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Review of progress in gathering, distributing and using satellite data for activities within COST 238 (PRIME)

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Abstract

Recent progress in using the satellite data for various PRIME purposes is briefly presented. The satellite data base is already in operation and contains data of local plasma and neutral atmosphere parameters taken from several ionospheric satellites. A method of tracing the locally measured parameters along the magnetic field lines down to hmF_2 is developed using a theoretical F-region code. This method is applied to receive $f_0F_{2_{\mathrm{sat}}}$ needed to test monthly median and instantaneous mapping methods. In order to reduce the uncertainties arising from the unknown photoionization and recombination rates, f_0F_2 is calibrated at one point on the satellite orbit with a Vertical Incident (VI) f_0F_2 and their ratio is then assumed constant along the whole satellite track over the PRIME area. The testing procedure for monthly median maps traces the measured plasma density down to a basic height of 400 km, where individual $f_0F_{2_{\mathrm{sat}}}$ values are accumulated in every time/subarea bin within the given month, then their median is calibrated with the available medians from the VI ionosonde network. From all available satellite orbits over the PRIME area, 35 of them were found to pass over two VI ionosonde stations. The second station in these orbits was used to check the calculated $f_0F_{2_{\mathrm{sat}}}$ with the measured VI f_0F_2. The standard deviation was found to be only 0.15 MHz.

Key words *satellite data – ionosphere – ionosondes – mapping*

1. Introduction

WP-8 of WG-5 formalizes the utilization of satellite data in various studies within the PRIME Project. Satellite data can be used in long term and instantaneous map testing, testing of electron density profile models, to supplement the studies of ionospheric storms, etc.

Among the various parameters measured by satellites, the ion (electron) density is mostly used. It is measured locally by plasma probes and remotely by topside sounders. The satellite data cannot be used for operational purposes (at least in the present PRIME practice), so they are proper for performing retrospective studies. The specifics in the processing and handling of the satellite data restrict their wider use. Being a center for gathering, distributing and using these data, the Geophysical Institute can supply any potential user with the required portion of data in a format suitable for his particular study. On the other hand, we develop methods for utilizing the satellite data in map testing for studying the F layer disturbances which also could be of help to the various working teams.

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2. Satellite data base

The Satellite Data Base (SDB) operates under the ACCESS commercial database. It is able to handle large amounts of data and to arrange output formats that can meet most of the requirements of the users (Kutiev and Stankov, 1994). One example of such queries is the task of selecting a data subset consisting of ion density measured on a portion of the orbits over the PRIME area, which passes over the ionosonde locations within the limits of ± 1° on latitude and ± 2° on longitude. Such data subset was extracted for the purpose of instantaneous map testing. Table I represents the *Catalogue* of the data available in SDB. There are four satellites listed, the time span of data are shown in column 2. Their perigees, apogees and inclination help to select the proper subset of data. The SDB does not contain topside sounding data, at present. *Intercosmos-19* topside ionograms and extracted f_0F_2 are available in IZMIRAN, with S. Pulinets being responsible for their circulation.

3. Map testing procedures

For the time being, map testing is the most important application of the satellite data. While the topside f_0F_2 can directly be applied for testing, the local plasma measurements should undergo some theoretical transformations.

4. Instantaneous map testing

Using the theoretical *F* region code, including continuity and momentum equations of O^+, H^+ and He^+ ions, the accuracy of obtaining *NmF* is estimated when the measured ion density is traced down to the maximum of the *F* layer (*hmF*) (Kutiev and Stankov, 1992). Figure 1 gives the result. The tracing method itself gives a maximum error of 22% in *NmF* and 10% in corresponding f_0F_2. The same error -10% – is obtained for *hmF*. While the method of the tracing gives a satisfactory accuracy, the total error of the projection is still quite uncertain, because it depends on the plasma temperature ($T_p = T_e + T_i$) and the ratio $n(\mathrm{O})/n(N_2)$; O^+ production rate is proportional to $n(\mathrm{O})$, and loss rate to $n(N_2)$. So, if we consider the probe measurements as independent data, we cannot use them to obtain f_0F_2 and *hmF*. A method was consequently developed, which to a great extent eliminates the above mentioned uncertainties. If we assume that along the orbit of the satellite over the PRIME area T_p and $n(\mathrm{O})/n(N_2)$ remain unchanged, then we can calibrate at a given point the traced $f_0F_{2_{\mathrm{sat}}}$ with the measured one by a ground-based ionosonde $f_0F_{2_{\mathrm{ion}}}$. Theoretically, this can be done by adjusting the unknown T_p and neutral ratio until $f_0F_{2_{\mathrm{sat}}}$ coincides with $f_0F_{2_{\mathrm{ion}}}$. Practically, the problem can be simplified by taking the ratio of the two f_0F_2's at the point where this is possible and then f_0F_2 along the orbit is obtained by a simple multiplication of $f_0F_{2_{\mathrm{sat}}}$ with this ratio. Therefore, the question is to what extent T_p and $n(\mathrm{O})/n(N_2)$ are constant along the orbit.

To check how plasma temperature and neutral density ratio deviate along the orbits, all available passes of DE-2 over the PRIME area were grouped on UT and averaged, relative to the corresponding values at 45° latitude. No correction for altitude changes was made. It is seen from fig. 2 that T_p deviations at all local

Table I. Catalogue of the available satellite data.

Satellite	Time span of data	Perigee-apogee, km	Inclination
AE-C	01-09-74/30-01-75	250-1200	90°
DE-2	01-09-81/30-08-83	300-1000	90°
B-1300	01-09-81/30-07-82	850 circular	82°
Hinotori	22-02-81/18-06-82	650 circular	30°

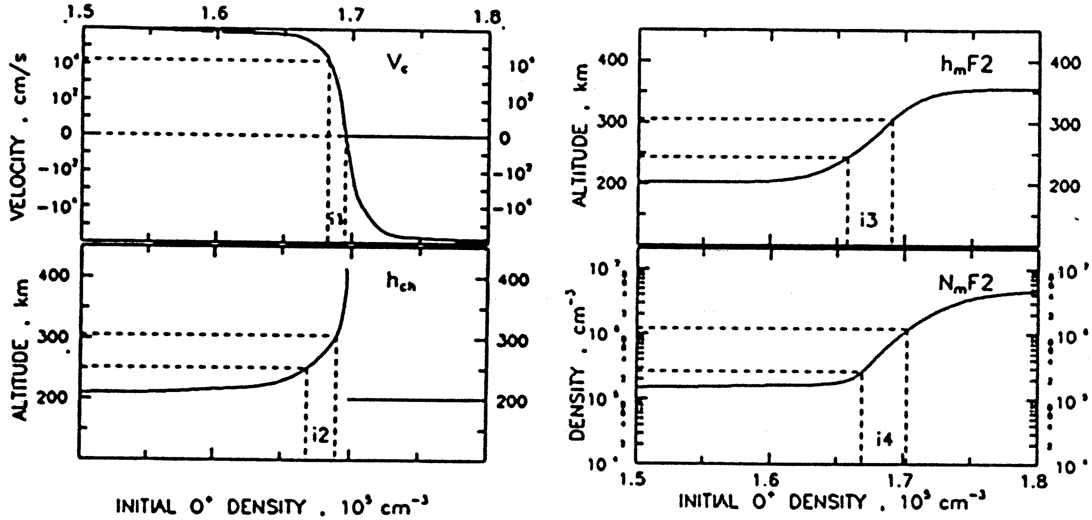

Fig. 1. Diffusive O^+ velocity $V(O^+)$, the height of its change *hch*, NmF_2 and hmF_2 *vs.* the starting value of O^+ at 200 km. Dashed lines mark the steepest range of the curves where the solutions are defined. The error in determining f_0F_2 and hmF_2 is 10%.

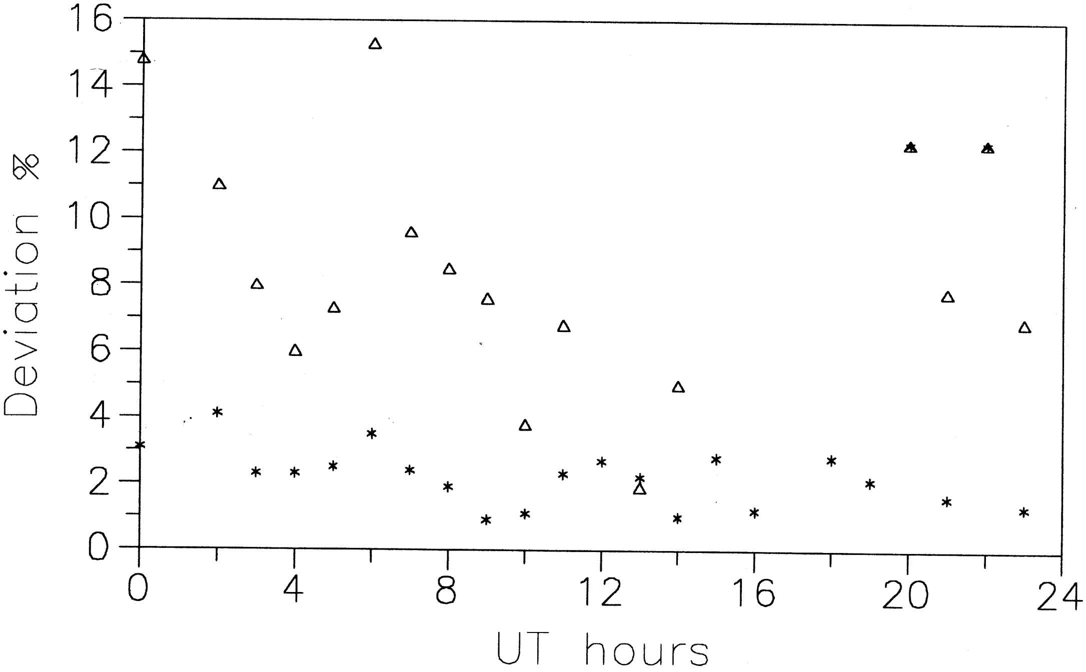

Fig. 2. Averaged relative deviations of plasma temperature (*) and $n(O)/n(N_2)$ (Δ) along the orbital paths *vs.* UT of measurements.

Table II. The measured ($f_0F_{2_{\text{ion}}}$) and calculated ($f_0F_{2_{\text{sat}}}$) values and their differences over the second station.

Date	UT	$f_0F_{2_{\text{ion}}}$	$f_0F_{2_{\text{sat}}}$	Difference (MHz)
1981.08.19	12.02	9.5	8.4	−1.1
1981.08.27	12.22	9.0	8.6	−0.4
1981.09.04	10.54	11.0	10.7	−0.3
1981.09.28	08.48	8.0	10.2	2.2
1982.04.16	07.40	7.5	7.0	−0.5
1982.05.05	06.25	6.2	7.5	1.3
1982.07.05	14.14	7.9	7.9	0.0
1982.08.13	11.38	7.6	7.6	0.0
1982.08.24	11.02	7.5	7.5	0.0
1982.09.26	08.50	7.6	7.6	0.0
1982.09.28	09.13	6.6	7.5	0.9
1982.10.10	07.50	10.4	9.5	−0.9
1982.10.20	07.15	6.4	7.3	0.9
1982.10.24	07.29	8.2	8.1	−0.1
1982.11.03	07.46	4.8	4.9	0.1
1982.11.05	06.13	5.3	6.0	0.7
1983.01.01	15.53	8.0	8.7	0.7
1983.02.03	12.48	11.3	9.4	−1.9
1981.10.08	20.39	8.0	6.9	−1.1
1981.10.11	19.55	7.6	8.4	0.8
1981.10.20	19.22	5.3	6.2	0.9
1982.02.14	23.36	3.5	2.0	−1.5
1982.10.05	20.49	6.8	6.6	−0.2
1982.10.12	20.52	5.5	5.5	0.0
1982.10.13	20.12	5.0	6.3	1.3
1982.10.17	20.34	5.1	5.5	0.4
1982.12.28	03.15	4.6	4.0	−0.6
1983.01.25	02.20	4.1	3.7	−0.4
1983.02.02	01.50	3.0	3.2	0.2
1974.12.17	11.33	5.8	6.4	0.6
1974.11.26	03.38	2.3	2.3	0.0
1974.12.11	13.43	4.9	5.9	1.0
1974.12.12	22.48	3.4	3.5	0.1
1974.12.20	11.58	6.7	8.3	1.6
1974.12.23	19.38	3.8	3.8	0.0

times are less than 4%. The density ratio variations do not exceed 16%, as most of the time they are less than 10%. The larger deviation of the neutral ratio reflects the lower accuracy of the measurement. However, this result shows that the scale height remains almost constant along the satellite path and the total error (tracing plus T_p uncertainty) is ~ 14%. The largest error occurs in determining the F peak shape, which reflects a larger error in *hmF*, but it will have a minor effect on $f_0F_{2_{\mathrm{sat}}}$.

According to requirements in Stanisławska and Jucknikowski (1994), we prepared a data subset, consisting of orbits of DE-2 and AE-C satellites passing over the ionosonde stations, where f_0F_2 are available for the same time. The value of $f_0F_{2_{\mathrm{ion}}}$ used for calibration was interpolated between two hourly values when the time difference exceeded 15 min. To check the accuracy of the method, those orbits which pass over two ionosonde locations were selected and the values of $f_0F_{2_{\mathrm{sat}}}$ and $f_0F_{2_{\mathrm{ion}}}$ of the second station compared in table II. The total number of these orbits is 35. The histogram of the differences, grouped in 0.4 MHz intervals is presented in fig. 3. The number of cases in each interval is indicated in the columns. The distribution looks very much like normal, with the exception of the 0.8 MHz interval. The number of cases is insufficient to expect a statistical significance of this result, but a conclusion can be made that $f_0F_{2_{\mathrm{sat}}}$ is of the same character as $f_0F_{2_{\mathrm{ion}}}$. The standard deviation is only 0.15.

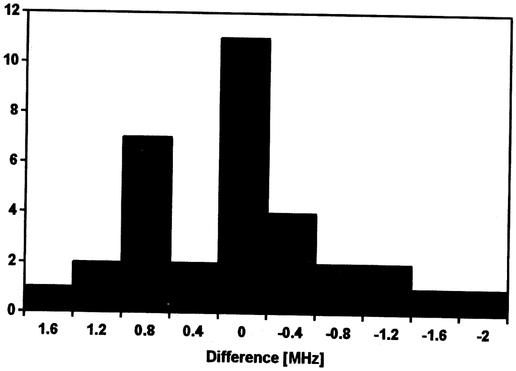

Fig. 3. The histogram of the differences between $f_0F_{2_{\mathrm{ion}}}$ and $f_0F_{2_{\mathrm{sat}}}$ over the second stations.

As far as $M(3000)F_2$ is concerned, we cannot use the same procedure as for f_0F_2. The propagation factor cannot be reproduced by the satellite data. The relation between $M(3000)F_2$ and *hmF* is statistical and depends on the geomagnetic conditions. An analysis made recently, shows that $M(3000)F_2$ depends more on the width of the F layer, than on its height. However, the relation between the propagation factor and the ion density at satellite heights needs to be carefully examined.

5. Monthly median map testing

Only data from the Retarding Potential Analyzer (RPA) on AE-C satellite were used to compile this data subbase. Due to a technical problem we failed to supply data for testing by 31 March 1994 and did this just before the computer experts pre-meeting in Eindhoven. The method of tracing was slightly changed because we had to gather data from different orbits within a given month and hour. So, from the actual height the measured ion density was first traced down to the height of 400 km and then calibrated with the $f_0F_{2_{\mathrm{ion}}}$ taken from several ionosonde stations.

Following the requirements in Sizun and Dick (1944), the measurements over Europe were distributed in 64 subareas, 2.5° by 5° in size. AE-C Unified Abstract Format has a 16 s data sampling, *e.g.* 130 km separation. In this case, in each subarea 2 or 3 values were allocated. Collected in each subarea in a given month and hour UT, data were traced down along the magnetic field lines to the fixed level of 400 km, using scale heights calculated from IRI plasma temperature model. At 400 km level median values were found in each space/time bin when the number of the values exceeds 4. The scatter and the standard deviations were calculated for each bin in order to check the accuracy of the method. To trace further the values to *hmF*, which is unknown, corresponding median f_0F_2 from 5 European ionosondes was taken and compared with the 400 km satellite medians. The five ratios were averaged to obtain a single coefficient which is used then to reduce the satellite data to the maximum F layer height. This procedure actually combines satellite and ground-based ionosonde data for the testing. On the upper panel of table III as a sample, the calculated monthly median f_0F_2 are given for September 1974, 12 UT. The numbers in brackets show the corresponding standard deviation. On the lower part, the hourly averaged standard deviations for September and December are also given.

6. Other applications of satellite data and future activities

As mentioned before, there are two more applications of the satellite data which are foreseen at this stage. First is the testing of the models which give the vertical electron density profiles above the *hmF*. Here, the probe measurements can be used directly in the testing. The second application is in ionospheric storm studies. Although in these studies the solar and geomagnetic indices are generally used, some measured parameters such as electric field, plasma drifts, energetic particle precipitation,

Table III. Monthly median $f_0F_{2_{sat}}$ and their standard deviations (in brackets). Lower panel: standard deviations for September and December, averaged over the whole area.

Long.-Lat.	350-355	355-360	0-5	5-10	10-15	15-20	20-25	25-30
52.5-55.0								
50.0-52.5					6.1 (0.2)	6.3 (0.1)		
47.5-50.0			5.7 (0.1)	5.7 (0.1)		6.0 (0.1)		6.5 (0.1)
45.0-47.5			5.5 (0.1)	5.7 (0.1)		6.2 (0.1)		6.2 (0.1)
42.5-45.0			5.6 (0.1)		6.2 (0.1)		6.1 (0.1)	6.0 (0.1)
40.0-42.5			5.3 (0.1)		6.2 (0.1)		6.0 (0.1)	6.1 (0.1)
37.5-40.0			5.3 (0.1)		6.3 (0.1)		5.9 (0.1)	6.4 (0.1)
35-0-37.5			5.4 (0.1)	6.6 (0.1)			6.7 (0.3)	

Averaged standard deviations

UT	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sept.	.1	.1	.2	.1	.1	.1	.1											
Dec.			.1		.2	.1	.1	.3			.2	.1	.2		.1	.1	.1	.1

plasma and neutral temperatures and composition, etc. give more adequate information on the processes controlling the midlatitude *F* region ionization. These parameters are already involved in a «case study» analysis of several ionospheric storms.

Satellite data could also be used in the proposed follow up Project COST 251 (Draft, 1994). In its WG 2- «Validation of COST 238 models for Earth-space system», plasma measurements will by necessary in evaluation of the «ionospheric corrections for navigational and geodetic satellite systems and interpretation of radio astronomical measurements». The satellite data base can also include navigational, geodetic and radio astronomical data to supply the theoretical studies in this working group. WG 3 – «further development of COST 238 models» pays greater attention to short-term variability which mainly includes ionospheric storm studies, where the satellite data are already in use.

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REFERENCES

DRAFT (1994): Memorandum of understanding for COST Action 251, Annex 2 of Doc. COST238TD(94)005.

KUTIEV, I. and ST. STANKOV (1992): Satellite data for use in the ionospheric mapping, in *Proceedings of PRIME Workshop, Roquetes, Spain, 4-6 May 1992* (Publicaciones del Observatorio del Ebro, Roquetes), *Memoria*, **16**, 100-104.

KUTIEV, I. and ST. STANKOV (1994): Satellite data base for map testing, in *Proceedings of PRIME Workshop, Eindhoven, May 1994*, 197-200.

SIZUN, H. and M. DICK (1994): Standard map-testing procedure for the May 1994 Eindhoven computer experts pre-meeting, Doc. COST238(94)005.

STANISŁAWSKA, I. and G. JUCHNIKOWSKI (1994): Proposal for map testing procedure for El Arenosillo computer experts pre-meeting, 2 August 1994, Warsaw.