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The HiLat satellite mission

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On June 27, 1983, USAF satellite P83-1 was launched from Vandenberg Air Force Base carrying the five ionospheric-effects and diagnostic payloads of DNA's HiLat satellite mission. A Scout launch vehicle placed the satellite in an 800-km circular orbit at an inclination of 82°. The HiLat experiments are as follows: (1) a VHF/UHF/*L* band coherent radio beacon for observing complex-signal scintillation and total electron content; (2) a three-instrument cold-plasma package for measuring number density and temperature, their spatial fluctuations, and plasma convection velocity and its fluctuations; (3) an electron spectrometer for detection of precipitating and upwelling electrons with energies between 20 eV and 20 keV; (4) a three-axis magnetometer, and (5) an optical assembly for imagery and spectrophotometry in the vacuum-ultraviolet spectrum and for photometry at two visual wavelengths. With the exception of partial launch damage to the electron sensor (Langmuire probe) in the cold-plasma package, all payloads initially operated as designed. After approximately 40 orbits of data collection, however, the imaging spectrophotometer failed. In spite of this failure, the optical instrument proved the concept of imaging the aurora, at vacuum-ultraviolet wavelengths, under conditions of full sunlight. Its visual-wavelength photometers continue to perform well, as do the other four HiLat payloads. This paper presents early observations from HiLat

OBJECTIVES

A wide variety of C^3I systems can suffer performance degradation due to phase, angle, and intensity scintillations produced in ionospheric plasma-density irregularities. The problem would be exacerbated by enhanced plasma density left after high-altitude nuclear detonations, but it occurs also under conditions of natural disturbance when substantial plasma-density gradients are present. At high latitudes, which we define here as extending from the plasmapause to the poles, the *F* layer is replete with macroscale gradients and with sources of free energy that can cause the neutral, ion, and electron gases to move along and across those gradients. When directional requirements are met, such conditions are unstable to the growth of irregularities throughout a large range of scales.

In the HiLat program, we seek to understand high-latitude structures over the range of scales extending from thousands of km down to tens of meters. Theory and experiment have matured mutually to the stage where such understanding is a realistic goal. Its realization requires physical models of microscale processes, geophysical models of global-scale dynamics, and simultaneous comprehensive diagnostics. The HiLat program is providing in situ measurements of the particles, fields, and currents that can lead to high-latitude irregularities, simultaneously with direct radio beacon observations of the scintillations they produce.

Reliable statistical characterization of the complex-signal (amplitude and phase) scintillation permits design of mitigation schemes. Besides the strength and radio-frequency dependence of the fluctuations (the latter well known), their spatial and temporal spectra are of particular interest.

From an operational point of view, points of concern include the observing-geometry dependence of scintillation, which is dictated by the three-dimensional shape of the irregularities. Beyond this, a useful capability would be an ability to predict when, where, and under what solar-geophysical conditions disruptive levels of scintillation will occur. This is possible now only in a crude, statistical sense.

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TABLE 1. The HiLat Experiments

Payload	Observables	Characteristics	Experimenters
Beacon	scintillation TEC	138, 390, 413, 436 MHz 1239-MHz reference circular polarization	Carlson et al. (AFGL) Forsyth et al. (UWO) Fremouw et al. (PDNW)‡ Rino et al. (SRI)§
Plasma monitor	$\Delta(\log N_e)$, N_e, T_e N_i, N_{O^+}, N_{H^+}, T_{H^+} $\mathbf{V}_d \rightarrow \mathbf{E}$	Langmuir probe* RPA resolution to 5 km ion drift meter resolution to 400 m	Hanson (UTD) Heelis (UTD) Rich (AFGL)§
Electron spectrometer	electron flux and energies	20 eV–20 keV zenith, nadir, 40° resolution to 400 m	Hardy (AFGL)§
Magnetometer	$\mathbf{B}$, $\Delta\mathbf{B} \rightarrow \mathbf{J}$	three-axis fluxgate quantization 12 nT resolution to 400 m	Bythrow (APL) Potemra (APL)§ Zanetti (APL)
AIM photometers†	aurora	3914 and 6300 Å	Huffman (AFGL)§ Meng (APL)

L. A. Wittwer (DNA), Program Manager.
*Not fully operable.
†VUV imager failed on July 23
‡HiLat project scientist
§Experiment Principal Investigator.
DNA, Defense Nuclear Agency
AFGL, Air Force Geophysics Laboratory
UWO, University of Western Ontario.
PDNW, Physical Dynamics, Inc., Northwest Division.
SRI, SRI International
UTD, University of Texas at Dallas.
APL, Applied Physics Lab, Johns Hopkins University

The first objective of HiLat is to provide definitive, quantitative information on high-latitude scintillation strength and, more particularly, on the spatial and temporal spectra of the intensity and phase fluctuations of which it is composed. The second is to extend into new locations and local times of day/night the diagnosis of three-dimensional irregularity shape begun with HiLat's single-experiment predecessor, the Wideband beacon satellite [*Fremouw et al.*, 1978]. The third is to provide the additional diagnostic information on background ionospheric processes that cannot be provided by a beacon experiment alone and that is necessary for definitive identification of irregularity development and dynamics.

DESCRIPTION

Wideband's sole experiment was a 10-frequency radio beacon for measuring total electron content (TEC) and for observing scintillation. The forte of a beacon experiment, for diagnostic purposes, is that it is directly sensitive to scintillation-producing irregularities and that it can provide three-dimensional shape information [*Rino*, 1979] through the geometrical dependence of scintillation [*Fremouw and Lansinger*, 1981] and, more directly, through spaced-receiver measurements [*Rino and Livingston*, 1982].

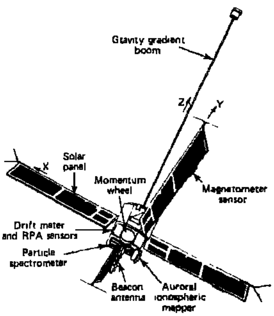

Fig 1. The HiLat satellite, P83-1

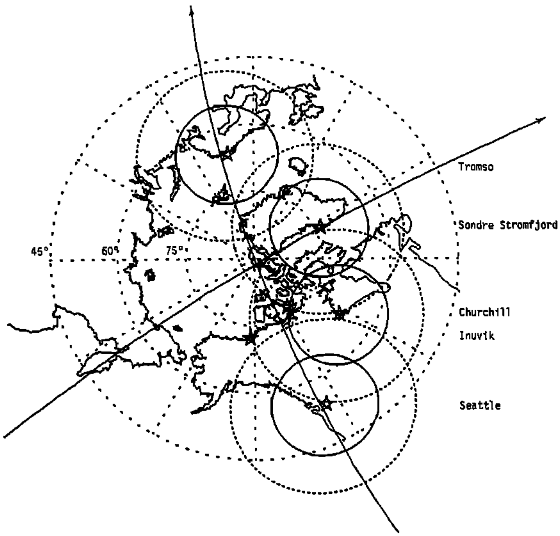

Fig 2 HiLat receiving stations and data coverage for beacon (solid circles) and other (dashed circles) experiments in offset magnetic dipole coordinates. Two representative passes are shown

It cannot reveal the processes leading to development of scintillation-producing irregularities, however, since it provides data only after the irregularities have developed.

Electric field driven convection and other ionospheric-magnetospheric processes may contribute to development of scintillation-producing irregularities. For instance, it is possible that precipitation

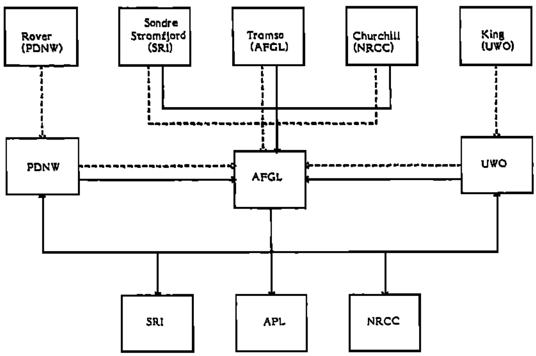

Fig 3 Data distribution network. (NRCC, National Research Council of Canada.) Dashed lines indicate raw data. Solid lines indicate summary data.

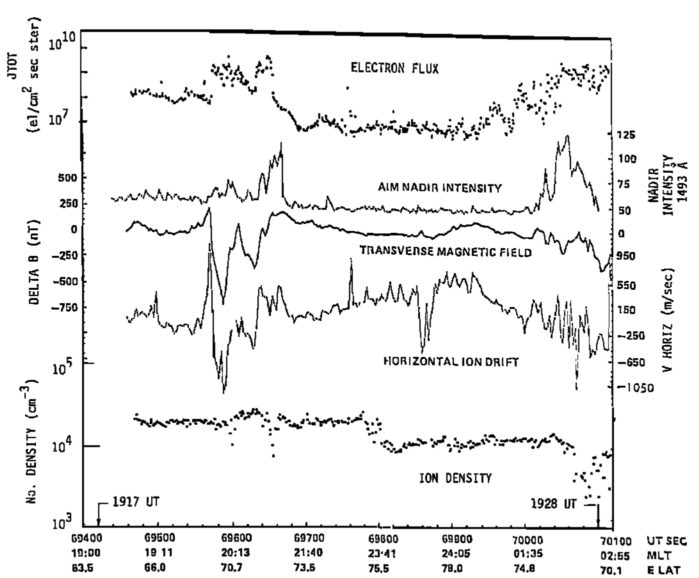

Fig 4 Data from onboard sensors taken during passage over auroral oval and northern polar cap on July 23, 1983

patterns of ion-producing electrons are structured on smaller than macroscales, even down to the scale of the scintillation-producing irregularities themselves. Moreover, the electric fields carried down the highly conductive magnetic-field lines from the magnetosphere also may be structured on the relevant scales. In addition to a scaled-down version of the Wideband beacon, HiLat carries experiment payloads designed to probe both finely scaled precipitation and electric fields, as well as magnetic field aligned currents. Moreover, it carries an optical remote sensing experiment intended to provide macroscale information on auroral activity as a general indicator of the disturbance state of the ionosphere.

Table 1 lists the HiLat experiments, their intended purposes and basic characteristics, and the principal experimenters associated with each. Figure 1 shows the location of the sensors on the HiLat satellite, P83-1, in the space test program of USAF Systems Command's space division (SD). The satellite is controlled by the Naval Astronautics Group (NAG), Point Mugu, California, which issues commands under a letter of agreement with SD. On-orbit operations are planned by the science team and carried out by NAG upon request from the project scientist.

Data are collected by means of real-time transmissions to the following four high-latitude stations shown by encircled stars in Figure 2: Tromso, Norway (auroral zone); Sondre Stromfjord, Greenland (polar cusp); Churchill, Manitoba (auroral zone); and Seattle, Washington (plasmapause). A second Canadian station (noncircled star) is planned for Inuvik, Northwest Territories (auroral cusp), with operations likely to begin in the boreal spring of 1985 The Seattle and Inuvik stations are intended to be transportable to other locations for limited-duration observing campaigns. Ephemeris information used for program tracking of the satellite at the receiving stations is provided by NORAD.

The data collected at the stations shown on Figure 2 (plus early-mission data from Laurel, Maryland, and Kiruna, Sweden) are distributed to the partici-

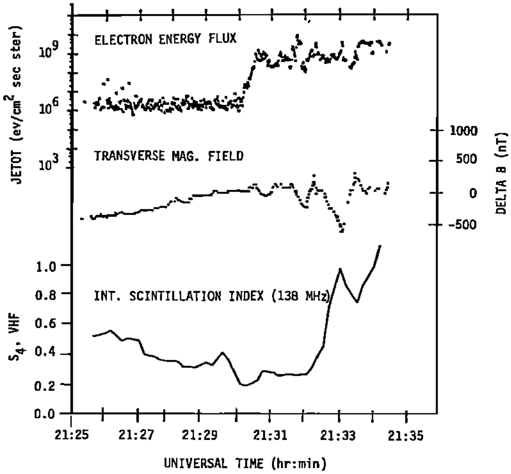

Fig 5 Data from a HiLat pass over Sondre Stromfjord, Greenland, as the satellite travelled equatorward essentially along the 2130 MLT meridian on September 19, 1983.

pating organizations via the network indicated in Figure 3. Raw data are reduced to summary form at the three fixed stations and at the home locations of the organizations operating the two transportable stations. Summary tapes (solid lines) are sent to AFGL for reproduction and routine distribution, while raw tapes (dashed lines) are archived at AFGL and copied for experimenters upon request.

The experiment payloads normally are operated over the northern quadrisphere of the earth, although they can be turned on for any quarter of the orbit. The satellite is in an approximately 800-km circular orbit at 82 inclination, and the orbital plane precesses through 24 hours of solar time approximately twice per year. Data collection is planned for 3 years.

EARLY DATA

Following launch, all experiments operated as designed, with the partial exception of the electron sensor (Langmuire probe) of the plasma monitor. Apparently, the connection from its electronics package to the outer grid of the Langmuire probe was severed during launch or orbital insertion, resulting in a locally floating ground. The upshot is that the probe is acting more as an omnidirectional detector of superthermal electrons than as a thermal-electron probe.

More distressingly, the high-voltage power supply to the imaging spectrophotometer in the optics package failed after producing several tantalizing images of both the nightside and dayside aurora, including some in full sunlight. This auroral ionospheric mapper (AIM) produced data simultaneously with the energetic-electron spectrometer, magnetometer, and plasma probe on approximately 40 passes during the engineering initialization phase of the HiLat mission. Unfortunately, the failure occurred prior to activation of the fully equipped HiLat receiving stations for the operational phase of the mission. Consequently, beacon data are not available from the passes that produced AIM images.

Plate 1 shows one of the spectacular vacuum-ultraviolet (VUV) images produced by AIM during the HiLat initialization phase, recorded at the ESRANGE station at Kiruna, Sweden. Figure 4 shows partial data from the in situ instruments. At about 69570 s UT, HiLat passed from the diffuse aurora into the discrete-arc oval on the eveningside of the earth (~1940 MLT) near 69° magnetic eccentric dipole latitude (ELAT). Plate 2 contains dynamic

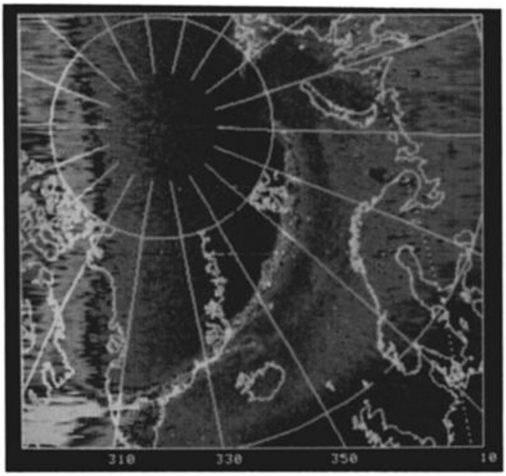

Plate 1 Vacuum ultraviolet (VUV) image of the aurora developed in daylight at 143 Å on July 23, 1983, between 1917 and 1928 UT Evening oval at bottom, morning at top Sunlit midnight oval to right. Moderate brightness at left is due to atmospheric limb brightening

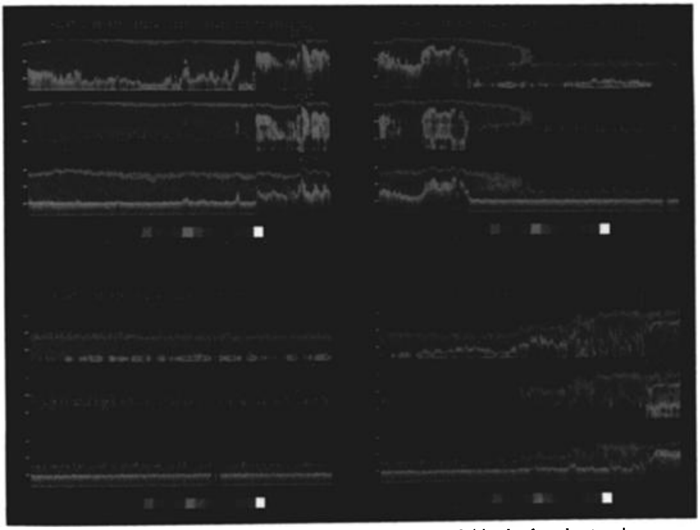

Plate 2 Energy spectra of precipitating and upwelling electrons recorded by the three directional sensors on HiLat's electron spectrometer during four contiguous portions of the pass on which the data in Plate 1 and Figure 4 were collected. Universal time seconds at start and end of each portion are indicated above each triplet of data. Energy scale in electron volts. Color brightness scale is in el/cm^{2}s sr keV

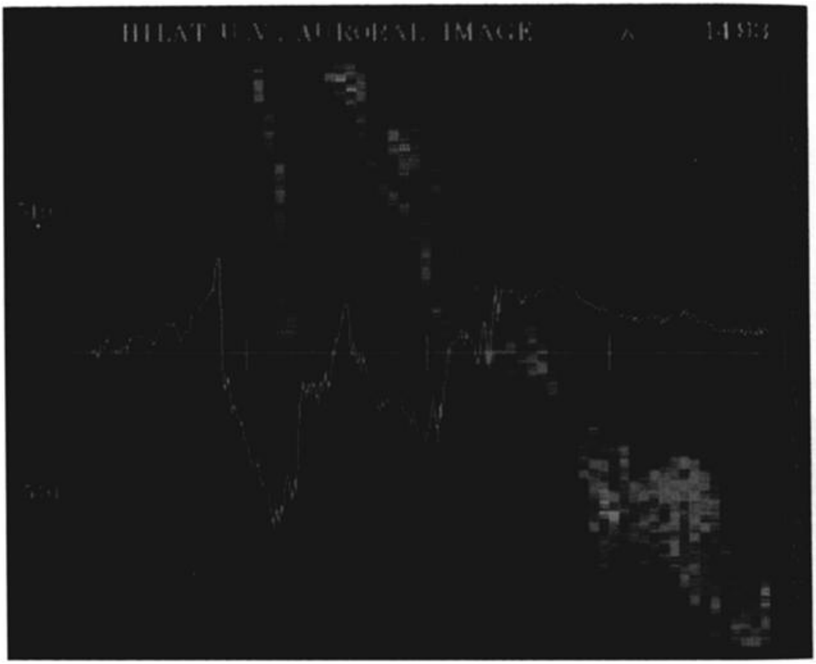

Plate 3. Horizontal magnetic perturbations recorded during HiLat crossing of the eveningside aurora shown in Plate 1 Negative (positive) gradients correspond to downward (upward) field-aligned currents.

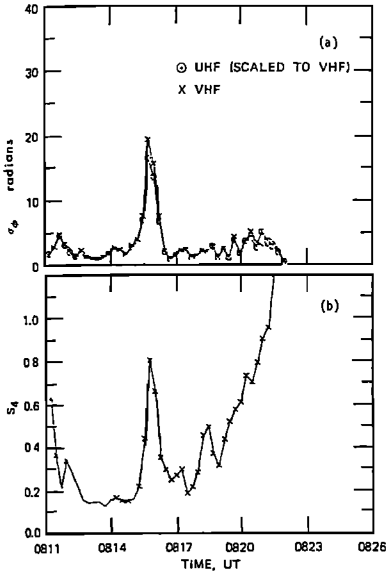

Fig. 6. Scintillation recorded at Sondre Stromfjord on November 4, 1983 (*a*) Phase scintillation index (standard deviation of phase over 30-s period). (*b*) Intensity scintillation index (normalized standard deviation) Note two-frequency corroboration in Figure 6*a*.

energy spectra from the three directional energetic-electron sensors, broken into four time segments. It clearly shows strengthening and hardening of both precipitating and upwelling electrons as the discrete-arc oval was reached, which persisted until the satellite passed into the polar rain about 100 s later. After traversing the polar cap, HiLat encountered the morningside oval near 75° ELAT at about 70000 s UT.

The two traverses of the discrete-arc oval are demarked clearly in Figure 4 by elevated fluxes of precipitating electrons (J_{tot}), multiple current sheets inferred from the magnetometer, and directly by the VUV emission recorded in AIM's nadir pixel. The thermal-ion sensors disclosed rapid shear flows in the auroral oval plasma, with the horizontal ion velocity closely correlated with the magnetic field perturbations on the eveningside. They also showed elevated plasma density on the eveningside, including the region of diffuse aurora, as compared with the early morningside, and some density enhancement associated with the nightside arcs. Although many topside density enhancements are related to precipitating-electron flux, there is by no means a one-to-one correspondence.

Direct application of Ampere's law permits evaluation of local currents from field perturbations recorded by the magnetometer. Specifically, given the orientation of the magnetometer's x, y, and z sensors, the steep inclination of high-latitude field lines, and HiLat's velocity (7.44 km/s in the x direction), field-aligned currents can be estimated as

$$J_{\parallel} \sim 0.1 \frac{dB_y}{dt} \ \mu\text{A/m}^2$$

where the rate of change of the y component B field is measured in nanoteslas per second.

Details of field-aligned currents associated with the vuv aurora can be inferred from Plate 3, which shows the magnetic perturbations measured by the transverse y sensor superimposed on a portion of the image shown in Plate 1. The straight line in Plate 3 represents both a local baseline (determined by means of a fifth-order polynomial fit to the undisturbed magnetometer data) and the track of HiLat from left to right over the eveningside auroral forms (shifted in time to account for field-aligned mapping from 800 km to the E layer). A negative gradient in the magnetic perturbation represents current flowing downward into the ionosphere, and a positive gradient represents upward current.

The brightest auroral region is one of generally upward current, presumably carried by the precipitating energetic electrons represented in the top panel of Figure 4 and Plate 2. Plate 2 also shows considerable flux of upwelling electrons, however, and the magnetometer indicates an intricate pattern of currents locally flowing downward and upward. The locally strongest current was one flowing downward near HiLat's first encounter with the auroral form. It extended over about 4 km and measured approximately 100 μA/m^2, which is about 20 times stronger than the larger-scale downward current in which it was imbedded.

Figure 5 shows data from an operational pass over the HiLat station at Sondre Stromfjord, Greenland, on September 19, 1983. The total energy flux (JETOT) carried by precipitating electrons clearly shows passage of the satellite from the polar cap into the nightside auroral oval near 75 ELAT, at about

2130 UT, as it moved equatorward essentially along the 2130 MLT meridian. The magnetometer again revealed considerable current flowing in the region. Moreover, the beacon receiver now showed that at least the equatorward portion of the oval was the seat of decidedly elevated levels of both phase and intensity scintillation, indicated in Figure 5 by nearly saturated intensity scintillation (normalized standard deviation, S_4, near unity) at VHF (138 MHz).

Figure 6 shows a scintillation event that is characteristic of a good many records from Sondre Stromfjord. The prominent feature just before midpass is the feature of interest. Such features typically coincide with localized increases in TEC and are believed to stem from localized, highly structured F region density enhancements This event and others like it have yet to be investigated by means of the in situ and optical data from HiLat

CONCLUSION

Careful attention must be given to the relative locations of the in situ sensors and the transionospheric radio propagation path prior to forming conclusions about development of scintillation-producing irregularities. Equally important will be consideration of the dynamics of the situation, as revealed, for instance, by yet-to-be-processed ion drift data from the plasma probe for scintillation events such as those shown in Figures 5 and 6. Early data from HiLat show promise toward this end, and we hope to be able to report substantial progress toward it at a future ionospheric effects symposium.

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