PIP Monitoring System GUI that can be utilized to monitor day to day activity, as well as tools to further analyze GPS scintillation. The monitoring system and the analytical tools can be used in conjunction with each other and even integrated for the use of analytical studies. The monitoring system displays daily readings from the fluxgate magnetometer, search coil magnetometer, and from GPS CASES receiver, along with AAL-PIP housekeeping data.

In the statistical analysis of GPS scintillation from Jan 24 - May 7 2012, a higher number of scintillation events occur during the magnetic local daytime, with the most occurring around dawn. The study also revealed a close relationship between the recorded GPS scintillation and magnetic activity caused by solar winds.

Both the GUI & scintillation analysis tools will be utilized to for further research of space weather activity from Antarctica .

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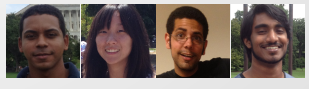

Los Pinguinos