EFFECTS OF ELECTROMAGNETIC WAVE PROPAGATION OVER THE CARIBBEAN FROM SATELLITE BROADBAND DATA

© 2025 O.V. Kapustina *, V.I. Gydook

Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Waves Propagation

Russian Academy of Sciences (IZMIRAN), Moscow, Troitsk, Russia

**e-mail:* olkap@izmiran.ru

Received May 29, 2024

Revised July 31, 2024

Accepted for publication September 26, 2024

Abstract. To study electromagnetic signals and search for functional connections with sources of disturbances of natural and anthropogenic origin, digital equivalents of recording observations in the frequency range from 20 Hz to 20 kHz on satellites over the Caribbean are used. Graphs of the dependence of the number of signals per minute on time along the satellite orbit are plotted. Fractionally dispersed whistlers at frequencies below 1 kHz (ELF fdw) ranged from 30 to 100% of the total number of fdw. This estimate coincides with the results of ground-based observations of the ELF atmospherics ("tails") under different conditions. There was an increased frequency of occurrence of fdw and ELF fdw during the action of typhoons in the Pacific Ocean, especially at the stage of depression, and hurricanes in the Atlantic, in the area located on both sides of the meridian passing through the Brazilian anomaly. These results are confirmed by the work of other researchers.

Keywords: *satellite, thunderstorm, cyclone, lightning discharges, electromagnetic waves, atmospherics, whistlers, fractionally dispersed whistlers (fdw)*

DOI: 10.31857/S00167940250205e7

1. INTRODUCTION

Satellite observations are used to study electromagnetic signals and search for functional relationships between these signals and sources of disturbances of natural and anthropogenic nature, as well as for environmental diagnostic capabilities. The following is a description of the satellites whose data were used in this work.

The Intercosmos-24 satellite (Project "Active") was launched on September 28, 1989, into an orbit with the following parameters: perigee height ~500 km, apogee height ~2500 km. The inclination of the orbit to the equatorial plane was 82.6º, the period of revolution around the Earth

− T ~115.8 min. For receiving electromagnetic signals, the ULF/VLF onboard instrument complex ANCH-2ME was used both in a wide band (8 Hz−20 kHz) and on narrow-band filters with central frequencies of 8, 20, 33, 50, 75, 150, 225, 430, 625, 970 Hz; 9 and 15 kHz. A description of the equipment and an overview of some results of the conducted research are published in works [Molchanov et al., 1993; Mikhailova et al., 2000], as well as in the article [Mikhailov, 2015] and in the book [Mikhailov, 2018; Mikhailov, 2020].

The Aureole-3 satellite (Soviet-French project "ARCAD 3") was launched on December 21, 1981, into an orbit with parameters: apogee height 2000 km, perigee height − 410 km. The inclination of the orbit to the equatorial plane was 82.5º. Studies of characteristics of ELF (f = 10−1500 Hz) noise emissions in connection with earthquakes have been published Larkina et al., 1984]. Experimental results were compared with theoretical calculations of characteristics of ELF electromagnetic wave propagation in multi-component ion plasma, a characteristic feature of which is the presence of attenuation at or below the local proton frequency [Rauch et al., 1984].

The Cosmos-1809 satellite (K-1809) was launched into a circular orbit with an apogee of 980 km, perigee of 950 km, inclination of 82.5° on December 18, 1986. In June−July 1992, at a station located in Havana (Cuba), analog VLF information from the satellite was recorded in the area of latitudes 0÷50°N and longitudes 64°÷100°W. Signals from lightning discharges caused by typhoons in the Caribbean region were recorded, which were accompanied by unusually high thunderstorm activity [Sobolev et al., 1998; Sobolev et al., 2006].

Lightning discharge-generated partially-dispersed whistling atmospherics (p. d. WA) with dispersion D ~ 5 and a maximum at a frequency of 2.5 kHz, propagating along a short path from the Earth-ionosphere waveguide to satellite altitudes, were recorded over Indonesia on 29.11.2006 05:00:00 UT (~13 LT) on the Vulkan-Compass-2 satellite [Kuznetsov et al., 2011]. In the works of the Space Research Group at Eötvös University (Budapest, Hungary) [Ferencz et al., 2009], an assumption was made about the possibility of high-order modes propagating in ducts. This assumption was confirmed based on calculations of whistler propagation taking into account the complete wave equation. A magnetized plasma was considered, in which the electron density distribution forms a concentric waveguide around the Hx -component of the magnetic field, where high-order modes can propagate - an "onion structure".

The possibilities of diagnosing near-Earth plasma using satellite observations of VLF-ELF phenomena, in particular proton whistling atmospherics (PWA), are detailed in the book [Likhter et al., 1988]. Observations of proton whistlers began with the first satellite flights carrying equipment for measuring electromagnetic waves in the VLF-ELF range [Gurnett et al., 1965,1966]. The theory of transformation of an electronic wave into an ionic one is given in the work [Budko and Ryabov, 1977]. The theoretical basis for the methodology of determining proton temperature is presented in the work [Budko, 1979], an example of diagnostics is given in the work [Budko et al.,1980], as well as in the work [Mikhailova and Kapustina, 1979]. Analysis of PWA data obtained from the DEMETER satellite is presented in the work [Shklyar et al., 2012] and the report [Shklyar et al., 2012], which also shows early spectrograms of PWA from the works [Gurnett et all, 1965; Gurnett and Shawhan, 1966] and the work [Watanabe and Ondoh, 1976] with a cutoff frequency of PWA ~300 Hz.

In the proposed work, the main focus was directed at investigating the propagation features of electromagnetic signals, namely: partially dispersed whistling atmospherics in the frequency range below 1 kHz (p.d. ELF WA), recorded over the Caribbean basin.

2. DATA PROCESSING METHODOLOGY AND ANALYSIS

The satellite information reception point, headed by Silvio Gonzalez Rodriguez, an employee of the Institute of Geophysics and Astronomy, IGA-Environmental Protection Agency, AEPA (*Institute of Geophysics and Astronomy, IGA. Environment Agency* , *Instituto de Geofísica y Astronomía,* IGA . *Agencia del Medio Ambiente,* AMA), was located in Havana (Cuba): 23°08'12"N, 82°21'32"W. Analog broadband recordings in the frequency range from 20 Hz to 20 kHz were stored on magnetic tape using a "Rostov" tape recorder. Then these recordings were played back on a similar tape recorder and through a sound card using the " *SoundForge* " program in "*.wav" format with a sampling frequency of 48 kHz, were input into the computer and saved on disk. Primary processing consisted of sequential calculation of spectra at an interval of $\Delta t \sim 0.02$ s and construction of dynamic spectra for ~20 s on the PC monitor screen. With such processing, events were recorded in the frequency range above $f = 1/\Delta t = 1/0.02 = 50$ Hz. During the review of these frames, the number of different types of signals per minute was counted, and then graphs of time dependence were constructed.

3. OBSERVATION RESULTS

Figure 1 shows dynamic spectra of different types of signals under study, namely: partially dispersed whistling atmospherics (WA) and p.d. ELF WA (f_{max}< 1 kHz), proton whistling atmospherics (PWA) (*a*), WA (whistlers) (*b*), complex WA with echo WA (*c*), duplet p.d. WA (*d*).

Figure 2 presents graphs of the dependence of the number of signals per minute on time along the orbit of the Intercosmos-24 (IK-24) satellite on turns 5337 (*a*); 5338 (*b*); 5375 (*c*); 5851 (*d*); 9413 (*e*). Table 1 includes the date and time of the beginning of reception and the results of data analysis.

Similar graphs (Fig. 3) were constructed based on data from the Aureole-3 satellite on orbits 3533 (*a*), 3559 (*b*), 9401 (*c*), 9408 (*d*), 9487 (*e*), 9547 (*f*), 14847 (*g*), and Table 2 contains the same information as in Table 1. A map of the Caribbean region is presented in Fig. 4, where squares show the locations of hurricanes in the Atlantic Ocean during satellite passes over them. Circles on the same figure show the locations of typhoons in the Pacific Ocean. The numbers at these points correspond to the designations on the maps from the resource "U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE NORTH ATLANTIC HURRICANE TRACKING CHART".

Fig. 5 shows graphs based on data from the Cosmos-1809 satellite on orbits 6316 (*a*), 16387 (*b*), 16986 (*c*), 21221 (*d*), 21222 (*e*), 23090 (*f*), 27961 (*g*), and Table 3 contains information similar to Tables 1 and 2.

4. DISCUSSION OF RESULTS

During winter nights on the orbits of the IK-24 satellite 5337 (Fig. 2 *a*), 5338 (Fig. 2 *b*) and 5375 (Fig. 2 *c*), a relatively large number of electron whistlers (e.w.) were observed, namely ~50-80 pulses per minute, as well as a series of proton whistlers (PW) at 10-15 signals per minute and up to 5 whistlers per minute. The relative number of proton whistlers is 14-28% of the number of electron whistlers for the entire reception session, decreasing closer to morning. The delay of the ion branch relative to the electron branch is about 2 seconds, which is consistent with the estimation in works [Shklyar et al., 2012; Shklyar et al., 2012]. The frequency of the PW maximum approaches 300 Hz, as in [Watanabe and Ondoh, 1976], but does not coincide with the data presented in [Budko et al., 1980], which were obtained on the Intercosmos-5 satellite, as well as in [Shklyar et al., 2012] based on data from the DEMETER satellite. Proton whistlers were also observed on orbit 9547 of the Aureole-3 satellite during summer nighttime, and their relative number averaged ~7%. On the Cosmos-1809 satellite, from the analyzed ~30 passes, only 17 PW events could be seen on orbit 16387 and one each on orbits 6316 and 27961.

During the day on orbit 5851 of the IK-24 satellite and in the morning on orbit 9413, the number of atmospherics (p.d. WA) is significantly less than at night (by 2-4 times). Signals with a maximum in the spectrum below 1 kHz (p.d. ELF WA), which in ground-based studies are called "tails," on orbit 5851 constituted up to 30% of the total number of discharges, and on orbit 9413 almost 100% (Table 1). This estimate coincides with the results of ground observations under various conditions [Hepburn, 1957; Tepley; 1959; Druzhin et al., 2023]. A large number of atmospherics (~1300 pulses/min) was observed on September 10, 1983, on orbit 9487 of the Aureole-3 satellite in the evening during hurricane "3" at the tropical depression stage, and somewhat fewer (~930 pulses/min) in the morning at 13:29.30 on orbit 9547, when the cyclone transitioned to the tropical storm stage. Increased activity of p.d. atmospherics was also observed on the Cosmos-1809 satellite on March 18, 1990, on orbit 16387 (~650 pulses/min), as well as on March 2, 1991, on orbit 21221 (~850 pulses/min), July 16, 1991, on orbit 23091 (~650 pulses/min) during typhoon "5", June 2, 1992, on orbit 27871 (1770 pulses/min) during typhoon "2" at the tropical depression stage, and July 1, 1992, on orbit 27953 (~680 pulses/min) during typhoon "3" at the tropical depression stage (Table 3 and Fig. 4). The number of "tails" varies widely from a few to 100 percent.

Whistling atmospherics (WA) were observed mainly at night, which corresponds to both theory and published observation data [Helliwell, 1963; Lichter et al., 1988]: on the IK-24 satellite (up to 16 per session), on Aureole-3 (from 20 to 178), and on the Cosmos-1809 satellite from a few to 136.

5. CONCLUSION

1. Broadband recordings of electromagnetic observations in the frequency range from 20 Hz to 20 kHz, made on satellites during flyovers of the Caribbean basin and recorded on a Rostov tape recorder at the Havana reception point, have been digitized at a frequency of 48 kHz.

2. Primary processing of 54 data files recorded on the computer disk showed that in the recordings of the Aureole-3 satellite (7), Intercosmos-24 (5), Cosmos-1809 (42), several different types of signals were observed, the sources of which could be lightning discharges.

3. Partially-dispersed whistling atmospherics (p.d. WA) were visible at any time of the day, with their number being significantly higher at night and especially during the action of tropical cyclones at the depression stage.

4. Proton whistler atmospherics (PWA) were detected at night on the Intercosmos-24 satellite (up to 30%), on the Aureole-3 satellite on orbit 9547 (67%), Cosmos-1809 on orbit 16387 (2.5%). In all cases, the cutoff frequency tended to ~300 Hz.

5. Partially dispersed VLF atmospherics ($f_{max} < 1$ kHz), so-called "tails" were observed during daytime and morning hours on IK-24 satellites (5851 and 9413), Aureole-3 on all orbits, C-1809 on almost all orbits.

6. Whistler atmospherics (whistlers), as well as whistler echoes and doublets of partially dispersed whistler atmospherics were observed on the IK-24 satellite at night in small quantities (up to 6%), on Aureole-3 - in the morning and evening up to 30%, and on C-1809 on almost all orbits.

In the future, it is planned to compare the properties of VLF atmospherics in satellite and ground data.

ACKNOWLEDGEMENTS

The authors thank the operators and Silvio Gonzalez Rodriguez - the head of the receiving center in Havana for the high-quality reception and preservation of satellite data.

FUNDING

The work was carried out within the framework of the State Assignment "Research of the structure and dynamics of the ionosphere and radio wave propagation conditions", State Registration No. 01201356396.

REFERENCES

Budko *N.I.* On the amplitude spectrum of ion-cyclotron whistling atmospherics near the ion gyrofrequency // Geomagnetism and Aeronomy. Vol. 19. No. 2. P. 363−365. 1979.

- *Budko N.I.* Amplitude spectrum of ion-cyclotron whistling atmospherics near the ion gyrofrequency in the upper ionosphere **.** In collection: Low-frequency waves and signals in the Earth's magnetosphere. Collection of articles. executive editor: Ya. I. Likhter; USSR Academy of Sciences. IZMIR. Moscow, 1980. P. 81−87.

Budko *N.I., Ryabov B.S* . On the transformation of an electronic wave into an ionic one in a multicomponent plasma during quasi-longitudinal propagation // Geomagnetism and Aeronomy. Vol. 17. No. 4. P. 751-753. 1977.

Druzhin *G.I., Malkin E.I., Kapustina O.V.* Atmospherics associated with sprites, according to ELF/VLF observations on the Kamchatka Peninsula // Geomagnetism and Aeronomy. Vol. 63. No. 5. P. 657–666. 2023. https://doi.org/10.31857/S001679402260051X .

Kuznetsov *V.D., Bodnar L., Garipov G.K., Danilkin V.A., Degtyar V.G., Dokukin V.S., Korepanov V.E., Mikhailov Yu.M. et al* . Orbital monitoring of the ionosphere and anomalous phenomena // Geomagnetism and Aeronomy. Vol. 51 No. 3. P. 333−345. 2011.

Likhter *Ya.I., Guglielmi A.V., Erukhimov L.M., Mikhailova G.A.* Wave diagnostics of near-Earth plasma. Moscow: Nauka. P. 86–122. 1988.

Mikhailov *Yu.M* . Experimental studies of the generation and propagation of ultra-extra-very low-frequency electromagnetic waves in near-Earth space. In the collection Electromagnetic and plasma processes from the depths of the Sun to the depths of the Earth. Anniversary collection IZMIRAN-75. Moscow, P. 185−200. 2015.

Mikhailov *Yu.M.* Low-frequency electromagnetic waves. Space and ground experiments / LAP LAMBERT Academic Publishing RU. 91 p. 2018.

Mikhailova *G.A., Kapustina O.V.* Determination of proton temperature in the outer ionosphere from amplitude spectra of proton whistling atmospherics (Satellite Intercosmos-5). Geomagnetism and Aeronomy. Vol. 19. No. 3. P. 564. 1979.

- *Sobolev Ya.P., Mikhailov Yu.M.* Registration of VLF phenomena caused by cyclones in the Caribbean region on satellites "Cosmos-1809" and "Intercosmos-24". Fourth All-Russian Open Annual Conference on Modern Problems of Remote Sensing from Space. Space Research Institute RAS. Abstracts. IV.D.17.2006 **.**

Shklyar *D.R., Irzhichek F., Nemets F., Parrot M., Santolik O., Storey L.R.O., Titova E.E., Khum Ya.* Spectral characteristics of ion-cyclotron waves excited by lightning discharges at low latitudes. Observations on the DEMETER satellite and numerical modeling. Plasma Physics in the Solar System, February 6-10, 2012. Space Research Institute RAS, Moscow.

Budko *N. I., Kapustina O. V., Mikhailova G. A* . Determination of the proton temperature in the outer ionosphere from the amplitude spectra of proton whistling atmospherics (Intercosmos-5) // Artificial Satellites. V. 15. N. 3. P. 194-198. 1980.

Gurnett *D.A. Shawhan., S.D., Brice N.H., Smith R.L.* Ion Cyclotron Whistlers // J.Geophys. Res. 70. N. 7. 1665. 1965.

Gurnett *D.A., Shawhan S.D.* Determination of Hydrogen Ion Concentration, Electron Density, and Proton Gyrofrequency from the Dispersion of Proton Whistlers // J.Geoph.Res. 71. N.3. 741. 1966.

Helliwell *R.A.* Whistlers and related ionospheric phenomena. Palo Alto Calif. Stanford Univ.Press. 1965. 350p.

- *Hepburn F.* Atmospheric waveforms with very low-frequency components below 1 kc/s known as slow tails. J. Atm. Terr. Phys. V/10. N5. P. 266–287. 1957.

Larkina *V.I., Migulin V.V., Mogilevsky M.M., Molchanov O.A., Galperin Yu.I., Jorjio N.V., Gokhberg M.B., Lefeuvre F.* Earthquake effects in the ionosphere according to Intercosmos 19 and Aureol 3 satellite data // Results of THE ARCAD 3 PROJECT and of the recent programmes in magnetospheric and ionospheric physics Toulouse 84 CNES CEPADUES-EDITIONS. France, Toulouse. P. 685–699. 1984.

Mikhailov *Yu.* Low frequency electromagnetic waves. Space and ground experiments. Second edition / LAP LAMBERT Academic Publishing RU. 91 p. 2020.

Mikhailova *G. A., Mikhailov Yu. M., Kapustina O. V.* ULF-VLF electric fields in the external ionosphere over powerful typhoons in Pacific Ocean // International Journal of Geomagnetism and Aeronomy. V. 2. No. 2. P. 153-158. 2000.

Molchanov *O.A., Mazhaeva O.A., Golyavin A.N., Hayakawa M.* Observation by the Intercosmos-24 satellite of ELF/VLF electromagnetic emission associated with earthquakes // Annales Geophysicae . V. 11. P. 431-440. 1993.

Rauch *J.L., Boudko N.I., Mikhailova G.A., Kapustina O.V* . Attenuation bands and cut off frequencies for ELF electromagnetic waves // Results of the ARCAD 3 PROJECT and of recent programmes in magnetosphere and ionosphere physics. Toulouse 1984. Toulouse: Cepadues-editions. P. 465-483. 1985.

Shklyar, *D. R., Storey L. R. O., Chum J., Jiricek F., Nemec F., Parrot M., Santolik O., and Titova E. E.* Spectral features of lightning-induced ion cyclotron waves at low latitudes: DEMETER observations and simulation, J. Geophys. Res. 117. A12206. 2012. https://doi.org/10.1029/2012JA018016

Sobolev *Ya.P., Mikhailov Yu.M* . Typhoons in Caribbean region registered on satellites in VLF band // Geomagnetic field and ionosphere variations. Proc. of Second INDO-RUSSIAN Symposium on Nature and Variations of the Geomagnetic Field. Moscow, 28-31 July 1997 / Ed. Kanonidi Kh., Ruzhin Yu.Ya: IZMIRAN. P. 230-231. 1998.

Tepley L.R. A comparison of sferics as observed in the VLF and ELF bands // J. Geophys. Research. V.64. N12. P. 2315-2329. 1959.

Table 1. Characteristics of VLF-ELF events observed on the IK-24 satellite

Orbit	Date	Start of registration Moscow time	Local time (LT)	Total number of events and relative to p.d. WA*			
				p.d. WA	p.d. VLF	PWA	WA
5337	01.12.1990	10:56:50	~03 (night)	258	72	(28%)	16 (6%)
5338	01.12.1990	12:52:05	~05 (night)	491	86	(~18%)	16 (3%)
5375	04.12.1990	12:15:20	~04 (night)	400	54(~14%)	54(~14%)	2
5851	01.01.1991	19:45:17	~12 (day)	113	33 (37%)	-	-
9413	24.10.1991	16:40	~09 (morning)	90	88 (79%)	-	-

*Note** : The table shows the total number of detected events of each type during the satellite's passage within the visibility zone of the receiving station. In parentheses, the percentage shows the number of corresponding events relative to the number of partially dispersed whistler atmospherics (p.d. WA) in this interval.

Table 2. Characteristics of VLF-ELF events observed on the Aureole-3 satellite

Orbit	Date	Registration start, Moscow time	Local time (LT)	Total number of events and relative to n.f. SA*			
				n.f. SA	n.f. ELF	SSA	SA
3533	16.06.1982	16:33:30	~09 (morning)	168	49 (29)	16	(10%)
3559	18.06.1982	15:51:15 "2"	~08 (morning)	105	26 (25)	28(~28%)	28(~28%)
9401	03.09.1983	12:44:55	~05 (morning)	204	2 (1)	55	(27%)
9408	04.09.1983	02:06:55	~19 (evening)	446	209 (47)	21	(~5%)
9487	10.09.1983	01:20:15 "3 *a* "	~16 (evening)	1304	584 (45)	2	2
9547	14.09.1983	13:29:30 "3 *b* "	~05 (morning)	928	?	67 (~7)	178 (~20%)
14847	18.10.1984	14:15:45 "11"	~06 (morning)	155	29 (20)	3	47 (~30%)

Note :

1. See Note* to Table 1.
2. The marking with the number " " in the "Registration start" column indicates the presence of a hurricane in the Atlantic Ocean during the satellite pass.
3. Coordinates and cyclone stage:

"2" - 27 °N, 85 °W STD no name 1982

"3 *a* " - 30 °N, 65 °W TD Shantal 1983

"3 *b* " - 40 °N, 50 °W TS Shantal

"11" - 44 °N, 57 °W TS Josefine 1984

.

Table 3. Characteristics of VLF-ELF events observed on the Cosmos-1809 satellite

Orbit	Date	Registration start,	LT	Total number of events and relative to ps*			
				ps SA	ps ELF,(%)	PSA	SA
6295	17.03.1988	00:30:10		46	13 (28)	2	2

6316	19.03.1988	12:20:20		72	15 (21)	1	8
6330	20.03.1988	12:39:10		49	11 (22)	8	8
6336	20.03.1988	23:42:17		3	-	-	3
6344	21.03.1988	12:56:25		1	-	-	6357
6357	22.03.1988	11:32:15		46	?	5	5
11018	22.02.1989	11:49:00		8	4	-	-
16381	17.03.1990	14:24:16		43	40 (93)	-	-
16387	18.03.1990	01:26:35		665	220 (33)	17(2.5)	4
16442	22.03.1990	10:57:50		61	40 (55)	4	4
16986	30.04.1990	10:05:49		33	11 (33)	17	17
16992	30.04.1990	21:08:22		321	40(12)	122(38)	122(38)
21221	02.03.1991			849	145 (17)	16	16
21222	02.03.1991			405	40 (10)	29	29
21227	03.03.1991	06:43		290	21 (7)	59	59
21228	03.03.1991	08:27:49		32	18 (56)	-	-
21332	10.03.1991			59	13 (22)	7	7
21345	11.03.1991			44	22 (50)	44	44
21351	12.03.1991			187	49 (26)	52	52
21352	12.03.1991			32	8 (25)	17	17
23051	13.07.1991	10:24 UT	06	7	5	-	-
23090	16.07.1991	07:51 UT "5"	03	100	100	6	6
23091	16.07.1991	05:36:55 cub "5"	05	638	?	136(21)	136(21)
27871	02.06.1992	04:22 UT "2"	00	1771	1771	-	-
27953	26.06.1992	"3"		681	26 (4)	75	75
27960	02.07.1992	10:12:53 "4"		16	8	64	64
27961	02.07.1992	11:57:30 "4"		167	46 (28)	1	5

Note :

1. See Note* to Table 1.
2. The mark with the number "   " in the "Registration Start" column indicates the presence of a typhoon in the Northeast Pacific during the satellite pass.
3. Coordinates and cyclone stage according to map data:

"5" 10-12 °N, 117 °W 1991

"2" 17 °N, 112 °W TD 1992

"3" 11 °N, 95 °W TD 1992

"4" 12 °N, 97 °W TD 1992

3. Unfortunately, not all orbits have explanations about what time is indicated, as we are working with archival data and we do not have an observation log. However, we are interested in statistical characteristics, and the absence of exact time is not critical.

Figure captions

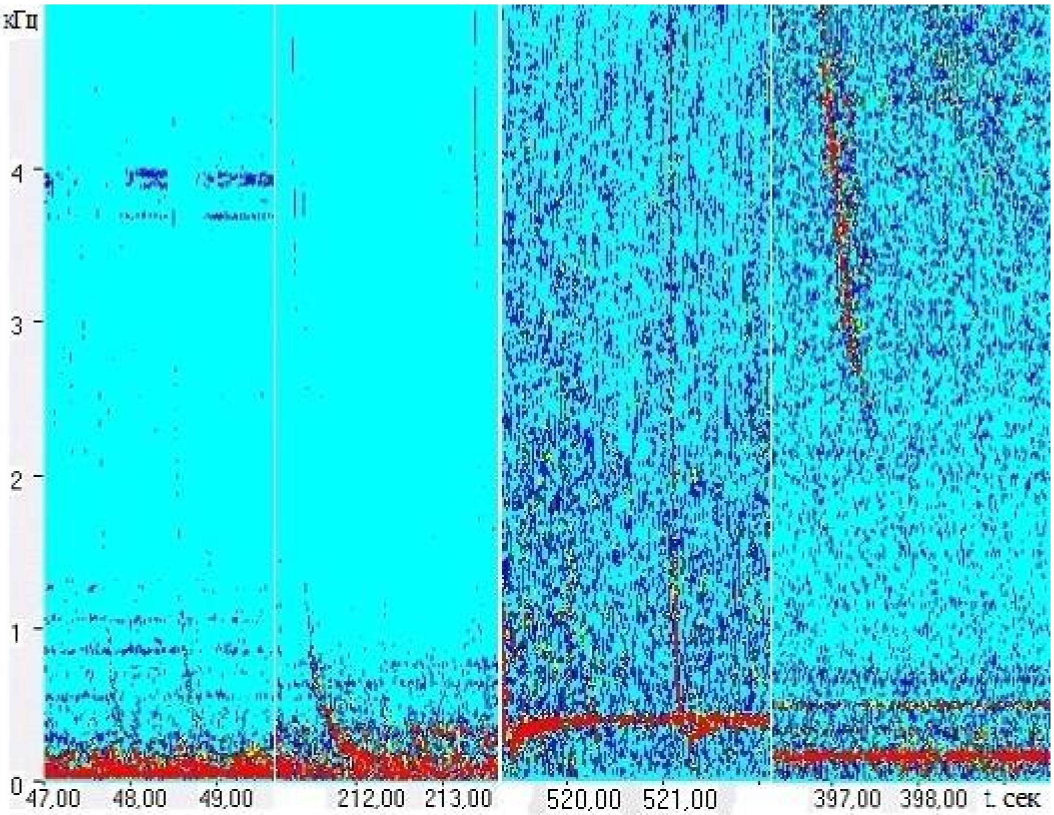
Fig. 1 . Examples of dynamic spectra: (*a* , *b*) − f.d. SA + f.d. ELF SA; (*c*) – PSA; (*d*) − SA.

Fig. 2. Time dependence of the number of signals per minute, n(t) along the orbit of the IK-24 satellite on orbits: (*a*) – 5337; (*b*) – 5338; (*c*) – 5375; (*d*) – 5851; (*e*) − 9413. Solid thick line and black dots – f.d. SA, thin line and crosses – f.d. ELF SA, dashed line and hollow circles – PSA, dotted line and hollow squares – SA of different types.

Fig. 3. Same as in Fig. 2 for the Aureole-3 satellite on orbits: (*a*) − 3533; (*b*) − 3559; (*c*) − 9401; (*d*) − 9408, (*e*) − 9487, (*f*) − 9547, (*g*) − 14847.

Fig. 4. In the right part of the figure, squares show hurricanes in the Atlantic Ocean during the Aureole-3 satellite pass. The inscription at the top right shows coordinates and stage of cyclones associated with orbits marked with numbers in Table 2. In the left part, circles indicate typhoons in the Pacific Ocean during the Cosmos-1809 satellite pass. The inscription at the top left shows coordinates and stage of cyclones associated with orbits marked with numbers in Table 3.

Fig. 5. The same as in Fig.2 for the Kosmos-1809 satellite on orbits: (*a*) − 6316; (*b*) − 16387; (*c*) − 16986; (*d*) − 21221; (*e*) − 21222; (*f*) − 23090, (*g*) − 27961.


f, кГц
4
3
2
1
0
47,00
48,00
49,00
212,00
213,00
520,00
521,00
397,00
398,00
t, сек

a *b* *c* *d*

Fig. 1.

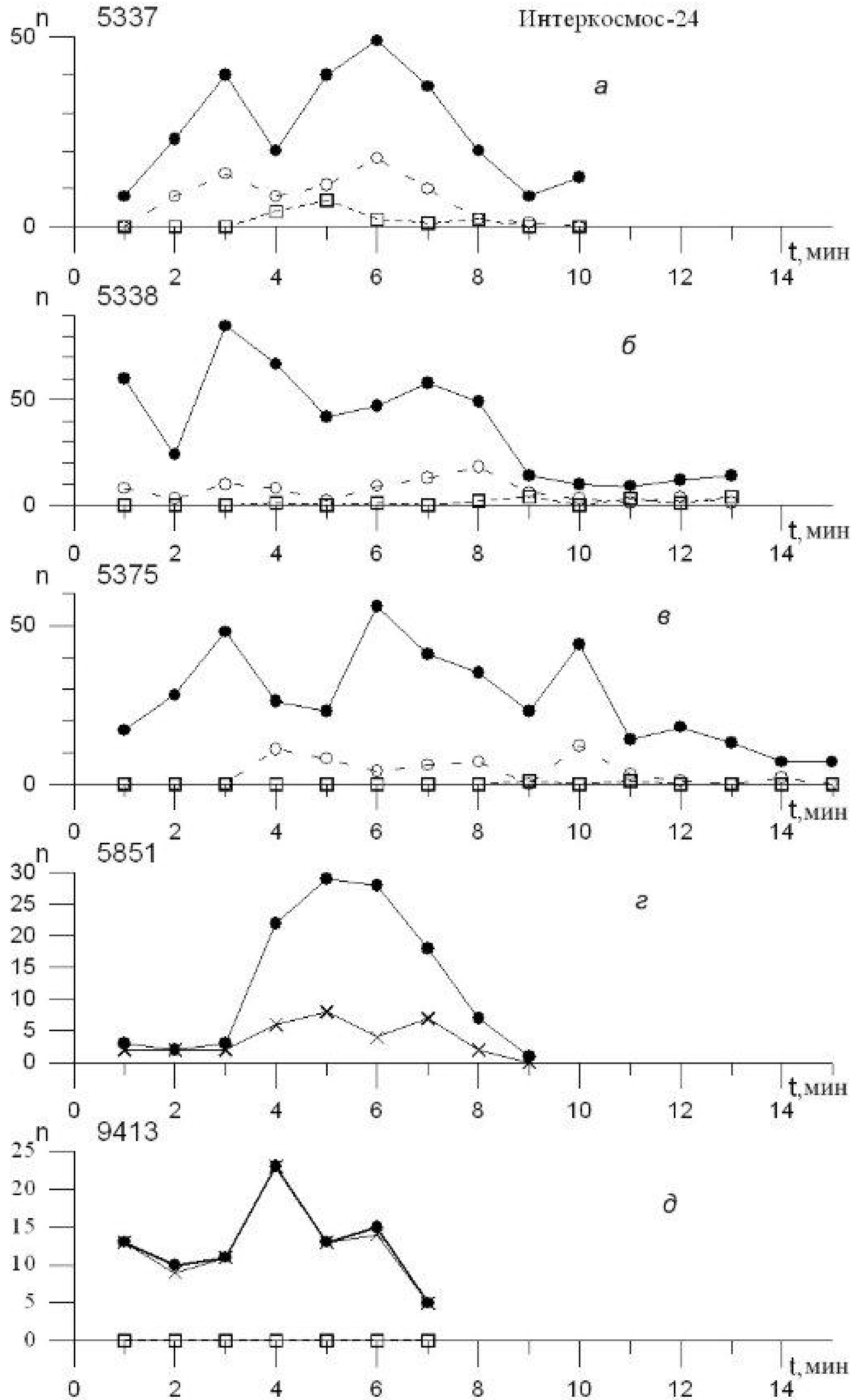
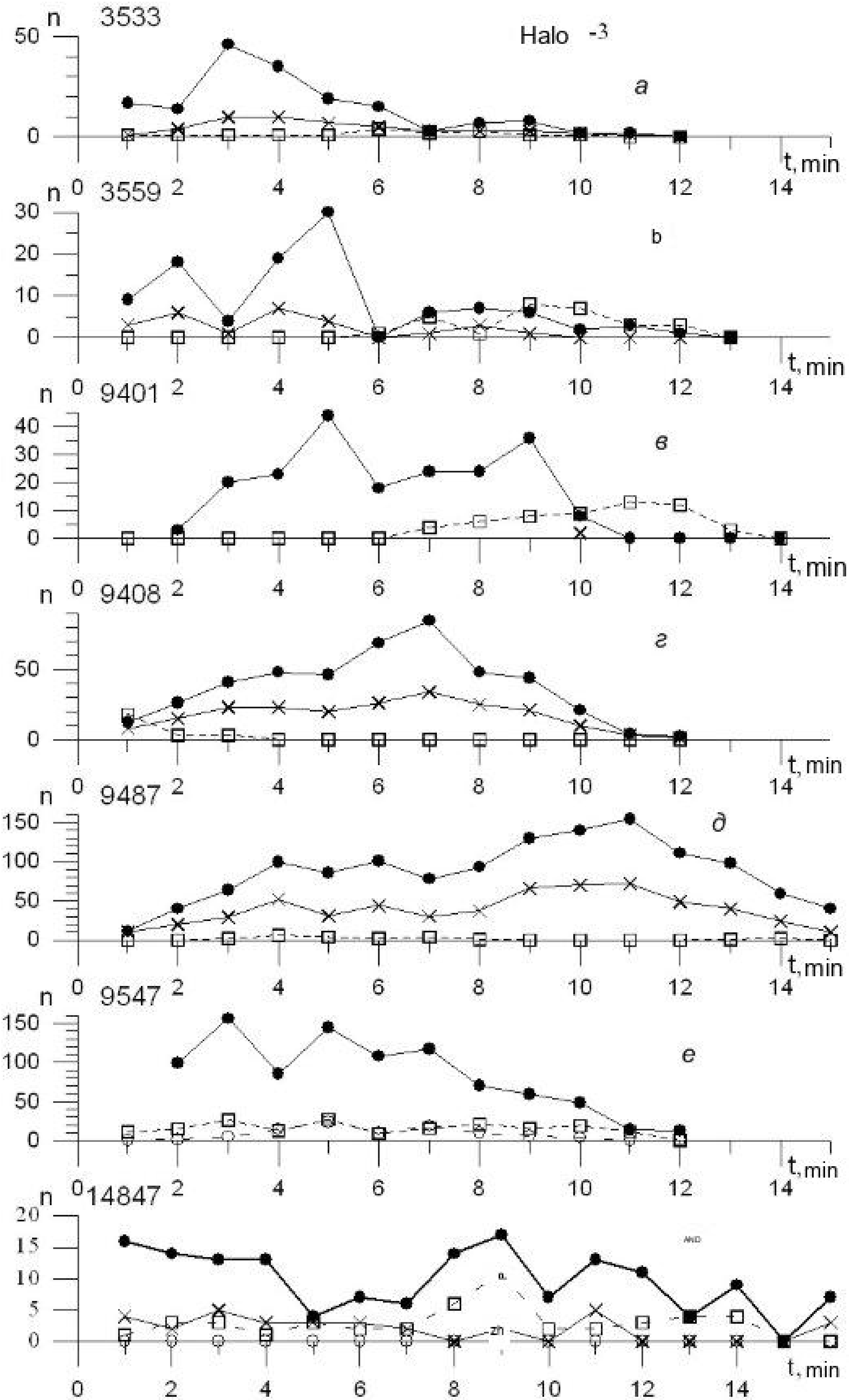
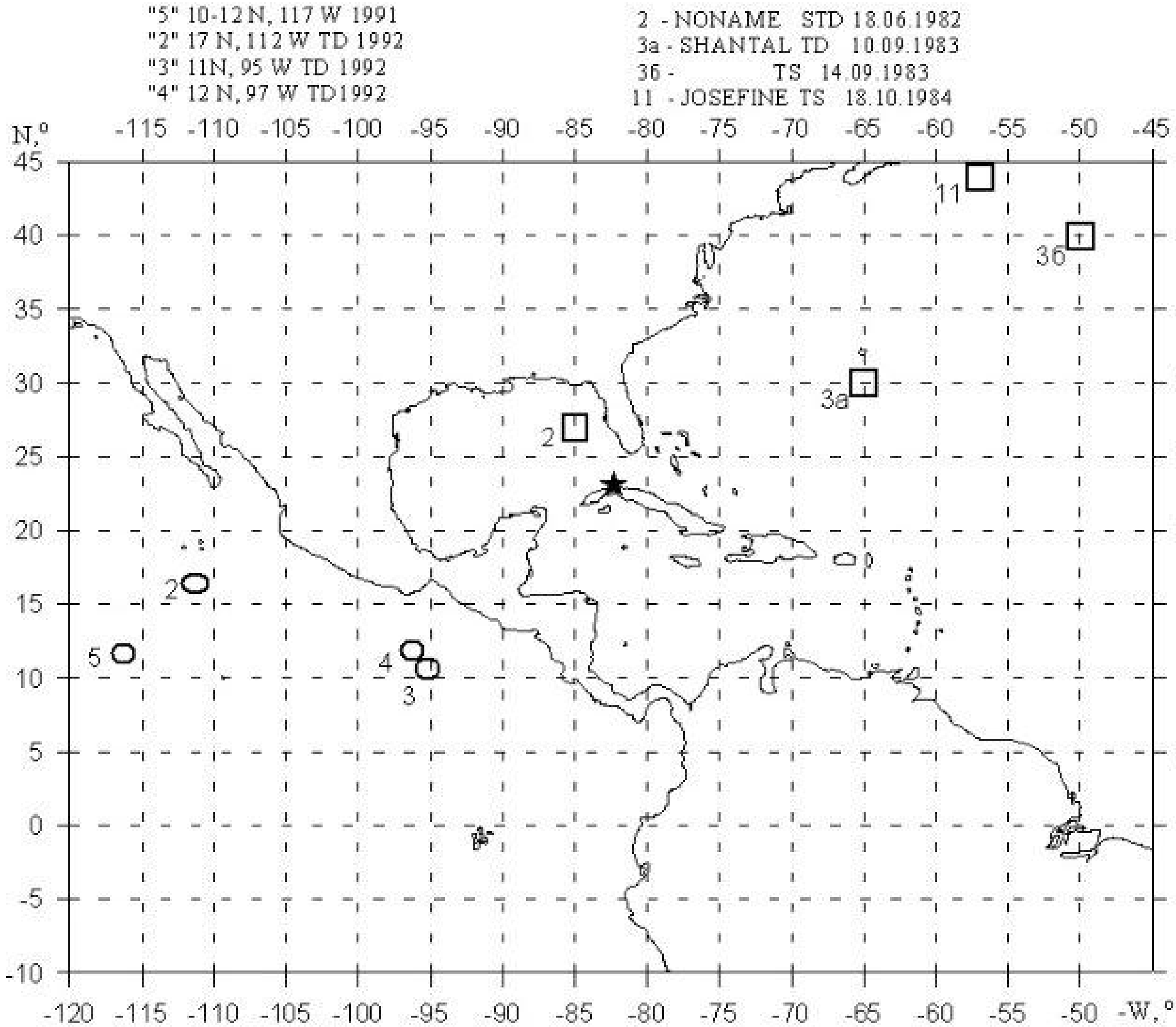

Интеркосмос-24
5337
а
5338
б
5375
в
5851
г
9413
д
n
t, мин
0
2
4
6
8
10
12
14
50
25
30
20
15
10
5

Fig. 2.



Halo -3
3533
a
3559
b
9401
в
9408
г
9487
д
9547
е
14847
n
t, min

Fig. 3.



"5" 10-12 N, 117 W 1991
"2" 17 N, 112 W TD 1992
"3" 11N, 95 W TD 1992
"4" 12 N, 97 W TD1992
2 - NONAME STD 18.06.1982
3a - SHANTAL TD 10.09.1983
36 - TS 14.09.1983
11 - JOSEFINE TS 18.10.1984
N,°
-W,°

Fig. 4.

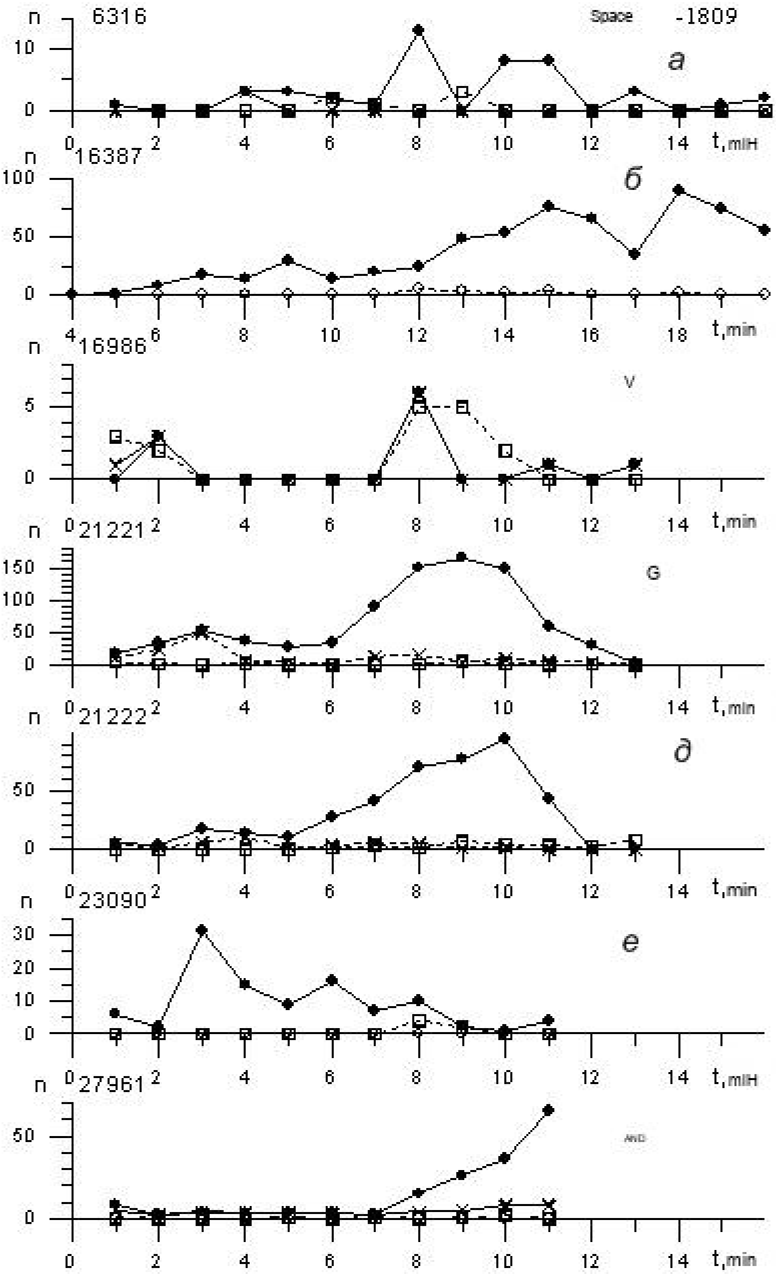

6316
Space
-1809
а
16387
б
16986
V
21221
G
21222
д
23090
е
27961
AND
n
t,min
t,mин

Fig. 5.