Studies of Ionospheric Irregularities: Origins And Effects

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LONG-TERM GOALS

The long-term goal of this project is to study waves, irregularities, and propagation in the earth's ionosphere, particularly with respect to GPS. The project has two foci: first, to understand how the ionosphere affects GPS signals and second, how GPS can be used for remote sensing of the ionosphere. In association with these goals, we additionally conduct in situ experiments on satellites and sounding rockets to directly measure ionospheric waves and irregularities that affect signal propagation.

SCIENTIFIC OBJECTIVES

The scientific objectives of the project are to:

1. develop GPS receivers for measuring scintillations and scintillation effects on GPS signals and receivers;

2. continue study of the effects of equatorial scintillation storms on GPS through field campaigns, deployment of GPS scintillation receivers at collaborating institutions in South America;

3. extend GPS scintillation measurements to high latitudes by fielding the Cornell GPS scintillation receiver at Poker Flat, Alaska and Longyearbyen, Svalbard;

4. develop new instrumentation for in situ studies of ionospheric irregularities based on the principles of very small payloads (nanosatellites), sounding rocket schedules and cost targets, and multiple (clustered) satellite missions.

Our research focuses on the study of waves, irregularities and wave-particle interactions in space plasmas as well as the effects of these processes on radio signals. The vast majority of the universe exists in a plasma state, including our own upper atmosphere, or ionosphere, which is both a natural

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laboratory for studying space physics and a part of our environment affecting satellites and their signals. If the plasma is collisionless, which applies to our own ionosphere above roughly 150 km altitude, energy exchange and plasma acceleration must be produced by electric fields, usually in the form of plasma waves. The process of energy exchange and plasma acceleration mediated by plasma waves is termed wave-particle interactions.

For many years, wave-particle interactions implied the study of whistler mode waves interacting with radiation belt electrons on closed geomagnetic field lines. Our study is much more general and includes the transverse acceleration of ions, the interaction of ion beams with the ionosphere, the production of auroral electrons, the production of waves by auroral electron beams, and the production and transport of ionospheric irregularities, including those producing scintillations.

APPROACH

We are known for developing unique and ground-breaking experiments and instruments. Our most widely known contribution has been the plasma wave interferometer, first developed on sounding rockets and then later included on such spacecraft as Viking, Freja, Polar, Fast, and Cluster. Another example of new instrumentation developed at Cornell is the intelligent snapshot receiver, which is now popular among many groups and was part of the Freja plasma wave experiment. More recently we have developed GPS receivers, both for making scintillation measurements and for providing time transfer capability on spacecraft.

Our scientific strategy emphasizes experimental development. We have chosen this route because the field of space science, especially the electrical properties of space, is still experimentally limited. Theories of space physics and space plasma physics are quite plentiful, but discriminating measurements are few and far between. Within this context one may well ask what areas need the most attention. The answer concerns nonlinear problems involving plasma waves and electric fields in collisionless environments and turbulent media. Incidentally, these areas are also examples that, at one extreme, can test theories of basic plasma physics and at the other extreme, are important for the development and application of new communication and navigation technologies.

WORK COMPLETED

1. Developed a GPS receiver for measuring scintillations.

2. Conducted one field campaign at the magnetic equator (Ancon, Peru) to measure GPS scintillations using the Cornell GPS scintillation receiver and a dual frequency TEX receiver.

3. Demonstrated that GPS scintillations could be used for measuring ionospheric irregularity drifts at the equator.

4. Demonstrated that velocity resonance could occur between irregularity drifts and GPS signal ionospheric penetration points, thereby greatly lengthening fade periods with major implications for GPS receiver design.

5. Published 12 papers on ionospheric irregularities and plasma waves, which were supported by ONR.

6. Delivered 3 invited reviews and 13 contributed papers at AGU annual meetings and international workshops.

7. (7) Awarded a Ph.D. to one graduate, who subsequently accepted a position with the Air Force Phillips Laboratory in Boston.

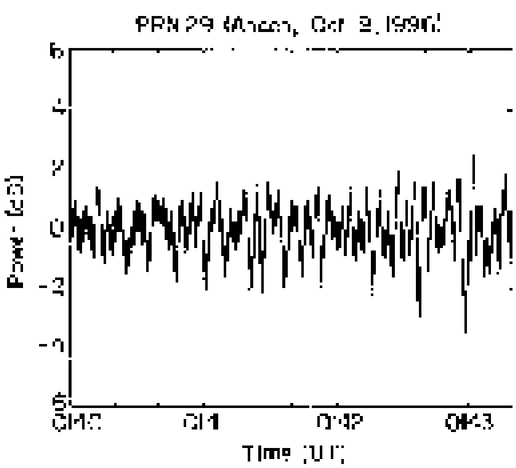
8. (8) Received a Cornell Teaching award for developing a GPS design course in Engineering.

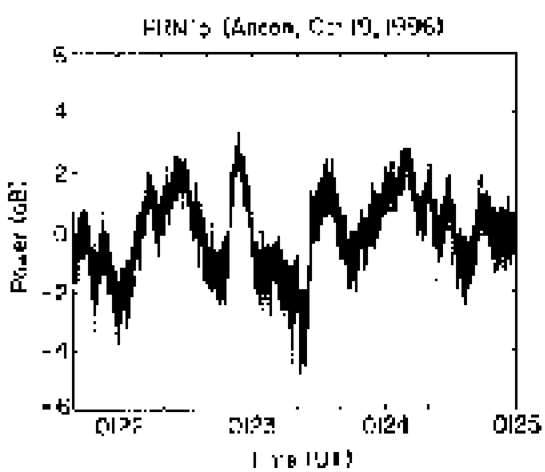
RESULTS

We demonstrated that velocity matching between equatorial spread-F irregularity drifts and GPS signal ionospheric penetration points greatly lengthens scintillation fade periods from seconds to tens of seconds or longer, with major implications for GPS receiver design. Although the velocity matching condition was demonstrated for a stationary receiver, it is not only expected to occur for mobile receivers, but is more likely to occur. This particularly applies to aviation receivers.

An example of the consequences of velocity matching is shown in the accompanying figure. On the left-hand side is an example of scintillations which are not in velocity resonance. The time scale of these scintillations is a few seconds, which a robust GPS receiver can survive. The right-hand side shows how the scintillations change during velocity resonance and in this case the time scales are tens of seconds to a minute. In the presence of larger amplitudes, scintillations, as expected during solar maximum, GPS receivers will likely fail to track signals during the long-period fades.

ONR funding of Cornell satellite instruments, particularly for Viking and Freja, along with NASA funding of Cornell sounding rocket experiments, has recently resulted in a major breakthrough in understanding high-latitude ion acceleration, the mass source for the magnetosphere. Of particular interest is that this breakthrough was made possible by a collaboration with NRL theorist Ganguli and laboratory experimentalists Walker and Amattuci. The critical breakthrough was the realization that the homogeneous theories were not applicable to the space environment and non-homogeneous models must be employed.





IMPACT/APPLICATIONS

The demonstration of velocity matching between irregularity drifts and GPS signal ionospheric penetration points and the subsequent discovery of lengthened scintillation fade periods has major implications for GPS receiver design. Since GPS is a CDMA system, which depends on code correlation to maintain signal tracking, we expect that during periods of velocity matching there will be a greatly increased rate of signal tracking failure, loss of lock, and lengthened acquisition times. Although the velocity matching condition was demonstrated for a stationary receiver, it is not only expected to occur for mobile receivers, but is more likely to occur. This particularly applies to aviation receivers. Where GPS integrity is an issue, this result has major implications.

TRANSITIONS

We will collect GPS scintillation data from several sites across South America to create a regional study of equatorial scintillations. We have selected four sites, chosen primarily because they have existing universities or institutes with ionosphere experts who can operate Cornell GPS scintillation receivers. The sites are:

- Geophysical Institute of Peru (IGP) at Ancon, Peru
- National University at Tucuman, Argentina
- National Institute of Space Investigations (INPE) at Sao Paulo, Brazil
- Northern Federal University at Natal, Brazil

At each site, a senior scientist has been recruited for collaboration who also attended a workshop on GPS scintillations at Cornell this past Spring. Cornell GPS scintillation receivers were provided to each institution, who will operate the receivers on a campaign basis.

One should note that constructing a regional model of equatorial scintillation storms and spread F is a major undertaking and that the chain of Cornell GPS scintillation receivers can only be one aspect of this ambitious objective. We will closely coordinate our work with Boston University, which has similar scientific objectives. They will be collecting and analyzing GPS TEC data from the JPL chain receivers at Arequipa, Bogata, Fortaleza, and Santiago. In addition, BU will be operating an airglow imager at Arequipa, Tucuman.

Additionally we will develop autonomous GPS receivers to conduct GPS scintillation measurements on a continuous basis, as opposed to operating in a campaign mode.

RELATED PROJECTS

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