Progress Report No. 9

"A Theoretical and Experimental Study of the Ionosphere Using Radio Signals from Earth Satellites"

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The Electrical Engineering Research Laboratory

University of Illinois

with the cooperation of the

University of Illinois Observatory

Urbana, Illinois

Introduction

This report describes the continuation of research on the morphology of the ionosphere, using as the general method the observation of perturbations induced by the ionosphere on radio signals from earth satellites. The program has been underway since the early part of 1958, having been instituted with the launching of the first artificial satellite, Sputnik I. The principal subjects for this research are the investigation of small scale ionospheric irregularities by means of scintillation of radio signals from satellites and the investigation of the total electron content of the ionosphere by observation of the Faraday rotation of the planes of polarization of radio signals from satellites. In addition theoretical studies have been undertaken concerning the phenomena under experimental investigation.

Field Operations

The previously established satellite-monitoring stations at Urbana, Illinois; Houghton, Michigan; and Baker Lake, Northwest Territories, Canada were continued in operation to record the signals of satellite 1961 Omicron, Transit 4A. The station at Adak, Alaska has been continued on a standby basis. As the attempted launching of the S-66 Ionosphere Beacon Satellite on March 19, 1964 was unsuccessful, the mission of the field stations remained unchanged from that of the previous reporting period.

No major changes in instrumentation have been made at any of the field stations. A new receiver power supply and a pair of Model B receivers have been sent to Adak. An all-transistor, six-channel, high-frequency, time-signal receiver has been designed and the prototype installed at Houghton.

Data Analysis

Mr. Kranz has been supervising the analysis of scintillation data from satellites 1959 Iota, 1960 Eta and 1961 Omicron. To date the scintillation indices for all records between August 1960 and August 1962 have been tabulated, thereby filling in a gap which previously existed. Thus, a continuous record of the scintillation index as seen from the Urbana station is available during the descending phase of the previous sunspot cycle. In order to fill in the gap from 1960 to 1962, it was necessary to compute ephemerides for all three satellites mentioned above. As the orbital elements were available in diverse form for the various satellites, this part of the project involved a considerable amount of computer programming.

Dr. J. P. McClure completed his Ph.D. thesis involving a study of the heights of scintillation-producing irregularities. A large number of observations were used, extending over a period of four years, to study the diurnal, seasonal, and latitude variations of the heights. The abstract of Dr. McClure's thesis is quoted below:

> Scintillation of radio signals from artificial earth satellites has been studied with a network of spaced receivers. The height of the irregularities responsible for scintillation was measured by the cross-correlation method for 130 satellite passages. Theoretical calculations show that the cross-correlation method used gives the average irregularity height when irregularities are uniformly distributed over a finite height range. The irregularity height measurements were made continuously for all scintillation observed sufficiently close to the receiver network. The irregularity height in the F-region was found to be fairly constant for about 2/3 of the passages examined, and to be more or less variable about 1/3 of the time. The average height gradient for individual cases where the irregularity height is not constant was near zero. Increases in irregularity height to the north and to the south occurred with approximately equal probability. Height gradients were seldom uniform for more than 50-100 km. The average height of all F-region irregularities increased to the north. This was not due to uniform layers of irregularities gently sloping upward

to the north, but to irregularity patches, large and small, being higher, on the average, in the north. The heights of the irregularities in the E-region below 130 km were constant, and had no gradients, unlike the irregularities in the F-region.

Sufficient data were obtained to determine the diurnal variation of the irregularity height distribution. The data show conclusively that most daytime scintillation originates in the E-region near 110 km height, and that most nighttime scintillation originates in the F-region at heights between 300 and 400 km. When E or F-region irregularities were observed near an ionosonde, they were nearly always accompanied by sporadic-E or spread-F echoes on the ionogram. The F-region irregularity height distribution was considerably broader after midnight than before midnight. There were not enough data to tell whether or not there was any seasonal variation of the irregularity height distribution.

Theoretical calculations resulted in a cross-correlation function describing the changes in the signal strength pattern on the ground which are observed in spaced receiver experiments. A concise expression was obtained for the cross-correlation as a function of the thickness and average height of a uniform slab of irregularities, the size of the irregularities, and the receiver spacing. After the cross-correlation has fallen to 0.5, it is approximately an inverse function of distance. These calculations are based on work in scattering theory by Yeh. A formula derived from the diffraction theory by James can be obtained as a special case of the cross-correlation function developed here. The cross-correlation function is applied to experimental data and the thickness of the layer of irregularities is found. For F-region scintillation the thickness varied from 50 km to over 300 km, with an average of approximately 120 km.

Under the direction of Dr. K. C. Yeh, electron content curves derived by Faraday-rotation analysis for the period February 1962 to December 1963 have been plotted, for both north-bound and south-bound passages of Transit 4A. These curves, when compared with similar curves obtained in the period September 1958 to December 1959 and published in J. G. R. 66, p. 1061, clearly demonstrate the sunspot dependence. At present the Faraday analysis has been carried to May 1964. It is hoped to have the data taken during the period December 1959 to February 1962 analyzed in the next six months.

In connection with the Faraday-rotation work, it is necessary to know the geomagnetic field at various points above the earth's surface.

Earlier work of this project resulted in the "M-Chart method" and in a magnetic-field subroutine for the old Illiac I computer, both of which were widely used by researchers at other institutions. With the retirement of the Illiac I, it became necessary to reprogram the magnetic field problem for the IBM 7094 computer. This has been done by Mr. R. H. Eckhouse, using Fortran. The new magnetic field program is also used as a subroutine in a program for determining total electron content from Faraday-effect null-positions on the satellite records.

A set of magnetic field data was computed for Dr. Somayajulu of the National Physical Laboratory, New Delhi.

Facilities and Equipment

No major additions to the facilities were made during the report period, with the exception of the phase-locked Doppler receiving system for the EGO beacon. This equipment was received from Smyth Research Associates and is being maintained on a standby basis while awaiting the launching of the Eccentric Orbiting Geophysical Observatory.

Theoretical Studies

Jointly with the eclipse project sponsored by NSF GP-411 a study of F2-region aeronomy has been initiated. As a by-product, it is discovered that the diurnal and the irregular thermal expansion of the neutral atmosphere may have a very important effect on the formation of the ionosphere--it tends to lift up the ionosphere. Its whole effect is equivalent to replacing the Earth's gravity by some effective value which may even become negative at some heights. This work is being done by Dr. K. C. Yeh, Dr. J. F. Phelan, and Mr. T. R. Pound.

Publications

The following publications appeared during the report period:

J. P. McClure, "Polarization Measurements during Scintillation of Radio Signals from Satellites," Journal of Geophysical Research, 69, No. 7, April 1, 1964.

J. P. McClure, "The Height of Scintillation-Producing Ionospheric Irregularities in Temperate Latitudes," Journal of Geophysical Research, 69, July 1, 1964.

K. C. Yeh and G. W. Swenson, Jr., "F-Region Irregularities Studied by Scintillation of Signals from Satellites," Accepted by NBS Journal of Research, Section D, Radio Science, August 1964.

N. C. Mathur and K. C. Yeh, "Multiple Scattering of Electromagnetic Waves by Random Scatterers of Finite Size," Accepted by Journal of Mathematical Physics, 1964.

Richard H. Eckhouse, Jr., "Fortran Computer Program for Determining the Earth Magnetic Field," Electrical Engineering Research Laboratory, University of Illinois, February 1, 1964.

J. P. McClure and G. W. Swenson, Jr., "Beacon Satellite Studies of Small Scale Ionospheric Inhomogeneities," Electrical Engineering Research Laboratory, University of Illinois, May 1964.

Personnel

The following persons were involved in project activities during the report period:

Dr. G. W. Swenson, Jr.	Principal Investigator	1/2 time *
Dr. K. C. Yeh	Co-Investigator	1/2 time
Dr. John P. McClure	Research Assistant	1/2 time
Dr. James F. Phelan	Research Associate	1/2 time
Bernard Flaherty	Electronic Engineer	1/3 time
Anthony Szelpal	Electronic Technician	Full time
Carl Stubenrauch	Research Assistant	1/2 time
Paul R. Kranz	Research Assistant	1/2 time
Richard H. Eckhouse, Jr.	Research Assistant	1/2 time (resigned June, 1964)

Note: Several hourly student assistants are also employed.

* Paid from project funds during summer only.