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A SURVEY OF IONOSPHERIC MODELS A PRELIMINARY REPORT ON THE DEVE--ETC(U)

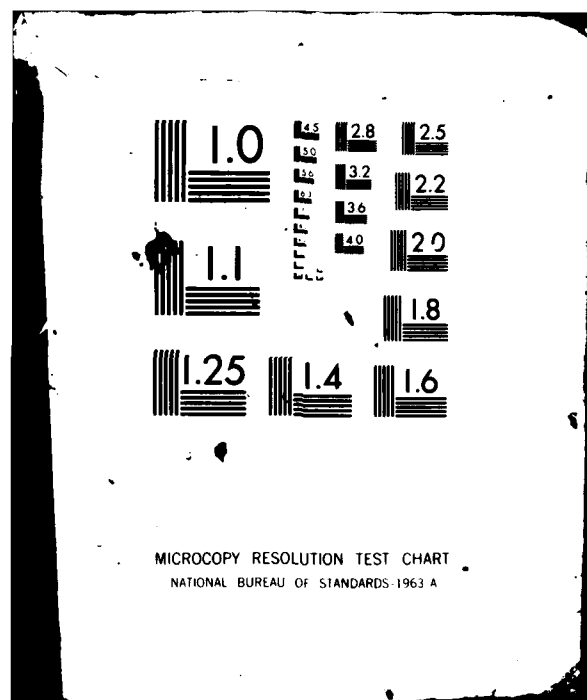
JUL 82 J M GOODMAN, E O MULBURY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This manuscript constitutes an interim progress report on an effort begun in early 1981 to compile a thesaurus and users guide for various ionospheric models which are used to assist in analysis of the radiowave propagation medium. The current status of the effort is given and future plans are outlined.		

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**A SURVEY OF IONOSPHERIC MODELS
A PRELIMINARY REPORT ON THE DEVELOPMENT OF AN
IONOSPHERIC MODEL THESAURUS AND USERS GUIDE**

1.0 Introduction

Ionospheric models of various categories have been developed for several decades with the greatest advances being made since the advent of the space age. The earliest models were developed to synopsise empirical data and/or to gather insight vis-a-vis the underlying physical and chemical processes operating in the atmosphere. These efforts have added considerably to our knowledge of the entire hierarchy of solar-terrestrial relationships and basic research programs of this category are still continuing. The quest for basic knowledge still exists but more current interest in modeling is directed toward the development of models which may be utilized by designers and operators of radiowave propagation systems. In the current DoD vernacular the contraction "C³I system" is employed. This term refers to Command, Control, Communication and Intelligence systems. In actuality C³I, a military term, may be used to describe a wide range of disparate applications. However, for the purpose of this report, the military application is emphasized. C³I is in actuality "the centralization and coordination of sets of various resources which are physically remote from the center, using all the required techniques available" [Morris, 1977]. In all C³I systems, including the military, there is the principal requirement of centralized coordination and amalgamation of resources and sensors which may be distributed over large global distances. This definition is particularly valid for the military which maintains that C³I is an effective "force multiplier". This can only be the case if the C³I systems enables more efficient operation, improved accuracy, greater speed, and higher reliability. It is important to recognize that communication - which may be regarded as the first "C" of C³I - is the "glue" which holds the whole system together. Even though other elements of the C³I family may use radio links to access or extract "data" or surveillance information, the fusion of all assets is accommodated only through reliable, timely and error-free connectivity. There are a number of radio systems currently employed to provide the "glue" for C³I. Other radio systems are central to specialized functions such as EAM (or Emergency Action Messages) and others may be principally utilized for specific surveillance functions. As the technology for C³I systems became more advanced through incorporation of modern computers, the most vulnerable part of the C³I system becomes that component which is least susceptible to control, the ionospheric/atmospheric channel.

The ionosphere, or more generally the geoplasma medium incorporating the free electrons which reside in the so-called exoatmosphere above 50 km in altitude, is probably the most obvious - if not the major - component of the total propagation channel. The troposphere is the other component. For radio frequencies between the Ultra Low (ULF) and the Super High (SHF), the ionosphere is the major medium of influence. At the Extremely High (EHF) or microwave frequencies, the troposphere becomes dominant. It is remarked that this statement must be modified for high zenith angles for which tropospheric ducting and refraction effects become important in the higher VHF and UHF bands. A discussion of this bifurcation in dominance is discussed in terms of system effects by Goodman [1980,1981] and Goodman and Aarons [1981].

Morris D.J., 1977, Introduction to Communication, Command and Control Systems, Pergamon Press, Elmsford, N.Y. 10523, USA.

Manuscript submitted March 18, 1982.

The purpose of this report is to outline the progress of an on-going NRL project to compile information pertinent to existing ionospheric and ionospherically sensitive radiowave propagation models. The total effort is supported in part through ongoing basic research programs but is principally directed toward applied research goals for support of HF and satellite communication/surveillance systems. The motivation for the study is derived from the author's affiliation with the Electromagnetic Wave Propagation Panel (EPP) of the Advisory Group for Aerospace Research and Development (AGARD) under the aegis of the North Atlantic Treaty Organization (NATO). The NATO/AGARD official interest is in the development of an "Ionospheric Model Thesaurus and Users Guide". This report constitutes the first step in that development.

2.0 Scope of the Study

There are, of course, a myriad of ionospheric models as well as radiowave propagation models which have been developed over the years. The first phase of the study undertaken in development of the "Ionospheric Model Thesaurus and Users Guide" is to identify the most current active models. In order to accomplish this task it was necessary to undertake a comprehensive literature search to obtain a data base. A set of references has been developed as a result of this search and this listing is attached as Appendix A. At this time the bibliography is incomplete and work is continuing. Another approach, and the principal subject of this memorandum, is to obtain the necessary information more directly, either through questionnaires or interviews. Two questionnaires have been developed for this purpose and they have been forwarded to the "ionospheric constituency". The mailing list included the following groups: Attendees at the 1975, 1978, and 1981 IES conferences, attendees at recent NATO/AGARD conferences, and selected individuals in the IEEE, AGU, and URSI standard mailing lists. Appendix B contains blank versions of the questionnaires which were forwarded to individuals and/or organizations on the mailing list. The scope of the effort outlined in this manuscript is basically limited to reporting the results of the questionnaires. However, a brief synopsis of current activities related to ionospheric prediction, mapping, and assessment, as well as propagation model development are included. The discussion concludes with a brief outline of future plans in connection with preparation of an AGARDOGRAPH.

3.0 Statistics Associated with Questionnaire Responses

Thirty-eight (38) individuals from twenty-five (25) different organizations responded to the questionnaire as of this writing. These individuals, who were not necessarily the custodians of code, primarily regarded themselves as developers (D) of models by a large margin. The following breakdown was found:

-
- Goodman J.M., 1980, "Environmental Constraints in Earth-Space Propagation", NRL Memorandum Report 4339, Washington, D.C. [Also presented at NATO-AGARD Conference May 1980 (London)].
- Goodman J.M., 1981, "The Environment and Earth-Space Propagation - Challenges for the Future" in Naval Research Reviews (Winter/Spring edition).
- Goodman J.M. and J. Aarons, 1981, "The Radiowave Propagation Environment - Science and Technology Objectives for the 80's" in Effect of the Ionosphere on Radiowave Systems, J.M. Goodman, (editor-in-chief) U.S. Gov't Printing Office, Washington, D.C.

TABLE I

	<u>Responses</u>	<u>Developers</u>	<u>Exclusively Developers</u>	<u>Users</u>	<u>Exclusively Users</u>	<u>Users & Developers</u>
No.	38	31	26	12	7	5
%	100	81	68	31	18	13

No editing of the respondent identification of him (her)-self as either a developer or a user was attempted. Although such editing is tempting, it was avoided to allow for the identification of a perception problem in the domain of the user-customer relationship. Some regard the ultimate user as, for example, the "white hat" in the Fleet who must use equipment which is dependent upon the ionospheric channel, a medium he knows little about. In this instance all echelons above this "ultimate" user are either developers or designers. Others, specifically scientists who regard themselves as developers, view the sponsor/funding agency as the customer/user which is usually an erroneous view if we are defining model utility strictly in terms of its specific impact on system development or operation. If the intent of model development is to advance one's knowledge of the ionosphere, however, the user may be simply the scientific community at large. In this instance a scientist may regard himself as a user of models or perhaps even both. Thus, a misinterpretation of the terms "user" suggests that we should consider the following bifurcation of terms: the scientific-user and the systems-user. Typically the systems-user is implied when referring to the term "user" alone.

There are also users of "long-term" models and another category of users for which model development and application is of more immediate concern. The former category contains system designers as well as architects who are responsible for an a-priori evaluation of system performance. This responsibility includes definition of the degree of system robustness required; i.e., the margins over which systems must be designed to adapt. In the latter category we include the ultimate user in the operational arena in addition to those managers who are in need of immediate band-aid fixes for inadequately designed systems. Inadequacy of design is, of course, not always a result of the non-recognition of potential problems which have been identified in R&D efforts many years before, although it may be. It is sometimes a result of a changing operational environment which necessitates greater system performance than previously envisioned. More often than not it is directly related to the perceived threat within a specified warfare area. Unfortunately these perceptions change from time-to-time. Because the environment of the ultimate user is so dynamic, user requirements usually have a short-fuse and this necessitates a flexibility of response by the R&D community. This argues for a broadly-based R&D program to achieve this goal. In the area of ionospheric research, or more specifically model development, this is no less true.

4.0 Listings of Respondees

Tables II and III below are alphabetical listings of organizations and individuals, respectively, which/who responded to the questionnaires.

TABLE II

ORGANIZATIONAL RESPONSE TO QUESTIONNAIRES

<u>ORGANIZATION</u>	<u>ADDRESS</u>
1. AIR FORCE GEOPHYSICS LABORATORY	L. G. Hanscom AFB Massachusetts 01731, USA
2. AIR FORCE WEAPONS LABORATORY	Wright Patterson AFB Ohio 45433, USA
3. APPLIED PHYSICS LABORATORY	Johns-Hopkins University Johns-Hopkins Road Laurel, Maryland 20707, USA
4. APPLIED RESEARCH LABORATORY	University of Texas at Austin P.O. Box 8029, 10000 Burnet Rd. Austin, Texas 78712, USA
5. CENTRE FOR RADIO SCIENCE	University of Western Ontario London, Ontario, Canada
6. COMMUNICATIONS SATELLITE CORPORATION	COMSAT Laboratories Clarksburg, Maryland, 20734 USA
7. EMMANUEL COLLEGE	400 The Fenway Boston, Massachusetts 02115 USA
8. ENVIRONMENTAL RESEARCH LABORATORIES	National Oceanic and Atmospheric Administration U.S. Dept of Commerce Boulder, Colorado 80303, USA
9. FORSCHUNGSINSTITUT FUR HOCHFREQUENZPHYSIK (FGAN)	Konigstrasse 2 D-5307 Wachtberg-Werthhaven FRG
10. GEOPHYSICAL INSTITUTE	University of Alaska 903 Koyukuk Ave. North Fairbanks, Alaska 99701 USA
11. INSTITUTE FOR TELECOMMUNICATION SCIENCE	U.S. Dept of Commerce NTIA/ITS, 3413-1 325 South Broadway Boulder, Colorado 80303, USA
12. LOS ALAMOS NATIONAL LABORATORY	Los Alamos, New Mexico 87545 USA

13. MITRE CORPORATION	Rt. 62 Bedford, Massachussets 01730 USA
14. NAVAL INTELLIGENCE SUPPORT CENTER	4301 Suitland Rd. Washington, D.C. 20390, USA
15. NAVAL RESEARCH LABORATORY	4555 Overlook Avenue Washington, D.C. 20375, USA
16. PHYSICAL DYNAMICS INC.	P. O. Box 3027 Bellevue, Washington 98009 USA
17. RCA GOVERNMENT & COMMERCIAL SYSTEMS	Astro-Electronic Division P. O. Box 800 Princeton, New Jersey 08540 USA
18. RICE UNIVERSITY	Weiss School of Natural Sciences P.O. Box 1892 Houston, Texas 77001, USA
19. SIGNATRON	12 Hartwell Avenue Lexington, Mass. 02173 USA
20. SPACE ENVIRONMENT LABORATORIES (SEL)	National Oceanic and Atmospheric Administration U.S. Dept of Commerce 325 South Broadway Boulder, Colorado 80303, USA
21. SOUTHWEST RESEARCH INSTITUTE	P.O. Drawer 28510 6220 Culebra Road San Antonio, Texas 78284, USA
22. STANFORD RESEARCH INSTITUTE INTERNATIONAL	333 Ravenswood Avenue Menlo Park, California 94025 USA
23. UNIV. OF CALIFORNIA AT SAN DIEGO	Dept. of E.E. & Computer Sci. Mail Code C-014 La Jolla, California 92093 USA
24. U.S. ARMY COMM-ELECTRONICS ENGINEERING INSTALLATION AGENCY	Attn: CCC-EME0 Ft. Huachuca, Arizona 85613 USA
25. UTAH STATE UNIVERSITY	Physics Department Logan, Utah 84322, USA

TABLE III

ALPHABETICAL LISTING OF RESPONDEES TO QUESTIONNAIRES

1.	AARONS, Jules, Dr.	Boston University Department of Astronomy 705 Commonwealth Ave. Boston, MA 02215 Phone: 617-353-2639	DEVELOPER	<u>X</u>	USER	<u> </u>
2.	ALBRECHT, Hans J., Dr.	FGAN, Konigstr. 2 5307 Wachtberg FRG	DEVELOPER	<u>X</u>	USER	<u> </u>
3.	AMES, John W., Dr.	SRI International, 333 Ravenwood Ave. Menlo Park, CA 94025, USA Phone: (415) 859-3662 TELEX: 910-373-1246	DEVELOPER	<u>X</u>	USER	<u> </u>
4.	ANDERSON, David N., Mr.	NOAA/ERL/SEL U.S. Dept of Commerce Boulder, CO 80302, USA Phone: (303) 497-5327	DEVELOPER	<u>X</u>	USER	<u> </u>
5.	BASU, Sunanda, Dr. (Also Dr. Santimay Basu)	Emmanuel College 400 the Fenway Boston, MA 02115, USA Phone: (617) 861-3974	DEVELOPER	<u>X</u>	USER	<u> </u>
6.	BEARCE, Loren S., Mr.	Code 7586 Naval Research Laboratory 4555 Overlook Ave., Washington, D.C. 20375, USA Phone: (202) 767-2400	DEVELOPER	<u> </u>	USER	<u>X</u>
7.	BRAMEL, Edwin F., Mr.	Commander U.S. Army Comm-Electronics Eng. Installation Agency, ATTN: CCC-EMEO Ft. Huachuca, AZ 85613, USA Phone: (AUTOVON) 879-6779 (FTS) 761-2151 Ext. 6779 (Com) (602) 538-6779	DEVELOPER	<u>X</u>	USER	<u>X</u>
8.	CHRISTOPHER, Paul, Mr.	Mitre Corporation Rt. 62 Bedford, MA 01730, USA Phone: (617) 271-3540	DEVELOPER	<u>X</u>	USER	<u> </u>

9. CLYNCH, James R., Dr. Applied Research Laboratory
University of Texas at Austin
P.O. Box 8029, 10,000 Burnet Road
Austin, TX 78712, USA
Phone: (512) 835-3380
DEVELOPER X USER
10. FANG, Dickson J., Dr. COMSAT Labs, Communication Satellite Corp.
22300 Comsat Drive
Clarksburg, MD 20871, USA
Phone: (301) 428-4131
TELEX: 8966
DEVELOPER X USER
11. FREMOUW, Edward J., Dr. Physical Dynamics Inc.
P.O. Box 3027
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DEVELOPER X USER
12. GANGULY, Suman, Dr. Dept of Space Physics and Astronomy
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Phone: (415) 859-3318
DEVELOPER X USER
13. HATFIELD, V. Elaine, Mrs. SRI International
333 Ravenswood Road
Menlo Park, CA 94025, USA
Phone: (415) 859-3318
DEVELOPER X USER
14. HAYDEN, Edgar C., Dr. Southwest Research Institute
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San Antonio, TX 78284, USA
Phone: (512) 684-5111
TELEX: 767357
DEVELOPER X USER X
15. HESSING, Anne R., Ms SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025, USA
Phone: (415) 859-3618
TELEX: 910-373-1246
DEVELOPER X USER
16. HORAN, Donald M., Dr. Code 4175H, Naval Research Laboratory
4555 Overlook Avenue, S. W.
Washington, D. C. 20375, USA
Phone: (202) 767-2350
DEVELOPER X USER
17. JOHNSON, Allen L., Mr. AFWAL/AAAD Wright Patterson AFB
Ohio 45433, USA
Phone: (513) 255-2697
DEVELOPER USER X

18. JONES, R. Michael, Dr.	NOAA Wave Propagation Laboratory U.S. Dept of Commerce Boulder, CO 80303, USA Phone: (303) 497-6464	DEVELOPER <u>X</u>	USER <u> </u>
19. KELLEY, Edward J., Mr.	Project Manager, Environmental Sciences Naval Intelligence Support Center 4301 Suitland Road Washington, D.C. 20390, USA Phone: (202) 763-1635	DEVELOPER <u> </u>	USER <u>X</u>
20. LANE, George, Mr.	USACEEIA, ATTN: CCC-EMEO-PED Ft. Huachuca, AZ 85613, USA Phone: (602) 538-6779	DEVELOPER <u>X</u>	USER <u> </u>
21. LLOYD, John L., Mr.	U.S. Dept of Commerce NTIA/ITS 3413-1 325 South Broadway Boulder, CO 80303, USA Phones: (COM) (303) 497-3701 or 3813 (FTS) 320-3701	DEVELOPER <u>X</u>	USER <u> </u>
22. MAC DOUGALL, John W. (Prof)	Centre for Radio Science University of Western Ontario London, Ontario, N6A 3K7, CANADA Phone: (519) 679-6294	DEVELOPER <u>X</u>	USER <u>X</u>
23. MALAGA, Alfonso, Dr.	Signatron 12 Hartwell Ave. Lexington, MA 02173, USA Phone: (617) 861-1500	DEVELOPER <u>X</u>	USER <u> </u>
24. MATHWICH, H.R., Mr.	Staff System Scientist RCA Gov't and Commercial Systems Astro-Electronics Division P.O. Box 800 Princeton, N.J. 08540, USA Phone: (609) 448-3400	DEVELOPER <u> </u>	USER <u>X</u>
25. MOSER, Philip J., Mr.	Code 7009 Concept Development Staff U.S. Naval Research Laboratory 4555 Overlook Ave., S.W. Washington, D.C. 20375, USA Phone: (202) 767-5865	DEVELOPER <u> </u>	USER <u>X</u>
26. PAUL, Adolf K., Dr.	NOAA-SEL R43 325 S. Broadway Boulder, CO 80303, USA Phone: (303) 497-3432	DEVELOPER <u>X</u>	USER <u> </u>

27. PHILBRICK, Charles R., Dr. Air Force Geophysics Laboratory
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28. PONGRATZ, Morris B., Dr. Project Leader MS 466
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DEVELOPER USER X
29. RICH, Frederick J., Dr. Air Force Geophysics Laboratory
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Phone: (617) 861-2431
DEVELOPER X USER
30. SAGALYN, Rita C., Mrs. Air Force Geophysics Laboratory
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Phone: (617) 861-2431
DEVELOPER X USER X
31. SCHUNK, Robert W., Prof. Utah State University
Physics Dept.
Logan, UT 84322, USA
Phone: (801) 750-2974
DEVELOPER X USER
32. SUGAI, Iwao, Dr. Applied Physics Laboratory
Johns Hopkins University
Johns Hopkins Road
Laurel, MD 20707, USA
Phone: (301) 953-7100
DEVELOPER X USER X
33. SZUSZCZEWICZ, Edward, P. Dr. Code 4187, Naval Research Laboratory
4555 Overlook Ave., S.W.
Washington, D.C. 20375, USA
Phone: (202) 767-3329
DEVELOPER X USER
34. THOMASON, Joseph F., Mr. Code 5324T, Naval Research Laboratory
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Phone: (202) 767-5926
DEVELOPER X USER
35. VATS, Hari Om, Dr. Electrical Engineering and Computer Sciences
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DEVELOPER X USER

36. WATKINS, Brenton J., Dr. Geophysical Institute, University of Alaska
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 Phone: (907) 479-7479
 DEVELOPER X USER
37. ZANETTI, Lawrence J., Dr. Research Ass't S.I.P.
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 DEVELOPER USER X
38. ZINN, John, Dr. Los Alamos National Laboratory
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 Phone: (505) 667-6403
 DEVELOPER X USER

We note that thirty six (36) of the thirty eight (38) responses were from the U.S. with the foreign responses being from Canada and FRG. Of the twenty five (25) organizations responding (some clearly with multiple respondees), the mix was almost equally divided between U.S. Government, University or University-affiliated laboratories/institutes, and industrial/other.

It is clear, and was certainly anticipated, that the response to the questionnaires would be weighted toward the U.S. This is no doubt a natural consequence of the imbalance in the mailing list utilized. It is also noteworthy that greatest organization response came from NRL and AFGL. This is not necessarily related to activity in modelling development or use by these organizations but is probably a result of the fact that the author is affiliated with the former organization and there is historically a strong interest in NATO-AGARD activities by individuals in the later organization. Even so, the questionnaire contributions by AFGL and NRL are certainly not complete from first-hand knowledge of work being conducted by these laboratories.

Obviously there are problems involved in applications of a questionnaire approach to obtain information. One of these involves the "procrastination syndrome" which is handled best by direct contact or telephone. Another is related to the psychology of the questionnaire approach itself with many individuals being biased against such an activity. Another is related to the "sampling algorithm" employed i.e., the mailing list. Steps have been undertaken to alleviate the "sampling" problem. This involves literature search, a time-consuming exercise at best.

5.0 Ionospheric Model Data from the Questionnaires

Table IV below is an alphabetical listing of the Ionospheric/Propagation models identified from the returned questionnaires. (In some instances, a short model name is used. In these cases the title is listed with quotation marks. The author of this report takes full responsibility for any inappropriateness.)

TABLE IV

List of Models Indicated in Questionnaire Responses

<u>MODEL</u>	<u>RESPONDEE(S)</u>	<u>CUSTODIAN(S)</u> (If other than respondent)
1. "AFGL Scintillation Occurrence"	<u>Aarons</u>	
2. "Albrecht Scintillation Model"	<u>Albrecht</u>	
3. AMBCOM	<u>Hatfield</u>	
4. ANTCAP/SETCOM	<u>Bramel</u>	Lloyd, NTIA/ITS
5. ARL:UT	<u>Clynch</u>	
6. ARMY Prophet (APES)	<u>Lane</u>	Rose, NOSC
7. Auroral Dynamic Ionosphere	<u>MacDougall</u>	
8. "Basu Scintillation Model"	<u>Basu and Basu</u>	
9. DMSP Thermal Plasma Density	<u>Sagaly</u>	
10. Fangs Plot	<u>Fang</u>	
11. F-Region Servo Model	<u>Ganguly</u>	
12. "Indian Subcontinent Scintillation Model"	<u>Vats</u>	Desphande, PRL/India
13. IONCAP	<u>Bramel, Lloyd</u>	Lloyd, Lucas Hayden, Teters NTIA/ITS
14. IONOS	<u>Zinn</u>	Zinn, Sutherland, LANL
15. ION04	<u>Christopher</u>	Rogers, Christopher Mitre Corp.
16. "Jones/Stephenson Ray Tracing Model"	<u>Jones</u>	Jones and Stephenson WPL/NOAA
17. Low/Mid-Lat F Region Model	<u>Anderson</u>	
18. NEC	<u>Bramel</u>	Burke
19. NRL Ionospheric Model	<u>Thomason</u>	
20. Polar/F	<u>Watkins</u>	
21. RADARC	<u>Hessing, Ames</u>	
22. SIMBAL	<u>Sugai</u>	Kaman-Tempo
23. Spectral Components of foF2	<u>Paul</u>	
24. S3 Empirical F-Region Model	<u>Philbrick</u>	
25. S3-3 Electron Temperature	<u>Rich</u>	
26. "Utah State Hi-Lat Ionospheric Model"	<u>Schunk</u>	Schunk, Sojka, Utah State U.
27. WBMOD	<u>Fremouw</u>	
28. WESCOM	<u>Sugai</u>	Kaman-Tempo
29. Wideband-HF	<u>Malaga</u>	
30. YTCHIU	<u>Hayden</u>	

In Table IV the respondent's name is underlined if he/she is identified to be the custodian as well. Otherwise the custodian is listed in column three (3). The affiliations of the respondents are given in Table III and are not repeated in Table IV.

Table V below is a breakdown of the models by category. We note that there are three (3) major groupings in terms of the volume of response. They are: HF propagation (8 responses), the Ionosphere (12 responses), and scintillation (7 responses).

TABLE V
Models Identified by Category

HF PROPAGATION

AMBCOM
ANTCAP/SETCOM
ARMY PROPHET
IONCAP
JONES/STEPHENSON RAY TRACING
NRL IONOSPHERIC MODEL
RADARC
WIDEBAND HF

IONOSPHERE

ARL:UT
AURORAL DYNAMIC IONOSPHERE
DMSP THERMAL PLASMA DENSITY
F REGION SERVO
IONOS
LOW/MID-LAT F-REGION
POLAR F
SPECTAL COMPONENTS OF foF2
S3 EMPIRICAL F-REGION
S3 ELECTRON TEMPERATURE
UTAH STATE HI-LAT
YTCHIU

SCINTILLATION

ALBRECHT
AFGL SCINTILLATION OCCURRENCE
BASU
FANGS PLOT
INDIAN SUB-CONTINENT
IONO4
WBMOD

NUCLEAR EFFECTS

SIMBALL
WESCOM

OTHER

NEC

Upon inspection of Table V, it is clear to any worker in the field (of Ionospheric physics) that there are many other models which are not listed. In addition there are numerous radiowave propagation models, sub-models, and computer codes not listed but known to exist. Identification of these models is in progress and a future report will take up this matter in some detail.

6.0 User Questionnaire Responses

There were twelve (12) respondees who regarded their activities as user-oriented at least in part; seven (7) were exclusively users.

6.1 Official User Needs

From the returned questionnaires the following were listed as documentation of official needs:

A. USACEEIA/CC-EMCO Ft. Huachuca, AZ

1. AR 10-13. Provide radio propagation technical services to the military services and to other government agencies.
2. CCR 105-6 (Annex A). High Frequency RF system performance predictions and analysis. Antenna electrical design. Advice and special studies on propagation and antenna matters.

6.1.1 Note: The U.S. Air Force and U.S. Navy official requirements were not identified through the questionnaire approach. General R and D objectives promulgated by the services typically outline the needs in these areas in broad terms. The general "Military Requirements for Satellite Data" are contained in a Joint Chief of Staff unclassified report MJCS 251-76 dtd 31 Aug 1976. Currently the U.S. Navy has no officially-documented Operational Requirement (OR) relating to solar-terrestrial or ionospheric modelling/monitoring. The view is held by staff under the Chief of Naval Operations (CNO) that Navy requirements are adequately covered by national resources including systems operated by the Dept. of Commerce (NOAA/SEL/SESC), the National Aeronautics and Space Administration (NASA), and the Air Force (AWS/AFGWC/SESS).

(It is noteworthy that Navy requirements in these areas were quite close to formalization in the late seventies when a Draft OR entitled "Environment Prediction and Assessment System" was "tabled" by CNO with the comment that such a system was ... "nice to have" ... but not affordable in view of sister service and national assets already in place.)

The U.S. Air Force, on the other hand, has promulgated a Statement Of Need (SON) -- as equivalent to the Navy OR document -- called IONSON which reflects the need for ionospheric monitoring in specific terms. In addition, another SON for solar/environmental monitoring, termed SEMSON, is now in process.

6.2 Unofficial Requirements

The following is a listing of the unofficial needs provided by that component of the "user" community which responded to the questionnaires.

A. Air Force Geophysics Laboratory/Hanscom AFB, MA/USA

1. Need access to as many models as possible because one of the missions of the organization is to review and suggest improvements to ionospheric models used by operational elements of the U.S. Air Force.

B. Applied Physics Laboratory (JHU)/Laurel MD/USA

1. Need specific models which are in useable form including: magnetic field, ionospheric conductivity and ionospheric current models. Models are used for identification of disturbances, field-line tracing, and electro-dynamic studies.
2. Need monthly-averaged electron density profiles for D, E, F1, and F2 layers for day and night conditions in compact, transportable FORTRAN subroutines for the purpose of investigating propagation between the Pentagon and SSBN's in PRE, TRANS, and POST nuclear environments.

- C. Centre for Radio Science/London, Ontario/Canada
 - 1. Need ionospheric models which include dynamic effects and effects of particle precipitation for research purposes; also to relate satellite propagation (at VHF) to (ionospheric) effects. Currently used models are semi-empirical and more refined (or physical) models would be better.
- D. Los Alamos National Laboratory/Los Alamos, N.M./USA
 - 1. Need prediction and/or real-time assessment of electron density profiles for active experiments (go-no go criteria).
- E. Naval Intelligence Environmental Sciences (NISC)/Washington, D.C./USA.
 - 1. Need to compare the efforts and effectiveness of other nations versus U.S. in (ionospheric) endeavors and to remain aware of the "state-of-the-art" in ionospheric predictions and their applications.
- F. Naval Research Laboratory/Washington, D.C./USA
 - 1. Need ionospheric globularity and short-term effects which could change or affect path delays and polarization. Models are needed to devise error budgets for system designs and analysis.
 - 2. Need to assess communication disturbances for SATCOM and over missile links at UHF, SHF and EHF, particularly in the case of nuclear bursts.
- G. RCA/Astro Electronics Division/Princeton, New Jersey/USA
 - 1. Need specific (computer) code representation of ionospheric models to study the relationship between topside ionosonde data and predictions based on ionospheric models.
- H. Southwest Research Institute (SWRI)/San Antonio TX/USA
 - 1. Need global models of electron density and collision frequency versus height and need models of "real-time" electron density to support ray tracing, determination of radio propagation characteristics, predictions of system performance, and real-time system management/operation.
- I. USACEEIA/CC-EME0/Ft. Huachuca, AZ/USA
 - 1. Upgrade S/N requirements for HF systems.
 - 2. Obtain programs and hardware necessary to create and correct the input data for the ionospheric programs.
 - 3. Upgrade the existing noise level predictions for IONCAP.
 - 4. Validation of predicted reliabilities made by IONCAP.
- J. U.S. Air Force Avionics Laboratory/Wright-Patterson AFB, Ohio/USA
 - 1. Need accurate ionospheric model to allow daily predictions of communication reliability over CONUS to polar routes of airborne satellite communication systems. This model should include the influence of magnetic index, solar flux, time of day and season on scintillation.

2. Real-time model of the (ionospheric scintillation) is needed to deduce the probability for getting a message through an airborne satellite communication system and to decide if special coding/interleaving/message repeating should be employed.

7.0 General Commentary on User Needs

There has been an almost continuous dialogue at scientific colloquia, various topical conferences, and at focussed NATO-AGARD meetings concerning the matter of user or customer needs. This stems, at least in part, from the urge for "scientific self preservation". We are well aware of the "publish or perish" admonition in academia and in other scientific institutions. In view of diminishing basic research resources relative to the size of the current ionospheric constituency, the analogue to this admonition is "technology-transfer or perish". In any case there has been a concern in the scientific community in recent years vis-a-vis relevancy of basic research and this concern was heightened by the inactment of the Mansfield Amendment by the U.S. Congress in the past decade. This precipitated numerous studies in the U.S. DoD and elsewhere to focus-in on the use of ionospheric research for example. One specific study of note was conducted for the Research and Advanced Technology Office of ODDR&E/OSD by E. Bauer and A. Krinitz of IDA [Bauer and Krinitz, 1977]. Another activity of interest was a workshop [Donnelly, 1979] held in Boulder in 1979 to address Solar-Terrestrial Predictions (See Section 7.2.1).

In addition there have been three (3) Ionospheric Effects Symposia held in 1975, 1978, and 1981 dealing with ionospheric models and scientist-user dialogue problems among other things [Goodman 1975, 1978, 1981] (See Section 7.2.2).

7.1 IDA Study of 1977

This study examined the relevance and utility of ionospheric research and anticipated future DoD needs. In view of the fact that anticipated future needs, as projected from a 1977 vantage point, may not be the 1982 current needs, it is interesting to examine some of the unclassified conclusions of that study (edited by the author of this report: JMG):

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- Bauer E., and A. Krinitz, 1977, "Ionospheric Research in DoD"(U), Secret Report, IDA Log No. HQ77-19163.
- Donnelly R.F.(Editor, 1979, Solar Terrestrial Predictions, four volumes: Prediction Group Reports, Working Group Reports, Solar Activity Predictions, and Predictions of Terrestrial Effects of Solar Activity, U.S. GPO, Washington, D. C. 20402.
- Goodman J.M. (editor), 1975, Effect of the Ionosphere on Space Systems and Communications, U.S. GPO, Washington, D.C. 20402
- Goodman J.M. (editor), 1978, Effect of the Ionosphere on Space and Terrestrial Systems, U.S. GPO, Washington, D.C. 20402
- Goodman J.M. (editor-in-chief), 1981, Effect of the Ionosphere on Radiowave Systems, U.S. GPO, Washington, D.C. 20402

1. No systems were identified whose performance could be improved dramatically by an improved understanding of ionospheric physics.
2. The DoD has special user and other needs which make it prudent to support technology base efforts in ionospheric physics.
3. Expertise in ionospheric physics is needed for the interpretation of potential adversary activities.
4. Certain R&D efforts deemed to be valuable to users:
 - Scintillation effects on SATCOM
 - Propagation effects on GPS
 - Propagation studies to support OTH-B
 - VLF/LF studies of MEECN
 - Propagation studies to support OMEGA
 - Special users
5. The trend (in 1977) is to go to systems which are user dependent on the ionosphere.
6. Directed research for ionospheric model development and predictions would best satisfy DoD-unique needs.

7.1.1 Commentary on the IDA Study (JMG)

The first conclusion is likely as true today as it was in 1977, the second conclusion is simply a recommendation, and the third conclusion is obviously still true. On the basis of a value assessment, the systems listed in conclusion #4 were identified. We note with interest that HF communications is not listed, the presumption in 1977 being that SATCOM would be the future primary mode of communications with HF as backup. This (1977) view is amplified in conclusion #5. Finally the study concludes that directed research is the best way to pursue the areas of model development and predictions.

It is now worth noting that HF as a communications medium is no longer viewed to be increasingly subordinate to SATCOM. It is recognized to have a place in the future DoD C³I "architecture", and as a result of this reassessment, the fifth (#5) conclusion reached in the IDA 1977 study is only partially correct today. Furthermore the "systems-list" in conclusion #4 should be augmented to include HF communications. The Defense Nuclear Agency and the Office of the Secretary of Defense recently sponsored an adaptive HF conference to examine existing HF technology and numerous DoD-sponsored HF working groups have been established to promulgate HF improvement programs. Some improvements utilize ionospheric sounders, some involve updated models, but most are based upon the development of robust systems which perform frequency management in a manner which is organic to the system. Nevertheless since most approaches to HF improvement involve MUF-seeking architectures, the ionosphere is clearly involved. The IDA study indicates that predictions (i.e. models) of the HF channel (i.e. the ionosphere) must compete with real-time sounding of the ionosphere, but implies that HF improvements could be achieved by updating skeletonized models with sounder or satellite data. Recent NRL studies have shown that mean morphological models are useful in connection with sounder data input. Various models are being investigated in this regard including MINIMUF (resident in the NOSC/PROPHET system), IONCAP, the Rodney Bent model, and a model developed by Ching and Chiu (see bibliography at the end of this report).

A considerable amount of SATCOM-related propagation work, has been conducted since 1977 and as a result the physical understanding of the equatorial scintillation environment is rather sound. However details of the morphology and application of existing knowledge to solve the problem of quasi-real-time forecasting is not well advanced at this time. Much of the current and future attention in the scintillation area is directed toward higher latitudes where considerable work needs to be done.

7.2 Meetings and Symposia Dealing with User Needs

7.2.1 Solar-Terrestrial-Predictions Workshop - Boulder 1979

Of particular interest in the proceedings of this workshop are sections on Communications Predictions (Section III of volume 2 prepared by A.P. Mitra, B.M. Reddy and J. Klobuchar) and Ionospheric Predictions (Section VI of volume 2 prepared by R.R. Vondrak et al). The reader is referred to these sections for an elucidation of the state-of-the-art and model needs for both ionospheric-reflected and trans-ionospheric propagation.

7.2.2 Ionospheric Effects Symposia, 1975, 1978, 1981; Washington, D.C.

These conferences dealt principally with DoD problem areas of current interest. Ionospheric models and ionospheric effects on specified systems were covered.

7.2.3 NATO-AGARD Meetings

One of the most fruitful activities for reviewing (and presenting) past, current, and planned-future ionospheric research (and model development) to support specific user needs is the series of meetings held by the Electromagnetic Wave Propagation Panel (EPP) of the Advisory Group on Aerospace Research and Development (AGARD) under the aegis of NATO. Unlike many conferences, the proceedings including full papers as well as discussion periods are documented and copies are available through the DDC.

8.0 Organizational Activities of Importance to Ionospheric Prediction and Modeling

8.1 CCIR Activities

Study Group 6 of the CCIR deals with international standards and issues relating to ionospheric radiowave propagation. It plays a role in coordinating the various (U.S. and foreign) models and techniques for evaluating or predicting radiowave propagation characteristics. United States user needs (and requirements) surface at the U.S. study group (USSG-6) and various U.S. interim working party (IWP) and working group activities. These are folded into the international arena and the tangible outcome is a document ("green" book) published every four years based upon a Plenary Assembly of CCIR. The most recent "green" book of interest to ionospheric researchers is Volume VI of Recommendations and Reports of the CCIR, XIV Plenary Assembly KYOTO, 1978 on Propagation in Ionized Media published by the International Telecommunications Union (ITU). A new version will be published in 1982.

8.2 Activities of URSI (l'Union Radio-Scientifique Internationale)

URSI was established at the end of WWI as a subset (union) of the International Council of Scientific Unions (ICSU) and its major purpose was the scientific study of radio telegraphy. The objectives of URSI include the

- (i) promotion of international cooperation of all aspects of radio from a scientific point of view,
- (ii) encourage in organizational aspects of radio research requiring international scale effort,
- (iii) promotion of common standards and standards of measurement,
- (iv) encouragement of publication and result dissemination,
- (v) to collaborate with other scientific unions on matters of benefit to mankind,
- and (vi) to stimulate and coordinate studies of the scientific aspects of telecommunications using electromagnetic waves (both guided and unguided).

Currently there are nine (9) commissions of URSI and the commission of primary interest in connection with this report is commission G: Ionospheric Radio and Propagation including ionospheric communications and remote sensing of ionospheric media. Other commissions of interest are Commission C: Signals and systems; and Commission H: Waves in plasma. For the United States the objectives of URSI are organized through the U.S. National Committee (USNC) of the Natural Research Council (NRC), Assembly of Mathematical and Physical Sciences (AMPS).

URSI to this day remains dedicated to the science underlying radio communications although efforts have been suggested to merge its activities with the International Association for Geomagnetism and Aeronomy (IAGA) of the International Union of Geodesy and Geophysics (IUGG).

8.3 Activities of COSPAR

COSPAR was established in 1958 by the International Council of Scientific Unions (ICSU) to continue the cooperative programs of rocket and satellite research successfully undertaken during the IGY (1957-58). In 1975, balloon research was added to the charter. Three recent publications based upon symposia organized by the COSPAR Beacon Satellite group are noteworthy for the purposes of this report [Mendillo, 1976; Checcacci, 1978; and Wernik, 1981]. The first official COSPAR-sponsored conference was held in Graz, Austria in 1972; in 1974, the second conference was held in the USSR. The last two bi-annual conferences were co-sponsored by URSI.

There are, as one might expect, many joint URSI and COSPAR activities or areas of coordination. One example is the development of the International Reference Ionosphere (IRI) which is directed by Prof Rauer of FRG for both organizations.

Mendillo M. (editor), 1976, The Geophysical Use of Satellite Beacon Observations, Boston University, Boston, MA.

Checcacci P.F. (editor), 1978, Beacon Satellite Measurements of Plasmaspheric and Ionospheric Properties, IROE-CNR, Florence Italy.

Wernik A.W. (editor), 1981, Scientific and Engineering Uses of Satellite Radio Beacons, Polish Scientific Publishers, Warsaw, Poland (Conference held in 1980).

8.4 Relationships Between URSI, AGU, IEEE, and CCIR

Other organizations have had a substantial effect upon the science and technology of ionospheric modelling and propagation predictions. The American Geophysical Union (AGU) regularly holds symposia during which the basic aeronomical features of the ionosphere - both benign and disturbed - are covered. It is unfortunate that only abstracts of papers presented at these meetings are available. (Of course, the same is true for symposia sponsored by URSI; the exception arising for cases where URSI acts as a co-sponsor of some meetings, viz; COSPAR meetings. It is remarked, however, that URSI's official publication Radio Science is a more than adequate substitute for conference proceedings.) There is clearly a synergistic relationship between AGU and URSI, with the former body principally involved in the science of geophysics and URSI principally involved in the science of radio. Clearly many techniques for understanding the physics of the ionosphere, for example, involve radiowaves as diagnostic probes; and at the same time an understanding of ionospheric physics is required to explain radiowave propagation effects. In addition, the IEEE has close ties to URSI and jointly-sponsored or collocated conferences are often held to satisfy the similar interests of members of both organizations. There is no conflict between these two organizations because URSI's function is to achieve a scientific understanding of problems relating to telecommunications, and the Communications Society (for example) of IEEE is concerned with engineering and commercial aspects. In 1975, the historically close relationship between the CCIR (of ITU) and URSI were strengthened with the formation of a liaison committee URSI-CCIR to avoid duplication of work. Activities of URSI and CCIR are unavoidably intertwined, although the study/working groups of CCIR are more structured with hard deliverables requirements and the commissions of URSI function more informally, being designed primarily as an organization to promote/encourage/stimulate radio science.

8.5 Activities of SCOSTEP

The Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) was organized to foster and promote solar-terrestrial physics studies. Organizationally it is comprised of scientific discipline representatives, data center representatives, international organization representatives, and committee chairman for steering functions such as MAP, MONSEE, SMY, and STP-MET. SCOSTEP sponsors (together with URSI, IAGA, and other organizations) international symposia on solar terrestrial physics.

9.0 U.S. Government Propagation Prediction Services and Related R&D

9.1 Non-DoD Government Efforts

9.1.1 Services of the NOAA Space Environment Laboratory (SEL) and it's Space Environmental Services Center (SESC)

For those who are familiar with the WW2 and Post-War services in ionospheric prediction and related services by the Dept. of Commerce, I apologize for the following historical reminder:

Since 1942, Space Environment Services have been provided under the aegis of the Department of Commerce. In 1942 the organization was located under the National Bureau of Standards umbrella and this relationship lasted until

1965. The original name of the organization was the Interservice Radio Propagation Laboratory (IRPL) but in 1946 it was renamed the Central Radio Propagation Laboratory (CRPL). In 1954 the laboratory was moved to Boulder, Colorado, the current location, and in 1965 the activity was run by the Space Disturbances Laboratory of the Environmental Science Services Administration (ESSA). Subsequently in 1970 and at present, the activity was associated with the Space Environment Laboratory (SEL) of the National Oceanic and Atmospheric Administration (NOAA). It is noteworthy that the activity was designated in 1968 by the Federal Council of Science and Technology as the center for providing or arranging for the provision of all space weather services for the nation [Williams and Leinbach, 1982].

The Space Environment Laboratory [Williams and Leinbach, 1982] provides "space environment monitoring, forecasting, alert and warning services on a continuing 24-hour per day basis, conducts research in solar terrestrial physics in support of long-range service needs, and is responsible for developing technique to improve the services provided".

Certain services of the Space Environmental Services Center (SESC) are joint with the Air Weather Service (AWS) of the U.S. Air Force. The joint AWS/SEL service operations include: SESC operations, real-time data services, high latitude monitoring, GEOS/TIROS space environment monitoring, and operation of the solar-optical and radio observatory network.

The products offered include: real-time forecasts, warnings and alerts of solar flares and geomagnetic activity; short and medium-term forecasts of the same; geophysical alert broadcasts on WWV; solar and geophysical conditions on recorded telephone; special support; duty forecaster support via telephone; archival support; and various solar-geophysical publications.

The Space Environment Lab operates a large real-time data base to provide warnings and forecasts. This data base includes data from satellites which monitor solar emissions, energetic particles and geomagnetic fields. There are also ground-based observations of solar-optical and radio data and the Lab runs 26 ground-based magnetometers for assessing geomagnetic disturbances. The laboratory also runs an interactive computer system (updated in real-time) for direct access by qualified users (SELDADS).

9.1.2 Institute for Telecommunication Sciences (ITS)

As the title of the organization suggests, the ITS has been involved heavily in a variety of R&D efforts relating to the science of telecommunications. They should also be regarded as being in a leadership position in the area of ionospheric heating modification and a number of other ionospheric studies having telecommunication implications. For the purpose of this report, most noteworthy is the development of specific radiowave propagation models including ITS-78 and IONCAP. Scientists at ITS work closely with the commercial and academic world as well as DoD on a wide range of telecommunication issues having domestic as well as international repercussions. In this connection ITS, through its personnel, is heavily involved in CCIR activities. Currently, the chairman of CCIR study group 6 (ionospheric propagation) is Dr. C. Rush of ITS.

Williams D.J. and H. Leinbach, 1982, Letter and attached Laboratory fact sheet (R43:DJW/HL dtd Feb 16, 1982), U.S. Dept. of Commerce NOAA/ERL.

9.2 DoD Efforts

9.2.1 U.S. DoD ECAC Initiatives in Model Specification and Validation

One of the objectives of the effort embodied in this preliminary report is to evaluate as well as enumerate various ionospheric and radiowave propagation models. While the effort was underway, another effort was initiated by the U.S. DoD Electromagnetic Compatibility Analysis Center (ECAC) [See Velie and Rigler, 1981] for NADC. The ECAC study is based upon the need (requirement) for analysis and prediction both in the near and long term. Of the numerous models evaluated, there were several which are included in the body of this report. They are naturally propagation-oriented, but ionospheric properties are contained within these models which are basically empirical in nature. The following listing are models (codes) of interest in the present context.

TABLE VI

<u>MODEL NAME</u>	<u>CODE NAME</u>	<u>DEVELOPER</u>
High Frequency Communications Assessment Model	HFCAM	ECAC
HF Electromagnetic Compatibility	HF EMC ²	NOSC
HF Maximum Usable Frequency Evaluation	HF MUFES-4	ITS
Ionospheric Comm Analysis and Prediction Program	IONCAP	ITS
Minicomputer Model for Predicting the MUF in HF Comm	MINIMUF	NOSC
Propagation in the Earth-Ionosphere Waveguide I	MODE CONVERSION	NOSC
Propagation in the Earth-Ionospheric Waveguide II	MODESRCH	NOSC
Effect of Nuclear Burst on HF Communications	NUCOM	SRI
Program for the Analysis of Comm Satellite Systems	PACSS	ESD
Propagation Forecasting and Assessment System	PROPHET	NOSC
Quiet-Time Lowest Usable Frequency	QLOF	NOSC
HF MUFES-4 Ionospheric Propagation Model	RADARC	NRL
Satellite Propagation Model	SATPROP	ECAC
Sudden Ionospheric Disturbance Grid	SIDGRID	NOSC
HF Skywave Propagation Model	SKYWAVE	ITS
VLF and LF Propagation Model	VLF/LF	ECAC
X-Ray Flare and Shortwave Fade Duration Model	XRAY FLARE	NOSC

The ECAC study identified "principal models" based upon their requirements. They included IONCAP and MINIMUF from the above list.

9.2.2 U.S. Army Efforts

9.2.2.1 Propagation Engineering Services of the Electromagnetics Engineering Office (Propagation Engineering Division) of the U.S. Army Communications - Electronics Engineering Installation Agency (USA/CEEIA)

The propagation engineering services of USA/CEEIA, located at Ft Huachuca, Arizona, are detailed by Merkel [1981]. The goal of the command's program is ... "to provide in a timely manner necessary and accurate design advice,

Velie E.R., and S. Rigler, 1981, "NAVAIR Analysis and Prediction Model Evaluation and Capability Improvement Program", prepared for NAVAIR Development Center (NADC) Warminster, PA, 2 volumes.

Merkel M., 1981, "Propagation Prediction Services" Technical Memorandum EMEO-PED-TM-81-1 dtd April 1981.

frequency selection data and performance predictions to both frequency managers and operations personnel of radio units...." The four (4) broad categories include:

- a) electromagnetic system performance analyses
- b) electrical design and performance determination of antennas
- c) electromagnetic wave propagation advice
- and d) propagation forecasts and reliability predictions.

The propagation services extend from VLF to SHF. The types of propagation analyses at VLF involve estimation of field strength versus range. Antenna and system analyses are also a product of the activity. In the latter case is included radiation system efficiency, power gain, path loss determinations, receive site noise level estimation, receive antenna system directivity, and S/N estimates for communication quality determination. Some qualitative nuclear effects are analyzed.

At low frequencies (30-300 KHz), which are not used extensively by the U.S. Army, both skywave and surface wave analyses are performed. Antenna and system analyses are performed at LF also.

The USACEEIA activity combines MF and HF into one grouping due to the commonality of propagation modes. The activity produces no regular MF propagation charts or forecasts but over 210,000 HF charts are prepared annually for customers within DoD and other government agencies. The USACEEIA ground wave prediction program may take the conductivity of different soil types into account as well as heavy forestation and ground cover. The skywave prediction techniques employed by USACEEIA are based upon a joint effort with ITS-Boulder. In essence, it is a variation of the IONCAP program developed by ITS. The deliverables of the skywave prediction program include ray elevation angles, usable frequencies (LUF, MUF), and path loss. Path conditions predicted include: probability of the seven most predominant modes, take-off angles, virtual height of the ionospheric reflecting surface, signal time delay, free space path loss, absorption loss, ground reflection loss, signal levels/statistics, and noise levels. A variety of antenna types are analyzed at USACEEIA and periodic frequency reliability tables are produced.

In the VHF/UHF/SHF bands a variety of analyses are performed and numerous computerized models are employed.

9.2.2.2 Radiowave Propagation Studies in the Army

Scientists at the U.S. Army Communications Systems Center of the Communications R&D Command (CORADCOM) have contributed significantly to our current understanding of the total electron content of the ionosphere/plasmasphere and its morphology. The work of Dr. H. Soicher and his colleagues is worthy of note.

9.2.3 U.S. Navy Efforts

The U.S. Navy relies heavily on its sister services, the U.S. Air Force and the U.S. Army, for support in the area of propagation prediction. It also obtains considerable input from the NOAA/SEL organization in Boulder. For support of HF propagation in the vicinity of and under the control of the specified Communication Area Master Stations (CAMS), the U.S. Navy sanctions

the publication of HF propagation forecasts (based upon future-predicted sunspot numbers) in the form of a document called NTP-6 Supp 1. The operational service support is obtained through data supplied by the AWS/SESS of Offutt AFB, Omaha, Nebraska. Scientific data is obtained from NOAA/SEL/SESC to support civilian Navy Laboratory research programs. As an example, NRL daily obtains solar-terrestrial data from the SEL data base SELDADS (SEL Data Acquisition and Display System) for use in support of the scientific programs involving radiowave propagation and ionospheric research.

The Fleet Numerical Weather Center (FNWC) is responsible for computational support in areas of sea state and tropospheric weather predictions. There is no plan for FNWC to offer propagation prediction services to Navy users since the view is held that these services are adequately handled elsewhere. Nevertheless Navy Laboratories have through the years contributed to the U.S. Fleet requirements for ionospheric-propagation information. Much of the practical work has been carried out at the Naval Ocean Systems Center (NOSC) and leading edge R&D has been conducted at NRL.

9.2.3.1 A Synopsis of Model Developments and Prediction Studies at NOSC

Rose [1981] has described the Navy-developed PROPHET system since its inception. The current version of PROPHET, which is based upon mini-computer technology, features over 15 HF prediction and assessment models. The NOSC efforts also include scintillation and long-wave modelling. Earlier versions of PROPHET included SOLRAD-PROPHET, the purpose of which was to exploit the real-time data retrieved from the two Navy SOLRAD HI satellite systems. Subsequently CLASSIC PROPHET was developed for the purpose of multi-station HF prediction and serving principally the needs of the HF-DF community. To serve the needs of the SIGSEC and COMSEC communities, the Tactical Prediction Module (TPM) was developed. A current development is embodied in ADVANCED PROPHET, the purpose of which is to maintain a test-bed for basic and exploratory research in forecasting technology. The success of the PROPHET concept is exhibited in spinoffs which satisfy certain short-term needs of the operational community. They include: FAA-PROPHET, FOTACS, and FOPS-MOD. The PROPHET technology is also contained in a U.S. Army system or APES, the Army PROPHET Evaluation System.

Rose, 1981, "PROPHET - An Emerging HF Prediction Technology" in Effect of the Ionosphere on Radiowave Systems, J. M. Goodman (editor-in-chief) U.S. GPO Washington, D. C.

Table VII below is a listing of models contained within the ADVANCED PROPHET architecture:

TABLE VII

Model	System	Action	Status
Flare detection	All hf, vlf navigation and comm	hf comm-freq shift reroute traffic	operational
Flare detection	all hf, vlf nav/comm	hf comm-freq shift reroute traffic	operational
SID GRID	all hf	hf comm freq shift reroute traffic	operational
SPA/vlf	vlf nav Omega	phase correction factor	developed
SPA inversion	all hf, vlf	estimate x-ray flare size (independent of satelli.) feed sid grid	in progress
PCA/vlf	vlf navig	phase correction factor for trans-polar circuits	developed
PCA/hf	all polar hf	hf comm-advice signal strength loss-freq shift	developed
PCA/vhf	all polar satellite	vhf comm-advice signal loss	developed
QLOF	all hf	hf comm-normal operations, freq management	operational
LOF split	covert hf systems	opt freq selection against known revrs	operational
MINIMUF-S	all hf	hf comm-normal ops freq management	operational
15 min update to MINIMUF using auroral E fields	all hf	correct MUF est. (real-time) minimize errors to ± 1 MHz (feeds MINIMUF)	in progress
RAYTRACE	all hf	hf comm-normal ops. antenna selection	operational
Launch angle multipath using quasi parabolic	all hf	hf comm-normal ops. antenna selection	operational
Polar and auroral ionosphere	all hf vhf satellite	hf comm-normal ops. polar circuits	in progress
Earth's magnetic field variations (ground)	ASM & any magnetically sensitive	corrections for field changes B_{st} and AE	in progress near completion
Mixing shock front from aurora? disturbances	all hf	hf comm-midlatitude (feeds MINIMUF)	in progress
Scintillation grid	vhf/vhf satellite comm	advisory-dB fade probability based on location	operational
Omega correction factors	Omega vlf	correction factors	operational
HFIELDS	hf	Diurnal MUF/LUF predictions with simplified field strength approximations	Operational
Ionospheric storm	hf	opt freq selection due to propagation changes	in progress
Ionogram	hf	optimum frequency selection	operational

Courtesy R. Rose, NOSC; in Rose [1981], (See bibliography in Appendix A).

9.2.3.2 Naval Research Laboratory Studies

NRL has an illustrious history in connection with ionospheric research and radio studies starting with the experimental verification of the ionosphere itself. Taylor and Hulburt [1926], of the newly-formed laboratory, sketched out the properties of the radio-reflecting layer including its day-night variations, seasonal changes, latitude effects, and general electromagnetic properties including estimates of the free electron number density. They also encountered and described the new phenomenon of "ship distance". Their early efforts fostered a strong radio engineering and physics program at the Laboratory leading to Navy development of conventional and over-the-horizon radar. The space program at NRL eventually gave rise to the U.S. National Aeronautics and Space Administration; and NRL still maintains a strong core program in space, solar, ionospheric, and terrestrial physics.

NRL has developed a number of satellite systems, and noteworthy among these for the purpose of this report is the SOLRAD series of spacecraft. The last of these, SOLRAD HI (or SOLRAD 11a/11b), consisting of a pair of spacecraft was successfully launched in 1976 into a supersynchronous orbit to monitor solar plasma beyond the magnetosphere as well as solar x-ray and ultraviolet flux. The data extracted from this twin-satellite system was downlinked to NRL in real-time, converted to engineering units and shortly transmitted to NOSC for the purpose of insertion into a variety of computer codes for near-real-time prediction of propagation effects on Navy systems. The outgrowth of this program was the NOSC/SOLRAD PROPHET computer system. Although the SOLRAD satellite data stream ceased functioning prior to 1980, NOSC continued its development of the PROPHET system for ionospheric assessment and prediction service to the FLEET and other users.

NRL is now involved in the study of various models which are best suited for ionospheric prediction in the short-term. Beginning in 1980, NRL 4180 initiated the study of a concept whereby specified remote sensing techniques could be applied to empirical models of the ionosphere to better assess propagation conditions at HF. Good results have been obtained using topside sounders as well as terrestrial oblique chirp sounders as update tools. The NRL update technique has been tested in the North Atlantic, the mid-Atlantic, and the Pacific/Indian Ocean zones with the result that rms errors in MUF predictions have been substantially reduced as compared to stand-alone modelling estimates. Customers have included NAVLEX, NAVSECGRU, and CINCLANTFLT. Future efforts will support U.S. Army and DCA requirements. Certain aspects of the work are coordinated with NOSC.

Recent studies have been detailed in several recent NRL reports [Uffelman, 1981; Uffelman and Harnish, 1981, 1982; and Uffelman et al, 1982].

NRL, and specifically the Plasma Physics Division, have long been involved in basic physics modelling of the benign and disturbed ionosphere, with the

Taylor and E.O. Hulburt, 1926, Phys. Rev. 27, 189.

Uffelman D.R., 1981, "HF Propagation Assessment Studies Over Paths in the Atlantic" NRL Memo Report 4599.

Uffelman D.R. and L.O. Harnish, 1981, "HF Systems Test for the SURTASS Operation of Feb 1981", NRL Memo Report 4600.

Uffelman D.R. and L.O. Harnish, 1982, "Initial Results from HF Propagation Studies During SOLID SHIELD", NRL Memorandum Report (to be published).

Uffelman D.R., J.M. Goodman, and A.J. Martin, 1982, "Ionospheric Remote Sensing Application: for HF Systems Vulnerability - Progress", NRL Memo Report (to be published).

latter being driven principally by support from the Defense Nuclear Agency. Of particular note is effort in ionospheric irregularity physics modelling [Ossakow et al, 1982] using computational physics techniques for simulation purposes. This work may ultimately be directed toward a predictive capability in terms of where irregular structures will occur and what their effect upon satellite C³I systems will be.

9.2.4 U.S. Air Force Efforts

9.2.4.1 Air Weather Service

Geophysical forecasting and ionospheric modeling studies at the USAF Global Weather Central (GWC) have been detailed by Thompson and Secan [1979] and Tascione et al [1979]. To present a flavor of the types of services provided by AFGWC, a portion of the abstract and introduction of the paper by Thompson and Secan [1979] is provided below:

"Advanced systems that either use or are affected by the environment above 50 kilometers require forecast support. The Air Weather Service provides a worldwide network of sensors and a central facility to monitor and forecast the state of the space environment, the sun, interplanetary field, magnetosphere and ionosphere.

The Air Weather Service (AWS), through its operational forecast centers of the Air Force Global Weather Central (AFGWC), provides space environmental support to the entire Department of Defense. Although the types and intensity of support are varied, the overall driving requirement is to minimize system effects caused by impulsive solar/geophysical activity and ionospheric variations. The knowledge of these effects, preferably beforehand, provides the decision maker with information to utilize his resources effectively. AFGWC provides around-the-clock service in forecasting and specifying the aerospace environment by applying varied data to the problem. The Air Force has been active in space environment research and forecasting for over a decade".

A comprehensive review by the USAF Scientific Advisory Board ad hoc committee on Aeronomy [May 1977] addressed a number of the problems and attributes of the USAFGWC/SESC.

The Space Environment Support System (SESS) run by AFGWC has the responsibility to generate ionospheric specifications and forecasts based upon ionospheric models run on in-house computer systems. It is noteworthy that forecasting capability covers relevant solar, magnetospheric and ionospheric factors. Data arrive at the center from a variety of sources located both in

Ossakow S.L., M.J. Keskinen, and S.T. Zalesak, 1982, "Ionospheric Irregularity Physics Modelling", NRL Memorandum Report 4741

Thompson R.L. and J.A. Secan, 1979 "Geophysical Forecasting at AFGWC", in Solar-Terrestrial Predictions Proceedings: Vol.1, edited by R.F. Connelly, U.S. GPO, Washington, D.C. 20402.

Tascione T.F., T.W. Flattery, V.G. Patterson, J.A. Secan, and J.W. Taylor Jr., 1979, "Ionospheric Modelling at Air Force Global Weather Central", in Solar-Terrestrial Predictions Proceedings: Vol 1, edited by R.F. Donnelly, U.S. GPO, Washington, D.C. 20402

space and on terra-firma. Some of the types of data sources include:

- 0 Solar Observing Optical Network (SOON)
- 0 Radio Solar Telescope Network (RSTN)
- 0 Magnetometer Network
- 0 GOES satellites
- 0 DMSP satellites
- 0 Vertical Incidence Ionosonde Network
- 0 Faraday Rotation (TEC) polarimeter network

Certain elements of the forecasting function are joint with NOAA/SEL/SESC (See section 9.1.1).

Ionospheric modelling has been conducted at AFGWC for some time with current stress being the development of the so-called 4-D ionospheric model. Currently this model is data-starved and the solution to this problem is dependent upon additional satellite sensors being launched. There is also the possibility of utilizing terrestrially-monitored propagation data (which can be extracted from the dual L-Band transmissions of the GPS constellation of satellites) to deduce worldwide estimates of the total electron content.

9.2.4.2 Air Force Geophysics Laboratory (AFGL)

AFGL is the R&D Laboratory for the U.S. Air Force and has been central in the development of ionospheric, magnetospheric, solar, and plasma research gains over the years. In the context of this report, it is noteworthy that most of the empirical effort in ionospheric scintillation and TEC modelling has been conducted at AFGL, and the various activities within AFGL have contributed heavily to the understanding of high latitude and equatorial phenomena and modelling.

9.2.4.3 Other U.S. Air Force Activities

Other Air Force organizations which have contributed in modelling efforts include RADC and AFAL. Air Force affiliated organizations such as Aerospace Corporation have also been users and developers of models.

10.0 Propagation Prediction Services Outside the U.S.

10.1 Forecasting and Prediction in France

Solar forecasting services are performed at the Forecasting Center in Meudon France [Simon, 1979] and short-term radio propagation predictions (in the decameter band) are carried out by the "Centre National d'Etudes des Telecommunications" located in Lannion [Lassudrie-Duchesne et al, 1979]. These predictions are confined to the "European" and "North European" zones. Data sets utilized in making weekly and daily predictions include URSIGRAMS (by TELEX), ionospheric sounders in Poitiers and Uppsala (by TELEX), an ionospheric sounder in Lannion (real-time) and a magnetometer at Lannion (real-time). Based upon analysis of prediction methods, CNET-Lannion is

Simon P., 1979, "The Forecasting Center of Meudon France" in Solar-Terrestrial Predictions Proceedings, R. Donnelly (editor), USGPO, Washington, D.C. 20402, Vol 1, p 1.

Lassudrie-Duchesne P., A.M. Bourdilo, and H. Sizun, 1979, "The French Short-Term Radio Propagation Predictions in the HF Band" in Solar-Terrestrial Predictions Proceedings, R. Donnelly (editor), USGPO, Washington, D.C. 20402, Vol. 1, p 12.

considering formulation of ionospheric predictions by adaptive methods to account more fully for small side variations.

10.2 Forecasting and Predictions in the Federal Republic of Germany

Damboldt [1979] has described the HF propagation predictions prepared by Forschungsinstitut der Deutschen Bundespost at Darmstadt, FRG. The process of long-term prediction is dissimilar to the CCIR method but is nevertheless computer-based. In the case of short-term predictions the process is essentially manual and relies on the forecaster's ability to interpret a combination of available solar-geophysical data with field strength records.

The field strength prediction method of the Deutsche Bundespost departs from the CCIR model by accounting for the non-vanishing field strength for frequencies operating above the "classical MUF". For real antennas and especially for longer paths propagation "above-the-MUF" is caused by a number of factors including: spread F scatter, D-layer scatter, meteor scatter, auroral scatter, FAI scatter, side-scatter due to ground irregularities, sporadic E effects, and gradient-induced off-great-circle propagations. The process applied by the Deutsche Bundespost involves application of an empirical factor to "classical" MUF's extracted from the CCIR maps to obtain an "operational" MUF. The frequency range between the MUF and the LUF is computed from expressions for deviative and non-deviative absorption [Beckman, 1965].

Radiowave propagation predictions are prepared for Central Europe and the following technical parameters are involved in the calculations: transmitter power (100 watts), antenna (8 m vertical rod for ground wave and a halfwave dipole for skywave), bandwidth (3 KHz for telephony, 1.1 KHz for radio teletype, and 0.2 KHz for radio telegraphy), ground conductivity (0.003 mho/m and a permittivity of 4.0), location (50°N, 10°E path mid-point), and the noise environment.

The center validates its long-term predictions with measurements of signal strength from 26 distant transmitters. These measurements also serve as the basis for short-term predictions.

10.3 Forecasting and Prediction in Japan

Marubashi et al [1979] describe the geomagnetic activity forecasts made at the HiraIso Branch of the Radio Research Laboratories. Using these forecasts HF propagation predictions have also been made although the details were not described. Results were mixed and it is felt that the short-term prediction of HF propagation by relying principally upon solar activity predictions alone is unreliable (JMG: editorial remark). The authors admit to this difficulty and suggest that the unreliability is due to lack of ability to forecast the magnitude of the geomagnetic storm itself which strongly controlled by the N-S component of the IMF (Interplanetary Magnetic Field).

Damboldt Th., 1979, "Propagation Predictions for the HF Range by the Research Institute of the Deutsche Bundespost" in Solar-Terrestrial Predictions Proceedings, R. Donnelly (editor), USGPO, Washington, D.C. 20402, Vol 1, p 25.

Beckman B., 1965, "Bemerkungen Zur Abhangigkeit der Empfangsfeldstarke von den Grenzen des Ubertragungsfrequenzbereiches, NTZ 19, S, 643-653.

Marubashi K., Y. Miyamoto, T. Kidokoro, and T. Ishii, 1979, "Forecasts of Geomagnetic Activities and HF Radio Propagation Conditions Made at HiraIso/Japan" in Solar Terrestrial Predictions Proceedings, R. Donnelly (editor), USGPO Washington, D.C. 20402, Vol 1, p 182.

Radiowave prediction services are described by Maeda [1979]. The basic approach is allied with the CCIR method and short-term forecasts rely upon real-time application of ISS-B topside sounder data for use in forecasts. Maeda maintains that the following problems must still be addressed for fully successful HF predictions:

- a) solar/geomagnetic activity predictions
- b) modify existing mean models with ISS-B data
- c) man-made noise input
- d) irregular mode propagation
- e) use ISS-B data to update models for short-term predictions

The radio disturbance warning issuance system of RRL in Japan has been described by Maeda and Inuki [1979]. Both solar-terrestrial disturbance services and HF propagation disturbance services are provided. [It is noteworthy that RRL administers the Western Pacific Region Center Tokyo which is one of five regional warning centers of IUWDS (the other four are located in Paris, Sydney, Darmstadt, and Moscow, with the world center in Boulder). URSIGRAMS such as GEOLERT, URANO and USIDS are provided over the Telex networks of the IUWDS which is maintained globally.]

10.4 Propagation Prediction Services in Australia

With respect to ionospheric predictions and warnings of ionospheric disturbances upon radio waves, there are four papers which describe Australian activity, all appearing in the Solar Terrestrial Predictions Proceedings [Cook and Davies, 1979; Wilkinson, 1979; Turner and Wilkinson, 1979; and McNamara, 1979]. The last three papers are principally relevant to the subject at hand. The Ionospheric Prediction Service (IPS) of the Dept. of Science and the Environment has developed two codes for forecasting foF2 either 1 day ahead (DALYPRED) or 0-3 hours ahead (HOURPRED). Both of these classes of forecasts are based upon the utilization of a so-called T-index which is similar in some respects to the ionospheric index IF2 due to Minnis and Bazzard [1960]. The T-index is used to develop IPS prediction maps to support HF communications.

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- Maeda R., 1979, "Radio Propagation Prediction Services in Japan" in Solar Terrestrial Predictions Proceedings, R. Donnelly (editor), USGPO Washington, D.C. 20402, Vol 1, p 212.
- Maeda R. and H. Inuki, 1979, "Radio Disturbance Warning Issuance Systems" in Solar-Terrestrial Predictions Proceedings, R. Donnelly (editor) U.S. GPO, Washington, D.C. 20402, Vol 1, p 223.
- Cook F.E. and P. Davies, 1979, "A Review of the Operations of the IUWDS Regional Warning Center at the Ionospheric Prediction Service" in Solar-Terrestrial Predictions Proceeding, Vol 1, edited by R.F. Donnelly, U.S. GPO Washington, D.C. 20402..
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- Turner J.F. and P.J. Wilkinson, 1979, "A Weekly Ionospheric Index" in Solar-Terrestrial Predictions Proceedings, edited by R.F. Donnelly, U.S. GPO Washington, D.C. 20402.
- McNamara L.F., 1979, "The Use of Ionospheric Indices to Make Real and Near Real-Time Forecasts of foF2 around Australia" in Solar-Terrestrial Predictions Proceedings edited by R.F. Donnelly, U.S. GPO Washington, D.C. 20402.
- Minnis C.M., and G.H. Bazzard, 1960, "A Monthly Ionospheric Index of Solar Activity Based on F2 Ionization at Eleven Stations", J. Atmos. Terr. Phys. 4, 297.

10.5 Propagation Prediction Services in the USSR

The Institute of Applied Geophysics (IAG) in Moscow USSR, is essentially the equivalent of the SEL/SESC in Boulder, CO. USA. It serves as the forecasting center of the national ionospheric and geomagnetic service as well as the Eurasian Regional Warning Center of IUWDS. Short-term predictions of ionospheric and magnetic disturbances are made and long-term predictions of the MUF and radiowave propagation around the world are also produced. Short-term predictions have been given the must emphasis [Avdyushin et al, 1979]. The prediction service depends heavily upon experimental data collection based upon a network of 22 vertical incidence sounders, riometer data from high latitudes, and effects data such as SID, SWF, and SPA. In addition to IAG in Moscow, there are four regional sub-centers in Murmansk, Khabarovsk, Novosibirsk, and Tashkent.

10.6 Propagation Prediction Services in India

The Radio Science Division (RSD) of the National Physical Laboratory has been providing solar and ionospheric predictions since the middle 50's. One of the main objectives is to predict the radio environment and to give advisories concerning telecommunications which use the ionosphere as part of the channel. Predictions made for the Eastern region are similar to those based on a method developed by the old CRPL organization in the USA (now SEL). The data base upon which forecasts are made consists of 40 ionosonde stations between 52° and 292° East longitude and between 80° N and 78° S latitude [Reddy et al, 1979].

There is strong interest in the low-latitude Indian subcontinent, as one might expect, and this is discussed by Aggarwal et al [1979] in the context of HF communication with emphasis upon indexing long-term ionospheric variability.

11.0 Other Models Identified Through Interview, Personal Knowledge and Literature Search

There is a vast literature dealing with ionospheric physics and radiowave propagation through ionized media. These contain references to "models" of the ionosphere but in many cases they have never been translated to computer code and have never been tested. The literature search required to locate the models and the associated custodians is an arduous task at best. As of this writing the process is incomplete. The most expedient process for identifying models aside from literature search by computer is that of contacting organizations which are users of models and by discussions with colleagues who are actively developing models. This is now in process.

Avdyushin S.I., A.D. Danilov, A.B. Malyshev, G.N. Novikova, and P.M. Svidsky, 1979, "Forecasting Ionospheric and Geomagnetic Conditions at the IAG Forecasting Center" in Solar-Terrestrial Predictions Proceedings, edited by R.F. Donnelly, U.S. GPO Washington, D.C.

Aggarwal S., D.R. Lakshmi, and B.M. Reddy, 1979, "A Simplified Indexing of F Region Geophysical Noise at Low Latitudes", in Solar-Terrestrial Predictions Proceedings, edited by R.F. Donnelly, U.S. GPO Washington, D.C. 20402.

Reddy B.M., S. Aggarwal, and D.R. Lakshmi, 1979, "Long-Term Solar Activity and Ionospheric Prediction Services Rendered by the National Physical Laboratory, New Delhi" in Solar-Terrestrial Predictions Proceedings, edited by R.F. Donnelly, U.S. GPO Washington, D.C. 20402.

Appendix A is a list of references deemed to be of interest for modeling, forecasting and prediction of the ionosphere and propagation effects due to the ionosphere. The list, although extensive is still likely to be incomplete. On the other hand, some references may not be fully relevant to the issues addressed herein.

12.0 Discussion

12.1 Recent Reviews of Ionospheric Modelling and Predictions

A review of recent (1978-1980) progress in development of ionospheric modelling has been given by Westerlund [1981]. Of interest are reviews of E and F Region dynamics (Section 3), ionospheric aspects of plasma instabilities (Section 5), influence of the ionosphere on radio systems (Section 6), morphological models of the ionosphere (Section 7), ionization and chemistry (Section 8), stratospheric-mesospheric-ionosphere interactions (Section 9), and finally, ionospheric sounding techniques and networks (Section 11). Of particular relevance to this report preparation were section 5 (parts dealing with spread F and scintillation), section 6 (all, but especially the parts dealing with forecasting), section 7 (all, but especially the part dealing with profiles of electron density), and section 11 (all).

Another useful source of recent progress in ionospheric predictions is due to Davies [1981]. His review is based in large part upon the proceedings of the Solar-Terrestrial Predictions Conference held in Boulder, Colorado in 1979 [Donnelly, 1979]. Nisbet [1978] has reviewed operational physical models of the ionosphere and Kohnlein [1978] has reviewed electron density models.

12.2 Some Thoughts on Categorization and Utilization of Models

Davies [1981] in his review of ionospheric forecasting breaks modelling into two classes: empirical and physical. Included within the empirical model class are numerical maps of ionospheric characteristics. Davies indicates the virtue of combining both classes in some instances.

Nisbet [1978], in his review of operational physical models of the ionosphere, defines three basic classes: mean morphological, dynamic, and forecasting. He maintains that the forecasting class is closely related to the mean morphological class of models. Using Nisbet's recipe, certain physical models could belong to either the mean morphological class or the dynamic class; whereas certain empirical models could belong to either the mean morphological or forecasting class. It is worth noting that almost any physical or empirical model can be used as a tool in forecasting although that may not be the original intent. They can certainly be useful in system design studies which require ionospheric vulnerability analyses to be performed.

Westerlund S., 1981, "Ionospheric Radio and Propagation" Chapter 8 of Review of Radio Science 1978-1980 edited by S.A. Bowhill, URSI publication, Brussels, Belgium.

Davies K, 1981, "Review of Recent Progress in Ionospheric Predictions", Radio Sci. 16(6) 1407-1430 (also appearing in Proceedings of IES '81).

Donnelly, 1979, cited earlier.

Nisbet J., 1978, "Operational Physical Models of the Ionosphere" in NATO/AGARD Conference Proc., Ottawa, Canada.

Kohnlein W., 1978, "Electron Density Models of the Ionosphere", Rev. of Geophy and Spa. Phys. 16 (3).

Predictions based upon physical models, other than those used for system design, may not be useful in relation to quasi-adaptive empirical models. Most certainly, short term forecasting requirements depend heavily upon the empirical approach having been suitably modified to allow update through injection of remotely-sensed ionospheric parameters. However some empirical models suffer over areas where the original data sets for model construction are sparse. For near-term forecasting the most advisable approach is to utilize an empirical mean morphology augmented by a physical model to extrapolate the model (or make it more accurate) in regions which are represented by an inadequate data set (i.e., over ocean areas or some portions of the Southern Hemisphere). For removing biases in this quasi-empirical approach, it must be made adaptive and one approach might be to inject the model with "fresh" data, from sounders, for example. In addition, certain modules must be added to account for time-varying solar and magnetic activity (or substorm) influences. (It has been recommended that sunspot number and magnetic activity indices be replaced by more physically meaningful parameters. Solar flux in the ultraviolet and x-ray bands and the Akasofu E parameter should provide improvement in prediction.)

As an example of this approach, NRL, in collaboration with NOSC, is testing specified mean morphological propagation models which have the capability for real-time update and may incorporate variable external source functions (i.e., solar, geomagnetic substorm). The models being used are MINIMUF and IONCAP, the source of model update is sounder (oblique, vertical incidence and topside) data, and the external source functions are parameters Kp and 10.7 cm. solar flux (or sunspot number). The approach has shown promise but is yet to be validated in the context of being operationally useful.

It is important to understand that certain classes of ionospheric variability are currently impossible to forecast irrespective of the complexity and elegance of the model being used. These include as a minimum: TID's and spread F (plumes). These phenomena introduce important perturbations on various C³I systems. Better physical models may provide better insight regarding the likelihood of occurrence of these phenomena and even a rough estimate of their properties (i.e., time duration, spatial extent, magnitude, etc.) but it is unlikely to yield an answer for a particular point in space-time. The only solution visualized at this time is real-time mapping with good spatial and temporal resolution, perhaps from space. The fusion of data from networks of sounding stations or polarimeters may be useful for producing snapshots of the ionosphere but these "pictures" would be of limited clarity because of finite number of stations in the networks - a consequence of both economics and global topography. It would be ideal if a satellite-borne remote sensing device could "map" the ionosphere and produce snapshots of ionospheric "weather" similar to those obtained to estimate "tropospheric weather" patterns. Current approaches using topside sounders such as the Japanese ISS-B [RRL, 1981] produce "time-exposures" too large to be useful in the short-term context. Satellite-borne scanning devices have offered considerable promise, but are limited in application at present. DMSP mosaics of the auroral zone luminosity have yielded significant information about auroral phenomena but the developments cannot be followed on the sunlit side of the earth. It is speculated [Rust and Bernstein, 1981]

RRL, 1981, "Atlas of Ionospheric Critical Frequency (foF2) obtained from Ionosphere Sounding Satellite-b Observation (Part 3), January to June 1978", Radio Research Laboratories, Japan.

Rust D.M. and P. Bernstein, 1981, "Application of X-ray Imaging Techniques to Auroral Monitoring" in Effect of the Ionosphere on Radiowave Systems edited by J.M. Goodman, F.D. Clarke, and J. Aarons, USGPO Wash., D.C.

that x-ray imaging may be used to partially resolve this problem but benign non-auroral properties cannot be examined by this technique. Huffman et al [1981] have suggested that ionospheric and auroral measurements are possible by using vacuum ultraviolet techniques. Support for this suggestion may be found in the OGO-4 and the STP S3-4 satellite experiences. NRL scientists are also interested in exploring the feasibility of producing UV images of the earth from either a highly elliptical or nearly synchronous satellite platform [Meier, 1981]. For the present, however, regional morphological models which are amenable to quasi-real time update (via oblique sounders, for example) must suffice for short-term forecasting. This is the approach followed by NRL to support certain fleet exercises and DoD programs. A similar approach has been followed by AFGWC through its AF4D ionospheric model development.

13.0 Future Plans

This effort is continuing. The next step is to provide, along with the identification of all available models, a brief description of the model (or an abstract of the referenced paper if a computer code is not available). The next step is to provide detailed information about selected models including data extracted from questionnaires. This is one of the ultimate goals. The final step is to assess the merits of each class of models (and in some cases specific models) in the context of user requirements. The process of assessment is yet to be determined. A better definition of specific user requirements is being pursued as a parallel effort.

Acknowledgments

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Huffman R.E., D.E. Paulson, F.J. LeBlanc and J.C. Larrabee, 1981, "Ionospheric and Auroral Measurements from Space Using Vacuum Ultraviolet Emission" in Effect of the Ionosphere on Radiowave Systems edited by J.M. Goodman, F.D. Clarke, and J. Aarons, USGPO Wash., D.C.
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APPENDIX A

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APPENDIX B
IONOSPHERIC MODEL AND MODEL USER QUESTIONNAIRES

A. ORIGINATOR DATA

NAME ☐ DR. ☐ MR. ☐ MRS. ☐ MS. ☐ OTHER ☐ SURNAME ☐ FIRST ☐ MID. INIT.

TITLE & MAIL CODE ☐

AFFILIATION ☐ TELEPHONE (☐)
AREA CODE ☐

ADDRESS ☐

B. DOCUMENTATION

Below please list all documented needs of your organization related to ionospheric or ionospheric effects characterization which are expressed in terms of "operational requirements", "statements of need", or kindred documents.

1. ☐
2. ☐
3. ☐
4. ☐
5. ☐

(Use Reverse Side for Continuation)

C. UNOFFICIAL NEEDS

Below please list all perceived needs of your organization related to ionospheric characterization. Such characterization needs should not exclude the assessment/forecasting/prediction of system effects.

- ☐
- ☐
- ☐
- ☐

(Use Reverse Side for Continuation)

D. Briefly indicate how knowledge of the ionosphere would be/is utilized in your programs. Are these needs being adequately addressed at present?

- ☐
- ☐
- ☐

(Use Reverse Side for Continuation)

E. General:

☐ I would be willing to provide further information concerning current and planned future utilization of model(s). ☐ YES ☐ NO ☐ NOT APPLICABLE

☐ Additional information is requested. ☐ Telephone ☐ Letter ☐ Visit

Signed: ☐

Please forward this questionnaire to: Dr. John M. Goodman
NRL Code 4180
Naval Research Laboratory
Washington, D. C. 20375
Phone (202) 767-3729

IONOSPHERIC/PROPAGATION MODEL INFORMATION SHEET

RESPONSE VITAE

NAME: ☐ PROF. ☐ DR. ☐ MR. ☐ MRS. ☐ MS. ☐ OTHER _____ LAST _____ FIRST _____ M.I. _____

ADDRESS: _____
ORGANIZATION _____
STREET ADDRESS _____
CITY _____ STATE _____ ZIP CODE _____
COUNTRY _____

TELEPHONE: _____ TELEX: _____

1. NAME OF MODEL: _____
2. AUTHOR (Custodian) OF MODEL: _____

3. TYPE OF MODEL: ☐ PHYSICAL ☐ EMPIRICAL ☐ HYBRID
(Check appropriate box)

4. BRIEF ABSTRACT:

[illegible]

5. ASSUMPTIONS:

6. PARAMETERS:

INPUT

OUTPUT

7. REFERENCE: (Articles/Reports/etc.)

8. APPLICABILITY/LIMITATIONS:

Diurnal

Seasonal

Solar Epochal

Geographical

Altitude

Magnetic Activity

Other Geophysical

System Relevance

9. HAS MODEL BEEN TESTED AGAINST:

Other
Models?

Data?

Other?

10. IF "OTHER" EXPLAIN:

11. RESULTS OF TEST: (accuracy/consistency/etc.)

12.

12.1 COMPUTER

12.2 INFORMATION

12.3 IMPLEMENTATION

Computer
(Make, Model)

Language(s)

Program Speed
(Running time)
typical)

A. _____

B. _____

C. _____

D. _____

12.4 I/O DEVICES REQUIRED:

A

B

C

D

Tape Systems

Terminals

Printers

Card Readers

Teletype

Plotter

Other

12.5. STORAGE DEVICES REQUIRED:

Core

Tape

Disk

Other:

12.6 OPERATING SYSTEM REQUIRED:

12.7 EXECUTION MODES:

Batch _____

Interactive _____

13. IS THIS MODEL CONSIDERED CURRENT?

☐
Yes

☐
No

14. WHAT CHANGES/IMPROVEMENTS ARE ENVISIONED? SUGGESTED?

15. IS THE MODEL CAPABLE OF UPDATE USING REAL-TIME DATA?

☐
YES

☐
NO

16. HOW WOULD THIS BE ACCOMPLISHED?

17. GENERAL REMARKS:

END

DATE
FILMED

8-82

DTIC