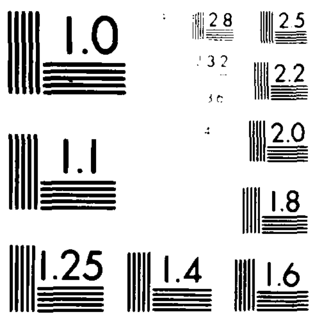
AD-A088 170 MEGATEK CORP SAN DIEGO CA F/G 20/14
SATELLITE SENSING OF THE SOLAR - TERRESTRIAL ENVIRONMENT AND RE--ETC(U)
SEP 79 R B ROSE, P H LEVINE N00123-78-C-0043

UNCLASSIFIED NOSC-TR-487-VOL-1 NL

1 OF 1
AD
A088170

NOSC

END
DATE FILMED
9-80
DTIC



MICROCOPY RESOLUTION TEST CHART

NOSC

NOSC TR 487 Vol. I

AD A088170

Technical Report 487

NOSC TR 487 Vol. I

SATELLITE SENSING OF THE SOLAR-TERRESTRIAL ENVIRONMENT AND REAL-TIME RADIO PROPAGATION FORECASTING

Lessons learned from PROPHET
Volume I — Executive Summary

R. B. Rose, NOSC
P. H. Levine, MEGATEK Corp

30 September 1979

AUG 1 5 1980

A

Prepared for
Naval Electronic Systems Command
(PME-106)
Washington, DC 20360

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

80 8 14 002

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

SL GUILLE, CAPT, USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

This report provides an overview of the development and testing of the PROPHET system, the evolution of which represents an 11-year effort at the Naval Ocean Systems Center (NOSC) under the SOLRAD satellite program. The work was performed for the Naval Electronic Systems Command (PME-106) and the Naval Material Command (NMAT-08T) by the Naval Ocean Systems Center, EM Propagation Division, Code 532, under projects MP11 and MP15. This report is a final project deliverable under FY79 task R2018-036-IF-2, contract N00123-78-C-0043, by Megatek Corporation of San Diego, CA. The continued assistance and constructive support provided by the Command and personnel of the Naval Communication Station, Stockton, CA, during the PROPHET Developmental Test and Evaluation the past three years contributed significantly to the success of the program.

Released by

Dr J.H. RICHTER, Head
EM Propagation Division

Under authority of

J.D. HIGHTOWER, Head
Environmental Sciences
Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(18) NOSC (19) TR-487-VOL-1

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NOSC Technical Report 487 (TR 487)

2. GOVT ACCESSION NO.
AD-A088170

3. RECIPIENT'S CATALOG NUMBER
(9) Final rept.

4. TITLE (and Subtitle)
(6) SATELLITE SENSING OF THE SOLAR - TERRESTRIAL ENVIRONMENT AND REAL-TIME RADIO PROPAGATION FORECASTING
Lessons learned from PROPHET
Volume I, Executive Summary.

5. TYPE OF REPORT & PERIOD COVERED
~~Executive Summary~~
1972 — 1979

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) R. B./Rose NOSC
P. H./Levine MEGATEK Corp

(15)

8. CONTRACT OR GRANT NUMBER(s)
N00123-78-C-0043

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Ocean Systems Center
San Diego, CA 92152

(12) 50

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
63451N, X0804-SL, X080, 4001

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Electronic Systems Command (PME-106)
Washington, DC 20360

(11)

12. REPORT DATE
30 Sep[redacted]79

13. NUMBER OF PAGES
46

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

(16) X0804 (17) X08...

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
PROPHET
SOLRAD
Propagation prediction
Frequency/antenna management
Satellite monitors

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
PROPHET denotes a class of radio propagation forecast terminals which represent the culmination of an 11-year development effort at the Naval Ocean Systems Center (NOSC) under the SOLRAD satellite program. The system is unique in that it provides a real-time link between Navy operations personnel and a worldwide network of ground-based and satellite-borne solar-terrestrial environment monitors. This link is used to generate — via distributed data processing — electromagnetic system performance predictions in formats specially tailored to

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

391984

20. Continued

meet the operational requirements of the user. An initial implementation of PROPHET has provided—over a 3-year period—highly successful hf frequency/antenna management support to the Technical Control Facility of the Naval Communication Station at Stockton, CA. This executive summary provides a concise overview of the evolution, structure, function, and accomplishments of PROPHET, together with recommendations for ways in which the PROPHET technology can be applied to recognized operational requirements of the Navy. Technical details are elaborated in volume II.

OBJECTIVE

Develop and demonstrate the feasibility of an operationally useful ionospheric propagation assessment system that provides Navy operations personnel with information on the current state of the environment as it relates to electromagnetic propagation; assess the effectiveness of supporting such a system with real-time satellite-borne solar-emission sensors; and provide forecasts of future conditions so that appropriate actions may be taken to mitigate or circumvent solar disturbances.

RESULTS

- Ionosphere-dependent systems (hf, vlf, SATCOM) can be provided with timely and accurate propagation forecasts by means of a distributed computation network driven by a real-time environmental sensor complement, including satellite-borne solar activity monitors.
- Navy operations personnel are well aware of environmental limitations on electromagnetic systems performance and will readily accept and use new propagation forecasting tools as soon as they perceive that these tools will reliably improve their ability to manage such systems.
- Computer-assisted propagation forecasting has a role in Naval operations under both quiet and disturbed solar/ionospheric conditions.
- Practical propagation forecasting is facilitated through the development of "minimal models" tailored to specific end-user requirements and simplified to the maximum degree consistent with the inherent predictability of the propagation itself.
- PROPHET's demonstrated success in improving Naval hf communications in Eastpac and elsewhere, coupled with diminishing practical Naval hf expertise (because of increased reliance on FLTSATCOM), argues for early deployment of a PROPHET-type system at CAMs and COMMSTAs.

RECOMMENDATIONS

- Conduct a design study to reconfigure the PROPHET terminal by using a modern high-performance disk-based minicomputer in place of the AN/UYK-20.
- Develop highly compact propagation forecast and disturbance models capable of extending PROPHET capabilities to other operational areas, including the North Atlantic and Indian Oceans.
- Demonstrate, test, and evaluate PROPHET terminals for applications other than hf communications.
- Develop shipboard and airborne versions of PROPHET.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

INTRODUCTION

Navy systems relying upon beyond-the-horizon radio propagation in the vlf (10 – 30 kHz) and hf (10 – 30 MHz) bands are critically influenced by the state of the ionosphere, since it is the ionosphere that provides the reflection mechanism required to support such long-range propagation. To a lesser, though still significant degree, ionospheric processes also impact on surface-to-satellite links operating in the higher frequency (vhf, uhf, shf) bands. These are specific examples of the general sensitivity of electromagnetic systems to environmental effects, as summarized in table 1.

The composition and structure of the ionosphere are primarily influenced by solar emissions which are themselves subject to marked – though largely predictable – diurnal and seasonal variations caused by the Earth's orbital motion. Superimposed on these variations are the somewhat less predictable 11-year solar sunspot cycle (figure 1) and the virtually unpredictable occurrences of solar flares.

Operations personnel responsible for the effective management of Navy electromagnetic systems must take appropriate actions to compensate for this variability. Operators of hf communications and surveillance networks must shift frequencies and/or antennas to maintain a high degree of circuit continuity and area coverage. Navigators using vlf systems such as OMEGA must apply appropriate corrections to compensate for the errors induced by variations in signal propagation velocity. Operators of SATCOM links must know when to expect degradation as a result of scintillation, so that communications schedules can be planned accordingly.

To a limited extent, these requirements are presently met by publishing voluminous tables of propagation predictions for use by operations personnel. For point-to-point hf radio operators at Naval Communications Stations (COMMSTAs), for example, NAVTELCOM generates a set of tables designated NTP-6 that provides forecasts of usable frequencies and antennas for links terminated at a given COMMSTA. OMEGA navigators apply phase corrections derived from tables published by the Defense Mapping Agency Hydrographic Center. The widely recognized limitations of these methods are as follows: (1) they do not reflect the actually occurring present state of solar activity and the ionosphere – only its statistical expectation – and therefore can be in error; (2) they are limited to the specific propagation paths for which the tables have been generated; and (3) they are time-consuming to use and otherwise logistically inconvenient. While means exist for disseminating prompt notification of in-progress solar/ionospheric disturbances to operations personnel, no useful guidance is provided on remedial actions or the expected duration and severity of the event and its performance implications for specific electromagnetic systems. Consequently, during strong solar flares hf and vlf systems are – for the most part – severely degraded.

Table 1. Environmental effects summary.

BAND	DoD	non DoD	PRIMARY PROPAGATION MODES	ENVIRONMENTAL COMPONENT: DIRECT SOLAR	IONOSPHERE: INCREASED D REGION IONIZATION BECAUSE OF SOLAR FLARE	IONOSPHERE: STORMS & IRREGULARITIES	IONOSPHERE: OTHER EFFECTS	ATMOSPHERE	SURFACE
VLF 3-30 kHz	NAVIGATION STRATEGIC COMMUN DATA TRANSMISSION DEFENSE COMMUN DEFENSE ATOMICS	WWV NBS TIMING FCC NAVIGATION	WAVEGUIDE (BETWEEN GROUND & LOWER IONOSPHERE) & GROUND WAVE		SUDDEN PHASE ANOMALY & SUDDEN SIGNAL ENHANCEMENT	RAPID PHASE & AMPLITUDE FLUCTUATIONS DURING MAGNETIC STORMS	PHASE AND AMPLITUDE SHIFTS ON POLAR PATHS (ASSOCIATED WITH PCA EVENTS)	LIGHTNING IS A MAJOR NOISE SOURCE UP TO UHF	
LF 30-300 kHz	NAVIGATION STRATEGIC COMMUN DATA TRANSMISSION WEATHER	NAVIGATION FCC COAST GUARD US WEATHER BUREAU			SUDDEN ENHANCEMENT OF ATMOSPHERIC NOISE				
MF 0.3-3 MHz		NAVIGATION FCC US WEATHER BUREAU CIVIL DEFENSE COMMON CARRIERS	GROUND WAVE OR REFLECTION FROM NIGHT TIME E REGION OF IONOSPHERE						
HF 3-30 MHz	NAVIGATION SURVEILLANCE ASW WEATHER STRATEGIC COMMUN DATA TRANSMISSION DEFENSE COMMUN DEFENSE ATOMICS	WWV NBS TIMING US WEATHER BUREAU FCC NAVIGATION CIVIL DEFENSE COAST GUARD	REFRACTION FROM THE E & F REGIONS OF IONOSPHERE GROUND WAVE AT CLOSE RANGES	NOISE BURST CAUSED BY SOLAR FLARE	INCREASED ABSORPTION SHORT WAVE FADEOUT (BECAUSE OF X RAYS) POLAR CAP ABSORPTION (BECAUSE OF PROTONS)	IONOSPHERIC STORMS IF REGION CAUSES CHAOTIC CHANGES IN MUF) SPORADIC E PATCHES ALTER PATHS SPREAD F FADING	ABSORPTION & SCATTERING ASSOCIATED WITH AURORAL ACTIVITY SUDDEN FREQ DEVIATION CAUSED BY SOLAR X RAY BURST		GROUND WAVE PATH LOSS INCREASES AS SEA ROUGHENS
VHF 30-300 MHz	ASW SURVEILLANCE TACTICAL COMMUN SATELLITE COMMUN		LINE OF SIGHT OR SCATTERING BY D & E REGION INHOMOGENEITIES		INCREASED ATTENUATION OF IONOSPHERICALLY SCATTERED SIGNALS	IONOSPHERIC IRREGULARITIES CAUSE SCINTILLATION OF TRANS IONOSPHERIC SIGNALS	CHANGES IN TOTAL ELECTRON CONTENT CAUSE BEARING & TIME DELAY ERRORS IN SATELLITE TRACKING		
UHF 300-3000 MHz	TACTICAL COMMUN SATELLITE COMMUN		LINE OF SIGHT OR SCATTERING BY TROPOSPHERIC IRREGULARITIES					ANOMALOUS REFRACTIVITY CAUSES DUCTING & RADIO RADAR HOLES; TROPOSPHERIC SCATTERING ALLOWS TRANS HORIZON PROPAGATION	
SHF 3-30 GHz	TACTICAL COMMUN SATELLITE COMMUN		LINE OF SIGHT OR SCATTERING BY TROPOSPHERIC IRREGULARITIES					RAIN CAUSES HIGH ATTENUATION OF SIGNAL	SEA STATE & ICE SNOW COVER INFLUENCE TERRAIN NOISE TEMPERATURE

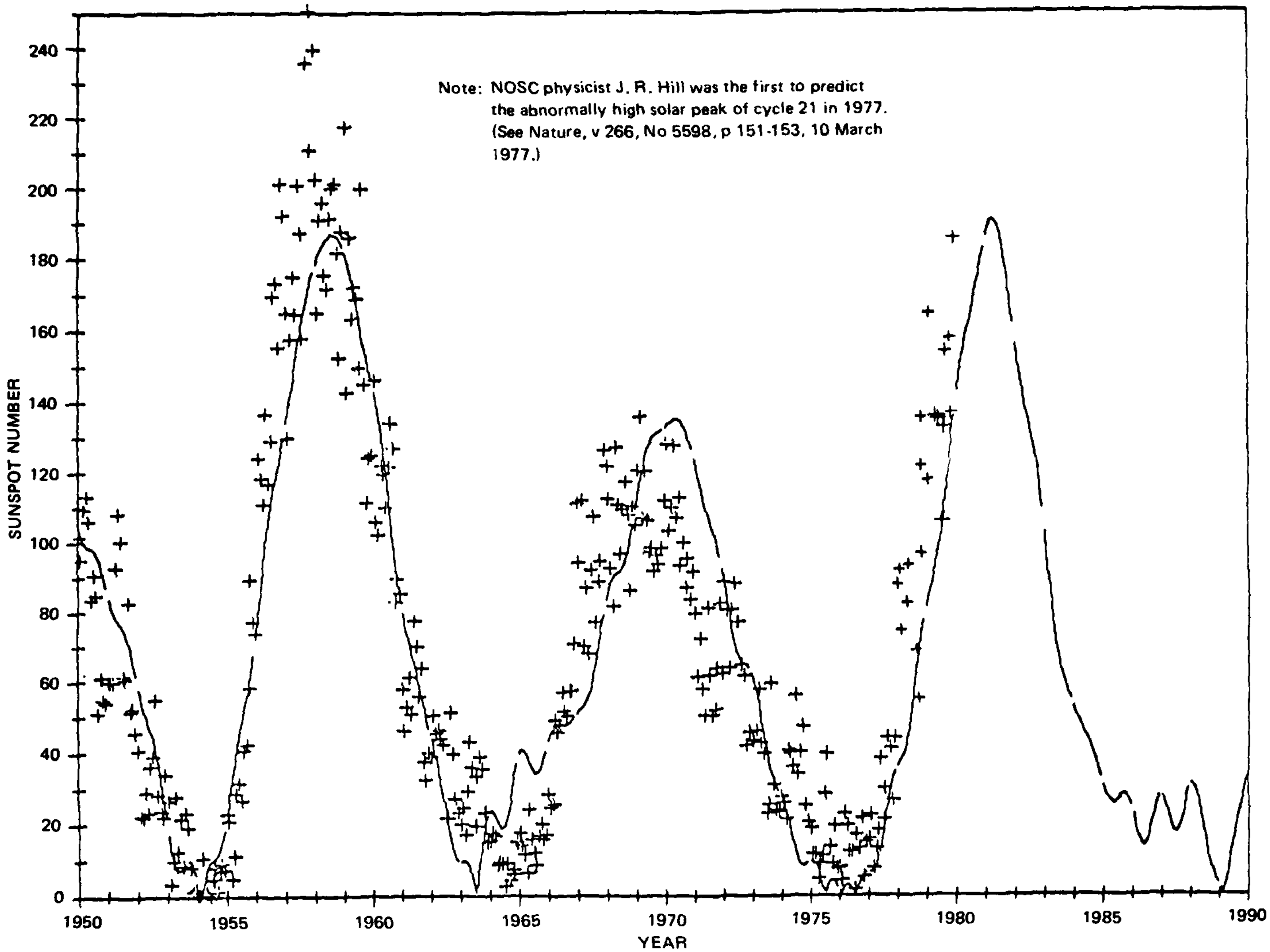


Figure 1. Observed (dots) and predicted (curve) monthly sunspot numbers. Note anticipated peak of solar activity near 1981.

Thus there exists an evident need to provide more effective assistance to operations personnel for optimizing their performance in the face of environmental variability. When the sun is "quiet", it would be desirable to replace manual recourse to tables with on-site automated computation based on the actual state of the ionosphere and tailored to the specific operational requirements of the user. During solar/ionospheric disturbances, assessments of the expected impact on systems performance should be provided, together with guidance on how best to operate while the disturbance is in progress.

The technology required to meet these objectives has become available in the past few years, just in time for the 1980 – 81 maximum of the current 11-year solar cycle. NOSC has developed a propagation assessment and forecasting terminal (dubbed PROPHET) that accepts space environmental data from a variety of sensors and provides real-time, quantitative forecasts of systems performance under operational conditions. The history of effort leading up to and deriving from this development is outlined in table 2.

Table 2. Project history.

PERIOD	PROGRAM	SPONSOR	DESCRIPTION
PREDECESSOR:			
1962 – 1966	SS267	NAVELEX	Formulated requirements and developed techniques for a Radio Frequency Propagation and Prediction System utilizing ground-based observations of solar radio emissions.
MAIN PROGRAM:			
1969 – 1972	SOLRAD APPLICATIONS	NAVAIR	Investigated potential of SOLRAD satellite data for assessment and prediction of solar activity effects on ionosphere-dependent systems.
1972 – 1976	SOLRAD-HI Environmental Prediction System	NAVAIR (AIR 370C1) NAVELEX (PME 106-3)	Hardware/software development of PROPHET hf propagation forecasting terminal.
1976 – 1979	SOLRAD/PROPHET DT&E	NAVELEX	Development Test and Evaluation of PROPHET terminal at NAVCOMMSTA/Stockton and NOSC Real-time Geophysical Laboratory.
SPINOFFS:			
1977 – Present	CLASSIC PROPHET	COMMNAVSECGRU	Application of PROPHET propagation forecasting models to HFDF.
1978 – Present	Polar Communication Prediction System	FAA	Develop microprocessor version of PROPHET for hf resources management in Alaska/North Pacific operation area.
1979 – Present	Tactical Prediction Module	NAVMAT 08T23, NOSC Code 532	Advanced mobile PROPHET system for hf communications, frequency management and tactical emission control

SOLAR EFFECTS ON THE IONOSPHERE

Figure 2 illustrates the diurnal propagation characteristics for the hf frequency band for a path from Guam to Hawaii under undisturbed ionospheric conditions. Frequency is plotted versus a 24-hour time period. Vertical deflections of the traces in the frequency – time plane indicate that communications over this path are possible; no deflections signify the contrary. The lowest observed frequency (LOF) follows very closely the secant of the midpath solar zenith angle. During the daylight hours, increased ionization in the ionosphere D-region (50 – 90-km altitude) results in increased absorption for hf frequencies. Frequencies above the maximum observed frequency (MOF) penetrate the ionosphere and are not reflected back to the desired receiver.

Figure 3 shows propagation conditions for this same path a few days later during a solar-flare period when the sun emitted large bursts of x-ray radiation. The 1 – 8-Å solar x-ray flux (in erg/cm^2·s) plotted in figure 3 shows two large peaks (at 1940 and 2100 GMT) during and after which the entire hf spectrum is unusable (so-called short wave fades or SWFs). At vlf, the enhanced D-region ionization leads to an effective lowering of the ionosphere with consequent decrease in the width of the earth – ionosphere waveguide responsible for propagation over large distances. This, in turn, leads to a vlf phase advance that causes a navigation receiver to appear to move suddenly towards the transmitter if the transmission path is sunlit (so-called sudden phase anomaly or SPA). Position errors as large as 10 nmi can occur with respect to a single station, although the hyperbolic position fixing used with OMEGA navigation usually reduces this error considerably as a result of vectorial cancellation of SPA-induced errors on different stations.

The various emissions during a solar flare and their effects on the ionosphere are schematically indicated in figure 4. Ultraviolet and x-ray radiation reach the ionosphere a few minutes after the eruption of a flare, to cause increased D-layer ionization with resulting SWFs and SPAs. With a delay of up to several hours, high-energy protons and alpha particles also cause increased D-layer ionization – mostly in the polar regions – which is why this phenomenon is called polar cap absorption (PCA). One or two days after a flare, low-energy plasma reaches the ionosphere to cause magnetic storms, aurorae, increased D-layer ionization, and enhanced ionization in the E-layer of the ionosphere (near 105-km altitude) – the so-called "sporadic E".

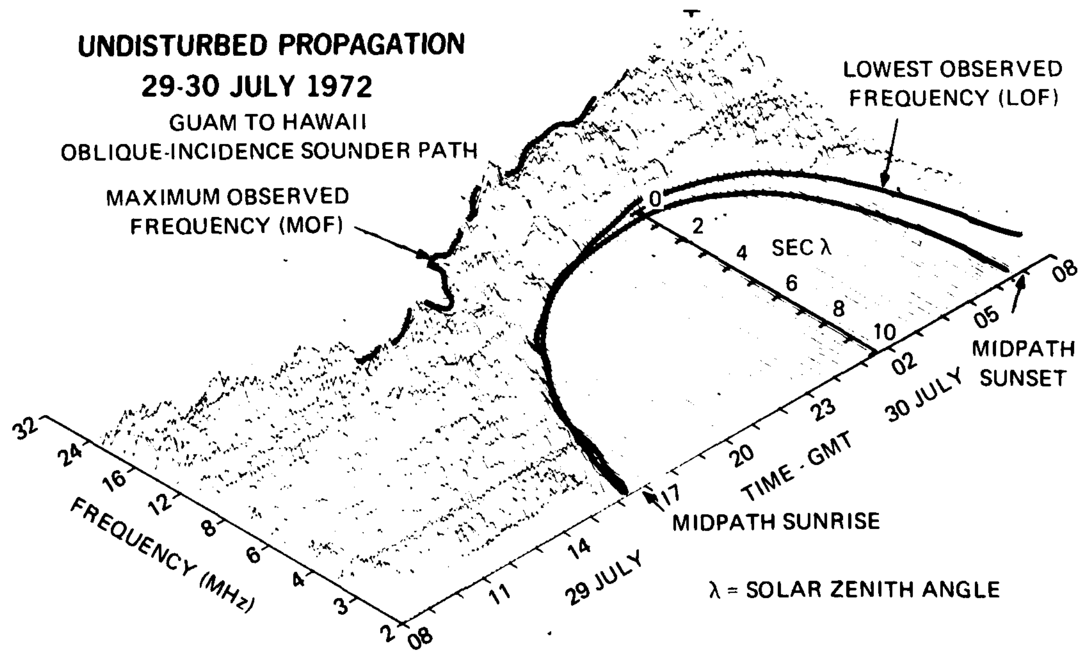


Figure 2. Undisturbed propagation, 29-30 July 1972.

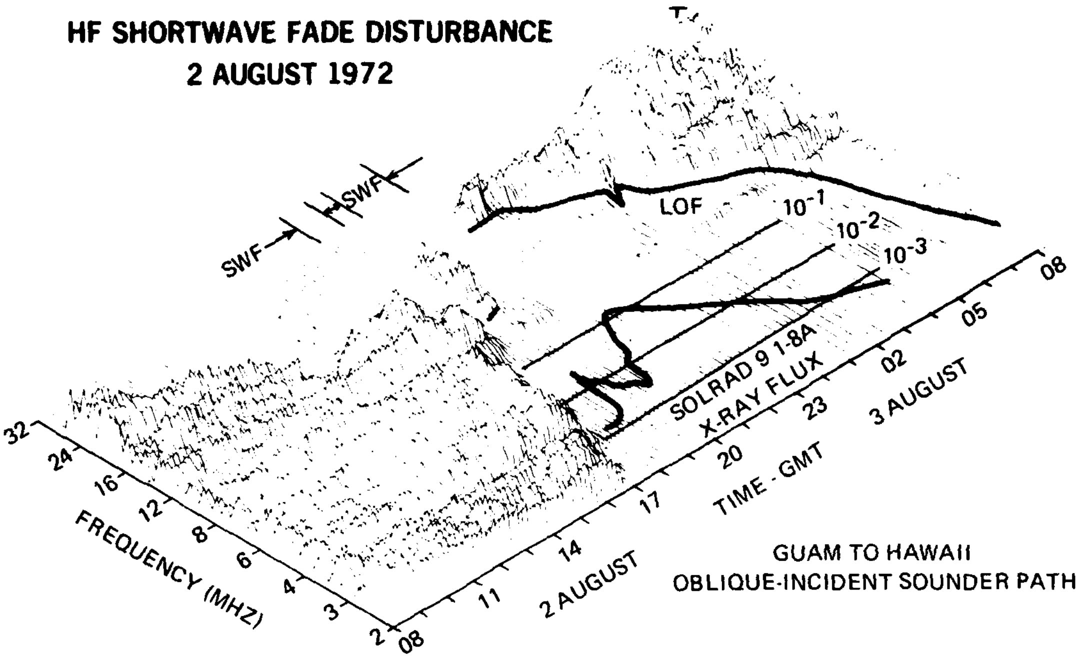


Figure 3. Hf short-wave fade disturbance, 2 August 1972.

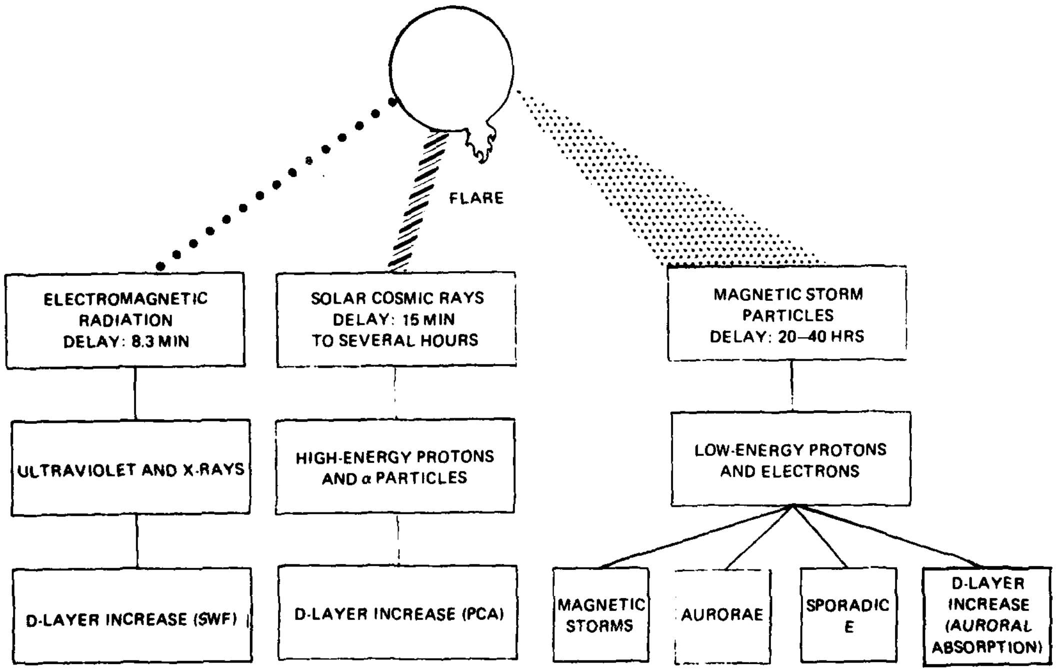


Figure 4. Flare emissions and ionosphere effects.

All the solar flare emissions need to be known if one wants to calculate and forecast their effects on the ionosphere and the resulting communication, surveillance, electronic warfare, or navigation systems performance. However, most of the radiation or particles never reach the surface of the earth; they have to be measured before they are absorbed in the ionosphere. This is being done operationally by a number of satellites, as shown in figure 5. While the higher (∿19-earth radii) orbit of the SOLRAD HI satellites — which extends well beyond the boundary of the magnetosphere (shaded structure) — does not convey any particular advantage over the NOAA SMS/GOES satellites in solar x-ray emission measurements, there are definite advantages in measurements of the solar wind and the delayed flare-induced particle emissions discussed earlier. Thus the existing complement of satellite-borne sensors, when taken together with ground-based measurements, provides sufficient real-time environmental monitoring resources to drive a radio propagation forecasting system.

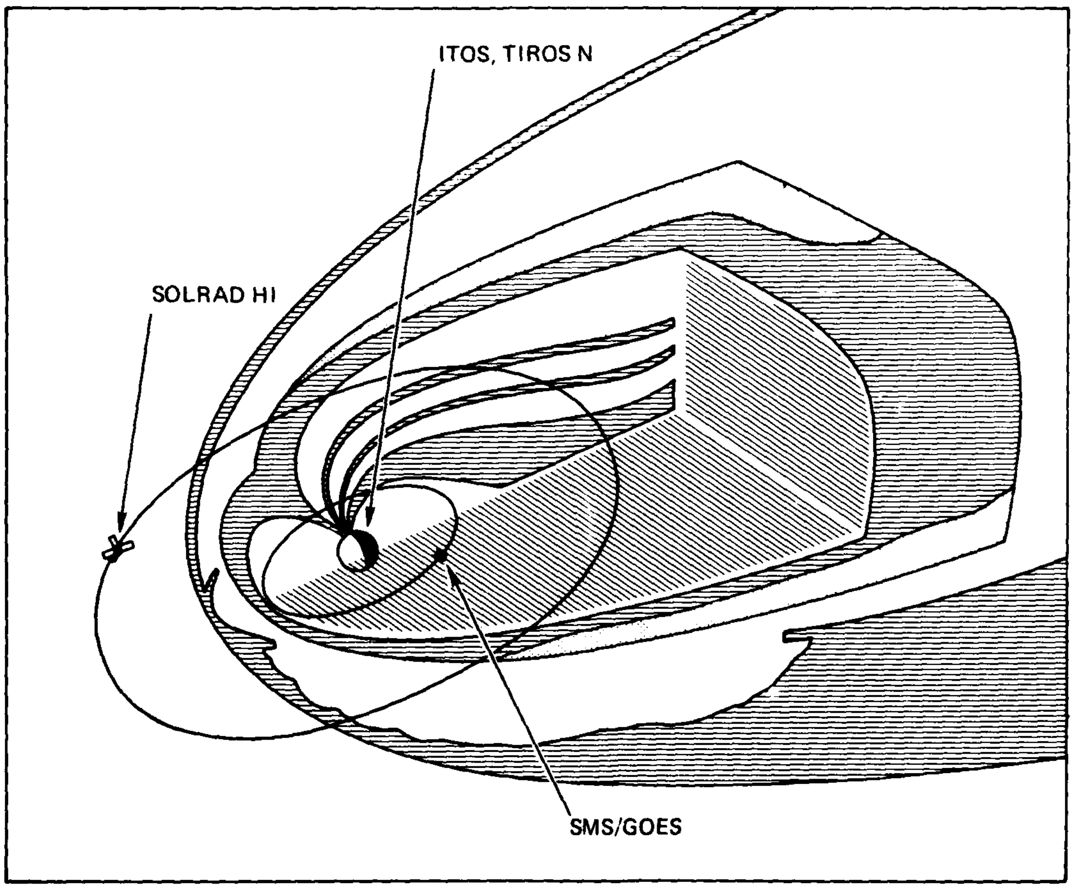


Figure 5. Orbits of dedicated real-time satellites, illustrating spatial coverage obtained.

The system concept which has been developed at NOSC is illustrated in figure 6. On the left, various inputs are depicted which range from on-site ground-based sensors (such as solar radiometers and ionospheric sounders), to satellite sensors, to data and support that are available from the Air Force and NOAA. The input data are sorted, converted, and relayed to various propagation forecast (PROPHET) terminals. On the right side of figure 6, a few applications are illustrated. They cover hf and vlf communications, ionospheric scintillations affecting satellite communication, vlf navigation, command and control advisory, and many others.

A PROPHET terminal itself (figure 7) consists of a stand-alone minicomputer system with an interactive graphic display and a hard-copy unit. In the initially implemented version, the (MIL-SPEC) minicomputer used is an AN/UYK-20 supported by magnetic tape mass storage. The unit also interfaces to a teletype for orderwire communications as well as to a paper-tape punch for the automatic generation of Fleet Broadcast messages (disturbance alerts) with proper headers for direct submission via the AUTODIN system.

The actual data flow in the initial implementation of PROPHET is shown in figure 8. The solar/space environmental data measured by the SOLRAD HI satellites and telemetered to the NRL ground station at Blossom Point, Maryland, are relayed to the NOAA Space Environmental Services Center at Boulder, Colorado. There it is combined with complementing data from the SMS/GOES satellites and sent on to the NOSC La Posta Astrogeophysical Observatory (figure 9). At La Posta, additional data are received over the Astrogeophysical Teletype Network, including specially generated hf forecasts from the Air Force Global Weather Central at Offutt AFB, Nebraska. All such information is sorted, decoded if necessary, and converted into a format directly usable by the remote PROPHET terminals.* Only those elements of the real-time environmental data stream which are specifically needed by a PROPHET terminal are transmitted to it. The first of these terminals was installed – for development test and evaluation purposes – at the Naval Communications Station, Stockton, CA, in December 1976.

*Note: Effective 1 October 1979, all real-time PROPHET support functions performed by the La Posta Observatory have been transferred to the new Real-Time Geophysics Laboratory at the NOSC Point Loma Complex.

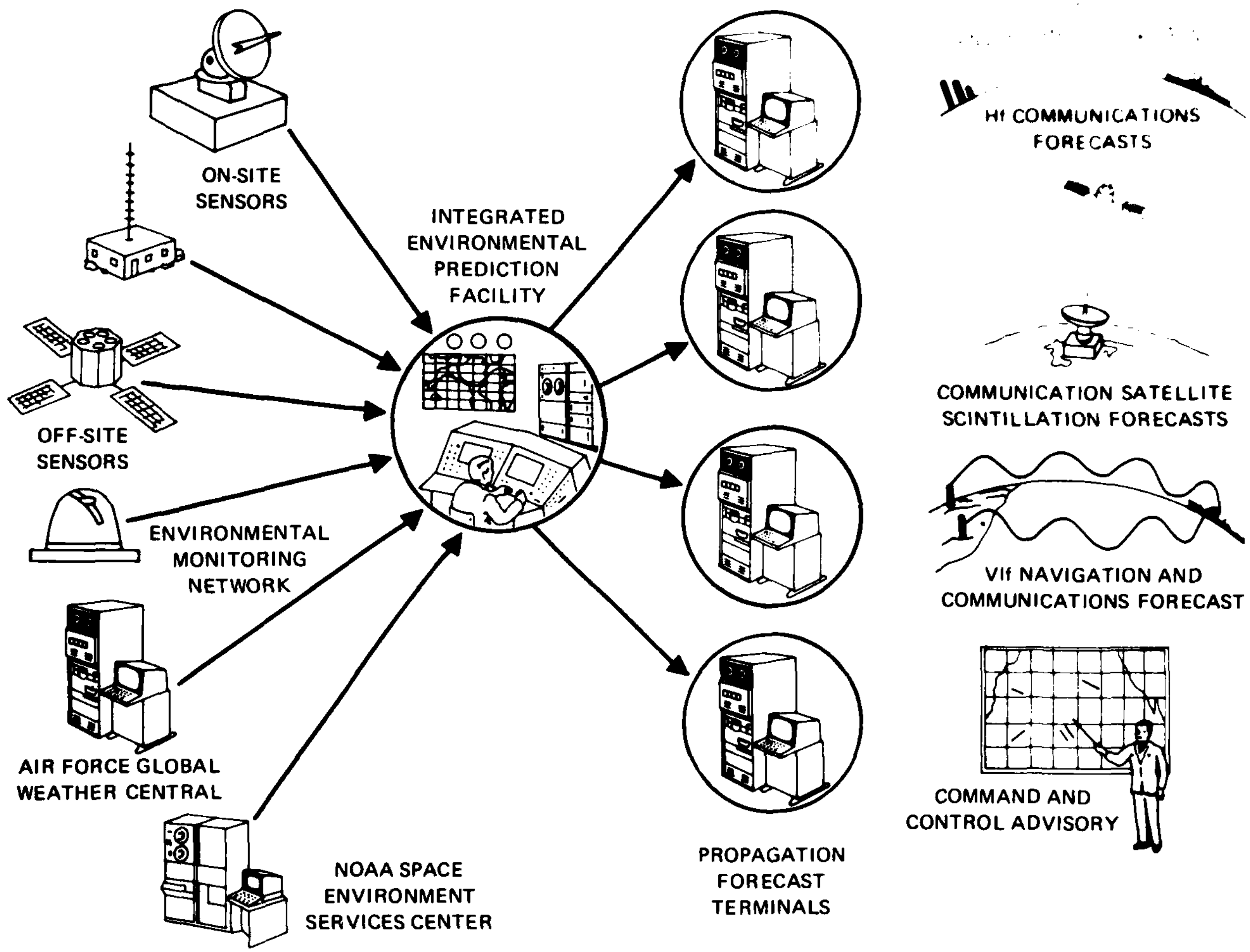


Figure 6. PROPHET: system concept.

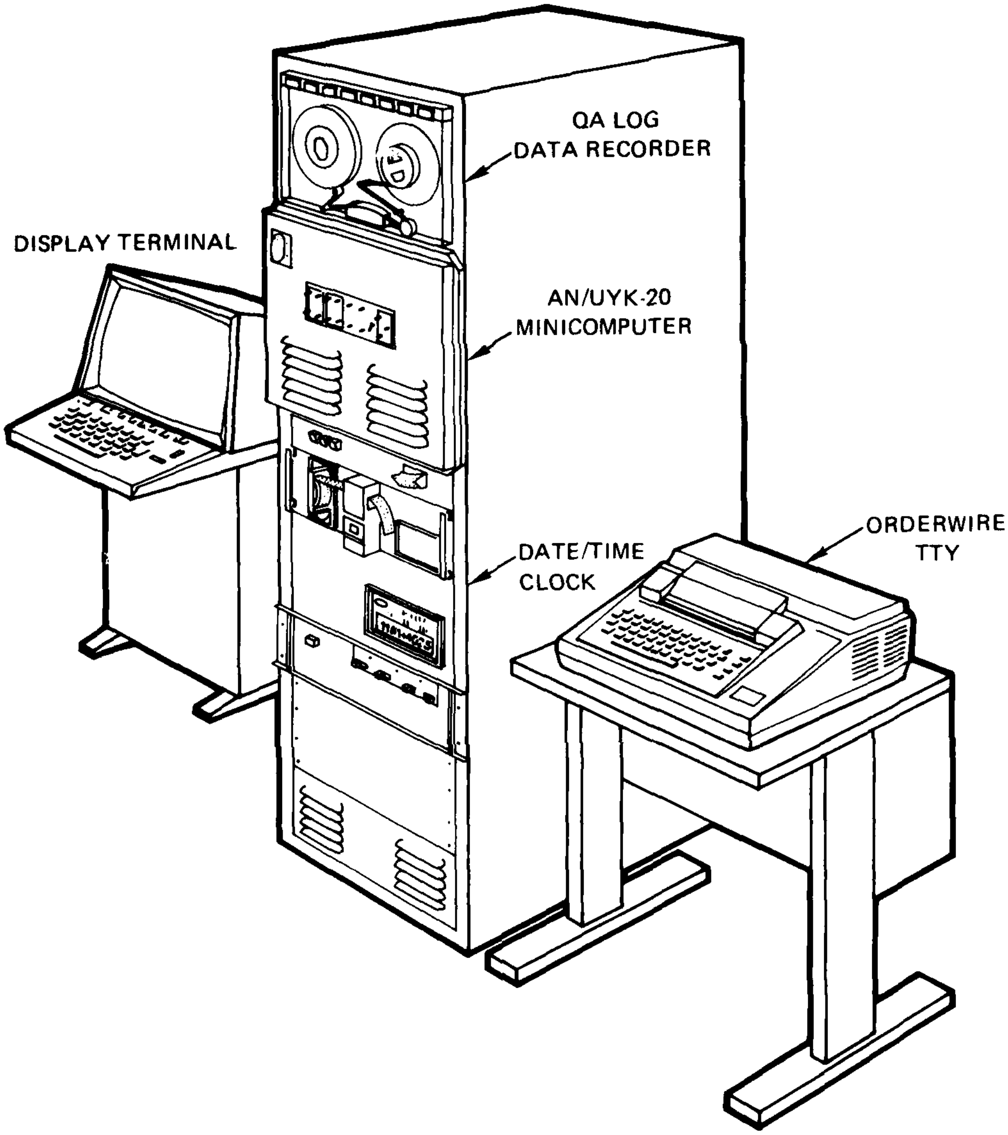


Figure 7. SOLRAD-PROPHET terminal.

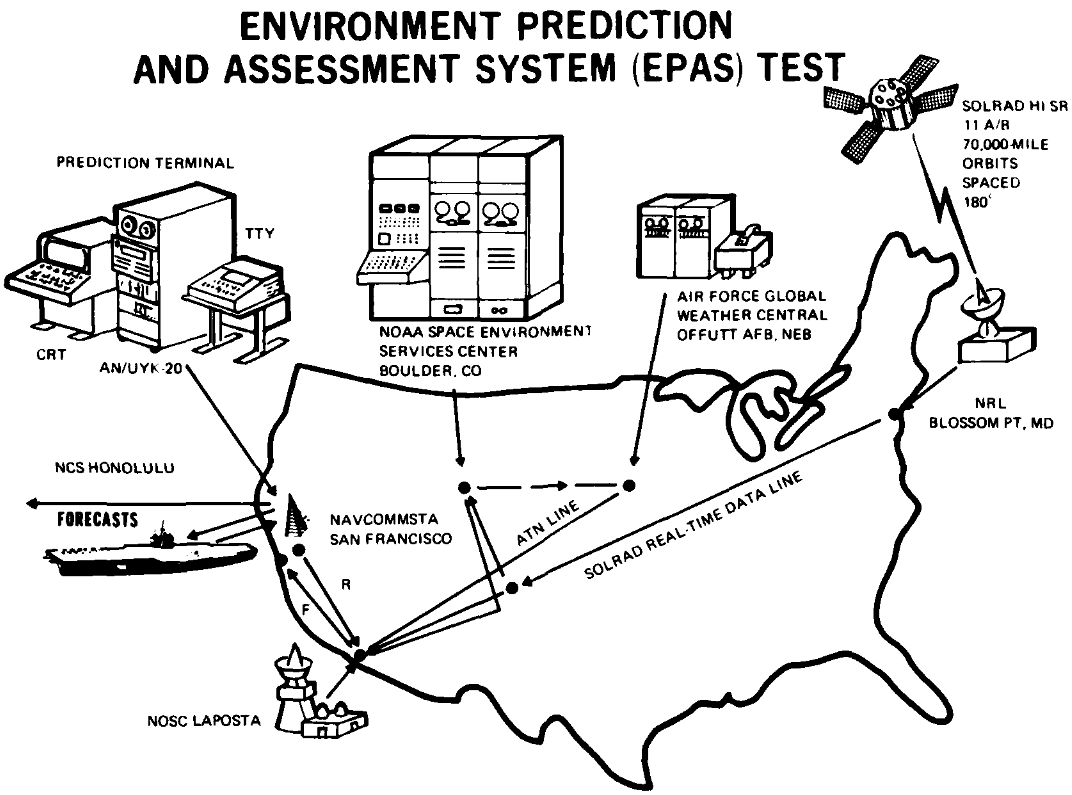


Figure 8. SOLRAD-PROPHET data links for hf communications test and evaluation.

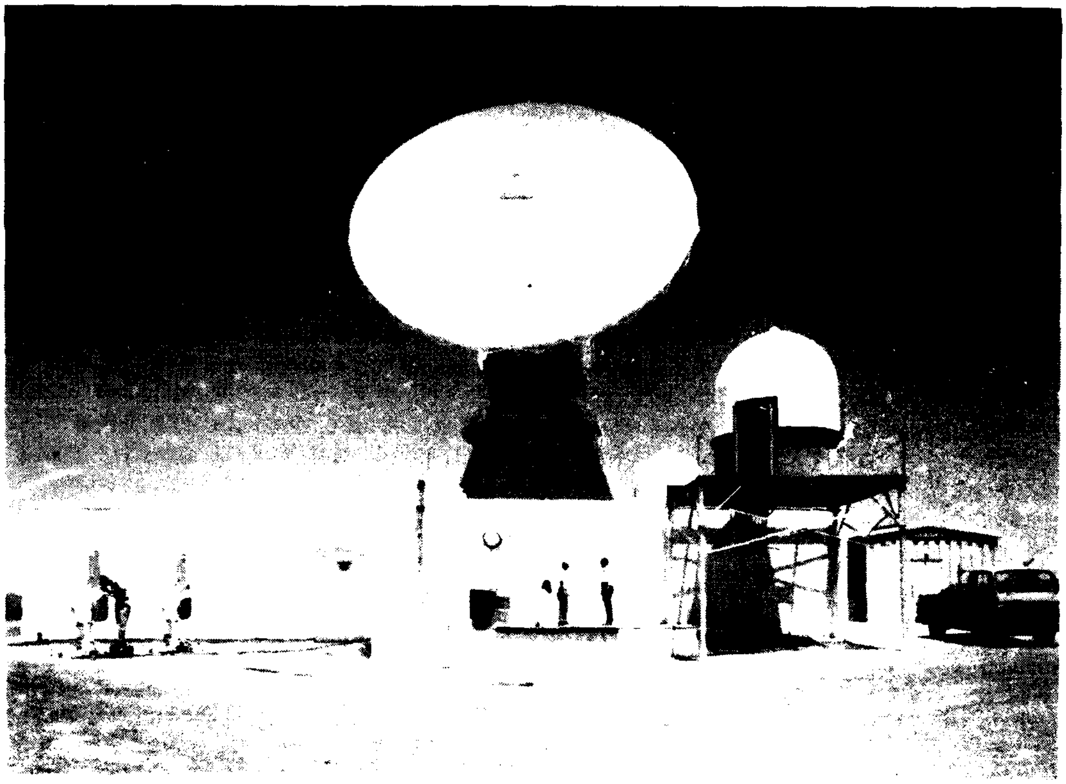


Figure 9. General view of the NOSC La Posta Astrogeophysical Observatory.

PROPHET PRODUCTS

The distinguishing feature of the PROPHET system is its use of distributed data processing. By putting a powerful minicomputer at the end-user's site, a wide variety of output products can be generated in formats specially tailored to the user's operational requirements. In typical operation, the PROPHET terminal is equipped with radio propagation forecast models that are applicable to normal (ie, undisturbed) environmental conditions. The environmental data stream coming from La Posta is then used to adjust these forecasts to the actually occurring conditions. This has been made possible through the development of special "minimal" propagation models which are highly compact and suitable for minicomputer implementation. Economies of storage and execution time are achieved by tailoring the accuracy goals of the models to both user requirements and the inherent predictability of the propagation itself within the limitations imposed by the environmental data. The "minimal" models developed for use in the PROPHET terminal are listed in table 3.

One major objective in the development of the PROPHET products was simplicity in presentation and ease in operation and understanding. Figure 10, a hard copy of an actual PROPHET display, is an example of how these objectives were met. On the display, a map depicts the area of concern for the communications controller. For the Navy Communications Station at Stockton, California (shown by an asterisk on the map), this is the eastern Pacific. At the upper left corner, a smaller graph is labeled SOLAR ACTIVITY. This graph displays the solar 1 – 8-Å x-ray flux received during the preceding hour from SOLRAD HI or alternate (SMS/GOES) satellites. The communications controller enters the geographic coordinates of the ships with which he wants to communicate, and the computer displays these positions on the map. The computer also generates a table that shows, for each ship, the frequency band and optimum frequency to be used for communication, based on the real-time space environmental data stream input into PROPHET. From the display in figure 10, for example, the controller can see that he has to use a frequency between 2 MHz and 11.2 MHz to communicate with the USS RANGER. The frequency of optimum transmission (FOT) is 8.9 MHz. The map and its information are updated every few minutes.

A more complete display of circuit information – useful when several communication circuits are being controlled at once – is available in the form shown in figure 11. Here the range and bearing to the ship, as well as the (operator-entered) current send/receive frequencies, are also displayed.

Table 3. PROPHET minimal models.

Model (Source)	Functions	Input Sensor Data	Primary Outputs	Systems Assisted	Indicated Actions
Flare detector/ duration estimator (NOSC)	Real-time detection of x-ray flares; real-time estimation of flare duration	1 – 8-Å x-ray flux	Event in progress flag; time to decay to threshold	All hf, vlf navigation	Warning to users
SID GRID (NOSC)	Disturbance warning (SWF)	1 – 8-Å x-ray flux	LUF during flare	All hf	Hf communications ● frequency shift ● reroute traffic HFDF ● net impact assessment
SPA/vlf (MEGATEK)	Disturbance warning (SPA)	1 – 8-Å x-ray flux	Phase advance during flare	Vlf navigation (OMEGA)	Correction factor for sunlit paths
PCA/vlf (NOSC)	Disturbance warning (PCA)	>10 MeV proton flux	Phase advance during flare	Vlf navigation (OMEGA)	Correction factor for transpolar paths
PCA/hf (NOSC, MEGATEK)	Disturbance warning (PCA)	>10 MeV proton flux	Attenuation on transpolar paths	All hf	Hf communications ● frequency shift ● reroute traffic HFDF ● net impact assessment
QLOF (NOSC)	LUF during normal times	None	Instantaneous LUF	All hf	Normal diurnal frequency shifts – hf communications
MINIMUF (MEGATEK, NOSC)	MUF during normal times	10-cm radio flux	Instantaneous MUF	All hf	Normal diurnal frequency shifts – hf communications
MINIOMEG (MEGATEK)	Vlf propagation phase corrections during normal times	None	Instantaneous OMEGA PPCs	Vlf navigation (OMEGA)	Correction factor for all navigation circuits
Scintillation grid (SRI, NOSC)	Disturbance warning/ tactical	None	dB fade probability based on location	Vhf/uhf satellite communications	Advisory: reroute traffic
MINIRAY (MEGATEK)	Receiver accessibility multipath warning antenna selection	10-cm radio flux	Ionospheric ray trace	All hf	Hf communications normal operations

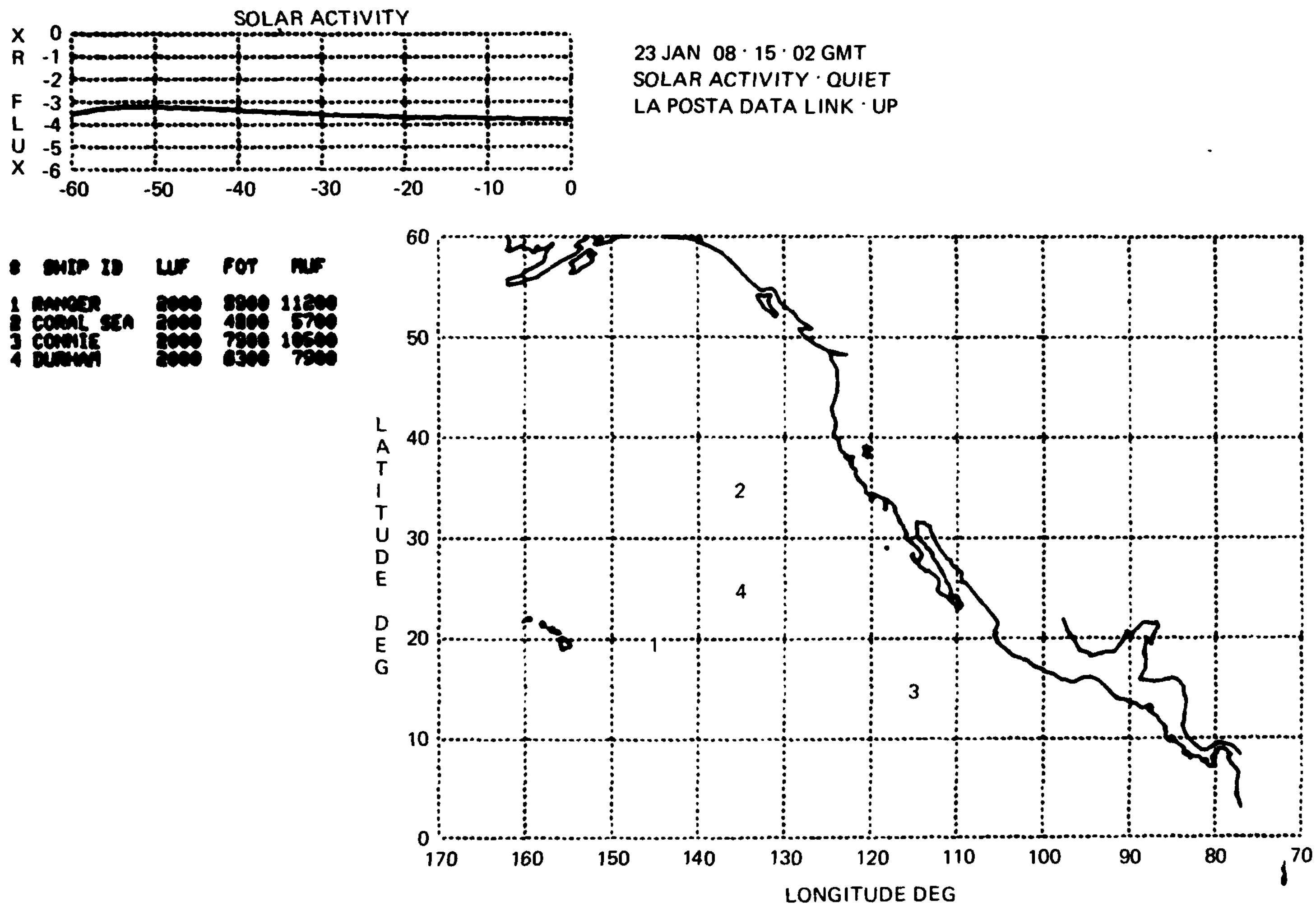
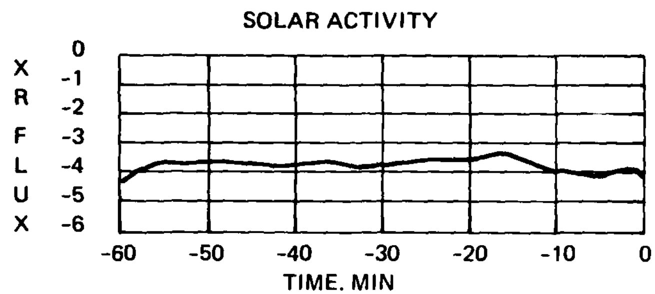


Figure 10. PROPHET "map" display.



01 APR 00.50.00 GMT
SOLAR ACTIVITY. QUIET
LA POSTA DATA LINK. UP

CIRCUIT ID	LAT DEG	LON DEG	RANGE NM	BRNG DEG	SEND 1 KHZ	SEND 2 KHZ	REC 1 KHZ	REC 2 KHZ	MUF KHZ	FOT KHZ	LUF KHZ
ENTERPRIS	32	128	459	220	4720	5800	5100	5174	9900	7500	3800
CONNIE	17	112	1371	154	15010	15150	14915	14980	23600	17300	5100
CORAL SEA	53	153	1560	315	10250	10400	10865	10950	17100	12700	7300
HONO	21	157	2069	250	6340	6480	6800	6850	19700	14400	9200
CHICAGO	46	139	888	308	13350	12050	16200	14200	13200	9800	5200
RANGER	31	142	1063	252	15000	13500	12500	10000	17700	13500	5800
TARAWA	28	94	1535	104	17500	19000	16200	14080	20300	15400	4100

x7 NEW
CIRCUIT ID x7DUBUQUE
LATITUDE x7.25
LONGITUDE x71.00
SEND FREQ (KHZ) x7 9800
SECOND SEND FREQ (KHZ) x7 9900
RECEIVE FREQ (KHZ) x7 9900
RECEIVE FREQ (KHZ) x7 6500
SECOND RECEIVE FREQ (KHZ) x7 7680

Figure 11. PROPHET "list" display.

A 24-hour forecast of propagating band and optimum frequencies – based on the current values of solar activity – is another PROPHET product. Figure 12 shows the corresponding display for the circuit between the USS DURHAM and Stockton ("SAN FRAN"). Without PROPHET, the communications controller would have to generate such forecasts laboriously by interpolating (in space in time) in the NTP-6 tables. PROPHET's forecasts have the additional advantage of being adjusted to the current value of solar activity.

A very important PROPHET capability is the production of raytraces that depict the path of the electromagnetic wave fronts. Figure 13 is an example of a raytrace over a 3000-km path. A number of important propagation features are evident from this presentation. No (skywave) communications are possible at the given 12.55-MHz frequency out to approximately 1400 km. This so-called skip zone may be of advantage if an unwanted receiver is located within this range. Focusing (ie, several rays concentrated in a small area) occurs between 1400-1500 km and, because of the different travel times of the rays, signal degradation through interference may be expected. A similar interference may be expected at about 2750 km. The USS DURHAM, indicated by the triangle below the horizontal axis, is seen to lie just at the edge of the zone of single ionospheric reflections, and thus is in a marginal propagation configuration that dictates the use of a somewhat higher frequency. Another application of the raytrace picture is the selection of specific antennas with launch angles that favor desired rays and suppress undesired rays for a particular optimum coverage situation.

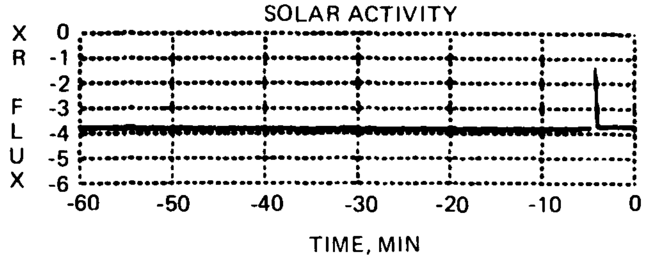
The correlation between 1 – 8-Å x-ray flux and the LOF evident in figure 2 led to the development of an empirical model which permits the prediction of the LOF as soon as the peak x-ray flux has been reached during a solar flare. This capability has important applications. Figure 14 is an example of a PROPHET product which can be used to predict the time to recover from a short-wave fade blackout as a function of operating frequency. In this example, a flare is shown to have peaked about 4 minutes previously, as indicated by the solar activity graph, and recovery forecasts are being generated for the USS CORAL SEA. The slanting line gives time to recovery versus frequency. Thus the current send frequency of 14 MHz is predicted to be blacked out for close to 100 more minutes while the receive frequency and other send frequencies – both below 6 MHz – will be blacked out for over 3 hours. If, however, these frequencies are moved up close to the 20-MHz MUF, service could be restored in 10 – 15 minutes. The recognition that a solar flare (and not equipment failure) was the cause of the outage, and the knowledge of when to resume communications as a function of frequency, are of critical operational importance.

To alert Fleet units promptly of impending difficulties in hf communications and vlf navigation during a solar flare, PROPHET generates a paper tape of a disturbance alert message suitable for direct transmission over Fleet Broadcast via the AUTODIN system. Figure 15 shows actual examples of such messages.

24 HR FORECAST

FROM	SAN FRAN	LAT 38.	LON 122
TO	DURHAM	LAT 25.	LON 135

TIME GMT	MUF KHz	FOT KHz	LUF KHz
0	25900	19200	5700
1	24300	18500	4300
2	21700	16500	2000
3	16600	12600	2000
4	13300	10100	2000
5	12600	10100	2000
6	12000	9600	2000
7	11500	9200	2000
8	11000	8800	2000
9	10700	8600	2000
10	10500	8400	2000
11	10200	8200	2000
12	10100	8100	2000
13	10000	8200	2000
14	9800	8100	2000
15	18000	14700	2000
16	22300	18300	3000
17	24600	18000	5000
18	26100	19100	6100
19	27100	19800	6800
20	27700	20300	7100
21	27300	20000	7800
22	27000	20400	7000
23	27000	20000	6500



22 JAN 00 · 00 · 00 GMT
SOLAR ACTIVITY · QUIET
LA POSTA DATA LINK · UP

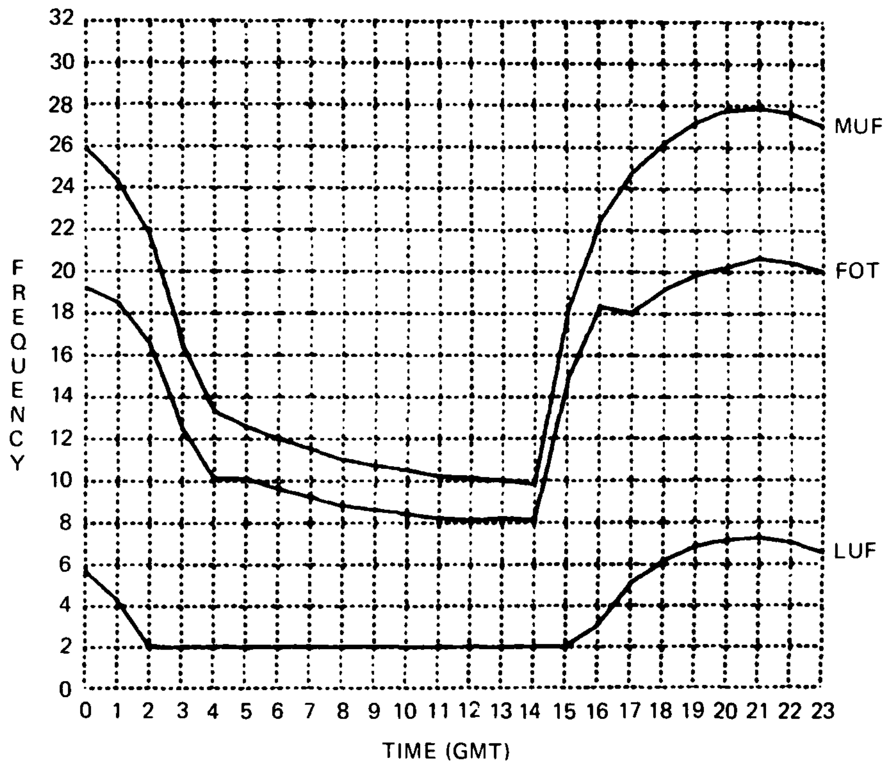


Figure 12. Propagation link performance prediction for undisturbed ionospheric conditions.

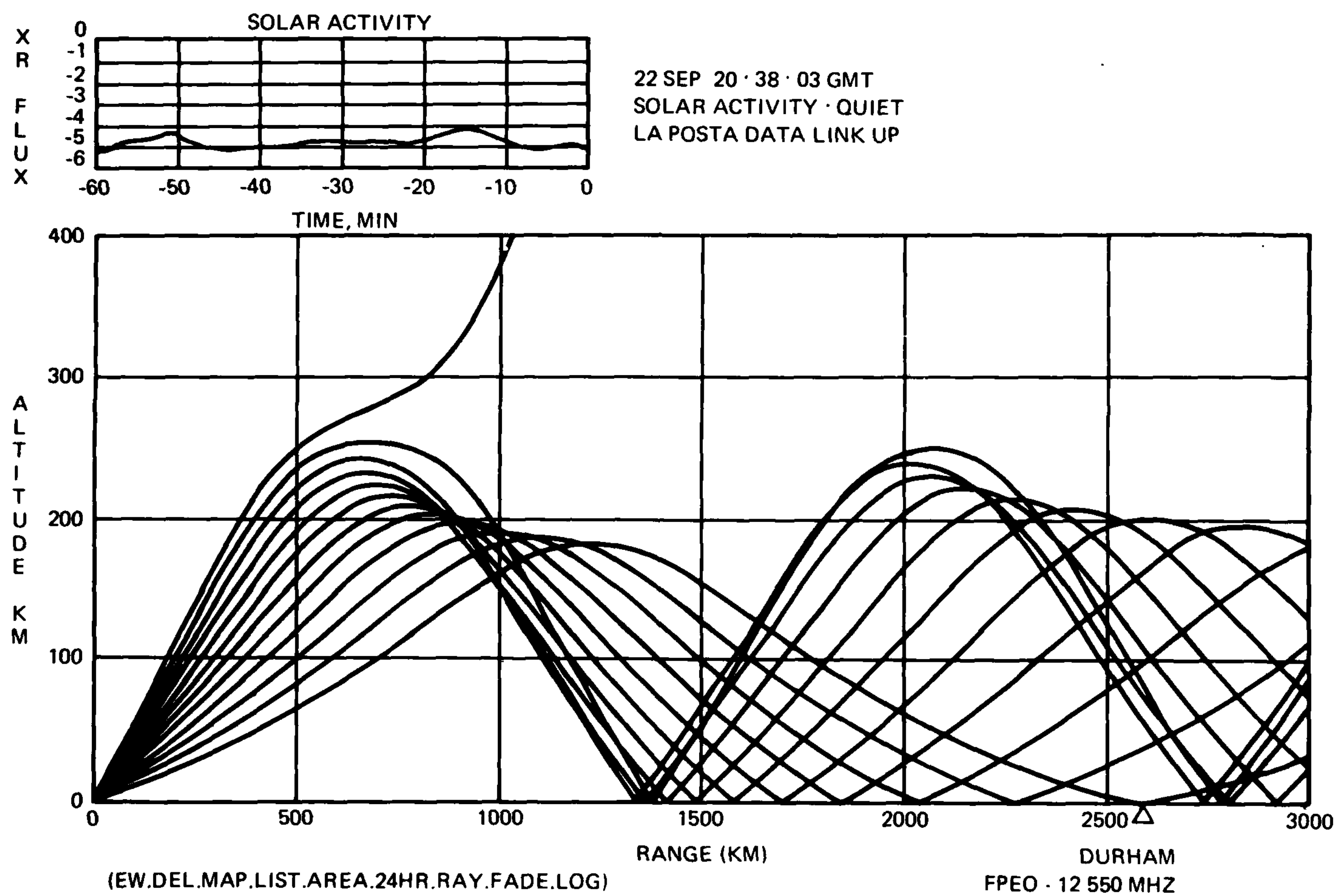


Figure 13. PROPHET raytrace example.

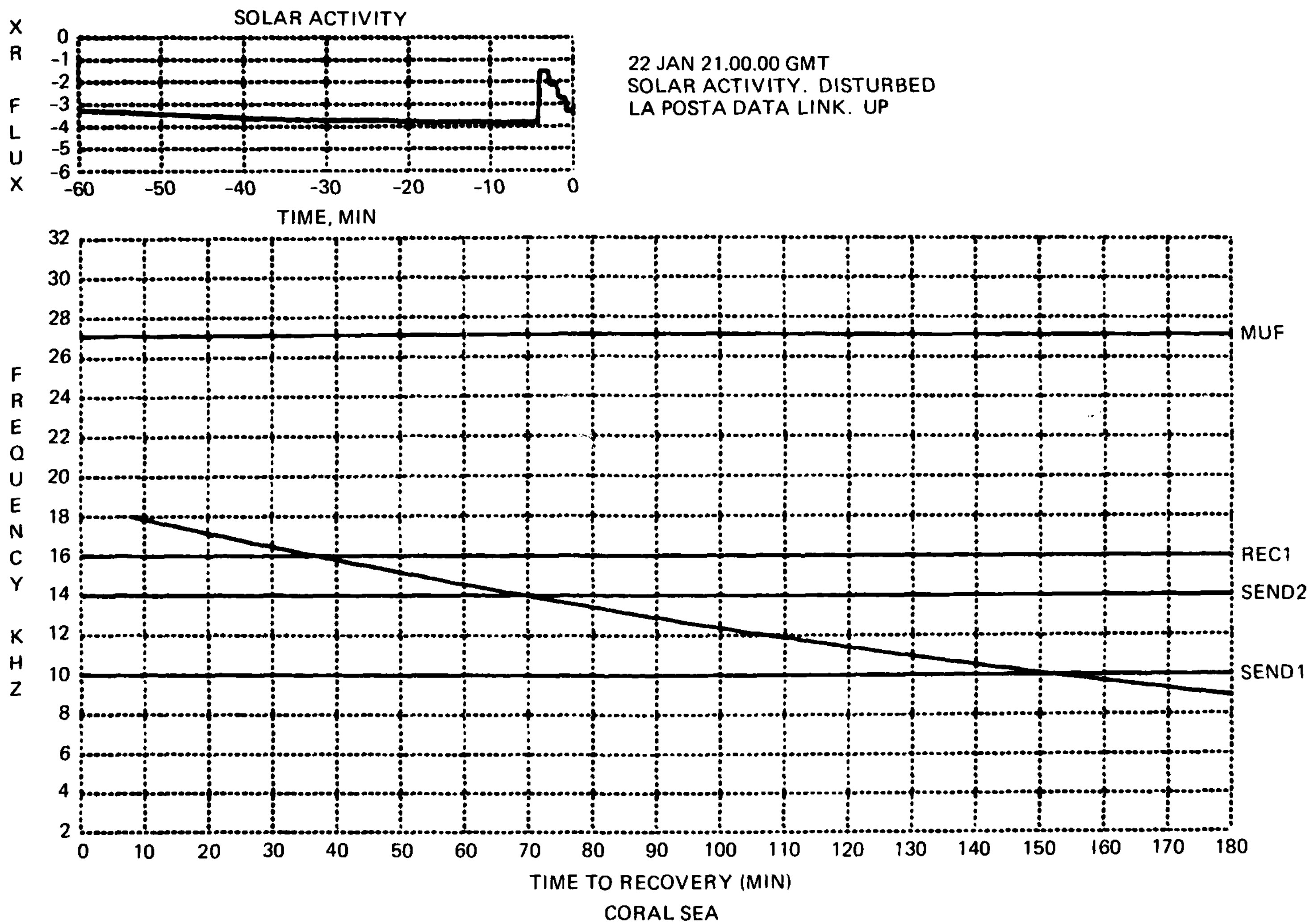


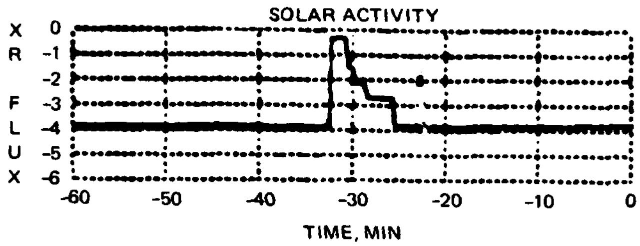
Figure 14. PROPHET "fade" display.

```
OTTUZYUW RUWNSAA0001 1902035-UUUU--RUHPSAA RHWZMKK.
ZNR UUUUU
O 092035Z JUL 78
FM NAVCOMMSTA STOCKTON CA
TO RUHPSAA/NAVCAMS EASTPAC HONOLULU HI
INFO RHWZMKK/ALL SHIPS COPYING PMKK
BT
UNCLAS //N02300//
COMMUNICATION ALERT
FOR SUNLIT PATHS DUE TO SOLAR FLARE AT 2035 GMT.
HF FADE AND OMEGA ERRORS POSSIBLE UNTIL 0022 GMT.
HIGHER FREQS WILL RECOVER SOONEST.
BT
#0001


NNNN

OTTUZYUW RUWNSAA0002 1902054-UUUU--RUHPSAA RHWZMKK.
ZNR UUUUU
O 092054Z JUL 78
FM NAVCOMMSTA STOCKTON CA
TO RUHPSAA/NAVCAMS EASTPAC HONOLULU HI
INFO RHWZMKK/ALL SHIPS COPYING PMKK
BT
UNCLAS //N02300//
COMMUNICATION ALERT
CANCELLATION
FULL RECOVERY FROM SOLAR FLARE AT 2047 GMT.
BT
#0002


NNNN
```

Figure 15. Standard disturbance alert message generated by PROPHET for Fleet Broadcast transmission.

In addition to the foregoing hf assessment capabilities, PROPHET also provides products useful for other types of electromagnetic systems. Figure 16, for example, shows a statistically-based forecast of SATCOM scintillation fade depth for a 24-hour period. The down links are from the GAPPAC satellite to the USS CONSTELLATION and to NAVCOMMSTA Stockton. In this case, the links are predicted to be free of scintillation. Figure 17 shows PROPHET predictions of phase corrections to be applied to OMEGA navigation signals received at the indicated position. These could be relayed to the ship over the orderwire if required. In the absence of solar flares, such corrections — although somewhat less accurate than those available from tables — would be sufficient for navigation on the open sea. During a flare, the PROPHET predictions change in proportion to the flare x-ray intensity and would thereby be more accurate than the (statistical) predictions obtained from tables.

Other PROPHET products are under development which will greatly extend the usefulness and scope of the terminal. They are listed in table 4. The column headed FOTACS refers to another NOSC-developed system designed primarily to handle the administrative details of telecommunications resource management, rather than for disturbance forecasting/assessment. It is equipped with a few of the PROPHET models but, as seen from the table, it is not equipped for practical real-time propagation forecasting.



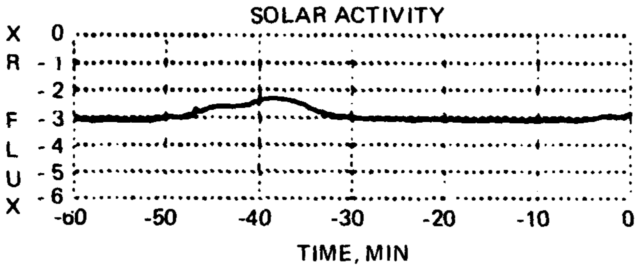
22 JAN 21.00.00 GMT
SOLAR ACTIVITY. QUIET
LA POSTA DATA LINK. UP

SCINTILLATION PREDICTIONS FOR SATELLITE GAPPAC
LONGITUDE 183 WEST, FREQUENCY 254 MHZ

UNITS ARE EXPECTED FADE DEPTH IN DB

HR	DOWN LINK TO CONNIE 15,115	DOWN LINK TO SAN FRAN 38,122
0	0	0
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0

Figure 16. PROPHET scintillation forecast.



29 NOV 20·25·17 GMT
SOLAR ACTIVITY · QUIET
LA POSTA DATA LINK UP

PHASE CORRECTIONS IN CEC AT LAT 31. LON 118

STATION		10 2 KHZ	11 3 KHZ	13 6 KHZ
NORWAY	A	-56	-98	-161
LIBERIA	B	-58	-113	-194
HAWAII	C	11	-10	-40
NORTH DAKOTA	D	3	-9	-27
LA REUNION	E	-225	-321	-477
ARGENTINA	F	17	-37	-111
TRINIDAD	G	9	-23	-66
JAPAN	H	-50	-99	-173

Figure 17. PROPHET OMEGA display.

Table 4. Present and future PROPHET capabilities.

Model	System	Action		FOTACS	Present PROPHET	Future PROPHET
Flare detection	All hf, vlf navigation and comm	Warning	Operational		x	x
Flare detection	All hf, vlf nav comm	Hf comm-freq shift reroute traffic	Operational		x	x
SID GRID	All hf	Hf comm-freq shift reroute traffic	Operational	x	x	x
SPA vlf	Vlf nav Omega	Phase correction factor	Developed			x
SPA inversion	All hf, vlf	Estimate x-ray flare size (inde pendent of satellite) feed SID GRID	In progress			x
PCA vlf	Vlf navig	Phase correction factor for trans-polar circuits	Developed			x
PCA hf	All polar hf	Hf comm-advice signal strength loss-freq shift	Developed			x
PCA vhf	All polar satellite	Vhf comm-advice signal loss	Developed			x
QLOF	All hf	Hf comm-normal operations, freq management	Operational	x	x	x
LOF split	Covert hf systems	Opt freq selection against known rcvrs	Operational			x
MINIMUF	All hf	Hf comm-normal ops freq management	Operational	x	x	x
15-min update to MINIMUF by means of auroral E fields	All hf	Correct MUF est (real time) minimize errors (to ≈ 1 MHz) (feeds MINIMUF)				x
Raytrace	All hf	Hf comm-normal ops antenna selection	Operational		x	x
Launch angle multipath by means of quasi parabolic	All hf	Hf comm-normal ops antenna selection	Near completion			x
Polar and auroral inosphere	All hf vhf satellite	Hf comm, auroral & polar circuits	In progress			x
Earth's magnetic field variations (ground)	ASW & any magnetically sensitive	Corrections for field changes	In progress			x
Mixing shock front from auroral disturbances	All hf	Hf comm-midlatitude (feeds MINIMUF)	In progress			x
Scintillation grid	Vhf/uhf satellite comm	Advisory-dB fade probability based on location	Operational	x	x	x
OMEGA correctional factors	OMEGA vlf	Correction factors	Operational		x	x
DMSP topside sounder ionospheric updates	Hf & satellite comm	Correct MUF est (real time)	In conception			x

DEVELOPMENT TEST AND EVALUATION

The deployment of a PROPHET terminal at NAVCOMMSTA Stockton was for the purpose of evaluating the accuracy of the propagation forecasts and the practical impact of the PROPHET products on COMMSTA operations. The chronology of the test is summarized in table 5. Phases III and V were used to obtain detailed profiles of terminal usage for hf forecasts under quiet solar/terrestrial conditions; important solar activity was virtually absent in this period. Phase VI provided results on hf performance during solar disturbances, while phase VII permitted tests of PROPHET vlf forecasts by means of a separate real-time terminal located at NOSC. Overall, the nearly 3-year period of continuous PROPHET usage at Stockton has provided a good assessment of performance under the full spectrum of operational conditions.

Table 5. Chronology of DT&E events.

PHASE I.	(October 1975 – October 1976): Design implementation of PROPHET products to assist hf communications management procedures of the COMMSTA. Accomplished via liaison visits which allowed COMMSTA personnel to participate actively in the design of the terminal "products".
PHASE II.	(October 1976 – December 1976): Initial PROPHET installation at Stockton. Shakedown period for terminal deployment, installation/checkout, operator training and familiarization, and general hardware/software debugging.
PHASE III.	(December 1976 – February 1977): Three-month continuous use of PROPHET at Stockton. System and operational evaluations of PROPHET products aiding communications management under quiet solar/terrestrial conditions.
PHASE IV.	(March 1977 – April 1977): Forty-day standdown for hardware/software upgrades suggested by PHASE III experience.
PHASE V.	(April 1977 – August 1977): Continuation of PHASE III hf evaluations.
PHASE VI.	(September 1977 – August 1979): Ongoing terminal deployment at Stockton. System and operational evaluations of PROPHET hf products under both quiet and disturbed solar/ionospheric conditions. Use of terminal as testbed for implementation of SATCOM scintillation and OMEGA phase-correction forecast products. Evaluation of experience of Fleet use of PROPHET via dissemination of PROPHET forecasts by NAVCOMMSTA Stockton.
PHASE VII.	(December 1978 – March 1979): Deployment of PROPHET validation system at NOSC to test vlf forecasts under both quiet and disturbed ionospheric conditions.

The methodology used in the DT&E is evident from the data flow diagram shown in figure 18. The PROPHET terminal at Stockton maintains a data base on magnetic tape that records all entries to the terminal as well as periodic dumps of the propagation forecasts and active circuits. This is used to reconstruct comparisons between PROPHET forecasts and the frequencies actually used, such as that shown in figure 19. Here it is seen that the two frequencies received at Stockton from the USS TARAWA track the PROPHET-predicted MUF/LUF envelope over the 24-hour period. Also indicated on the plot are the times and modes of access to PROPHET with specific reference to the TARAWA. Between 0300 and 0400 UT, for example, the operator requested two raytraces – presumably one for each frequency in connection with the sunset frequency shifts.

The additional data bases accumulated at the NOSC Real-Time Geophysical Laboratory (the successor to La Posta for real-time environmental data coordination and dissemination) are very useful in providing complete reconstructions of solar/ionospheric disturbances. For example, figure 20 shows the processed Hawaii–San Diego oblique hf sounder data for 29 April 1978. A large (class X3) solar x-ray burst was produced in connection with a flare that began at 1815 UT and ended at 1945 UT. The consequent shortwave fade is indicated in the figure by the absence of propagating frequencies at these times. Prior to this x-ray event, three ships had hf terminations with NCS Stockton. At 1902 UT, the x-ray flux had crossed the threshold level and an alert was issued by the PROPHET terminal. The chronology of events associated with one of the ships, the USS CONSTELLATION (NNUL), is shown in figure 21.

At 1904, 2 minutes after the audible alert had been sounded by PROPHET, a COMMSTA operator requested a "fade" display (see figure 14) for the circuit NNUL to gauge the outage time and plan remedial action. PROPHET indicated that the flare had not yet peaked, so that later updates of the FADE forecasts would be required. (Such updates were in fact requested at 1918, 1921, and at the flare peak at 1928). Next, at 1905, the operator requested a scintillation forecast for that circuit, presumably to determine whether any difficulties were anticipated on the satellite link to the ship. Then, at 1907, the operator requested PROPHET to punch a tape of the SWF alert message (see figure 15) for transmittal over Fleet Broadcast to the ships in the Eastpac area. Shortly thereafter, an outage was noted on the NNUL hf circuit. Similar actions were taken for the other two ship-shore hf circuits (NWDX and NGDV).

When PROPHET indicated that the flare had peaked, the operator (at 1927) requested a MUF/FOT/LUF forecast ("24 HR"), presumably to plan the frequency shifts as the flare decayed. These shifts started at about 2015 as shown in the figure; a fade recovery message was sent to the CONSTELLATION at 2018. It is interesting to note that the SWF would have lasted at least 30 minutes longer if the operator had not shifted frequency as directed by PROPHET. Furthermore, a frequency shift executed too prematurely – at 1950, for example – would have failed to restore communications. Therefore, the value of PROPHET forecasts was to indicate both <u>where</u> and <u>when</u> to shift frequencies.

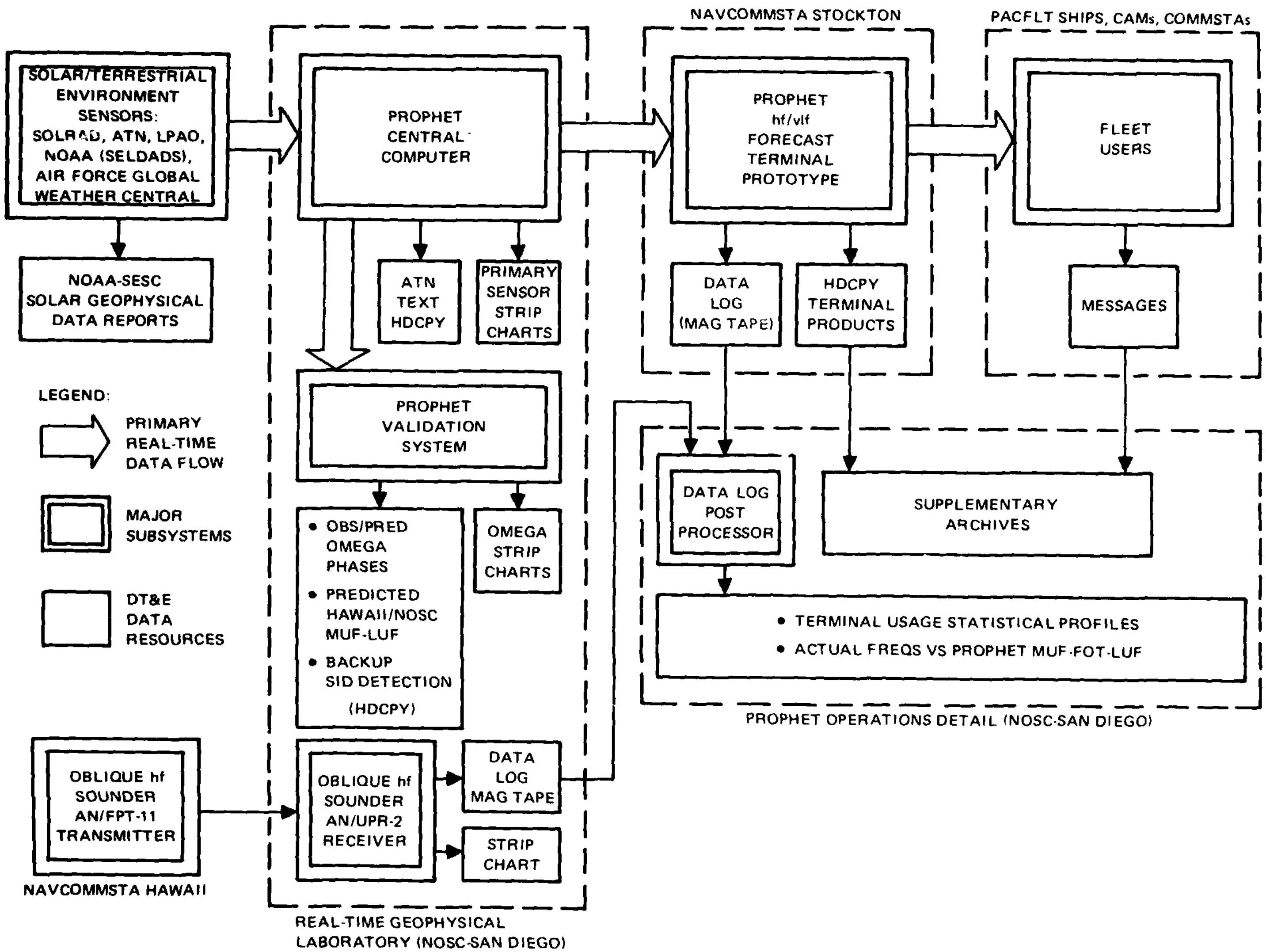


Figure 18. PROPHET DT&E data flow.

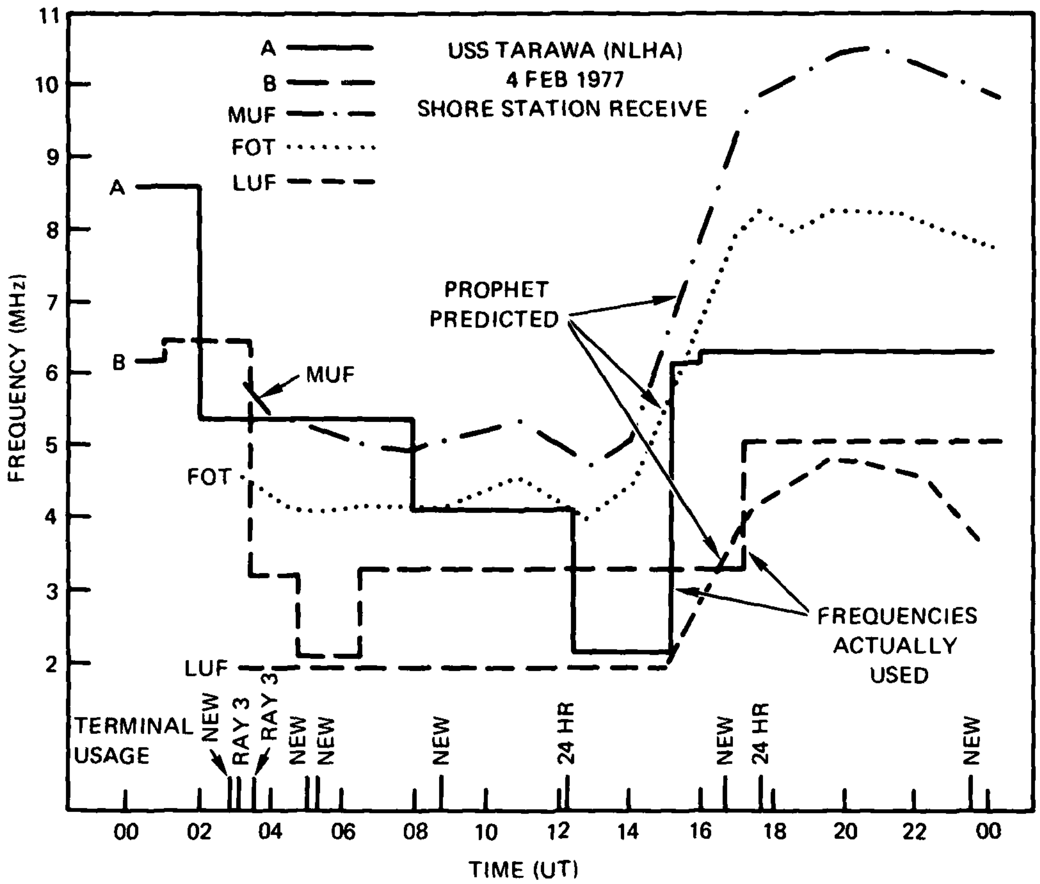


Figure 19. Comparison of predicted and actual frequencies versus time.

This example is also indicative of a high degree of sophistication in the operator's use of PROPHET capabilities. Precisely the proper products were called for at just the appropriate times, with little or no wasted motion or avoidable delay.

Operationally, the PROPHET terminal and associated data links were extremely reliable, with downtime averaging less than 3%. User acceptance was very good and on-the-job training requirements for PROPHET use were minimal — averaging less than one-half hour. COMMSTA personnel accessed the terminal about every 9 minutes and rated its usefulness at 8 on a scale of 10. The consensus was that the number of frequency shifts and outages resulting from propagation conditions were reduced by PROPHET by about 15%, and that the duration of outages when they occurred was reduced by 15 — 20%. Fleet units for which PROPHET forecasts had been generated to assist them in the selection of their transmitting frequencies were similarly favorable in their evaluation. The USS CONSTELLATION, for example, now uses PROPHET — in place of the NTP-6 tables — as the first guide to frequency selection, and quote an average accuracy for PROPHET of 77% versus a 69% accuracy for NTP-6. In the words of the Commanding Officer, NAVCOMMSTA Stockton: "Today, the NAVCOMMSTA Stockton Technical Controllers consider the PROPHET terminal to be one of the most valuable real-time frequency prediction equipments made available to technicians since radio communications first began."

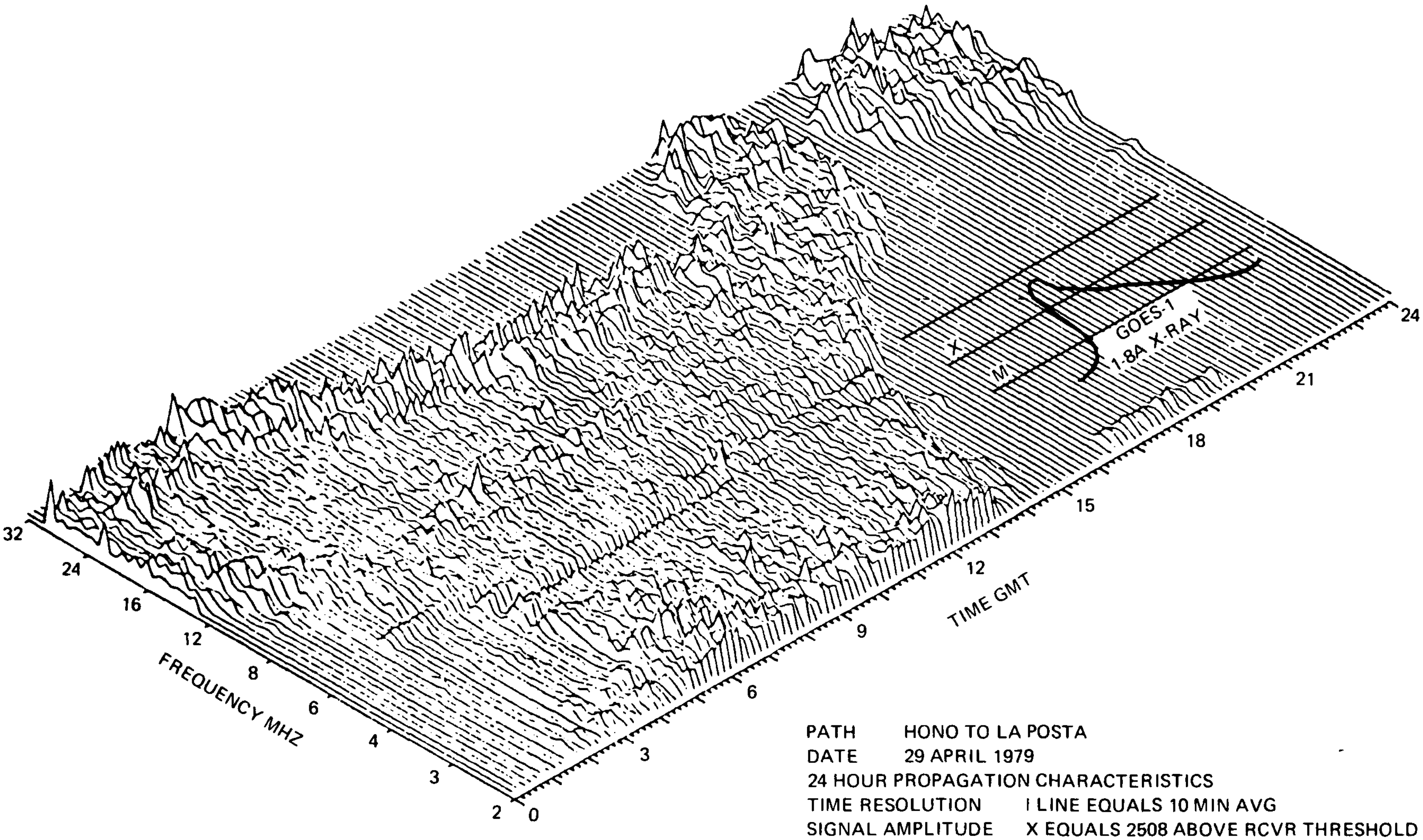
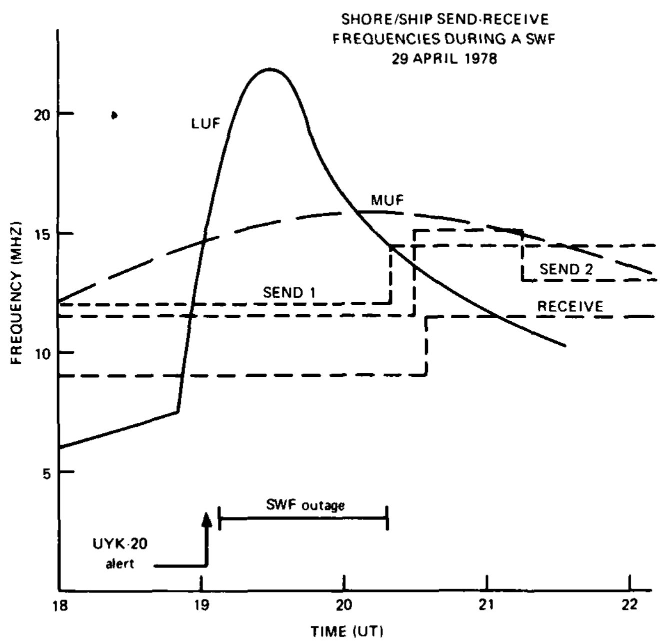
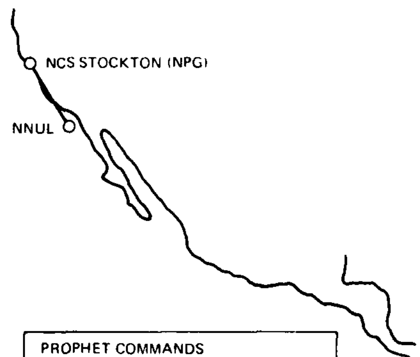


Figure 20. Hf propagation between Hawaii and California, 29 April 1978 (short-wave fade at 1900 UT).





PROPHET COMMANDS

TIME	COMMAND	
1904	FADE	NNUL
1905	SINT	NNUL
1907	TAPE	TAPE MSG SENT
1918	LIST	
1918	FADE	NNUL
1918	FADE	NGDV
1921	LIST	
1921	FADE	NNUL
1922	FADE	NWXD
1923	FADE	NGDV
1925	LIST	
1925	DEL	NNUL
1925	DEL	NWXD
1925	DEL	NGDV
1925	LIST	
1925	NEW	NNUL
1926	NEW	NWXD
1926	NEW	NGDV
1927	LIST	
1927	24HR	NNUL
1928	LIST	
1928	FADE	NNUL

Figure 21. Effects of 29 April 1978 on hf communications between NPG and NNUL.

RECOMMENDATIONS AND CONCLUSIONS

Prior to PROPHET, it was not known whether solar/terrestrial environment data could be brought in real time to Navy personnel in a form that would help them to better meet their operational requirements. In the particular applications area of frequency/antenna management for hf communications, it has now been demonstrated that this is both feasible and useful. One should not get the impression, however, that all the Navy's hf propagation forecasting requirements have therefore now been met, nor should one lose sight of PROPHET's broader objectives to assist the Navy in operation of systems across the whole radio spectrum. Rather, the present situation may be summarized by saying that PROPHET has laid the foundation for a bolder approach to Navy electromagnetic systems management in the face of environmental uncertainties and variabilities.

NEAR-TERM UPGRADE CAPABILITIES

An obvious first step is to build on the experience gained thus far with PROPHET to get the most out of the environmental sensors currently available to the Navy. The hf communications management functions already developed for PROPHET, although far from complete for reasons to be discussed presently, nevertheless constitute a useful package as is and it has been suggested that they should be made available to the four NAVCAMs (Honolulu, Guam, Norfolk, and Naples) and to those NAVCOMMSTAs which terminate an average of five or more ships at a time. On the other hand, the specific hardware implementation of the PROPHET terminal should be upgraded to reflect the current computer technology. In particular, the PROPHET terminal should be reconfigured as a disk- (or "floppy" disk-) based system rather than as a stand-alone core-resident system (its present form). Therefore, once the end users have been identified and budgets have been established, a system design study should be performed to recommend a cost-effective configuration. Once this has been done, it is a relatively straightforward matter to implement the hf communications by assisting in the software packaging of the present terminal. In this way, the existing PROPHET capabilities – by now use-tested over a 3-year period – could be made broadly available to Navy shore stations in a time frame on the order of 1 year.

PROPHET, even when thus reconfigured, will still be limited to the requirement for a real-time environmental data link. Obviously, one would like to make PROPHET capabilities available on mobile platforms as well. One approach to this objective would be to link a mobile PROPHET terminal to the Fleet Broadcast system, over which environmental data could be periodically transmitted with suitable headers for activating PROPHET recognition. This could be accomplished by directly linking the central PROPHET computer through an automatic dial-up modem to the Autodin system. Indeed, with this readily implemented modification, PROPHET terminals could access the required real-time environmental data at any installation worldwide that has Autodin access.

A second approach is suggested by the experience with the PROPHET Validation System, with which it was demonstrated that solar flares could be detected automatically in real time from the sudden phase anomalies which they produce on OMEGA vlf signals. Thus one can envision a PROPHET system that consists of a disk-based minicomputer, interfaced with both an OMEGA navigation receiver and a Fleet Broadcast teletype, which would be capable of both hf frequency selection and OMEGA navigation correction under both quiet and disturbed solar/ionospheric conditions. It is therefore recommended that this PROPHET variation – dubbed PROPHET AFLOAT – be developed for shipboard use.

Another near-term application of the tools already developed for PROPHET would be to implement the highly compact models for forecasting normal diurnal hf MUF/LUF and vlf phase variations in an inexpensive microcomputer. This would – in many situations – free the shipboard radio operator and navigator from time-consuming reliance upon voluminous tables such as NTP-6 and the OMEGA PPC tables. The algorithms and hardware exist "off the shelf" and it would be simply a matter of packaging and documentation to bring these tools – dubbed MICRO PROPHET – to widespread use.

On a longer-term basis, the success achieved thus far with PROPHET should motivate a new look at future sensor resource planning. In particular, <u>by working backwards from the anticipated end-user applications</u>, it should be possible to identify the key environmental data elements required for given propagation forecasting objectives. Appropriate sensors can then be specified to supply such data. This approach, in which the environmental sensor is designed as an integral part of a total propagation forecasting system, would be far simpler than deploying comprehensive sensor packages capable of providing very detailed environmental characterizations and then using only a small subset of the available data for driving the propagation forecasting algorithms.

Such considerations, in turn, underscore one of the main lessons learned from PROPHET, viz, that <u>model development</u> must be closely integrated with both sensor design and end-user applications. In the past, sensor platforms such as SOLRAD HI were configured to meet the requirements of gaining a fundamental understanding of solar/terrestrial interaction phenomenology. Model development tended to be similarly complex. Yet experience has now shown that more modest modeling/propagation forecasting objectives can be identified that sidestep much of the real-world complexity and yet, nevertheless, are quite useful most of the time. PROPHET has proven the value of identifying those propagation forecasting techniques which are: (1) amenable to simple – albeit approximate – modeling; (2) directly useful to Navy operations personnel; and (3) modest in their input data requirements. Having identified such tasks, it is possible rapidly to develop forecasting hardware and put it in the hands of operations personnel. Then, as the fundamental understanding of solar/terrestrial interactions gradually grows, newer models and capabilities can be added to those already in place.

NAVAL PROPAGATION FORECASTING REQUIREMENTS BEYOND CURRENT CAPABILITIES

Unfortunately, the Navy must operate in propagation environments that do not always conform to the simplified models thus far developed. Both of the (geomagnetic) polar regions and the equator have anomalous features, even in the absence of solar disturbances. Thus, while current PROPHET capabilities should be applicable (for example) to most of the Pacific of tactical interest to the Navy and to the Mediterranean, there exist important operations areas such as the North Atlantic and the Indian Ocean/Arabian Sea where PROPHET-type modeling is either still in progress or yet to be initiated.

Since each geographical region has its own peculiarities as regards propagation and environmental vulnerability, it is recommended that over the longer term, PROPHET be developed on a region-by-region basis. PROPHET for Eastpac and Westpac can be considered fairly well along (ie, within one hardware/software iteration of a usable product). For the Mediterranean, the existing PROPHET models, tuned for this region and supplemented by an hf surface-wave propagation model, should provide an initial approach. It is therefore recommended that liaison with NAVCAMS Naples be initiated with the objective of beginning a PROPHET DT&E program for the Mediterranean. This would involve, in essence, a repetition of the steps followed at Stockton and described in the present report, and would begin with a review of existing communications/navigation capabilities and problems and an analysis of where PROPHET could help, as well as what environmental data resources would be required.

Propagation forecasting models for the North Atlantic are currently under development at NOSC, and will require validation under operational conditions before they can be confidently applied. Since it is felt that the Stockton tests have provided sufficient data for design of PROPHET for the Pacific, it is recommended that the current system (with minor modifications) be redeployed at Norfolk in order to (1) provide a test bed for exercise of new propagation forecasting models as they become available and (2) immediately begin compiling a data base from which the inadequacies of the existing models can be catalogued.

For the Indian Ocean, it is recommended that PROPHET modeling studies be initiated as soon as possible in view of the emerging strategic importance of this region. Fortunately, an extensive data base of hf and vlf propagation on the Indian subcontinent already exists and provides initial guidance in modeling. However, it will undoubtedly be necessary to supplement these data by examining recent Navy experience on Diego Garcia – Persian Gulf circuits.

SUGGESTED APPROACH BASED ON PROJECT EXPERIENCE

PROPHET has emerged as an offspring of the SOLRAD project and, with the termination of SOLRAD at the end of FY79, PROPHET necessarily moves into a new and more independent phase of existence. A de facto (but not yet de jure) operational requirement for such propagation forecasting tools has now been clearly established in the arena of hf communications, and — through related efforts — for HFDF as well. The considerable success and unequivocal acceptance of PROPHET during its 3-year DT&E deployment at NAVCOMMSTA Stockton argue strongly for its expanded use.

To facilitate this future development, it is worthwhile to conclude this project report with a concise summary of the lessons learned from PROPHET and the recommended course of future action derived from such lessons. These are given in table 6, and should be viewed (with some degree of urgency) in the context of minimizing the impact on Naval operations of the solar/ionospheric disturbances which will become an almost daily reality as we move towards solar maximum in 1980-1981.

Table 6. Summary of conclusions and recommendations.

CONCLUSIONS:

- Ionosphere-dependent systems (hf, vlf, SATCOM) can be provided with timely and accurate propagation forecasts by means of a distributed computation network driven by a real-time environmental sensor complement including satelliteborne solar activity monitors.
- Navy operations personnel are well aware of environmental limitations on electromagnetic systems performance and will readily accept and use new propagation forecasting tools as soon as they perceive that these tools will reliably improve their ability to manage such systems.
- Computer-assisted propagation forecasting has a role in Naval operations under both quiet and disturbed solar/ionospheric conditions.
- Practical propagation forecasting is facilitated through the development of "minimal models" tailored to specific end-user requirements and simplified to the maximum degree consistent with the inherent predictability of the propagation itself.
- PROPHET's demonstrated success in improving Naval hf communications in Eastpac and elsewhere, coupled with diminishing practical Naval hf expertise (because of increased reliance on FLTSATCOM), argues for early deployment of a PROPHET-type system at CAMs and COMMSTAs.

RECOMMENDATIONS:

- Conduct a design study to reconfigure the PROPHET terminal using a modern high performance disk-based minicomputer in place of the AN/UYK-20.
- Develop highly compact propagation forecast and disturbance models capable of extending PROPHET capabilities to other operational areas, including the North Atlantic and Indian Ocean.
- Demonstrate, test, and evaluate PROPHET terminals for applications other than hf communications.
- Develop shipboard and airborne versions of PROPHET.

BIBLIOGRAPHY

1. NELC TN 2762, Propagation of Covert Signals, by D.B. Sailors, D. Adrian, and W.R. Stone, 7 August 1974.

2. Collins Radio Co TR 523-0556223-103B30, Engineering Compendium HF Antenna Selection, by R.C. Fenwick, 15 June 1969.

3. Davies, K., Ionospheric Radio Propagation, U.S. Government Printing Office, 1965.

4. Environmental Science Services Administration TR IER-1-ITSA-1, Predicting Statistical Performance Indices for High-Frequency Ionospheric Telecommunication Systems, by D.L. Lucas, G.W. Haydon, et al, August 1966.

5. ESSA TR ERL-110-ITS-78, Predicting Long-Term Operational Parameters of High Frequency Sky Wave Telecommunication Systems, by A.F. Barghausen, et al, May 1969.

6. ESSA TR ERL-131-ITS-92, Required Signal-to-Noise Ratios, by H. Akima, G.G. Ax, and W.M. Berry, August 1969.

7. Koide, F.T., A Computer Method of HF Ionospheric Propagation Prediction and Analysis, IEEE Transactions on Antenna Propagation, no AP-11, p 540-557, September 1963.

8. National Bureau of Standards TN 337, Advances in Ionospheric Mapping by Numerical Methods, by W.B. Jones, R.P. Graham, and M. Leftin, 12 May 1966.

9. NELC TR 1808, HF Shipboard Antenna System Design and Utilization Criteria, by J.M. Horn and W.E. Gustafson, 1 December 1971.

10. NELC TR 1383, Calculation of Signal-to-Noise Ratio for HF Propagation Prediction, by D.B. Sailors, 21 June 1966.

11. Stanford Research Institute TR 2/Contract DA-36-039-SC-85052, The HF Propagation Prediction Programs for the IBM 7090 Computer, by E.M. Young and E.A. Clarke, May 1962.

12. SRI Project 5481 Final Report, The Prediction of Nuclear Effects on HF Communications, by D.C. Nielson, J.B. Lomax, and H.A. Turner, November 1967.

13. Morris, P.B., The Determination of OMEGA Signal Coverage Through Theoretical Prediction and Experimental Validation, Proceedings, Third Annual Meeting, International OMEGA Association, p 212-214, September 1978.

14. U.S. Coast Guard TR ONSOD 01-76, New Coefficients for the Swanson PPC Model as Utilized by OMEGA at 10.2 kHz, by A.I. Tolstoy, October 1976.

15. NELC TN 2101, An Equivalent Single Mode (ESM) Model for Global VLF Predictions, by I.J. Rothmuller, August 1972.

16. NELC TN 2814, Development of a Scintillation Prediction Grid, by R.W. La Bahn, October 1974.

17. Albrecht, H.J., Predicted Scintillations in Satellite Signals, Proceedings, 11th Symposium on Tactical Satellite Communications, 2 September 1971, The Hague, Netherlands, issued by NATO European Coordination Test Center, p 43-54.

18. SRI Final Report on Contract NAS5-21551, Development of a Worldwide Model for F-Layer-Produced Scintillation, by E.J. Fremouw and C.L. Rino, Radio Science, no 8, p 213, 1973.

19. NELC TN 2501, Considerations of World-Wide Scintillation Prediction Techniques, by R.W. Majors, 18 October 1973.

20. Pope, J.H., High-Latitude Ionospheric Irregularity Model, Radio Science, no 9, p 675, 1974.

21. Koster, J.R., Equatorial Studies of the VHF Signal Radiated by Intelsat II, F-3, 1. Ionospheric Scintillation, progress report 3, contract F61052-67-C-0027, University of Ghana-Legon, Accra, Ghana, 1968.

22. Keipenheuer, K.O., Solar Activity in The Sun, ed by G.P. Kuiper, University of Chicago Press, p 322-463, 1953.

23. Kundu, M.R., Solar Radio Astronomy, Interscience Publishers, New York, 1965.

24. Cole, J.W., Periodicities in Solar Activity, Solar Physics, no 30, p 103-110, 1973.

25. Hill, J.P., Long Term Solar Activity Forecasting Using High-Resolution Time Spectral Analysis, Nature, no 266, p 151-153, 10 March 1977.

26. Svestka, Z., On Long-Term Forecast of Proton Flares, Solar Physics, no 4, p 18-29, 1968.

27. NELC TN 3211, An Analysis of Ap and Class M Flare Forecasts as Made by NOAA's Space Environment Services Center During 1973-1975, by M.P. Bleiweiss and B.J. Hurley, 17 August 1976.

28. Air Force Cambridge Research Laboratory Report 55-293, Sunspot Flare Occurrence as a Function of Sunspot Size, by I. Enger et al, April 1966.

29. AFCRL Report 69-0148, Flare Occurrence Tomorrow as a Function of Area and Flariness of Sunspot Today, by A.E. Reilly, I. Enger, and A. Pavlowitz, April 1969.

30. Taraka, H., and S. Enome, Microwave Structure of Coronal Condensation and its Relation to Proton Flares, Solar Physics, no 40, p 123-131, 1975.

31. Mayfield, E.B., J. Higman, and C. Samson, Variations in Solar Emission at 3.3mm Wavelength and Their Relation to Flares, Solar Physics, no 13, p 372-388.

32. Aerospace Corp Report ATR-73(8102)-4, Solar Flare Forecasts Based on mm-Wavelength Measurements, by K.P. White 1972.

33. ESSA TR ERL-81-SDL2, Early Detection of a Solar Flare: A Study of X-ray, Extreme Ultraviolet, W-alpha, and Solar Radio Emission from Solar Flares, by R.F. Donnelly, July 1968.

34. Pennsylvania State University, Department of Astronomy, Science Report 019, The Real-Time Prediction of Microwave Solar Radio Burst Flux Density Levels, with an Application to a Rocket-Borne X-ray Experiment, by F.L. Wefer, July 1970.

35. Risbeth, H., and O.K. Garriott, Introduction to Ionospheric Physics, International Geophysics Series, no 14, Academic Press, 1969.

36. Norwegian Defense Research Establishment, Kjeller, Norway, International Report E-284, Geophysical Disturbance Effects and their Predictability, by E.V. Thrane, 3 April 1978.

37. Bain, W.C., and E. Hammond, Ionospheric Solar Flare Effect Observations, Journal of Atmospheric and Terrestrial Physics, no 37, p 573-574, 1975.

38. Donnely, R.F., Solar Flare x-ray and EUV Emission: A Terrestrial Viewpoint, in Physics of Solar Planetary Environments, Proceedings, International Symposium on Solar Terrestrial Physics, ed by D.J. Williams, American Geophysical Union, p 178-192, 1978.

39. MEGATEK Corp Report R2018-023-IF-1, The PROPHET PCA Model, by F. Wefer and M.C. Lee, 15 July 1979.

40. Mayr, H.G., and A.E. Hedin, Significance of Large-Scale Circulation in Magnetic Storm Characteristics with Application to AE-C Neutral Composition Data, Journal of Geophysical Research, no 80, p 2217-2228, 1975.

41. Roble, R.G., Variations of the Mean Meridional Circulation in the Thermosphere, in Dynamical and Chemical Couplings of Neutral and Ionized Atmosphere, ed by B. Grendal and J.A. Holtet, Reidel Publishing Co., Dordrecht, Holland, p 217-234, 1977.

42. Belrose, J.S., and L. Thomas, Ionization Changes in the Middle Latitude D-region Associated with Geomagnetic Storms, Journal of Atmospheric and Terrestrial Physics, no 30, p 1397-1413, 1968.

43. Larsen, J.R., et al, A Coordinated Study of Energetic Electron Precipitation and D-Region Electron Concentrations over Ottawa During Disturbed Conditions, Journal of Geophysical Research, vol 81, no 13, May 1, 1976, p 2200-2213.

44. Brandt, J.C., and S.P. Maren, The Physics of the Sun, in Introduction to Space Science, ed by W.N. Hess and G.D. Mead, Gordon and Breach Science Publishers, p 643-718, 1967.

45. Wild, J.R., Spectral Observations of Solar Activity at Meter Wavelength, in Radio Astronomy Today, ed by H.P. Palmer et al, Harvard University Press, 1963.

46. Lyons, L.R., and A.D. Richmond, Low-Altitude E-Region Ionization by Energetic Ring Current Particles, Journal of Geophysical Research, no 83, p 2201, 1978.

47. Stormer, C., The Polar Aurora, Oxford University Press, 1955.

48. Hartz, T.R., and N.M. Brice, The General Pattern of Auroral Particle Precipitation, Planetary and Space Sciences, no 15, p 301, 1967.

49. Hartz, T.R., Particle Precipitation Patterns, in The Radiating Atmosphere, ed by B.M. McCormack, D. Reidel Publishing Co., Dordrecht, Holland, 1971.

50. Reagan, J.B., Ionization Processes, paper presented at the NATO Advanced Study Institute on Dynamical and Chemical Coupling at Neutral and Ionized Atmosphere, Spatind, Norway, 13-23 April 1977.

51. National Oceanographic and Atmospheric Administration TR ERL 357-SEL37, SELDADS: An Operational Real-Time Solar-Terrestrial Environment Monitoring System, by D.J. Williams, March 1976.

52. NELC TR 1839, DoD and Civilian Systems Affected by Solar Activity Emission: SOLRAD Applications Study, Task I, by R.B. Rose, M.P. Bleiweiss, and W.K. Moision, 31 August 1972.

53. NELC TR 1774, System Performance Degradation Due to Varying Solar Emission Activity: SOLRAD Applications Study, Task II, by R.B. Rose, D.G. Morfitt, and M.P. Bleiweiss, 28 June 1971.

54. NELC TR 1815, Solar Emission Data-Input Requirements to Support Disturbance Forecasting: SOLRAD Applications Study, Tasks III and IV, by R.B. Rose, P.E. Argo, and M.P. Bleiweiss, 28 January 1972.

55. Bleiweiss, M.P., and F.L. Wefer, La Posta Astrogeophysical Observatory, Solar Physics, no 43, p 253-259, 1975.

56. NELC TR 1716, La Posta Microwave Space Research Facility, by P.L. Voss and N.R. Ortwein, 1970.

57. NELC TR 1890, Solar Videometer: An Automatic Solar Flare Identification and Classification System, by P.E. Argo, D.A. Wulfing, and V.E. Hildebrend, 1973.

58. Ward, F., R.F. Carnevale, and R.G. Hendl, Solar Flare Observations from a Pair of Matched Instruments, Solar Physics, no 31, p 131, 1973.

59. NOSC TR 255, X-ray Flare and Short-Wave Fade Duration Model, by P.E. Argo, I.J. Rothmuller, and J.R. Hill, 1978.

60. Argo, P.E., and I.J. Rothmuller, PROPHET: An Application of Propagation Forecasting Principles, paper presented at the International Solar-Terrestrial Prediction Workshop, Boulder, CO, 1979.

61. NELC TR 1938, Sudden Ionospheric Disturbance Grid, by R.B. Rose, J.R. Hill, and M.P. Bleiweiss, 1 December 1974.

62. MEGATEK Corp Report R20005-109-F-1, MINIOMEG: A Compact VLF Phase Model for PROPHET, by P.H. Levine, 28 February 1978.

63. MEGATEK Corp Report R2018-015-INTERIM-1, PROPHET Validation System — Initial Test Results at the NOSC Real-Time Geophysical Laboratory, by P.H. Levine, 15 June 1979.

64. NELC TR 1950, Modeling OMEGA PCA Phase Advances, by P.E. Argo, 1975.

65. NELC TD 480, OMEGA Navigation Disturbance Correction Tables, Polar Cap Absorption Events; East Pacific, 10.2 kHz, by P.E. Argo, 1976.

66. NELC TN 3249, High Frequency Polar Cap Absorption Model: SOLRAD Application, by P.E. Argo and J.R. Hill, 1976.

67. NELC TR 1851, A Prediction Scheme for the Lowest Observed Frequency (LOF) of the Guam-Northwest Cape HF Propagation Path and Eight Other Pacific Paths, by M.P. Bleiweiss, 5 December 1972.

68. MEGATEK Corp Report R2005-078-IF-1, MINIMUF: A Semi-Empirical Model of Maximum Usable Frequencies in HF Propagation, by P.H. Levine, 18 November 1976.

69. NOSC TR 186, MINIMUF-3: A Simplified HF MUF Prediction Algorithm, by R.B. Rose, J.N. Martin, and P.H. Levine, 1 February 1978.

70. NOSC TD 201, MINIMUF-3.5: Improved Version of MINIMUF-3, A Simplified HF MUF Prediction Algorithm, by R.B. Rose and J.N. Martin, 20 October 1978.

71. Levine, P.H., R.B. Rose, and J.N. Martin, MINIMUF-3: A Simplified HF MUF Prediction Algorithm, International Conference on Antennas and Propagation, Part 2 — Propagation, 28-30 November, London, IEEE Conference Publication 169, p 161-167, 1978.

72. MEGATEK Corp Report R2005-078-IF-2, MINIRAY: A Compact Two-Dimensional Ionospheric Raytrace Program for the Minicomputer, by P.H. Levine, 16 December 1976.

73. U.S. Naval Postgraduate School, Automation of a Technical Control Facility, by G.W. Herrick and J.G. Reedy, master's thesis, 1974.

74. U.S. Naval Postgraduate School, Analysis of the Need for a Propagation Forecasting Capability (PROPHET) in the U.S. Navy, by M.M. Zielinski, master's thesis, March 1969.

INITIAL DISTRIBUTION

NAVAL SECURITY GROUP COMMAND
G-53 (LT J. LITCHKO)
G-83 (RAY RICH)

NAVAL ELECTRONICS SYSTEMS COMMAND
PME-106-3 (D. G. ROBBINS) (5)

CHIEF OF NAVAL OPERATIONS
NOP-941C (CDR C. LAVARRE)
NOP-941F (H. A. FEIGLESON)

NAVAL ELECTROMAGNETIC SPECTRUM CENTER
NAVAL COMMUNICATION UNIT, WASHINGTON DC
CAPT J. MADIGAN (2)

NAVAL RESEARCH LABORATORY
CODE 7560 (JOHN GOODMAN)
LIBRARY

NEW LONDON LABORATORY
NAVAL UNDERWATER SYSTEMS CENTER
CODE 341 (J. R. KATAN)

NAVAL AIR SYSTEMS COMMAND
AIR-370 (T. J. CZUBA)

NAVAL COMMUNICATION STATION
STOCKTON, CA (3)

NATIONAL SECURITY AGENCY
R-52
R-931

CENTER FOR NAVAL ANALYSES

U.S. ARMY COMMUNICATIONS RESEARCH
AND DEVELOPMENT COMMAND
DON CAMPBELL

U.S. ARMY COMMUNICATIONS-ELECTRONICS
ENGINEERING INSTALLATION AGENCY
CCC-EMCO-ECD (GEORGE LANE) (3)

U.S. ARMY INSTITUTE FOR MILITARY ASSISTANCE
ATSU-CD-MO (MSGT J. L. WALKER)

U.S. ARMY COMMUNICATIONS COMMAND
LTCOL J. DEMPSEY

MEGATEK CORP.
1055 SHAFTER ST.
SAN DIEGO, CA 92106
DR. P. H. LEVINE (2)

MITRE CORPORATION
WESTGATE RESEARCH PARK
MC LEAN, CA 22101
CAPT W. SMITH

SOUTHWEST RESEARCH INSTITUTE
8500 CULEBRA RD.
P.O. DRAWER 28510
SAN ANTONIO, TX 78284

DEFENSE TECHNICAL INFORMATION CENTER (12)