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A Study of the D-Region Winter Anomaly in Western Europe, 1975/76

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Abstract. A campaign of integrated groundbased, balloon- and rocketborne experiments for the study of the D-region winter anomaly was performed in winter 1975/76 in Western Europe. Twenty-three balloons and 47 rockets were successfully launched from the range El Arenosillo in southern Spain. Coordinated ground observations took place in Spain, France, Great Britain, Italy, Austria, and Germany. The scientific objectives of the campaign, its structure, performance and geophysical background are described in the present introductory paper. Individual experiments are described in the subsequent papers.

Key words: Winter anomaly – D-region – Mesosphere – Lower thermosphere – GBR campaign.

The dynamical, photochemical and energetic behaviour of the mesosphere and lower thermosphere is still a largely unknown domain. This is on the one hand due to the complexity of processes controlling the atmosphere and ionosphere in this altitude regime (50–140 km). On the other hand this region is not readily accessible to remote measurements, either ground based or satellite borne, and therefore our knowledge is mostly based on a rather limited number of rocket experiments. To improve this situation it is not sufficient to launch a few more rockets. The above mentioned complexity makes it mandatory to concentrate a large number of rockets in one campaign and thus measure as many atmospheric parameters as possible at a time (or at nearly the same time). Complementary and coordinated ground based and satellite measurements are of course very important. Balloon borne experiments in the stratosphere help to define the conditions at the lower boundary of the altitude regime considered.

To understand a complex system like the atmosphere, it is sometimes very helpful to study it under disturbed conditions rather than in the normal state. A suitable disturbance in the altitude region of interest is the winter-anomaly

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of the electron density in the ionospheric D-region. This anomaly is believed to reflect—at least under certain conditions—a profound disturbance not only in the ionosphere but also in the neutral atmosphere.

Enhanced electron densities in the D-region may be caused by- or associated with the following events:

Solar flares (see for instance Mitra, 1975; Beynon and Williams, 1976).

Magnetic storms and storm after effects (for a collection of references see Denny and Bowhill, 1973; Sechrist, 1975; Paulikas, 1975. Recent measurements are reported for instance by Wratt, 1976).

Meteorological events (This was first suggested by Dieminger, 1952. For detailed references of more recent work see Denny and Bowhill, 1973; Sechrist, 1975).

The "meteorological" type of electron enhancement is considered to be the most promising one for a study of atmospheric behaviour. It is therefore mandatory for such study to select events of this type and to exclude the other disturbances as far as possible.

Several different explanations for this winter anomaly have been suggested:

Vertical and/or horizontal transport of atmospheric constituents with low ionization potential as NO (Gregory, 1965; Geisler and Dickinson, 1968; Christie, 1970; Manson, 1971; Geller et al., 1976).

Changes in the ion chemistry (water cluster ion chemistry) as caused by transport of trace constituents like O and H_2O (Newell et al., 1966; Newell, 1968; Sechrist, 1970; Geller and Sechrist, 1971; Sechrist, 1972).

Changes in the neutral and ion chemistry by temperature variations (Sechrist, 1967; this paper was discussed by Geisler and Dickinson, 1968; Reid, 1970).

To take these possibilities into account, it is not sufficient to measure electron and ion densities and composition only (to define the status of the ionosphere), but also the relevant neutral atmosphere parameters have to be determined. This pertains especially to the neutral gas density and composition with emphasis on specific minor constituents as O, NO etc., the temperature profile, and transport processes as winds and turbulence. Obviously the study of the D-region winter anomaly requires a set of atmospheric and ionospheric measurements as complete as possible with respect to structure, dynamics, and chemistry of the atmosphere.

A number of respective groundbased, balloon and rocket borne experiments was therefore integrated in one GBR campaign, which was performed in Western Europe from December 1975 to February 1976. Table 1 shows a list of the participating scientific groups (in an alphabetic order of the respective institutions) and of the experiments performed by them. A total of 22 experimenters groups took part in the campaign and performed 38 different types of measurements. Some of the experiments were duplicate and thus allow for a check on the reliability of the instruments. Also were a number of atmospheric parameters determined by two or more different techniques. This applies especially to the winds, the neutral composition, density and temperature, and the electron density. Thus a valuable intercomparison is possible. The rockets and balloons

Table 1

Institution	Experiment	Atmospheric parameter
Rocket and balloon experiments		
1. DFVLR, Köln (Becker, Papanikas)	Pitot tube, ion gauge	Neutral gas density, temperature
2. DFVLR, Oberpfaffenhofen (Beran)	NO photometer	NO
3. DFVLR, Oberpfaffenhofen (Drescher)	5577 Å photometer	Atomic oxygen
4. INTA, Madrid (Satrustegui, Cisneros)	Walmet sonde Radiosonde balloon wind Balloon ozone sonde	Wind, temperature temperature, pressure, ozone
5. IPW, Freiburg (Spenner)	Retarding potential analyzer	Electron density, temperature
6. IPW, Freiburg (Unger)	Radio propagation	Electron density
7. MPAE, Lindau (Widdel, Rose, Borchers)	Chaff Guard ring sonde Gerdien condenser Thermotron	Wind, density Electron density Ion mobility, conductivity Density
8. MPAE, Lindau (Loidl, Schwentek)	Ly-α photometers X-ray spectrometer	O_2, neutral gas density, pressure, temperature Solar emission
9. MPK, Heidelberg (Arnold, Krankowsky)	Cryo pumped mass spectrometer	Ion and neutral gas density and composition
10. NDRE, Kjeller (Thrane)	Ly-α photometer Particle detectors	O_2, neutral gas density, pressure and temperature Energetic electrons
11. TU Graz, (M. Friedrich, Riedler)	Faraday rotation Gerdien condenser Balloon	Electron density Ion density Wind, pressure, temperature
12. Universität Bonn (V. Friedrich, Offermann)	Cryo mass spectrometer	Neutral gas composition
13. Universität München (Bangert, Bolle)	Infrared radiometer	$O_2(^1\Delta)$
14. University College, London (Rees)	Lithium vapour trail, ground photometers at Mazagon (near the rocket range) and San Fernando (near Cadiz)	Winds, turbulence
Ground based experiments		
15. CNET, Issy les Moulineaux (Testud, Bernard)	Incoherent Scatter Radar (St. Santin, Nançay, Mende, St. Cassien)	E-region wind and temperature
16. CNET, Issy les Moulineaux (Glass, Fellous)	Meteor wind radars (Garchy, Montpazier)	D-region winds
17. CNR, Bologna (Verniani, Formigini)	Meteor wind radar (Bologna)	D-region winds

Table 1 (continued)

Institution	Experiment	Atmospheric parameter
18. INTA, Madrid (Satrustegui, Cisneros)	Ozone sonde (El Arenosillo)	Total ozone
19. MPAE, Lindau (Rose, Widdel, Lauche, Lange-Hesse)	Ionosonde (El Arenosillo) Magnetometers (El Arenosillo) Airglow photometer (El Arenosillo) A3 absorption (El Arenosillo, Balerma, Tortosa, transmitter at Aranjuez)	Electron density Magnetic activity Atomic oxygen Electron density
20. MPAE, Lindau (Schwentek)	A1 and A3 absorption (Lindau, transmitter for A3 at Norddeich)	Electron density
21. Ulster College, Jordanstown (Smith)	5577 Å Doppler width (Jordanstown)	Temperature (90–100 km)
22. TU Graz (M. Friedrich, Riedler)	A3 absorption (Graz, transmitter near Coburg)	Electron density
23. Universität Bonn (Volland)	VLF propagation (Stockert)	
24. University of Sheffield (Muller)	Meteor wind radar (Sheffield)	D-region winds

were launched from the Spanish rocket range El Arenosillo (37°6′ N; 6°44′ W). Groundbased stations were operated in Spain, France, Italy, Great Britain, Austria and Germany. Their geographical distribution is shown in Figure 1.

A number of experiments listed in Table 1 was used to forecast launch opportunities, to define the launch criteria, or to verify that these criteria had been fulfilled. The A3 absorption measurement on the range was used for launch decisions. A noon absorption larger than 50 dB (measured between 11.20 UT and 12.20 UT) was assumed to indicate an anomalous winter day. This corresponds roughly to >47 dB in the afternoon (14.00 UT–15.00 UT). A noon absorption smaller than 25 dB was taken to define a low absorption day. These measurements were supplemented by the data obtained at Balerma. The A3 absorption was monitored continuously. Therefore also the development in time of the absorption was used for launch decisions. Further information was contributed by the ionosonde on the range. A second important launch criterion was defined by the ground photometers for tracking the day light lithium vapour trails: Very clear sky was needed around the range for the optical site at Mazagon (37°8′ N; 6°49′ W), a second optical site at San Fernando (36°28′ N; 6°44′ W) near Cadiz, and in the direction of the rocket trajectory. Happily this condition was fulfilled during most part of January, 1976.

As mentioned above the major experiments should not be launched during solar flares, magnetic storms, or storm after activity. To achieve this Ursigrams and magnetic forecasts were obtained on a daily basis from the Observatoire de Paris at Meudon. These data were supplemented by magnetometers on the

Fig. 1. Geographical distribution of ground based stations

range. Solar x-ray data from the SMS satellite and flare forecasts were obtained every day from the Space Environment Center, NOAA Boulder, USA.

As there is a correlation between winter anomaly events and stratospheric warmings (for a review see Bowhill, 1969; Patel and Kotadia, 1972), stratospheric weather was monitored during the campaign. Daily STRATALERT messages of the WMO and respective forecasts were received from the Institut für Meteorologie, Freie Universität, Berlin. During high activity phases of the campaign, there were – in addition to the daily routine messages – person to person contacts with the three stations at Meudon, Boulder, and Berlin for detailed discussion of the geophysical situation. Finally, a number of rocket experiments (x-ray-spectrometers, particle detectors) were used to verify that the launch criteria concerning flares and magnetic disturbances had been fulfilled.

The rocket and balloon experiments listed in Table 1 were allocated to 7 different types of rocket payloads and 2 types of balloon payloads. Table 2 shows this allocation together with the number of successful rocket or balloon flights. (Only experiments which had at least one successful flight, are contained in Table 2.) As is seen from this table, there was a large number of launches of the small payloads BI and BVII, and only 2–3 launches of the medium or heavily equipped payloads BII, BIII, BIV, and BV. Also only three vapour trails were available. Therefore the rockets were divided into three groups:

Table 2. Payload allocation of experiments

Payload designation	Vehicle	Number of successful launches	Typical apogee	Atmospheric parameter	Technique	Experimenter
B I	Skua 2, 3	15	95 km	Wind, density	Chaff	Widdel, Rose, MPAE, Lindau
				Electron density	Guardring sonde	Widdel, Rose, MPAE, Lindau
B II	Skylark 3	2	117 km	Neutral gas density, temperature	pitot tube, ion gauge	Becker, Papanikas, DFVLR, Köln
				Neutral composition	Mass spectrometer with shock-freezing cryo ion source	V. Friedrich, Offermann, Univ. Bonn
				NO	Filter photometer	Beran, DFVLR, Oberpfaffenhofen
				$O_2(^1\Delta)$	Infrared filter photometer	Bolle, Bangert, Univ. München
				Ly-α	Ionization chambers	Loidl, Schwentek, MPAE, Lindau
				X-rays	0, 1–60 Å spectrometer	Loidl, Schwentek, MPAE, Lindau
				Electron density, temperature	Retarding potential analyzer	Spenner, IPW, Freiburg
B III	Petrel	3	85 km	Ion mobility-conductivity, gas density	Gerdien-Condenser Thermotron	Widdel, Rose, Borchers, MPAE, Lindau
B IV	Nike-Apache	2	130 km	Ion composition and density (positive and negative), neutral gas composition and density	Cryopumped mass spectrometer	Krankowsky, Arnold, MPK, Heidelberg
				Electron density	Radio propagation	Unger, IPW, Freiburg
				Electron density	Faraday rotation	M. Friedrich, Riedler, TU Graz
				Ion density	Gerdien condenser	M. Friedrich, Riedler, TU Graz
				Ly-α	Ionization chambers	Thrane, NDRE, Kjeller
				Energetic electrons	Solid state detector	Thrane, NDRE, Kjeller
B V	Skua 4	3	105 km	Wind, neutral gas density	chaff	Widdel, Rose, MPAE, Lindau
				atomic oxygen	5577 Å filter photometer	Drescher, DFVLR, Oberpfaffenhofen
B VI	Petrel	3	130 km	Wind, turbulence	Li-trail	Rees, Univ. College London
B VII	Super-loki	19	65 km	Wind, temperature	walmet sonde	Satrustegui, Cisneros, INTA, Madrid
A II	Balloon	4	35 km	Wind, pressure, temperature		M. Friedrich, Riedler, TU Graz
R	Radio-Balloon	19(+1)	30 km	Wind, temperature, pressure, ozone		Satrustegui, Cisneros, INTA, Madrid

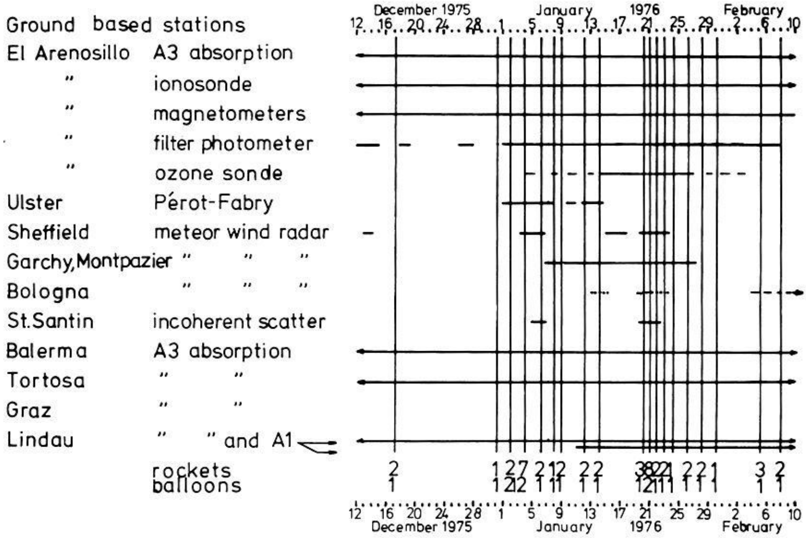

Fig. 2. Periods and dates of ground based, balloon and rocket measurements. Numbers of launches per day are given in the bottom

groups 1 and 2 were called "salvoes" because their rockets were launched on two days with strong winter anomaly within a timespan as short as possible. The first salvo contained one round of each type of rocket and balloon payloads, amounting to 7 rocket and 2 balloon launches. The second salvo also contained one round of each payload. In addition it contained the spare vapour trail and a second AII balloon payload. (This payload AII and a radio balloon payload R were flown on the same balloon). The remaining third group of rockets mainly consisted of the small payloads BI and BVII. Most of them were launched in pairs BI–BVII because this yielded a nearly continuous wind profile from 20 km–95 km. These pairs were normally accompanied by a radio balloon (payload R) which extended the wind and temperature profile down to the ground. The launches of these pairs plus balloon were about evenly distributed over the month of January and begin of February, 1976. They sensed days of high as well as of low winter anomaly activity, thus providing a data background for the two salvoes (see Fig. 2). Table 3 shows the launch times and dates of all successful rocket and balloon flights together with the apogee or maximum flight altitude, and the nominal azimuth of launcher setting. The A3 absorption (noon values) of the respective days are also given. It is seen from this table that a total of 47 rockets and 23 balloons were successfully launched during this campaign.

Table 3 shows that the rockets of the two salvoes (Jan. 4 and Jan. 21, 1976) were launched in a specific sequence (BIII, IV, II, I, VI, VII, V). This sequence and the time intervals between the respective launches resulted from a number of scientific and operational requirements:

1. The central part of the salvo should be launched in the early afternoon.
2. The rockets should follow one another as quickly as possible.

Table 3. Successful rocket and balloon flights

Date	Time	Payload/vehicle	Apogee (approx)	Nominal Azimuth	A3-Absorption (noon)
17. 12. 1975	11:04:00 GMT	B I/Skua 3	93 km	206°	25 dB
	12:00:00 GMT	B VII/Super-Loki	69 km	210°	
	13:35:00 GMT	R /Radio-Balloon	110 km		
31. 12. 1975	10:46:00 GMT	B VII/Super-Loki	66 km	200°	45 dB
	12:39:00 GMT	R /Radio-Balloon	33 km		
2. 1. 1976	11:14:00 GMT	A II/Balloon	15 km		51 dB
	14:59:00 GMT	B I/Skua 3	95 km	200°	
	15:59:00 GMT	B VII/Super-Loki	62 km	200°	
	17:42:00 GMT	R /Radio-Balloon	17 km		
3. 1. 1976	13:49:00 GMT	R /Radio-Balloon	12 km		46 dB
4. 1. 1976	13:40:00 GMT	B III/Petrel	86 km	195°	56 dB
	14:30:00 GMT	B IV/Nike-Apache	131 km	200°	
	15:30:03 GMT	B II/Skylark 3	117 km	200°	
	15:47:00 GMT	B I/Skua 3	103 km	197°	
	16:00:00 GMT	B VI/Petrel	132 km	202°	
	16:52:00 GMT	B VII/Super-Loki	57 km	197°	
	17:06:00 GMT	A II/Balloon	35 km		
	19:35:00 GMT	R /Radio-Balloon	33 km		
	22:58:00 GMT	B V/Skua 4	96 km	200°	
6. 1. 1976	15:46:00 GMT	B I/Skua 2	97 km	200°	50 dB
	16:40:00 GMT	B VII/Super-Loki	70 km	200°	
	18:42:00 GMT	R /Radio-Balloon	32 km		
8. 1. 1976	12:00:00 GMT	B VII/Super-Loki	70 km	200°	60 dB
	13:13:00 GMT	R /Radio-Balloon	31 km		
9. 1. 1976	15:53:00 GMT	B VII/Super-Loki	70 km	200°	25 dB
	16:11:00 GMT	B I/Skua 2	99 km	220°	
	18:47:00 GMT	R /Radio-Balloon	31 km		
12. 1. 1976	15:50:00 GMT	B VII/Super-Loki	56 km	200°	30 dB
	16:20:00 GMT	B I/Skua 3	92 km	220°	
	17:47:00 GMT	R /Radio-Balloon	31 km		
14. 1. 1976	15:50:00 GMT	B VII/Super-Loki	70 km	200°	61 dB
	16:10:00 GMT	B I/Skua 3	91 km	230°	
	17:53:00 GMT	R /Radio-Balloon	24 km		
20. 1. 1976	13:40:00 GMT	B III/Petrel	59 km	195°	35 dB
	15:50:00 GMT	B VII/Super-Loki	63 km	190°	
	16:10:00 GMT	B I/Skua 3	93 km	225°	
	17:38:00 GMT	R /Radio-Balloon	32 km		
21. 1. 1976	11:48:30 GMT	A II/Balloon	4 km		67 dB
	13:40:00 GMT	B III/Petrel	82 km	195°	
	14:32:09 GMT	B IV/Nike-Apache	129 km	200°	
	15:31:00 GMT	B II/Skylark 3	117 km	200°	
	15:40:00 GMT	B I/Skua 2	98 km	197°	
	15:55:00 GMT	B VI/Petrel	134 km	202°	
	16:40:00 GMT	B VII/Super-Loki	70 km	197°	
	18:17:00 GMT	B VI/Petrel	125 km	202°	
	18:57:00 GMT	A II/R/Balloon	29 km		
	22:30:00 GMT	B V/Skua 4	109 km	235°	

Table 3 (continued)

Date	Time	Payload/vehicle	Apogee (approx)	Nominal azimuth	A3-Absorption (noon)
22. 1. 1976	15:56:00 GMT	B VII/Super-Loki	70 km	200°	44 dB
	16:16:00 GMT	B I/Skua 2	93 km	221°	
	17:54:00 GMT	R /Radio-Balloon	33 km		
23. 1. 1976	15:50:00 GMT	B VII/Super-Loki	70 km	195°	51 dB
	16:10:00 GMT	B I/Skua 2	104 km	230°	
	18:05:00 GMT	R /Radio-Balloon	33 km		
24. 1. 1976	13:09:00 GMT	R /Radio-Balloon	33 km		53 dB
	16:41:00 GMT	B VII/Super-Loki	70 km		
26. 1. 1976	12:28:00 GMT	R /Radio-Balloon	31 km		44 dB
	15:59:00 GMT	B VII/Super-Loki	70 km	180°	
	16:19:00 GMT	B I/Skua 3	100 km	200°	
28. 1. 1976	12:58:00 GMT	R /Radio-Balloon	31 km		64 dB
	15:50:00 GMT	B VII/Super-Loki	63 km	220°	
	16:10:00 GMT	B I/Skua 3	94 km	190°	
30. 1. 1976	12:29:00 GMT	R /Radio Balloon	28 km		30 dB
	15:58:00 GMT	B VII/Super-Loki	70 km	220°	
5. 2. 1976	11:39:00 GMT	R /Radio Balloon	28 km		18 dB
	15:51:00 GMT	B I/Skua 2	104 km	205°	
	16:27:00 GMT	B VII/Super-Loki	70 km	205°	
	22:30:00 GMT	B V/Skua 4	103 km	190°	
8. 2. 1976	11:05:00 GMT	R /Radio Balloon	32 km		31 dB
	15:34:00 GMT	B I/Skua 2	100 km	193°	
	16:20:00 GMT	B VII/Super-Loki	70 km	195°	

3. The Li vapour trail must not disturb other measurements.

4. Spare rockets (in case of a misfire) were available only for the smaller payloads.

5. The number of launchers, telemetry and radar stations was limited. One launcher had to be reloaded during the sequence.

As is seen from the table it was managed to launch the first 6 rockets of a salvo within about 3 h. This is certainly sufficient for the study of medium and large scale atmospheric variations as tidal and planetary waves. It could, however, be marginal for short period disturbances as gravity waves. The BV payloads were intended to search for night effects possibly connected with a winter anomaly event. Two of them were therefore launched in the nights after the 2 salvoes. The third Li vapour trail (spare of payload BVI) was launched after the second salvo at twilight conditions in 100 km altitude. The balloons had low priorities on the salvo days and were launched at times when they did not disturb the rocket flights.

The ground based measurements which were coordinated with the balloon and rocket flights are listed in Table 1. Not all of these stations were able to operate continuously. Therefore their activities were concentrated on certain time periods, which were especially centered around the two salvoes. For this

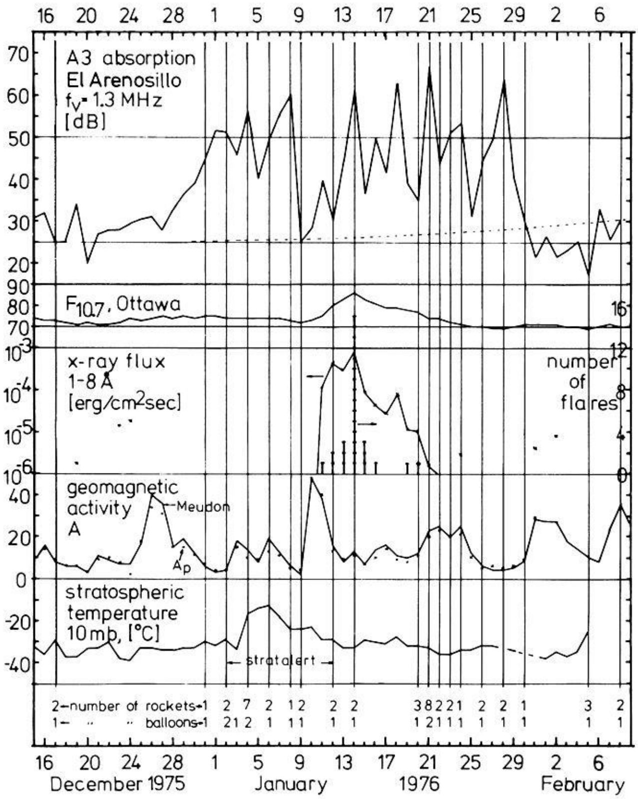

Fig. 3. Geophysical data. Dates of balloon and rocket flights are indicated as vertical lines. Numbers of flights per day are given in the bottom

purpose the ground stations were in permanent twx contact with the rocket range. Figure 2 shows the activity periods of the groundbased stations together with the number and dates of balloon and rocket launches. It is seen from this picture that the period documented best is that from January 20–January 24, 1976. This includes the second salvo on January 21, 1976, which was launched on the day with the strongest winter anomaly event (67 dB) of that winter.

Figures 3 and 4 show a number of geophysical parameters for the duration of the campaign. The data are shown as they were available on the range. The A3 absorption values given in Figure 3 show an unexpectedly strong winter anomaly activity during all of the month of January, 1976. It is interesting to note that the time span between every two strong absorption events (>50 dB) is in nearly all cases 3–4 days. The rocket and balloon launches are indicated by vertical lines in Figure 3. The number of launches is given in the bottom of the picture. It is seen that the two salvoes on January 4 and January 21, 1976 met strong winter anomaly events. The solar activity is shown in Figure 3 in terms of the 10.7 cm radio flux F numbers (Ottawa), by the 1–8 Å x-ray flux, and by the number of flares per day (SMS satellite data, Boulder).

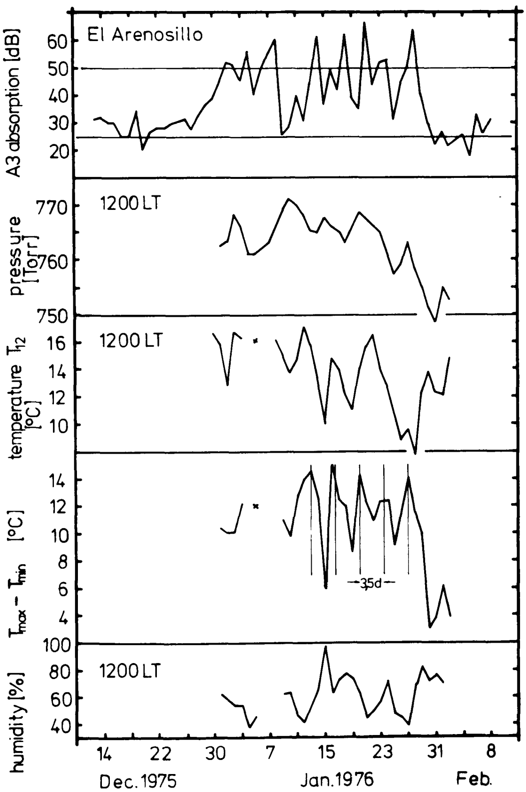

Fig. 4. Meteorological data from ground based measurements on the range. A 3 absorption is given for comparison

The first salvo (January 4, 1976) was launched under very quiet solar conditions. By mid of January, however, a sun spot appeared which strongly expresses in all solar data shown in Figure 3. The second salvo (January 21, 1976) therefore was not launched until this activity decayed and had nearly disappeared (note the logarithmic scale of the x-ray flux in Fig. 3). The geomagnetic field was characterized by moderate recurrent disturbances. The planetary Ap index as well as the local Meudon index are given in Figure 3. It is seen that the first salvo was launched under quiet conditions whereas the second salvo went into the beginning of a small recurrent disturbance. The local magnetometers on the range showed, however, that this disturbance had not fully developed by the time when the salvo was finished.

Figure 3 also shows the 10 mb stratospheric temperatures as supplied by the Berlin Stratalerts. Maximum temperatures which occurred in the northern hemisphere are given to characterize the overall situation. A minor stratospheric warming occured in the beginning of January 1976 (including a stratalert). Most of it, however, did not take place over Western Europe but over Sibiria.

Figure 4 shows some meteorological data as they were measured on the range. For comparison the A 3 data of El Arenosillo are also given. As mentioned above the weather was unexpectedly good during most part of January, 1976.

Figure 4 shows that this was due to a pronounced high pressure period. It is tempting to look for a link between this high ground pressure and the winter anomaly, because the periods of generally high A3 absorption and high pressure coincide. Superimposed on the mean ground pressure there is a wavelike structure which appears to be present in a similar but time shifted form in the noon temperatures T_{12} (see Fig. 4). Again superimposed on this wave structure there is a diurnal and semidiurnal variation of the ground pressure (not shown in Fig. 4). It reaches peak to peak values up to 4 Torrs! The maximum daily temperature variation $T_{max}-T_{min}$ is also given in Figure 4. It exhibits a wavelike structure with a period of about 3.5 days. Longer periods may have been eliminated by the method of taking differences of temperature values so close together in time. Periods similar to this and longer ones were found in various balloon and rocket data at higher altitudes during the campaign. Generally speaking it appears that the geophysical situation by the time of the campaign was characterized by pronounced wavelike structures in the atmosphere.

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