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# INVESTIGATIONS OF THE NATURE AND BEHAVIOR OF PLASMA-DENSITY DISTURBANCES THAT MAY IMPACT GPS AND OTHER TRANSIONOSPHERIC SYSTEMS

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As solar maximum approaches, the "space-weather" vulnerability of systems that depend upon transionospheric radio propagation will increase. Likely effects include variable range errors in the Global Positioning System (GPS) due to variations in ionospheric "total electron content" (TEC), spatial gradients in such errors, and the "scintillation" of signals employed in a variety of navigation, communication, and other systems. This report summarizes research performed in the first year of a contract aimed at (a) investigating the behavior of naturally occurring variations in TEC and the plasma-density irregularities that produce scintillation as solar activity increases and (b) observing such phenomena and others that may be produced artificially by means of high-frequency (HF) heating of the ionosphere in the HF Active Auroral Research Program (HAARP). The first-year efforts included collection and processing of TEC data from USAF's Ionospheric Measuring System (IMS); campaign operation of a portable ionospheric monitor for measurement of TEC and scintillation at Ascension Island; preliminary assessment of plasmaspheric contribution to TEC; and coordinating development of a variety of diagnostic instruments for HAARP.

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# Contents

## Preface

This report summarizes work completed during the period from 10 September through 31 August 1998 on a project to investigate effects of the earth's ionosphere on transionospheric systems.

In addition to the authors, other contributors to the efforts described herein include Northwest Research Associates (NWRA) staff members Angela Andreasen, Charley Andreasen, Wilbur F. Pierce, Guan-Shu Rao, and J. Francis Smith, and NWRA consultants John Rasmussen, A. Lee Snyder, and Jens Ostergaard.

# Acronyms and Initials

| | |
|---|---|
| 55SWXS | 55th Space Weather Squadron |
| AFRL | Air Force Research Laboratory |
| APTI | Advanced Power Technology, Inc. |
| AWN | Automated Weather Network |
| CORS | Continuously Operating Reference Station |
| DCP | Differential Carrier Phase |
| DGD | Differential Group Delay |
| GPS | Global Positioning System |
| HAARP | High-frequency Active Auroral Research Program |
| IMS | Ionospheric Measuring System |
| IPP | Ionospheric Penetration Point |
| JPL | Jet Propulsion Laboratory |
| NOAA | National Oceanic and Atmospheric Administration |
| NWRA | NorthWest Research Associates |
| PRISM | PaRameterized Ionospheric Specification Model |
| RTM | Real-Time Monitor |
| SFG | Scale Factor Generator |
| TEC | Total Electron Content |
| TELSI | TEC and Scintillation (message format) |
| UPS | Uninterruptible Power Supply |
| UT | Universal Time |

# Investigations of the Nature and Behavior of Plasma-density Disturbances that may Impact GPS and other Transionospheric Systems

## I. Introduction

The ionosphere can both disrupt and enhance the operation of military communication, navigation, and surveillance systems. For instance, the integral of plasma density along ray paths through the ionosphere (the "total electron content," or TEC) imposes range errors on signals received from satellites in the Global Positioning System (GPS). Indeed, GPS transmits two frequencies specifically for the purpose of correcting such errors. The correction depends on reliable measurement of frequency-differential "pseudorange." Such corrections can also be applied to nearby or remote single-frequency receivers, a procedure that can be degraded by temporal changes and spatial gradients in TEC.

An objective of this project is to characterize the temporal changes and gradients in TEC as measured by means of GPS pseudorange and more precise measurements of frequency-differential carrier phase as the sun advances in its eleven-year activity cycle. To meet this objective, Northwest Research Associates (NWRA) is (a) operating, calibrating, and maintaining GPS-based equipment, including the Air Force Ionospheric Measuring System (IMS, AN/GMQ-35), at various locations and (b) processing and analyzing data obtained thereby. Further description of the IMS and its operations are provided by Fremouw, et. al. (1998).

It may be possible to enhance operation of some low-data-rate but high-priority communication systems by exercising a degree of control over ionospheric disturbance by means being investigated in the High-frequency Active Auroral Research Program (HAARP). Under HAARP, the Air Force Research Laboratory (AFRL) and the Office of Naval Research (ONR) are developing a facility in Alaska for upper-atmospheric, ionospheric, and solar-terrestrial research. An objective of this project is to contribute to characterizing processes triggered in the upper atmosphere and ionosphere by high-power radio waves to be transmitted from the HAARP facility, specifically as those processes relate to large-scale and km-scale irregularities in ionospheric plasma density and to radiowave absorption. HAARP activities are reported in Section III.

## II. GPS Topics

### 1. Standard IMS Operations

Data files are processed, reviewed, and archived to tape at each of the deployed Ionospheric Measuring System (IMS) sites at Eareckson Air Force Station, Shemya, Alaska; Thule Air Base, Greenland; Croughton Royal Air Force Base, United Kingdom; and Otis Air National Guard Base, Massachusetts. Additionally, the same activities are being performed for the fifth IMS, located at Hanscom AFB, during its testing and qualification prior to deployment. Tapes are catalogued for content and indexed for local storage upon arrival at AFRL each month.

The 15-minute total electron content (TEC) data reported by the IMS are retrieved and plotted for each day at each site, to monitor the calibrations, data anomalies, and recent changes in the active GPS constellation. Additionally, a quick bias calibration is performed automatically on the Companion PC at each site, to facilitate detection of bias variations requiring re-calibration. These calculations are subject to some bias errors due to data anomalies, so operator judgment is required in evaluating the results. Because of IMS data utilization by 55th Space Weather Squadron (55 SWXS) for the PaRameterized

Ionospheric Specification Model (PRISM), a regular schedule of calibrations has been established, so that the individual sites are re-calibrated no less often than once every two weeks, and sooner if circumstances or data results indicate a need.

GPS ephemeris files are retrieved from Holloman AFB on a weekly basis, for use in determining the apparent sky positions of GPS satellites and the coordinates of the associated ionospheric penetration point (IPP), which are used by the bias-determination process.

A summary log is being maintained for the Otis IMS, the Croughton IMS, the Thule IMS, and the Shemya IMS, primarily to monitor the duration of operations for each of the two UNIX computer systems in each IMS. The cause of each system shutdown is also recorded in this log. A histogram of system operating-time durations, by month, is included in this summary log for each IMS, and a summary table displaying the total percentage of operating time for each month and the number of occurrences of various outage causes also has been included.

Quarterly Status/Performance Reports for the IMS sites were prepared, covering the quarters ending in September 1997, December 1997, March 1998, and June 1998. This report includes the monthly performance statistics and outage causes for each deployed IMS, as well as other notable events and developments.

The primary hard drive on the local PC used to monitor the remote IMS systems failed on 7 January 1998 and was replaced, along with re-installation of the operating system and user accounts. Supplementary hard drives on the same system, which contained the data and processing procedures for the IMS, were not affected.

One of the local computers at AFRL was configured with an additional modem and appropriate phone-line connections to perform a backup role for the current PC being used to monitor the remote IMS sites. The processing procedures and appropriate sub-directories previously had been installed on the backup monitoring system, for general analysis support.

## 2. IMS Investigations

### A. Daylight Time Transition

All of the operating IMS units had reported time problems during the transition to Daylight Time on 6 April 1997, with several system swaps, but the situation eventually resolved itself, without operator action. The time-zone definitions for the UNIX operating system had been examined, tested, and redefined in September 1997, in preparation for the next transition from Daylight Time, on 26 October 1997. Subsequent monitoring confirmed that the systems operated without problems through this transition.

### B. Missing Satellites

Daily monitoring for Shemya for early December 1997 indicated that PRN 25 was no longer being reported, although it was still reported at other IMS sites. A complete reset of the Shemya IMS resulted in the reappearance of PRN 25, so a transient problem with the receiver was suspected. Because the receiver supports the capability of excluding individual satellites, this condition could have arisen from improper use of the receiver command panel or a garbled command from the IMS software. Consequently, the daily monitoring was extended to include a detailed survey of satellite coverage, based on the 15-minute data reports.

As a consequence of the satellite-coverage survey, GPS PRN 26 was found to be absent from the Croughton IMS data reports from 6 to 9 August 1998. An IMS restart invoked on 10 August resulted in reappearance of this satellite, which was not absent from data reports at the other IMS sites. The response to this event was delayed because the occurrence was predominantly during a weekend.

C. Anomalous Biases

Close daily monitoring of the IMS data revealed a phenomenon in which a single satellite that had previously been calibrated appears to have a bias value significantly different from its normal value for an entire satellite pass. This condition has been dubbed "anomalous biases" and has been observed for each of the IMS sites, but only with relative rarity (typically twice per month per site, over all active GPS satellites). The problem has not been remedied by a firmware upgrade to the 1G02 level. A similar phenomenon has been reported for the National Imaging and Mapping Agency (NIMA) GPS stations using similar receivers and apparently has been remedied by the version of firmware available to them.

Negotiations between AFRL personnel and the receiver manufacturer, Ashtech, resulted in arrangements to acquire a receiver firmware upgrade (version 1I11) for installation in some of the available IMS receivers and to ship other receivers back to Ashtech for a hardware upgrade and firmware installation. One spare Ashtech receiver was selected for firmware testing at AFRL, being a sufficiently recent model to allow local installation of the firmware, which was acquired from Ashtech through the Internet. The performance of this receiver was checked prior to the firmware upgrade, using the Laboratory IMS, and its operation after the firmware upgrade was checked again using the Laboratory IMS, for a period of a week. The upgraded receiver then was installed in the IMS at Otis on 20 August 1998, with the data subsequently being monitored as a regular part of IMS operations. If no anomalous biases or other data anomalies attributable to the receiver are detected for six weeks after the Otis installation, installation of the new firmware on other spare Ashtech receivers will proceed.

D. Periodic Shutdowns at Thule

In late November 1997, a pattern of regular shutdowns was observed to be occurring for the Thule IMS. Initially, two shutdowns were occurring approximately twelve hours apart, and subsequently, three shutdowns were occurring regularly, with the third approximately an hour after the midday shutdown. The pattern was observed to be synchronous with the GPS constellation, rather than at a fixed Universal Time (UT). It was not associated with the rising of any GPS satellite, however, although a small group of GPS satellites was associated with all three daily shutdown occurrences. In mid-January 1998, one of the receivers with upgraded firmware (1G02 level) was shipped to Thule and was installed in the IMS on 20 February 1998 by on-site personnel. The problem was not resolved by this change, so existing plans for the March 1998 maintenance visit to Thule were completed.

To support diagnostic investigations to be conducted during the maintenance visit to Thule, a notebook PC was configured to operate the Real-Time Monitor (RTM) data-collection program, and several evaluation procedures were developed to perform comparisons between the RTM and IMS operations. These procedures were documented and described to NWRA and AFRL personnel who would be participating in the maintenance visit. Documentation concerning the installation of the serial-port tap for capturing raw receiver data was prepared on a contingency basis. Other diagnostic procedures were developed for implementation using the remote connections to the Thule IMS, but IMS outages attributed to temperature extremes prevented these from being implemented. Investigations into the cause of the periodic outages were conducted using data archived to tape by the Thule Companion PC, with no clear outcome. However, a review of the log summaries for the Thule IMS indicates that the onset of the problem coincided with the appearance of PRN 8 in the GPS constellation.

Initial efforts during the March 1998 maintenance visit addressed the restoration of normal IMS operations and stabilization of the environment against weather and temperature extremes. The IMS processor was found to be operating, but not fully functional, in an apparent recurrence of an early problem involving the data storage disk. The cause of a lack of network connection capabilities from the Companion PC could not be determined, but the problem did not recur for the duration of the visit and has not occurred since.

A number of observations and experiments were conducted to determine the specific cause of the system shutdowns, including direct monitoring of the GPS receiver display panel just prior to the shutdown event and various settings of the data-collection parameters, especially the collection rate. None of the settings produced any improvement in the IMS operations except for the exclusion of PRN 8, which appeared in the GPS constellation in late November 1997.

Because exclusion of other satellites or adjustments in the data rate did not resolve the problem, it was decided to accept the exclusion of PRN 8 for the Thule IMS, and this exclusion was implemented in a manner that would survive system restarts. Although this resolution did reduce ionospheric coverage at Thule, the impact is somewhat limited because PRN 8 is only an active spare and provides coverage close to that of PRN 9.

E. Extreme TEC Measurements

Rare cases of sudden, large recorded TEC values followed by a gradual return toward normal levels have been observed for the Thule IMS. These have been traced to a phase discontinuity that is either not detected or not properly treated by the IMS software, so that normal phase-averaging occurs across the discontinuity, instead of re-initializing after the discontinuity. Discovery of an older Matlab script on one of the Thule IMS UNIX systems prompted a re-examination of the known occurrences of these events, which could have arisen as a consequence of the lack of warning-flag checks in the older script. The cases that were examined all were associated with the new version of the Matlab script, however, indicating that a further data-quality check may be required by the Matlab processing.

**3. Site-Specific Activities**

A. Otis

A trip was conducted to the IMS at Otis on 9 December 1997 to install an upgraded Windows NT Companion PC, in conjunction with replacement of the Automated Weather Network (AWN), and to install a receiver with upgraded firmware (level 1G02) in association with continuing investigation of the anomalous-bias problem.

A trip was conducted to the IMS at Otis on 17 April 1998 to resolve problems with the IMS initialization, which coincided with installation of the router for the network to succeed the AWN.

A trip was conducted on 29 May 1998 to resolve a file-corruption problem on the Companion PC by reinstalling software. Recurrence of the file corruption prompted a trip on 12 June 1998 to replace the Companion PC there. The file corruption manifested itself as the loss of file-transfer capabilities between the Companion PC at Otis and the central monitoring PC at Hanscom. Further investigations continued for the Companion PC that was retrieved from Otis, and the problem was traced to a setting in the Windows NT registry, apparently arising from an improper system shutdown during a thunderstorm. Tests confirmed that the settings could be corrected remotely, by appropriately editing the registry, and the procedure was documented for future reference.

A separate problem was encountered during exchange of the Companion PC. The replacement PC could not establish network communications with the successor to the AWN until both the network connections and the associated network addresses were exchanged for the two network interfaces in the Companion PC. No network communications problems existed for the connections to the IMS UNIX systems in either configuration. No further progress in resolving this apparent incompatibility has been achieved.

A trip to Otis was conducted on 20 July 1998 to replace the uninterruptible power supply (UPS) for the Companion PC. The original UPS was exhibiting signs of deterioration and had been bypassed by local technicians, but lack of electrical isolation was not advisable for the summer weather conditions at Otis.

B. Croughton

A maintenance trip was conducted for the IMS at Croughton during the period 15 October 1997 to 24 October 1997. In addition to the scheduled preventive maintenance tasks, some software on the Companion PC was updated.

The Companion PC for the IMS at Croughton exhibited some errors in its tape-backup processing, and normal processing could not be resumed. Because it was planned to upgrade this PC from Windows-95 to Windows NT as part of the AWN transition to a successor network, a Windows NT Companion PC, which had been certified for use at Hanscom, was shipped to Croughton and installed for use with the IMS by on-site technicians. The Windows-95 PC then was shipped to Hanscom, where it was determined that the tape drive had experienced a hardware failure; it was shipped for repair. The Windows-95 Companion PC was reconfigured for Windows NT and was equipped with a refurbished tape drive when these were delivered to Hanscom.

A trip was conducted to the IMS at Croughton from 3 June 1998 to 11 June 1998, for regular maintenance.

C. Thule

One of the two IMS UNIX processors at Thule had been deactivated in October 1997 because TELSI message transmissions were not possible for its associated AWN communications line, due to poor line quality. In mid-December 1997, the dormant processor was reactivated, and normal operations were resumed, after some initial problems with the UNIX time setting. By late December 1997, AWN communication-line problems were occurring for the other processor, so that processor was deactivated. The line-quality problem was examined during the planned maintenance visit to Thule from 4 March 1998 to 12 March 1998, but initial assessments that the problem was remedied permanently were optimistic, because later discussions with personnel at 55 SWXS indicated that TELSI transmissions had not resumed from that single processor, and it was deactivated in late March. The Thule IMS continued normal operations, but using only one UNIX processor.

On 1 June 1998, power restrictions at Thule Air Base produced an extended loss of IMS operating time at that site, until NWRA personnel made arrangements with on-site personnel to have the building containing the IMS placed on backup generator support. Some power outages occurred even on generator support, but these were generally of short duration.

In mid-July 1998, the IMS UNIX processor that had been deactivated in late March 1998 was re-activated by local technicians. Because the processor clock battery had become depleted during the inactive period, the processor was initialized with an incorrect date and could not re-synchronize with the GPS receiver. The situation was remedied by NWRA personnel through a remote connection from

Hanscom, but a period of about two weeks was obliterated from the IMS log by the large number of error reports during the synchronization attempts. Operating time statistics for this period were reconstructed from the data coverage provided by the 15-minute reports.

Preliminary discussions were conducted between AFRL personnel and Thule personnel regarding relocation of the Thule IMS from its current building to the radar building. This move would have the mutual benefits of alleviating maintenance requirements for the current IMS building by the Thule staff and placing the IMS in a much more stable operating environment. A relocation of the IMS to the radar building also provides for future development of direct IMS support to the radar, although this would be in a manner quite different from the simple scale factor provided for the COBRA DANE radar at Shemya. NWRA personnel visited the Thule radar in late August 1998 to evaluate possible locations for the IMS within the radar building, to assess the options for installation of the antenna for the GPS receiver, and to conduct further discussions about the relocation arrangements and the role of the IMS. Another trip to Thule is planned for early October 1998 to move the IMS into the radar building and install the GPS antenna.

An additional accomplishment during the August 1998 trip to Thule was resolution of the TELSI transmission problem from the single UNIX system that had been deactivated. A loose connection was discovered for one of the telephone lines, and the remedy was verified by observing the transmissions at the central communications site.

D. Shemya

In late September, personnel from 55 SWXS reported the absence of TELSI messages from the Shemya IMS, at a time when IMS log errors indicated problem transmissions to the IMS associated with the AWN. The problem was believed to occur in a local segment of the AWN and was finally resolved in early October 1997, after many discussions with on-site and network personnel.

On 7 January 1998, communications with the Companion PC at Shemya could not be established, and discussions with on-site personnel indicated a problem with the power supply. A spare Windows NT Companion PC that previously had undergone testing at Hanscom was configured specifically for operations at Shemya and shipped to Shemya for installation by on-site personnel. Some initial problems concerning the multiple network connections were resolved, and satisfactory operations were restored. Activities at Shemya delayed the return shipment of the failed Companion PC, but examination of this PC after its arrival at Hanscom confirmed the on-site diagnosis. A new power supply was installed, and the system was configured with Windows NT for testing and evaluation as a stand-by spare.

The daily plots that are used to monitor data quality for each IMS site displayed considerable variability for the Shemya IMS during the early part of 1998, interspersed with brief periods of relative stability but apparently diminished accuracy. Examination of the detailed multipath patterns indicated relative day-to-day stability, and evaluation of the general multipath magnitude indicated no excessive variation, but the equivalent vertical TEC profiles generated from the 15-minute data were distinctly different from corresponding profiles generated from post-processed calibrated TEC data. Discussions with on-site personnel indicated possible problems associated with some repairs to the antenna cabling. These were examined and addressed during the maintenance visit to Shemya conducted from 11 to 19 April 1998, with the installation of a high-quality cable to the spare antenna, formerly used for the RTM, mounted on the radar building.

E. Hanscom

The batteries for the UPS for the IMS at Hanscom were replaced in early July 1998. The original batteries were found to be in poor condition, beyond the expectations from their low storage capacity.

Antenna cables being used at the AFRL facility at Hanscom were replaced or repaired, as necessary, in August 1998 because some cables were exhibiting poor performance, while another had incompatible connectors. The conduit for the cables became obstructed during the process of installing the replacement cables, so no cables could be installed until the problem was remedied by laboratory maintenance personnel about a week later.

## 4. Scale-factor Generator

The TEC and scale-factor log files from the scale-factor generator (SFG) program at Shemya were reviewed periodically. Range correction tables are retrieved monthly from the 55 SWXS bulletin board and used to determine the appropriate sunspot number for the ionosphere model incorporated into the SFG program.

Previous documentation concerning the SFG program was updated and presented to the COBRA DANE radar operational staff at Shemya as a reference. An identical version of the SFG program currently is operating on a computer for the operators there, as well as on the Companion PC for the IMS. Arrangements were made with the radar operators at Shemya to record scale factors determined from radar measurements into the TEC and Scale Factor log files, and this process was commenced by 4 February 1998. The radar scale factors then can be compared directly to the SFG scale factors, using an extended version of the program and a procedure for plotting values from the SFG data logs. Daily predictions of the hourly scale factors also are retrieved from the 55 SWXS bulletin board, for future inclusion with these comparisons.

A small set of days was selected for further examination of radar scale factors against scale factors derived from the IMS data. The days selected appeared to have relatively stable and reasonably accurate bias values, but did occur during a period when bias variability was a problem at Shemya. Detailed IMS data were retrieved from archive tapes and were recalibrated, to allow a comparison to the real-time 15-minute data, to evaluate its accuracy and the accuracy of the associated scale factors. The bias variability was found to be significant even for these days, so a valid comparison could not be conducted.

## 5. Data-network Upgrade

Discussions were conducted with AFRL personnel to develop and implement a plan for network data transmissions to succeed the current Automated Weather Network (AWN) transmissions. The proposed method minimizes software changes to the IMS and is compatible with the network intended to support the Digital Ionospheric Sounding System (DISS). Consequently, development efforts are being coordinated with the Principal Investigator for DISS. As part of this development, a Windows NT Companion PC was tested, to implement a more robust networking capability, using the fifth IMS at Hanscom. This testing period included utilization of the SFG program, which is incorporated only for the Shemya IMS. An auxiliary program also was included to generate a file in the form of a TELSI message whenever new data are acquired from the IMS. This TELSI file is then transmitted to its destination using the standard FTP (file-transfer protocol). During the testing phase, the destination was a local PC, instead of the data collection system to be established at 55 SWXS. This Windows NT Companion PC was deployed to Otis in early December 1997, with the SFG program deactivated.

In conjunction with developments for the AWN successor and to evaluate the possibilities for reconfiguration of equipment within the IMS enclosure, the Netblazer communications processor for the IMS at Hanscom was powered off and disconnected, with no effect on IMS operations or network links to the Companion PC. This processor was intended originally for a dial-up networking function for the IMS UNIX processors, but the original requirement never was implemented completely; similar functions now are provided by the Companion PC. The Netblazer processor can be considered expendable for development of a laboratory working model of an IMS and as a necessary item to be acquired as spares.

The network support at Otis was installed on 16 April 1998, shortly after installation of the network node at Hanscom. After IMS initialization problems at Otis were resolved, data transmissions were established from the Otis Companion PC to the Hanscom node by 8 May 1998, and a file-forwarding procedure was established on the Hanscom node to transfer the data files to the primary IMS monitoring computer at Hanscom. Real-time monitoring of the arrival of the data transmissions from Otis allows a quick response to IMS outage conditions.

Preliminary information from the DISS Principal Investigator indicated that 55 SWXS would require encryption of TELSI messages transmitted over the successor network, so available encryption software was investigated. Early candidates were Windows-oriented applications, which were not suitable for the automated processing methods developed on the IMS Companion PC, but a command-line program finally was discovered, acquired, and tested. It appears that the encryption capability will not be required by 55 SWXS, however, at least for the near future.

Developments for the new network to succeed the current AWN continued after the initial installation at Otis, with prototype testing using the fifth IMS and its Companion PC at Hanscom. The file-forwarding procedure was extended to transfer additional status reports from the IMS UNIX systems and the Companion PC. This alternative network proved valuable when the normal dial-up file transfer method between Otis and Hanscom failed. A graphical display of the current TEC data also was implemented for 15-minute data from both Otis and Hanscom. These data reports, acquired incrementally through the network, are being compared to the daily reports generated at each site, to ascertain the reliability of the network transmissions.

A set of five computers was received at AFRL to augment the Companion PCs deployed at each IMS site. These will be either backup systems for the Companion PCs or complementary systems, depending on the final requirements for the successor network, and they have been designated as IMS-Net PCs. Each is configured in a manner similar to a Companion PC, and each is accompanied by a spare removable hard drive. Some component discrepancies among the initial systems were resolved, so that the baseline systems are all identical. Further problems with the serial port, used for the external modem, were resolved by installing internal modems, as in the Companion PCs. The systems were configured with Windows NT, pcANYWHERE remote control, Netmanage networking utilities, Backup Exec tape archiving, Diskeeper disk defragmenter, and the IMS post-processing and analysis software. The system disks were duplicated onto the spare hard drives as backup units. Testing of these systems was commenced using the fifth IMS at Hanscom and the Laboratory IMS.

A revised physical configuration of the components within the IMS enclosure is being investigated, using the fifth IMS at Hanscom. In this configuration, the Netblazer communications processor and the original video monitor have been removed, with the video monitor being replaced by a flat-panel monitor capable of supporting both the UNIX and Windows processors. Both the Companion PC and the IMS-Net PC are installed within the IMS enclosure, with a shared membrane keyboard and touchpad mouse and also sharing the flat-panel monitor with the UNIX systems, by means of a switch-control panel. Some of the original modems for dialup to the UNIX systems were replaced by smaller high-speed modems, but the AWN modems were retained, although these would become expendable when the successor network implementation is completed. This configuration eliminates the additional floor space or height requirements of the Companion PC and IMS-Net PC while retaining all of the functions of the current IMS configuration. Further evaluation of this configuration and alternatives is continuing.

The Companion PC at Shemya exhibited sporadic performance problems beginning in late July 1998, with occasional dialup connection problems becoming more frequent by late August, and with the additional occurrence of interrupted processes and system restarts. No specific source for the problems has been ascertained, but the symptoms resemble a processor-fan failure. An IMS-Net PC will be sent to Shemya as an interim replacement after its testing phase has been completed.

## 6. Laboratory IMS

A laboratory working model of an IMS, without the enclosure or redundancy of the fielded IMS units, has been constructed at Hanscom, for development and testing operations. In addition to serving as a platform for preparation of replacement components (especially processors) for the fielded IMS units, the laboratory model allows testing of replacement components for circumstances in which the original components are no longer available. The laboratory model also allows testing for software modifications.

The working model initially consisted of a spare IMS processor connected to some spare IMS components and to some components of the fifth IMS for which spares were not currently available, the most notable of these being the UPS. Preliminary efforts were conducted to identify and obtain a compatible replacement UPS and other peripherals, which would be available also for use as spares for the deployed IMS units. Operation of the laboratory working model was demonstrated, initially using components of the fifth IMS, but later with a compatible UPS and other peripherals in a completely independent configuration. Further developments are required to validate normal stand-alone operation.

A Hewlett-Packard Model B132L "Visualize" computer was acquired by AFRL for evaluation as a successor to the Hewlett-Packard Model 700 "Apollo" computers that are incorporated into the IMS units. The "Visualize" computer was delivered with HP-UX version 10.2 of the UNIX operating system, while the "Apollo" computers used HP-UX version 9.01. The remaining software required to support IMS operations was installed on the "Visualize" computer, and some incompatibilities were resolved with regard to device drivers and directory specifications, but other problems remain to be resolved. The new processor also presents some problems for physical installation in the existing IMS enclosure, because the case dimensions are larger than for the "Apollo" computer. The "Visualize" computer was installed in the Laboratory IMS, and the original "Apollo" processor used in the Laboratory IMS was transferred to the fifth IMS at Hanscom, for Year-2000 testing. Normal IMS data collection was resumed for both systems, although the Laboratory IMS still lacks an automated restart capability.

Operation of the temperature monitors and associated software for the Laboratory IMS was validated during the summer of 1998, when an air-conditioning outage for the laboratory produced sufficiently high temperatures to trigger an automatic shutdown. Compatibility tests for the new UPS also were successful, bolstering prospects for modifying the IMS response to temperature shutdowns and power outages, which currently require operator action to restart the system. Problems are being encountered in initializing the custom IMS application software, despite additional time allowances for the initialization process, and the problems are significantly worse when the newer Matlab version 5 is utilized in place of the original Matlab version 4.2 to support the IMS numerical calculations. Investigation of these problems is continuing.

## 7. Tests of Replacement Components

The Micropulse antennas that were deployed originally with the IMS units were found to be associated with the "ghost" satellite problem, due to the substantial gain levels produced. These antennas have been replaced with Ashtech antennas in all of the fielded IMS units, but they were reconsidered for use as spare components for the IMS, based on information from Ashtech that the 1G02 receiver firmware upgrade already acquired by AFRL for some GPS receivers may be adequate to resolve the "ghost" problem. A Micropulse antenna was installed for the IMS at Hanscom on 12 January 1998, and methods for monitoring the "ghost" occurrence were re-instituted for this system by 31 January. After 26 days of monitoring (with some interruptions for other tests), "ghost" occurrences were detected on the IMS at Hanscom on 8 March 1998, indicating that the receiver firmware upgrade was not a complete solution to the problem but did provide some amelioration of its occurrence.

A Trimble 4000 dual-frequency GPS receiver was evaluated using software acquired for it and installed on a notebook computer. Several incompatibilities were found between the software requirements and the hardware configuration of the receiver, and further documentation was obtained in attempting to resolve this situation. Investigation of this receiver has temporarily halted.

The secondary spare 90-MHz Companion PC exhibited deteriorating performance while being reconfigured for testing, apparently due to a failed component on the main system board, and further efforts for its reconfiguration as a spare Windows NT Companion PC have been abandoned. If the problem can be remedied, this role of this system will be reconsidered.

## 8. Software Development

### A. IMS Ada Software

The IMS software received from Charles Stark Draper Laboratory was reviewed for information regarding IMS operations and functionality, with special concern for "Year-2000" effects and the "GPS Week Rollover," expected on 22 August 1999. The Software Development system for the IMS was utilized in this effort, with initial efforts directed toward rebuilding the executable files for IMS operations, for comparison to the fielded software. This reconstruction demonstration was successful. Network connections have been established between the Companion PC or the Development System and the local AFRL network when needed.

A structural outline of the IMS Ada code was developed and annotated to indicate the review status of the IMS source code and areas of potential concern for either the "Year-2000" effects or the "GPS Week Rollover." All of the Ada modules have been reviewed with the exception of those associated with AWN transmissions, which will become obsolete when transition to the successor network is completed.

Software modifications for validation testing for the "Year-2000" and "GPS Week Rollover" effects have been performed. Based on a suggestion by AFRL personnel, these tests have been conducted by introducing an offset to the GPS Week value acquired from the receiver, effectively advancing the date to any desired future date. A suitable choice of the code module for implementing this offset allowed the date setting to be effective for both the UNIX operating-system date-and-time comparison and the Informix database storage. The UNIX operating system (HP-UX version 9.01) was found to be operational for dates up to 2036, and critical dates from the "GPS Week Rollover" through the year change into 2001 were simulated and tested. Specific tests are listed in Table 1. Successful results were obtained for each test case.

Table 1. "Year-2000" and "GPS Week Rollover" Tests

| |
|---|
| GPS Week Rollover: operation from 20 August 1999 to 23 August 1999 |
| Operation through 9 September 1999 (9-9-99 "magic number" date) |
| Transition from 30 December 1999 through 3 January 2000 |
| Extended operation in 2000 (6 January 2000 to 17 January 2000) |
| Operation through 10 January 2000 (first nine-character numeric date, 2000-1-10) |
| Transition from 28 February 2000 through 2 March 2000, for proper leap year treatment |
| Operation through 10 October 2000 (first ten-character numeric date, 2000-10-10) |
| Transition from 31 December 2000 through 1 January 2001 |

The IMS UNIX system being utilized for "GPS Week Rollover" and "Year-2000" testing was observed to experience system shutdowns without logging error termination reports, irrespective of the date settings or the nature of the tests being conducted. A fault in either the physical or software heartbeat generation and detection system was suspected, and a separate investigation of the problem was pursued. A sustained period of operations using one of the original IMS UNIX processors instead of a test processor verified that the physical heartbeat detection system was fully functional, so modifications of the software on the test processor were investigated. The heartbeat generation module was unaffected by the changes required for the "GPS Week Rollover" and "Year-2000" date simulations, although a software error in the main software module arising from these modifications could not be precluded. Examination of the processes running near the time of a shutdown indicated that all of the required IMS software processes were present, reducing the likelihood of a terminating error for the main software module. Further examinations indicated that the heartbeat generation process was failing because of insufficient system memory, which is consistent with the smaller virtual-memory allocation implemented for the test processor. The cause of the gradual depletion of available system memory remains to be determined.

The IMS Software Requirements Specification document was reviewed to extract an index of requirements for IMS operations and performance. The current IMS configuration, operations, and performance will be compared to this index, and modifications imposed by the AWN transition will be noted in this index.

B. IMS Processing Software

The Windows NT directory replication capability was invoked to distribute current versions of the GPS receiver data-processing procedures and programs to most of the AFRL computers utilized for such processing, evaluation, or research. Previously, revised versions of these files were distributed manually to each system.

To accommodate augmented processing capabilities for the Companion PC, the program that performs file cleanup was modified to have a time resolution of an hour, instead of a day. This modification has proved particularly advantageous for file maintenance for the many small TELSI files that are generated daily during development of the successor to the AWN. It will also be useful if 55 SWXS defines an expiration period for TELSI transmissions delayed by network or destination-node problems.

Extended capabilities were incorporated into the program that defines site-specific parameters in order to accommodate larger TEC ranges and more appropriate axis divisions. This program was used to redefine parameters for the plots that are generated each day to monitor IMS data.

Calibration processing for the IMS receivers could be affected by a delay in availability of almanac files from Holloman AFB, so an alternative method was developed that utilized the azimuth and elevation values reported by the receiver to perform the calculations required by the calibration processing. The receiver values are reported in quantized form, and therefore are not as accurate as the values derived from the almanacs, so the normal processing method was reinstated as soon as updated almanacs became available.

The program that generates ionospheric penetration-point databases, which are used for bias calculations, was modified to enhance its capabilities in handling data bordering a date transition. This eliminates a problem encountered in associating data files from all satellites for a given date, if initial portions of a satellite pass straddling midnight are missing.

The procedure for generating reference files of azimuth and elevation angles for GPS satellites was modified to allow provision for alternative working directories, instead of enforcing a particular directory-tree structure. This modification also allows greater flexibility for the file-distribution system that has been implemented.

A Visual Basic program was written to perform the file monitoring required for the automation of IMS data-file processing on the Companion PC. Some flexibility was incorporated into this program to allow specification of the required processing commands without requiring recompilation of the monitoring program. This functionality was originally provided by an interpreted Basic program, but the interpreted Basic program uses an excessive amount of CPU resources in Windows NT. The Visual Basic program was tested on the Companion PC associated with the fifth IMS at Hanscom and on the central IMS monitoring PC at Hanscom, where the data-processing operations invoked are different from those employed on the Companion PC. This program was installed on the Companion PC at Otis and will be deployed to each Companion PC at the remaining field sites.

GPS data collected during "Year-2000" tests were reviewed and utilized for testing of the TEC processing programs. A number of small changes were made to propagate a four-digit year through successive data formats and to interpret four-digit years properly for calculations and date comparisons.

UNIX scripts invoked by operator interaction were reviewed for potential "Year-2000" problems and revised as necessary. These scripts are employed on an occasional basis and were not tested in the same manner as the scripts invoked for the automated IMS processing, but they were run during "Year-2000" simulations.

The program that plots GPS satellite coverage based on the azimuth and elevation files derived from the Holloman almanacs was enhanced to provide an elevation threshold for the satellite coverage. This allows the coverage plot to represent more closely the actual data-collection coverage, which generally is implemented with an elevation threshold.

C. Other Software Developments

Coordinated efforts are being conducted with the Applied Research Laboratory (ARL) at the University of Texas at Austin and AFRL personnel to determine the causes and remedies for differential carrier phase (DCP) data losses encountered by a number of distinct Real-Time Monitor (RTM) systems deployed to various locations. Data from some data-collection sessions were processed and reviewed to evaluate the effectiveness of changes in the data-collection parameters for eliminating the problem.

Preliminary results were encouraging, but the problem was not fully resolved. Training in data processing and evaluation also was provided to AFRL personnel as part of this effort.

The program that performs concatenation of pass file segments for IMS data files was extended to allow its use for other pass file formats that are commonly processed. This capability can be used when circumstances of the data collection or processing cause fragmentation of satellite pass data, but it is especially useful in concatenating pass segments that are split arbitrarily by the day transition at midnight.

The latest version of the bias-calibration program was applied to a pair of Scandinavian GPS stations to evaluate possible improvements in the calibration process by the use of a reference station. The more southerly station of the chain, Tromso, Norway, was calibrated independently, using the standard bias-calibration method. The northern station, Ny-Alesund, Norway, was then calibrated using its own TEC measurements, with the calibrated Tromso measurements used as additional reference values. The Ny-Alesund TEC profile calibrated in this manner then was compared to the Ny-Alesund TEC profile calibrated independently, using data solely from Ny-Alesund, and a small difference of about 2 TEC units was observed between the profiles. This difference is attributed to localized variability of the TEC measurements, detrimentally influencing the correlations required for the bias calibration. Including a reference station, especially one at a more southerly latitude, is expected to improve the bias calibration by providing additional TEC correlations in a less variable environment.

An index, with brief functional descriptions, was prepared for all of the binary executable programs, batch files, and Basic programs used for the IMS data processing and analysis, as well as for the somewhat different processing applied to data from the RTM, National Oceanographic and Atmospheric Administration (NOAA) Continuously Operating Reference Station (CORS) sites, or International GPS Geodynamics Service (IGS) sites. These processing files are distributed to many computers at AFRL by means of the Windows NT directory replication service.

Procedures for acquiring and processing data from the Jet Propulsion Laboratory's (JPL's) distribution center or the NOAA CORS network were updated, documented, and demonstrated for AFRL personnel. Assistance was provided to AFRL personnel in acquiring and processing selected datasets from the NOAA CORS network.

## 9. Plasmasphere Investigations

Collaborative efforts are being conducted with the University of Wales at Aberystwyth (UWA) to investigate using the AFRL/NWRA bias-calibration procedures for evaluation of the plasmasphere content. UWA investigators developed a testing scenario for the bias-calibration method using the Sheffield University Plasmasphere-Ionosphere Model (SUPIM) developed by Graham J. Bailey and GPS satellite pass files synthesized from the actual GPS constellation; they obtained bias values that were too low by approximately 2 TEC units, with correspondingly high equivalent vertical TEC values. A similar test using no plasmasphere contribution produced an excellent match between the derived ionosphere and the model ionosphere, so the discrepancy was identified as a plasmaspheric effect.

Based on the geometry of the plasmasphere, a variation of the bias-calculation process was proposed by NWRA personnel, in which a lower-latitude limit is imposed on the data selected for use in the bias calibration. Provisions for this limit already had been incorporated into the process, so one of the UWA investigators performed a series of tests to find the best limiting value for the simulated data incorporating the plasmasphere. The optimal lower latitude was found to be approximately one degree south of the receiver location and close to the northernmost value for which the apparent IPP paths of the satellites remain contiguous.

The effects of a similar lower-latitude limit for actual GPS data were investigated using data from the Croughton IMS (latitude 52.0°, day 97-341) and the Otis IMS (latitude 41.7°, day 97-350). Several calibrations were performed for each site with progressively more northern lower-latitude limits for the selected data, starting with a southerly latitude limit that included all of the available data. The equivalent vertical TEC values shifted to lower levels as the lower-latitude limit moved closer to the site latitude, but the nighttime GPS satellite passes appeared to be affected more than the daytime satellite passes, probably because of the larger relative contribution of the plasmasphere to TEC at night.

Both the simulation study by UWA and the examination of actual IMS data indicate that the plasmasphere contribution to TEC needs to be removed, or otherwise accounted for, prior to the normal bias-calibration processing. An extension of the current bias-calibration method has been defined, and development of software to represent a simple line-of-sight distance through the plasmasphere has commenced.

## 10. Data Evaluations for 55 SWXS

A sample of TEC data being provided to 55 SWXS by JPL was provided to AFRL by 55 SWXS for evaluation. The data format differed from that of earlier data sets provided by 55 SWXS, but because only one site of the dataset was being examined, it was decided to synthesize the old format from the new data instead of revising the processing software. The latitude and longitude values for the IPP were observed to be appropriate for the site location, except for an East-West inversion of the longitude values, and the diurnal TEC profile appeared typical for the site location.

## 11. Portable Ionospheric Measuring Systems

### A. Ascension Island Campaign

A notebook computer containing the RTM software was configured with an external ZIP drive, for use in diagnostic studies, and a short testing program was conducted. This system then was designated for a campaign deployment at Ascension Island beginning in late 1997, with significant data-collection requirements, so a 6-GB external hard drive was configured for use in place of the ZIP drive. Device-driver limitations prevented utilization of the entire hard drive, however, resulting in only 4 GB of available storage, which was considered adequate for at least the initial campaign phase. Difficulties with the data collection at Ascension Island and an apparent failure of the external hard drive as a consequence of a power outage led to the resumption of data collection using the ZIP drive, but some of the data-collection problems remained. Processing of a set of data from the initial days of the campaign indicates many outages or reduced sampling, and discussions with on-site personnel could not alleviate this problem. This initial set of data indicates that scintillation-detection capabilities exist for the associated Ashtech receiver, even with a data sampling rate of only 1 Hz.

Data collected on ZIP disks at Ascension Island were delivered to AFRL, and were transcribed to local computer systems for later processing. Most of the procedures to be utilized for the processing were completed and documented, but one set of programs and procedures for processing the GPS phase data remains to be developed. The RTM system itself, including the external hard drive that was initially used for data collection at Ascension Island, also was delivered to AFRL. Examination of the external hard drive was conducted, to assess recovery of the data stored there. All of the available data were recoverable, with much of the data previously having been transferred to AFRL by tape.

Data collected at Ascension Island are being processed for TEC profiles and signal intensity, with a supplementary survey of the signal-intensity data for scintillation occurrences. Data files were recovered for most of the data-collection period from 23 January 1998 to 10 April 1998, but six days of coverage are missing and several days exhibit only partial coverage. Increasing the data-collection interval from one second to two seconds after 27 March 1998 produced a significant, but not complete, improvement in the data-collection coverage, with some losses apparent during periods with ten or more satellites visible. Approximately 25 days of data remain to be processed for TEC and signal intensity, with the majority of these days being in March 1998.

Samples of the GPS data from Ascension Island are displayed in Figures 1 through 4. Figure 1 is a diurnal profile of the equivalent vertical TEC data, calibrated using the standard bias-calculation algorithm but with an adjustment of 10 TEC units lower for the biases, to compensate for the effect of the plasmasphere. Figure 2 is a survey plot of the intensity scintillation index, $S_4$, as calculated within the RTM program for the L1 GPS intensity signal, on a one-minute basis. Figure 3 displays the detailed two-second sampling of intensity for both L1 and L2, confirming scintillation occurrences beginning after about 75000 seconds UT (21:00 UT). Figure 4 displays the raw (uncalibrated) slant TEC measured for the same GPS satellite track. The severe excursions in differential group delay (DGD) for this plot can be associated with the most significant signal attenuations for the GPS L2 frequency in Figure 3.

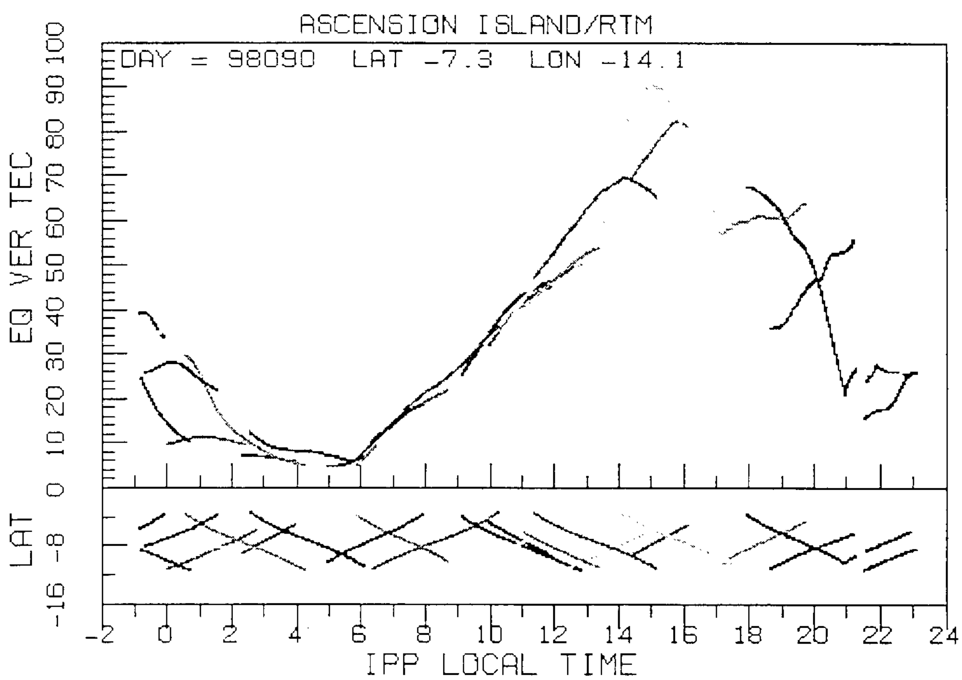


**Figure 1. Equivalent Vertical TEC diurnal profile for Ascension Island on 31 March 1998. The TEC data have been increased by 10 TEC units from the calculated calibration to accommodate the error introduced by the plasmasphere. The individual segments arise from the different GPS satellite passes.**

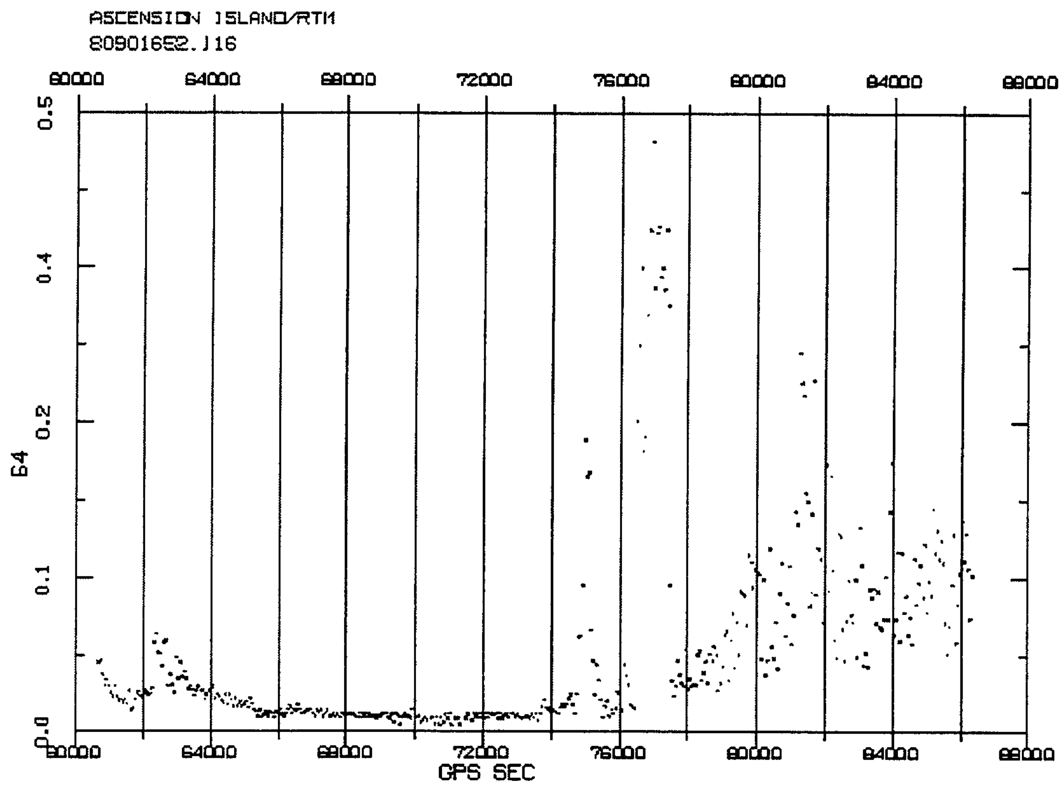


**Figure 2. Survey plot of intensity scintillation index for GPS satellite 16, for one-minute intervals.**

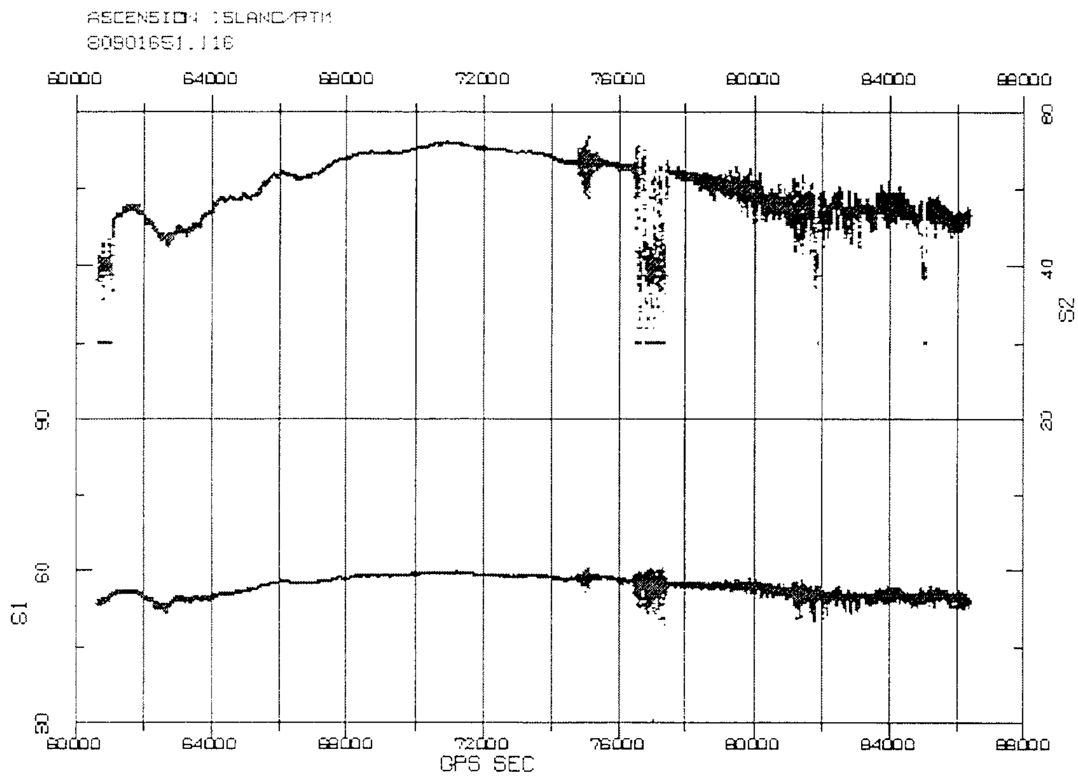


Figure 3. Detailed intensity record for both GPS signals for satellite 16 on 31 March 1998, showing effects of scintillation. The S1 measurements were performed at the GPS L1 frequency, while the S2 measurements were performed at the GPS L2 frequency.

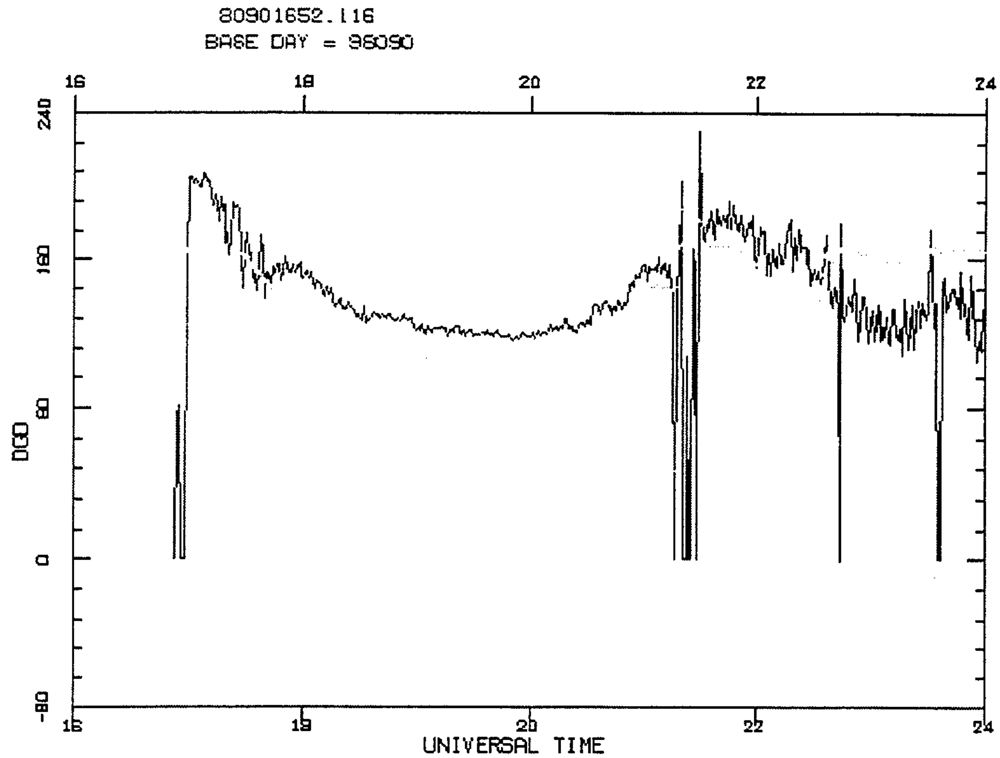


**Figure 4. Raw slant TEC (DGD - solid line, DCP - broken line) for GPS satellite 16 during scintillation events. Phase discontinuities are corrected before bias calculation is performed.**

B. Thule

A second notebook computer was configured with the RTM software and an external ZIP drive, to pursue further diagnostic studies. A number of alternative data-collection configurations were defined and tested on this system to evaluate data-storage requirements and data-processing alternatives. Some studies also were performed on this system while attempting to diagnose the problems at Ascension Island, but the problems could not be replicated at Hanscom. This system was designated to accompany the maintenance personnel during the March 1998 trip to Thule.

Data collected by this second notebook RTM system during its testing phase were processed for possible correlation with DISS measurements and transionospheric transmissions. Unfortunately, a data-collection gap during the middle of the day detrimentally affected the calibration of the TEC data, and data available from the IMS at Hanscom were utilized to pursue this investigation.

This RTM system accompanied NWRA and AFRL personnel on the Thule IMS maintenance visit. This system verified that the original IMS receiver for Thule was functioning normally, and did not exhibit the same symptoms as the IMS during the shutdown occurrences, but the RTM system did exhibit sporadic symptoms similar to those described for the RTM at Ascension Island. These symptoms were alleviated at Thule by decreasing the sampling rate, and a similar setting was prescribed for the system at

Ascension Island. The symptoms may be associated with the large number of visible GPS satellites at the two sites and the limited serial-port speed for the RTM software.

## 12. Data-collection Evaluations

A computer system using the RTM software is being employed for further investigations of the GPS "ghost" problem, in which a spurious GPS satellite observation is reported. For these investigations, an adjustable attenuator was inserted between the Micropulse antenna and the Ashtech receiver. A preliminary calibration of attenuation setting against reported signal level was conducted, and the attenuation setting required to eliminate "ghosts" was estimated, based on the antenna gain profile in elevation and the elevation threshold for "ghost" occurrences of about 70 degrees. Data collection for test settings is in progress, with review of the data to be coordinated with AFRL personnel.

Version 2.5 of the RTM software was acquired from ARL and installed on the system performing the "ghost" investigation. This version is expected to resolve the sporadic loss of phase data and can perform data acquisition at a rate greater than 1 Hz. Preliminary testing has begun, concurrent with continuing "ghost" investigations.

## 13. International Collaborations

NWRA personnel attended meetings at AFRL in March 1998, conducted as part of an ongoing collaboration between AFRL and researchers from the United Kingdom. Developments during the past year and plans for the next year were presented and discussed. Further meetings were conducted with local participants to plan data collection and analysis for instruments to be deployed in the United Kingdom.

A computer system was configured for use with the RTM software and a separate device for monitoring continued computer operation, in a manner analogous to the "heartbeat" detector for the IMS. Initial tests with the PC "heartbeat" monitor were satisfactory, and an auxiliary program was created to coordinate "heartbeat" outages with error terminations for the RTM program, allowing the possibility of resetting the receiver when it causes an RTM error termination.

RTM data-collection parameters were defined for studies to be performed from the Shetland Islands. The detailed data, at a sampling rate of 1 Hz, are time sequences of signal strength and phase for each of the two GPS frequencies, while the time-average data records, at a sampling rate of once per minute, consist of DGD, DCP, and the intensity-scintillation index. The detailed data are intended to monitor scintillation and clutter phenomena, and the average data are intended to monitor TEC and survey the scintillation occurrences. The data-collection process and directory assignments were defined to facilitate tape archiving and file handling for each day of data, including ephemeris and log files generated by the RTM program. A testing period for this system was conducted at AFRL, with review of the associated data. The RTM system, with its associated receiver and antenna, were packaged and shipped to the United Kingdom in late August 1998, with instructions for reassembling the components and initializing the data collection. Remote monitoring of this system from AFRL is planned for its period of operation.

## 14. Simulation of Scintillation

A poster presentation was conducted at the Space Weather Workshop (Space Weather Effects on Propagation of Navigation and Communication Signals) concerning the method for a statistical simulation of scintillation effects and the preliminary results of the June tests at Wright-Patterson AFB. A synopsis of the method was presented to one of the discussion subgroups.

Further plans were developed to address the need for improvements in the scintillation-simulation process, in consideration of further receiver testing prior to the solar maximum expected near the year 2000. These plans encompassed further evaluations of the current simulation process as a realistic representation of scintillation, remediation of some limitations of the process, and extension of the process for more general scenarios. Efforts were coordinated with AFRL/SN (formerly Wright Laboratory) to define the appropriate parametric values to be used for tests and to represent best various physical conditions for preliminary phases of the testing sequence.

## III. HAARP Topics

Under HAARP, a major observatory is being constructed in Gakona, AK, to conduct upper-atmospheric, ionospheric, and radio-propagation research. In addition to a high-power HF transmitter being installed by Advanced Power Technologies, Inc. (APTI), an array of geophysical diagnostic instruments is being assembled. Under this contract NWRA is preparing instruments for measurement of transionospheric radio-propagation effects and facilitating installation of other diagnostics. In the contract's first year, NWRA's HAARP activities involved several of these diagnostics, as well as coordination with other researchers, with APTI, and with the interested general public, as described in the following subsections.

### 1. Riometer

The HAARP classic riometer operates at 30 MHz at Gakona. A riometer measures the average amplitude of galactic radio noise within the instrument's antenna beam, as received through the absorbing region of the lower ionosphere. Ionospheric absorption during particle-precipitation events can be deduced by subtracting measurements performed during quiet ionospheric periods from measurements made during disturbed periods. The measurement performed during quiet ionospheric conditions produces a 'quiet-day curve'. Traditionally, riometer data analysis has been performed well after the fact, when a considerable body of data (e.g., a month's worth) is available. A quiet-day curve then can be determined by various techniques, such as mass plots, the inflection method, etc., as described in the literature. At HAARP, where the riometer is used to gauge the instantaneous level of absorption during modification experiments, this approach is not suitable. Rather, a method is needed to determine the level of absorption in real time.

The quiet-day curve is linked to sidereal time rather than solar time (which differ by about four minutes per day) because the radio noise being measured originates from the stars of our galaxy, notably those close to the ecliptic plane. Even here, the radio-noise sources are not evenly distributed, so quiet-day curves depend on the latitude of the riometer antenna, as well as on azimuth and elevation. Thus, derivation of universally applicable quiet-day curves is not possible; each riometer has its own. Also, the curve is displaced due to the difference between solar and sidereal time.

Ionization in the lower ionosphere is produced by a number of sources. A background absorption is linked to the solar zenith angle and the regular solar flux. Particle precipitation causes additional auroral and polar-cap absorption (PCA). The background contribution to the absorption measurement varies with season at a given riometer site. A quiet-day curve determined in late December will represent the galactic noise seen through the diurnal variation of the background absorption during a period when the solar zenith angle is largest. Thus, this curve should represent a lowest baseline of background absorption and may be used as a universal quiet-day curve. Such an approach currently is used with the HAARP classic riometer.

Two problems arise from use of a universal quiet-day curve. First, increased background absorption during the summer will be a dominating feature of the diurnal absorption measurement. The background absorption usually is not of interest to experimenters, and it should be suppressed to isolate the auroral and/or PCA components of the total absorption. Furthermore, a quiet-day curve derived during late December will include periods when the ionosphere above the station is sunlit. In the summer time, these periods may be in darkness due to the difference between solar and sidereal time. This difference can lead to negative absorption values apparently being measured during parts of the night.

Adaptive corrections of the quiet-day curve are possible at high-latitude stations where auroral absorption events are rare or absent and where, consequently, most days are quiet days. At auroral latitudes, however, there may be no quiet days at all during a month, and adjustment of the quiet-day curve will not lead to usable results. The HAARP riometer is situated at such a latitude.

The seasonal variation of background absorption is quite regular. Quiet-day curves derived for particular days of the year are almost identical on consecutive years, leading to the suggestion that a seasonally adjusted quiet-day curve can be derived for universal use at a particular station. NWRA consultant Jens Ostergaard has begun efforts to generate a seasonally adjustable quiet-day curve for the HAARP classic riometer.

Fifteen months of data, covering the period from June 1996 to September 1997, have been examined day by day. The number of disturbed days varies from none at all in June 1996 to all days in September 1997. A total of 70 quiet days distributed throughout the year have been selected for further analysis. The quiet-day curve derived during the late part of December fits well during all of December. During November, the quiet-day curve fit is quite good, but it exhibits an increasingly better fit toward the end of the month. A larger change of fit is observed during the month of October, where the fit also gets better during the month.

On the other side of the late December period, the fit of the quiet-day curve becomes progressively worse during the first two weeks of January. Then only a small deterioration of the fit is seen throughout the summer period. This seasonal difference suggests that solar zenith-angle control of the background absorption should be related to the solar zenith angle at altitudes well above the earth's surface, which is not unexpected. An examination of the galactic noise in sidereal time vs. the solar zenith angle for the year may show whether a single parameter such as the solar zenith angle at a certain altitude may be used as the controlling parameter for seasonal adjustment of the quiet-day curve. Software for such an investigation is under development. The software is based on an existing computational model of PCA events, especially the parts of the model computing the day/night transition of solar zenith-angle control over absorption levels associated with detachment of free electrons from negative ions. The aim of this work is not a first-principles model of the background absorption mechanism, however, but rather a simple, adjustable quiet-day curve, and the analysis will not be brought beyond such a state.

## 2. TEC/Scintillation Receivers

NWRA operated HAARP's Novatel single-frequency GPS receiver at Gakona and archived data from it until the trailer housing the receiver was relocated near the end of March. Participants in the RF Ionospheric Interactions Workshop held in April discussed the utility of installing a two-frequency GPS receiver at Gakona having a sufficiently high sample rate that intensity and differential phase scintillation could be recorded (at least 10 Hz, and preferably 20 Hz). NWRA was tasked with investigating such receivers.

The January 1998 issue of *GPS World* contains a survey listing specifications for 429 receivers from 70 manufacturers. Many of those listed are unsuited for ionospheric measurements, but candidates from

Allen Osborne Associates, Ashtech, and Novatel appeared worthy of assessment. All of the candidates are two-frequency receivers capable of tracking at least eight GPS satellites (most 12) simultaneously and employ choke-ring antennas for mitigation of ground multi-path. Following review of the survey, Ed Fremouw (NWRA) conferred with Santi Basu (AFRL), Greg Bishop (AFRL), Clayton Coker (ARL at the University of Texas at Austin), Anthea Coster (Lincoln Lab), Keith Groves (AFRL), Bob Livingston (Scion Associates), Andy Mazzella (NWRA), and Jim Secan (NWRA).

Based on the survey and subsequent discussions, Fremouw sought information from Ashtech about its Z-12 series of Geodetic Reference Stations and its Model Z-FX Continuously Operating Reference Station and from Novatel about its MiLLenium. With special-purpose firmware, the Z-12 can provide scintillation data at 20 Hz. A (more expensive) version of it, designated the ZY-12, can employ the encrypted P code for precise positioning even when selective availability (SA) is turned on (given authorization to employ a decryption key). Theoretically, it also provides three to six dB of additional signal-to-noise ratio (SNR) on the L2 frequency (private communication, Gourevitch, Ashtech), but Coker reports "little practical evidence of this."

The ZY-12 and a single-frequency Novatel receiver were tested in the GPS simulator at Wright Lab, and Bishop et al (1998) have reported preliminary results of the ZY-12 tests. Employing a sample rate of one Hz, the tests showed good fidelity between receiver output fluctuations and the simulated intensity scintillation input for weak, moderate, and severe scintillation ($S_4$ = 0.2, 0.6, and 0.9, respectively). Phase output fidelity also was good for weak and moderate scintillation; severe scintillation produced many cycle slips. David Coco (ARL) is analyzing 20-Hz data acquired with the special-purpose firmware, and Groves plans additional analysis of those data at AFRL.

The (single-frequency) Novatel tested at Wright Lab produced (4-Hz) data of little or no utility for assessing its scintillation efficacy. The MiLLenium provides 10-Hz samples; Coker (private communication) reported, "We examined Novatel's MiLLenium (dual-frequency OEM) last year, and it compared well with Ashtech except the phase noise on L2." He also related, "Novatel has since released new firmware that claims to have fixed the L2 phase noise." Coker also points out that Ashtech's Z-Sensor is directly comparable to the MiLLenium, in both performance and price, being a dual-frequency receiver with 10-Hz capability. While neither the Z-Sensor nor the MiLLenium has been tested at Wright Lab, Coker suggests that "the ZY-12 'calibration' gives a good indication of the Z-Sensor's capabilities because the technology and data formats are the same for the Z-Sensor and the ZY-12."

The Novatel single-frequency GPS receiver now has been reinstalled at Gakona to monitor whatever L-band scintillation may be encountered there, and AFRL has taken over responsibility for its operation and data archiving. NWRA is facilitating installation by Scion Associates of eight lower-frequency (and, therefore, more sensitive) scintillation receivers employing spaced antennas at Slana, AK. Otherwise, NWRA has been directed to concentrate its scintillation/TEC activities on TEC measurements and to recommend an approach for monitoring precision location as reported by GPS. As of this writing, the most likely approach is (1) to procure an Ashtech Z-Sensor to measure absolute TEC and provide coarse (precision) location in the presence (absence) of SA and (2) to employ a separate, government-owned Precision Lightweight GPS Receiver when and if precision location is desired in the presence of SA. Recently, however, a new receiver – the Leica CRS1000 – has entered the market. Before an instrument is procured, NWRA will investigate it as an alternative to the Ashtech Z-Sensor.

Under an earlier contract, NWRA developed an ionospheric tomography system (ITS) capable of producing two-dimensional images of ionospheric plasma-density structures on scales from several km to thousands of km. The system includes a coherent receiving subsystem (the NWRA ITS10 receiver) for measuring relative TEC by recording the dispersive phase between VHF and UHF signals transmitted from the U.S. Navy's Transit satellites. Subsequently NWRA augmented the ITS10 to permit measurement of intensity scintillation at both VHF and UHF (the scintillation-capable receiver being designated the ITS10S), as well as phase fluctuations produced in smaller- corresponding to TEC variations on scales down to a fraction of a km. Four Government-owned ITS10S receivers are located in NWRA's laboratory.

NWRA has been directed to modify one ITS10S receiver and its on-line computer (PC) and data-processing software for operation as an ITS10 capable of measuring relative TEC by recording dispersive phase and its fluctuations (but not intensity scintillation) during Transit passes over Gakona. Such passes over Alaska will provide latitudinal scans of ionospheric TEC and its small-scale gradients in the auroral zone (night-side oval) and sub-auroral trough.

Work has begun to configure an ITS10 for real-time display (on its PC monitor) and permanent recording of VHF-UHF dispersive phase at 10 samples per sec (sps), corresponding to a sample spacing of about 300 (100) m in the F (E) layer overhead. We intend then to smooth the dispersive phase to 1 sps and convert it to TEC with a sample spacing of about 3 (1) km in the F (E) layer overhead. Data will be stored on the HAARP server in netCDF. Our objective is to permit a visitor to the HAARP web site to view superposed time-series plots of the 10-sps differential phase and the smoothed relative TEC, in addition to geometrical information regarding the pass trajectory.

### 3. Scientific Collaboration on Diagnostics

NWRA consultants and staff members organized and attended two diagnostic-software meetings at which data-format standards were established, the status of software was reviewed, and approaches were developed for displaying, networking, archiving, and distributing HAARP data. AFRL personnel described a database and distribution system developed at the laboratory, and alternative data systems were discussed. A representative of APTI reported the status of the HAARP information-transfer (IT) system. The netCDF data format has been adopted for all IT data. A set of metadata for the files was presented and discussed at the second of the meetings, held on 6 May at AFRL.

The HAARP data system will consist of a central server and mass storage device located at Gakona. Experimenters using the local area network are to mount the file system of this server and write netCDF files to it as data are taken. Real-time and archival access then are to be accomplished, both locally and via the Internet, by client programs written in Java and communicating with server programs also written in Java using the CORBA HOP protocol. Using an applications programming interface (API) that implements a small subset of the netCDF API, Java clients will access netCDF files remotely and render the data. CORBA services will be used to permit clients that register with the server to be called back when new data become available and their displays need to be updated. The data-access API will be made available publicly so experimenters can write their own data-access routines. Researchers will be provided with group-wide software Applets to allow limited data access and analysis. The Applets will use the Visigenic object request broker shipped with Netscape Communicator. The National Science Foundation (NSF) is developing Web-based archiving and data-search software, and the May meeting concluded with a decision to investigate cooperation with NSF on such development.

### 4. Broader Scientific and Educational Collaboration

NWRA consultants coordinated proposed continuation of participation in HAARP by the Geophysical Institute of the University of Alaska, Fairbanks (UAF). This coordination included discussions at the university; preparation of draft work statements; and making contacts for an expanded Copper Basin educational outreach program. The latter involved discussions with representatives of the Prince William Sound Community College and teachers from the area of Glennallen, AK. The educational outreach program being considered would include teacher in-service training, hands-on class demonstrations, a one-day for-credit course, an evening lecture, and an open house.

NWRA consultants also conferred with UAF and ONR regarding survey of Alaskan sites for operation of ULF-VLF receivers. The discussions resulted in a draft work statement that would facilitate completion of the surveys in preparation for a winter observing campaign to characterize the ionospheric source of ULF-VLF waves generated by the HAARP HF transmitter.

NWRA personnel participated in the RF Ionospheric Interactions Workshop held in Santa Fe, NM, in April. The workshop attracted 105 scientists to participate in a program of tutorials, invited talks, presentations on facility status, poster presentations, and planning for research campaigns. At the request of the Ionospheric Interactions Steering Committee, NWRA consultants John and Jane Rasmussen investigated alternative sites for future RF Ionospheric Interactions Workshops. Fourteen sites in California were selected for on-site visits, based on meeting facilities, cost, size, and amenities. From the fourteen, four were reported to the workshop sponsors as potential sites that could meet the needs of the workshop. NWRA consultant A. Lee Snyder attended a review in May of the Global Tomography of Underground Structures Program and prepared a summary thereof and resulting recommendations for AFRL.

Consultant John Rasmussen prepared and submitted a HAARP Activity Announcements for the Copper River (AK) Country Journal.

### 5. Diagnostic Infrastructure

The former conference room in the HAARP operations trailer is being transformed into a new diagnostics operation center. The objective is to free space in the trailer and consolidate diagnostic equipment to promote interdisciplinary understanding of phenomena monitored by HAARP's diagnostic instruments and other sensors (e.g., at the Poker Flat Research Range and the NOAA Space Environmental Center) accessible via the Internet. The expanded area will accommodate the network hub, data server, instrument displays, and workstations for visiting scientists. NWRA coordinated with APTI to initiate assembly of the new diagnostics center and placement of equipment racks therein. Electronics for the magnetometer, the 30-MHz classic riometer, and the imaging riometer have been installed. In addition, a computer display has been put in place for the HAARP ionosonde, and workstations have been installed for additional data display.

NWRA consultants specified on-site computational equipment needed for diagnostic instrumentation. This equipment, similar to that employed by UAF at the Poker Flat Research Range operations center, will optimize use of space in the temporary trailer-based HAARP operations center. It also will be ideal for use in the permanent HAARP operations center to be developed within the power-plant building.

Consultant John Rasmussen participated on the Diagnostic Road and Pad Integrated Product Team in development of the onsite infrastructure required to support diagnostic deployment. This work resulted in a 2000-ft extension of the existing road, establishment of pads for ionosonde transmitter and receiver antennas, and redeployment of the optical shelter to a new pad that is shielded from optical interference. Rasmussen also developed specifications for a second diagnostic-instrument shelter.

### 6. Coordination with APTI

Consultant Rasmussen participated in the 30% design review meeting with APTI and the USKH civil-engineering firm in January. In collaboration with APTI, Consultant Snyder developed an alternative approach for the HAARP operations center. The approach emphasizes development of the first floor of the HAARP power-plant building and use of cost as an independent variable to better match expectations with available resources. Snyder produced a survey intended to define the approximate floor space needed for a variety of functions and distributed it to approximately twenty-five scientists experienced with working at remote research facilities. Eleven survey responses were received and then summarized and discussed at an Operations Center planning session held in April as part of the Santa Fe Workshop. The planning session was supported by APTI and by the USKH architectural firm. APTI and USKH emphasized the need to undertake structural repairs to the existing power-plant building. Such repairs are needed to bring the building to a weather-tight and structurally sound condition to preclude further deterioration until the Operations Center build-out can be undertaken.

### 7. Other HAARP Activities

NWRA consultants participated in several HAARP planning meetings over the year, collaborating with the Air Force Program Office, AFRL, APTI, ONR, and others. Topics included overall program content, planning estimates for completion of the HF transmitter array, and numerous diagnostic matters. They also facilitated and coordinated visits by several high-ranking DoD officials to the HAARP site and other research facilities in Alaska.

Consultant John Rasmussen arranged a strategic planning meeting held in Tenants Harbor, Maine in July. The meeting brought together the HAARP staff for a status review, for planning the 1999 program, and for consideration of plans for the year 2000 and beyond.

Working with APTI and USKH, Consultant Snyder established priorities for those construction activities that might be undertaken with FY98 funds to bring the existing HAARP power-plant building up to a weather-tight and structurally sound condition and to initiate interior work to prepare for FY99 construction of a permanent HAARP Operations Center. USKH and APTI solicited bids for the FY98 work, but funds are not available to undertake the work. As a result, the FY98 planned work will be delayed until the 1999 outdoor Alaskan construction season, and the existing temporary Operations Center trailers will need repairs to ensure their integrity for another 12 to 15 months.

Continued use of the temporary Operations Center will require additional investments in maintenance and repair of the trailers. The HAARP transmitter array also may have to be operated at less than the available 960-kW power level to preclude electromagnetic interference with the computer systems. This latter issue provides continuing motivation to complete the power-plant building repairs and to establish a permanent Operations Center.

## IV. Publications and Presentations

Mazzella, A.J., Jr., E.J. Fremouw, J.A. Secan, C.H. Curtis, Jr., and G.J. Bishop, An Algorithm for Simulating Scintillation, presented at Space Weather Effects on Propagation of Navigation and Communication Signals, Bethesda, MD, 1997.

Lunt, N., L Kersley, G Bishop and A Mazzella, Protonospheric Electron Contents from GPS/NNSS Observations, Acta Geod. Geophys. Hung., vol 33(1) pp137-146, 1998.

## V. References

Fremouw, E. J., A. J. Mazzella, Jr., Investigations of Ionospheric Total Electron Content and Scintillation Effects on Transionospheric Radiowave Propagation, NorthWest Research Associates, Inc., Bellevue, WA, 1998.