PROGRESS IN RADIO SCIENCE 1960-1963

Volume VIII

PROGRESS IN RADIO SCIENCE 1960-1963

VOLUME VIII

SPACE RADIO SCIENCE

XIVth GENERAL ASSEMBLY OF URSI,
TOKYO, SEPTEMBER, 1963

edited by

KEN-ICHI MAEDA

Department of Electronics, Kyoto University (Japan)

and

SAMUEL SILVER

Space Sciences Laboratory, University of California, Berkeley (U.S.A.)

ELSEVIER PUBLISHING COMPANY
AMSTERDAM / LONDON / NEW YORK
1965

ELSEVIER PUBLISHING COMPANY
335 JAN VAN GALENSTRAAT, P.O. BOX 211, AMSTERDAM

AMERICAN ELSEVIER PUBLISHING COMPANY, INC.
52 VANDERBILT AVENUE, NEW YORK, N.Y. 10017

ELSEVIER PUBLISHING COMPANY LIMITED
RIPPLESIDE COMMERCIAL ESTATE
BARKING, ESSEX

LIBRARY OF CONGRESS CATALOG CARD NUMBER 65-13889

WITH 110 ILLUSTRATIONS AND 17 TABLES

PRINTED IN THE NETHERLANDS

PREFACE

This monograph contains the papers presented at the Space Radio Research Session of the XIVth General Assembly of URSI held at Tokyo in September 1963, which was organised by the Committee on Space Radio Research, URSI, headed by Professor S. Silver. The first paper prepared by the Chairman gives the general description of the activities of the Committee and briefly introduces the four scientific papers that followed this talk in the Session. The order of arrangement of the four papers is the same as in the oral presentation at the General Assembly.

The monograph also contains five papers prepared for presentation at the Satellite Communication Systems Session of URSI organized by Commission VII. Inclusion of these papers was arranged for thorough discussion between Prof. Silver, the Chairman, and Prof. Shepherd and Dr. Burgess of Commission VII.

K. MAEDA
S. SILVER

CONTENTS

Preface, *K. Maeda and S. Silver* v

Space Radio Research

Report of the Space Radio Research Committee, *S. Silver* 1
Ionospheric research by means of rockets and satellites, *R. E. Bourdeau, J. H. Chapman and K. Maeda* 5
Planetary research in the millimetre and infrared region of the spectrum, *H. F. Weaver and S. Silver* 71
Space communication systems—results and problems, *E. F. O'Neill* 129
Data processing and its relation to the communication of deep-space experiments, *S. W. Golomb* 160

Satellite Communication Systems

Foreword 169
Satellite communication devices, *J. R. Pierce* 170
A commentary on communication satellite devices, *L. D. Jaffe* 207
Attitude, orbit and antenna control for a spinning satellite, *H. A. Rosen* 220
Stabilisation électronique du pinceau d'énergie électromagnétique rayonné par un satellite, *J. C. Simon* 221
Long-range communication by orbiting dipole belts, *W. E. Morrow, Jr.*. 224

SPACE RADIO RESEARCH

REPORT OF THE SPACE RADIO RESEARCH COMMITTEE XIVTH GENERAL ASSEMBLY, URSI

The Committee on Space Radio Research was set up at the 1960 General Assembly to advance the participation of the URSI in the rapidly developing fields of the space sciences. It grew out of the work of two earlier ad hoc committees on space radio research and space radio relay set up by the Union in 1957 in recognition of the vast research potentialities of satellites and space probes. The functions of the Committee are to stimulate the undertaking of new programs in space research by the Commissions and to act as a liaison between the URSI and the other unions and the COSPAR.

The Committee met at the General Assembly in London and formulated plans for two symposia to be held during the following three year period 1960–1963. Only one major symposium, convened by Dr. J. R. Pierce, was held; it took place in Paris in September 1961. It dealt with Space Communications, the proceedings of which have already been published by Elsevier in book form.* The other proposed symposium did not materialize for various reasons one of which is that the past three years have been heavily loaded with a large number of international meetings which covered much of the same ground. Among them we may note the Cosmic Ray and Earth Storm Conference in Kyoto in September 1961 and the London Conference on the Ionosphere of July 1962, and, of course, the annual COSPAR symposia in which members of URSI took an active part.

The various National Committee Reports contain a great deal of information about space research conducted by means of rockets, satellites, and space probes. I had given thought to presenting a review of the national activities at this session but I should only be repeating much of what will

---

* *Space Radio Communication*, edited by G. M. Brown, Elsevier, Amsterdam, 1962.

be heard later in the technical programs of the Commissions. I shall make only a few brief remarks of a general nature. It is striking how many countries, large and small, are already participating in space radio research either on their own or by international cooperation in concert with one or another major research center. As the European Space Center takes on more definite form we may expect an even greater degree of participation on the part of scientists of the smaller countries. The space research conducted during the past three years which is of special interest to the URSI is the series of investigations of the ionosphere and the magnetosphere, and of the solar plasma in the interplanetary region. The experiments have enriched considerably our understanding of the subject of solar–terrestrial relationships and we must realize that we must move the boundaries of our interest in the ionosphere to many earth radii beyond and, in fact, we must turn to an even larger sphere of interest, namely, that of solar–planetary interactions in general. Another point that I should note is the strengthening of the field of aeronomy which has resulted from studies of the atmosphere conducted in rockets and satellites and the importance to us of recognizing that our classical commitments to radio investigations of the upper atmosphere are now but part of a larger and increasingly more important field of investigation.

It was my privilege to serve as the URSI representative to the COSPAR meeting in Warsaw in June of this year. I have already submitted a rather detailed report to the Board of Officers and I merely wish to call some points of general interest to your attention. The COSPAR added two new working groups, one on Space Biology (Group V) and the other on the Physics and Chemistry of Near Space (Group VI) to its already existing four on Tracking and Telemetry (I), the IQSY (II), Data and Publications (III), and the International Reference Atmosphere (IV). Except for the one on Space Biology every working group is concerned with problems and areas of research in which the URSI is also deeply interested. It is important for the URSI to maintain an active and effective participation in these working groups and, moreover, give some thought to the ever increasing overlap of the functions of COSPAR, URSI, and the IAU, and the IUGG. Representatives of each of these organizations met informally during the assembly in Warsaw and discussed the interaction of the Unions and the changing character of a large area of science in which they are all involved. We shall hear more about these matters in the course of our General Assembly.

The executive council of the COSPAR considered a number of specialized symposia on topics of space science and proposed a program of symposia to be held over the next four years. It is the intention of COSPAR that each symposium be organized jointly with those Unions most directly interested in the particular subject. Those in which the URSI will undoubtedly be called upon to participate actively are as follows:

Subject	*Earliest year to be held*
Dynamics of the Upper Atmosphere	1964
The Radiation Belts	1964
Interaction of Corpuscular Radiation with the Atmosphere	1964
Solar Wind and the Boundaries of the Magnetosphere	1964
Basic Relations between Space Experiment Design and Telemetry and Data Reduction Requirements	1964
Venus and Mars	1965
Ionospheric Currents and Drifts	1966
Solar Control of the Composition of the Atmosphere and Ionization under Minimum Conditions	1966

The Warsaw assembly passed a number of resolutions that are also of vital interest to the URSI. I have noted them in my report to the Board of Officers and I trust that copies of the resolutions will be circulated to the members and the National Committees.

I now wish to turn to the technical program of this session. The Committee on Space Radio Research had given Prof. V. Ilyin and me the assignment of convening a symposium on the Consideration of Data Acquisition and Reduction in the Design of Scientific Experiments in Space, one of the topics, you will note, which appears in the list of COSPAR symposia. It proved to be impracticable to organize the symposium in the past three years, and I was unable to do so also for this General Assembly. Acting on the instructions of our Coordinating Committee, I proceeded to organize instead a session on space research of a broad nature which would serve also as an introduction to the many specialized space research programs prepared by our Commissions for this Assembly.

I selected four topics which I believe are of general interest and will provide the orientation toward the specialized sessions of the Commissions. The first deals with Ionospheric Research by means of satellites and space probes. The paper, prepared by Prof. Maeda of Japan, Dr. Chapman of

Canada, and Dr. Bourdeau of the United States, will introduce us to a wide range of problems about the upper atmosphere and the exosphere, to experiments which can be carried out in rockets, satellites, and space probes, and to the instrumental techniques for such experiments. The second topic is planetary research in the millimetre and infrared region. This paper, prepared by Prof. Weaver and me, has as its purpose to stimulate URSI work in millimetre and infrared ranges of the electromagnetic spectrum and to direct your attention to a larger field of study, that of planetary atmospheres of which the terrestrial atmosphere is but one component. The third paper is intended to be a status report on the art of space communications. In this paper Dr. O'Neill gives us a review of the extensive work which has already been done in space radio relay systems for global communications and points the way of future developments and problems that are yet to be solved. The fourth paper by Dr. Golomb introduces us to the subject of data acquisition and reduction as a component of the design of a space experiment. It lays out for us a number of important ideas and considerations which we should study more fully in the very near future and, in my opinion, shows the importance and depth of the problem. And I cannot help but remark that Dr. Golomb has helped me discharge my original responsibility to some extent, at least. With these brief introductory remarks let us turn to the more interesting part of this session.

SAMUEL SILVER
Chairman, Committee on Space Radio Research

IONOSPHERIC RESEARCH BY MEANS OF ROCKETS AND SATELLITES*

R. E. BOURDEAU
Goddard Space Flight Center, NASA, U.S.A.

J. H. CHAPMAN
Defence Research Telecommunications Establishment, Canada

K. MAEDA
Department of Electronics, Kyoto University, Japan

CONTENTS

1. Ionospheric Research Results from Rocket Soundings
   1.1. The neutral atmosphere
   1.2. D region electron densities under quiet solar conditions
   1.3. D region ion densities
   1.4. The disturbed D region
   1.5. D region electron collision frequencies
   1.6. Solar radiation intensity in the E and lower F regions
   1.7. Ion production and abundance in the lower ionosphere
   1.8. The diurnal behavior of the E region
   1.9. Rocket measurements of electron and ion densities above the F2 peak
   1.10. Rocket measurements of electron temperature

2. Ionospheric Research Results from Satellite Experiments
   2.1. Satellite measurements of electron temperature
   2.2. Satellite measurements of ion composition
   2.3. Local charged particle density measurements from satellites
   2.4. Topside sounding—introduction
   2.5. Plasma spike phenomena
   2.6. $N_e(h)$ profiles
   2.7. The equatorial anomaly
   2.8. Spread F phenomena
   2.9. Propagation along field-aligned ionization

---

* The whole part of section 1 and sections 2.1 – 2.3 were prepared by R. E. Bourdeau, the remaining part of section 2 and sections 3.1 – 3.2 by J. Chapman and the remaining part of section 3 and the whole part of section 4 by K. Maeda. It is acknowledged that valuable informations from U.S. sources have been kindly supplied to K. Maeda by R. E. Bourdeau.

References p. 64–70

3. Sounding Techniques and Vehicles
3.1. Topside sounding technique
3.2. Characteristics of topside sounders
3.3. Langmuir probe
3.4. Resonance probe
3.5. Antenna impedance
3.6. Doppler shift
3.7. Faraday rotation
3.8. Other methods
3.9. Rockets for sounding use
3.10. Satellites for use of ionospheric research

4. IQSY Program in Ionospheric Research
4.1. Synoptic rocket soundings in the IQSY
4.2. Satellite launchings in the IQSY

1. IONOSPHERIC RESEARCH RESULTS FROM ROCKET SOUNDINGS

1.1. *The Neutral Atmosphere*

The decisions as to the mechanisms governing the characteristics of ionospheric ions and electrons depend heavily on our knowledge of the ionizing radiations, of the absorption and ionization cross-sections of the ionizable constituents, and of the structure of the neutral atmosphere. The important atmospheric structural parameters are temperature, composition and density. Rocket grenade and pilot-static-tube experiments conducted on an international scale have contributed significantly to reference atmospheres below 100 km and have recently been reviewed by LaGow and Minzer [*85*].

Unfortunately, because of relatively few direct measurements, models of neutral gas parameters above 100 km depend heavily on theoretical application of the hydrostatic law to assumed boundary conditions at uncertain altitudes of diffusive separation. There is general theoretical agreement that maximum heating occurs between 100 and 200 km while above this level conduction keeps the temperature at a nearly constant level for any geographic location. A typical vertical temperature distribution [*71*] is illustrated in Fig. 1. A theoretical model of the fractional composition of the atmosphere below 500 km is illustrated in Fig. 1. This model is proposed by Johnson [*71*] who emphasizes the uncertainties involved. From the standpoint of the physics of the lower ionosphere one critically needs to know the

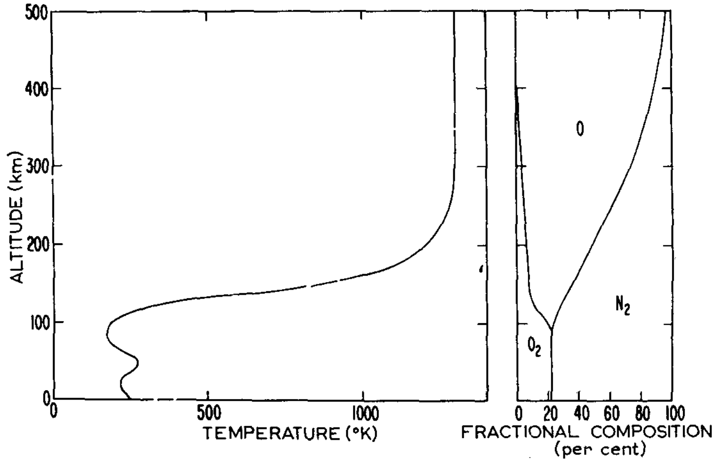

Fig. 1. Altitude dependence of neutral gas (a) temperature and (b) fractional composition (after Johnson [*71*]).

ratios O/O_2 and O/N_2. According to Schaefer [*117*], the early rocket r.f. mass spectrometer O/O_2 results of U.S. [*91*] and U.S.S.R.[*110*] investigators are subject to question because of the high probability of surface recombination effects within the instruments. Schaefer obtained a ratio for O/O_2 of 0.5 at 110 km by use of a rocketborne massenfilter. According to LaGow and Minzner [*85*], this result agrees with that derived from ultraviolet absorption measurements by Hinteregger [*54*] and Kupperian *et al.* [*84*], and all these results together can be expected to change some model atmospheres markedly.

Harris and Priester [*51*] have proposed a time-dependent model atmosphere assuming time invariant boundary conditions at an assumed altitude for diffusive separation, assumptions which have not yet been verified experimentally. In Fig. 2a are illustrated their curves of the altitude dependence of mean molecular weight at the diurnal extremes for both solar maximum and solar minimum conditions. These curves infer the variability of the thickness of the helium region in the exosphere, the existence of which was first suggested by Nicolet [*103*]. It generally is agreed from satellite drag determinations [*62, 76, 106*] that temperatures in the isothermal altitude region (above 200 km) exhibit a large diurnal and solar cycle variation and that these can be related empirically to the flux of decimeter radiation observed at the earth. The temporal thermospheric temperature variations

References p. 64–70

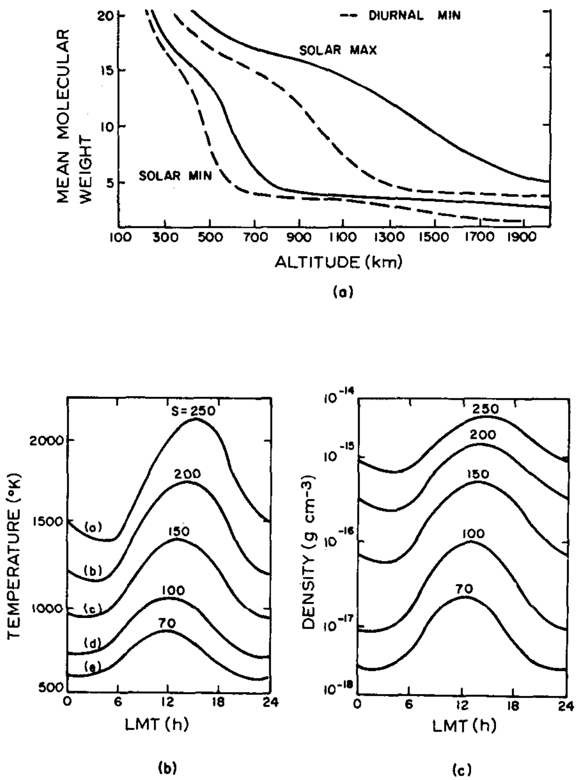

Fig. 2. Time-dependent model of neutral gas (a) mean molecular weight, (b) thermospheric temperature, and (c) 600 km density (after Harris and Priester [51]).

inferred by Harris and Priester are illustrated in Fig. 2b where the indices of decimetre radiation $S = 250$ and $S = 70$ correspond respectively to solar maximum and minimum conditions. Superimposed on these are "27-day" and semi-annual fluctuations, the latter leading to the suggestion [63] of a secondary heat source associated with the solar wind. Although the general shape of the temporal variation of thermospheric temperature appears to be agreed upon by workers in reference atmospheres, it should be pointed out that a direct measurement by French investigators of the neutral gas temperature with the use of a rocketborne sodium release experiment [15] exhibits a value higher in absolute magnitude than most reference atmospheres including that shown in Fig. 2b.

Satellite drag determinations have yielded considerable information on atmospheric density above 200 km. The Harris and Priester density model which is illustrated in Fig. 2c for an altitude of 600 km is consistent with these previously-determined results. Direct checks of densities deduced from satellite drag measurements have been made by pressure gages flown on the Sputnik 3 and U.S. [*119*] satellites. Density is perhaps the best known neutral gas parameter for altitudes above 200 km.

1.2. *D Region Electron Densities under Quiet Solar Conditions*

Spaceflight observations made during the absence of solar flares show that the three most probable ionizing agents for the mid-latitude D region (50–85 km) are cosmic rays, Lyman α (1215.7 Å) and X-radiation (2–8 Å). The Lyman α

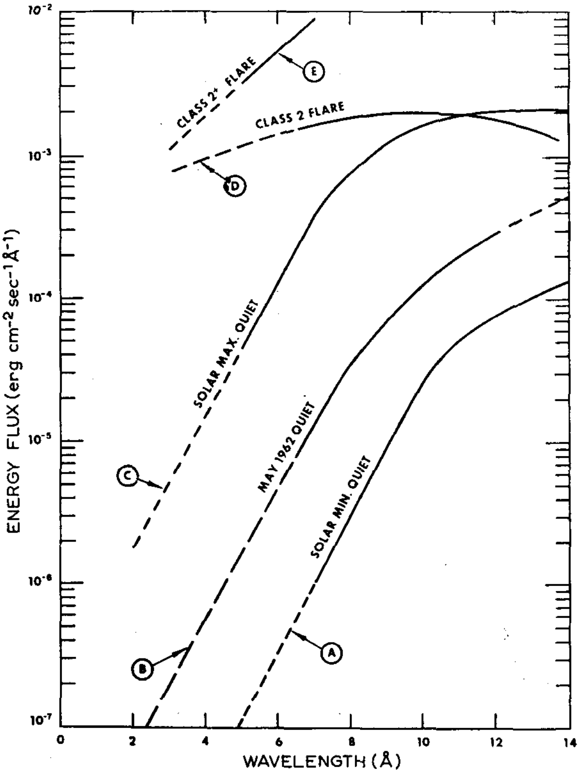

Fig. 3. The variability of solar X-ray emissions. Curves A, C and E are from Friedman [*39*]. Curves B and D are from Pounds and Willmore [*112*].

energy flux (3–6 erg cm^{-2} sec^{-1}) is relatively constant with solar condition. Measurements made principally from U.S. [*39*] and British [*112*] satellites show that the X-ray energy flux, on the other hand, is extremely variable (Fig. 3).

Theoretical models are harmonious in characterizing the region below 70 km as one produced by cosmic rays and containing a high negative ion density (N_-). However, there is some discord in the hypotheses for the formation of the 70–85 km region, some models [*93*, *104*] preferring the action of Lyman α radiation on nitric oxide, a trace constituent, to the ionization of the major atmospheric constituents by X-radiation [*111*].

Electron density (N_e) profiles for the "quiet" D region have been measured from rockets with r.f. probes by U.S.S.R. investigators [*82*] and with a Faraday rotation technique involving transmission from the ground to the rocket of a 3 Mc/s signal by a team of U.S.–Norwegian investigators [*1*]. The latter result (Fig. 4) is quite consistent in the 70–85 km with that obtained [*13*] in Canada by ground-based methods. In their discussion of the result illustrated in Fig. 4, the investigators emphasize:

(a) that the electron abundance in the region believed to be produced by cosmic rays is higher than theoretical expectation;

(b) that even using fluxes typical of a disturbed sun, X-radiation is insufficiently energetic to account for the observed ionization at altitudes between 70 and 85 km (theoretical curve II);

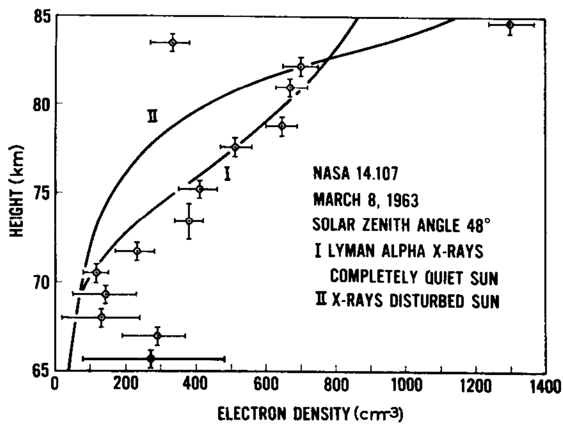

Fig. 4. Comparison of experimental D-region profile obtained under "quiet-sun" mid-latitude conditions with theoretical models (solid curves), taken from Aikin *et al.* [*1*].

(c) that the experimental electron density profile is better fitted by the Lyman α hypothesis (theoretical curve I); and

(d) that the minimum in electron density at 83.5 km which coincides with the mesopause is possibly due to either a decrease in the NO concentration or to attachment of electrons to dust whose existence has been detected at this altitude by rockets flown in Sweden [*124*].

1.3. *D Region Ion Densities*

There have been preliminary experimental attempts to describe the ionic characteristics of the D region by Japanese [*4*, *5*, *58*] and U.S. [*18*, *115*, *120*, *139*] workers, using different techniques but all involving direct sampling of the rocket's environment. The need for additional theoretical work to permit translation of the measured ion currents into meaningful geophysical parameters at altitudes below 90 km has been emphasized by some of these investigators [*58*, *139*]. This precautionary statement applies throughout the discussion of Fig. 5 which summarizes those positive ion density (N_+) profiles reported for the entire D region. As with the N_e values in Fig. 4,

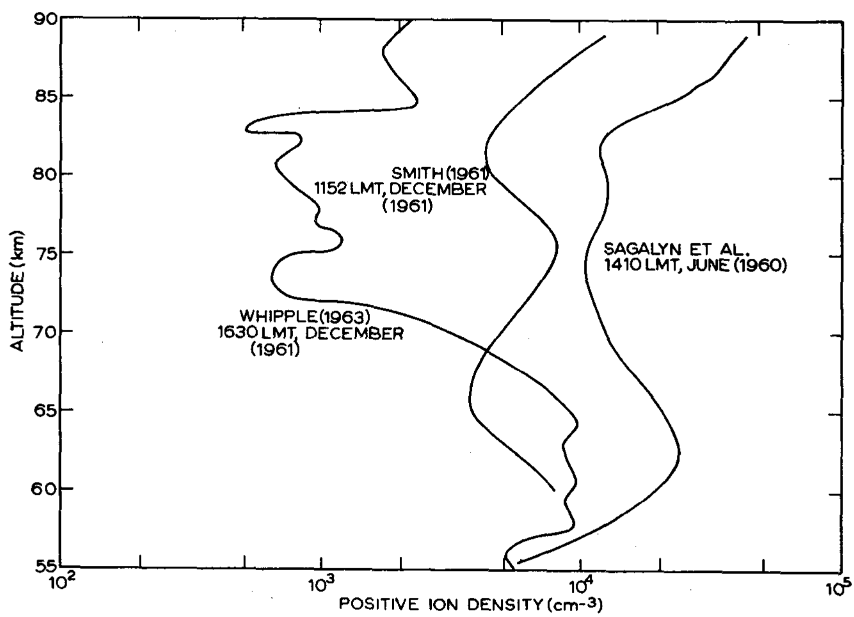

Fig. 5. Comparison of experimentally obtained D-region positive ion density profiles.

References p. 64–70

all three profiles show a higher N_+ abundance than theoretical models for the cosmic ray-produced region below 70 km. The order of magnitude difference in the profiles at altitudes 70–85 km would not be expected from data presumably obtained under similar solar conditions.

Ion densities measured by Japanese workers are not included in Fig. 5, only because they do not extend below 80 km. At 80 km, their spread of values brackets Whipple's result. Between 75 and 85 km, the N_+ values reported by Whipple agree within a factor of 2 with the N_e values from Fig. 4. This in turn is in qualitative agreement with the theoretical D region models of Nicolet and Aikin [*104*] and of Whitten and Poppoff [*142*] which claim a negligible N_- above 70 km. On the other hand, the model of Moler [*93*] contains a ratio of 10 for N_-/N_e at 70 km which would be more consistent with the Smith and Sagalyn experimental N_+ profiles. It is obvious that more work is required to (a) bring the theoretical D region models into closer agreement and (b) determine if the wide spread in the reported N_+ values is real or represents the need for refinement of the experimental techniques.

1.4. *The Disturbed D Region*

There are many phenomena which enhance D region ionization and a resulting increase of electromagnetic wave attenuation. The measured degree of N_e enhancement for different types of events is illustrated in Fig. 6. The measured quiet sun profile from Fig. 4 is included for comparison.

Simultaneously with the appearance of a solar flare, radio absorption is observed in the D region on the sunlit side of the earth for periods lasting up to approximately one hour (Sudden Ionospheric Disturbance). It is possible to ascribe the increased ionization to abnormally high X-ray fluxes which were observed from rockets [*30*] at extremely low D region altitudes. An empirical correlation has been found [*39*] between the occurrences of radio fadeouts and the times when the X-ray flux (<8 Å) measured on the Greb satellite exceeded a critical value of 2×10^{-3} erg cm^{-2} sec^{-1}. SID electron density profiles have not been measured from rockets. However, a profile (curve C) illustrated in Fig. 6 was obtained experimentally at the time of a 2^+ flare by Belrose and Cetiner [*13*] using ground-based methods.

The influx of energetic protons at auroral latitudes during solar flares produces enhanced ionization (Polar Cap Absorption) unique to this latitude region. Rocket measurements of the N_e profile during a PCA event are limited to the result (curve E of Fig. 6) of Jackson and Kane [*64*] obtained