

Data of Project on Atmospheric Circulation and
Material Cycle in the Antarctic, Part 3.
Backscattering Properties of Tropospheric Clouds and
Aerosols Observed by a Lidar at Dome Fuji Station in 1997

Masahiko Hayashi¹, Masaki Sudo¹, Kouichi Shiraishi¹, Naohiko Hirasawa²,
Takashi Yamanouchi², Takashi Shibata³, Yasunobu Iwasaka³,
Masahiro Nagatani⁴ and Akira Nakada⁴

¹Fukuoka University, 8-19-1, Nanakuma, Johnan-ku, Fukuoka 814-0180

²National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515

³Graduate School of Environmental Studies, Nagoya University, Furo-cho,
Chikusa-ku, Nagoya 464-8601

⁴Solar Terrestrial Environment Laboratory, Nagoya University, Hononara, Toyokawa 442-8507

1. Introduction

Since 1997, the Japanese Antarctic Research Expedition (JARE) has conducted a study of “Atmospheric Circulation and the Material Cycle in the Antarctic”. The project was aimed at clarifying the transport and transfer of atmospheric minor constituents due to atmospheric circulation. During the wintering of the 38th Japanese Antarctic Research Expedition (JARE-38) in 1997, extended observation with a vertical pointing lidar, aerosol sondes, rawinsondes, short-wave and long-wave radiometers, aerosol samplers and aerosol counters at the surface were made at Dome Fuji Station (77°19'S, 39°42'E, 3810 m a.s.l.). Observations of atmospheric phenomena at Dome Fuji Station made by JARE-38 are described in Yamanouchi *et al.* (1999), Hirasawa (1999), and Hayashi (1999). The data obtained by aerological observations in 1997 are reported in Hirasawa *et al.* (1999). The data of tropospheric clouds and aerosols obtained at Dome Fuji Station by the lidar in 1997 are reported here.

2. Instruments

2.1. Lidar system

The schematic diagram and specifications of the lidar system used at Dome Fuji Station are shown in Fig. 1 and Table 1, respectively. Two wavelengths from the Nd:YAG laser were used, a fundamental wavelength of 1064 nm and a second harmonic wavelength of 532 nm. The output energy of a laser pulse at each wavelength is 100 mJ for 1064 nm and 150 mJ for 532 nm, respectively. The pulse repetition rate of the

laser is 20 pulses per second. The laser beams of both wavelengths are linearly polarized. They are emitted in the vertical direction through a transmitter that was collimated to about 0.2 mrad beam divergence.

Light backscattered by the atmosphere with Mie, Rayleigh, and Raman scattering processes is corrected by a telescope of 28 cm diameter. The received light is divided into four photo-multiplier tubes (PMT) as shown in Fig. 1. PMT1 and PMT2 are used for detecting parallel and perpendicular polarization components of the primary polarization plane of the transmitted laser light, with a wavelength of 532 nm. The light, with a wavelength of 532 nm, is separated from corrected light by a beam-splitting mirror (B1) and interference filter (IF), and divided into two components by a polarization beam splitter (P). These data are used for retrieving a scattering ratio and depolarization ratio (see Section 4) at 532 nm.

PMT3 is used for detection at a wavelength of 607 nm, a Raman shifted one by Nitrogen molecules excited by 532 nm light. Light with a wavelength of 607 nm is separated using a beam splitting mirror (B2), a blocking filter (CF) and an interference filter (IF). This data is used for retrieving air density. PMT4, which is cooled to about -20°C to reduce thermal noise, is used for detection at a wavelength of 1064 nm. The light with a wavelength of 1064 nm is separated using a beam splitting mirror (B2) and interference filter (IF). The data are used for retrieving the scattering ratio at 1064 nm.

The electrical signals from PMTs are processed simultaneously, using a two-channel A/D converter (ADC) as an analog measurement system and a four channel multi-channel scaler (MCS) as a photon counting measurement system. The analog measurement system is used for observations of tropospheric clouds and aerosol properties and the photon counting measurement system is used for observations of aerosol properties in the lower stratosphere. The vertical resolution is 5 m for the analog measurements and 30 m for the photon counting measurements. Two PMTs are arbitrarily connected to the ADC, because the ADC has only two channels.

The present report presents data of backscattering properties at 532 nm from 3.8 km to 12 km, corresponding to the troposphere and the lower most stratosphere, observed by PMT1 and PMT2 with ADC. The reliability of data below 4.2 km, however, is low because the telescope's field of view does not perfectly cover the transmitted laser beam.

2.2. Aerological sonde

Air density must be used for the lidar signal analyses to obtain cloud and aerosol

backscattering components. In the current study, we use the data obtained by aerological sounding observation with VAISALA RS80 radio sondes at Dome Fuji Station (Hirasawa *et al.*, 1999).

3. Observations

Table 2 is a summary of lidar observations at Dome Fuji Station in 1997. The number of total observation days is listed in line (1); line (2) represents the number of days on which clouds are detected by lidar; and, line (3) denotes the number of days on which lidar observation is impossible because cloud cover is too dense to observe with lidar.

The lidar observation started on April 18, 1997 and closed on December 22, 1997. System troubles in May resulted in a limited number of total observation days in May. The total number of observation days was also limited from October to December because of strong background light from the midnight sun. Cloudy days are defined as the appearance of a layer with a scattering ratio larger than 2 (see Section 4). This criterion is so low as to define a sub-visible scattering layer as a cloud. When the cloud density is too high, the lidar observations cannot be carried out. There were few such cloudy conditions from April to September, as shown in Table 2, which suggests that the optical thickness of clouds over inland Antarctica is usually thin in winter and spring.

Signals of 2400 laser pulses, corresponding to 2 min, were accumulated as one data set of vertical profiles, and observations are performed for 20 min or 2 hours in one day.

4. Data

Vertical profiles of the scattering ratio ($SR(z)$) and depolarization ratio ($DR(z)$) are calculated using the methods presented by Fernald (1972). The scattering ratio at altitude z , $SR(z)$, is defined as follows:

$$SR(z) = \frac{\beta_R(z) + \beta_M(z)}{\beta_R(z)} = 1 + \frac{\beta_M(z)}{\beta_R(z)}, \quad (1)$$

where β_M : backscattering coefficient of Mie scattering ($\text{sr}^{-1}\text{m}^{-1}$); and,

β_R : backscattering coefficient of Raileigh scattering ($\text{sr}^{-1}\text{m}^{-1}$).

Mie scattering is caused by cloud and aerosol particles in the troposphere, and Rayliegh scattering is caused by air molecules. Equation (1) indicates that SR becomes unity in the layer that is free from clouds and aerosols.

The ratio of extinction coefficient to backscattering coefficient for scattering

objects, called “ S_1 parameter”, is required for the analyses. The S_1 values of aerosol and cloud layers vary with particle shape, size distribution, optical thickness, and so on. The backscattering coefficients for aerosols and/or clouds are calculated by following equation.

$$\beta_M(z) = \frac{P(z)z^2 \exp\left\{-2(S_1 - S_R) \int_{z_c}^z \beta_R(z) dz\right\}}{\frac{P(z)z^2}{\beta_M(z_c) + \beta_R(z_c)} - 2S_1 \int_{z_c}^z P(z)z^2 \exp\left\{-2(S_1 - S_R) \int_{z_c}^z \beta_R(z) dz\right\}} - \beta_R(z), \quad (2)$$

where $P(z)$: received signal intensity,

S_R : S_1 parameter for air molecules, with value of $8/3 \pi$; and,

z_c : normalizing altitude, where β_M and β_R are known.

For optically thick scattering layers like clouds, in which multiple scattering occurs, S_1 values sometimes become much smaller than those in the usual aerosol layers ($S_1 = 40$).

Here we use the following value of S_1 :

$S_1 = 40$ for the scattering layer with small optical thickness,

and

$S_1 = 3 \sim 37$ for the scattering layer with large optical thickness.

The values of S_1 for the dense scattering layer are determined as the values, for which the scattering ratio becomes unity, assuming a condition free from clouds and aerosols, below the dense scattering layer.

The depolarization ratio, $DR(z)$, is defined as follows:

$$DR(z) = \frac{\beta_{\perp}(z)}{\beta_{\parallel}(z)}, \quad (3)$$

where β_{\parallel} and β_{\perp} are backscattering coefficients in planes parallel and perpendicular to the primary plane of the transmitted laser (532 nm). The depolarization ratios are calculated as ratios between signal strengths of the two polarized components.

Five raw data, integrated for 2 min, are accumulated together to reduce error caused by weakness of the backscattered signal. The accumulation period for each profile is 10 min.

The left panels of Fig. 2 shows vertical profiles of SR and DR, observed every 10 min over a one-day period. The vertical profiles of air temperature, observed with aerological sondes are also shown in the right panels of Fig. 2. The reliability of the high altitudes region sometimes becomes low because of the weakness of the

backscattered signal. These parts of the vertical profiles are indicated by the adjacent vertical bars. In contrast, the reliability at low altitudes is sometimes too low because the backscattered light, caused by lower clouds, was too strong for the detection system. These conditions are shown by asterisks (*) at the right part of the panels.

The maximum value of the backscattering coefficients for each cloud layer vary from 10^{-6} to $10^{-3} \text{ sr}^{-1}\text{m}^{-1}$, case by case, averaging at approximately $4 \times 10^{-4} \text{ sr}^{-1}\text{m}^{-1}$. The integrated backscattering coefficient (IBC) for tropospheric clouds ranges from 0.001 to 0.07 sr^{-1} , averaging at approximately 0.03 sr^{-1} over Dome Fuji Station.

Most clouds show high depolarization ratios, suggesting that they are composed of ice particles, a reasonable conclusion under temperature conditions below -40°C at Dome Fuji Station. In contrast, cloud layers with low depolarization ratios have also been detected, although temperatures were lower than -40°C , on June 2nd, 9th, 15th, August 19th, and September 16th. Generally, low depolarization ratios suggest that the layers are composed of spherical particles similar to liquid cloud droplets.

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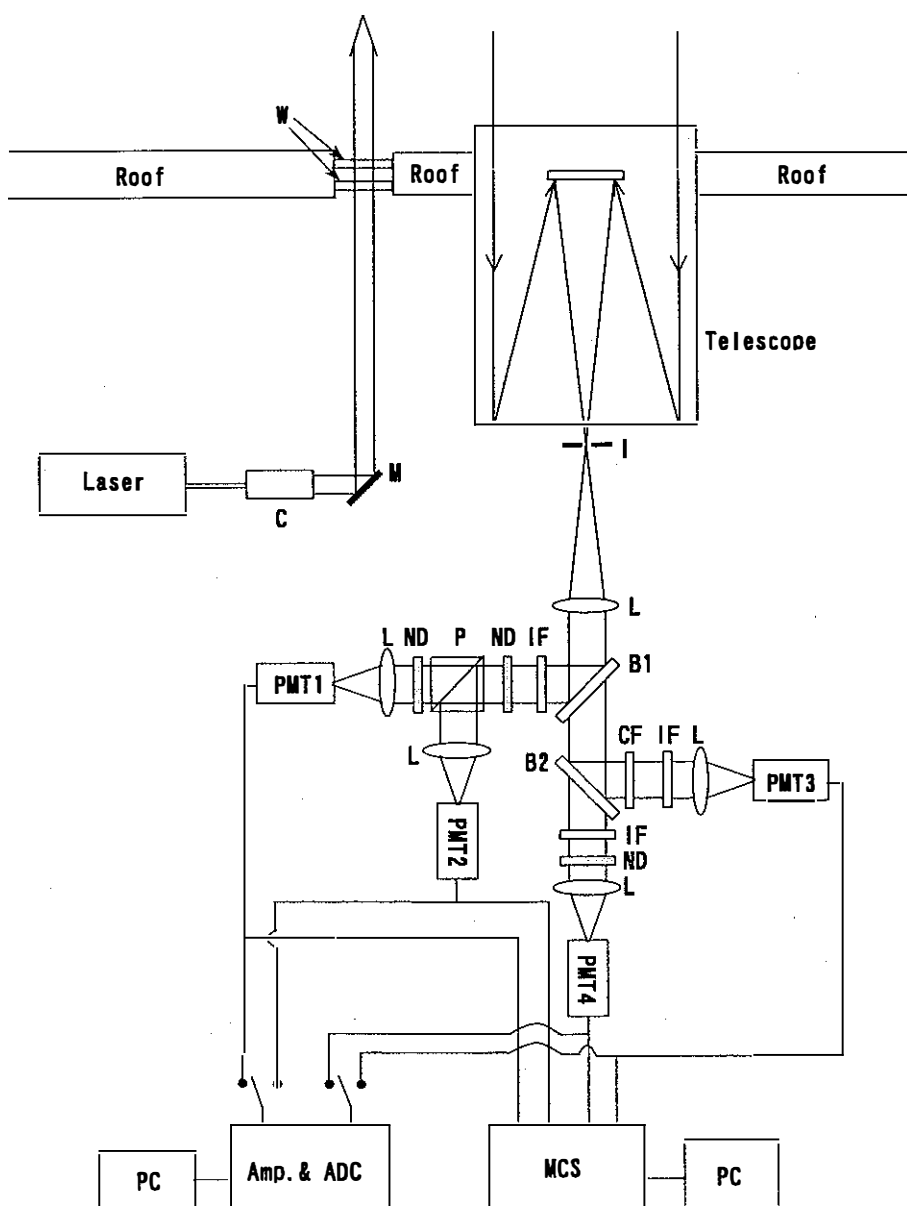


Fig. 1. Schematic diagram of lidar at Dome Fuji Station.

ADC: A/D converter, Amp: amplifier, B1 and B2: beam splitting mirrors, C: collimator CF: Mie and Rayleigh cut filter, I: iris for field stop, IF: interference filter, L: lens, M: reflecting mirror for 1064 and 532 nm, MCS: multi-channel scaler, ND: neutral density filter, P: polarizing beam splitter, PC: personal computer, PMT1~4: photo-multiplier tubes, W: anti-reflecting window for 1064 and 532 nm.

Table 1. Specifications of lidar system installed at Dome Fuji Station.

Transmitter		
Laser		Nd:YAG
Wavelength		1064 nm (Fundamental) 532 nm (Second harmonic)
Output energy		150 mJ/pulse (Fundamental) 100 mJ/pulse (Second harmonic)
Pulse repetition rate		20 Hz
Laser beam divergence		0.2 mrad (after collimation)
Collimator		
Magnification		$\times 5$
Receiver		
Telescope		Schmitt-Cassegrain type
Telescope diameter		280 mm
F-Number		7.5
PMT for visible		HAMAMATSU
PMT for IR		HAMAMATSU R3236
IF filters		
Center wavelength		532 nm, 607 nm, 1064 nm
FWHM		about 1 nm
blocking filter for 607 nm detection		
transmittance		$< 10^{-2}$ at 532nm
Signal and Data processor		
MCS for Photon counting mode		
Channel number		4
Range resolution		30 m
Control and data recording		NEC PC-9810
Operating time resolution		2 or 10 min
A/D converter for analog measurement mode		
Channel number		2
signal selection		(a) polarization components of 532 nm or (b) 1064 nm & 607 nm
Signal resolution		12 bit
Range resolution		5 m
Control and data recording		NEC PC-9810B
Operating time resolution		2 min

Table 2. Summary of the lidar observations at Dome Fuji Station in 1997.

	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year Total
Total observation days ⁽¹⁾	13	14	28	29	31	28	20	20	10	193
Cloudy days ⁽²⁾	7	4	19	19	17	11	11	3	6	97
Lidar observation impossible ⁽³⁾	0	0	2	2	0	2	—	—	—	6

(1) Number of days on which lidar observations were carried out.

(2) Number of days on which scattering layers of $SR > 2$ were detected.

(3) Number of days on which cloud cover was too dense for lidar observations.

Reasonable number of days for this group was not obtained from Oct. to Dec. because of strong background light from midnight sun and twilight.

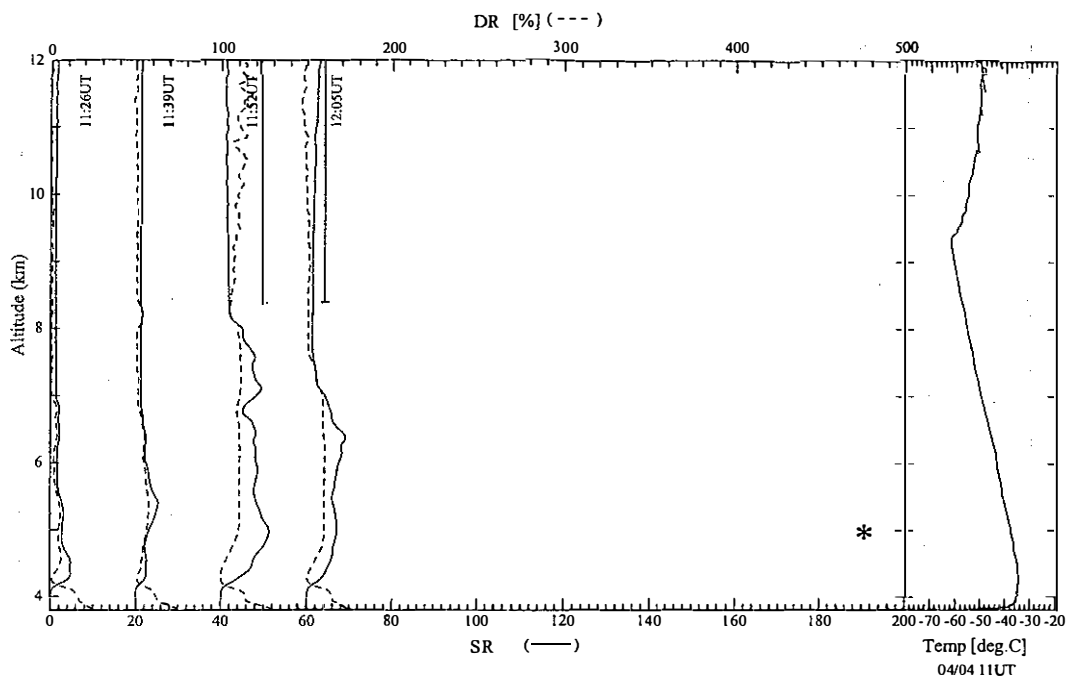
Fig. 2 (opposite). Vertical profiles of scattering ratio (SR) and depolarization ratio (DR) observed with lidar (left panel); and, temperature observed with radio sondes (right panel) at Dome Fuji Station.

(Left) SR: solid line, DR: dashed line

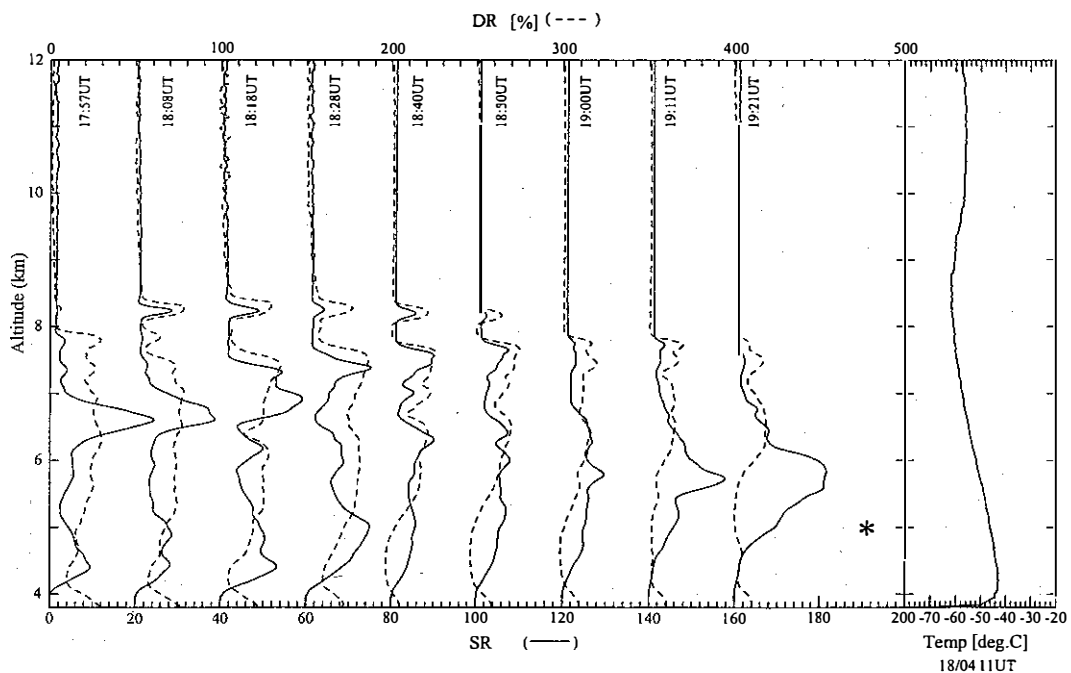
(Right) temperature: solid line

Successive profiles are displaced by 20 or 40%, depending on the full scale, 50% in the case of scattering ratio (depolarization ratio). Date and time (UT) for lidar observations are shown at the top of each panel and beside each profile (time), respectively. Launching time of radio sondes are also shown at bottom of right panel.

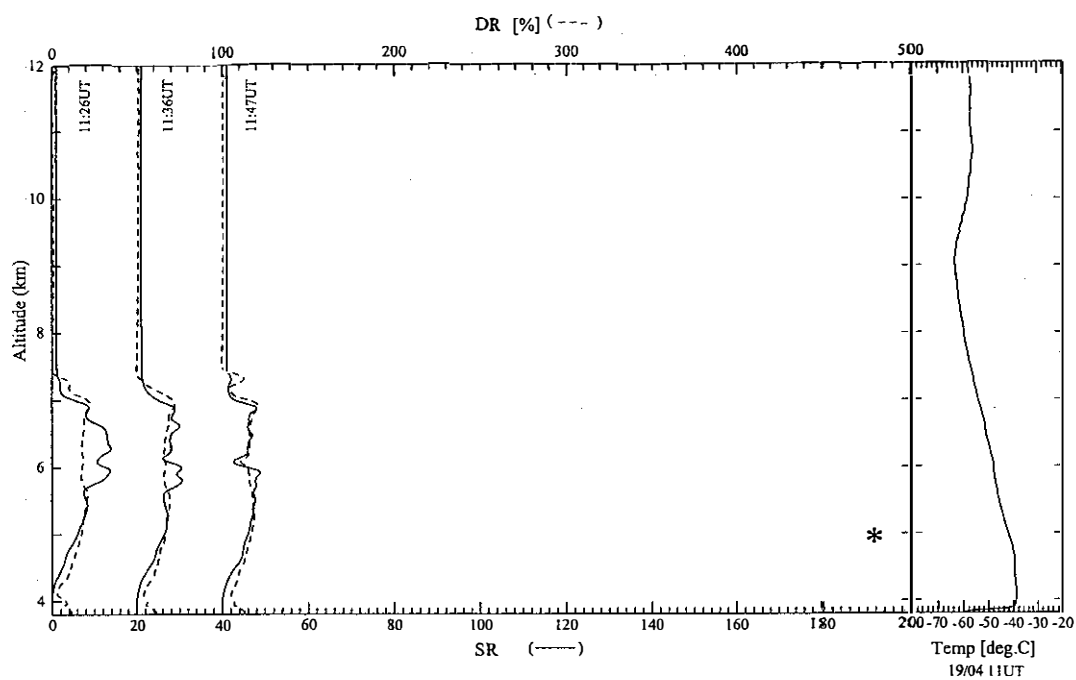
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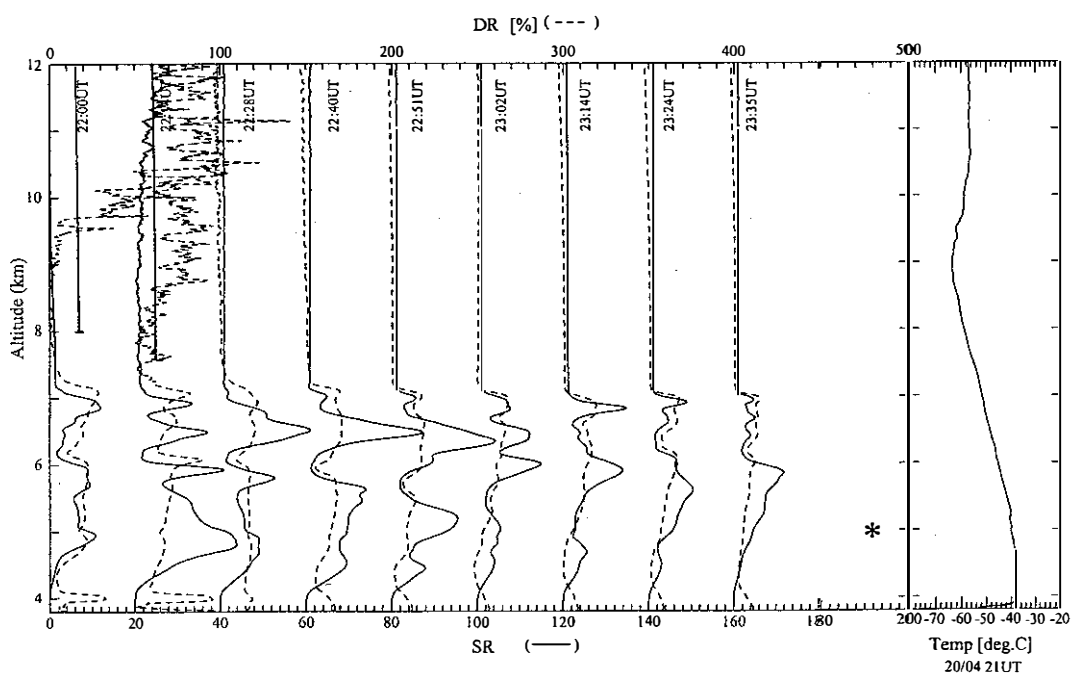
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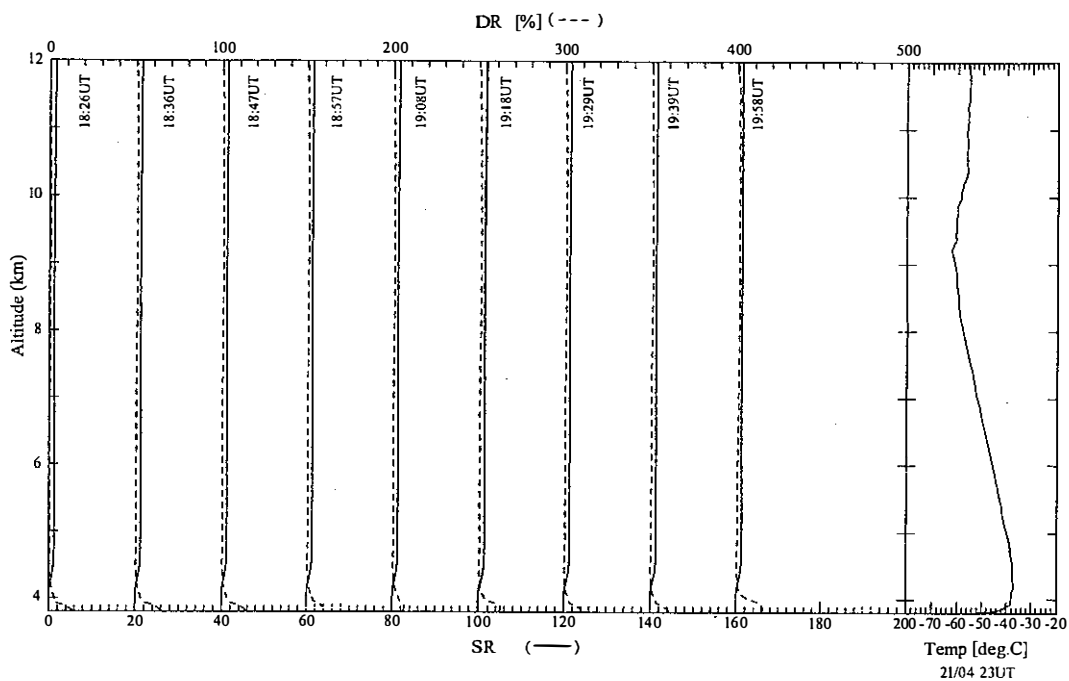
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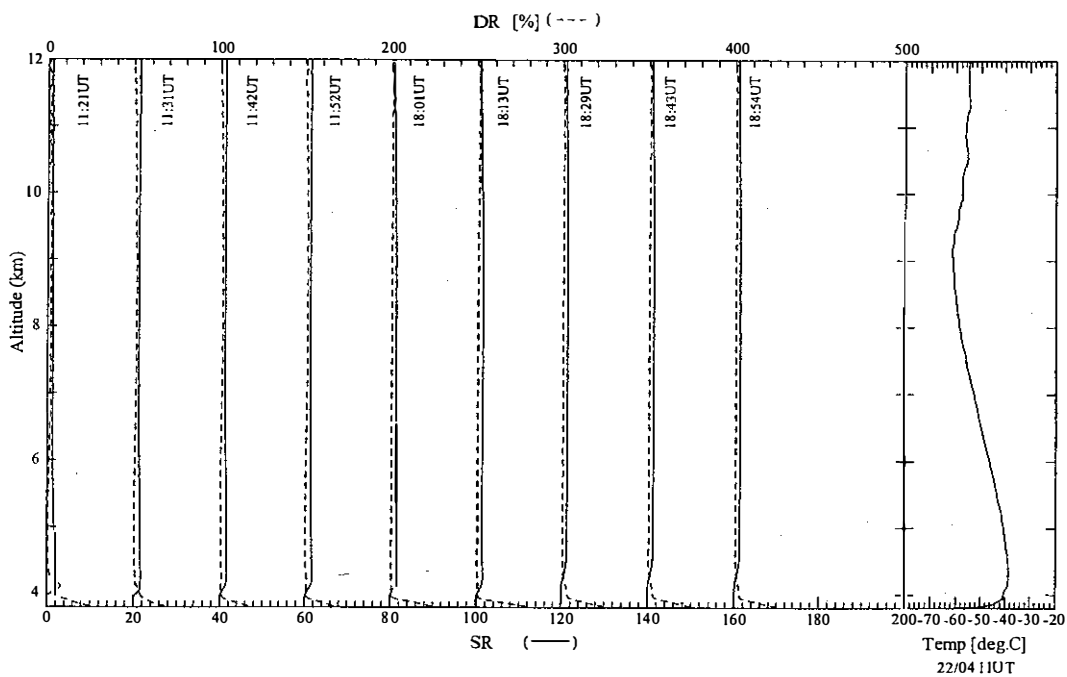
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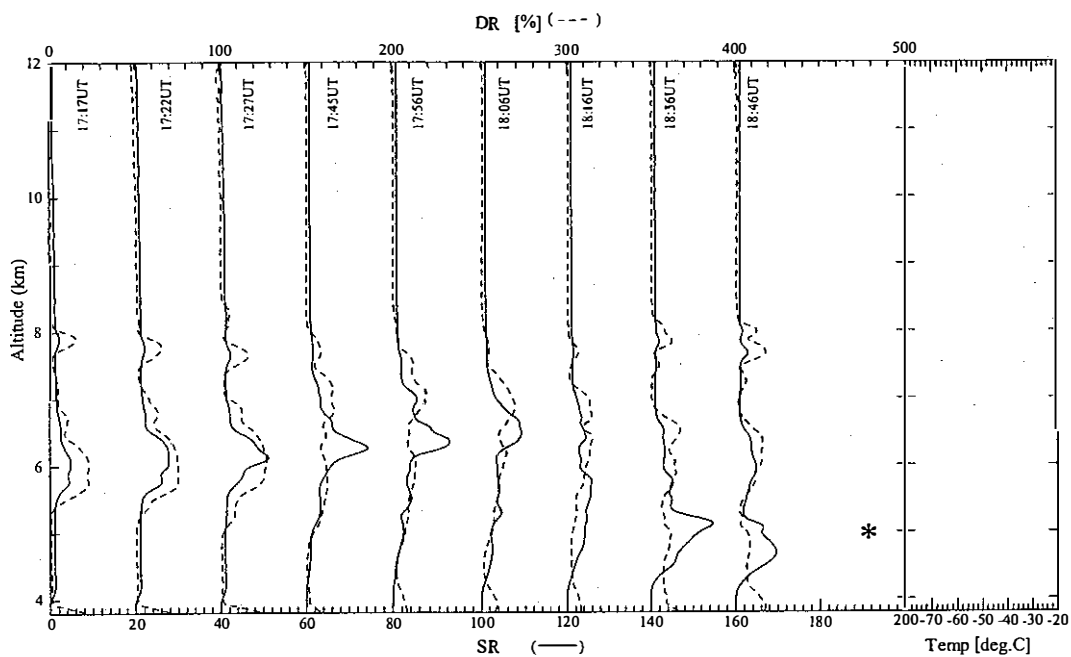
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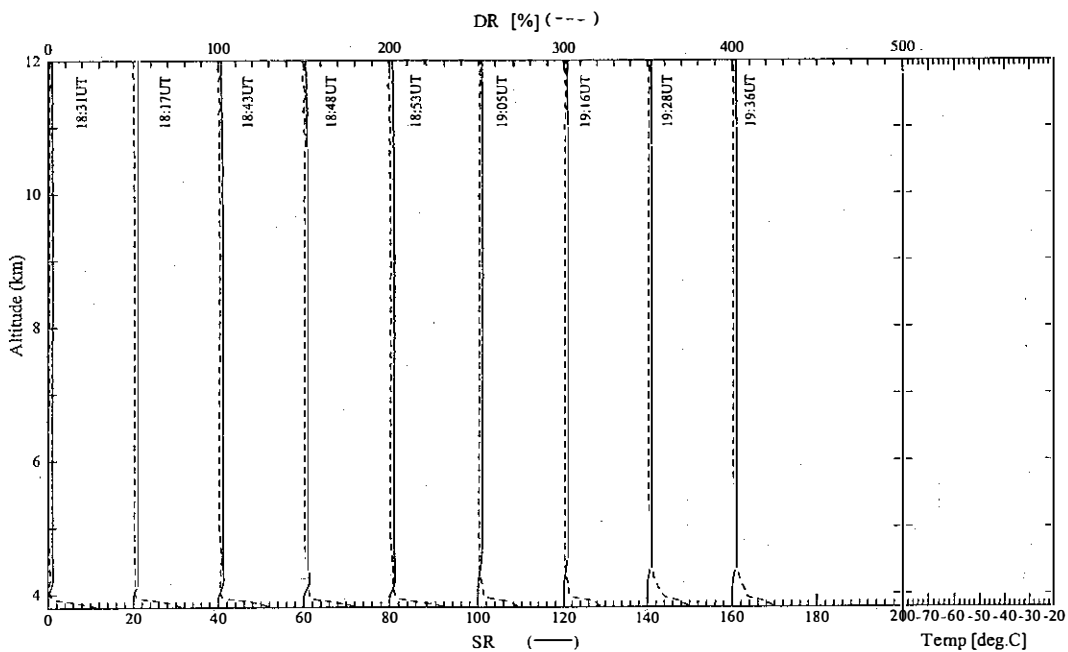
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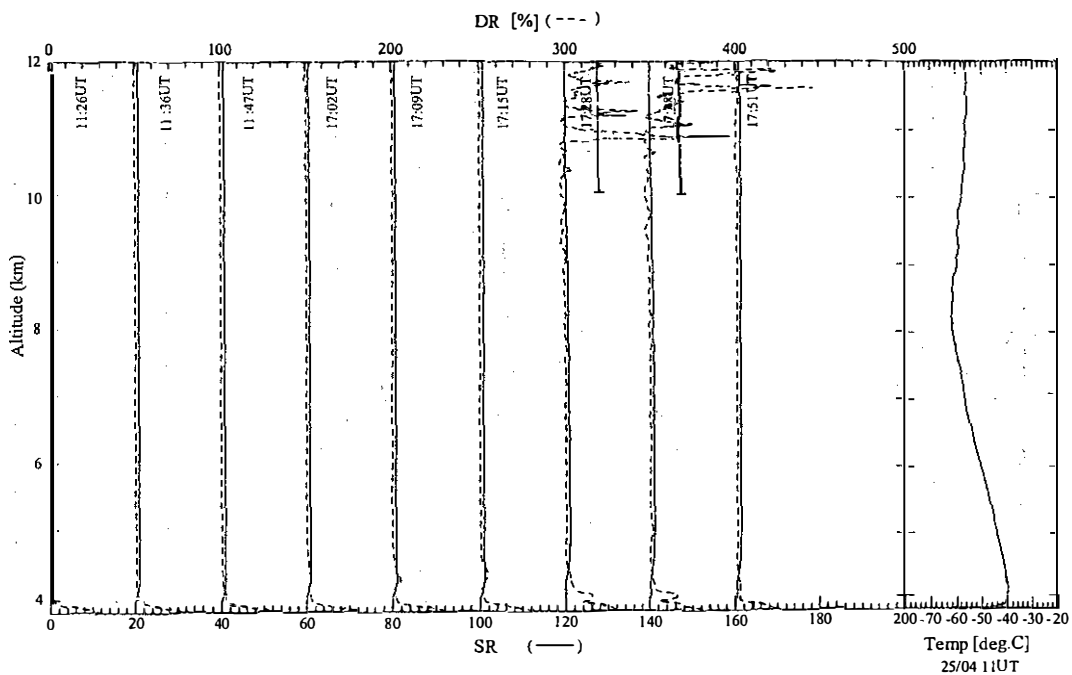
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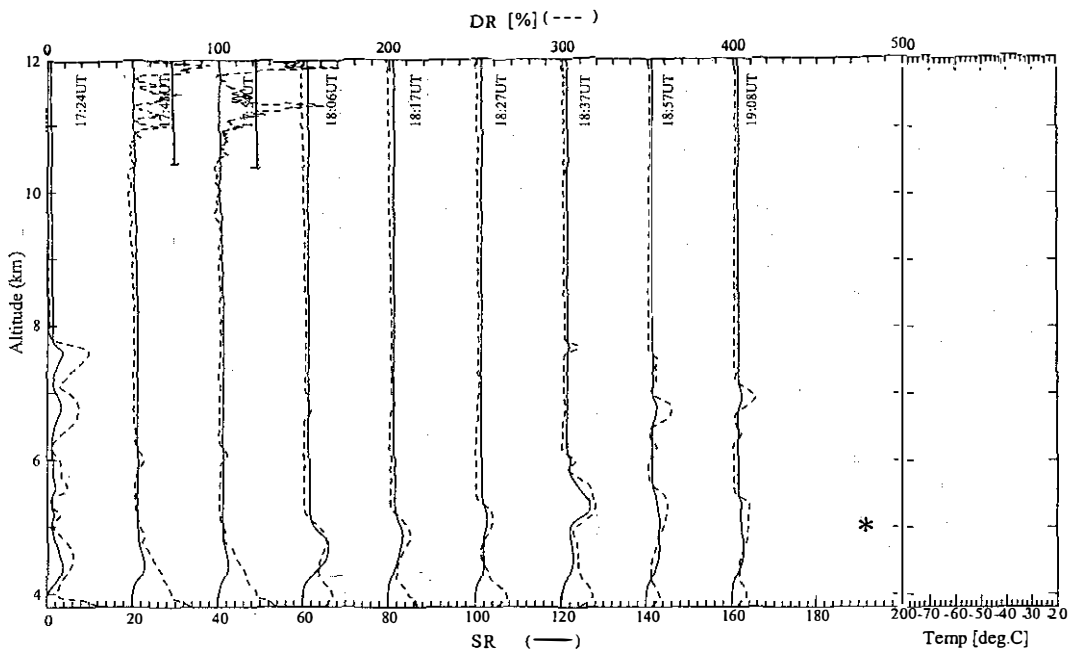
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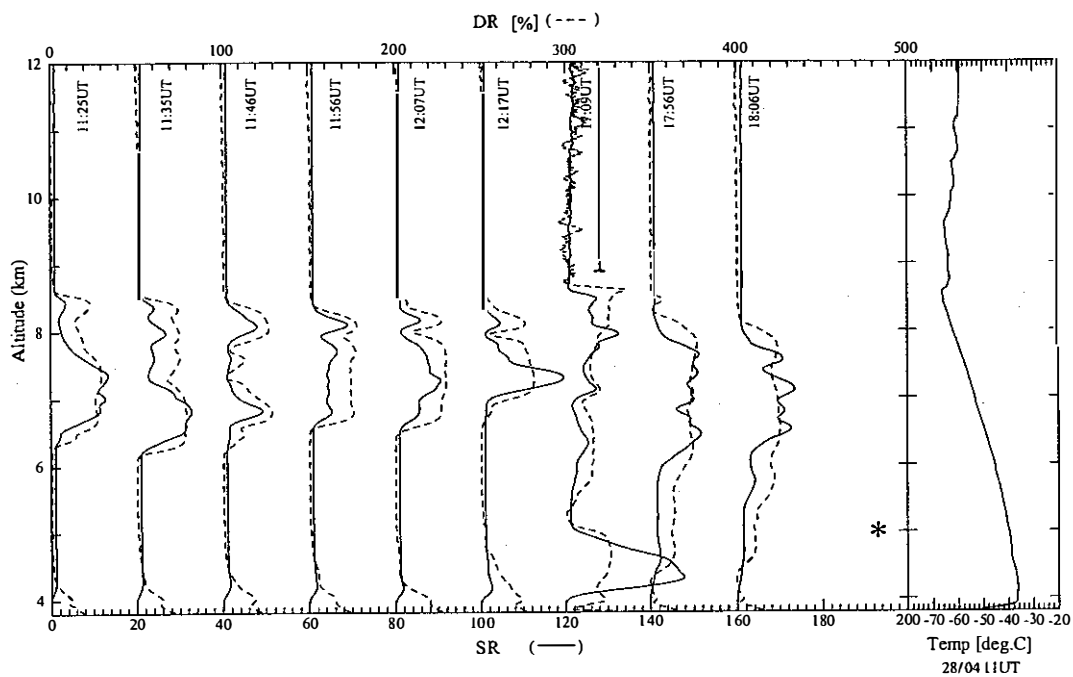
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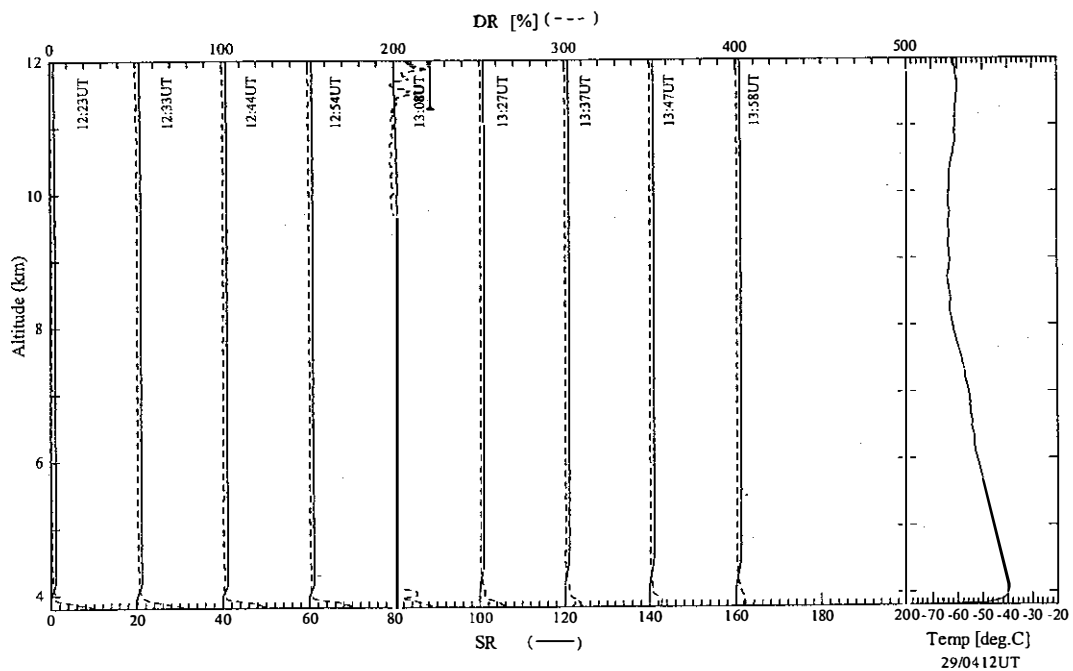
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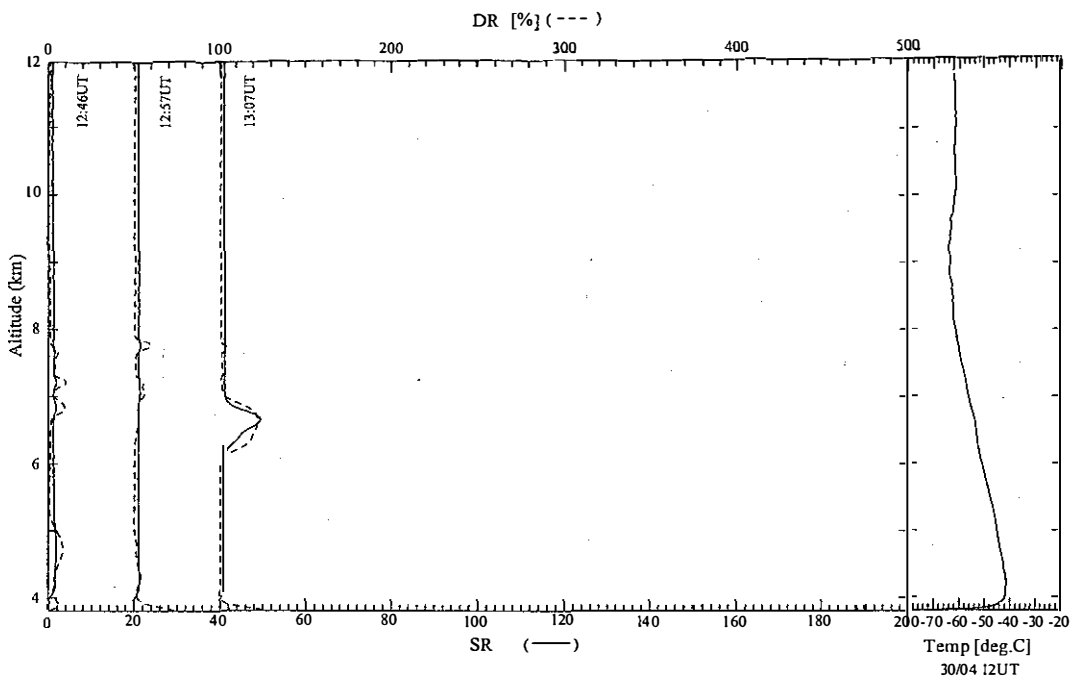
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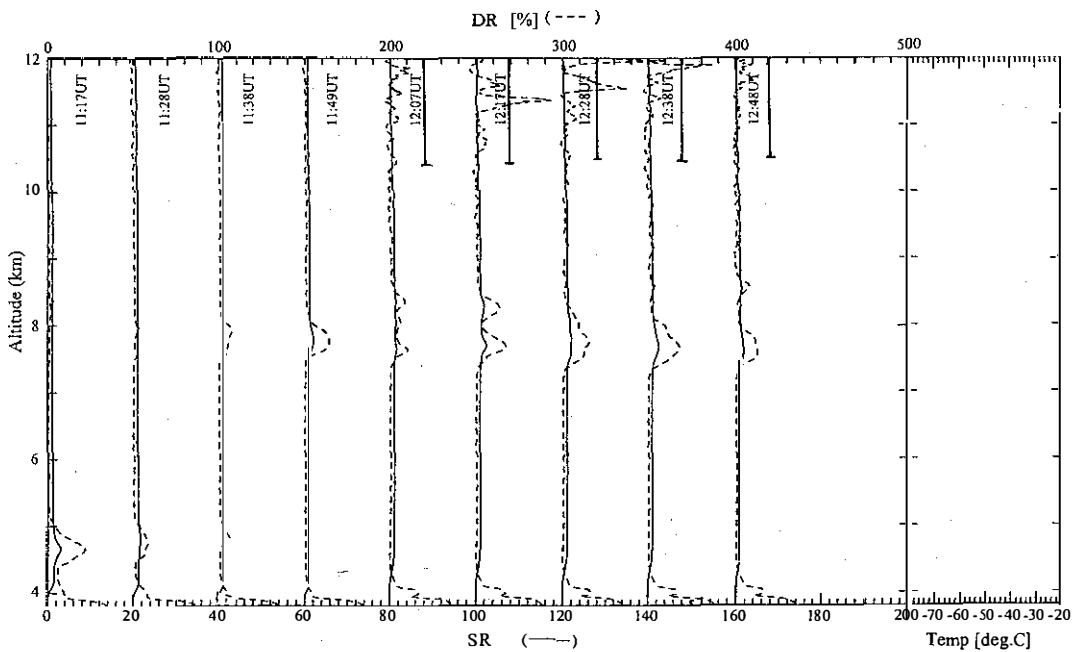
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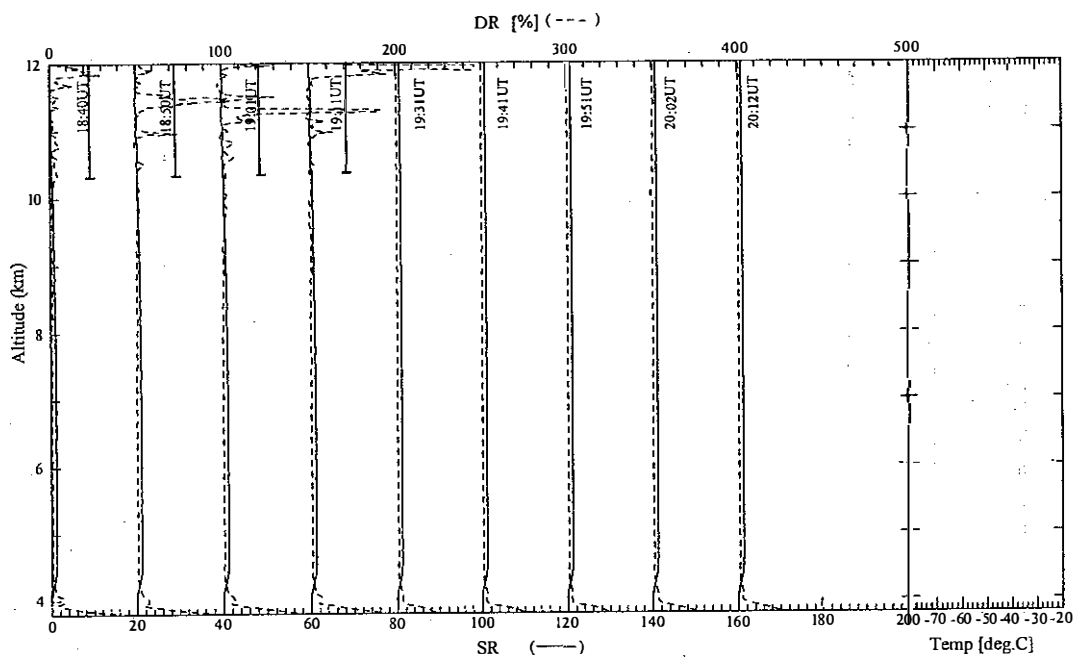
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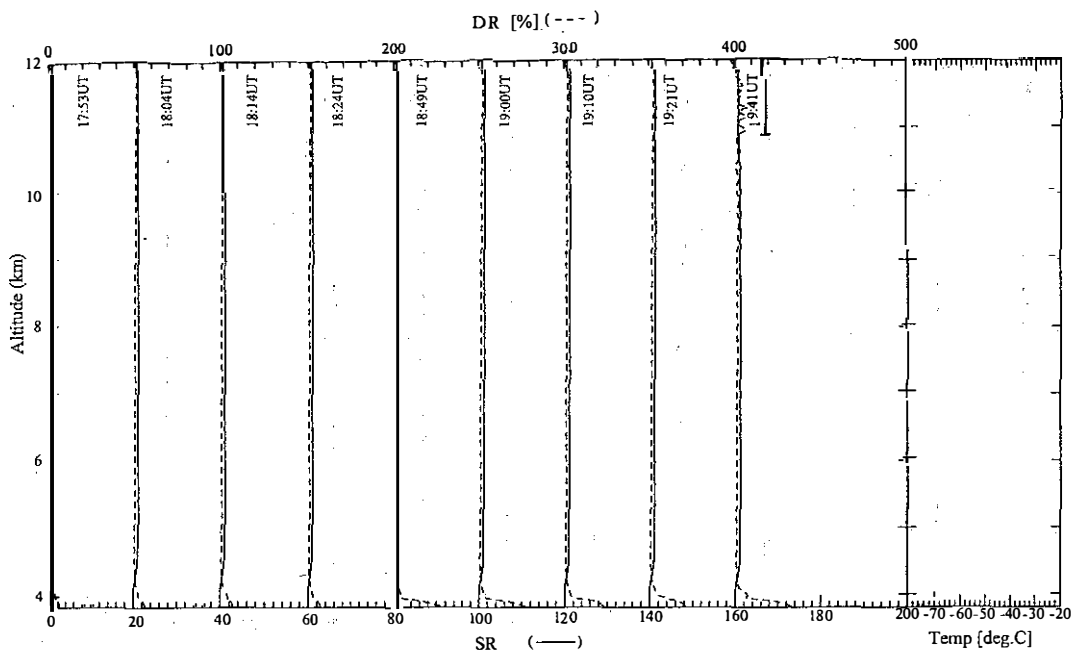
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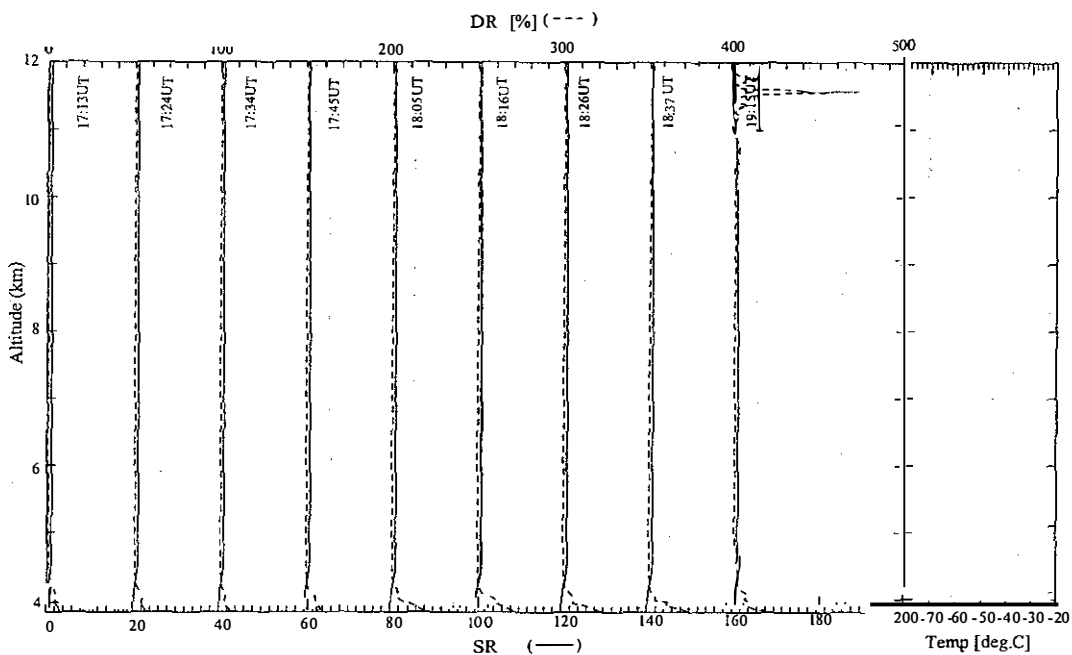
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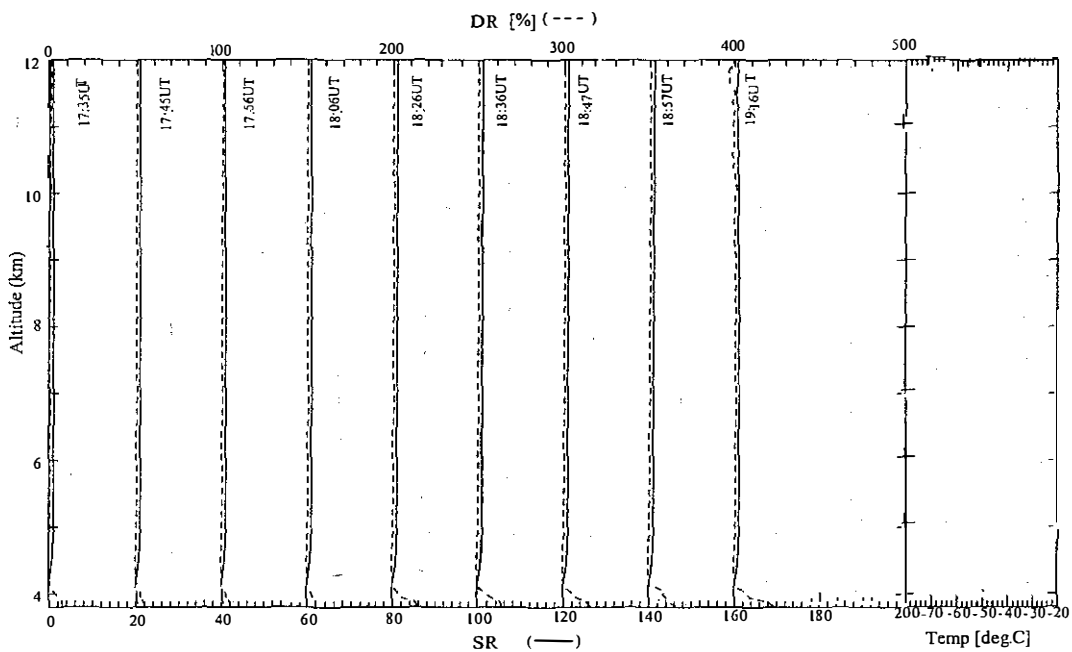
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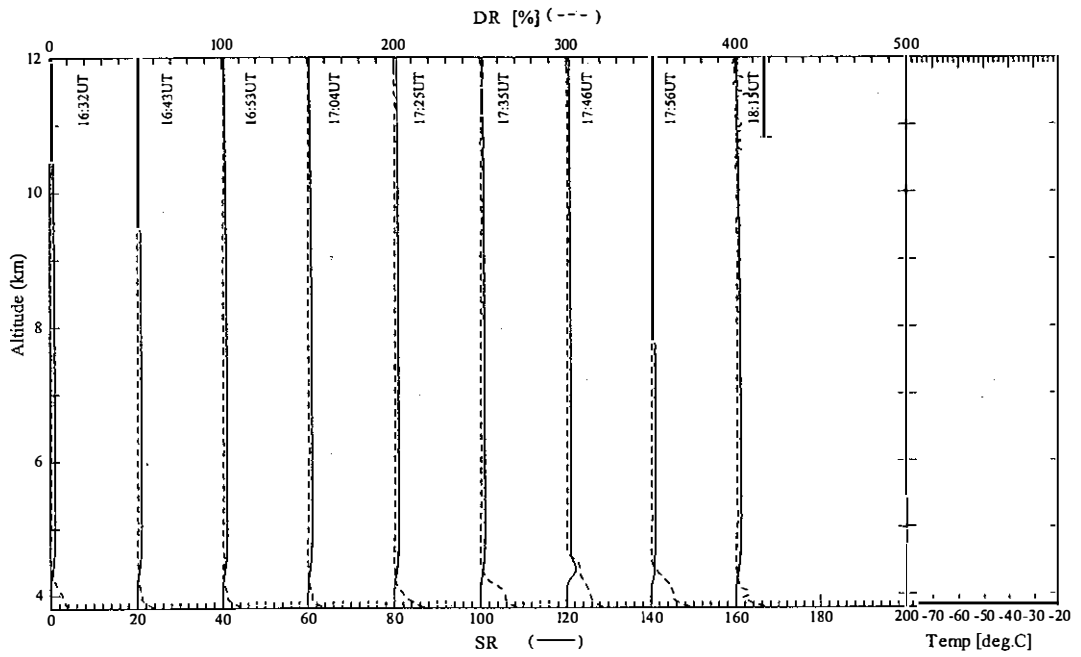
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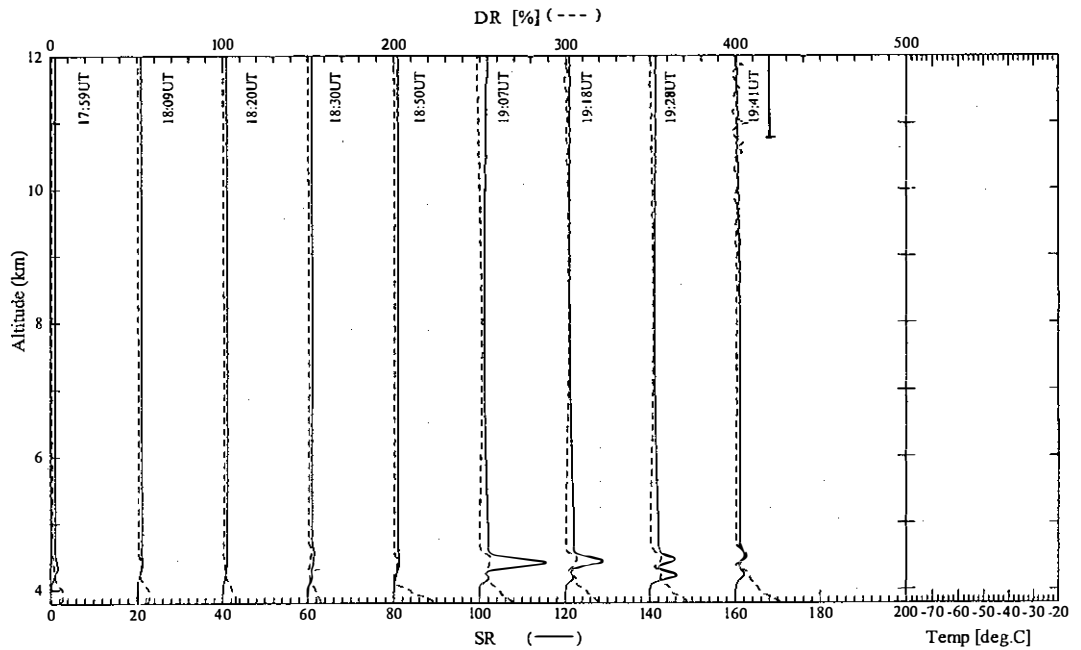
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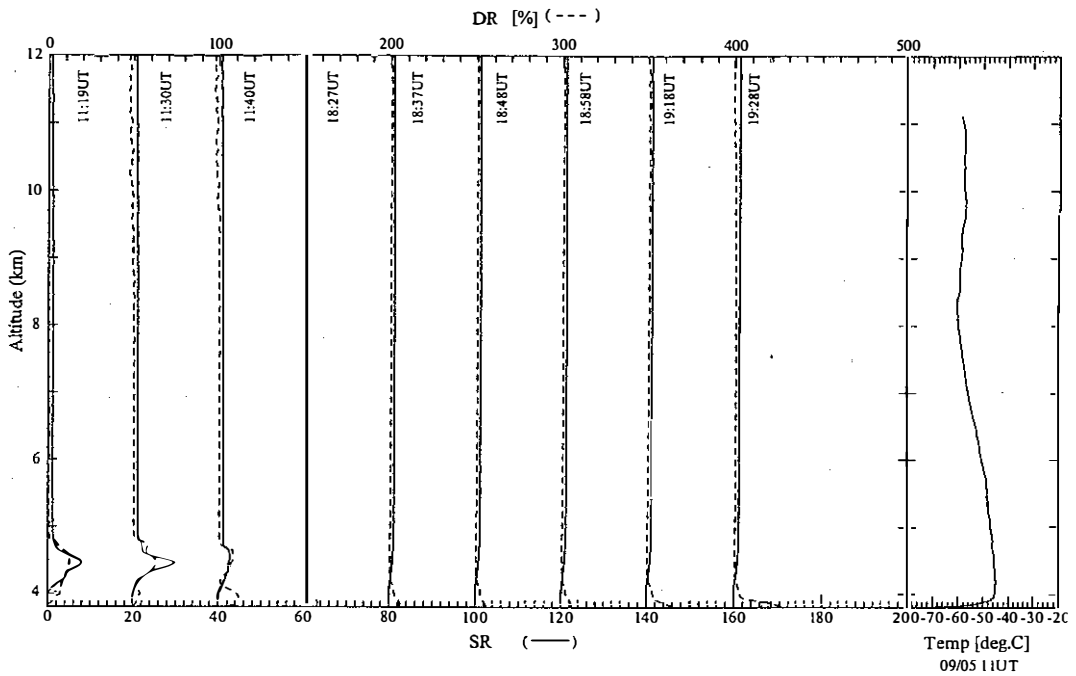
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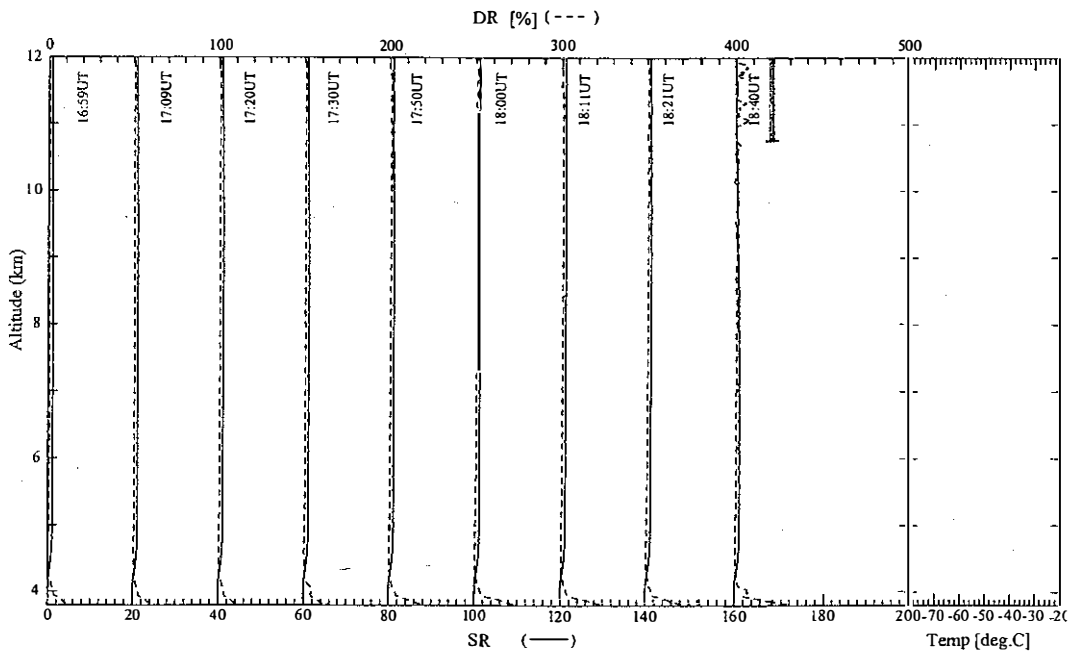
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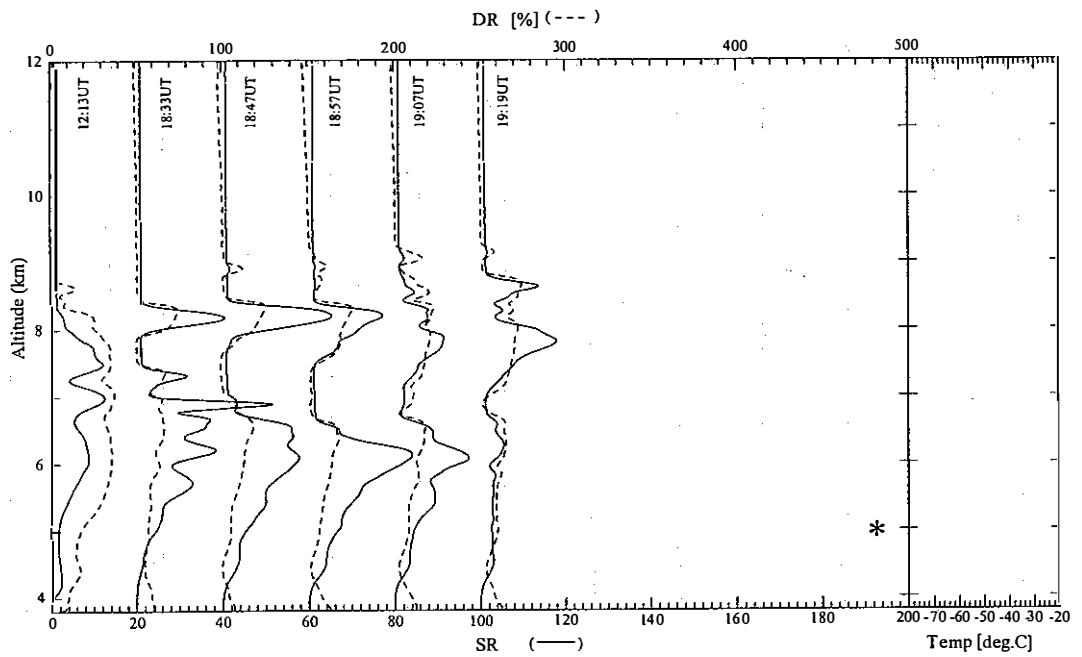
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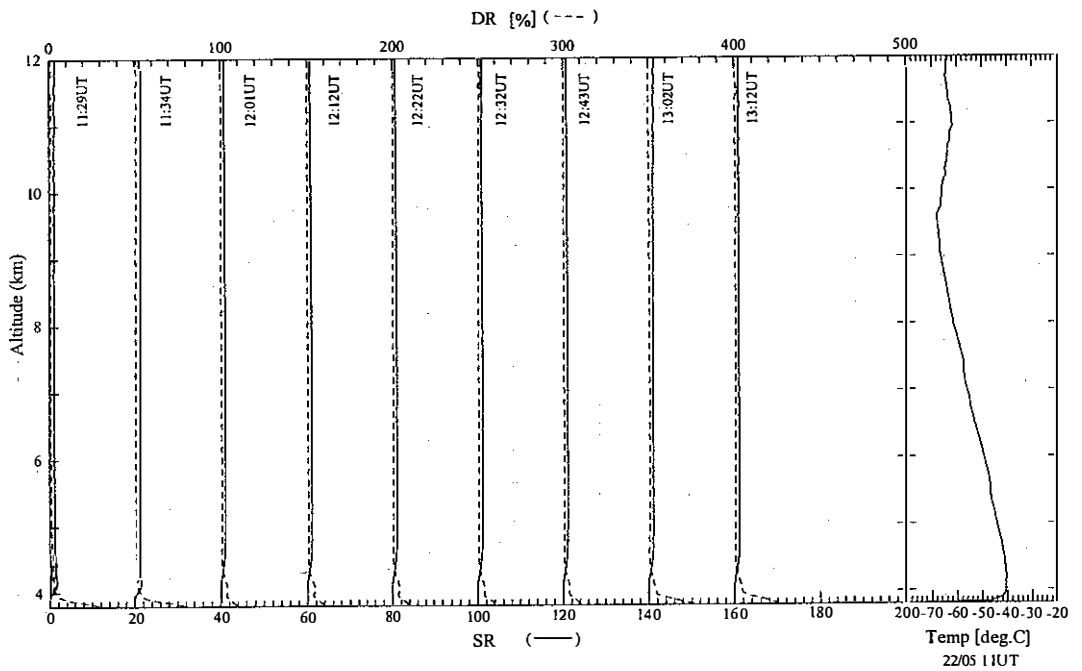
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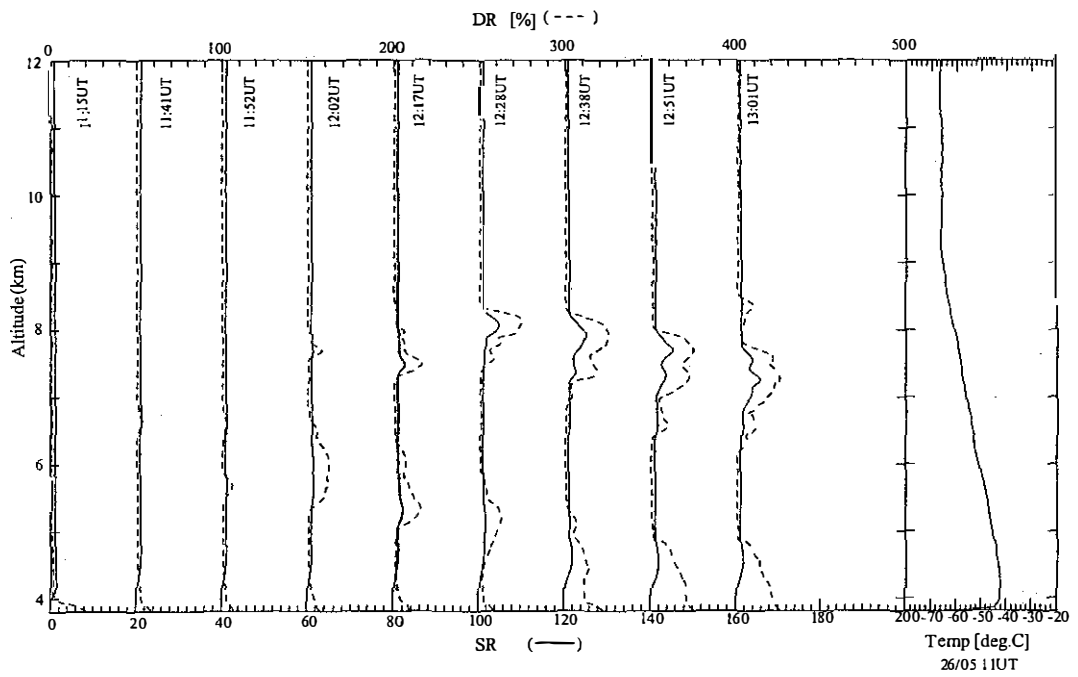
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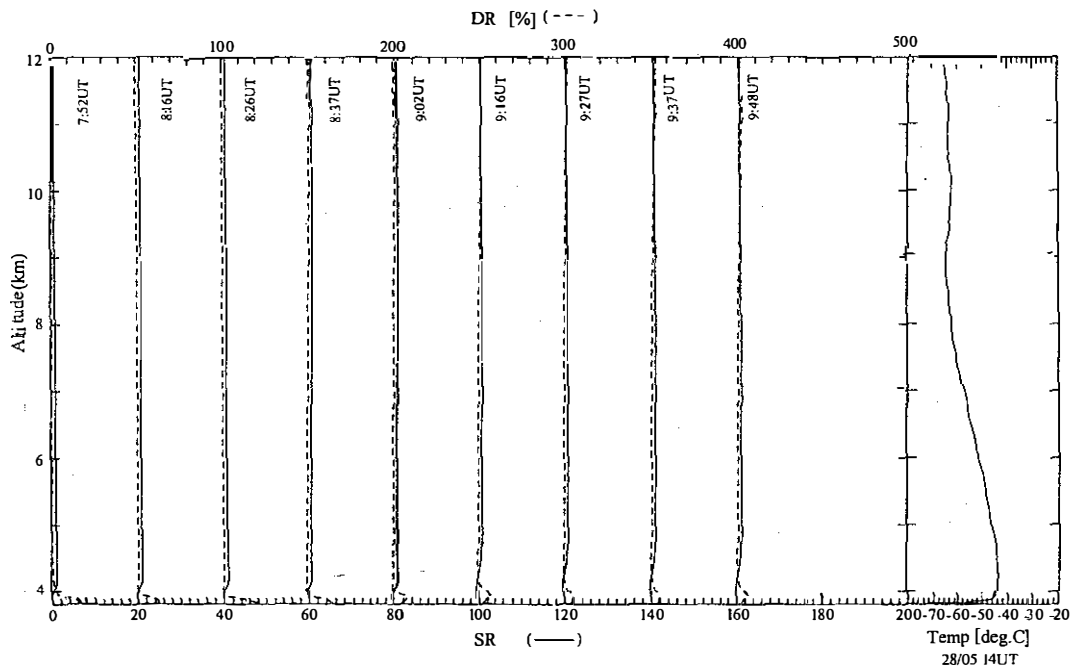
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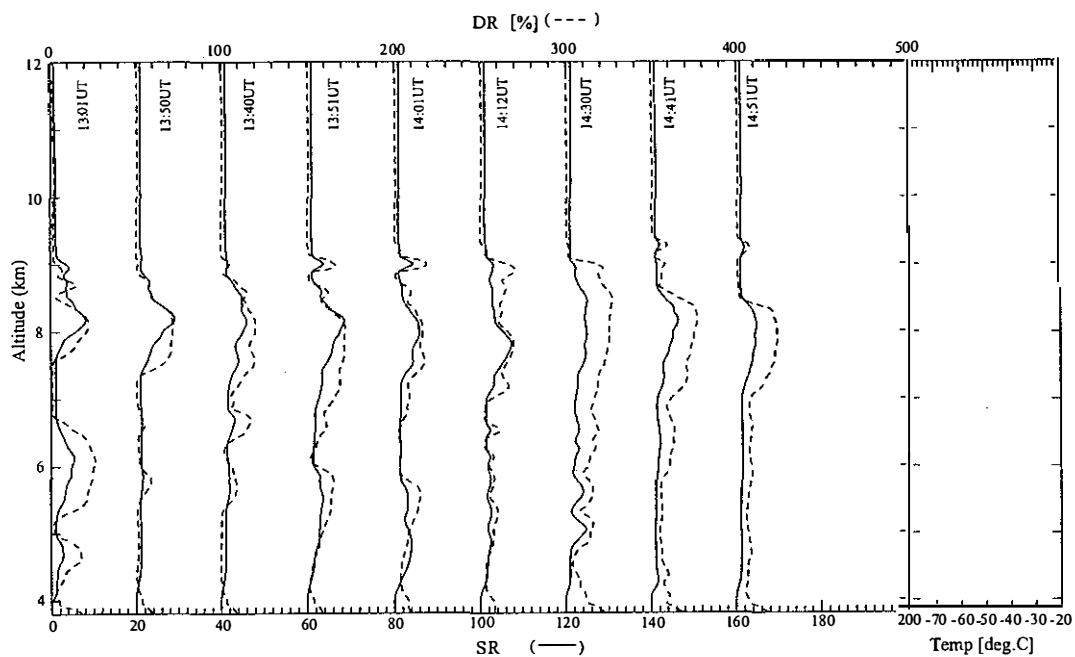
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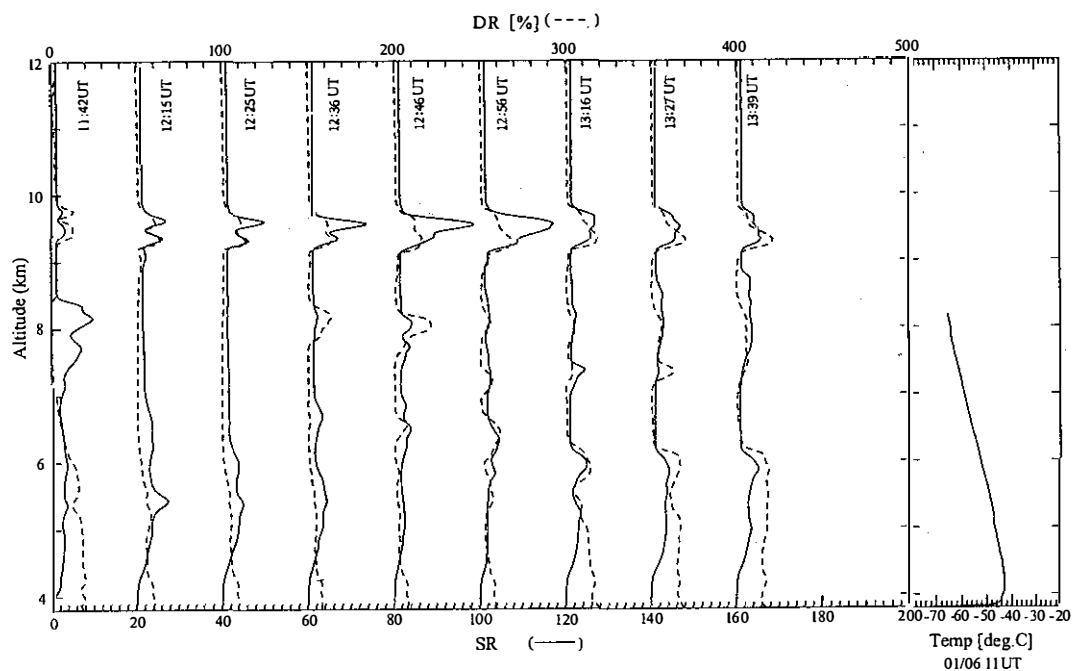
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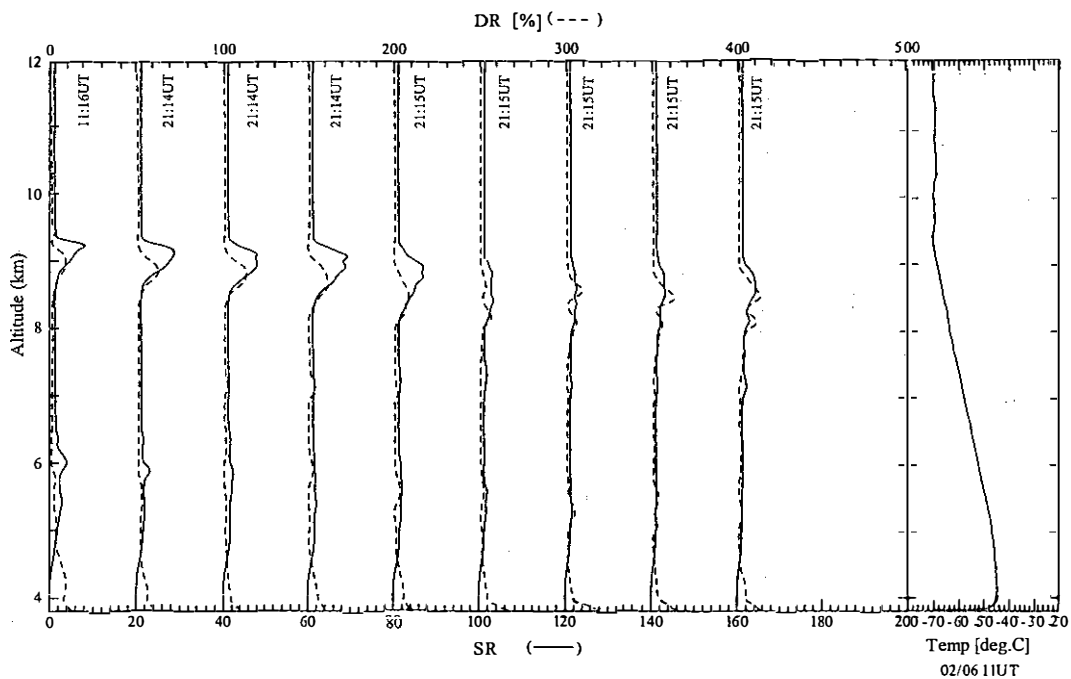
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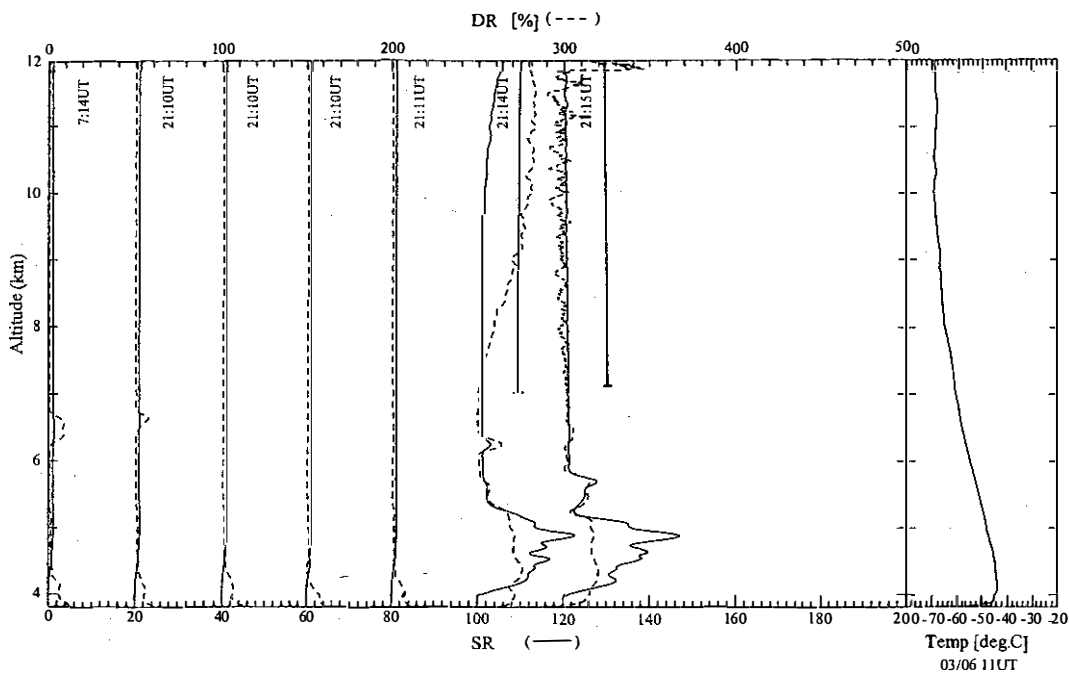
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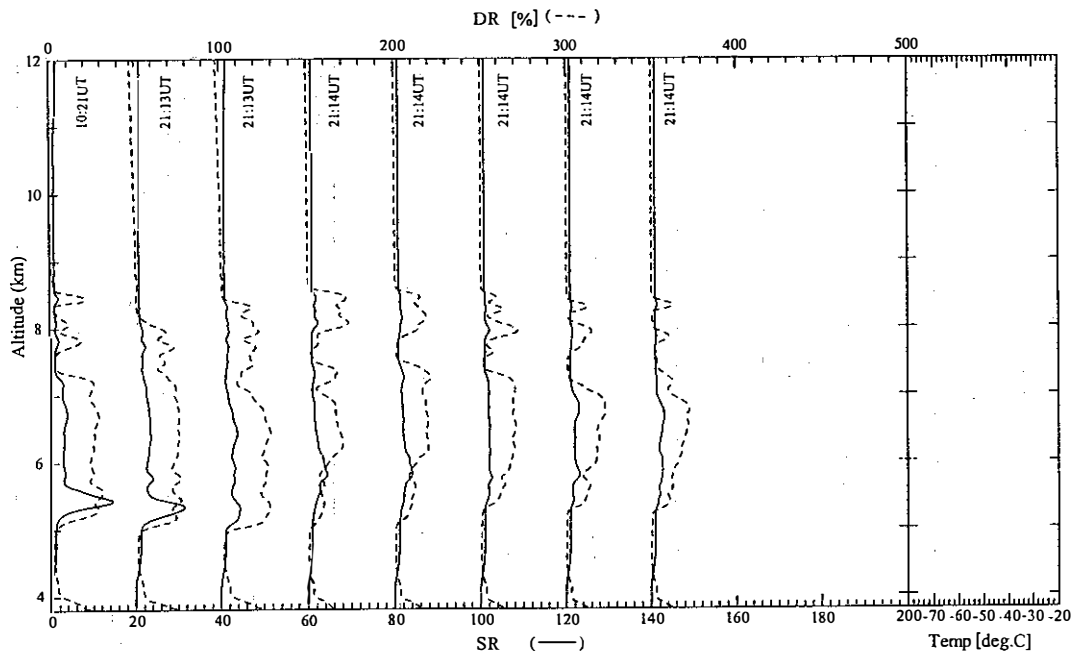
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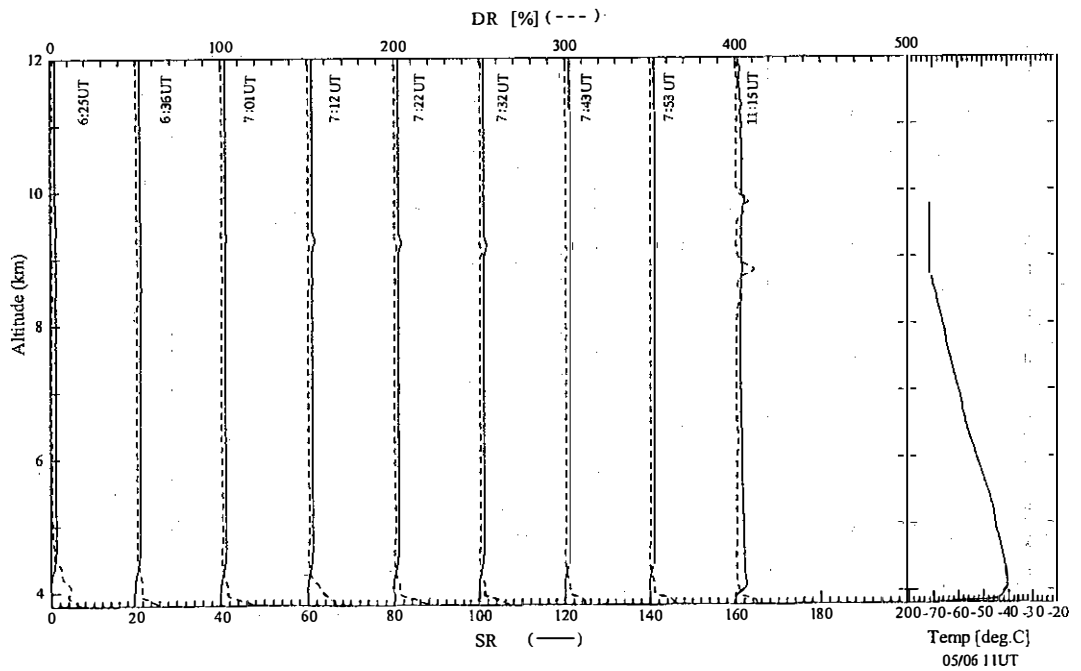
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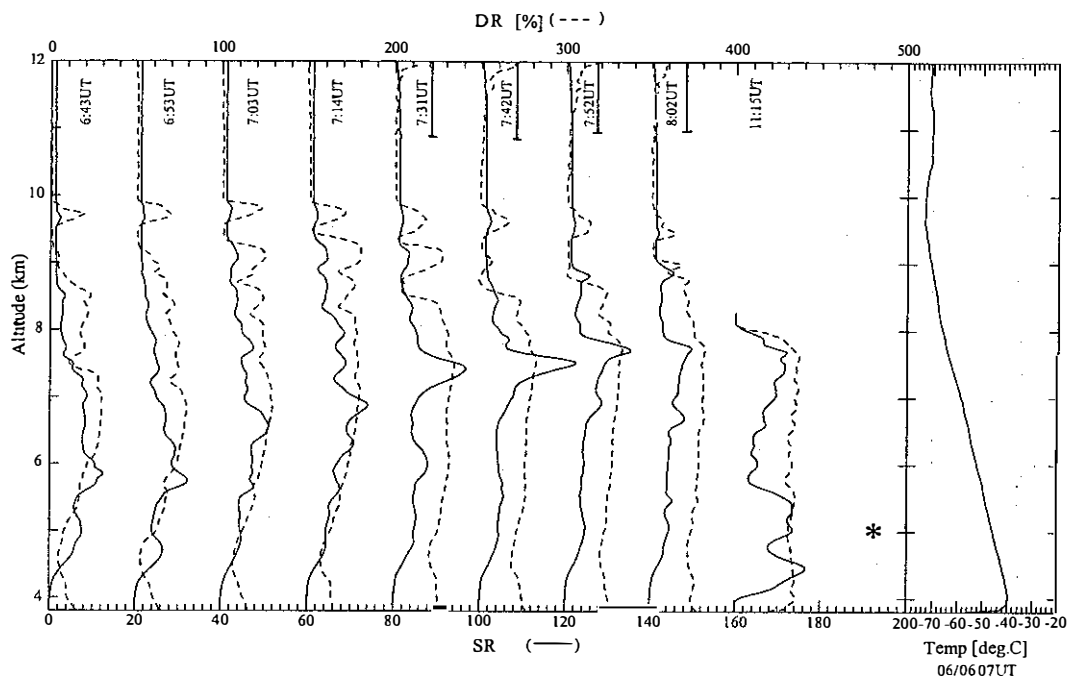
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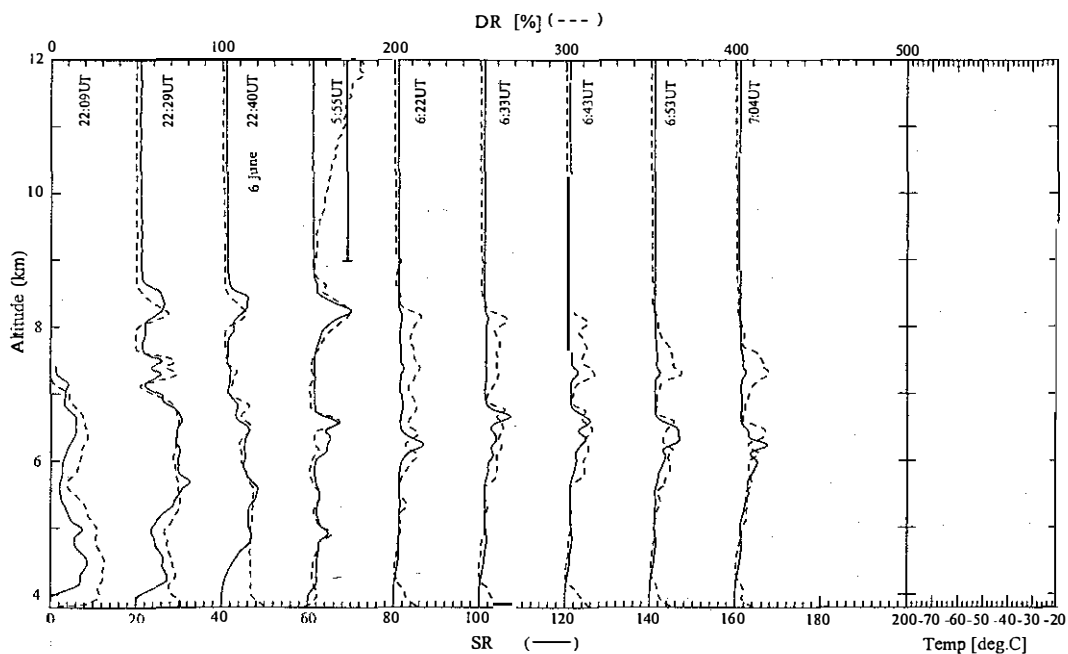
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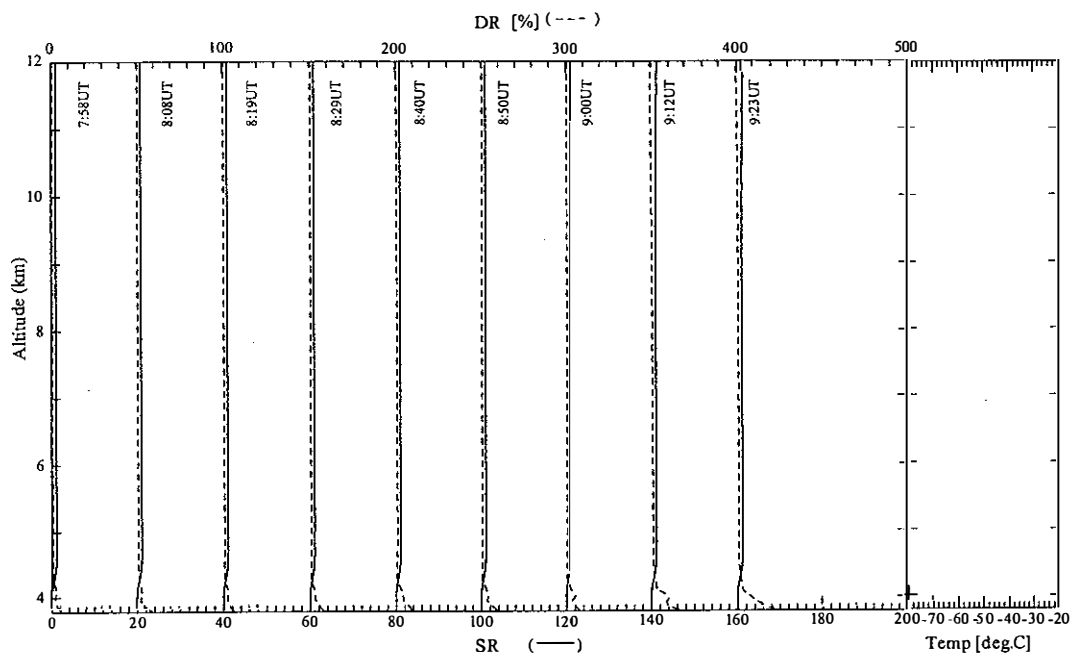
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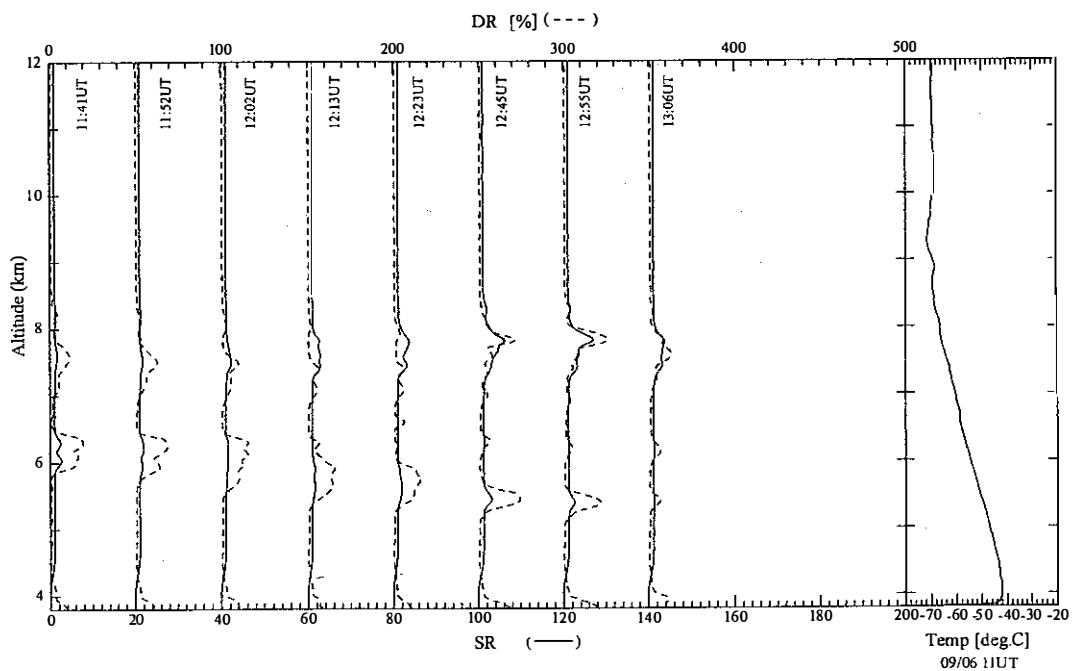
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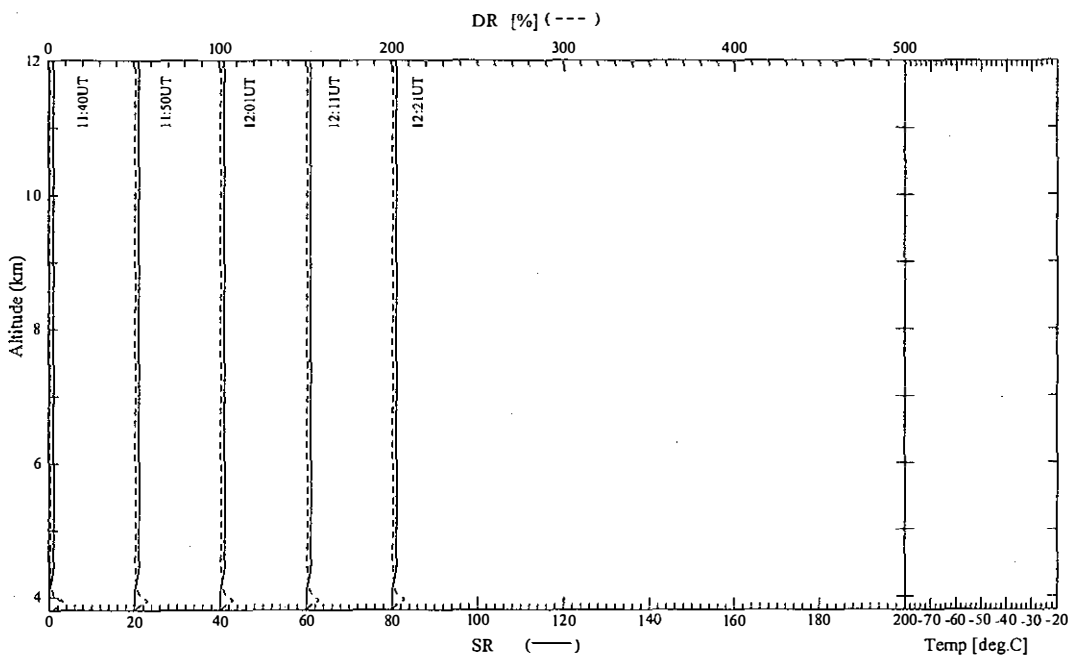
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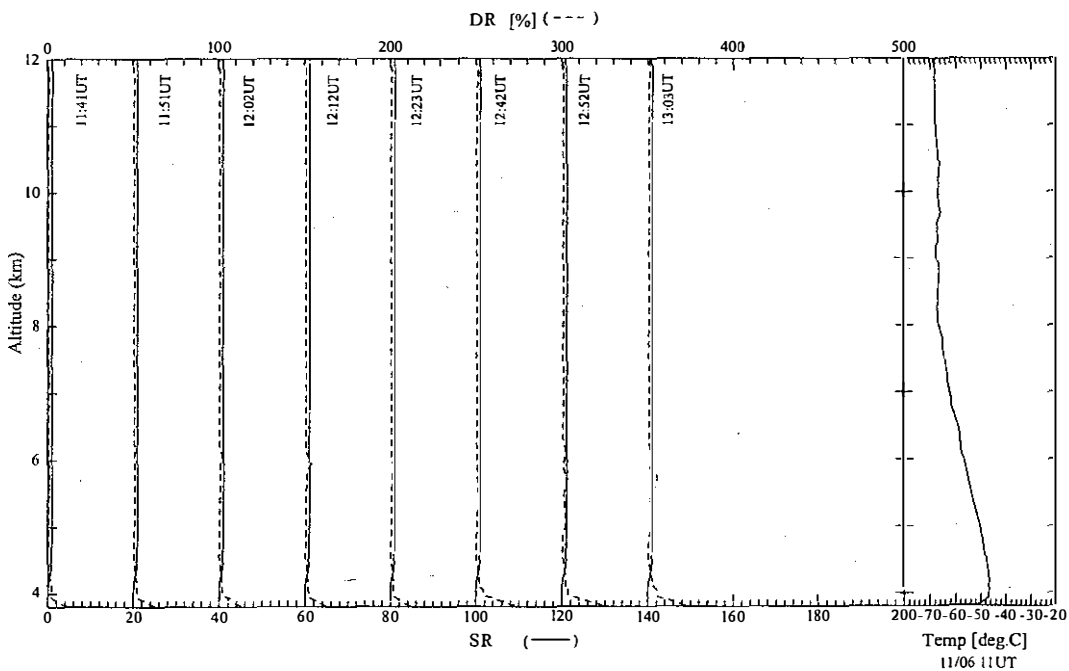
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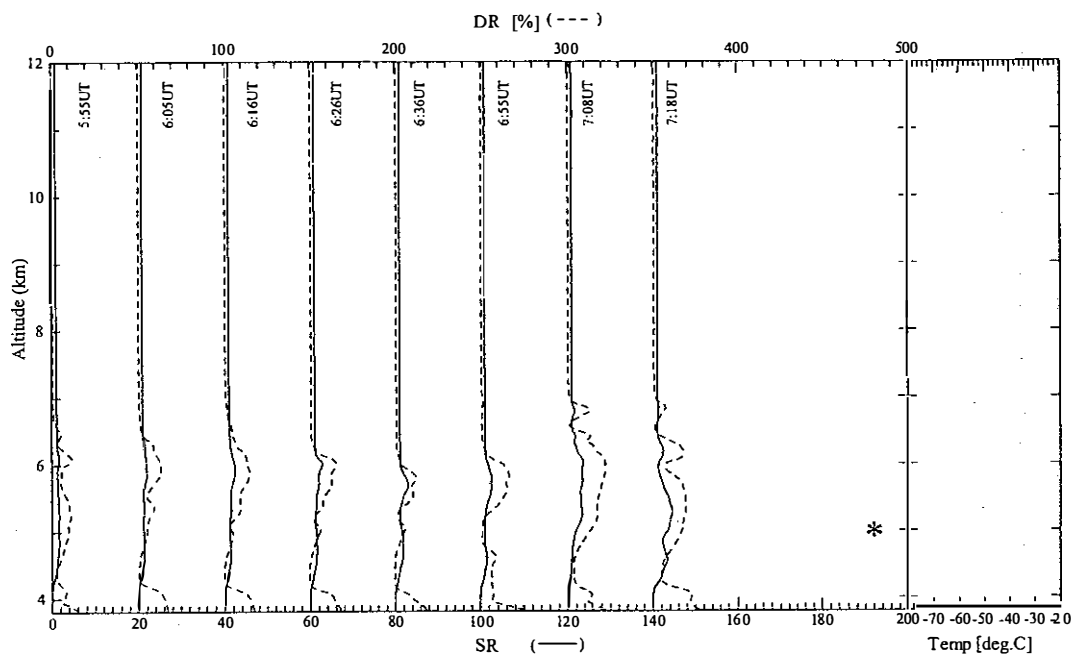
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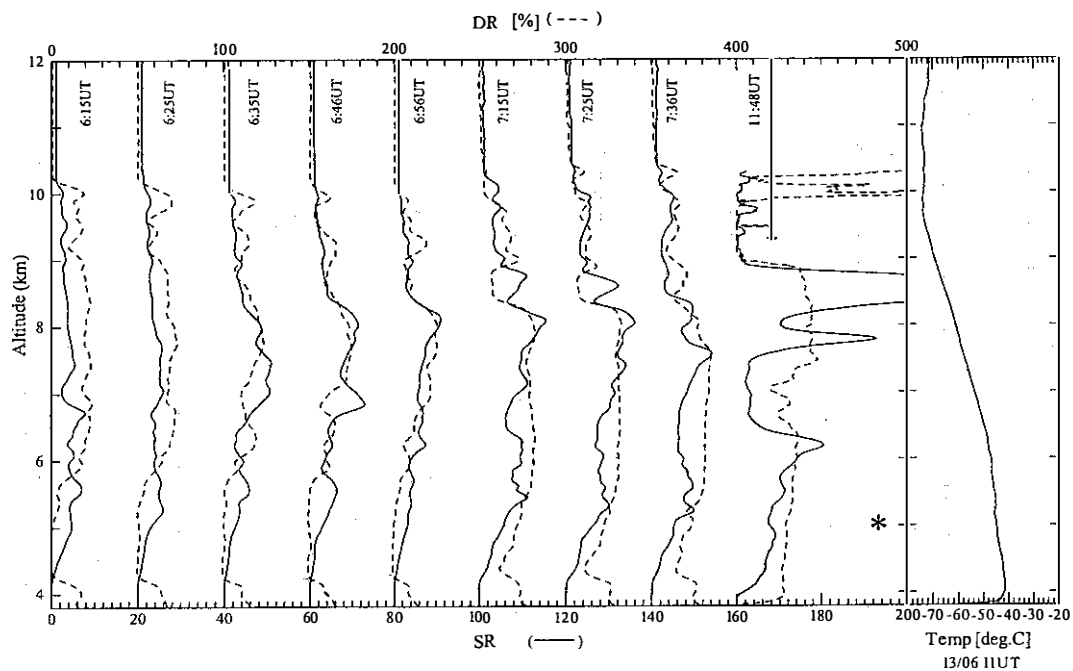
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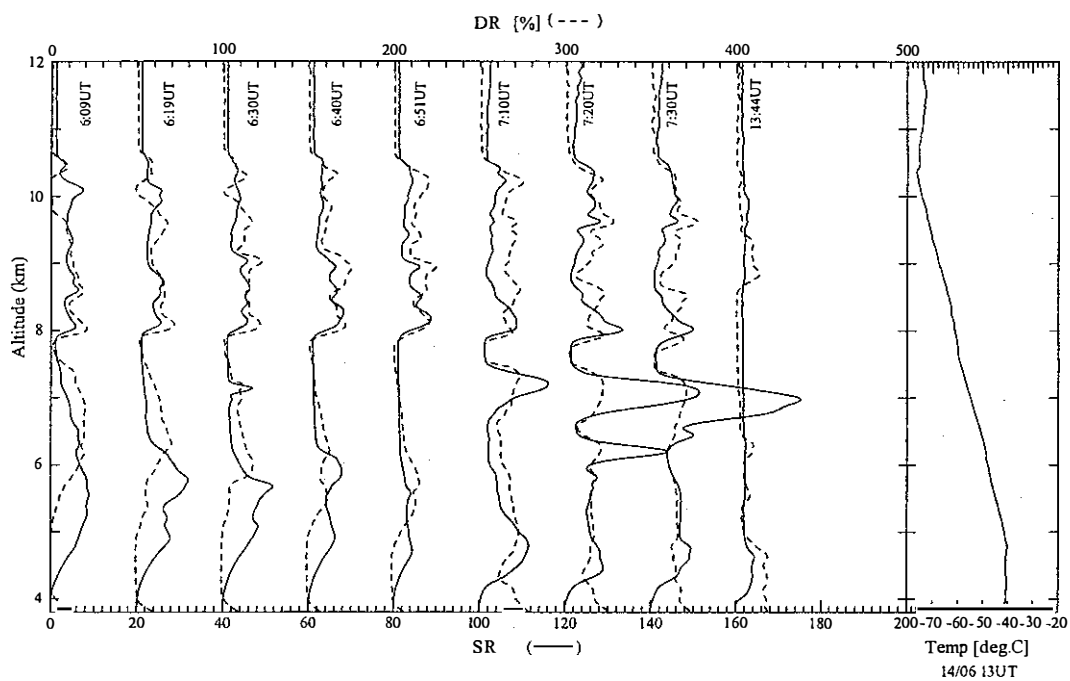
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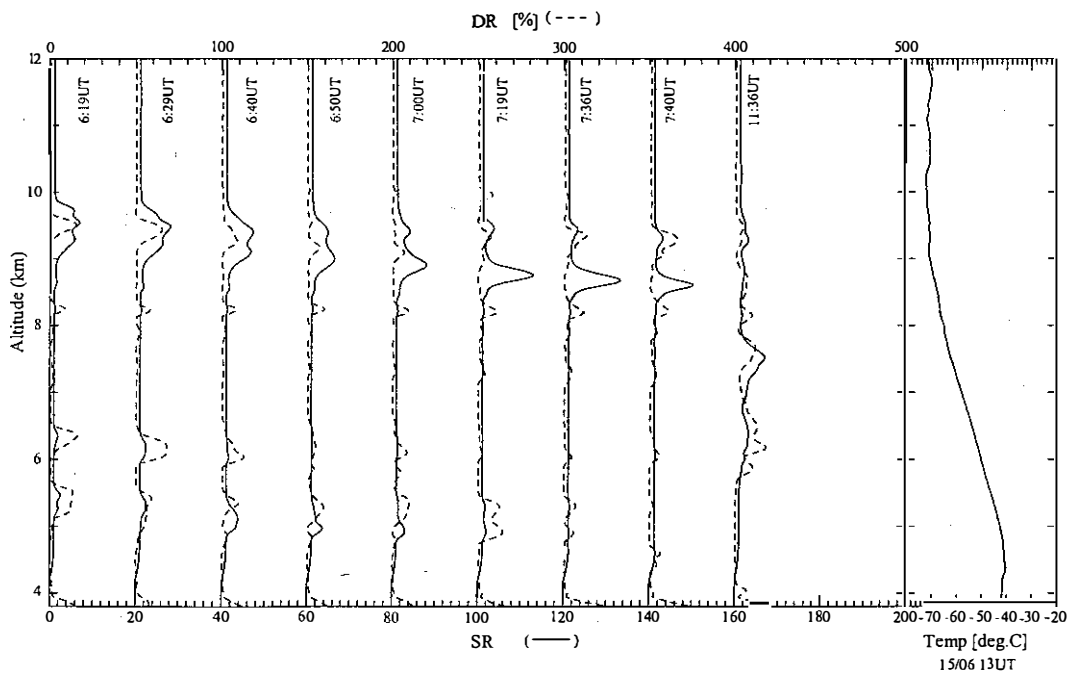
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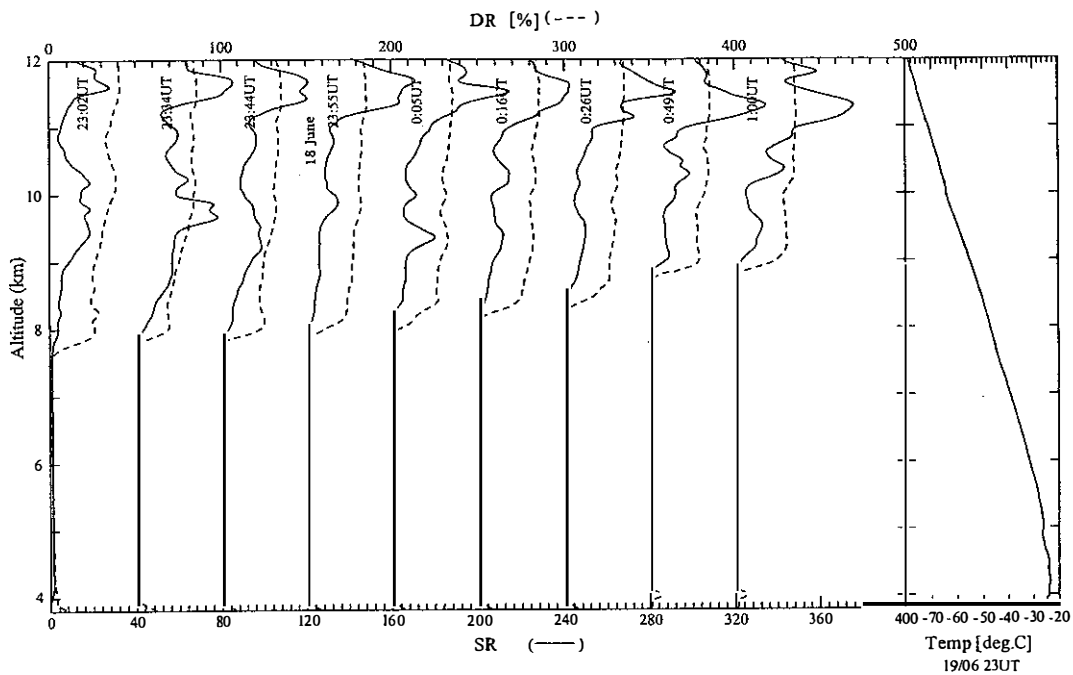
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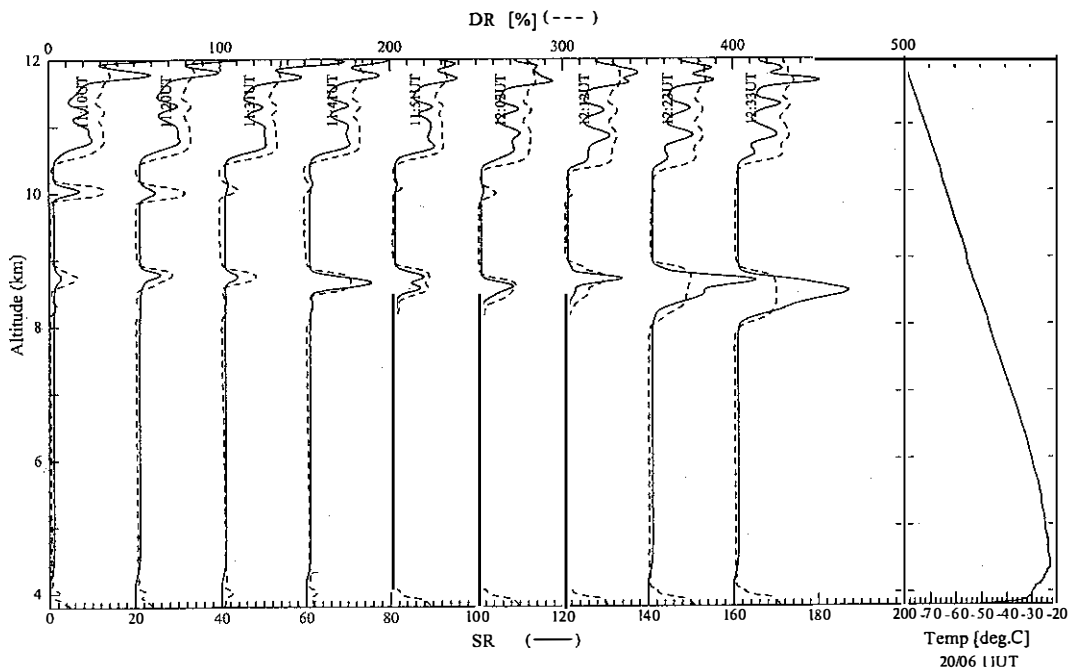
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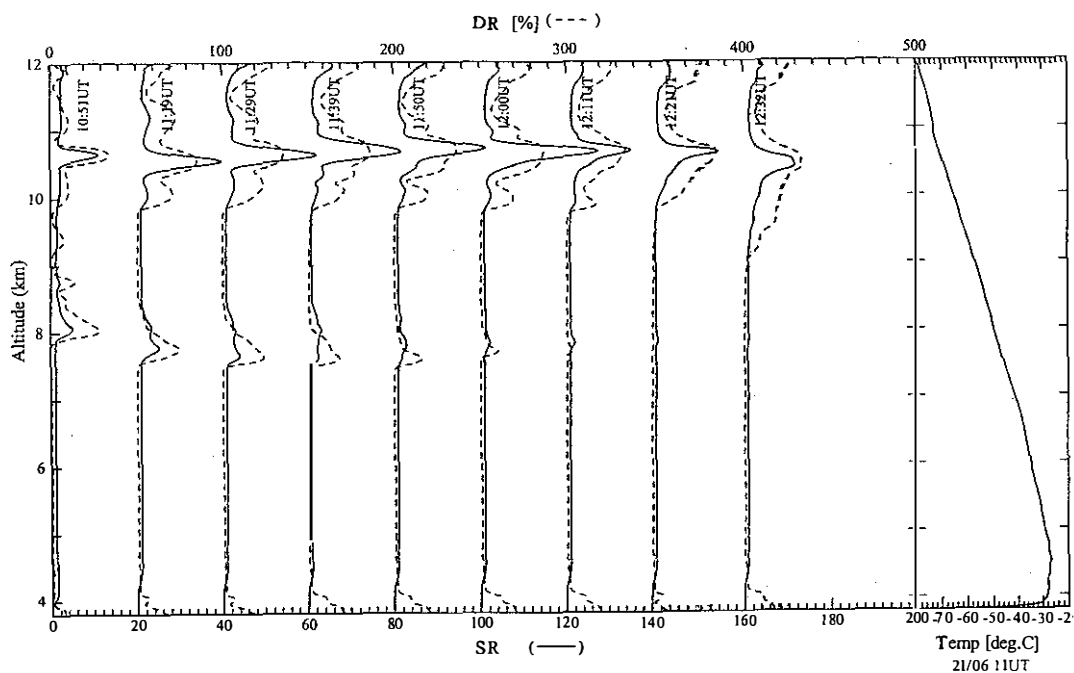
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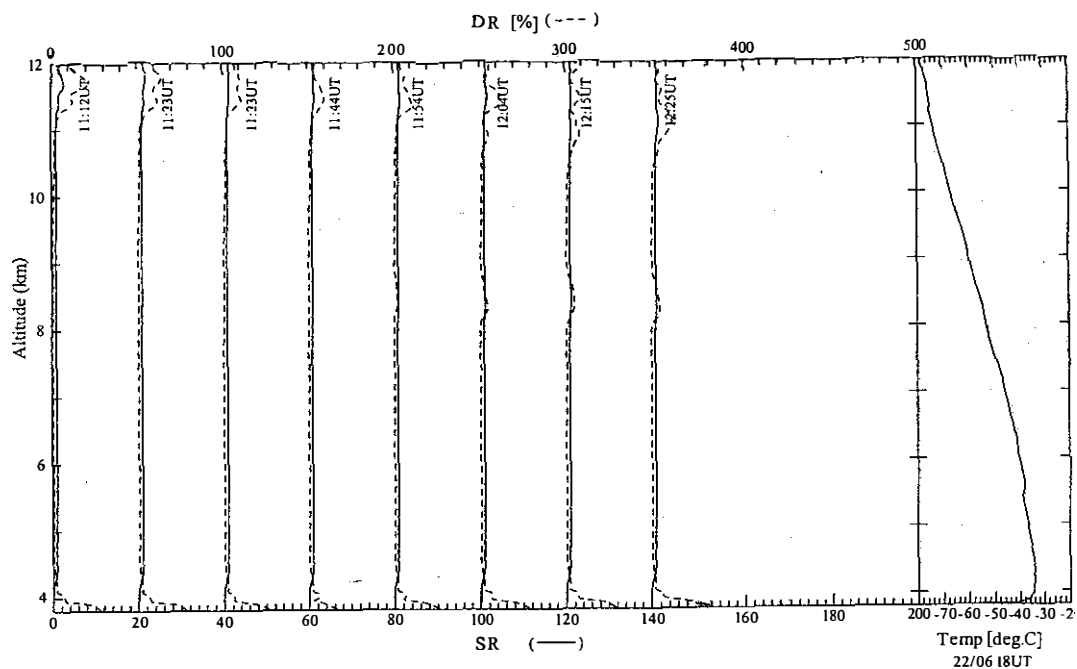
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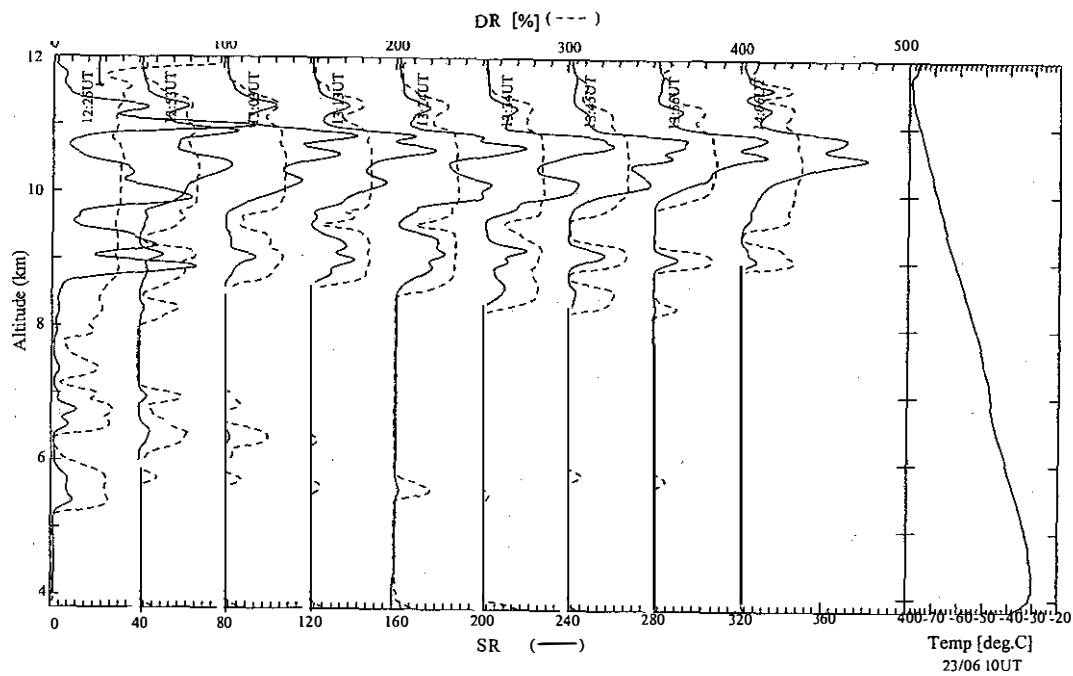
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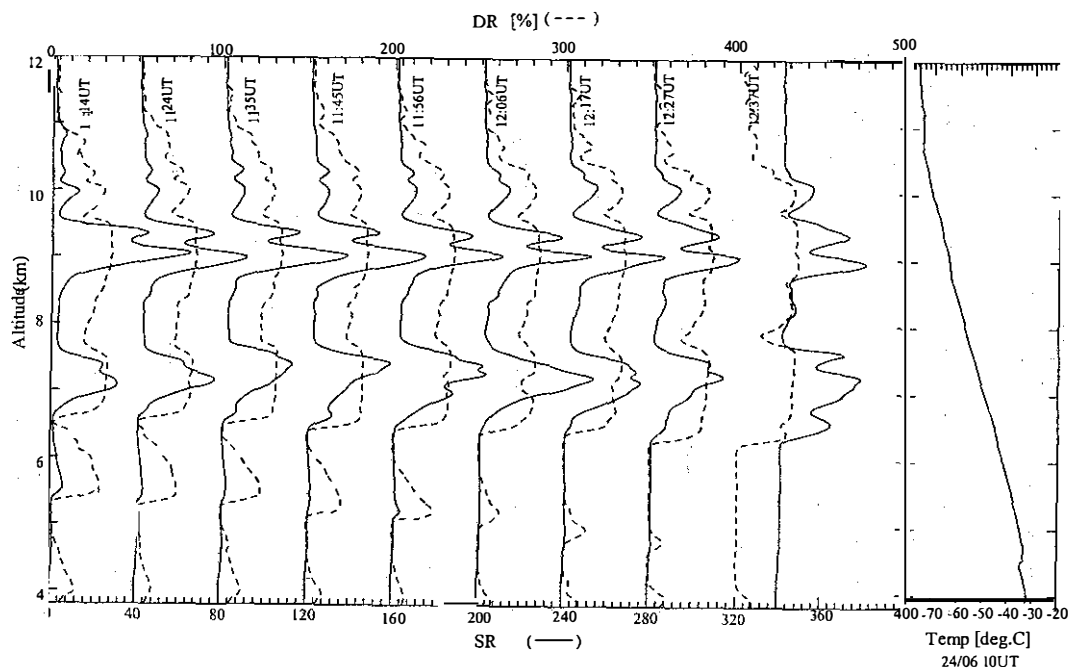
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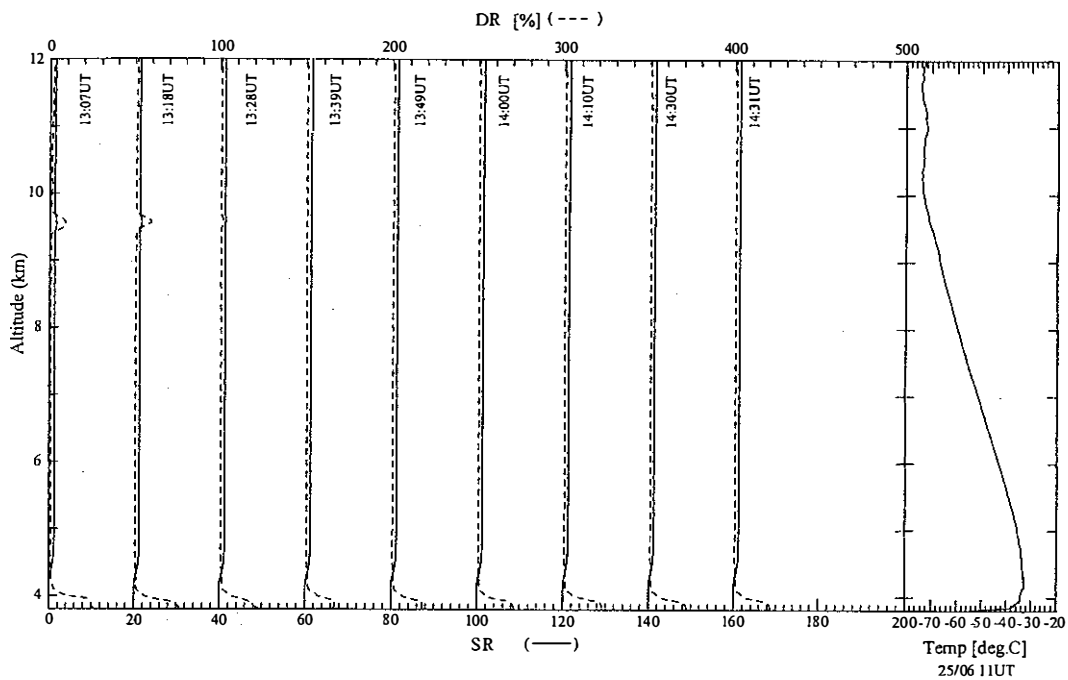
23/06/1997



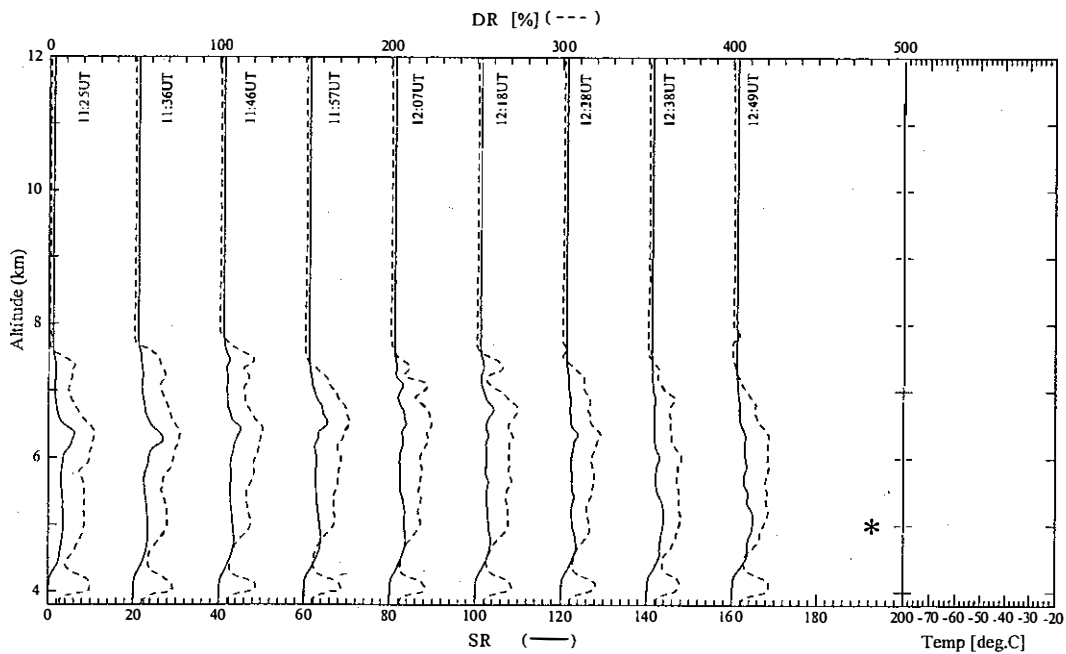
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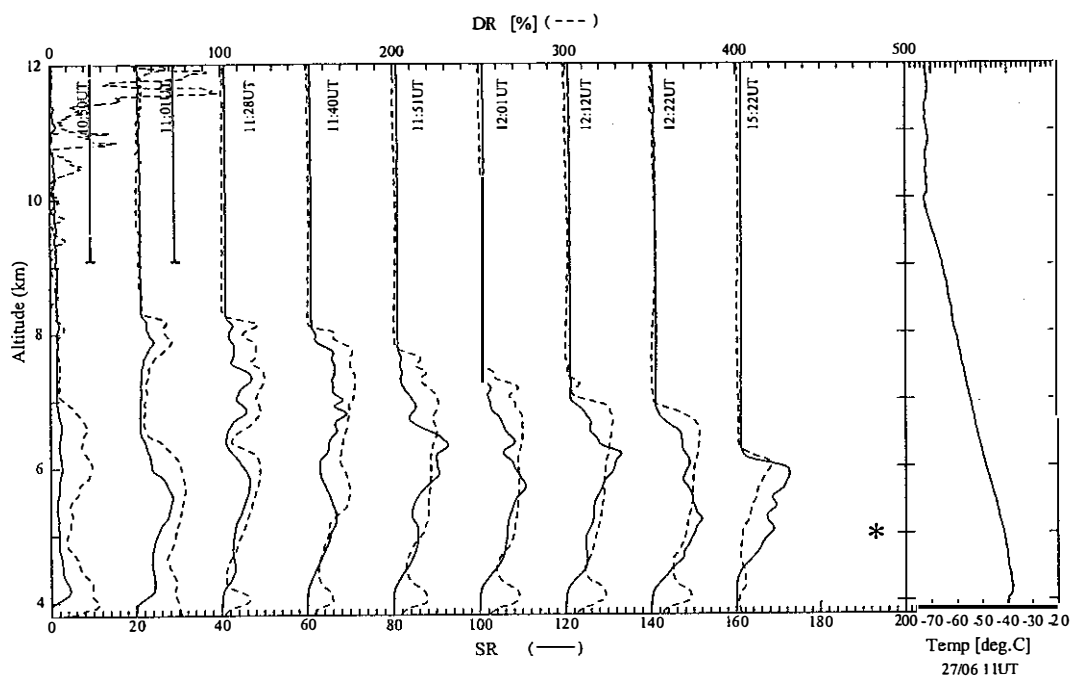
25/06/1997



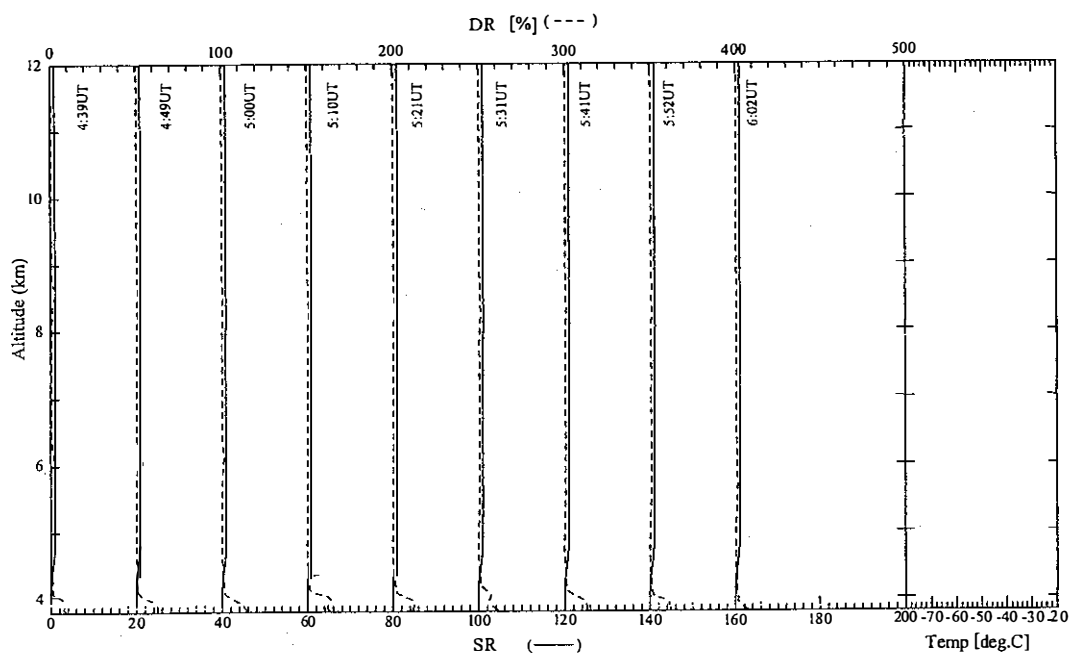
26/06/1997



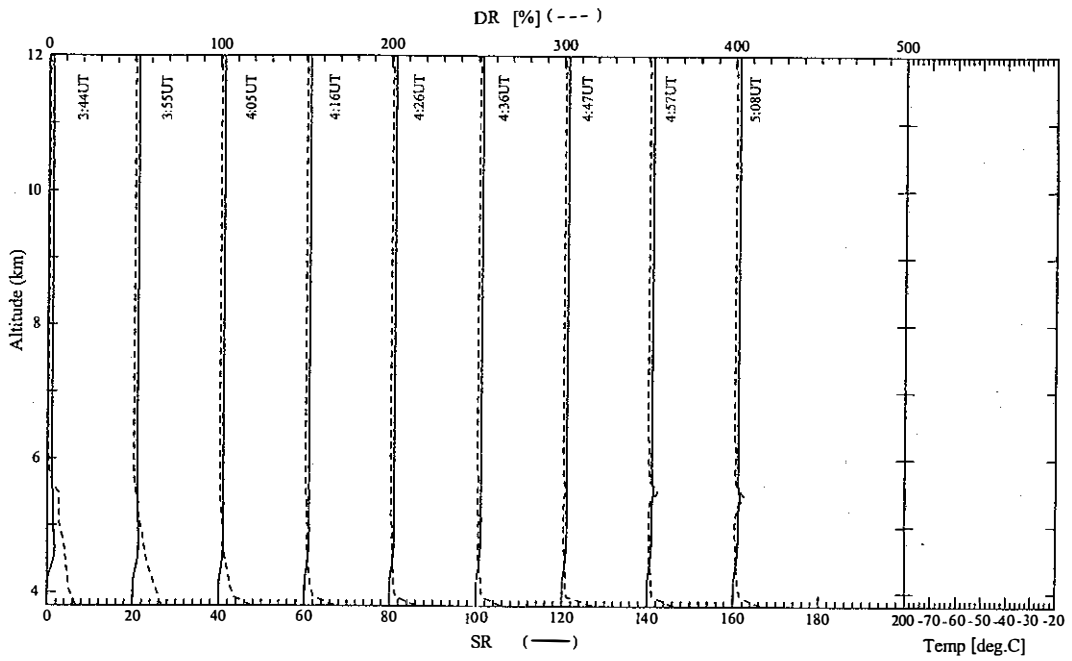
27/06/1997



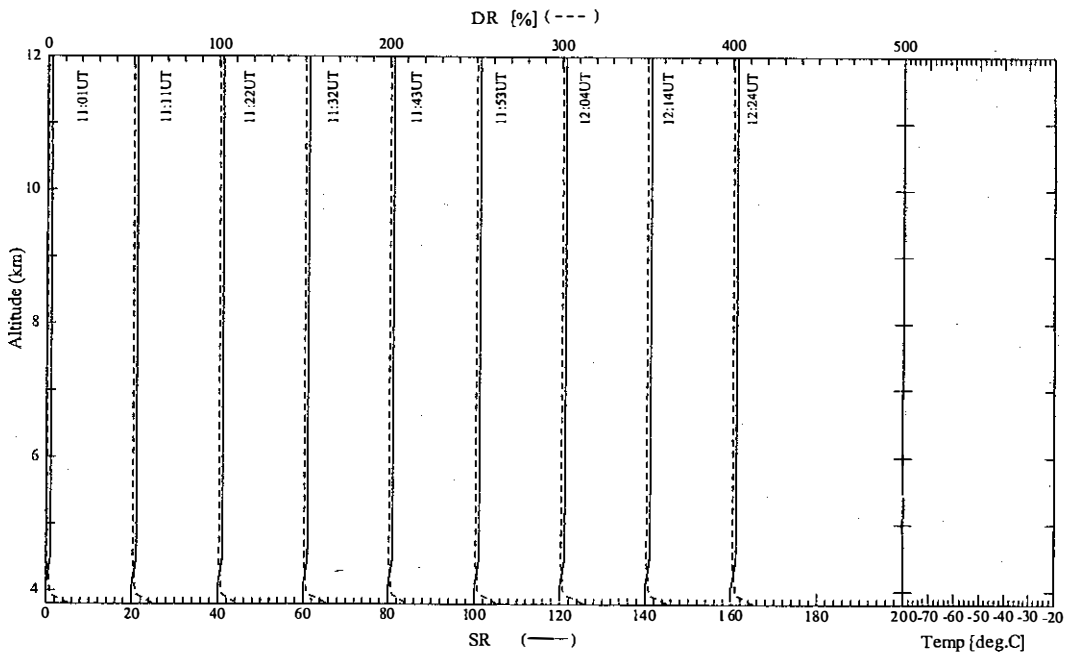
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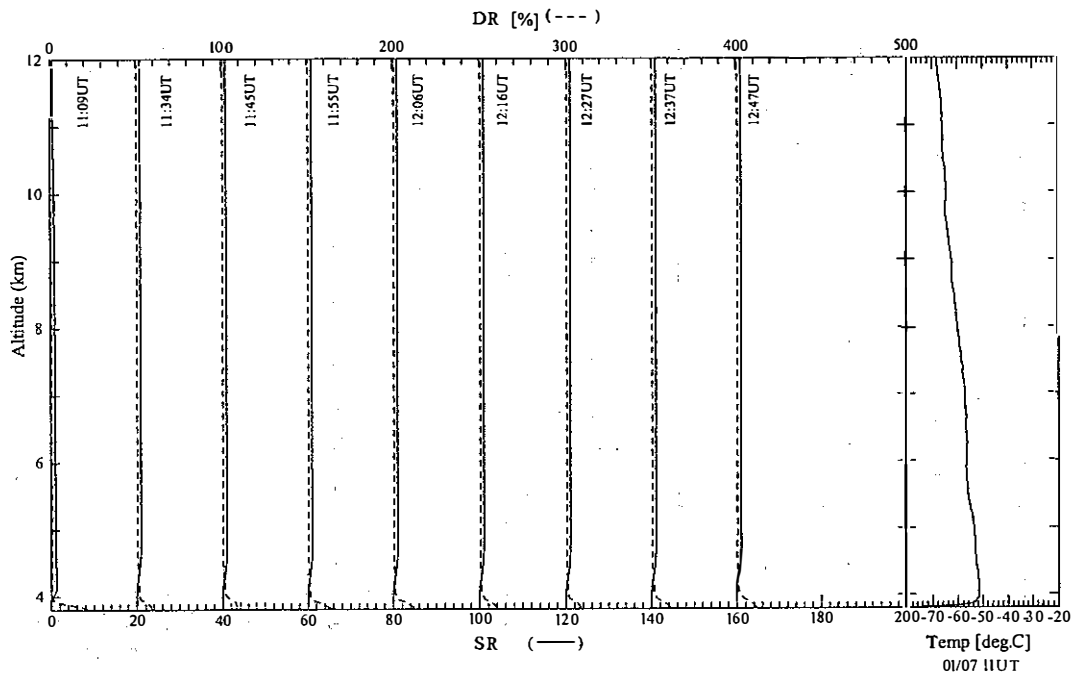
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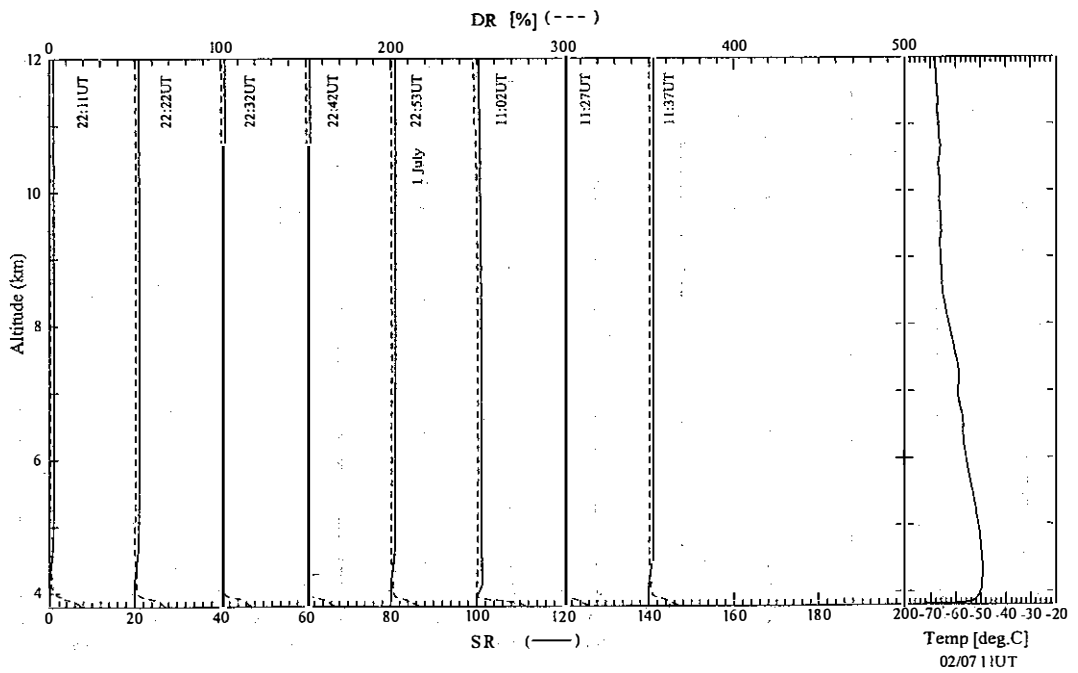
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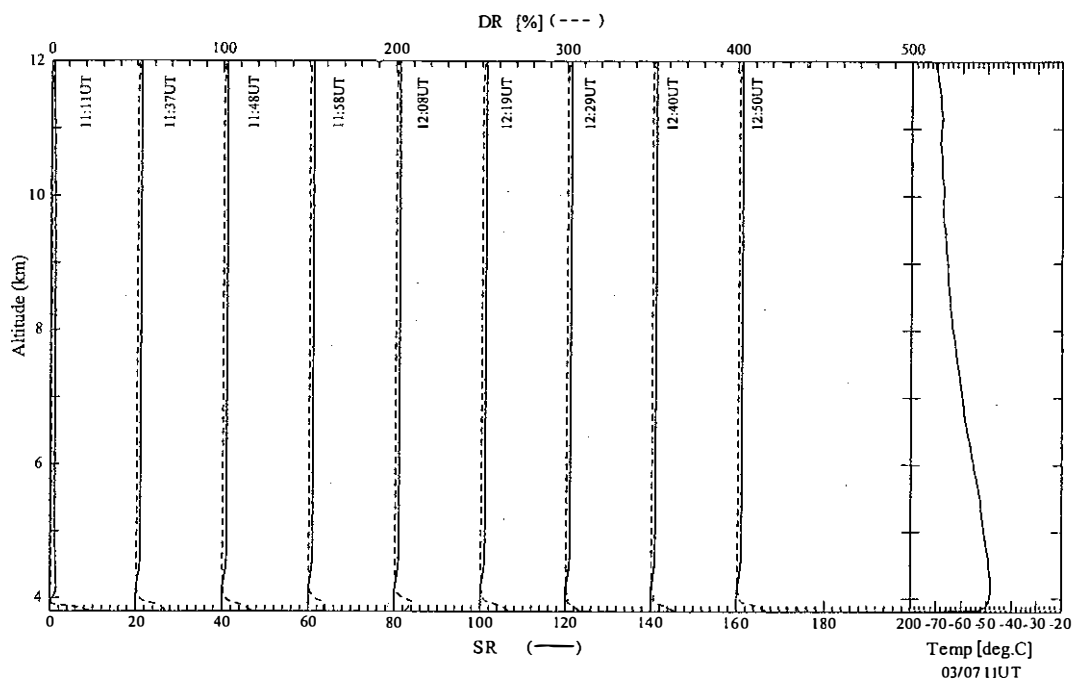
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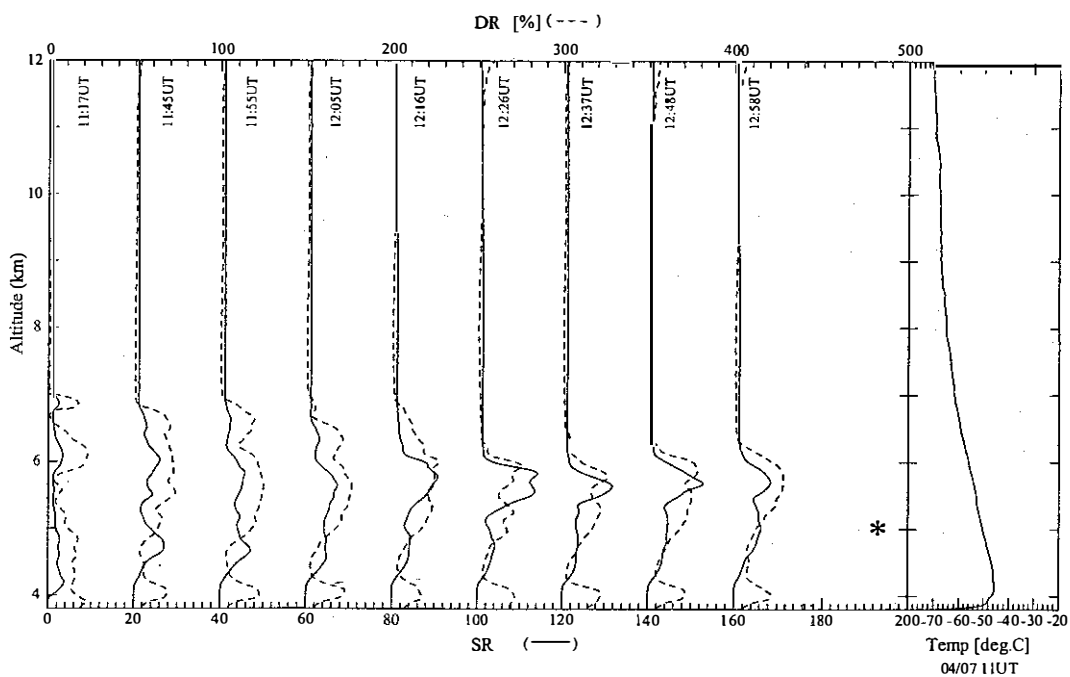
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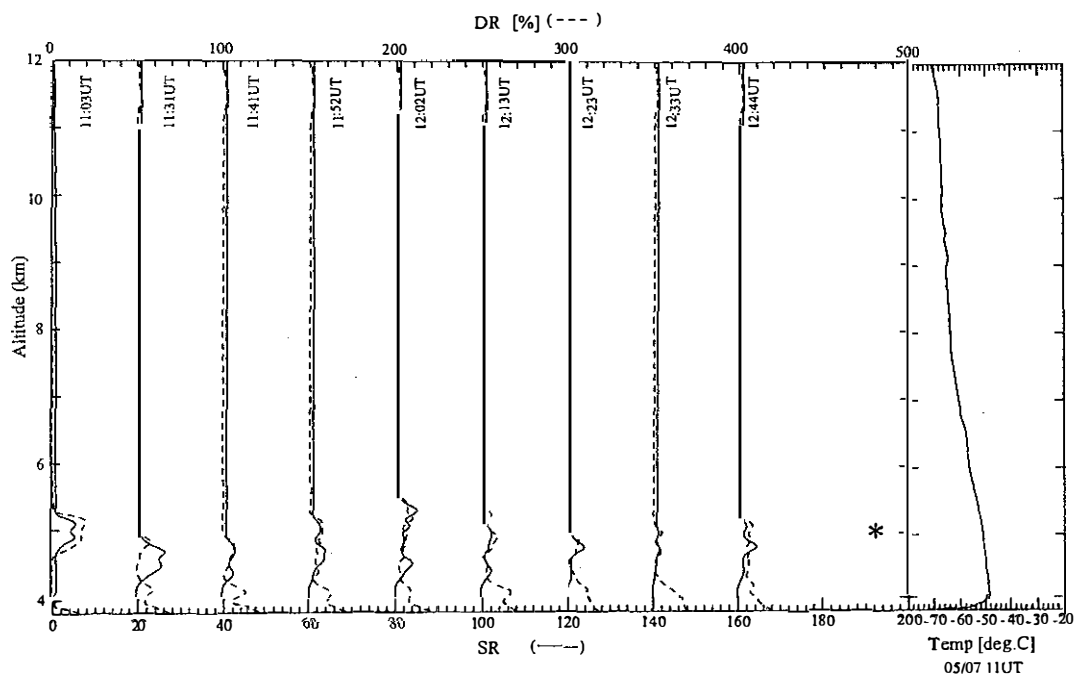
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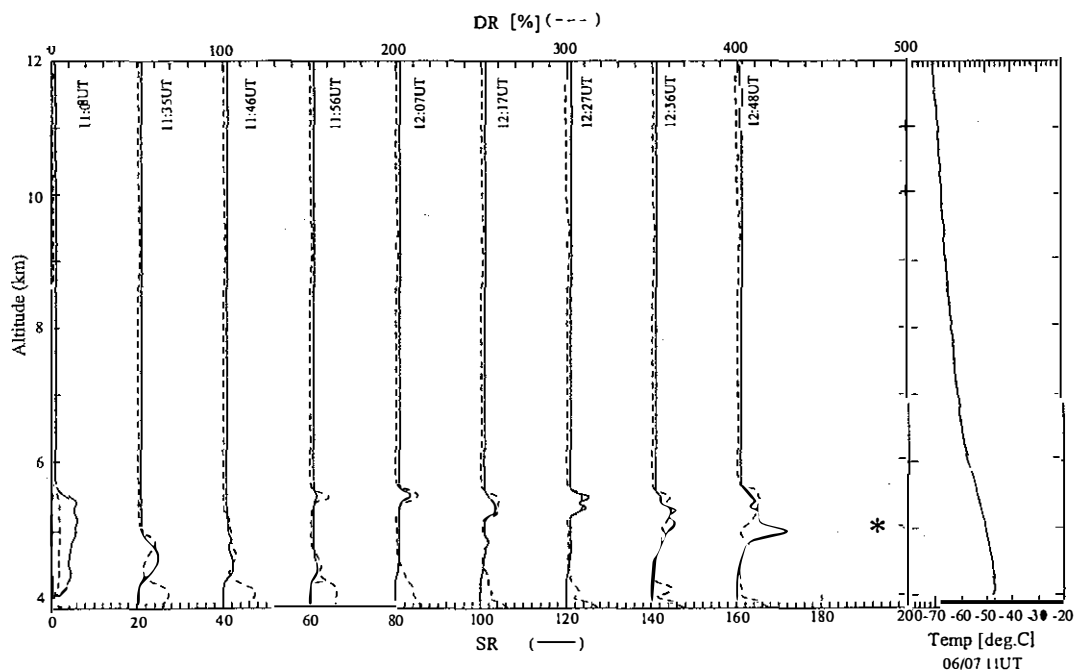
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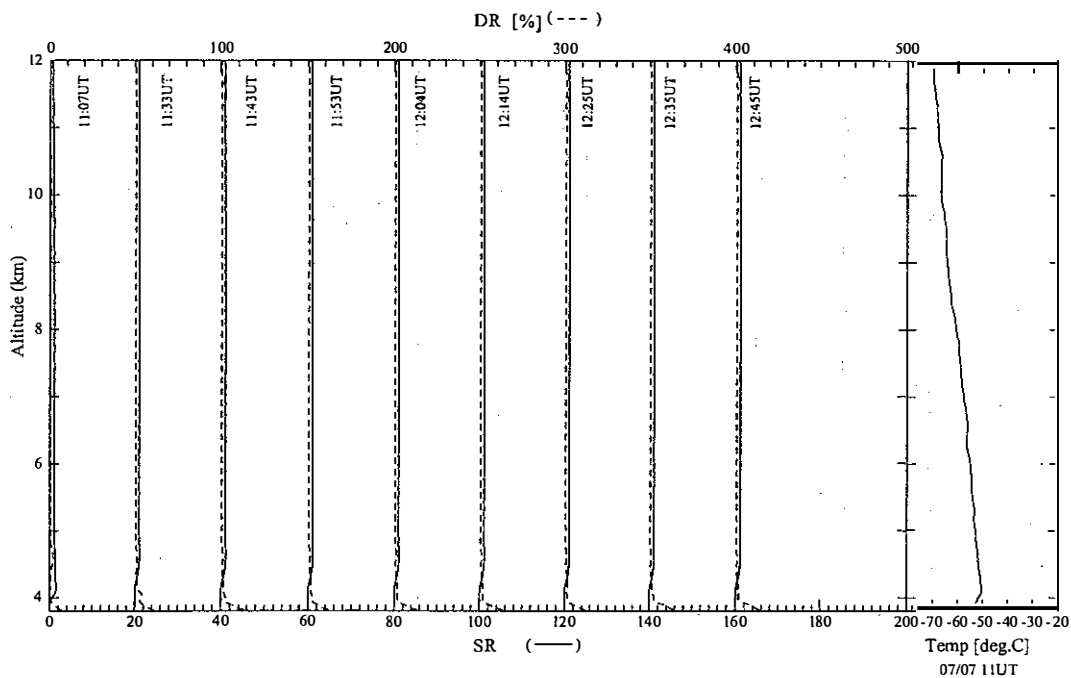
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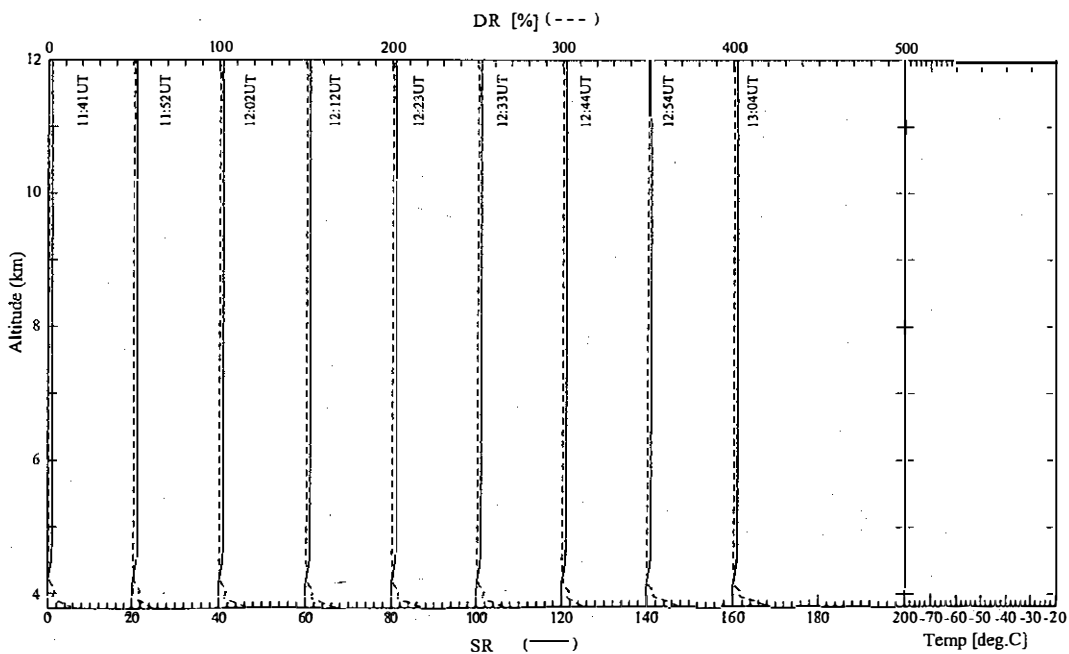
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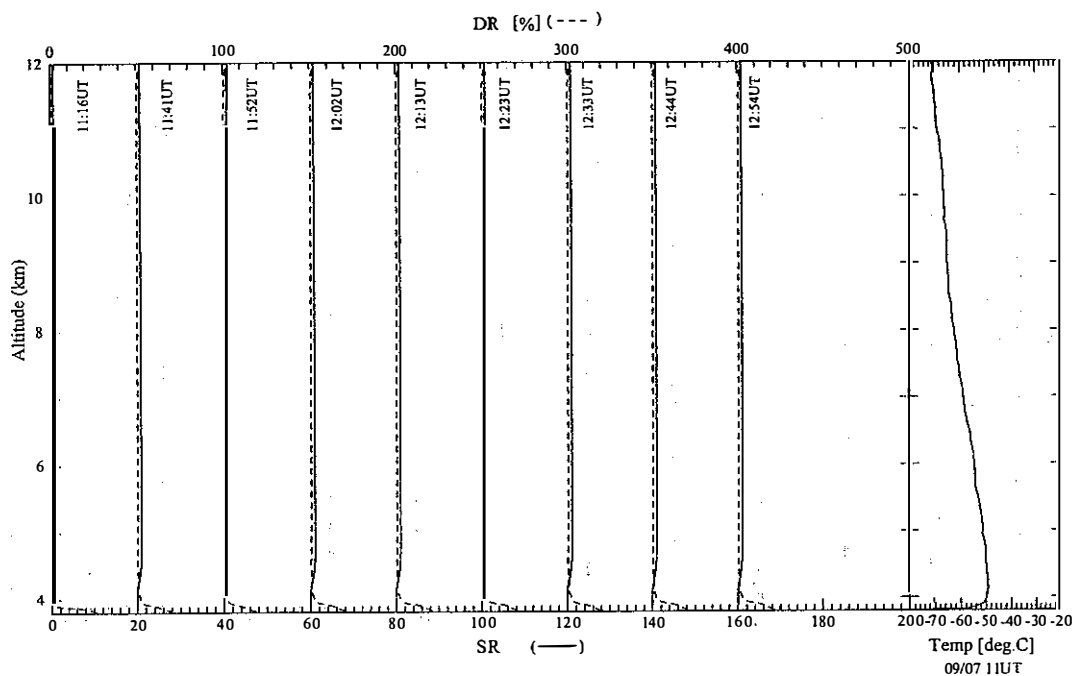
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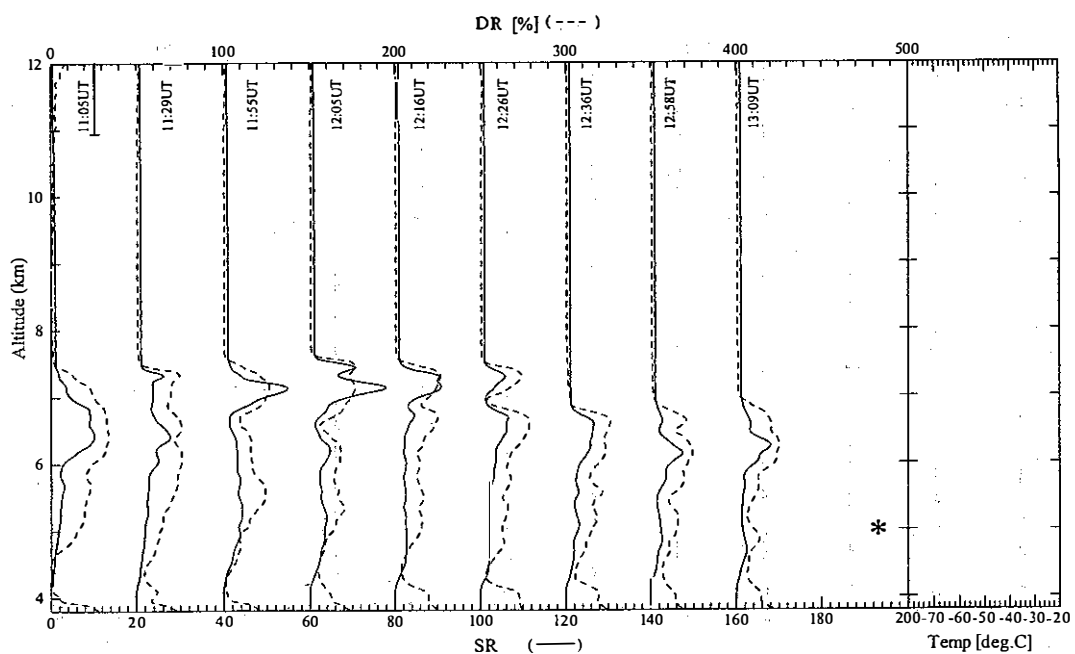
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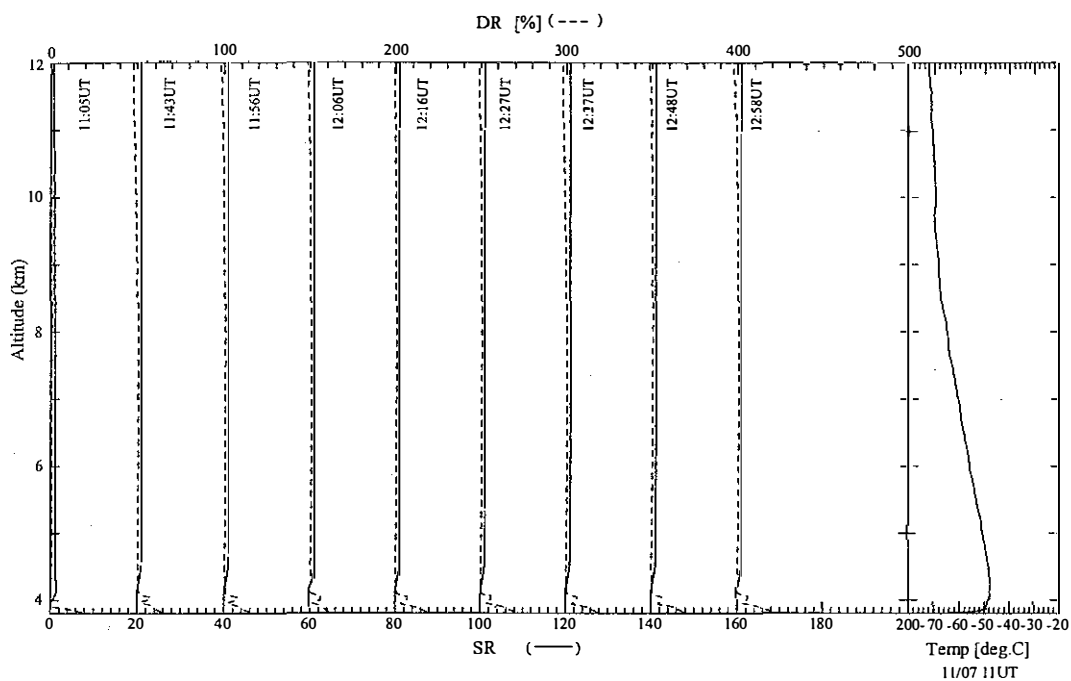
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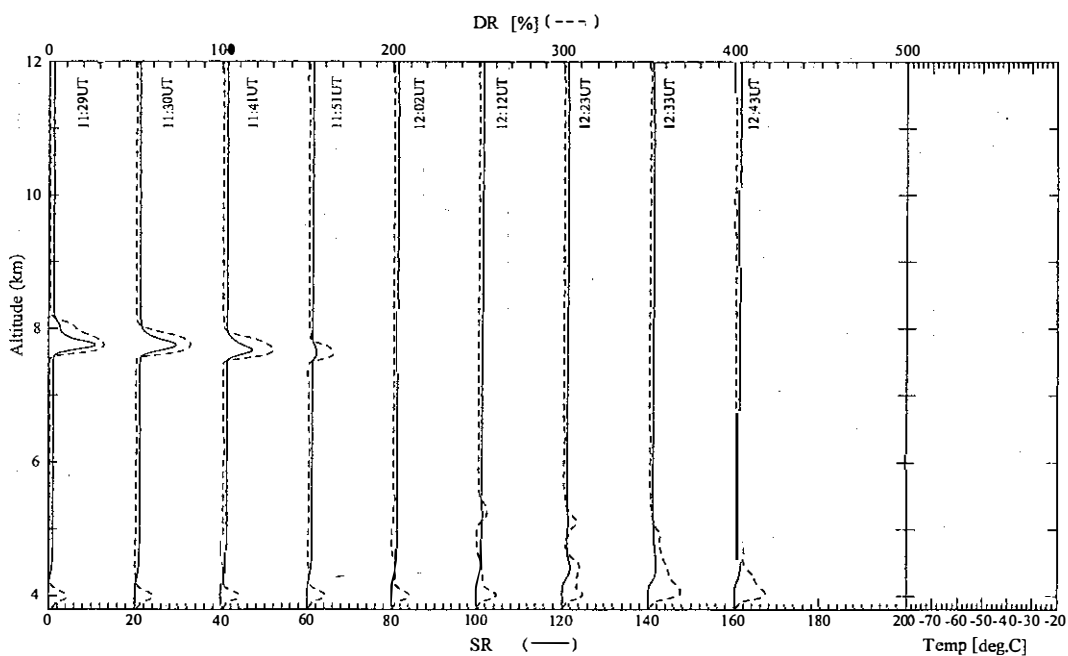
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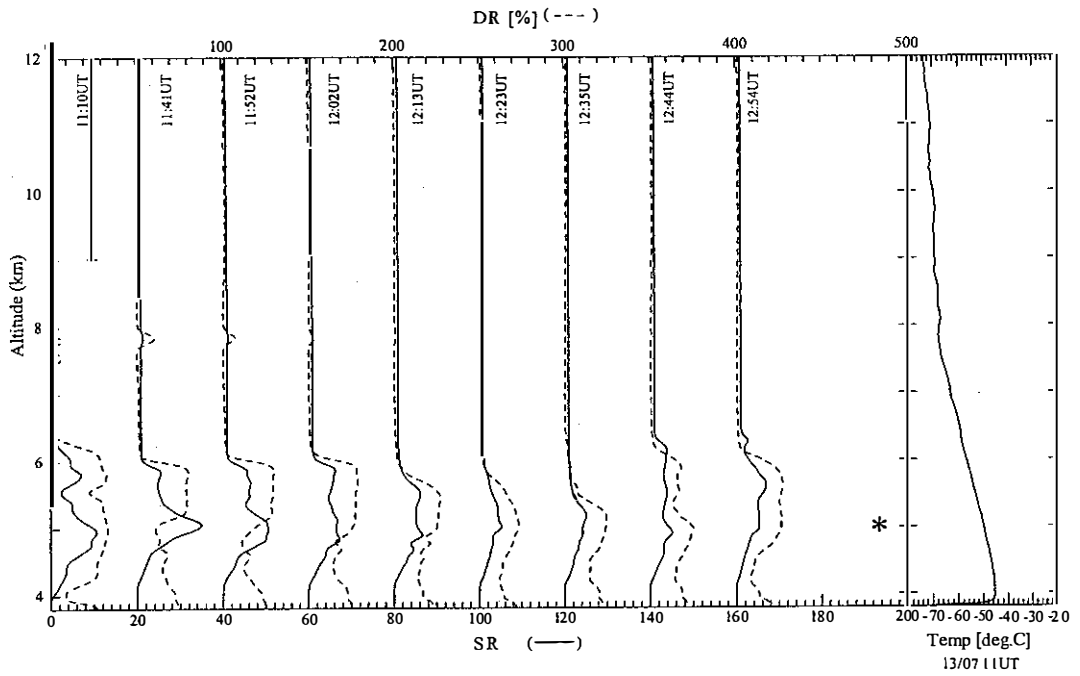
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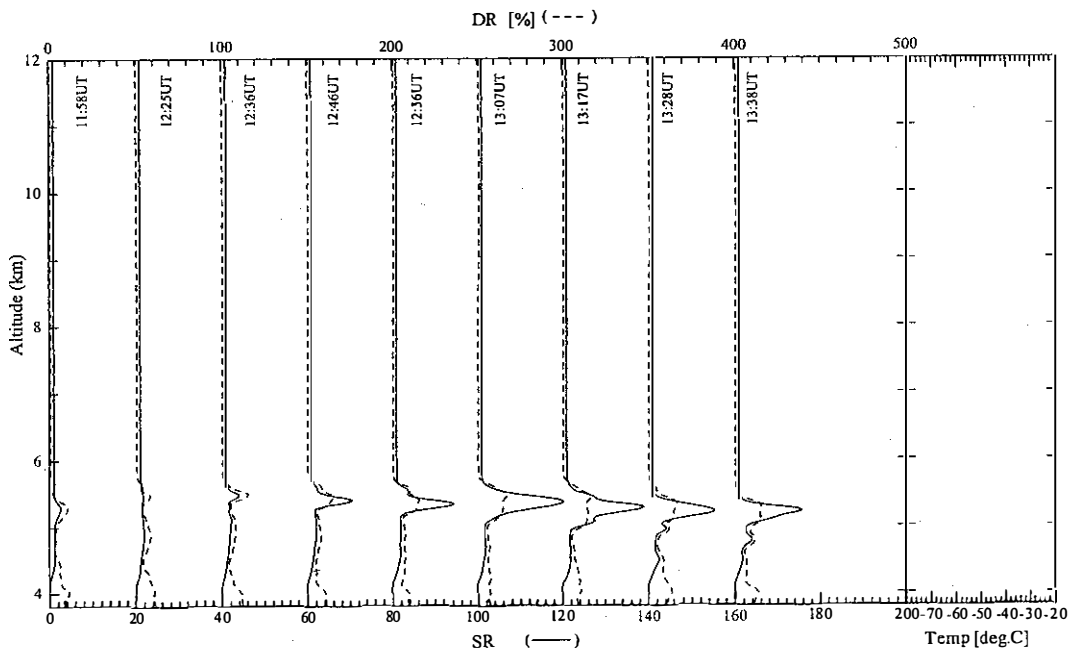
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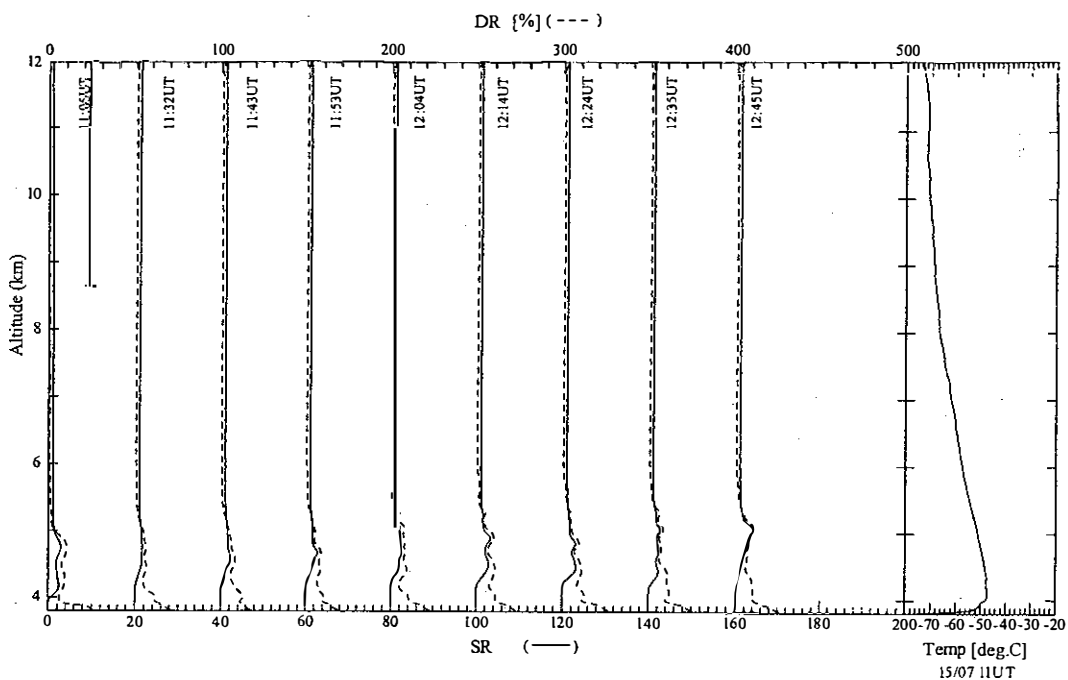
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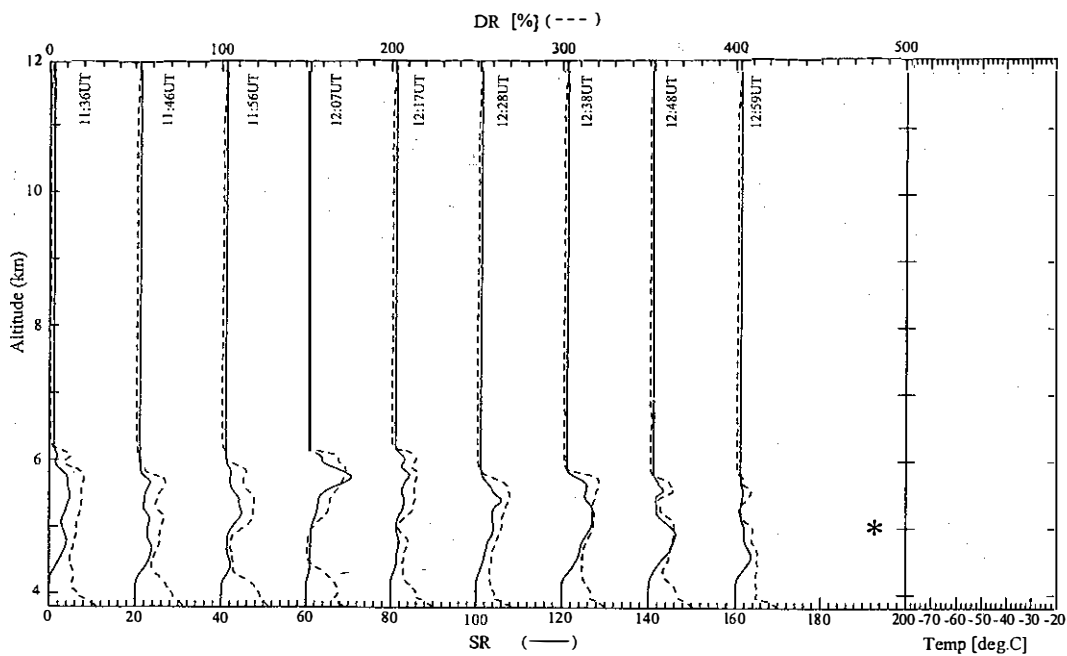
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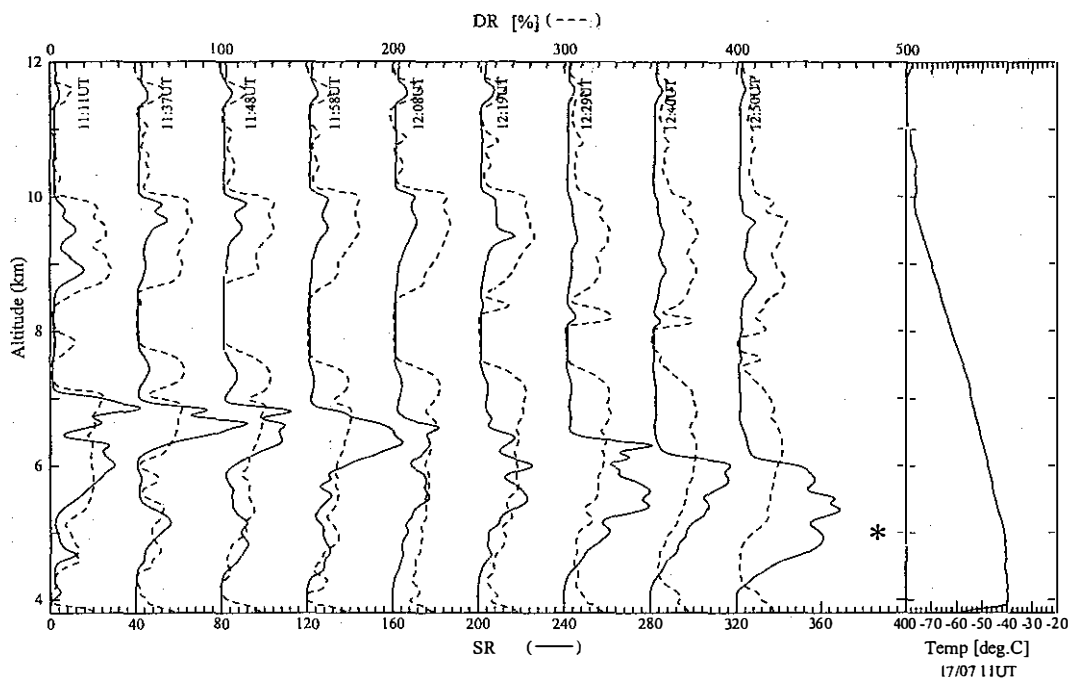
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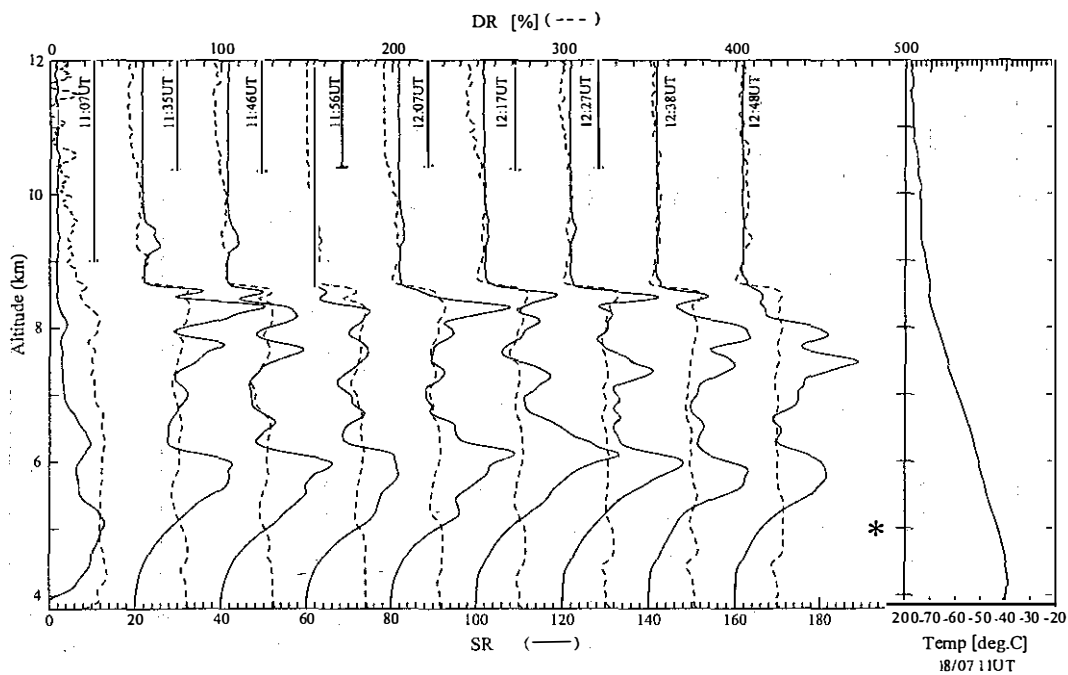
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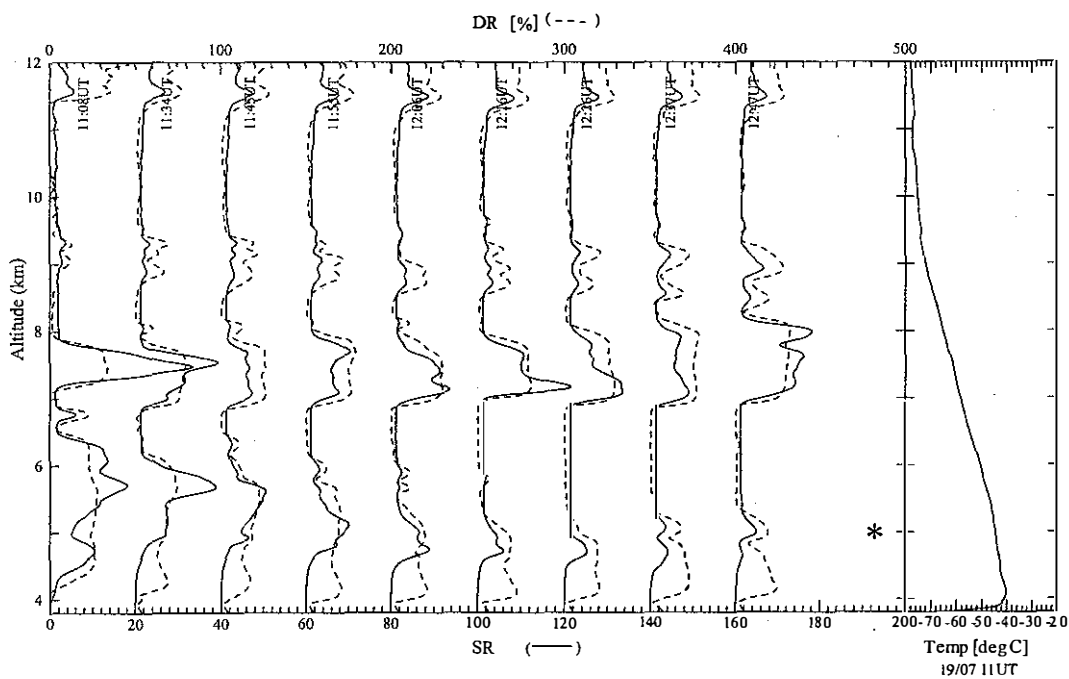
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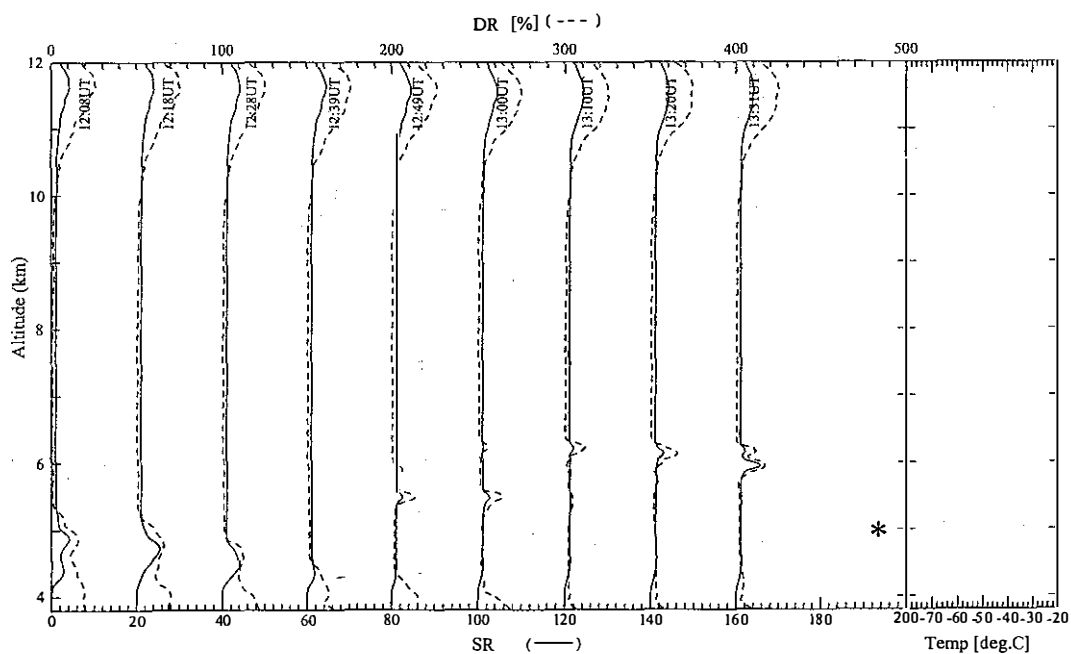
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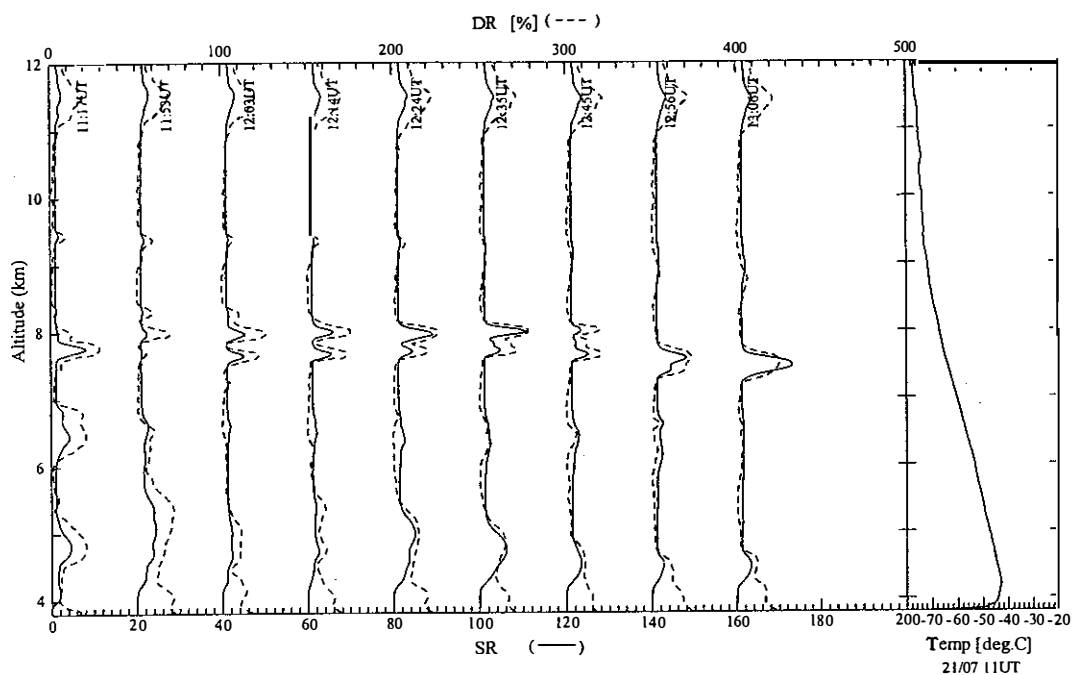
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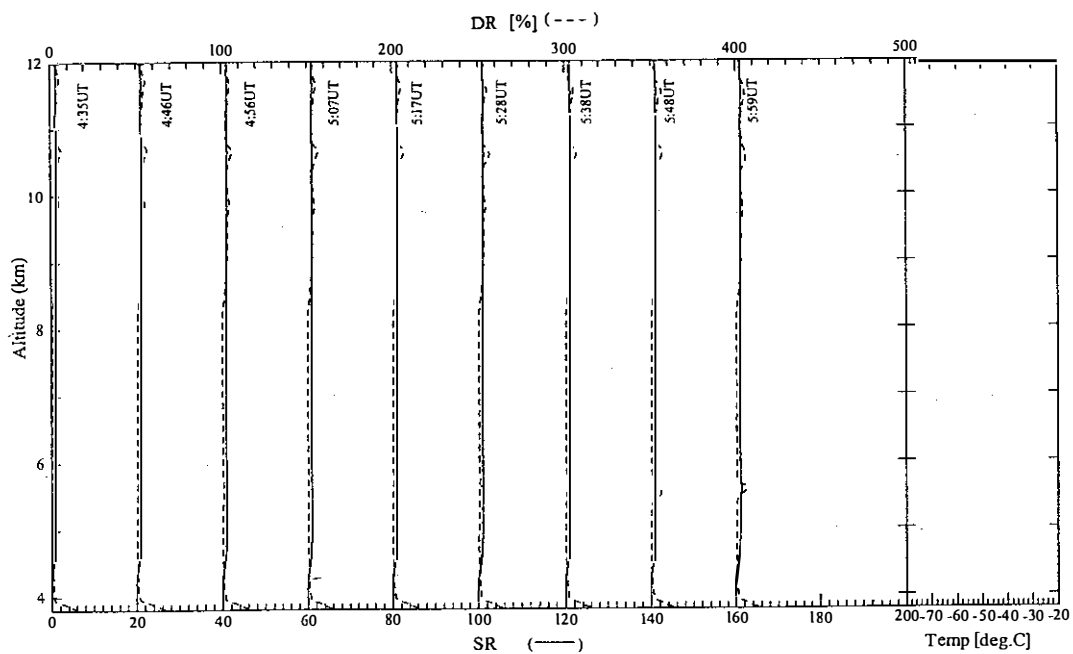
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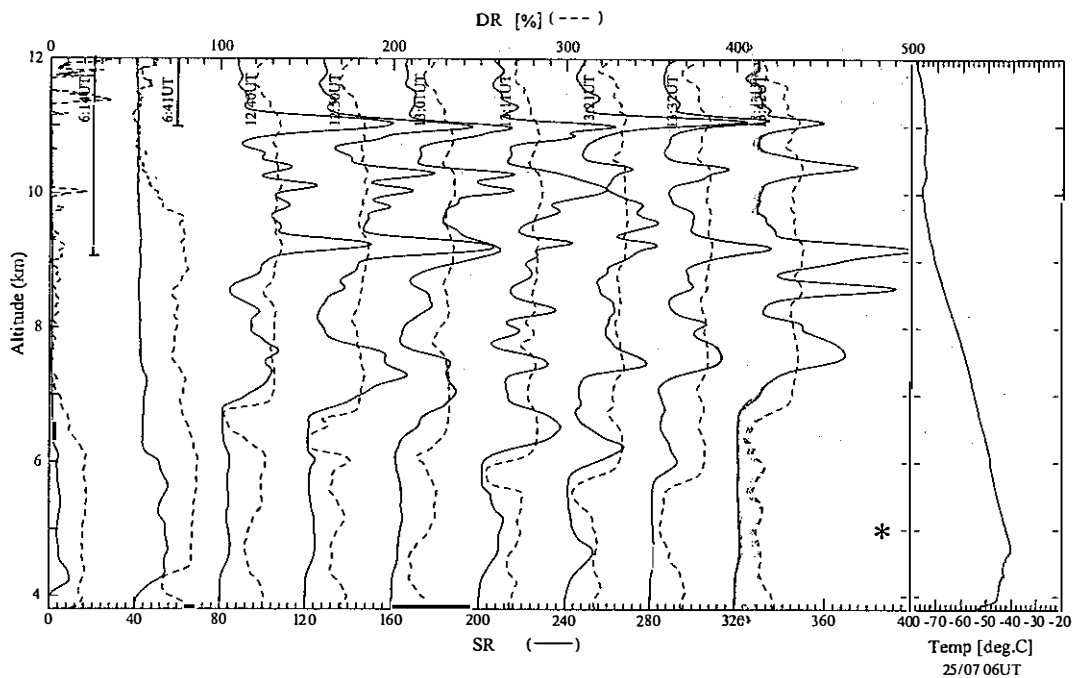
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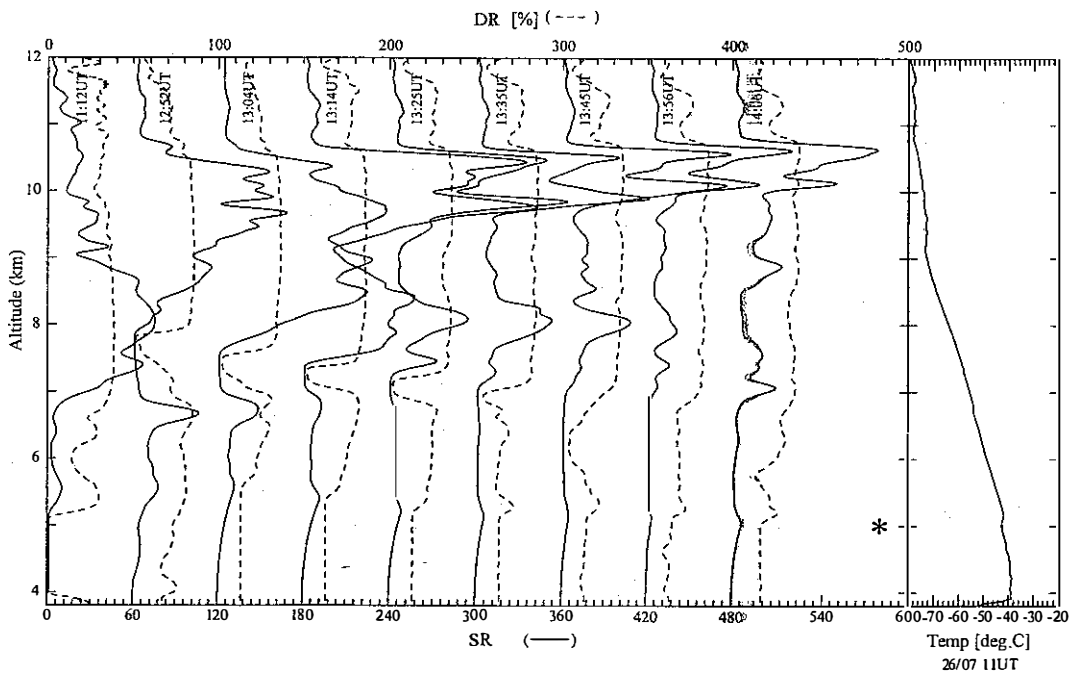
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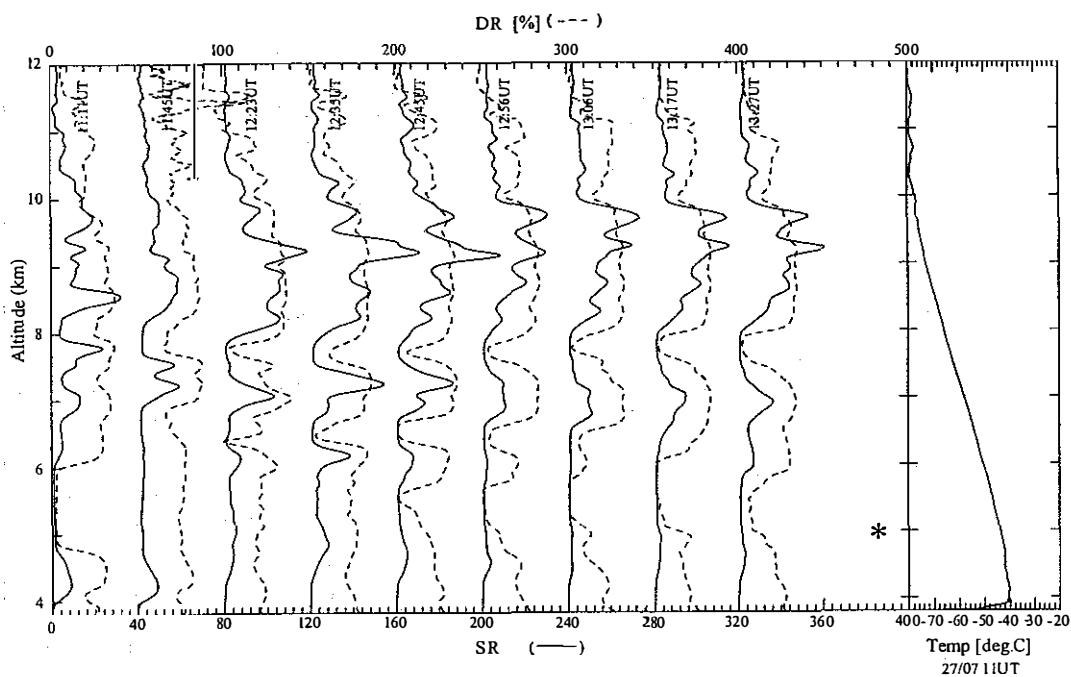
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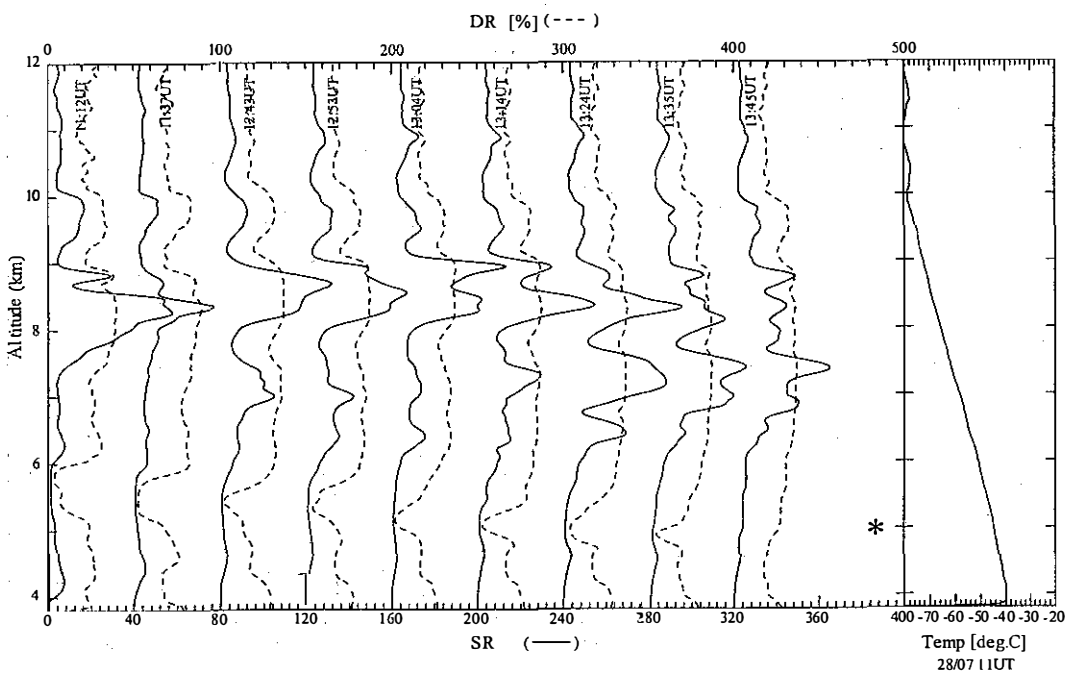
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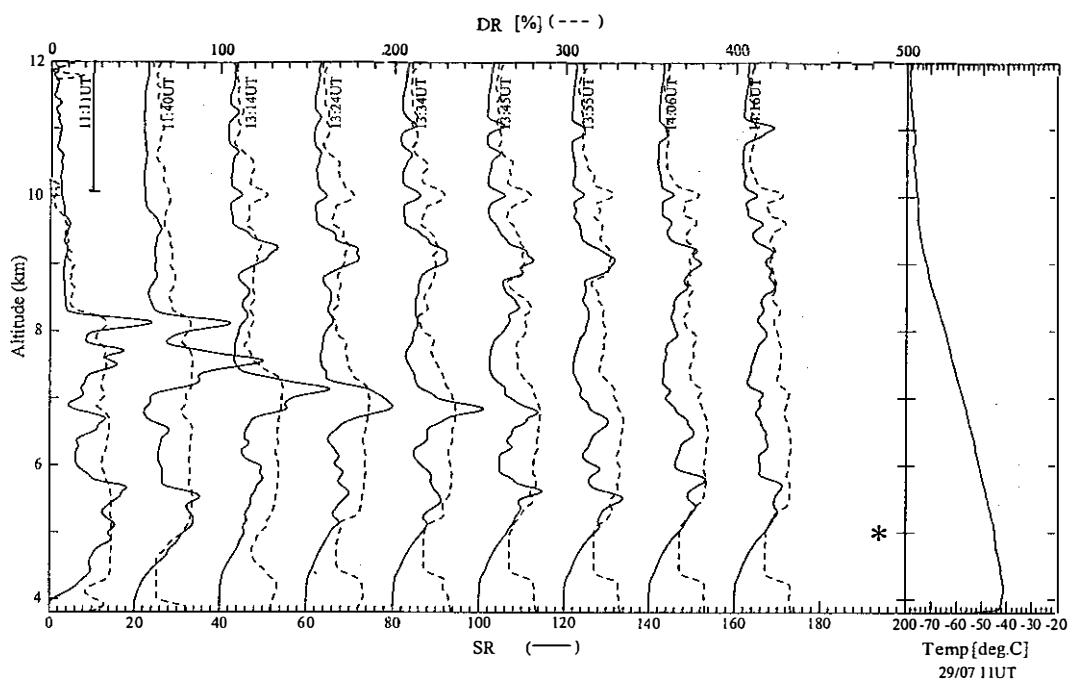
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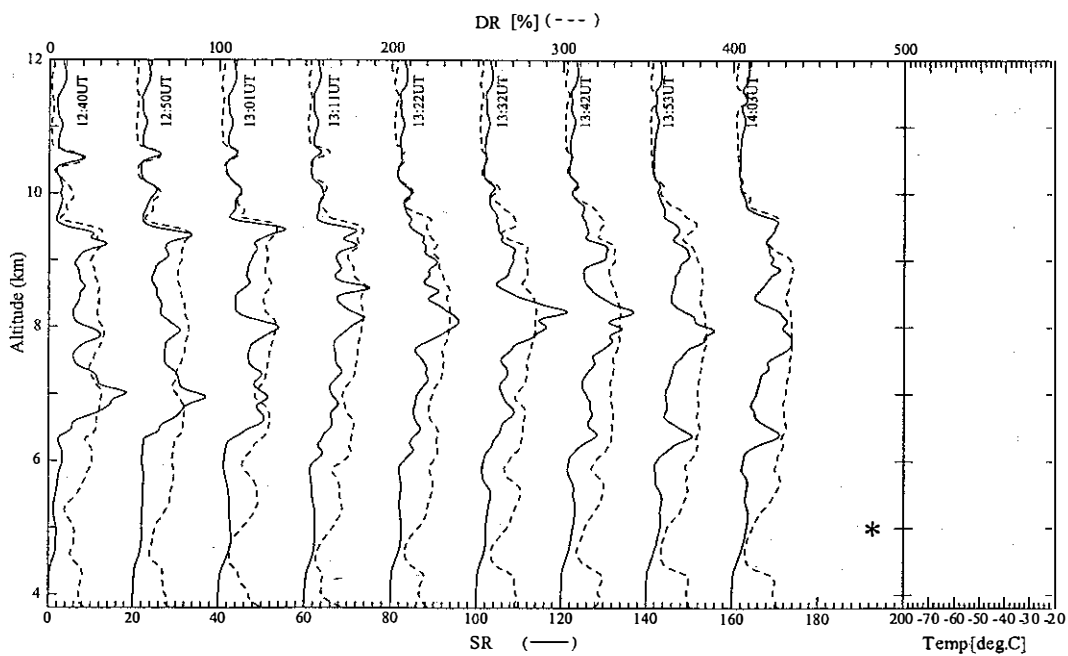
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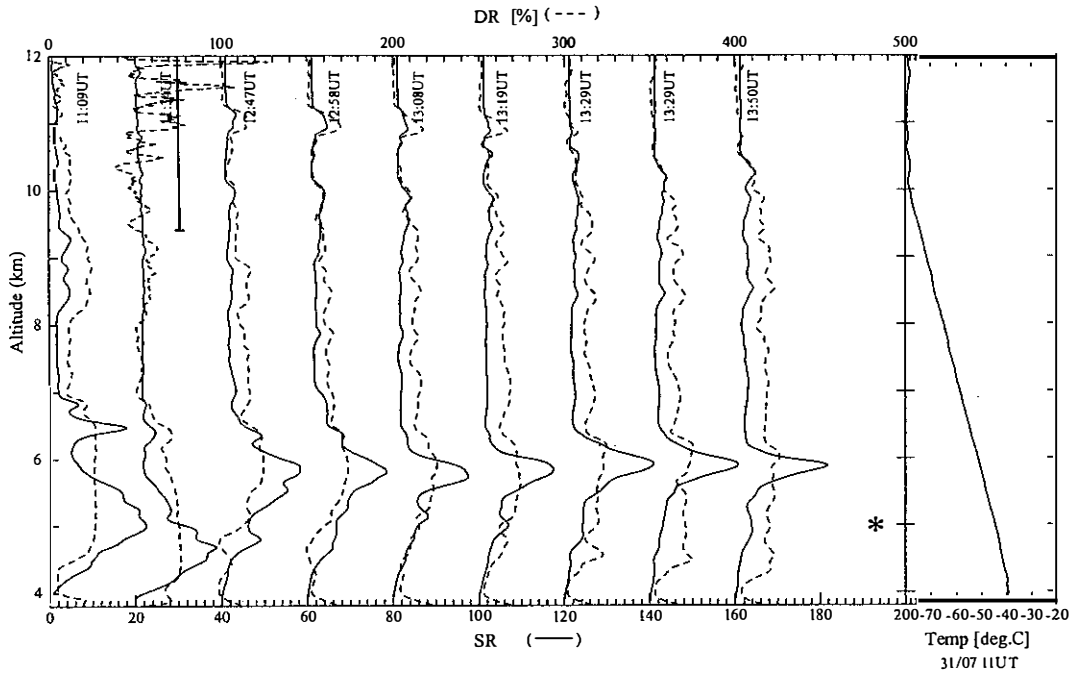
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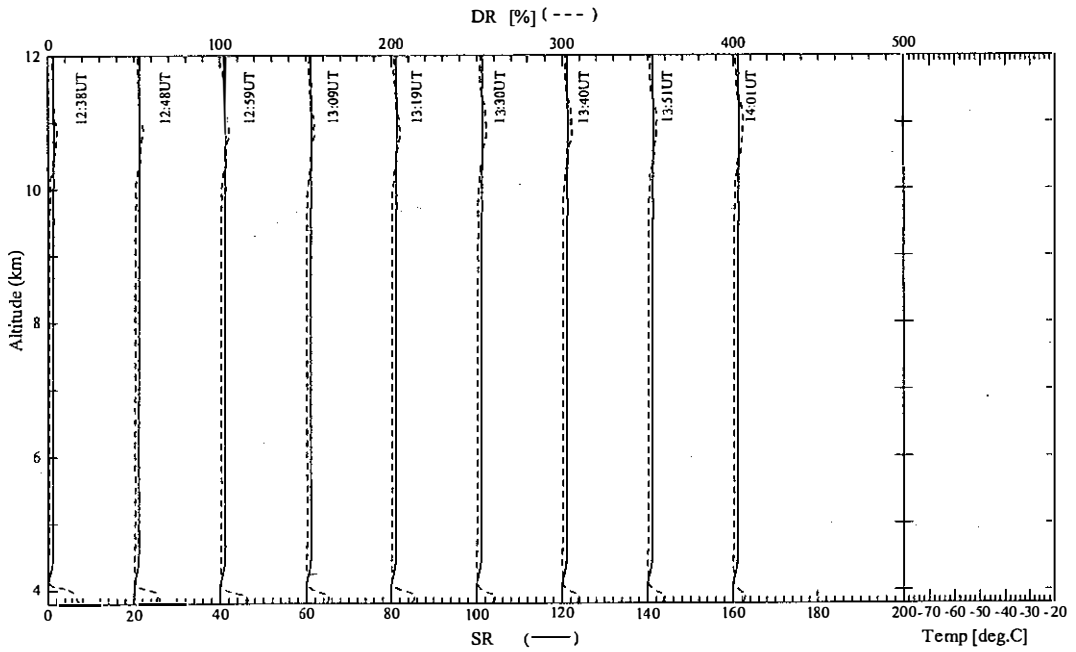
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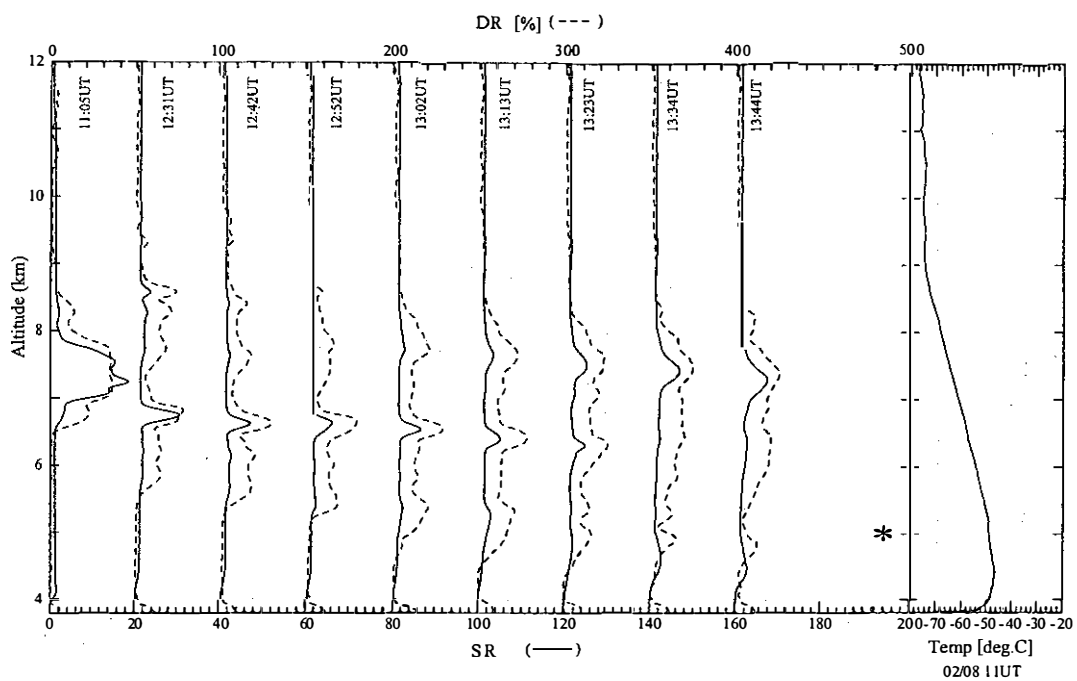
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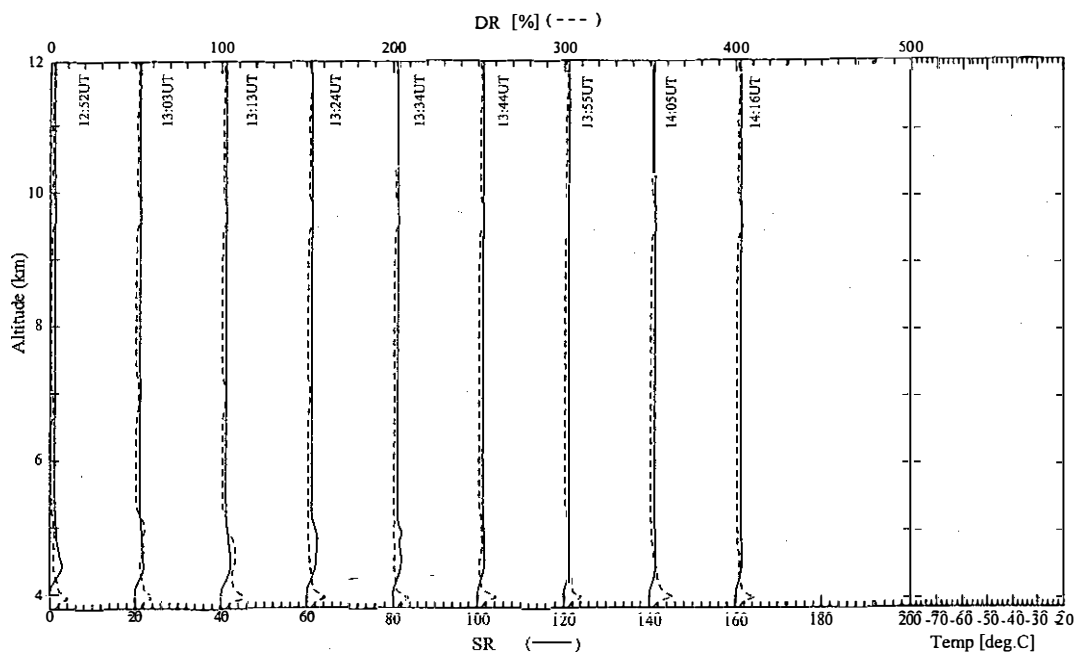
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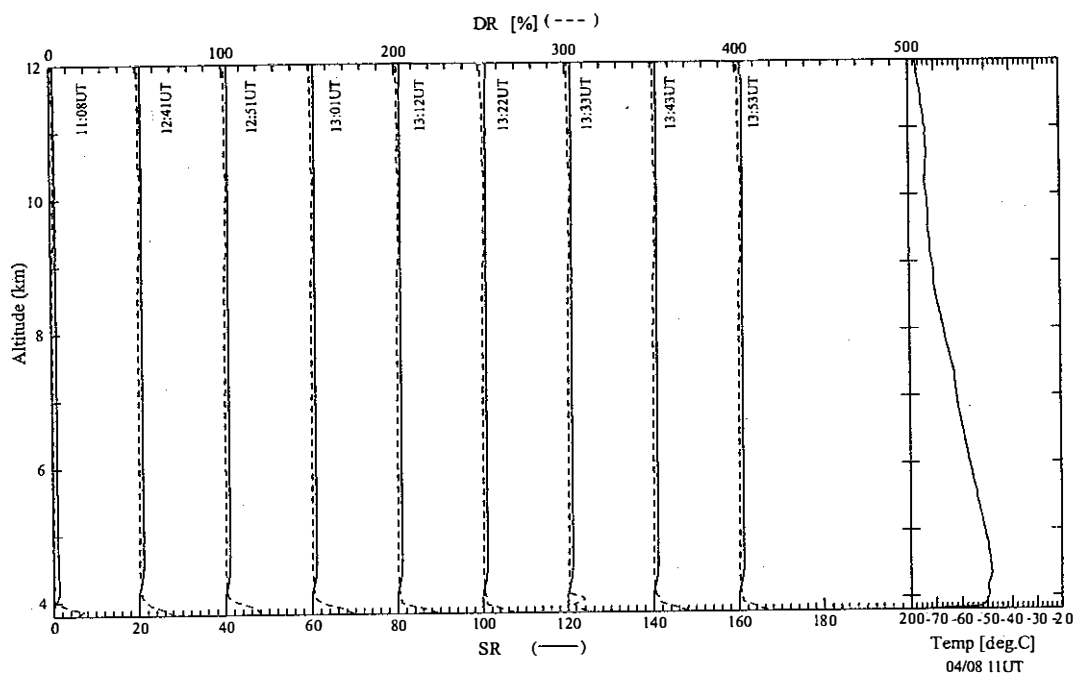
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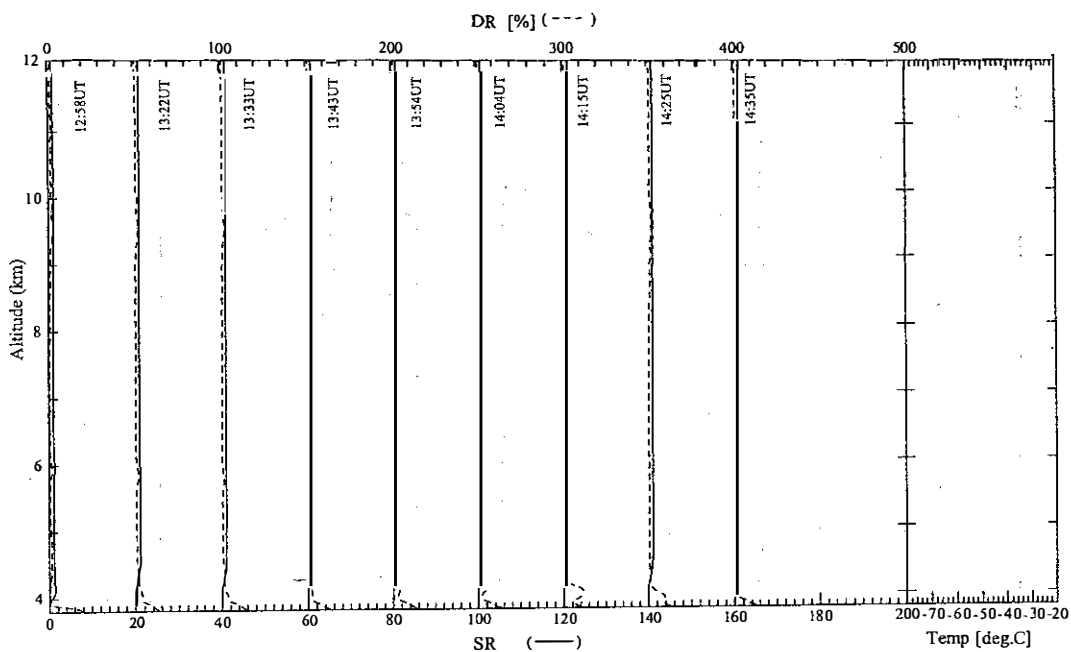
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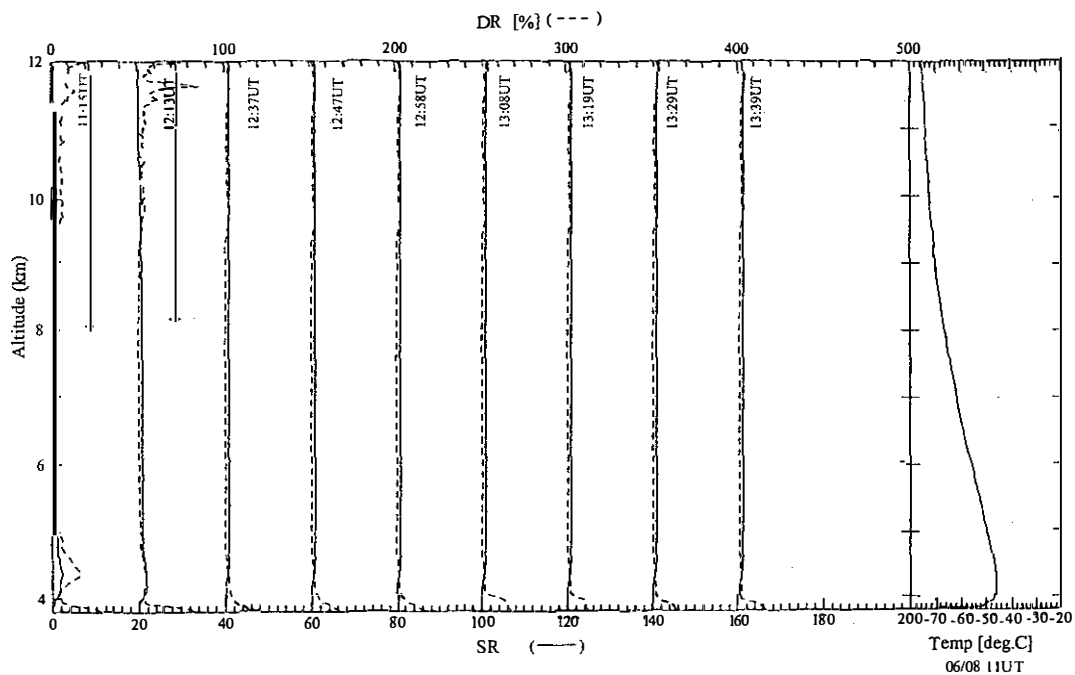
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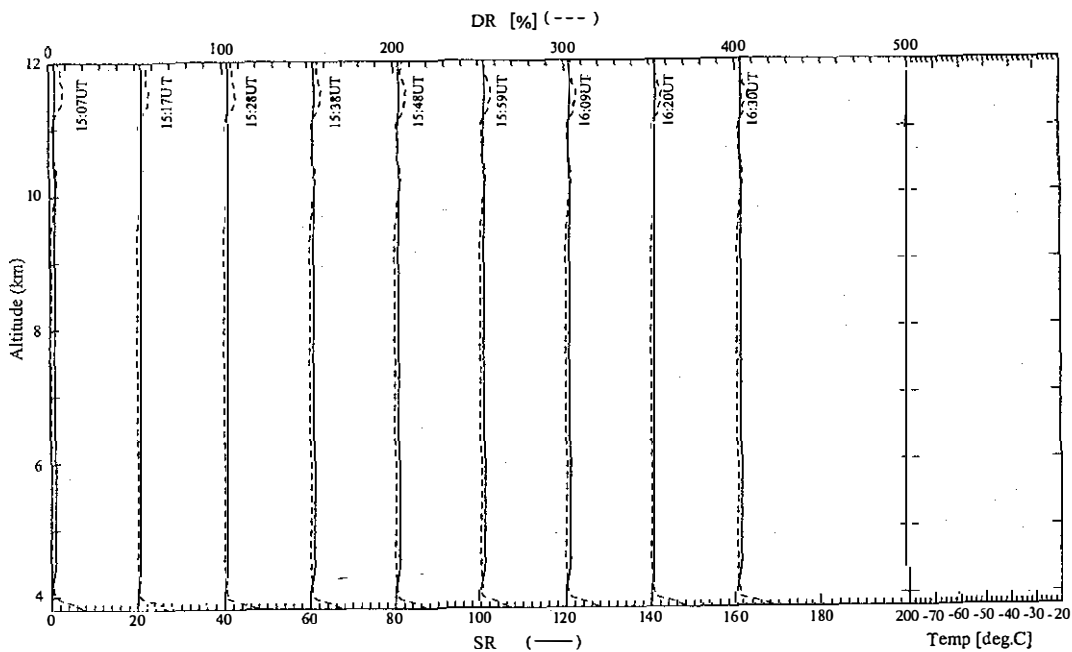
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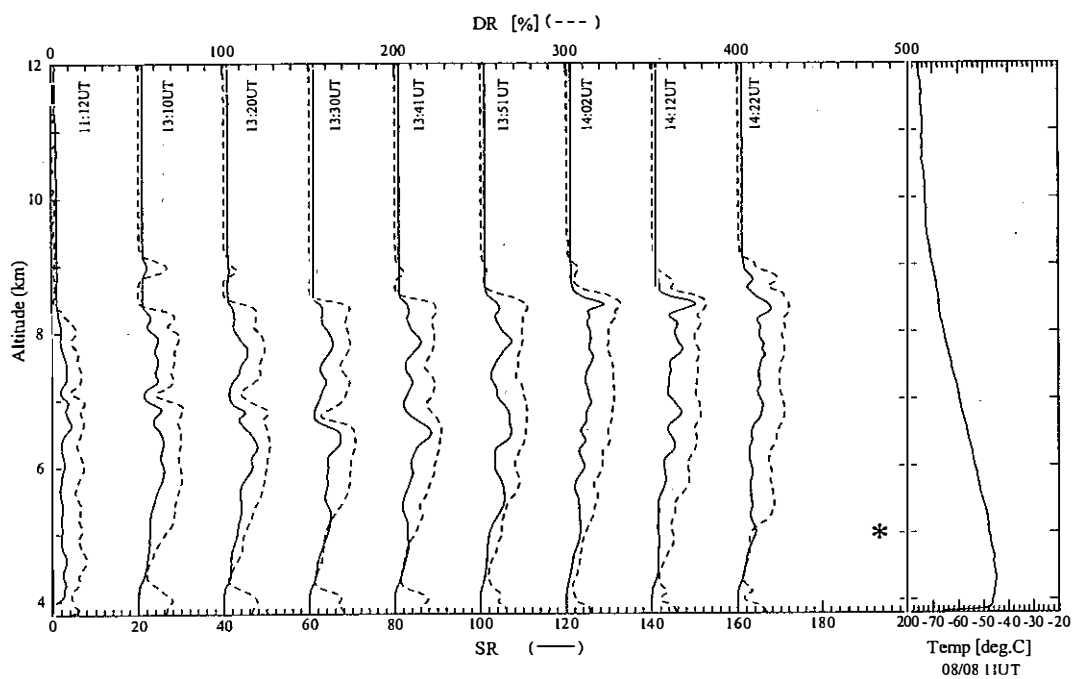
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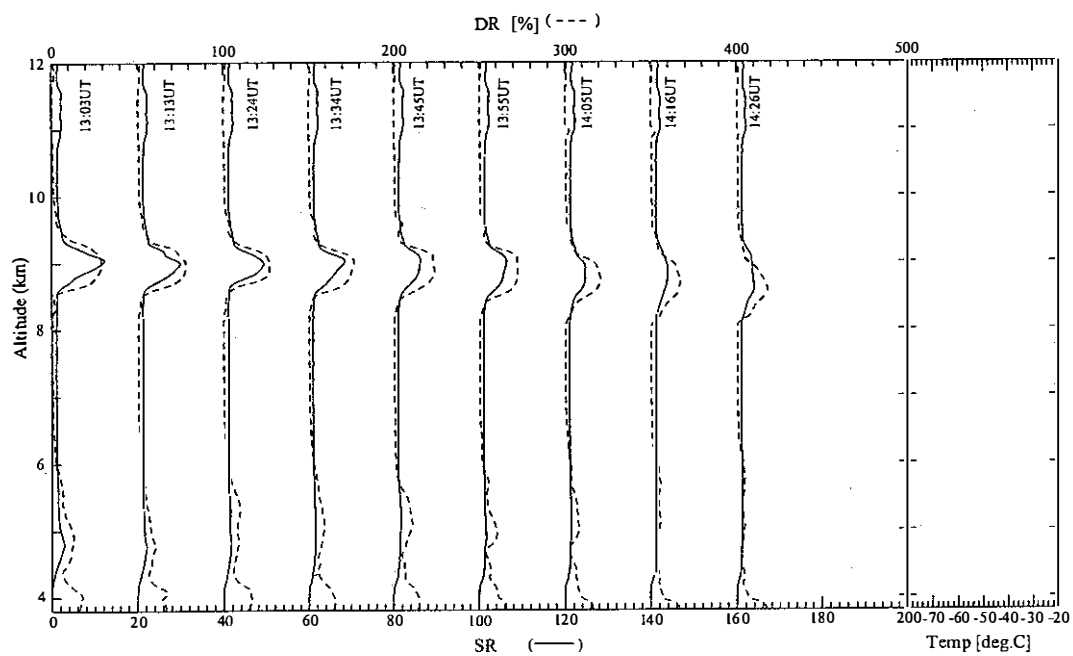
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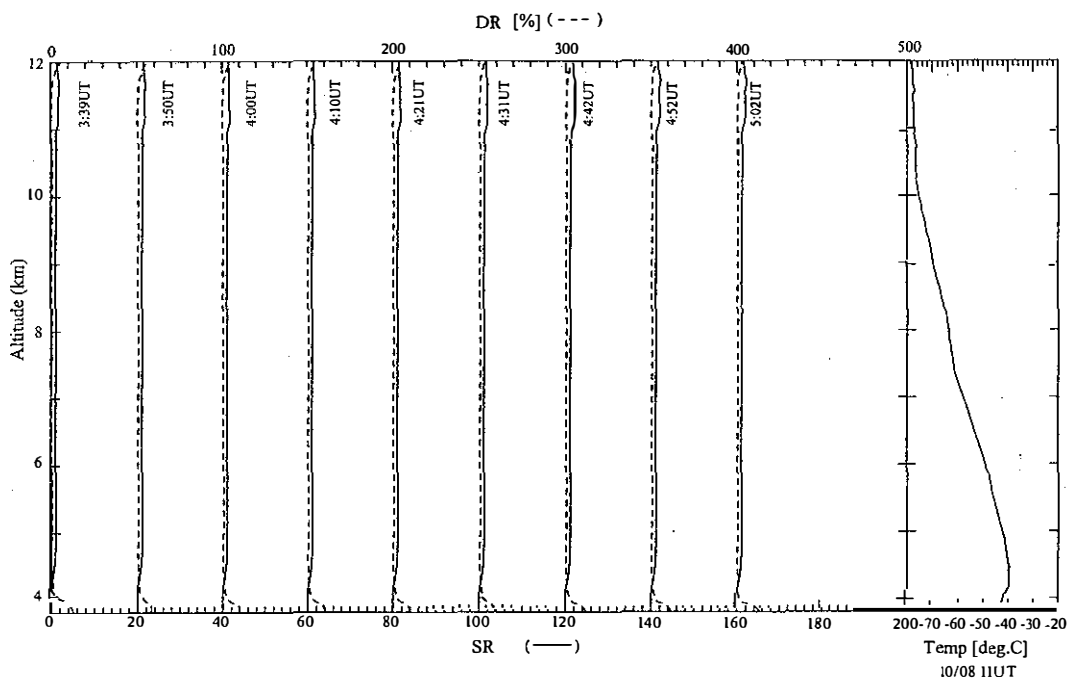
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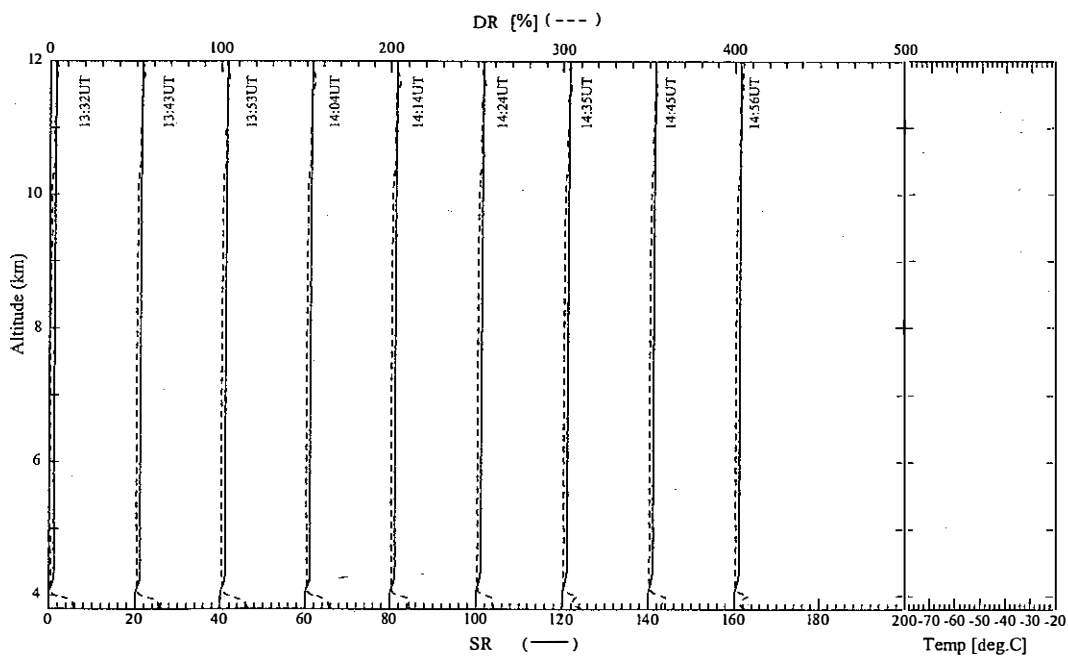
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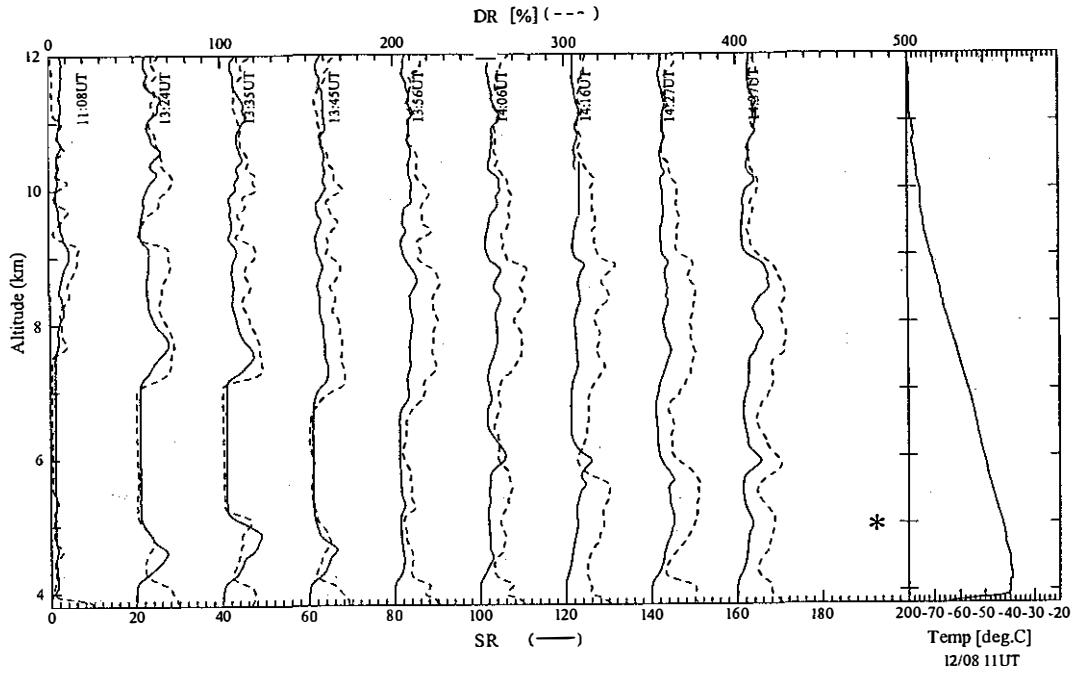
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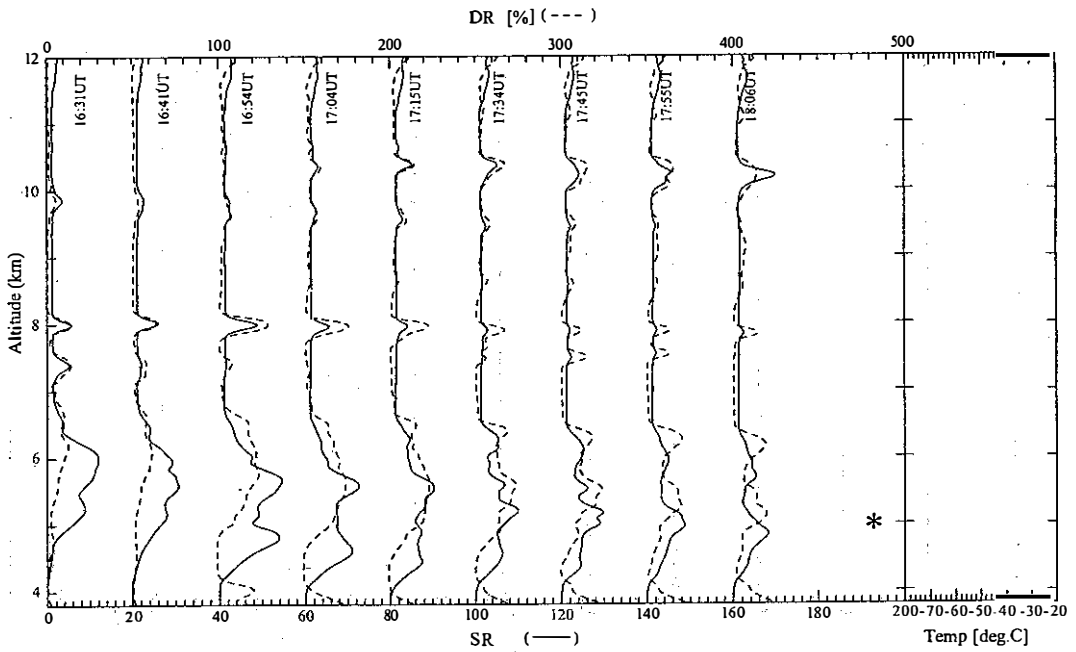
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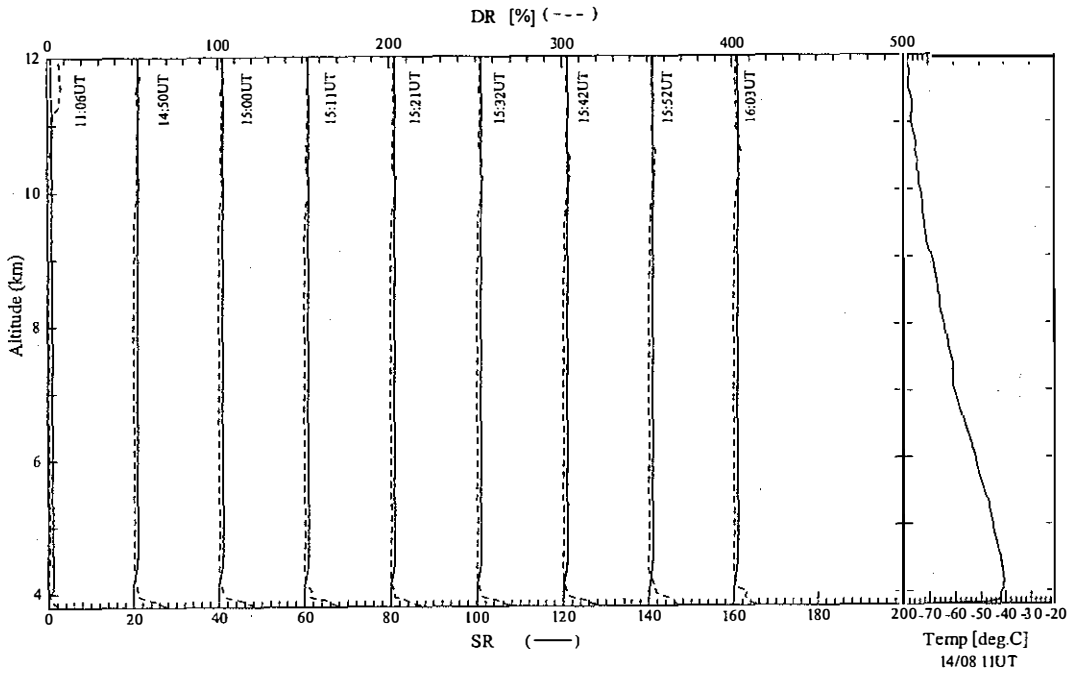
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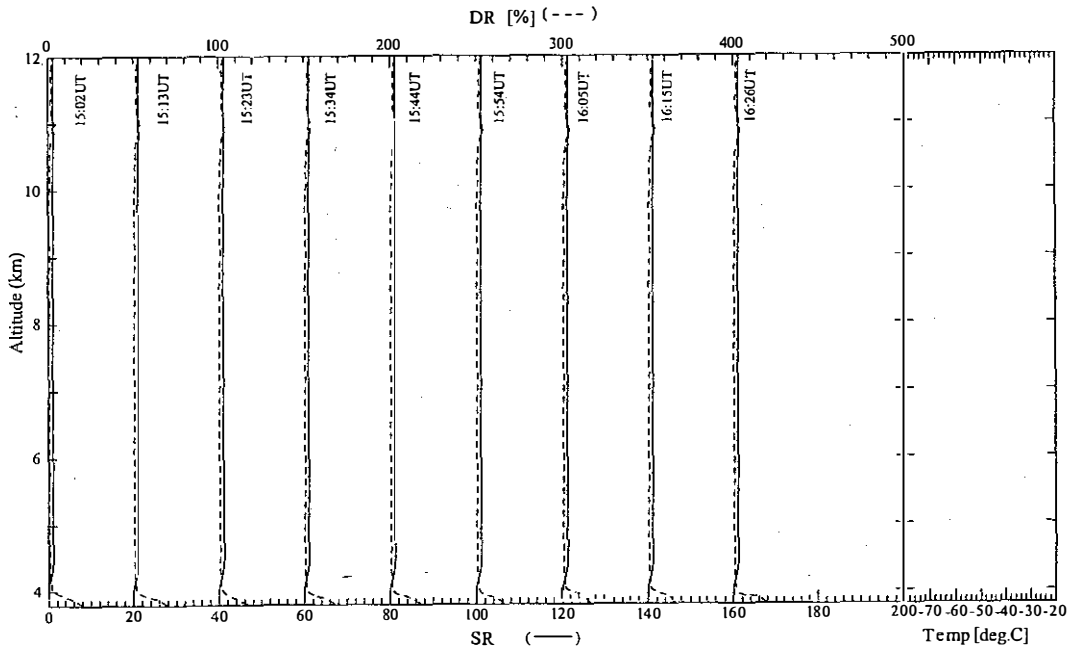
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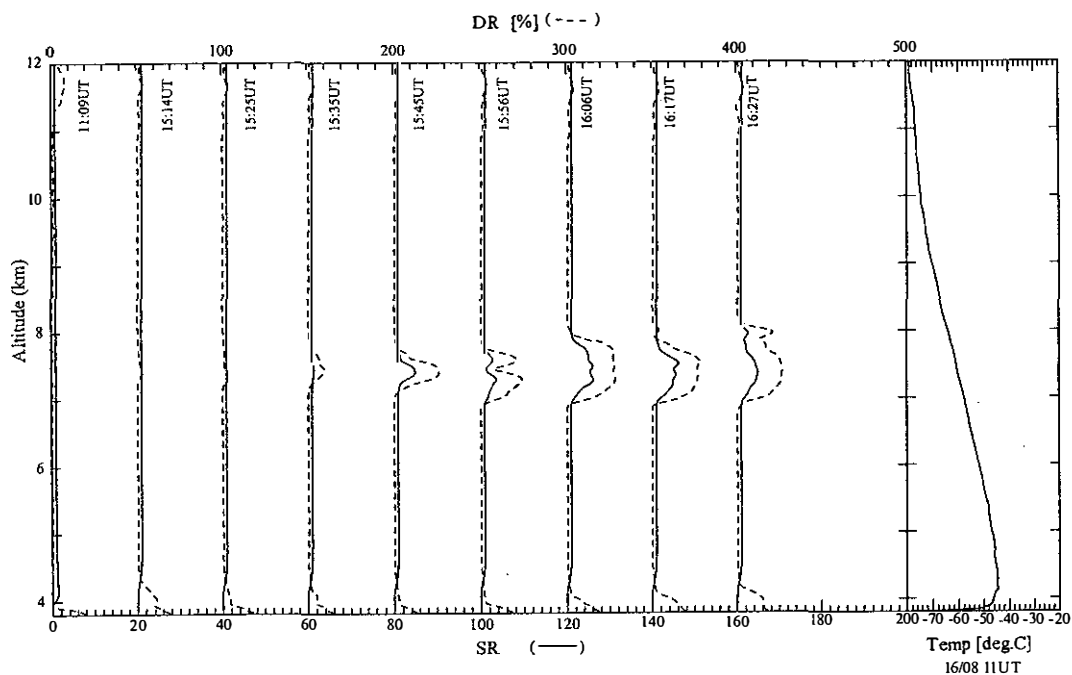
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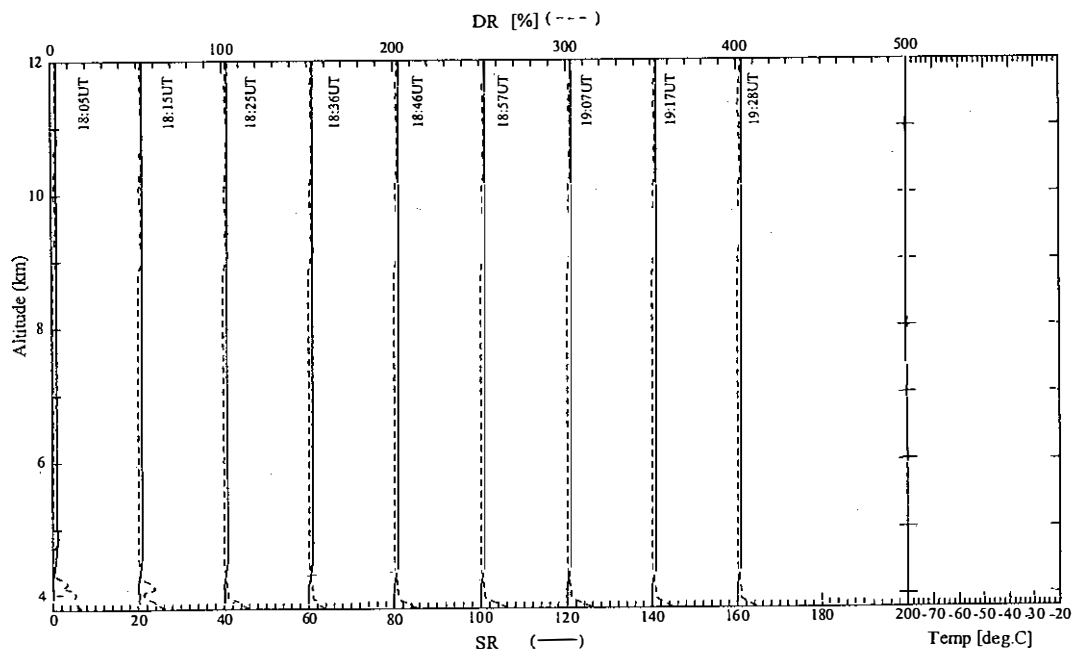
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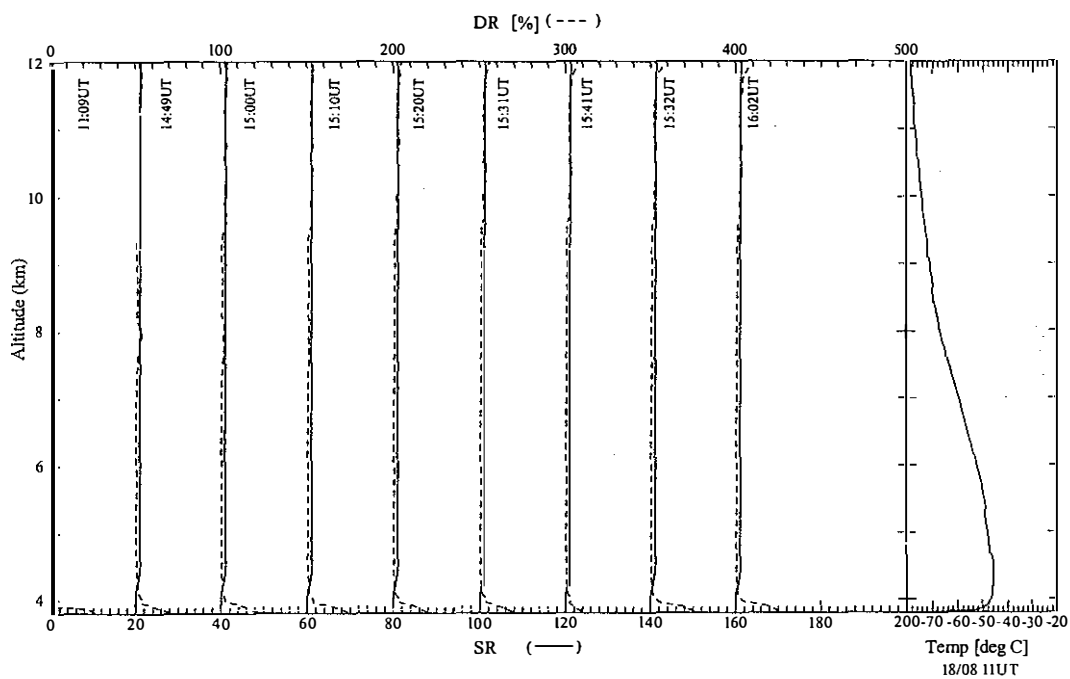
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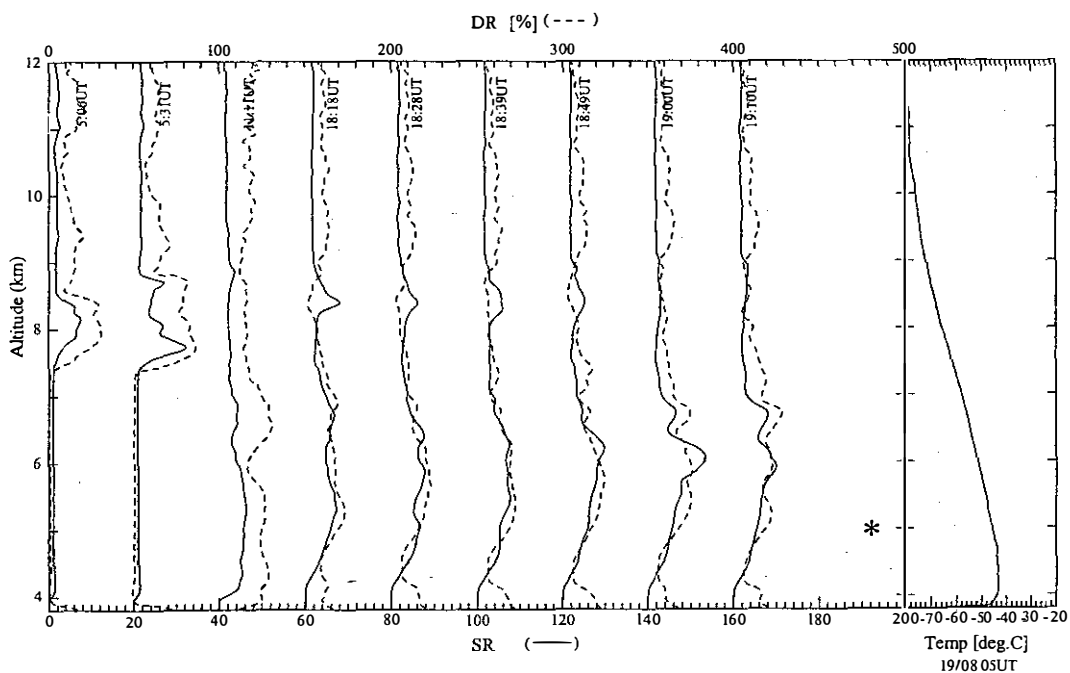
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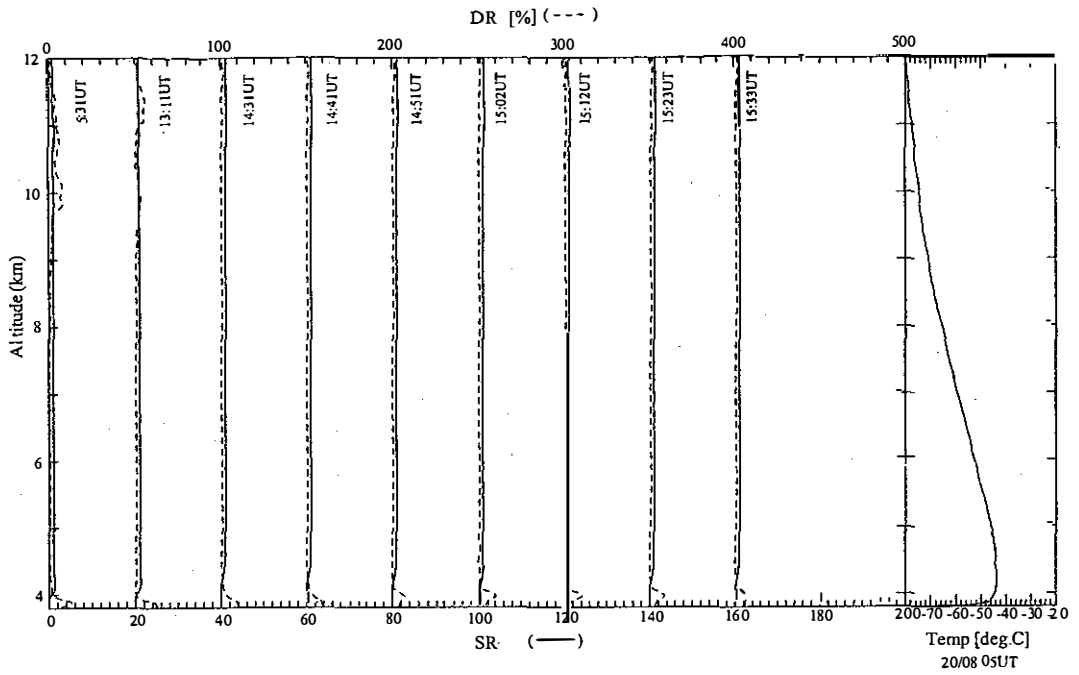
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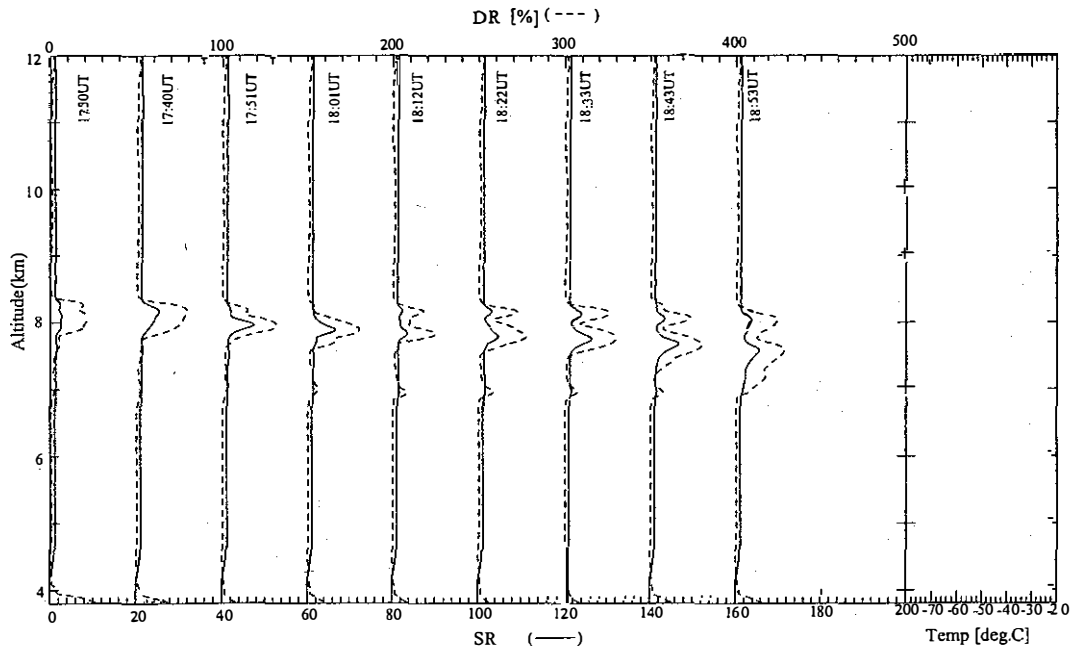
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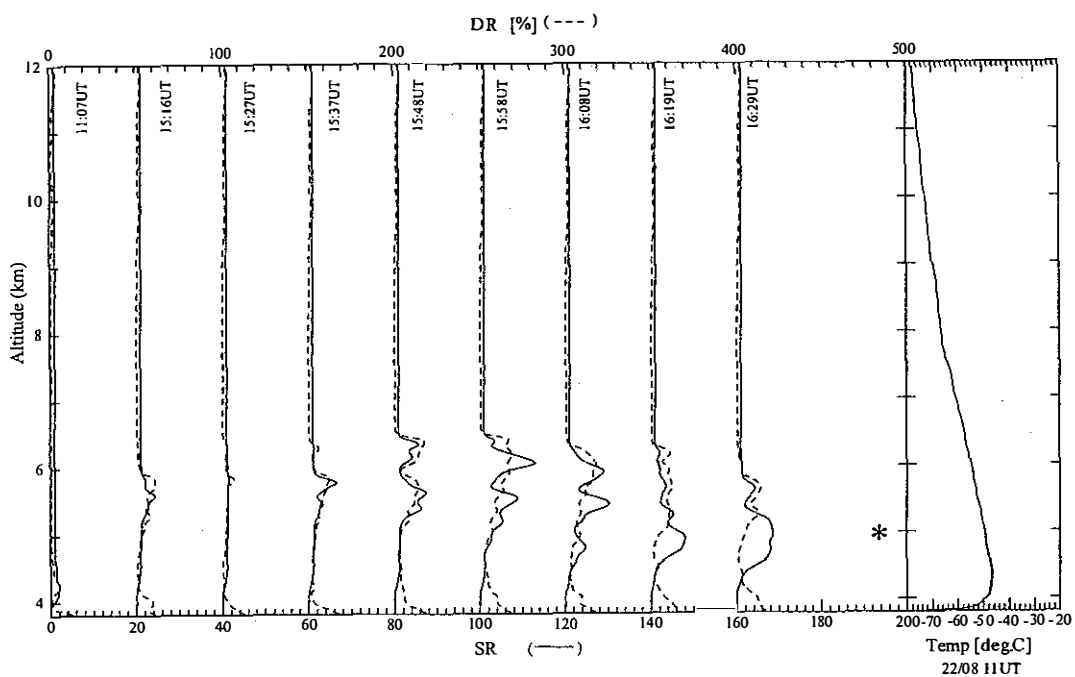
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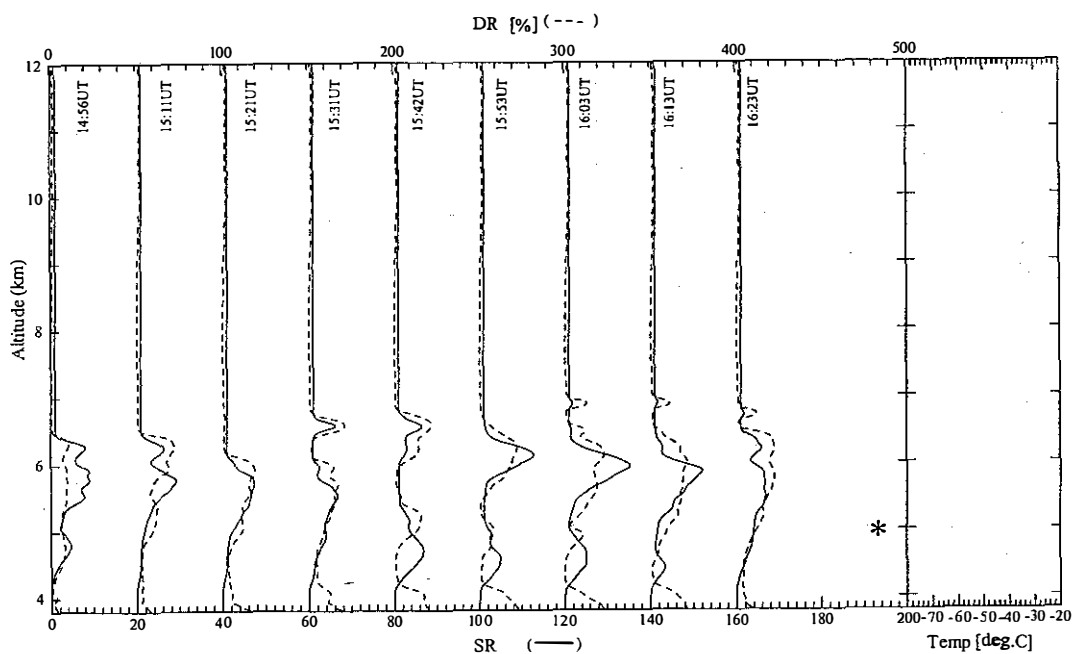
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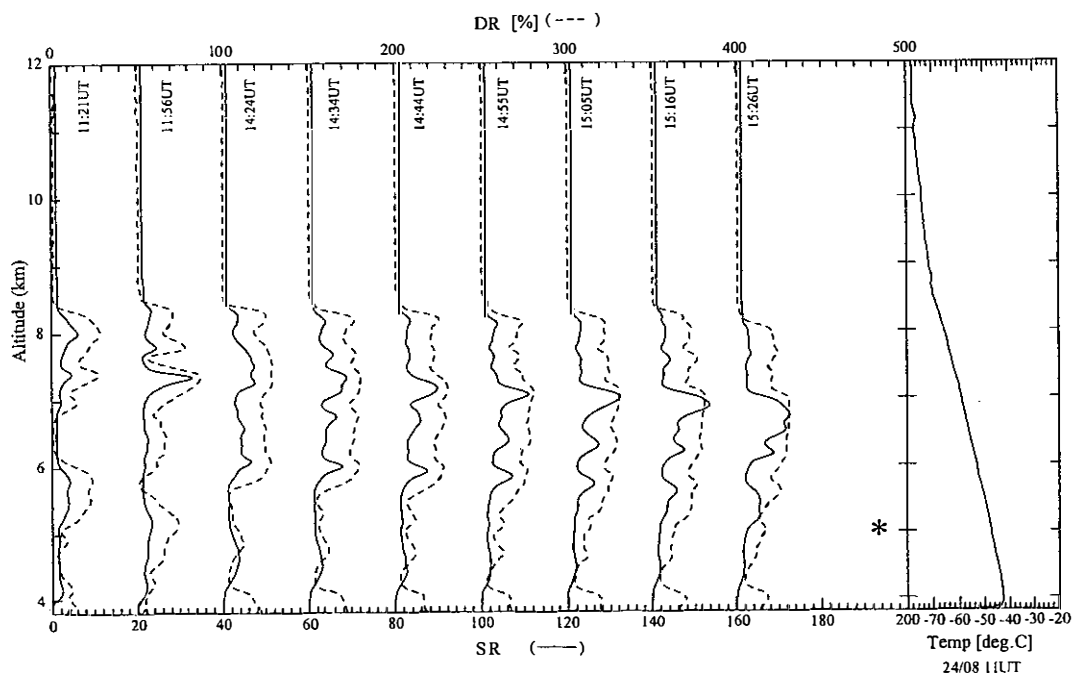
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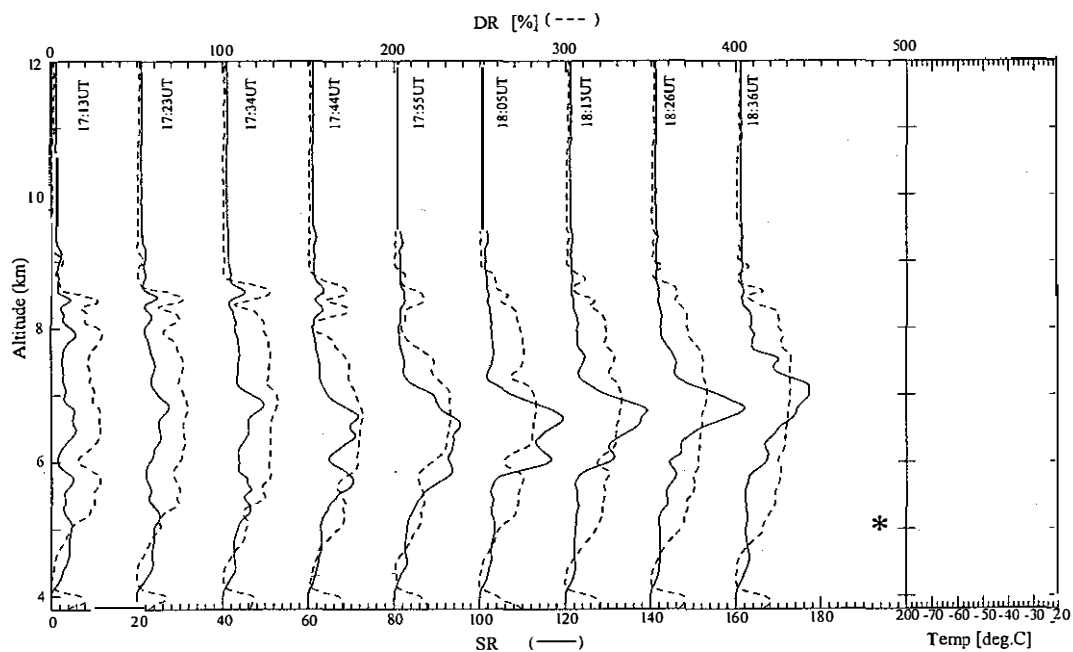
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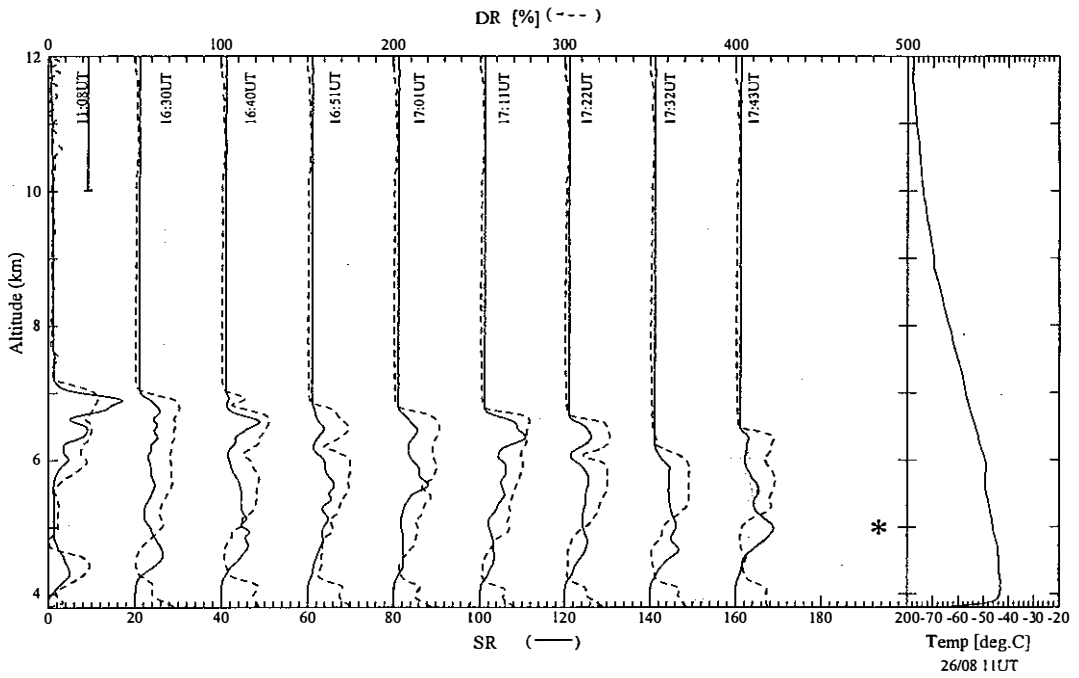
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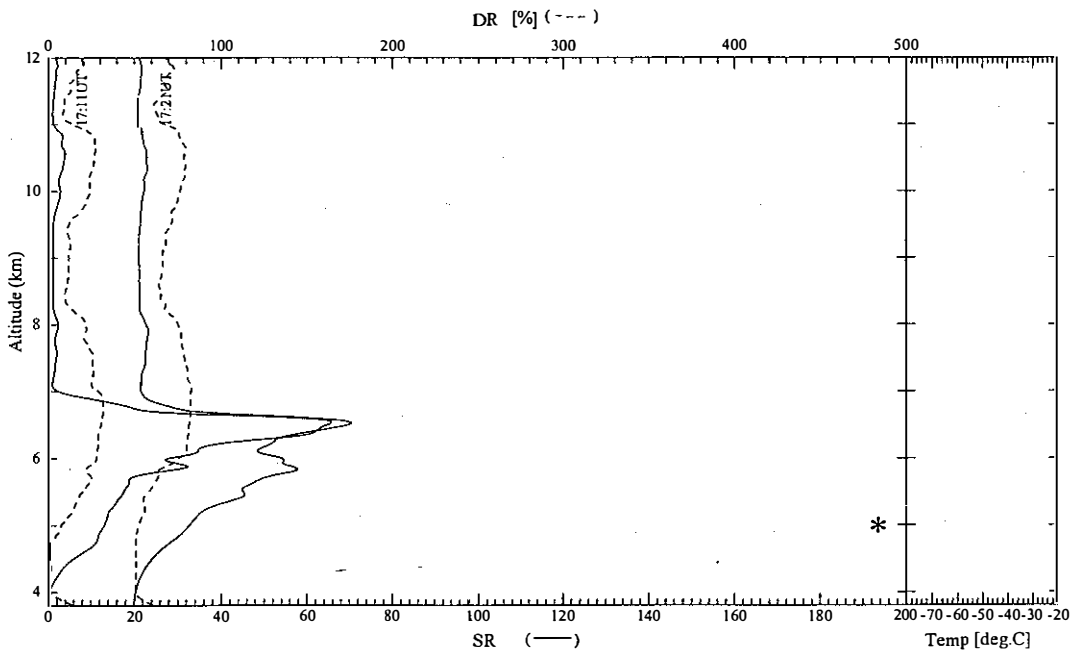
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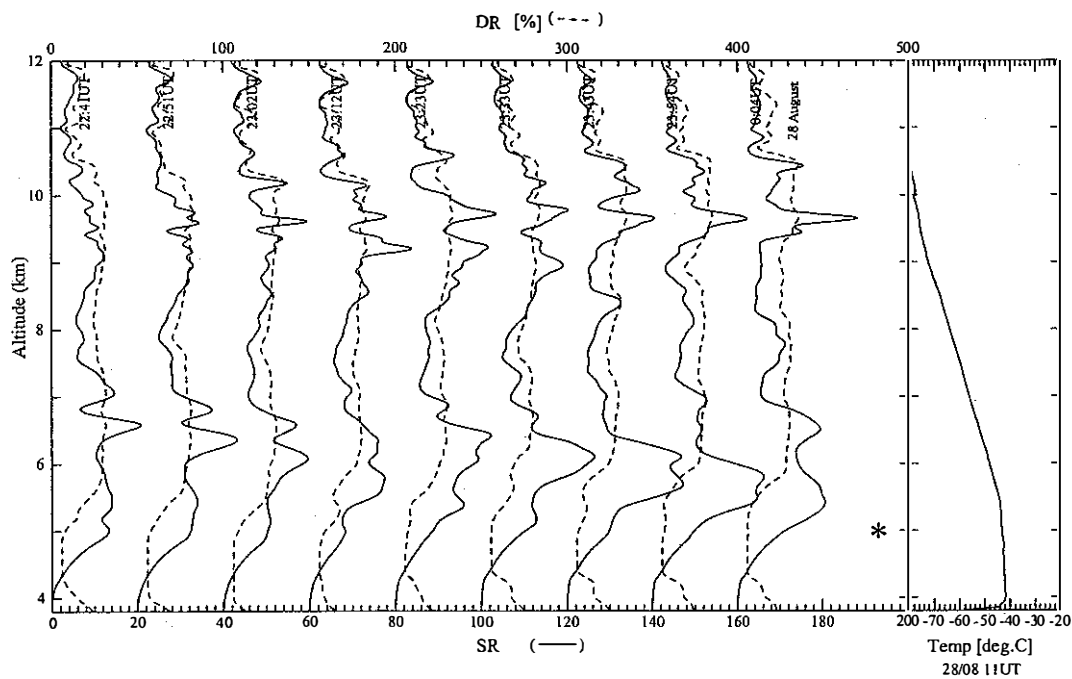
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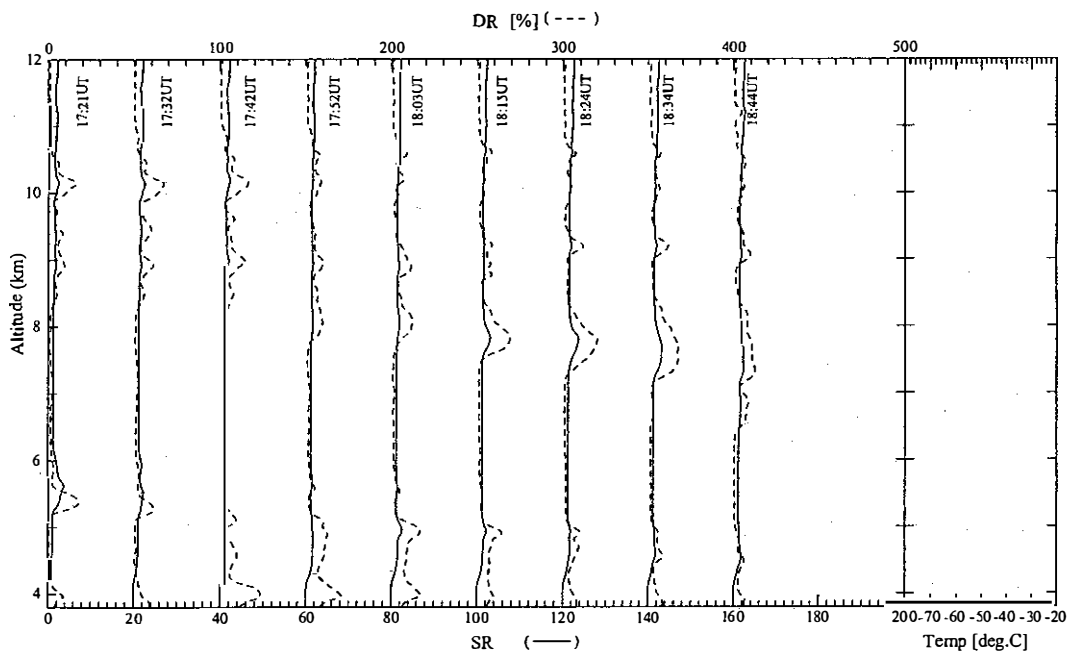
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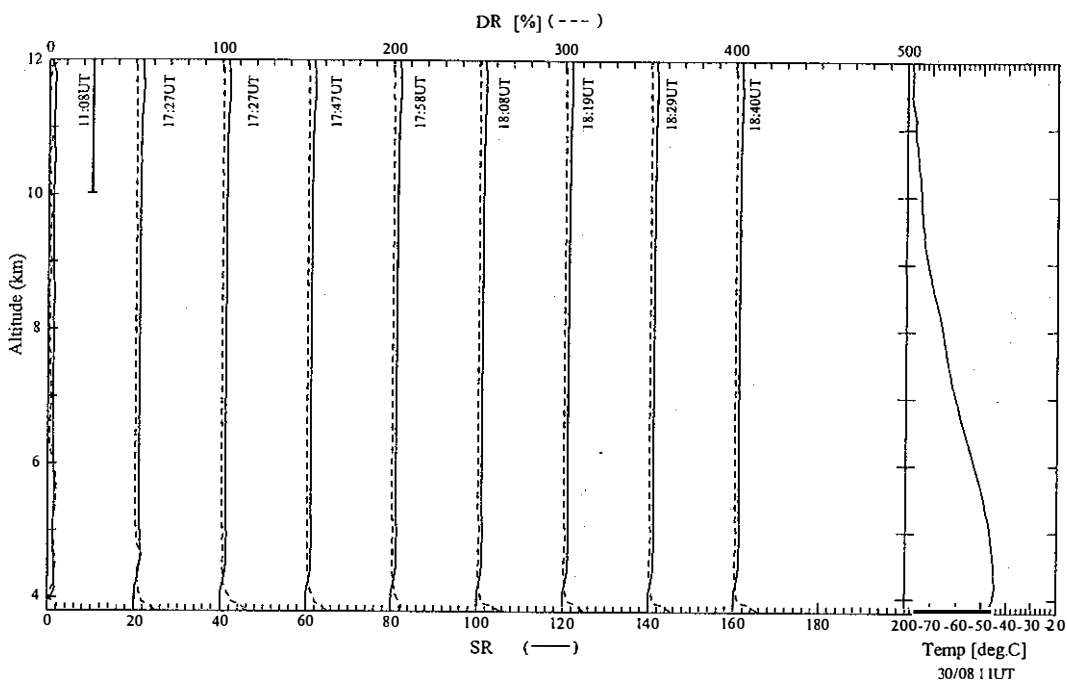
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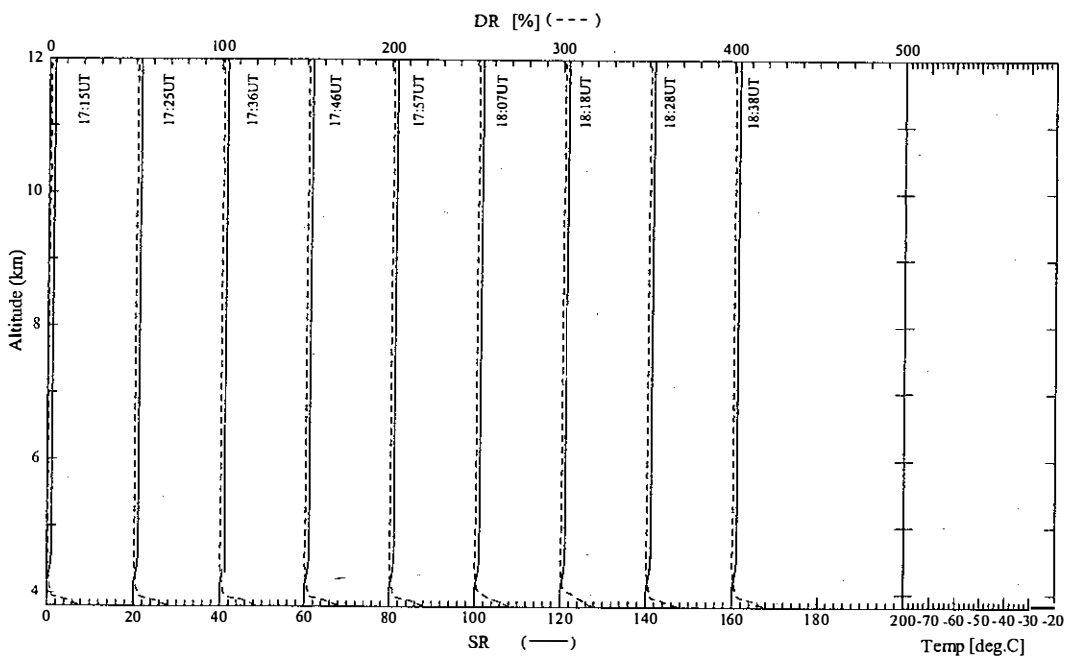
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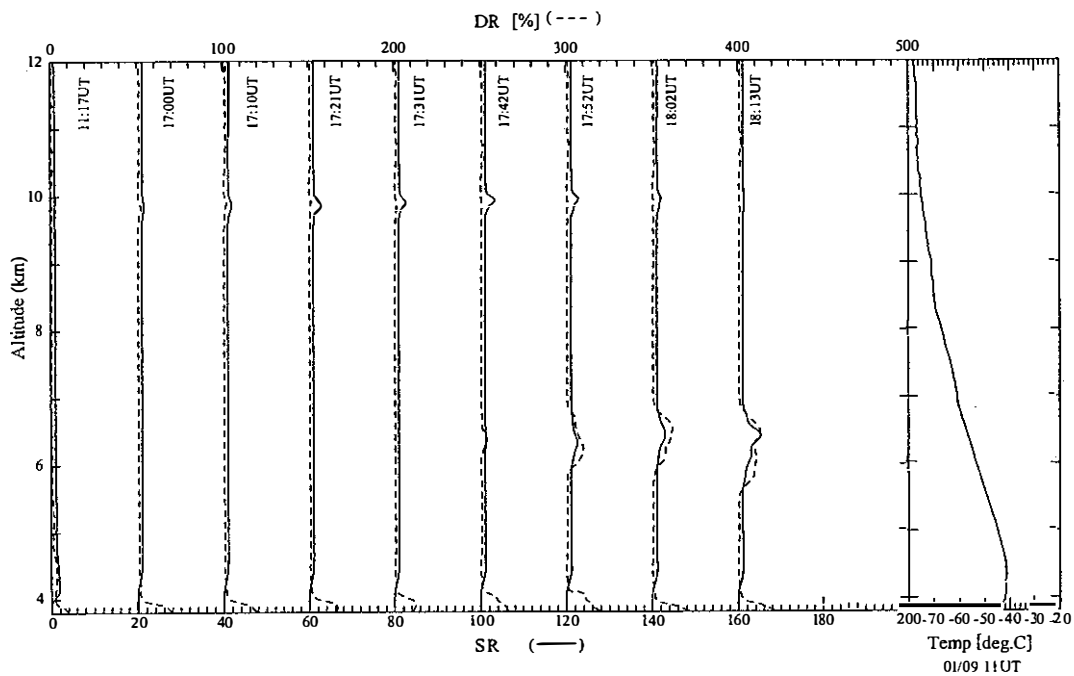
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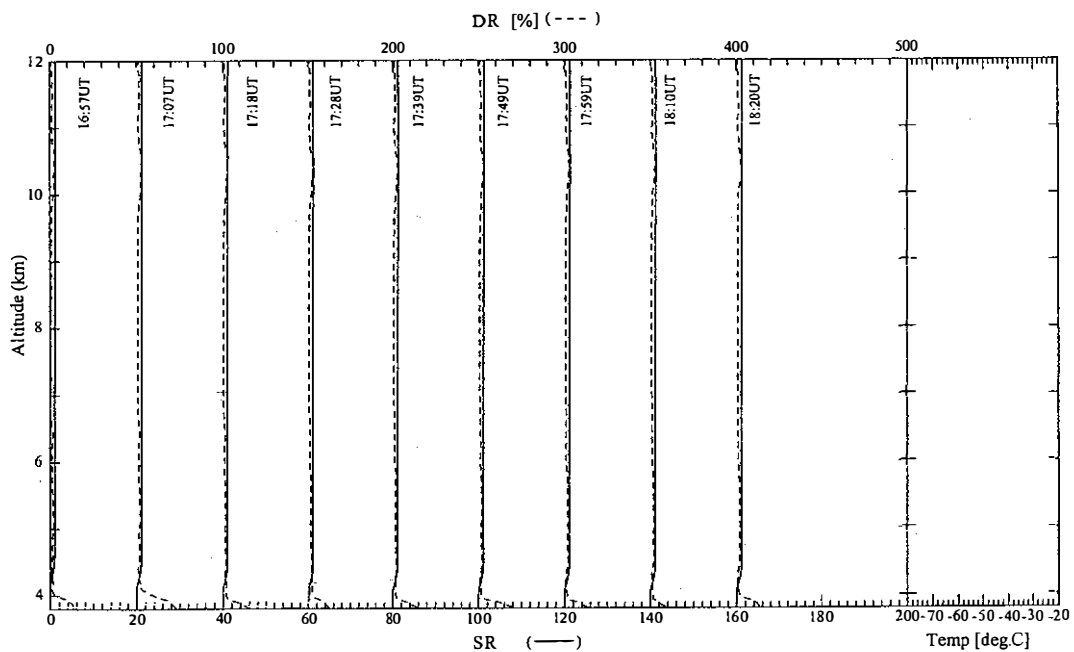
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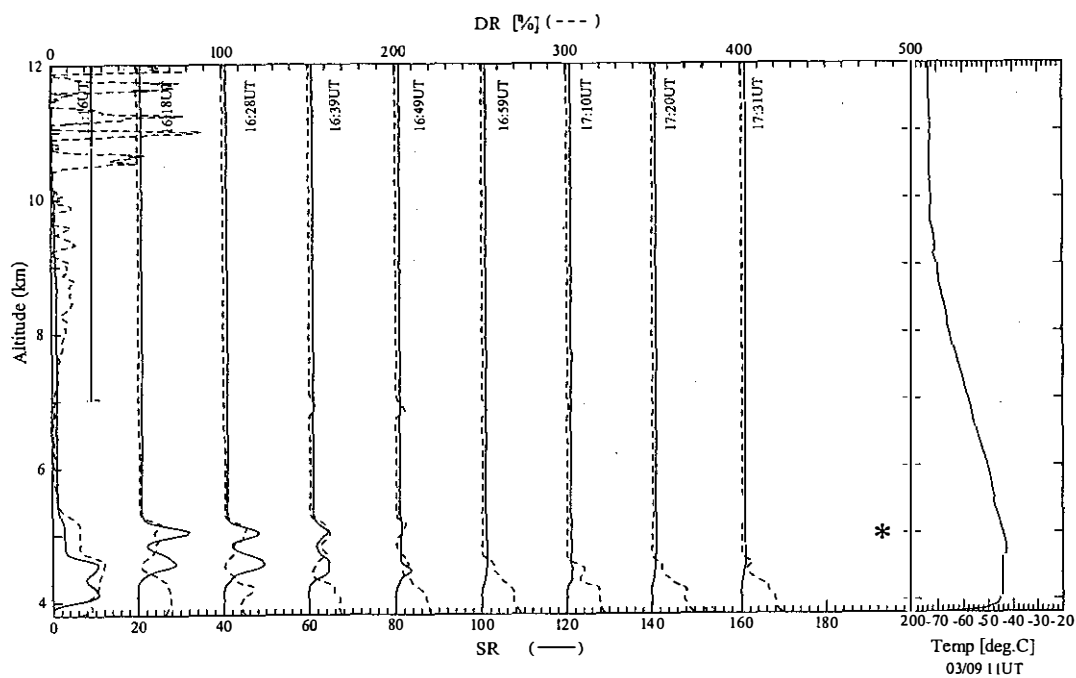
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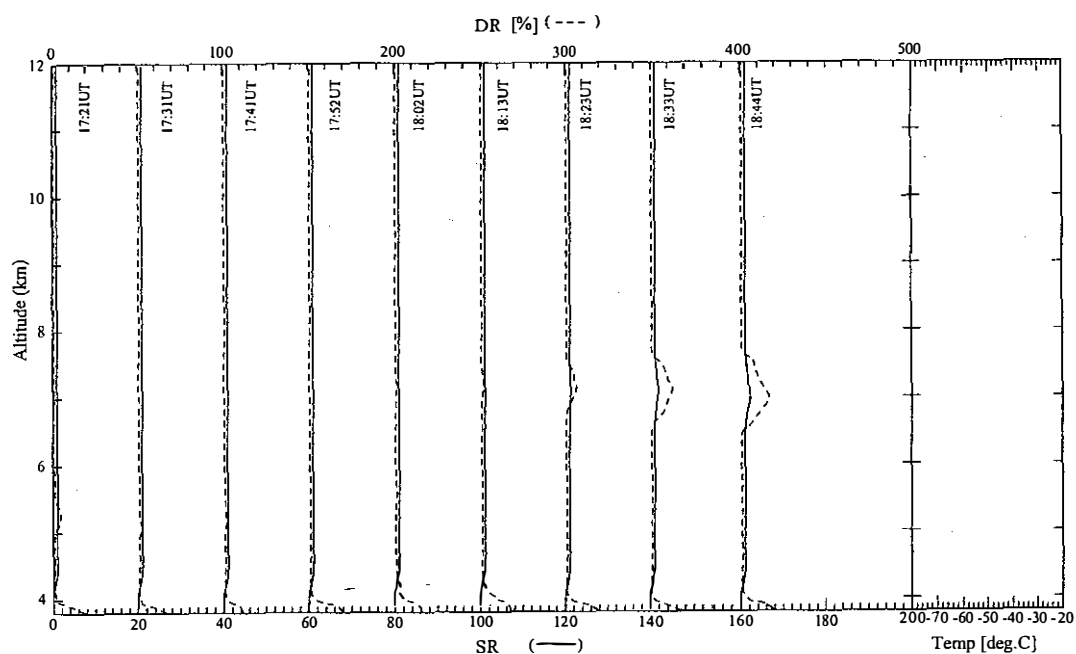
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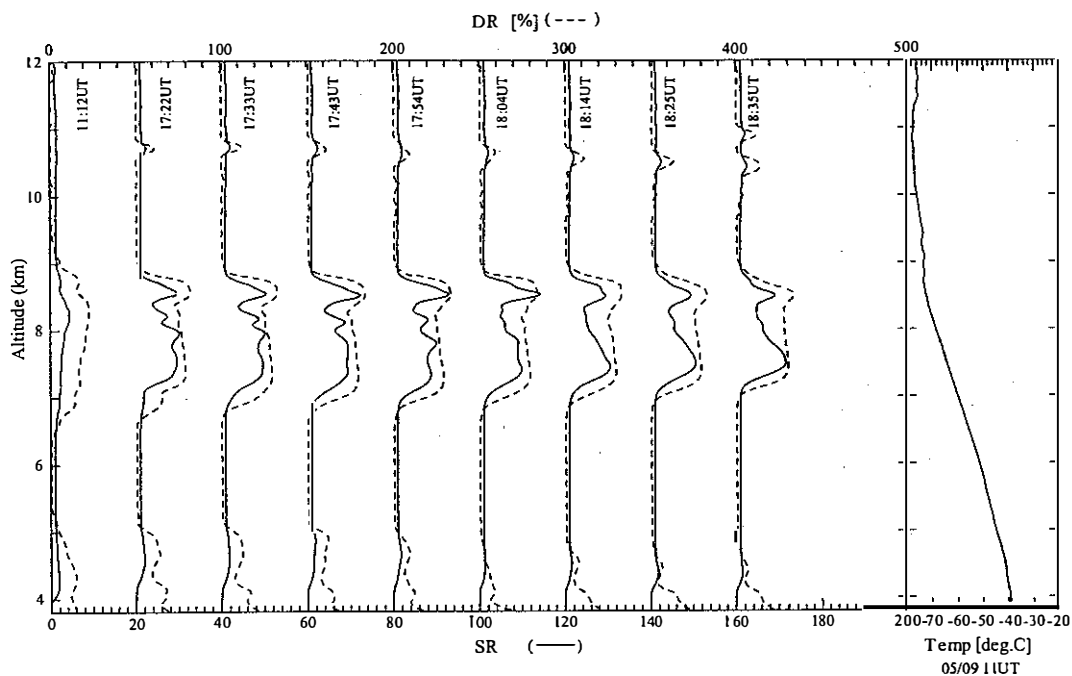
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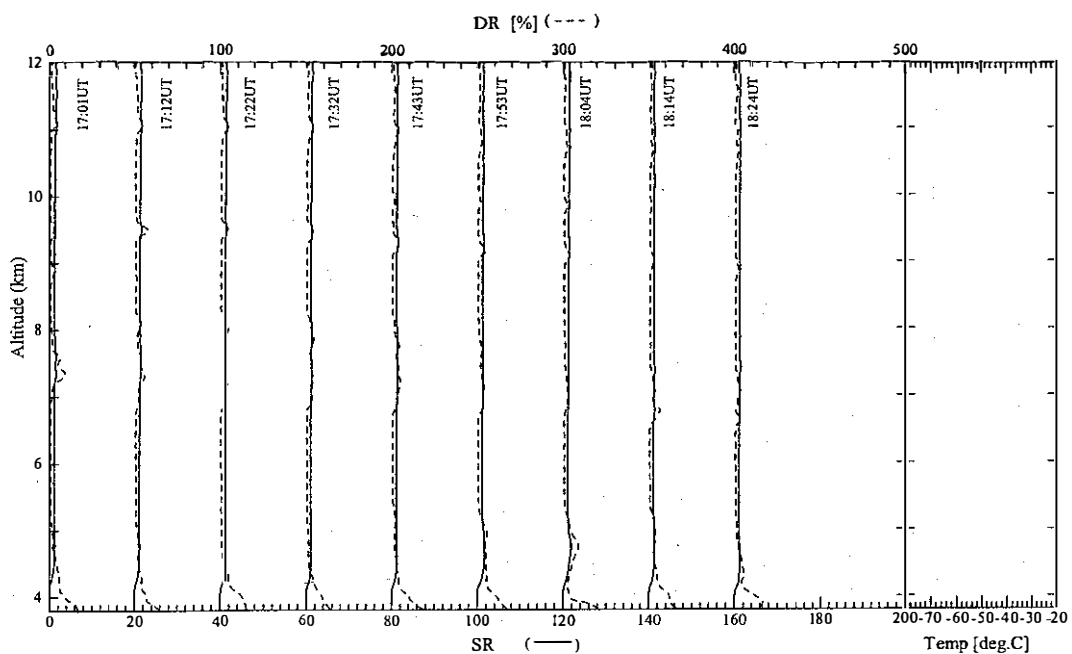
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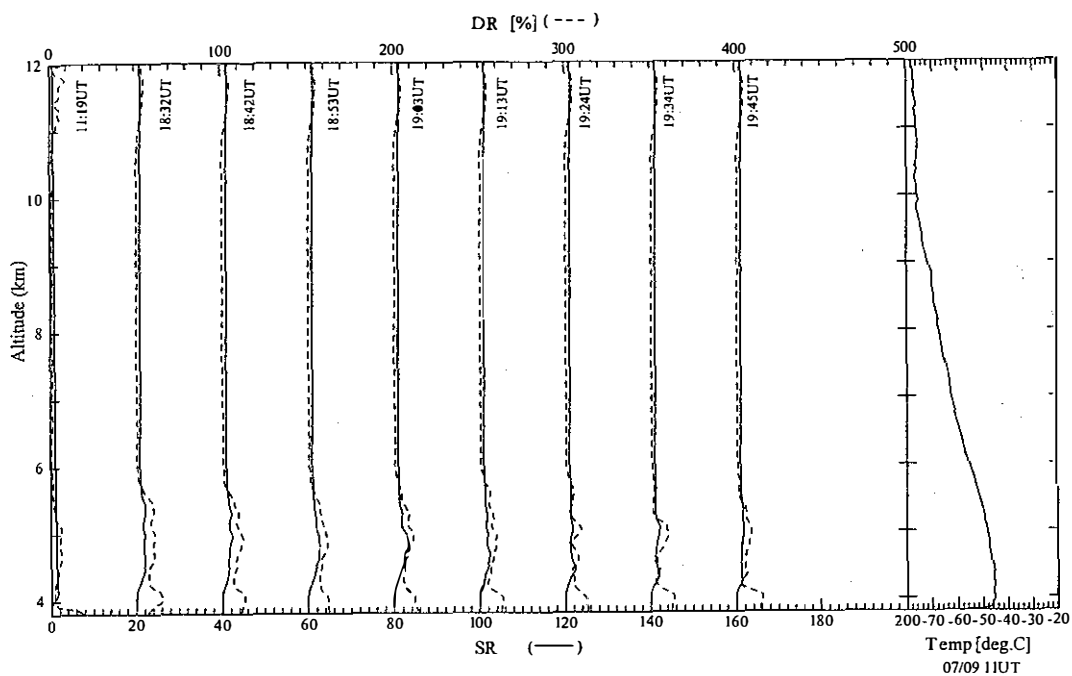
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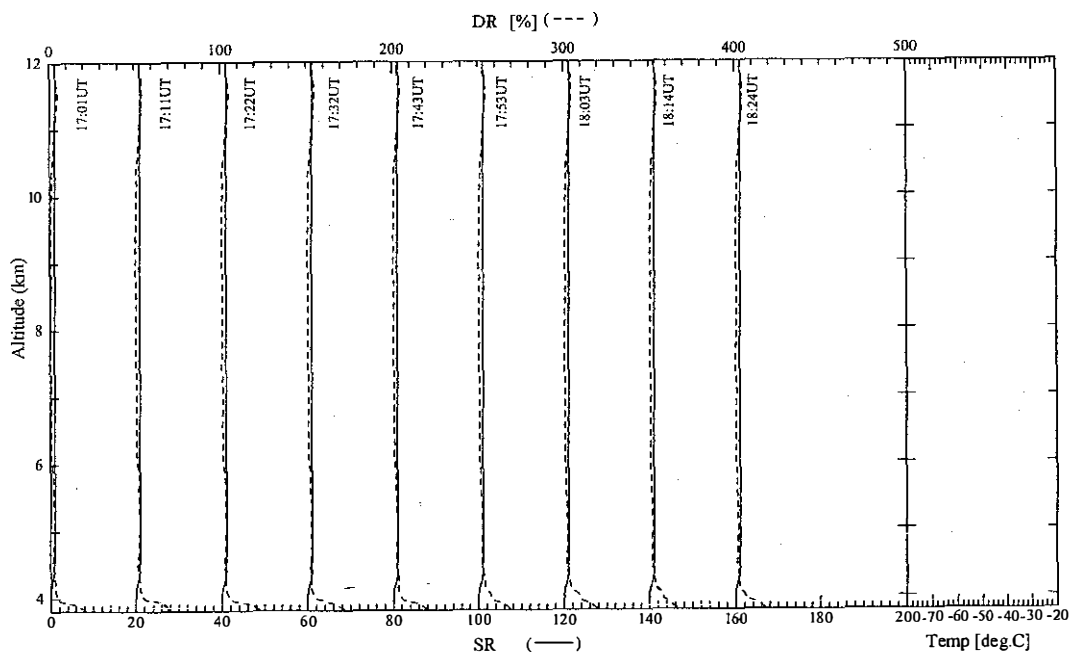
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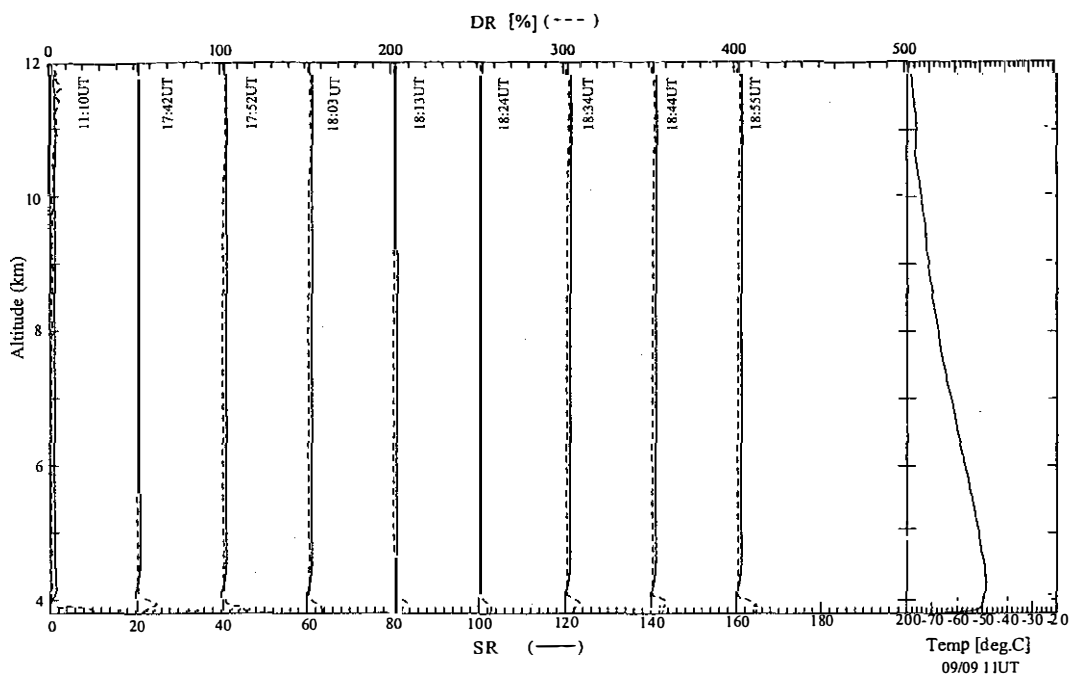
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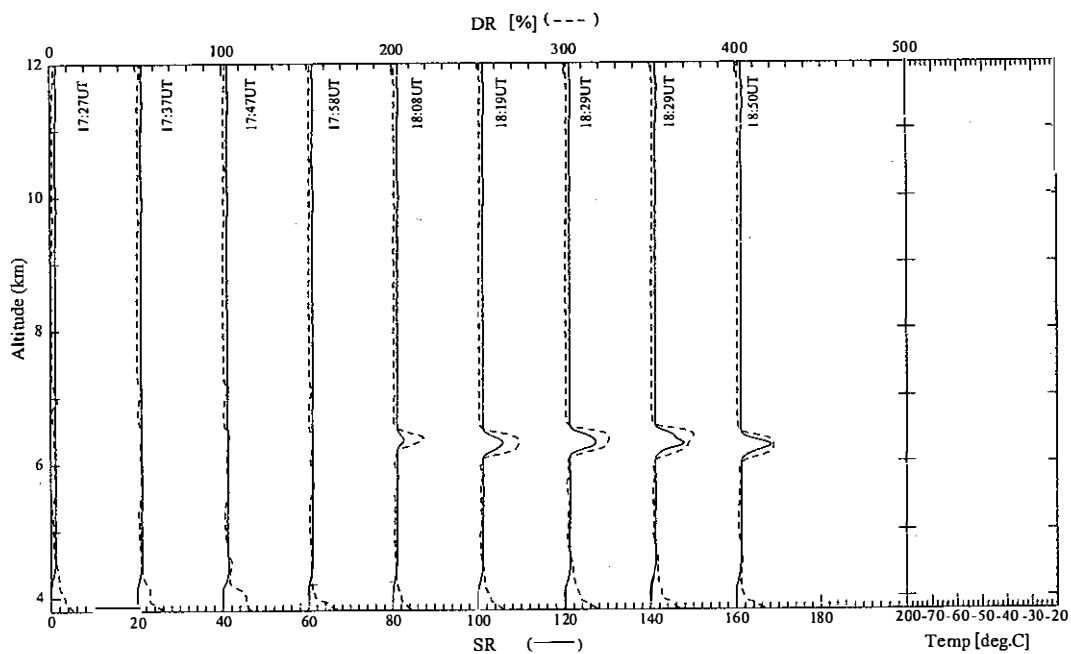
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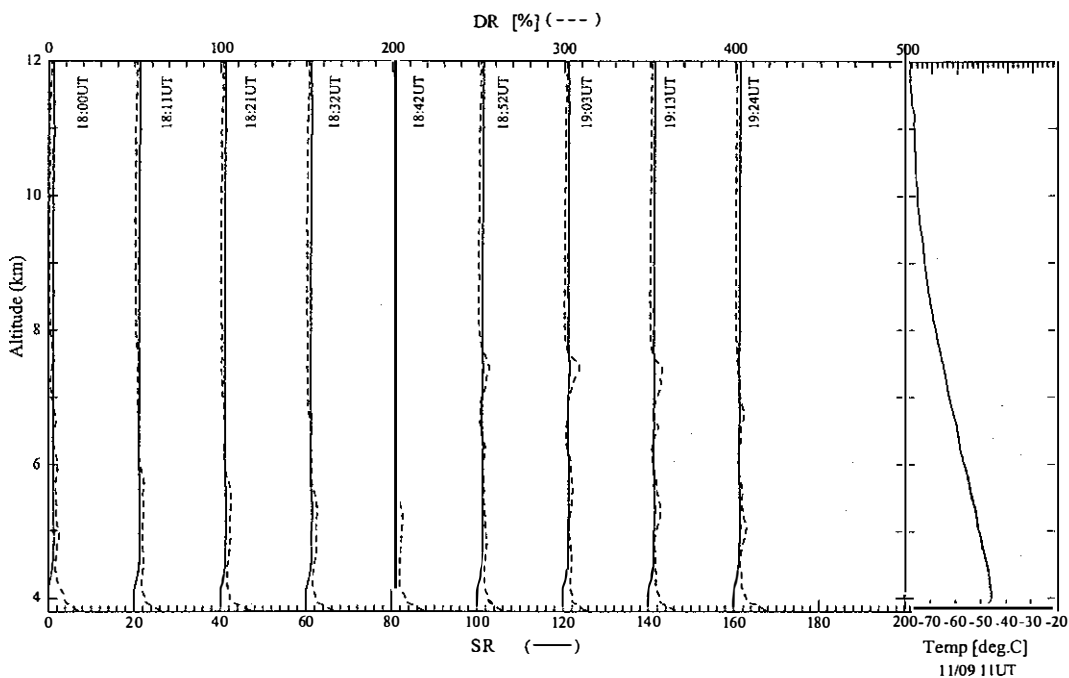
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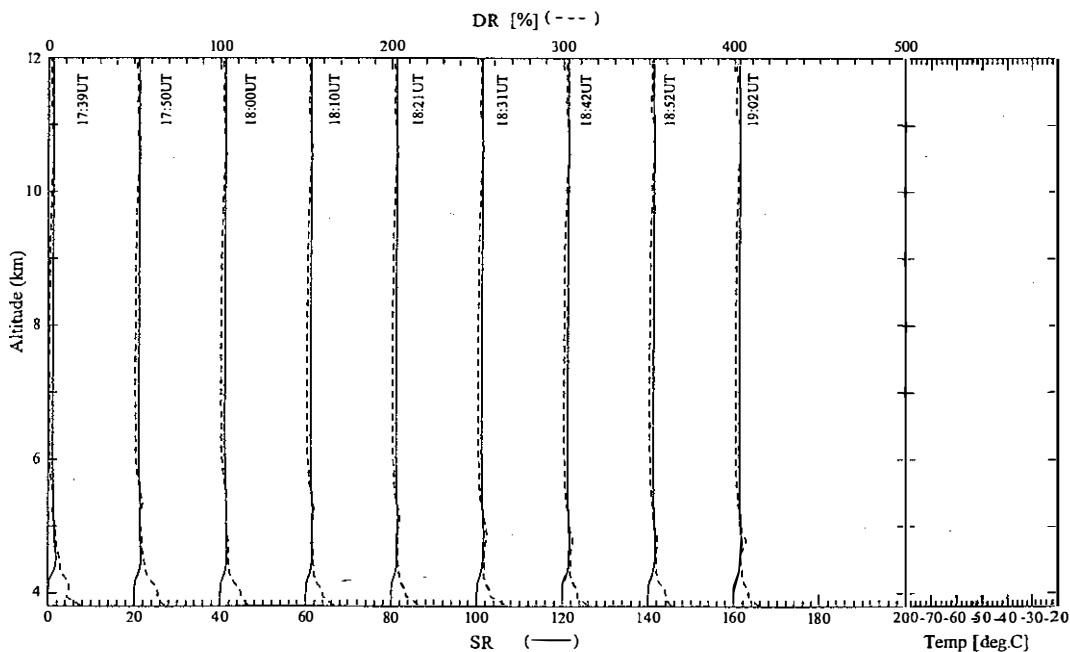
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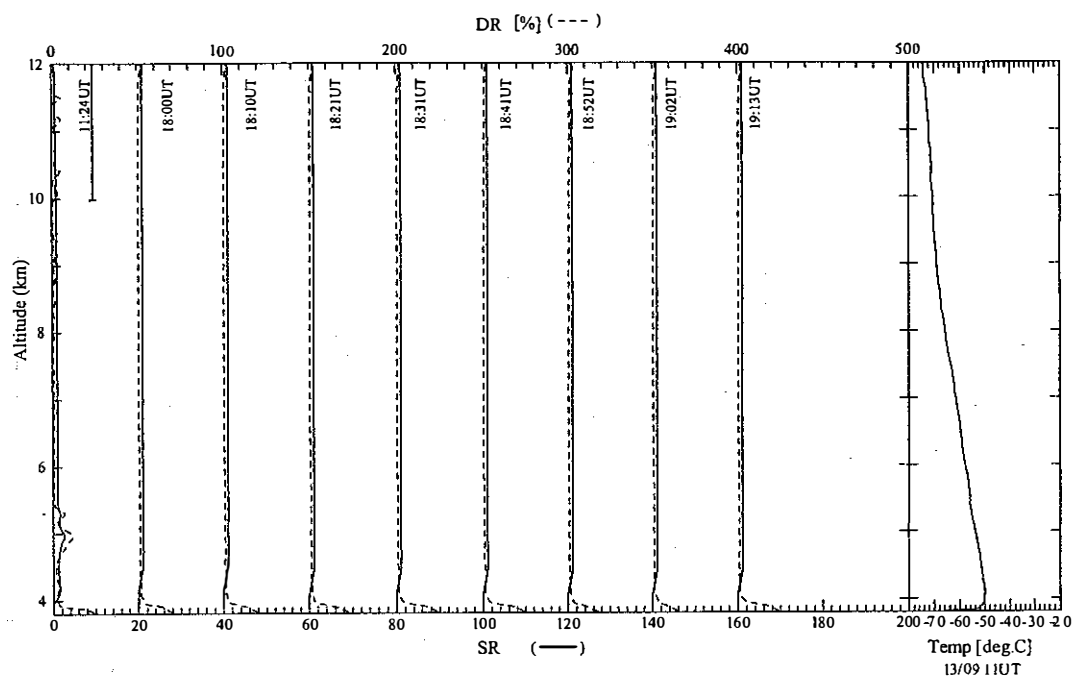
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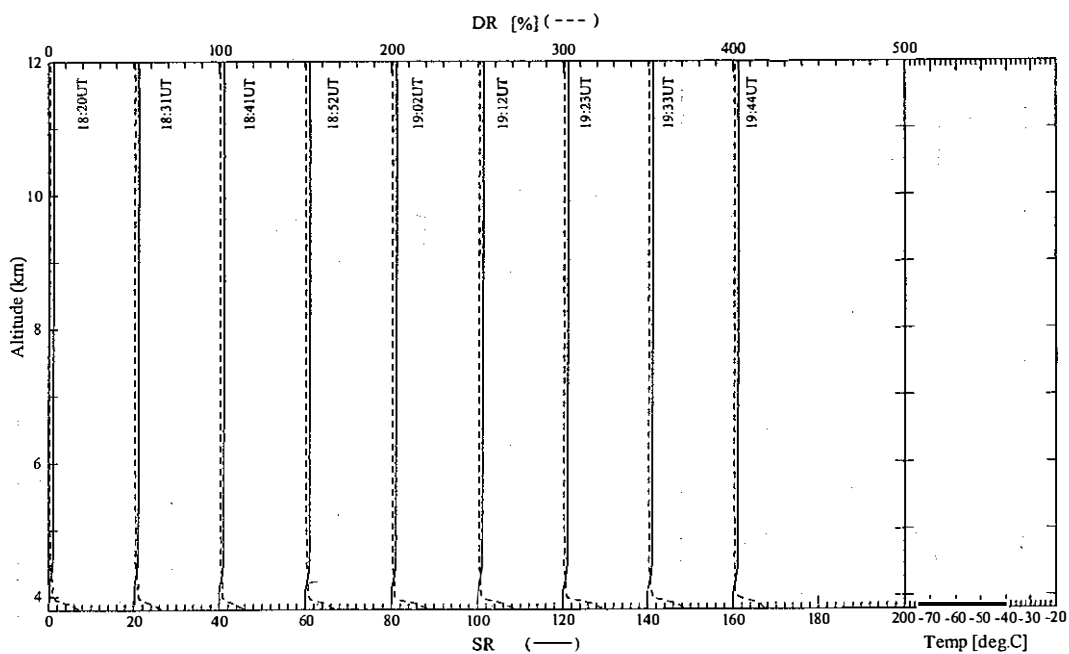
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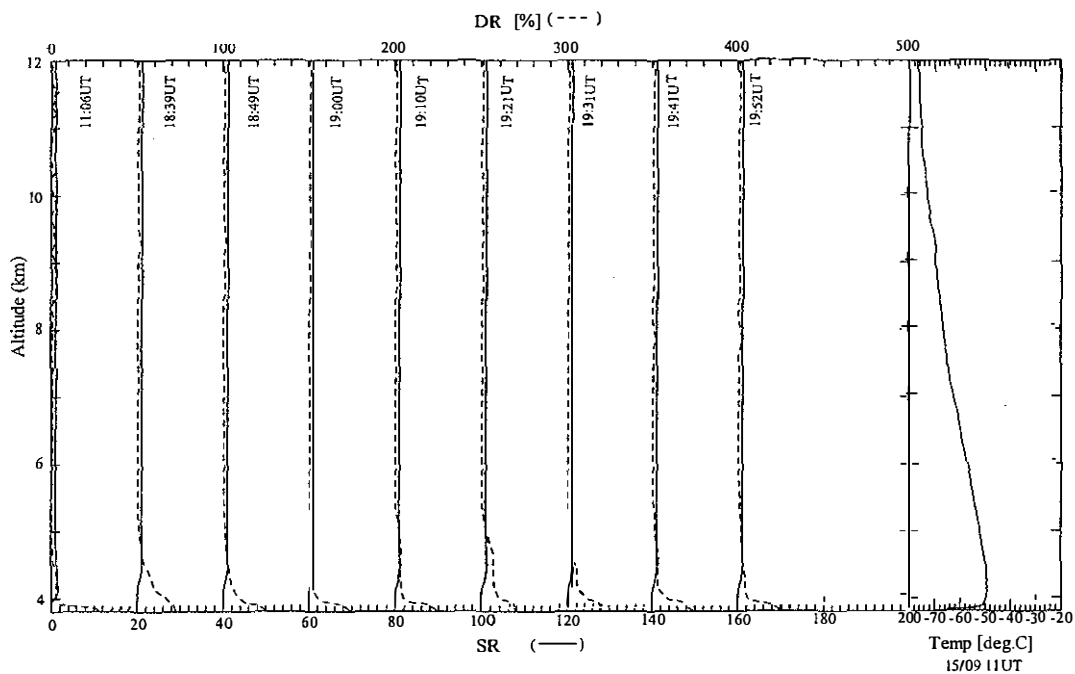
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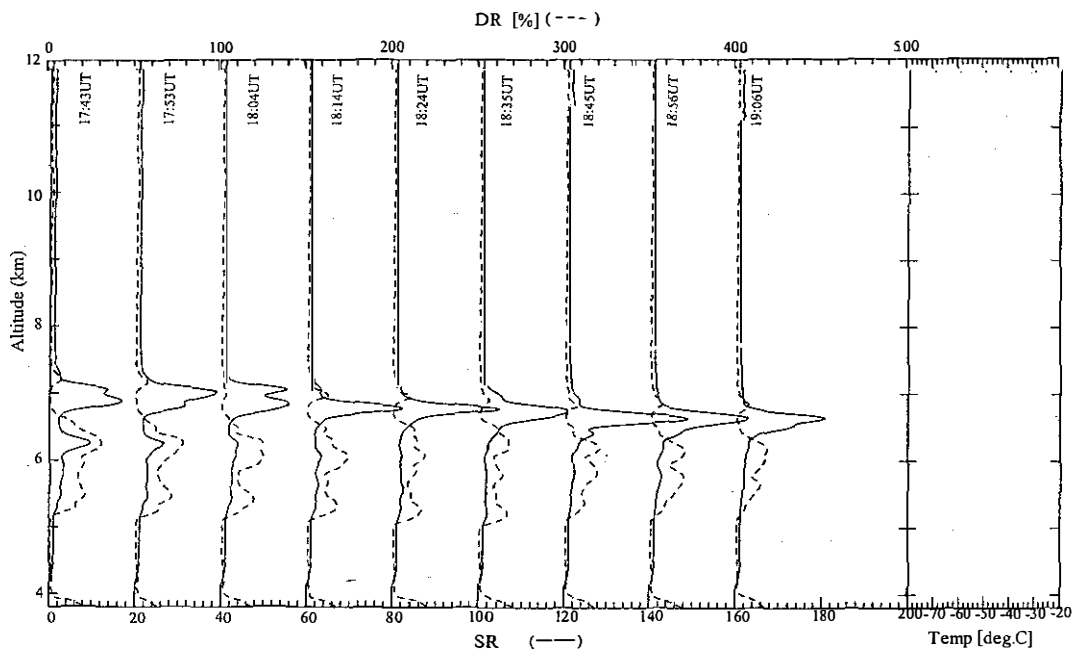
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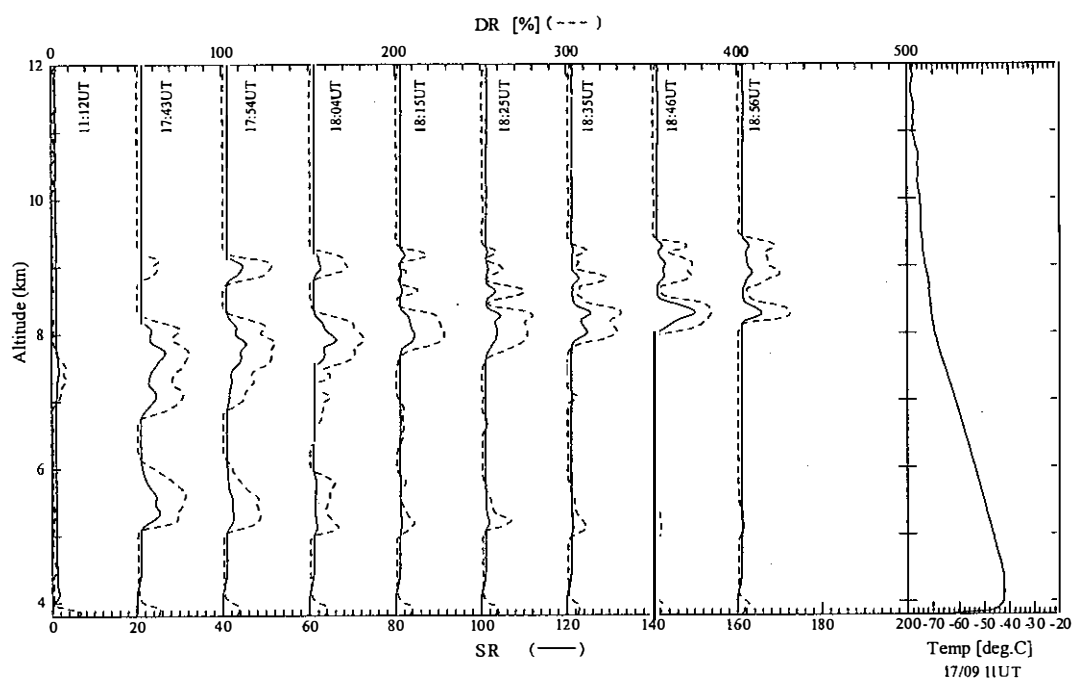
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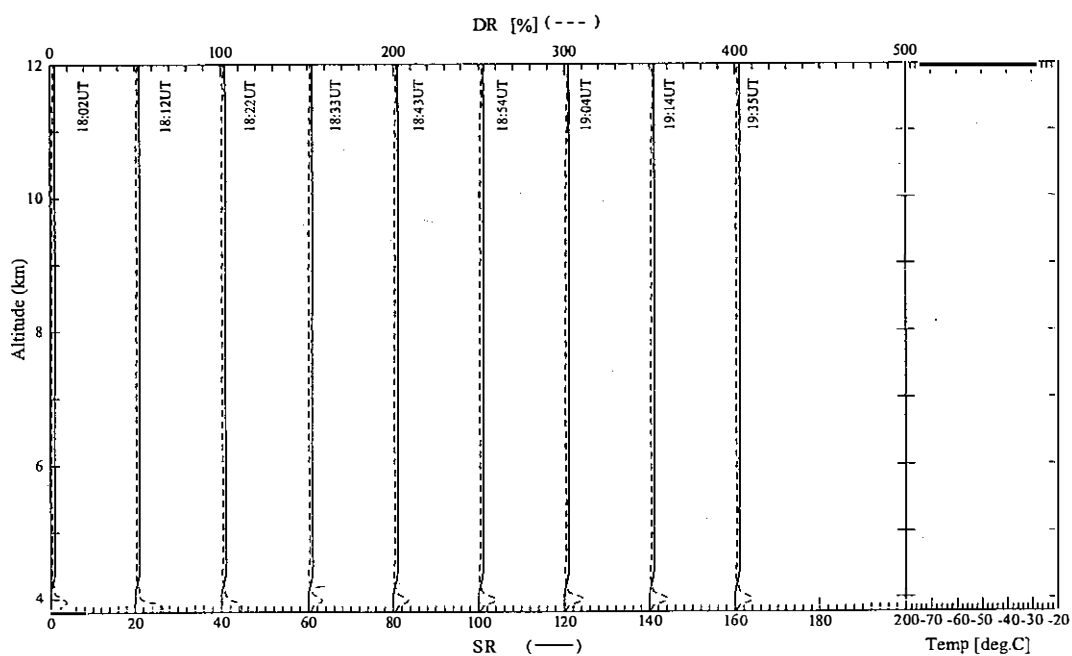
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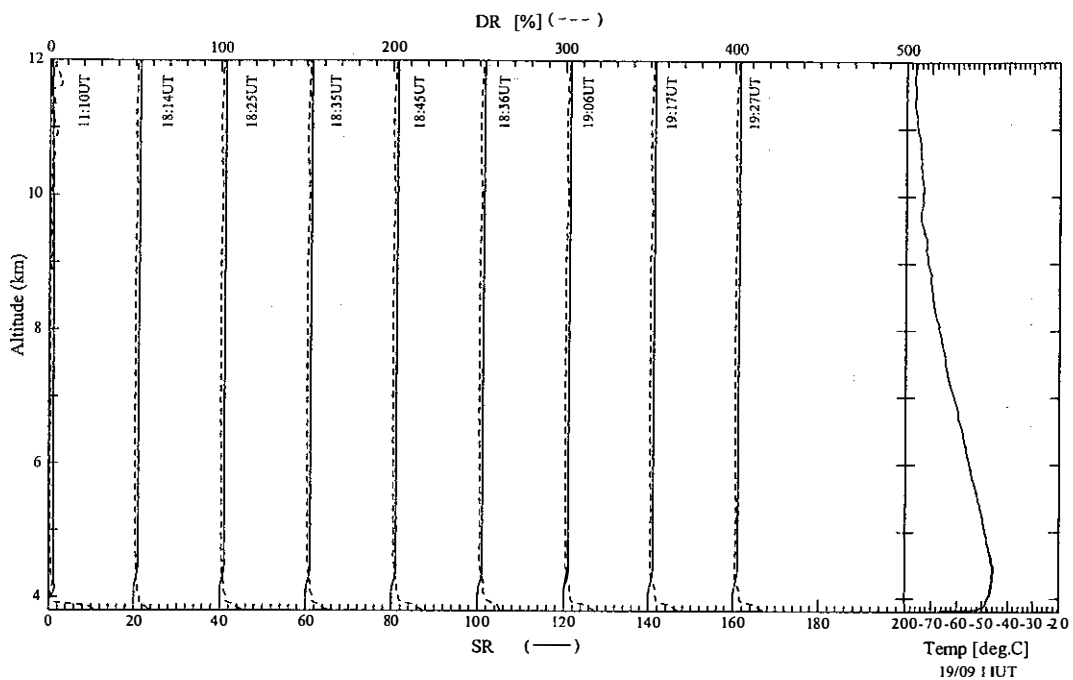
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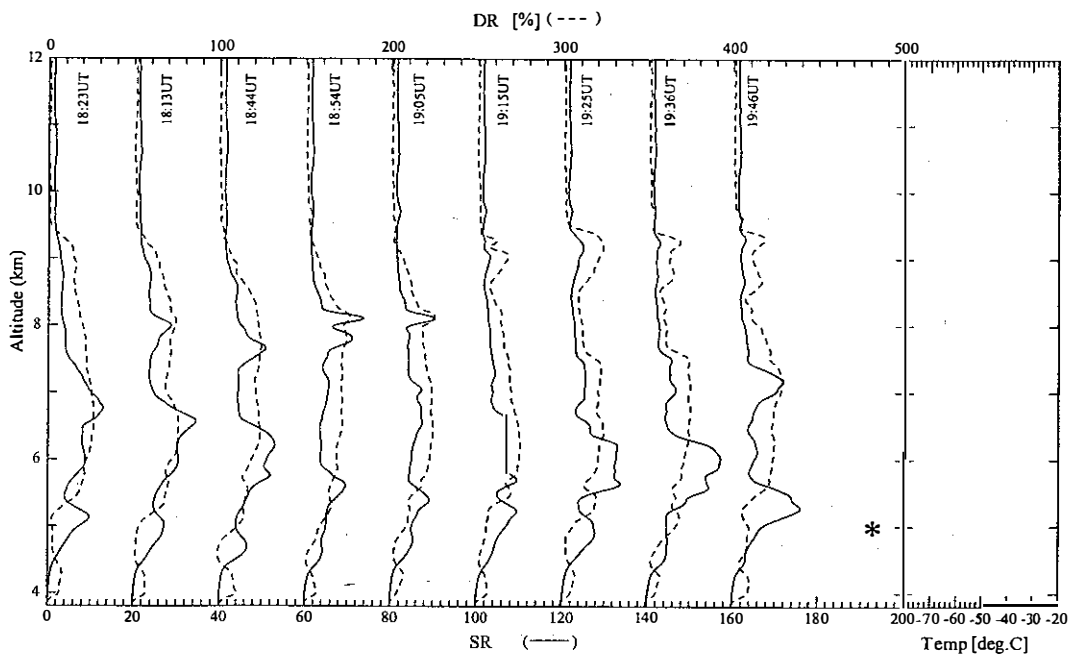
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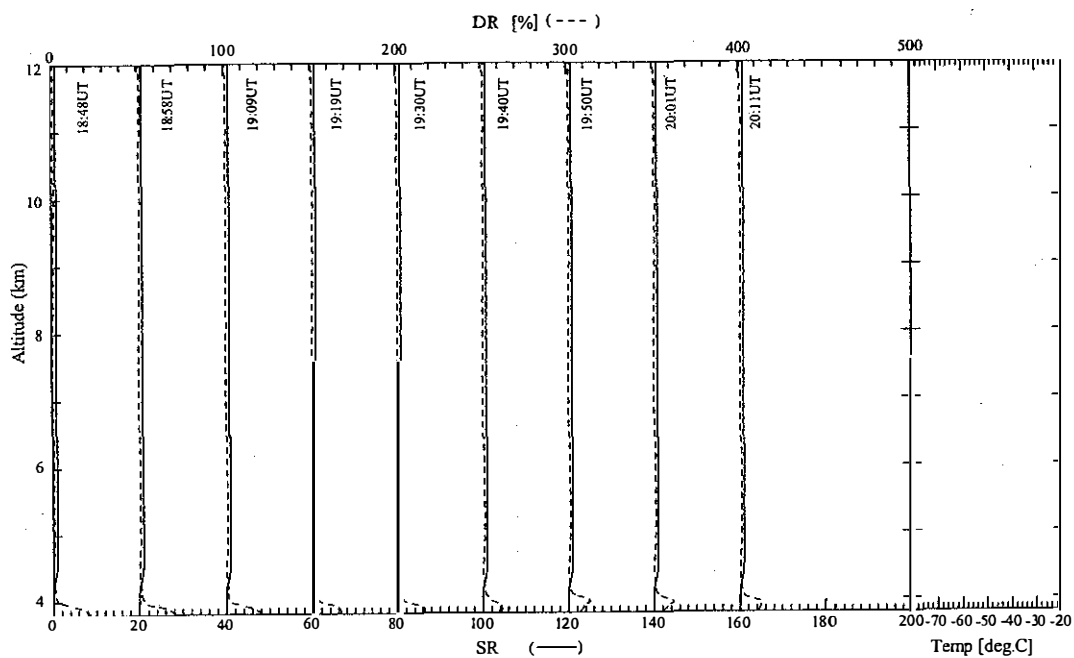
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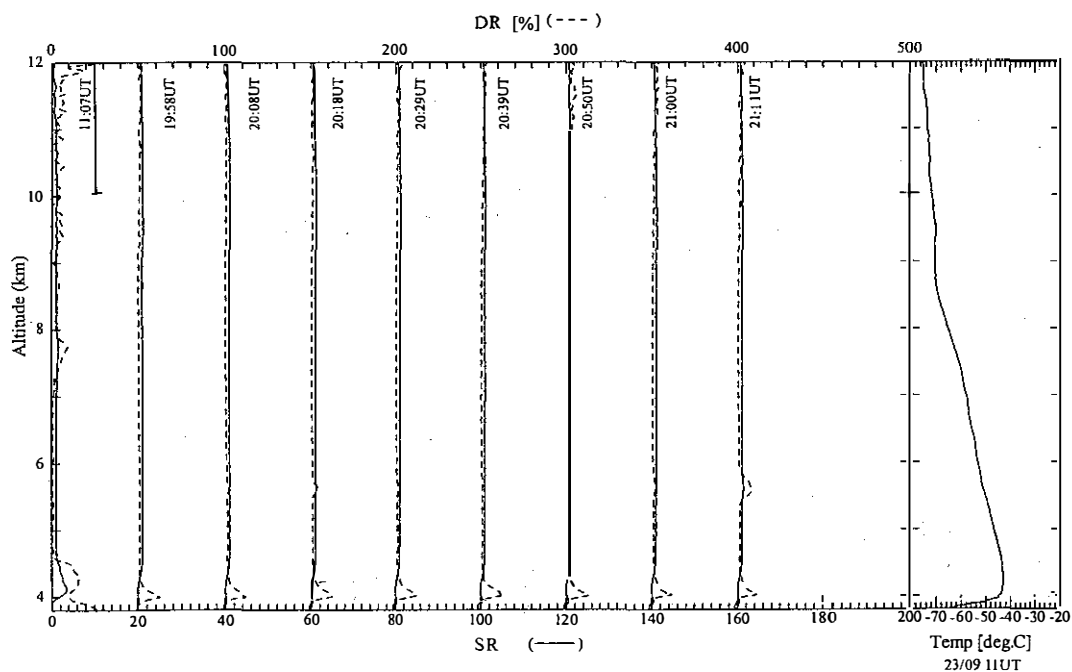
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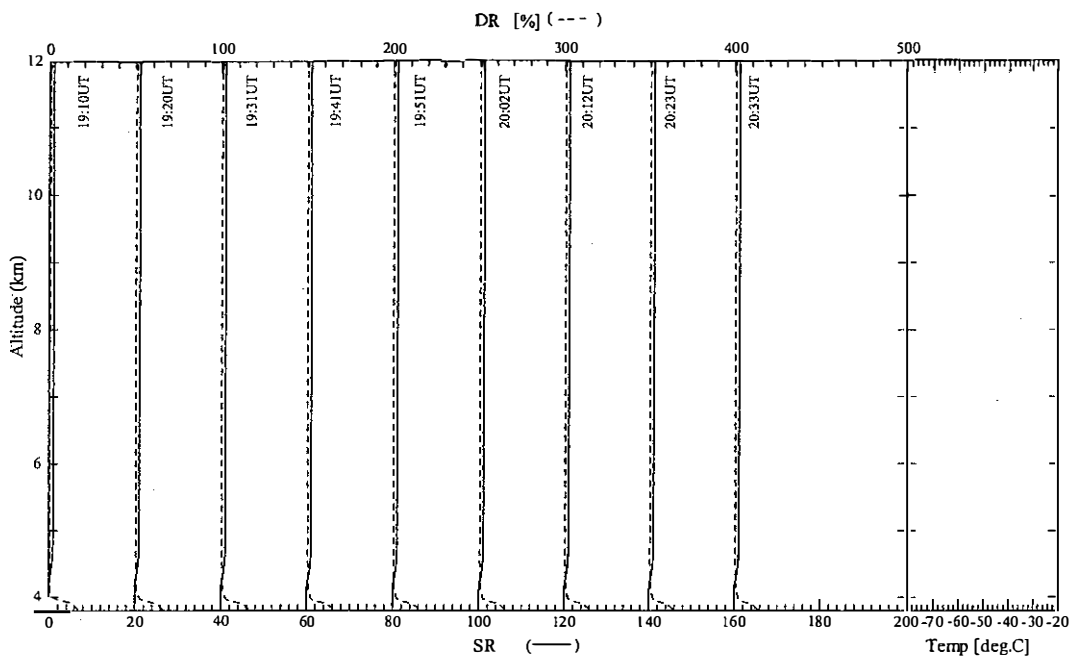
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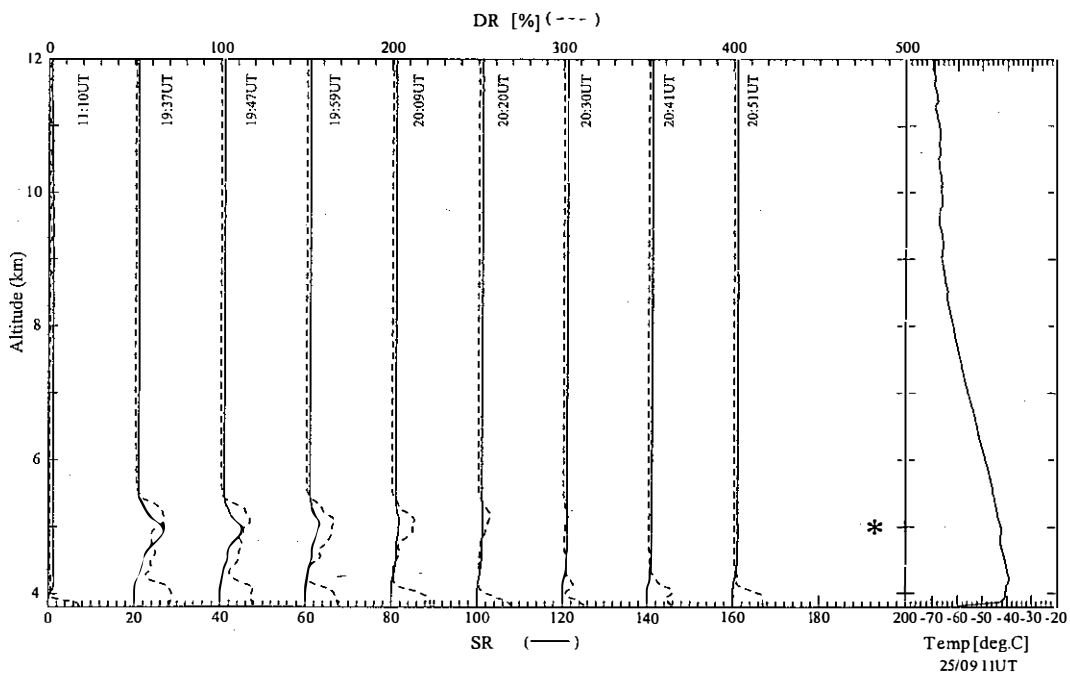
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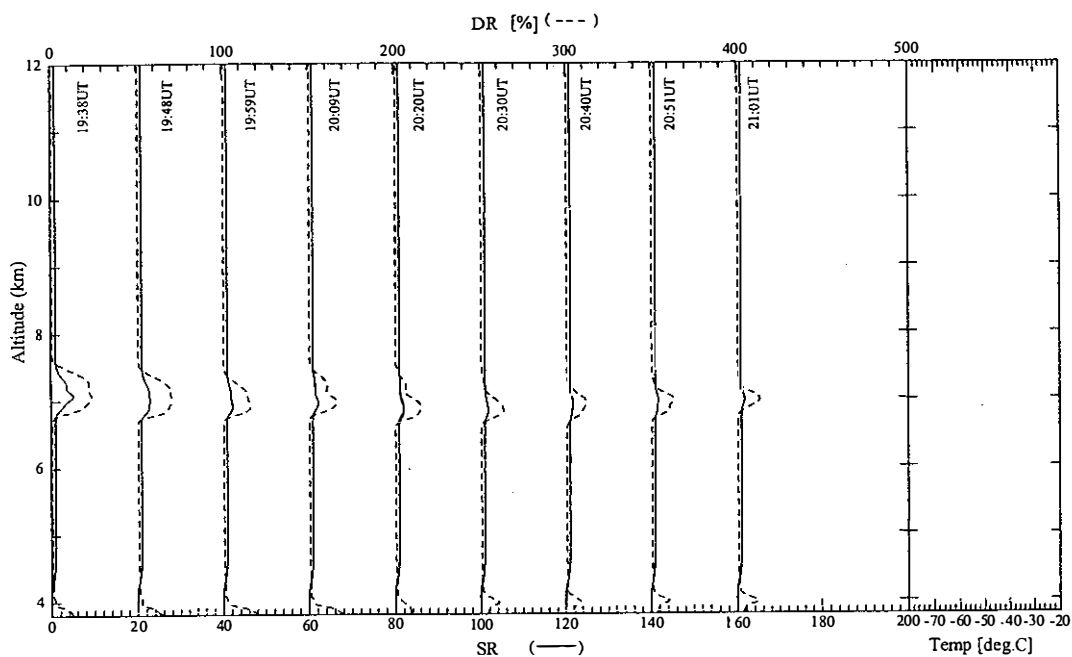
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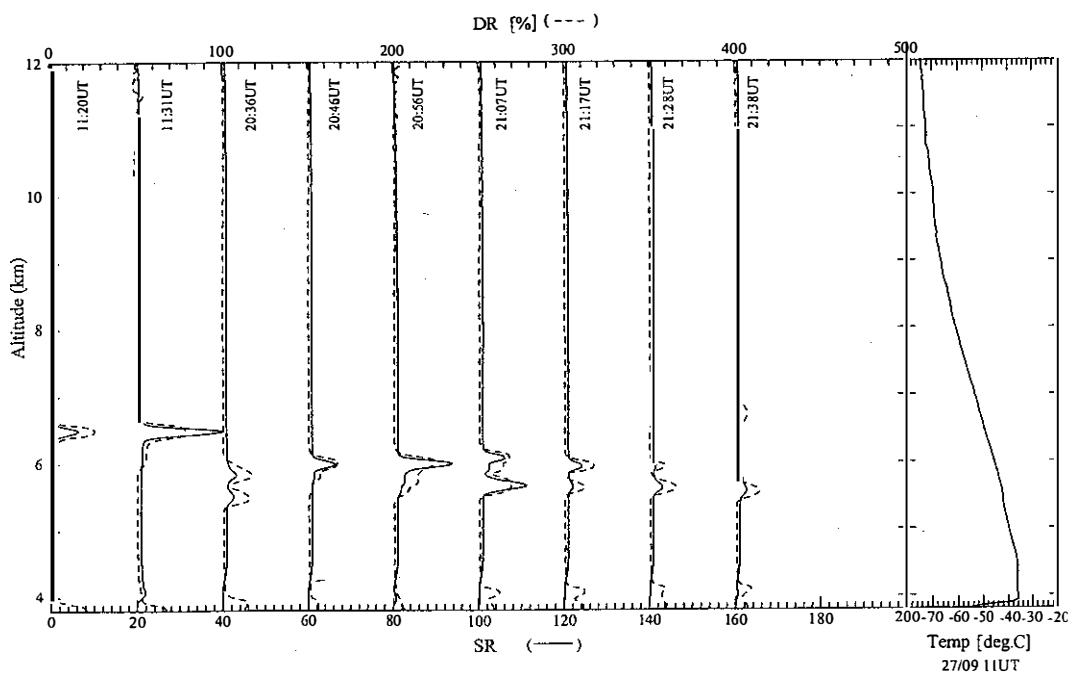
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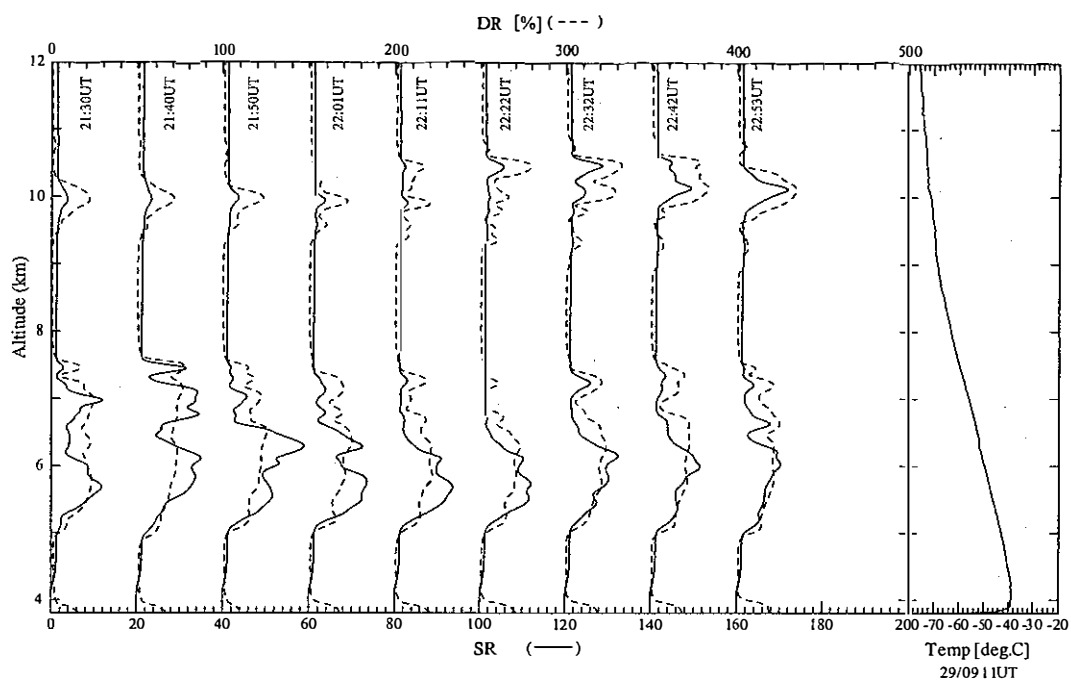
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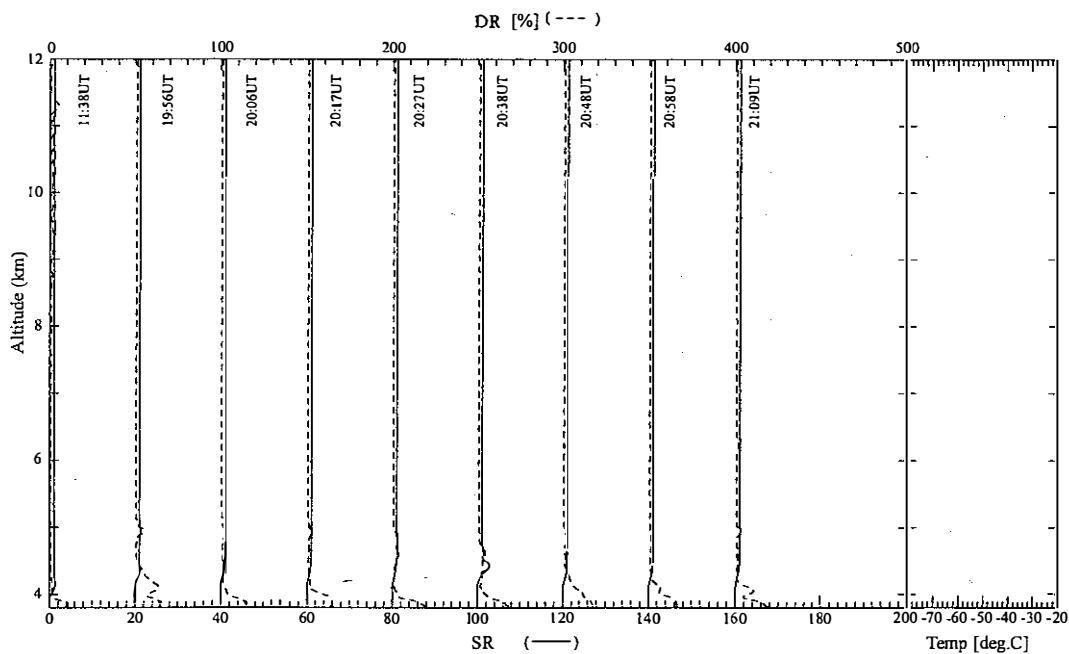
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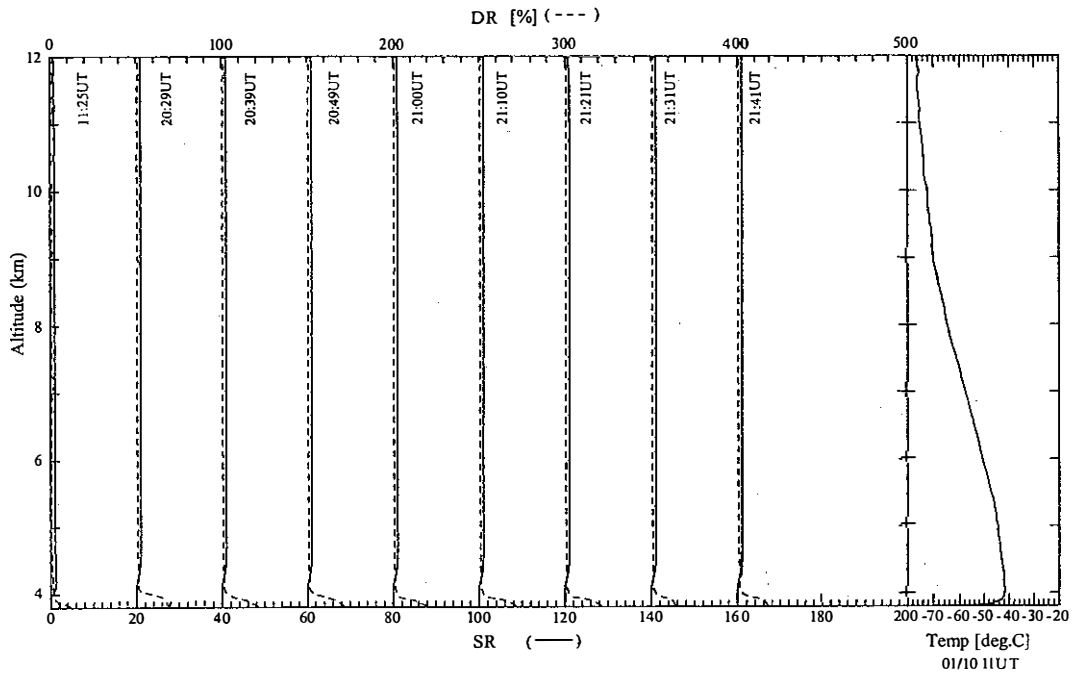
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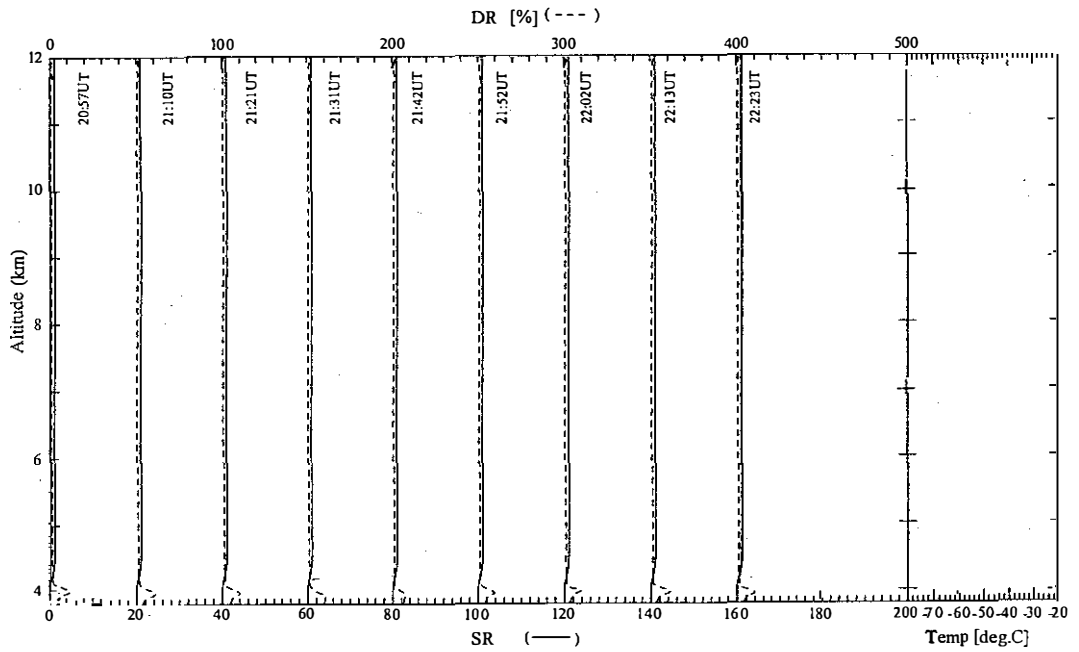
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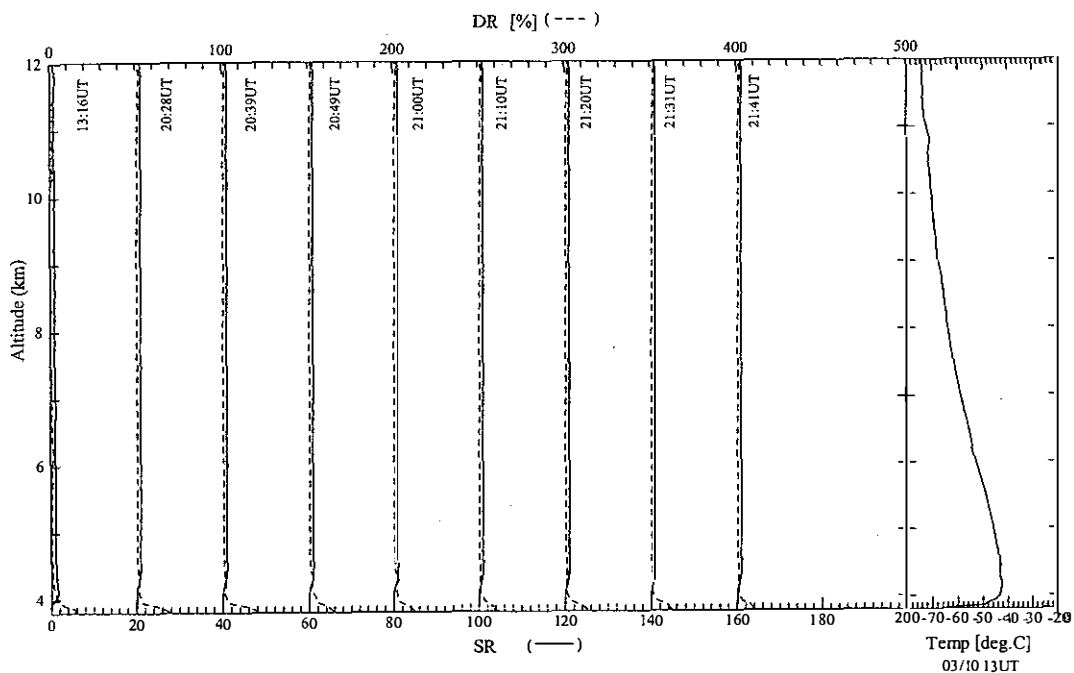
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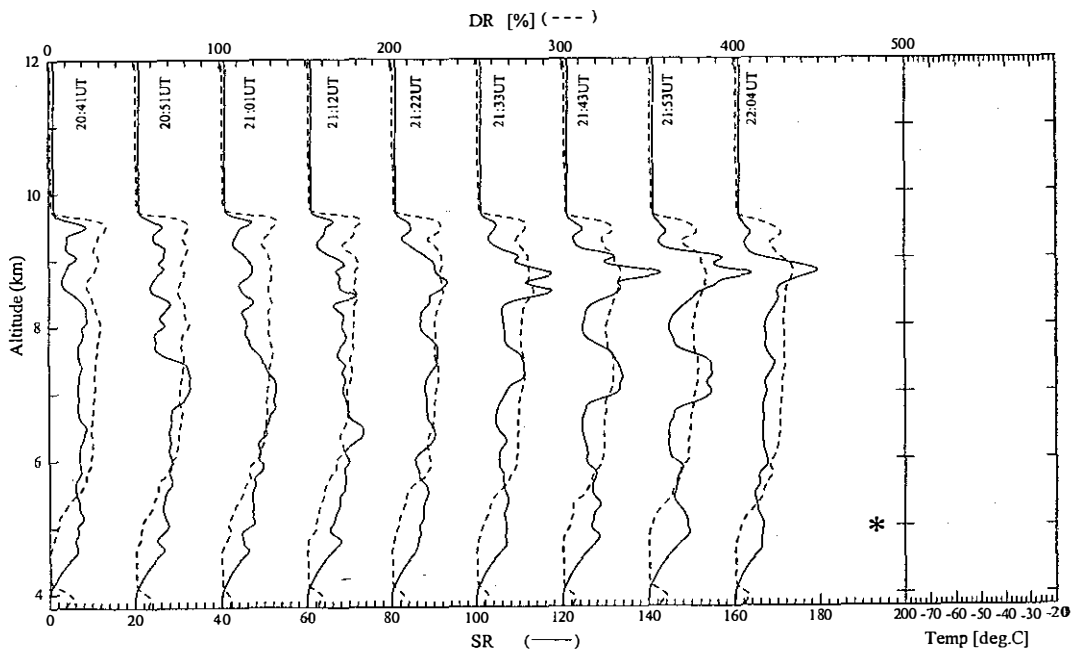
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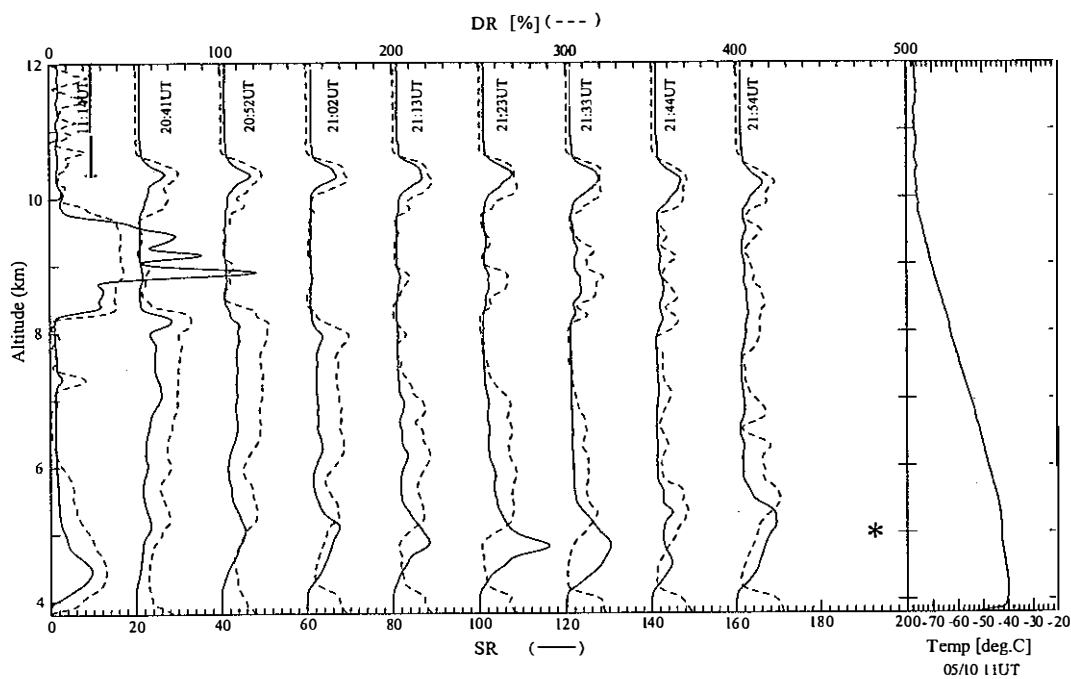
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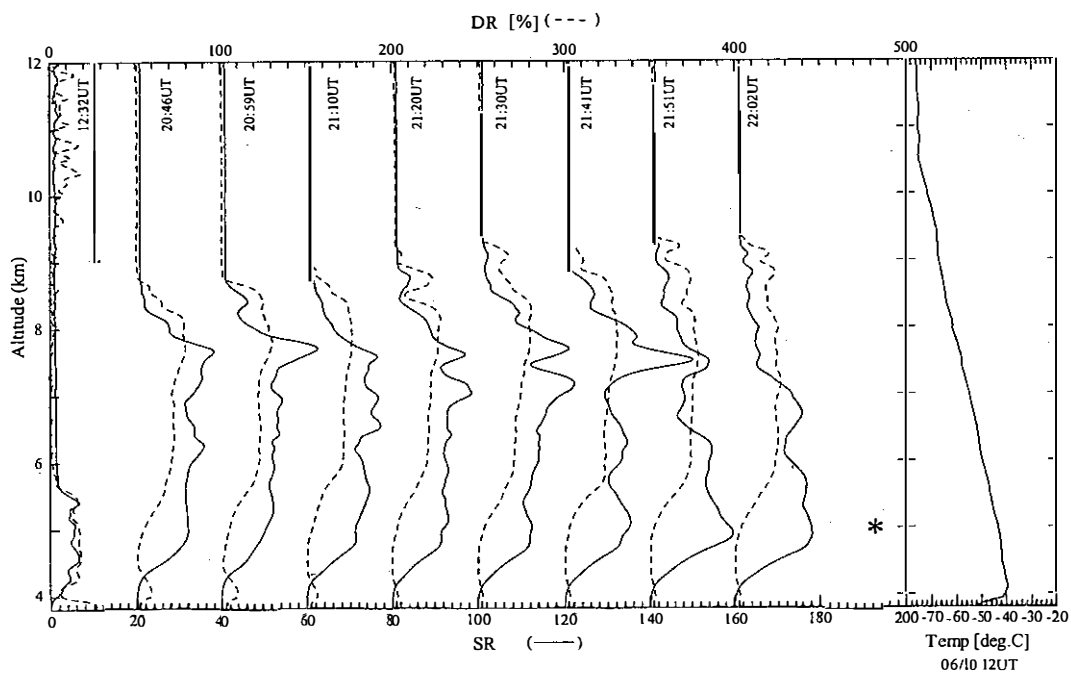
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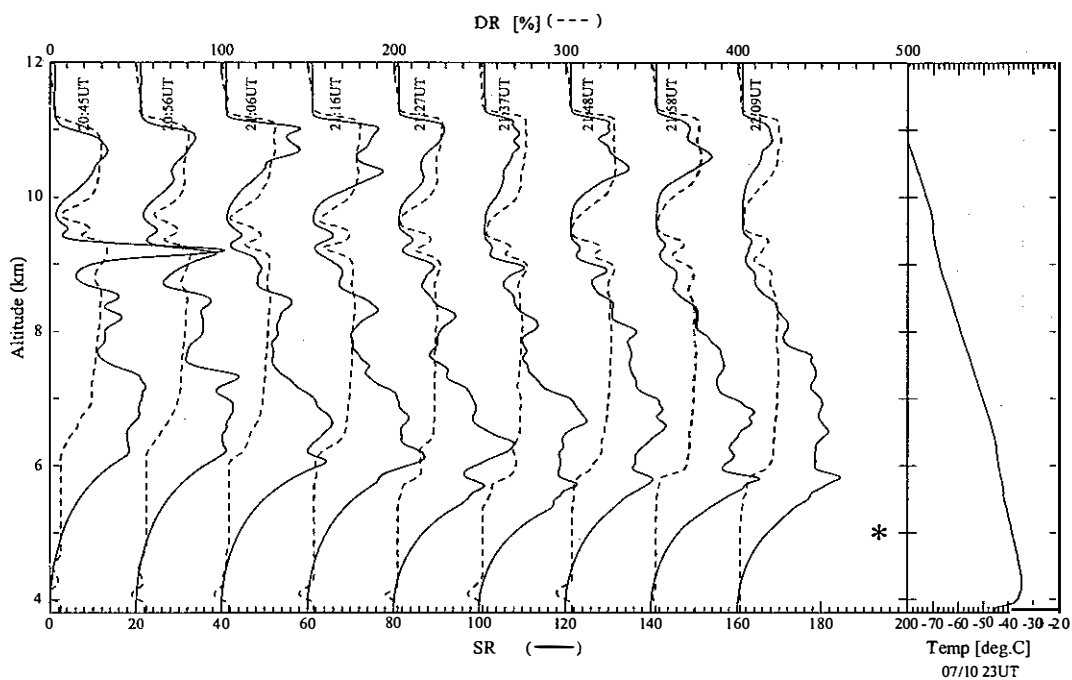
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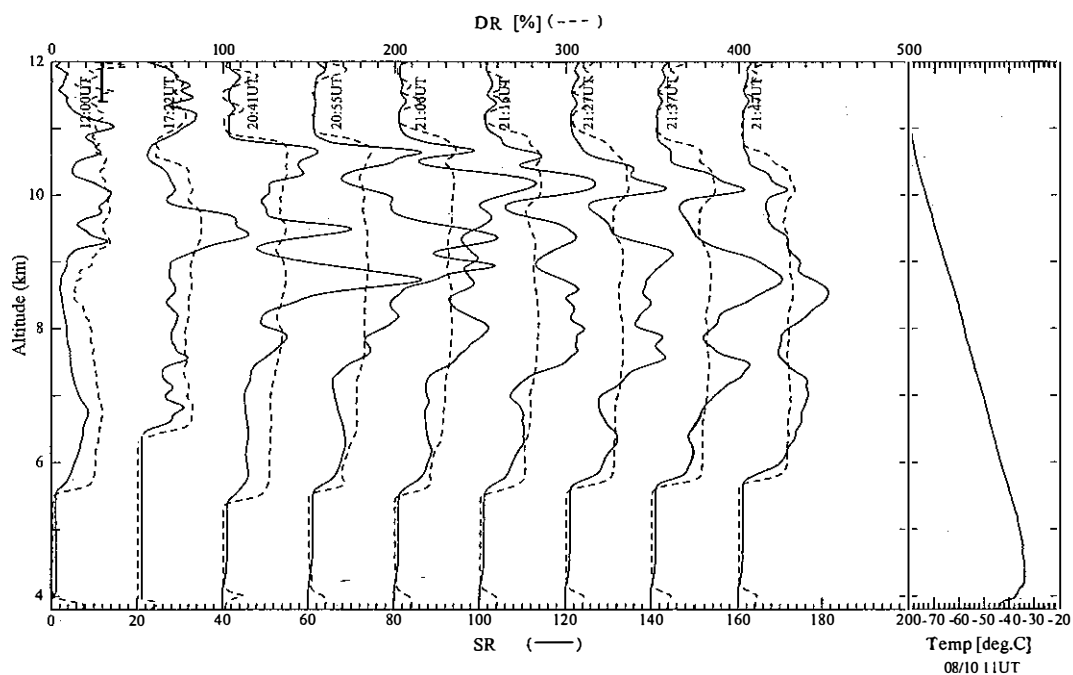
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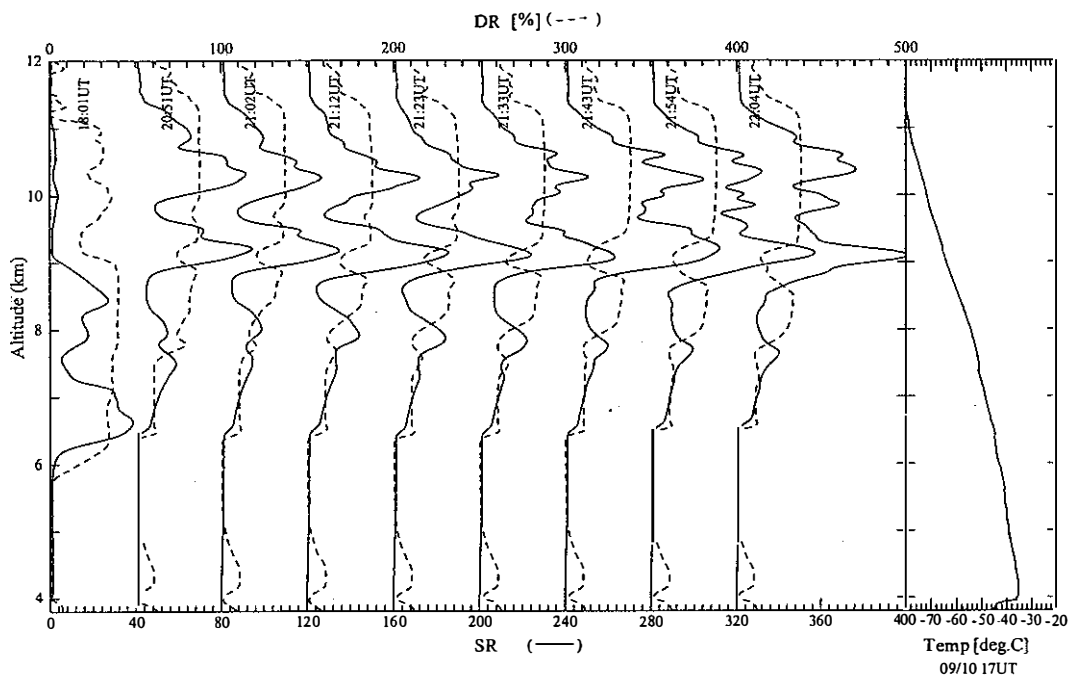
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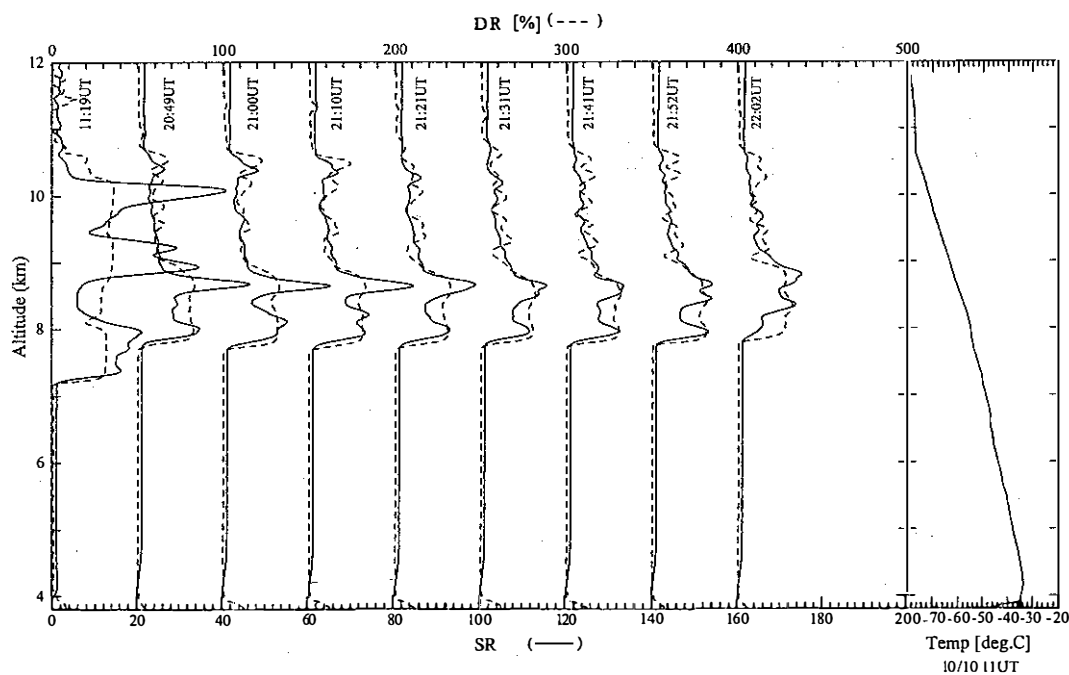
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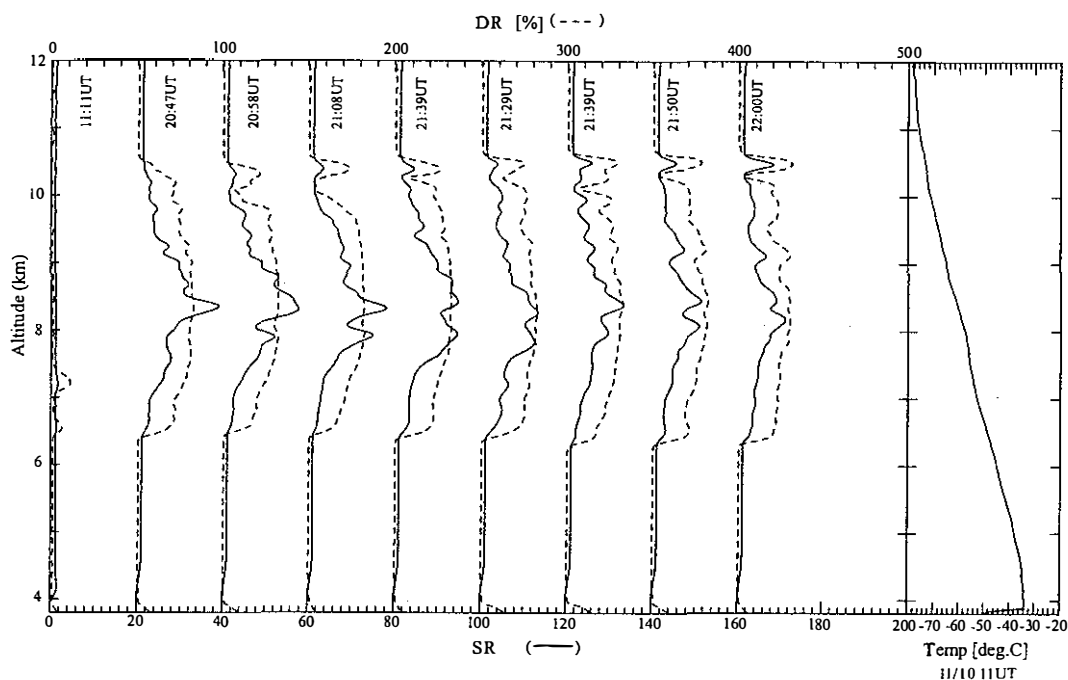
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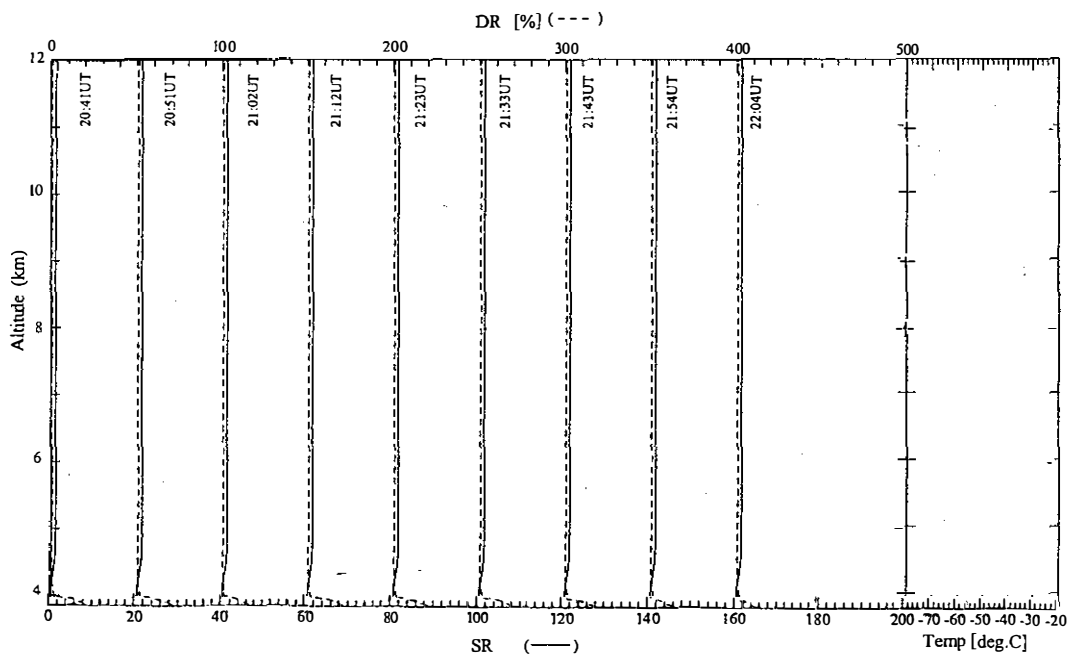
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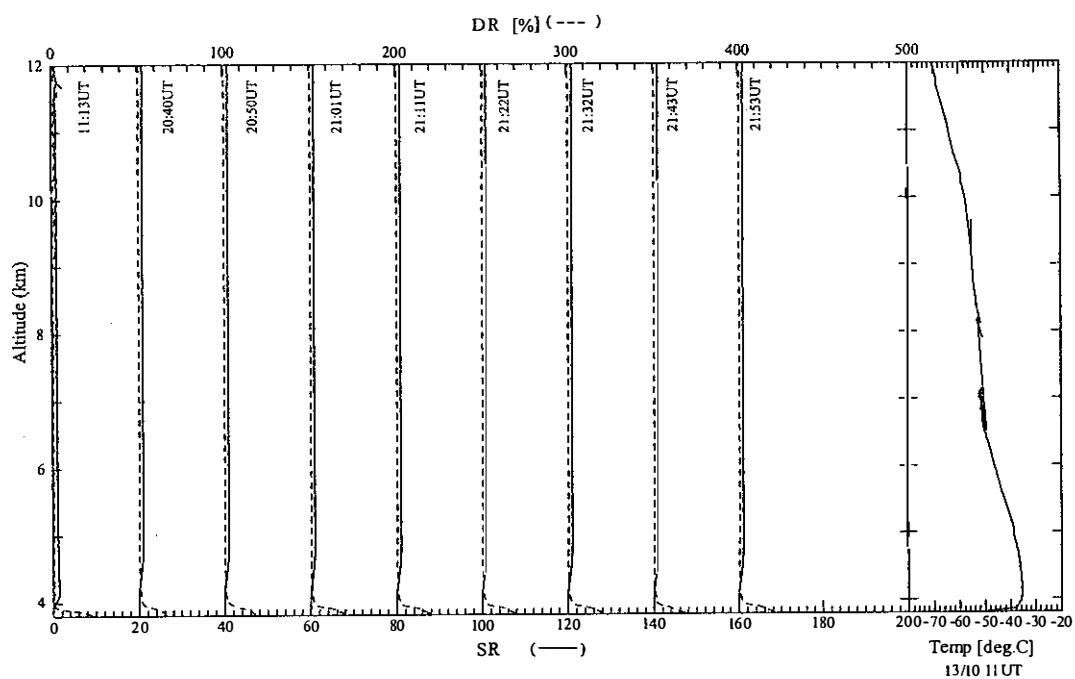
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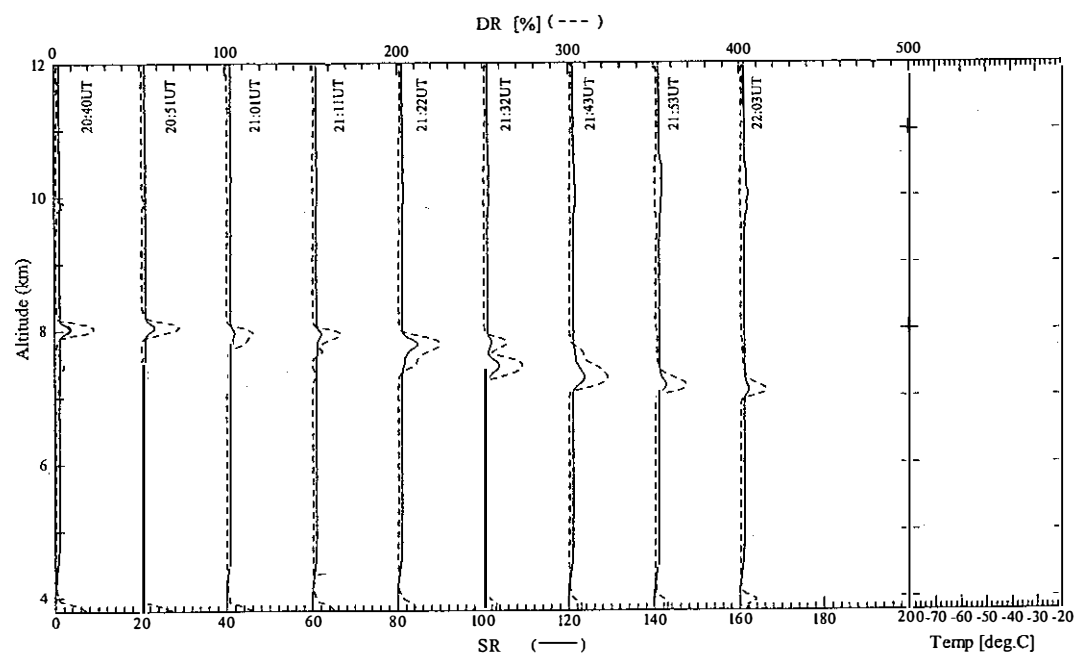
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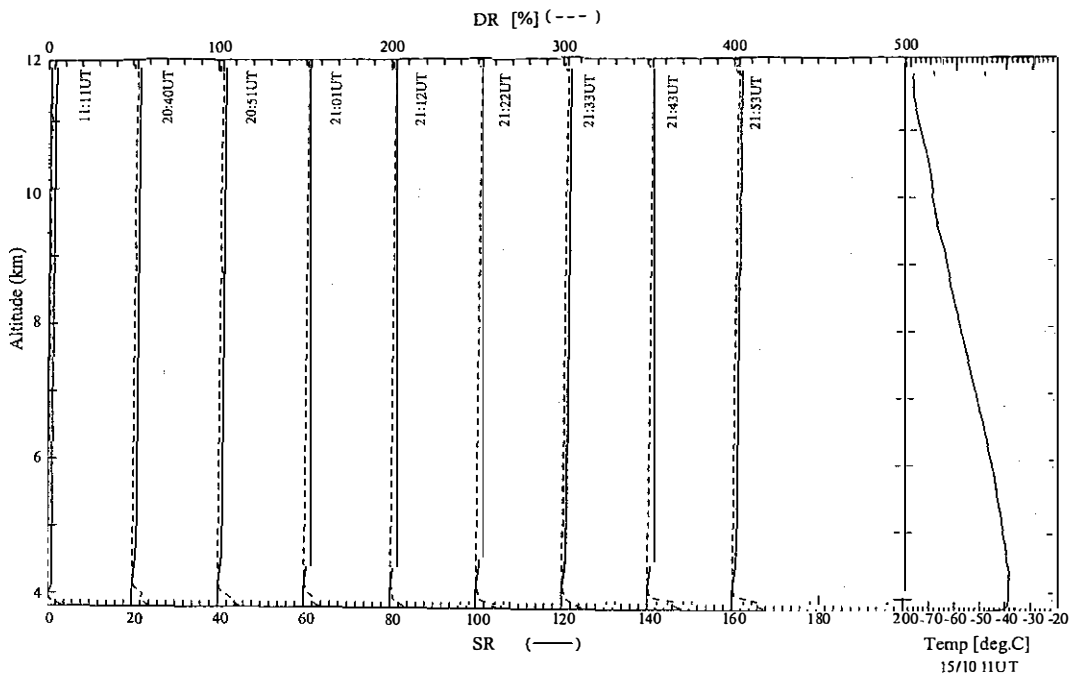
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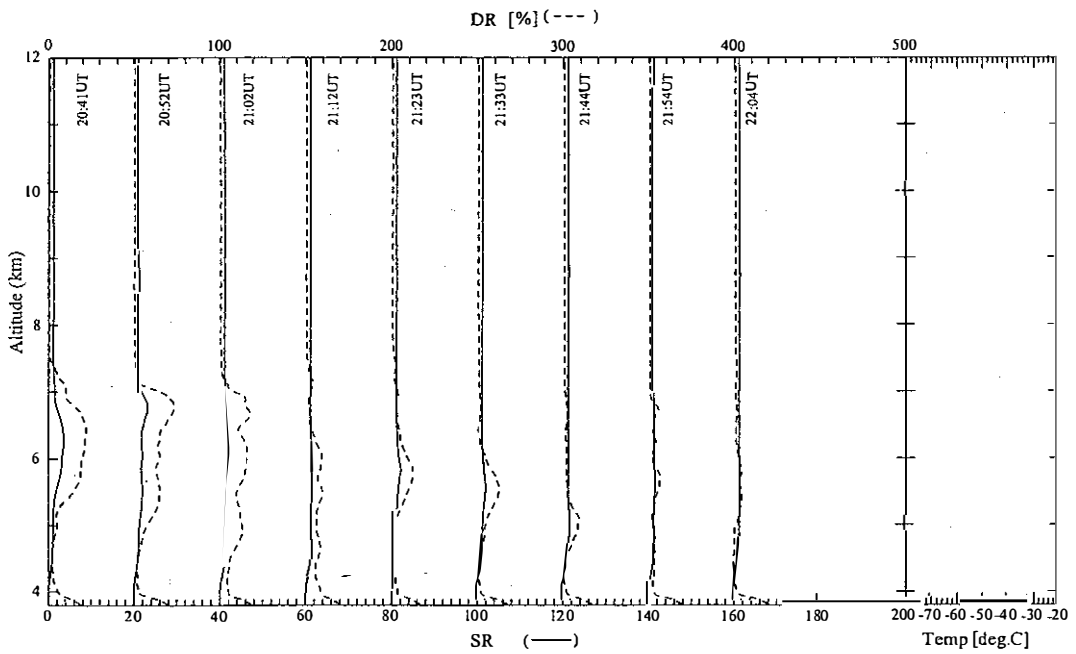
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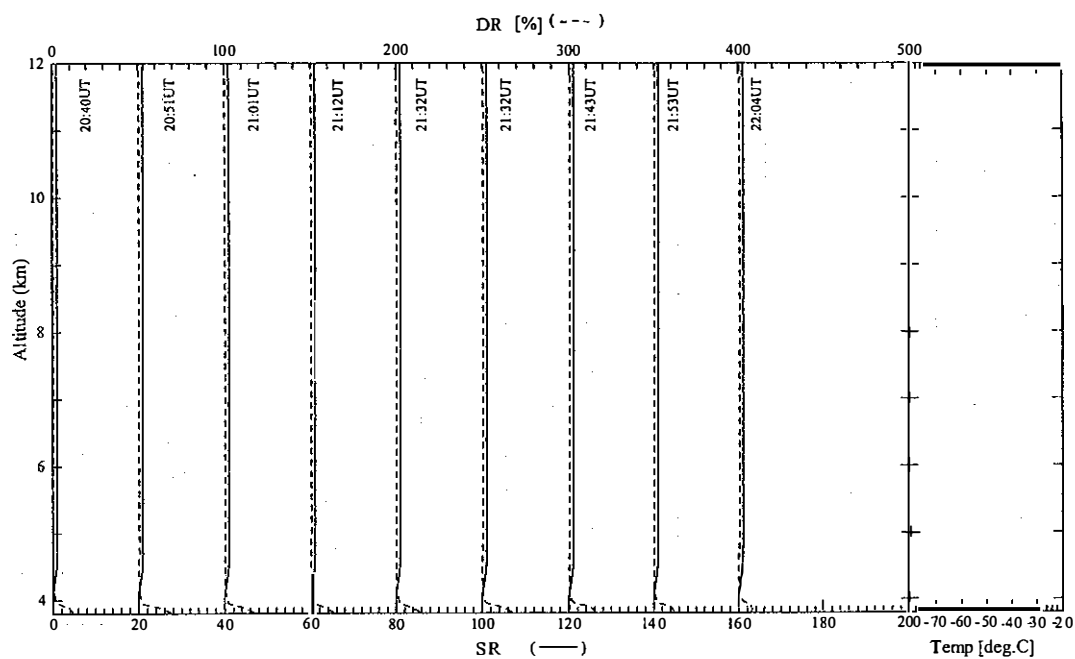
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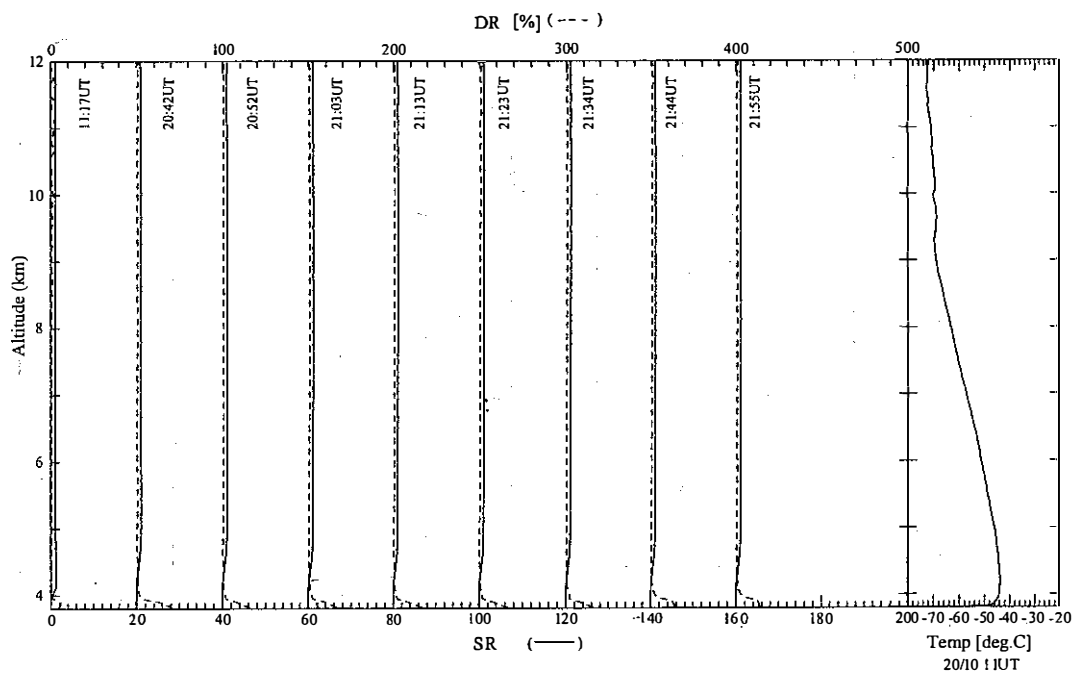
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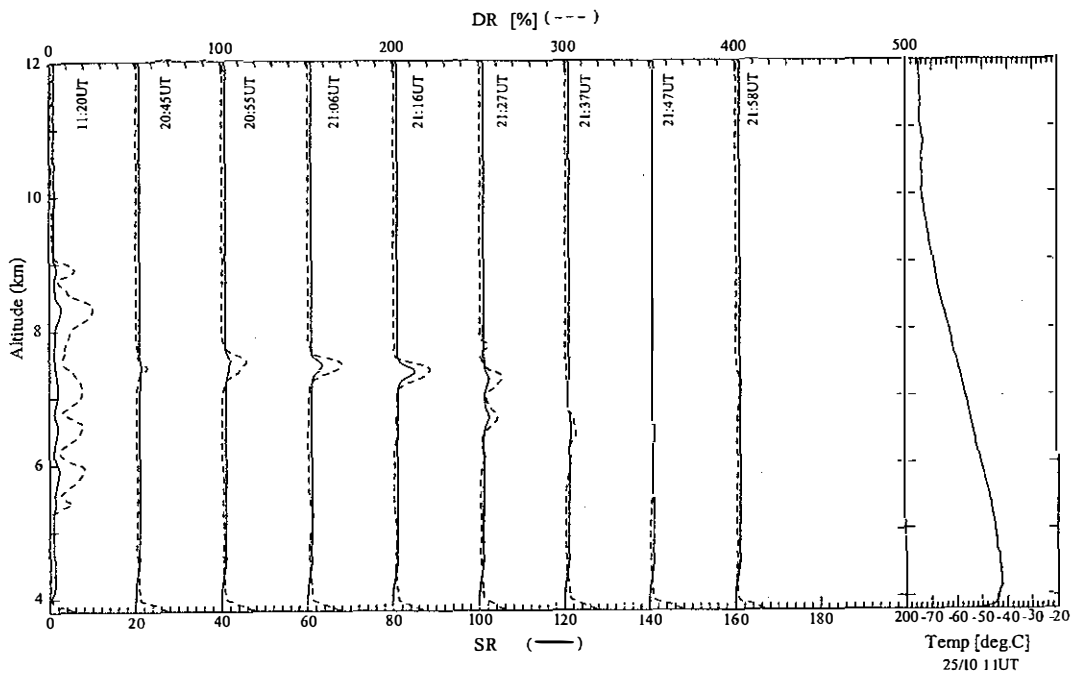
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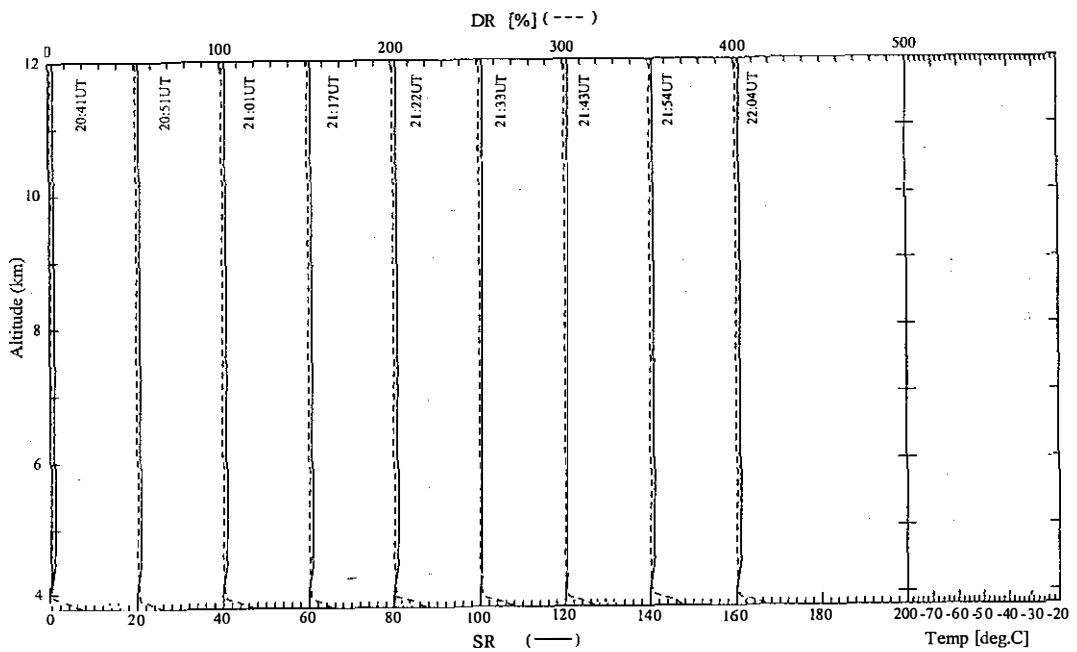
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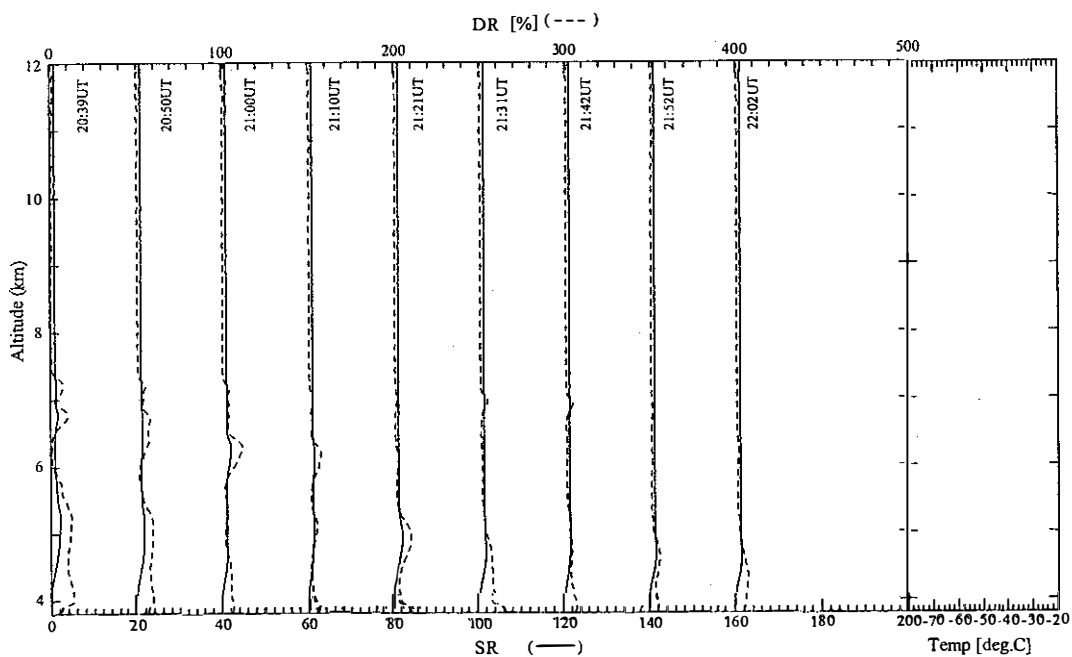
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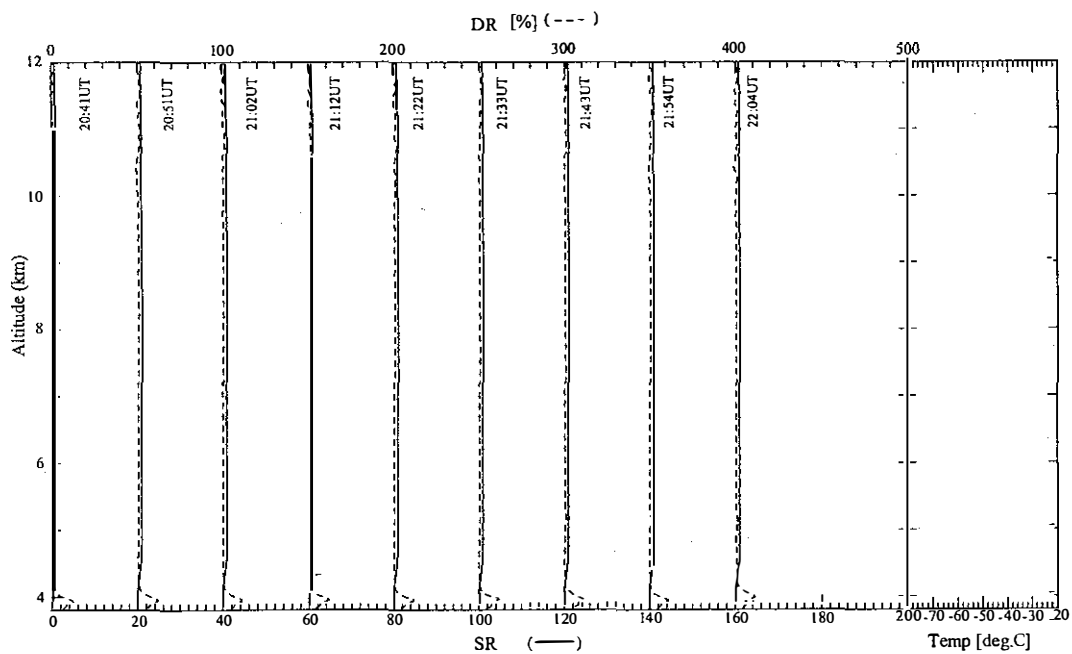
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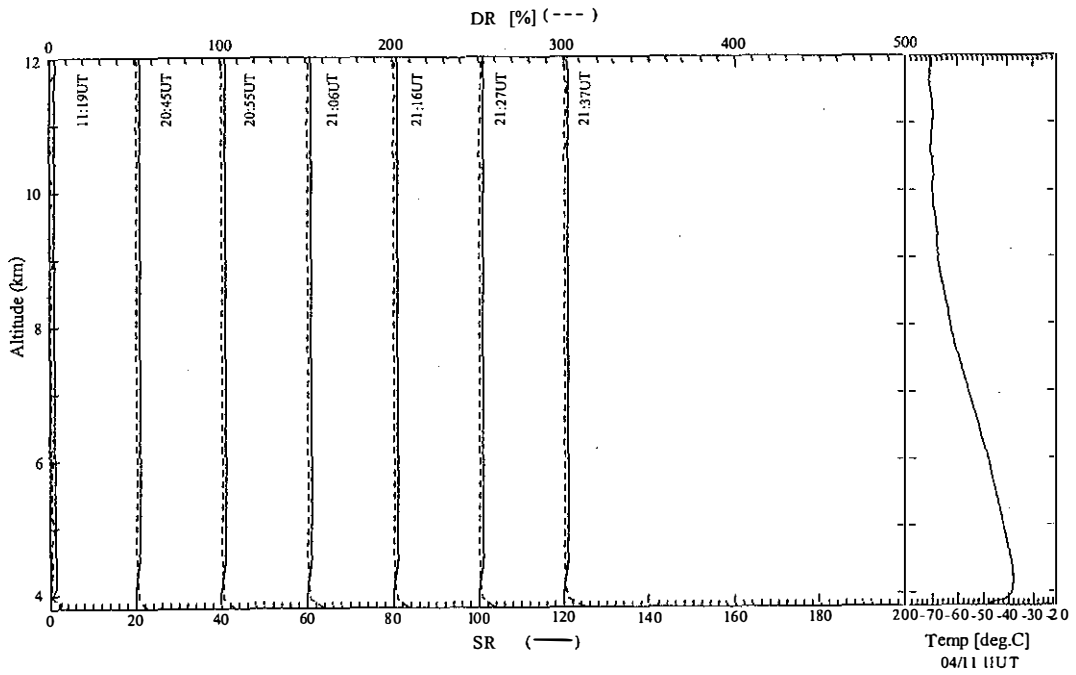
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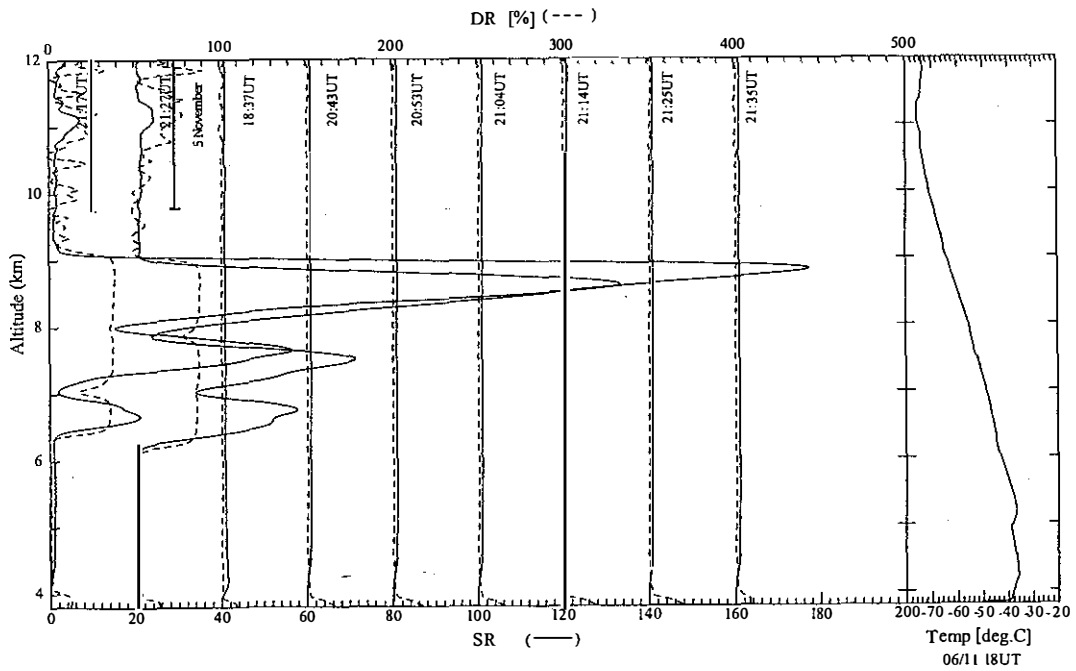
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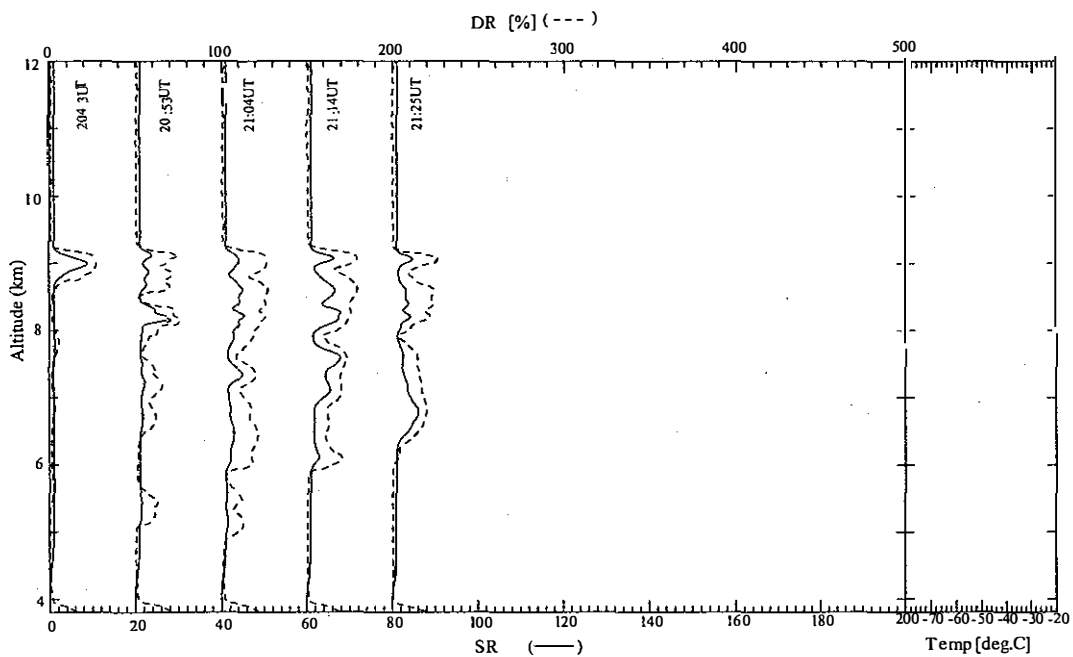
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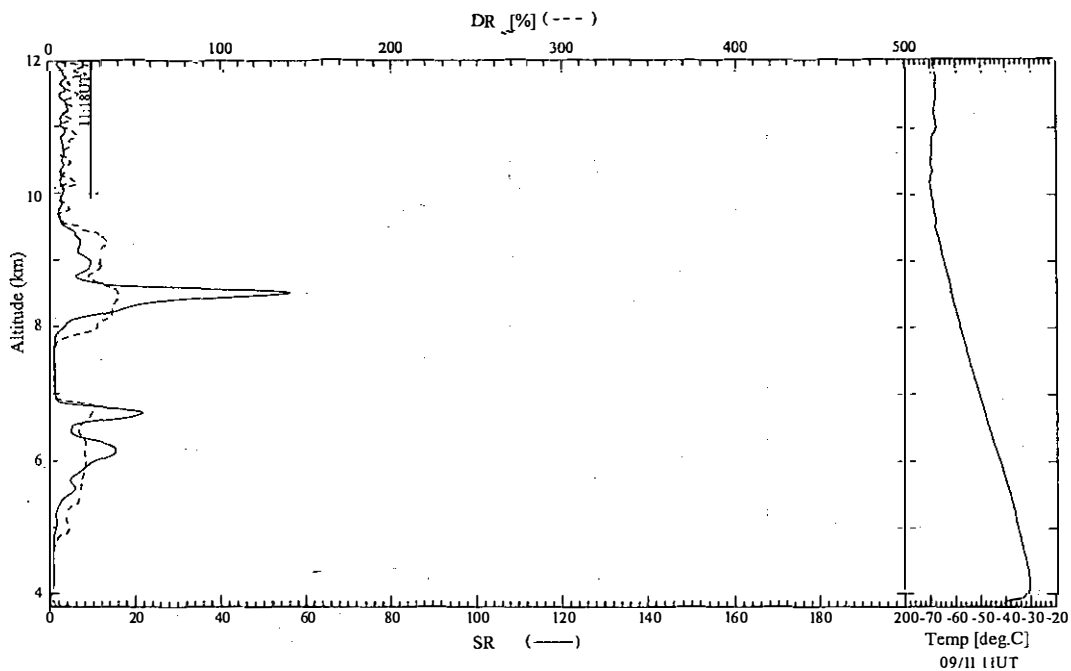
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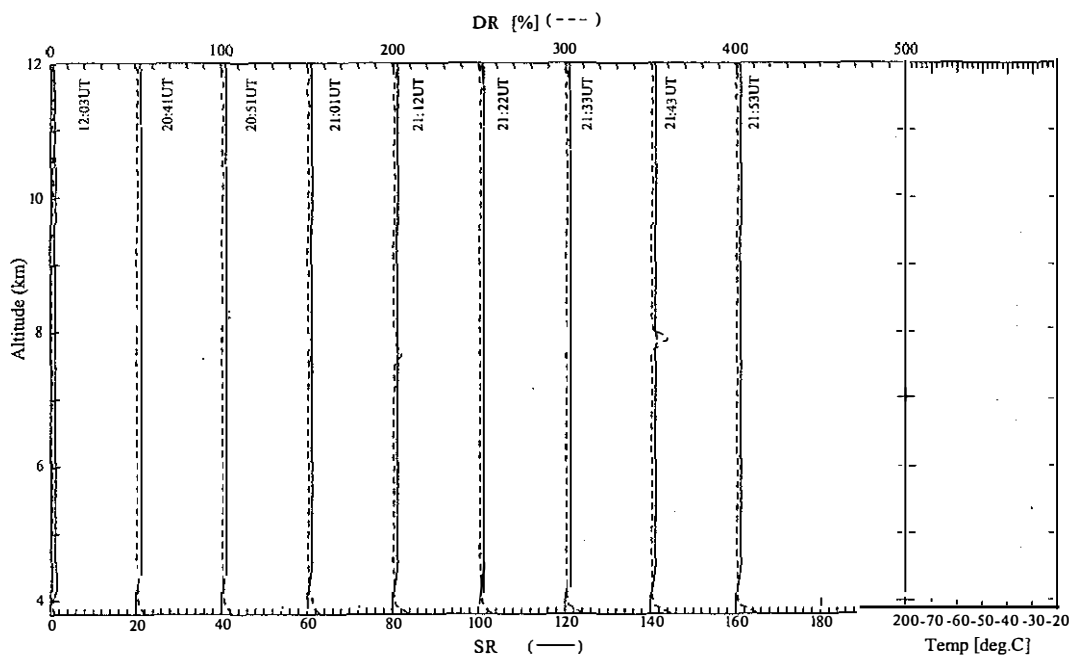
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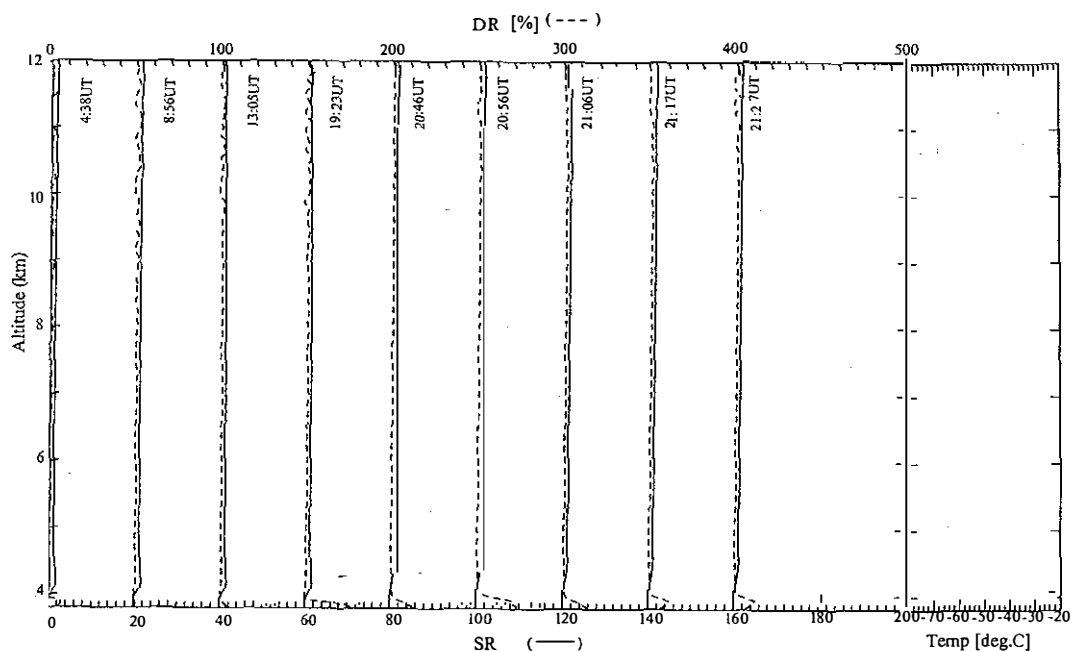
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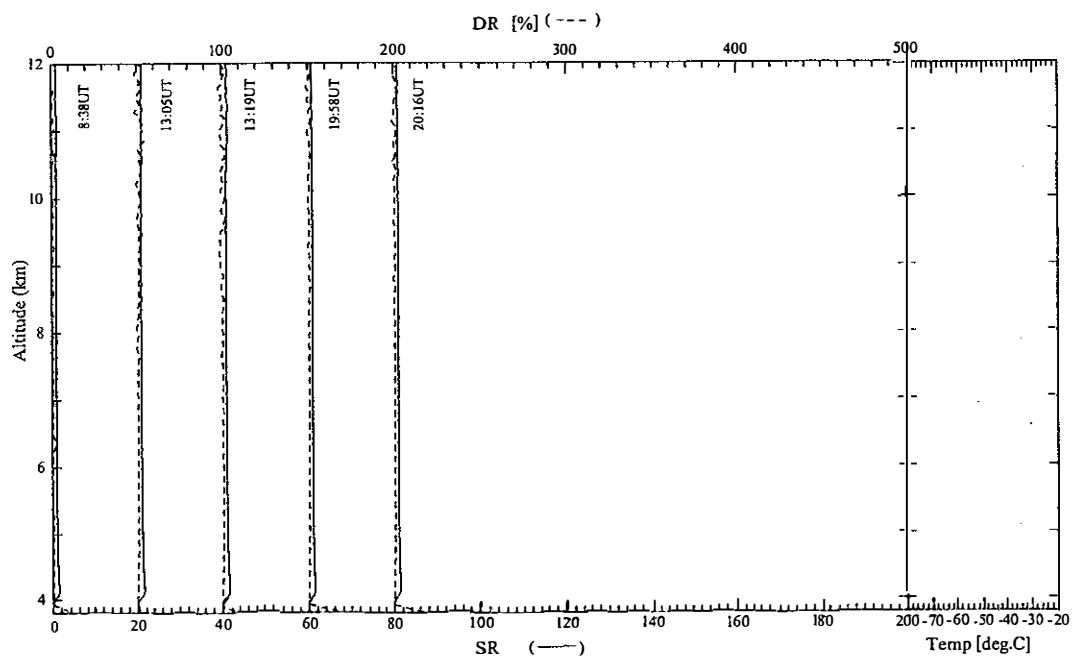
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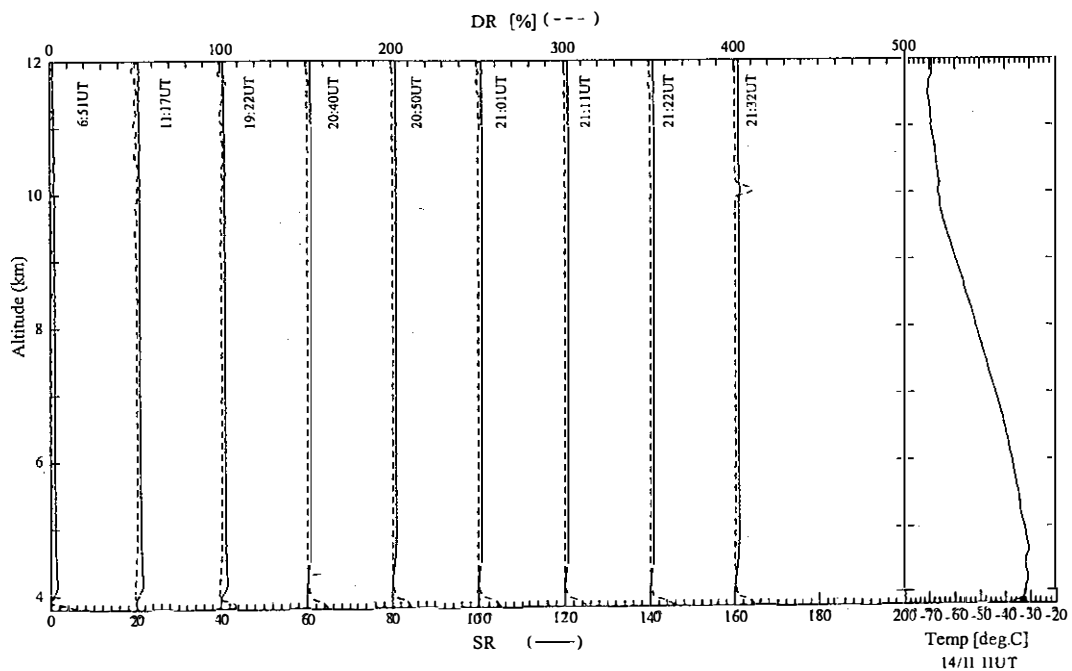
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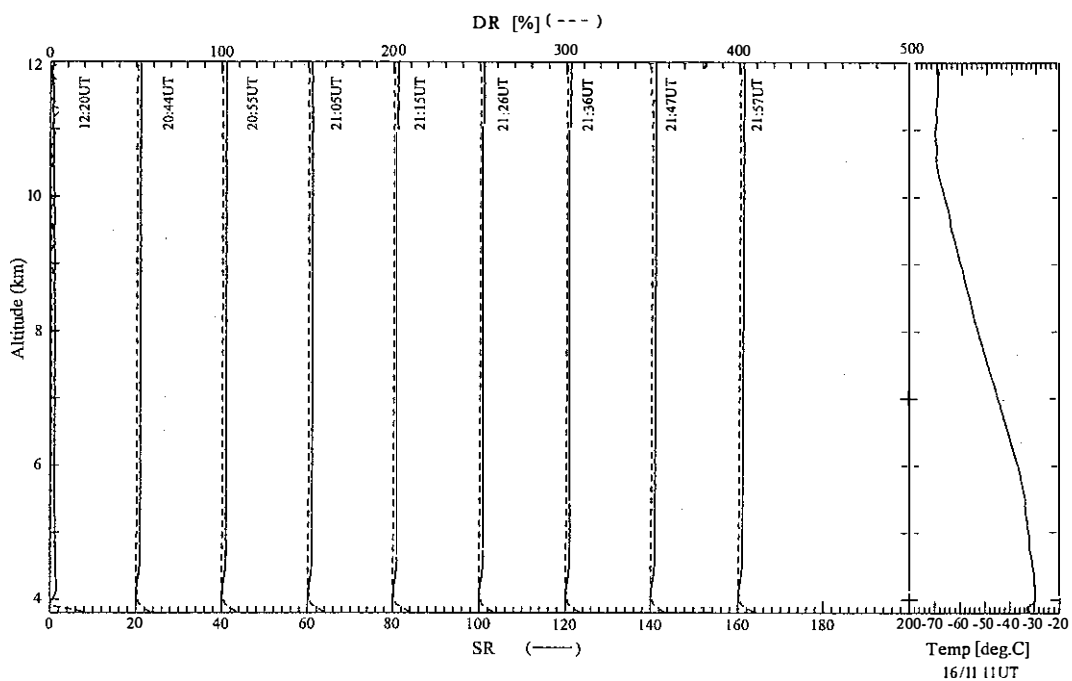
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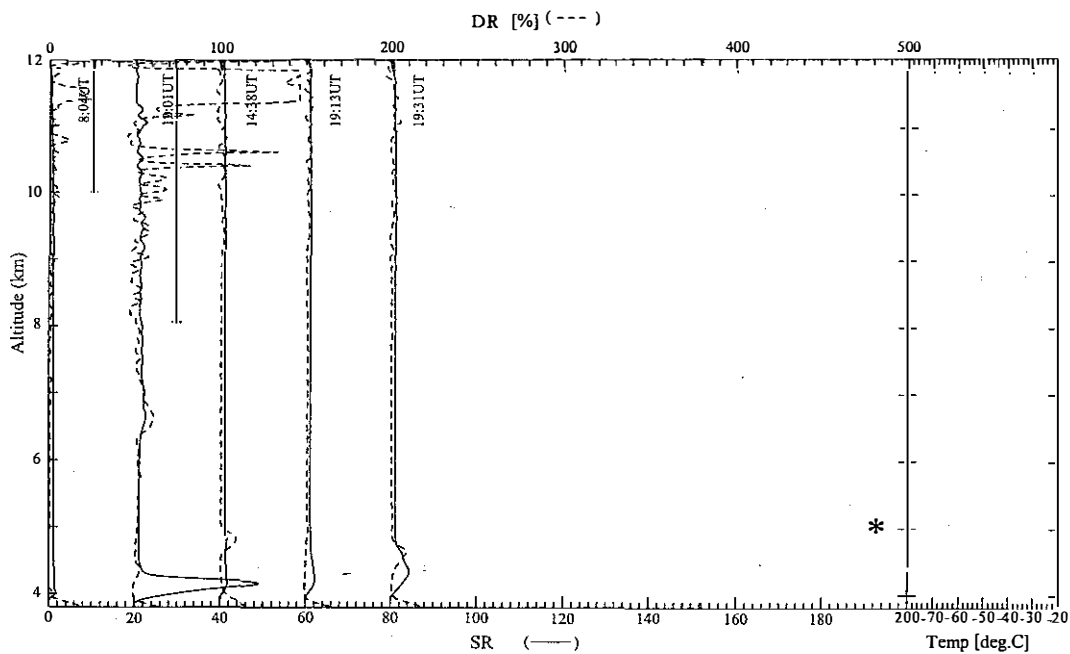
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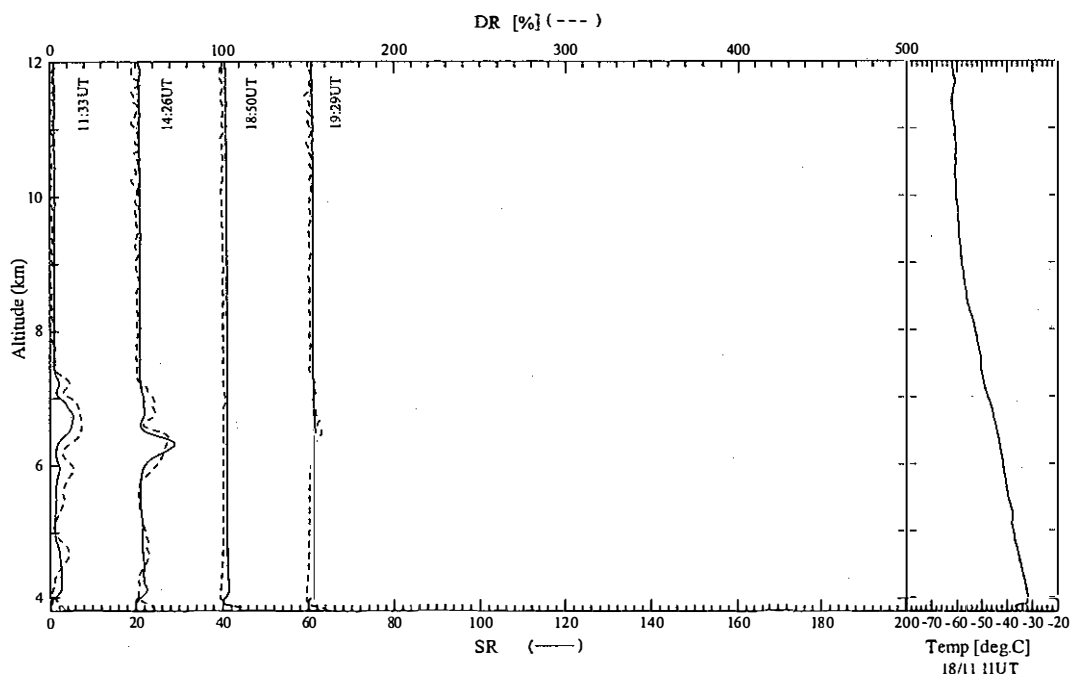
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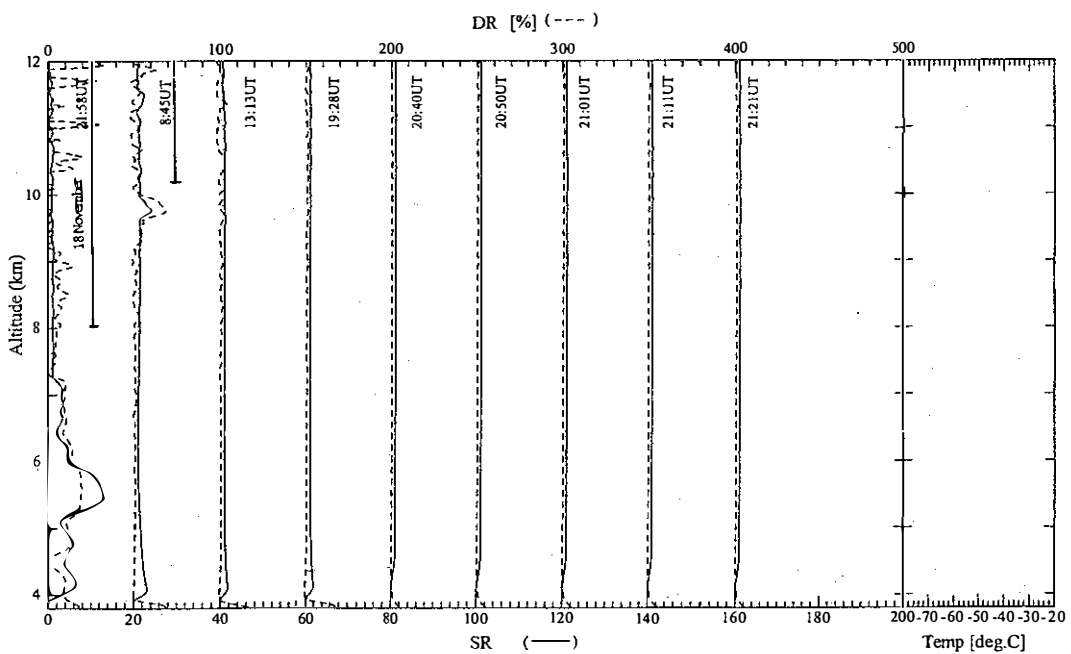
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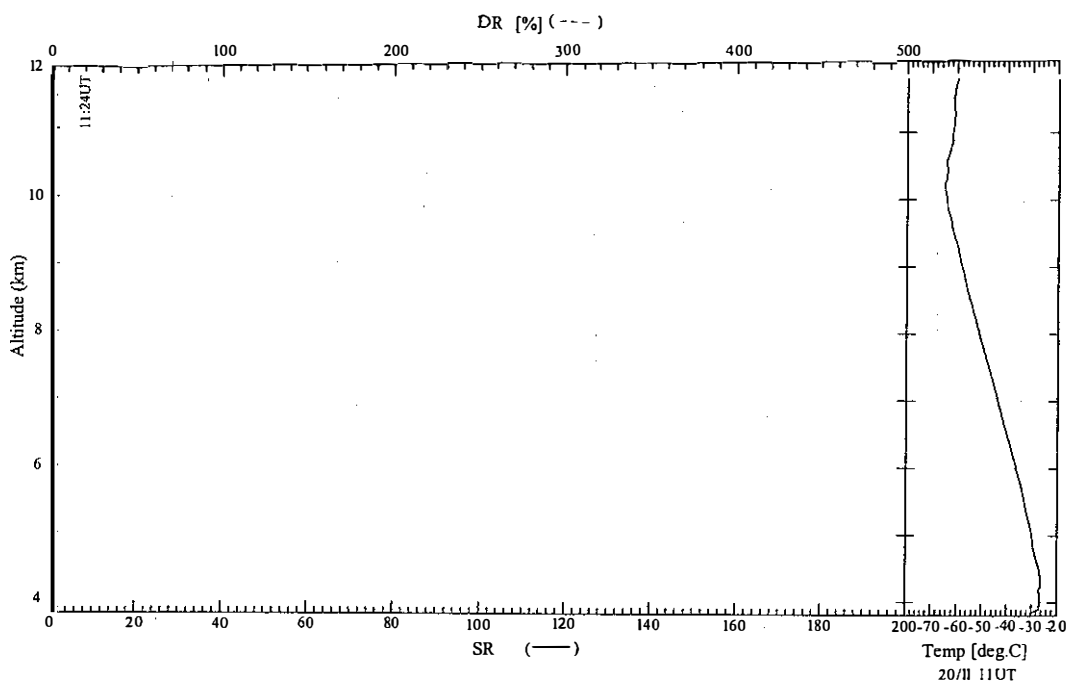
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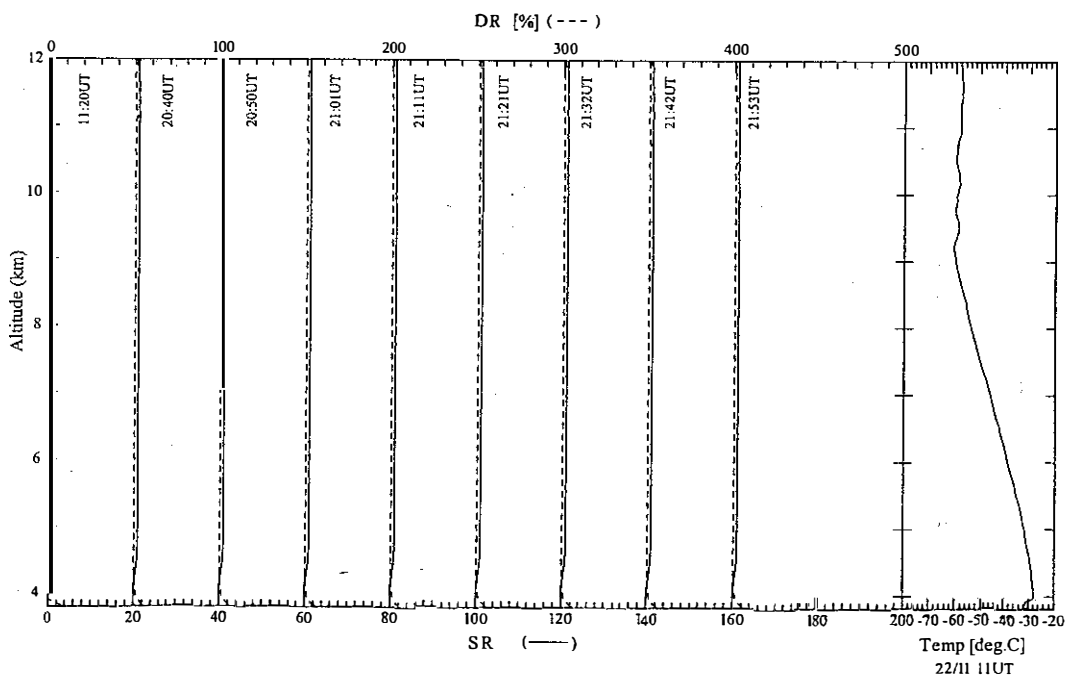
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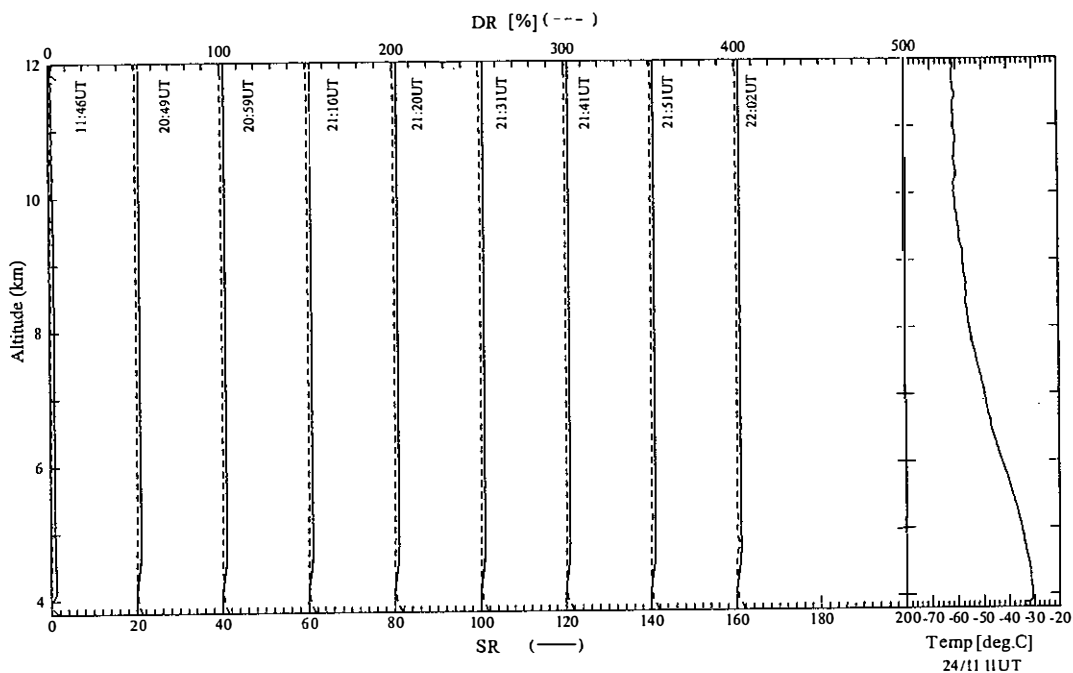
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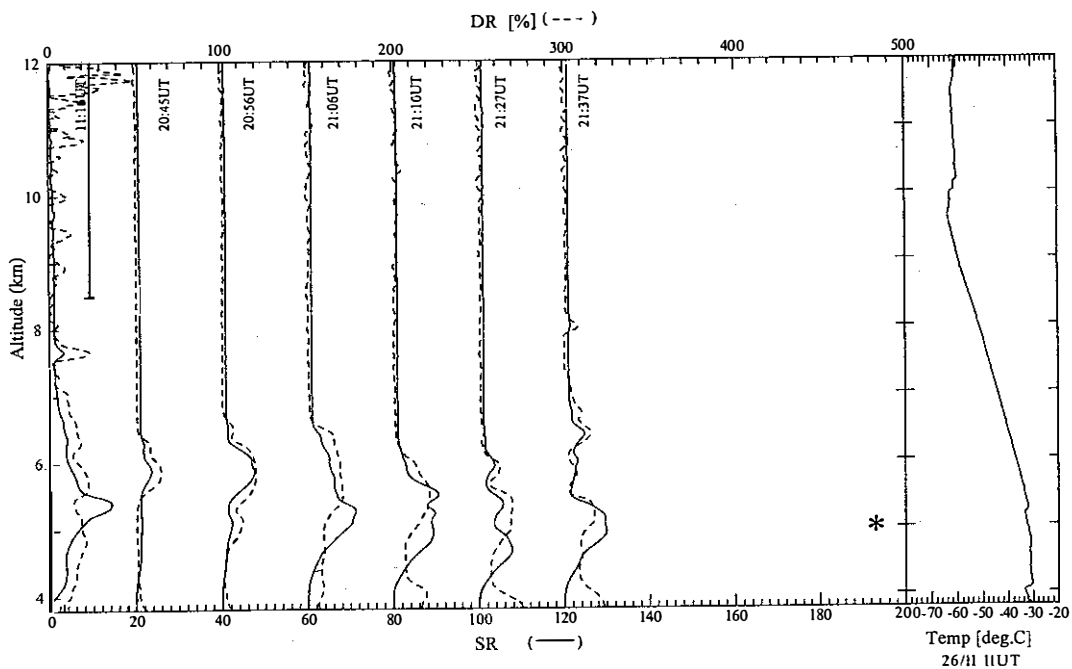
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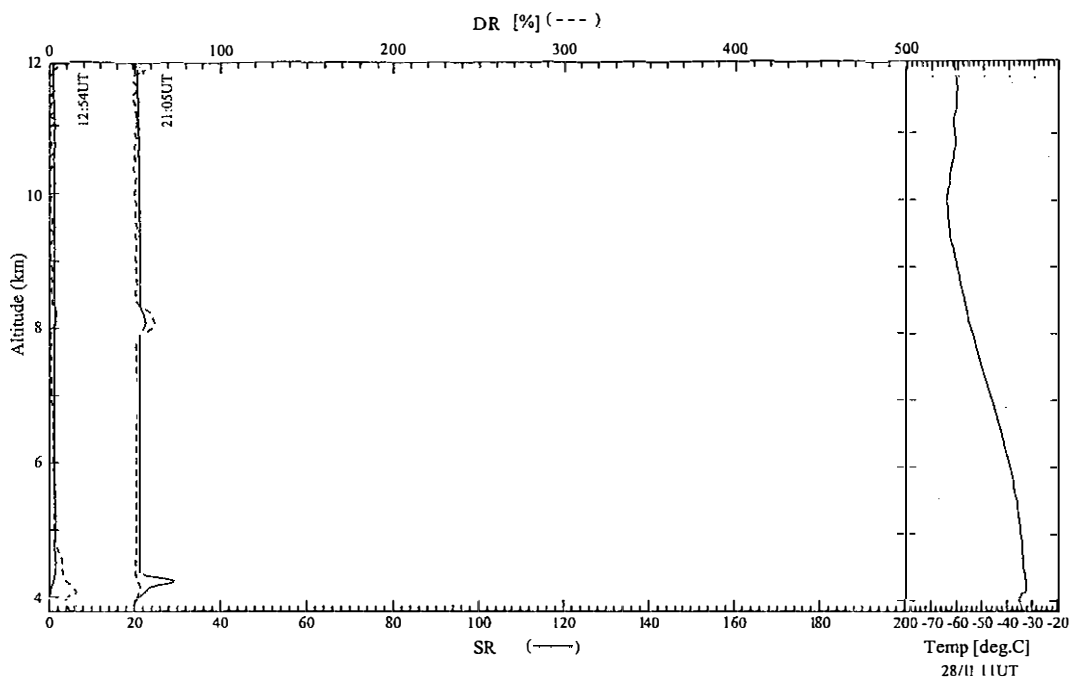
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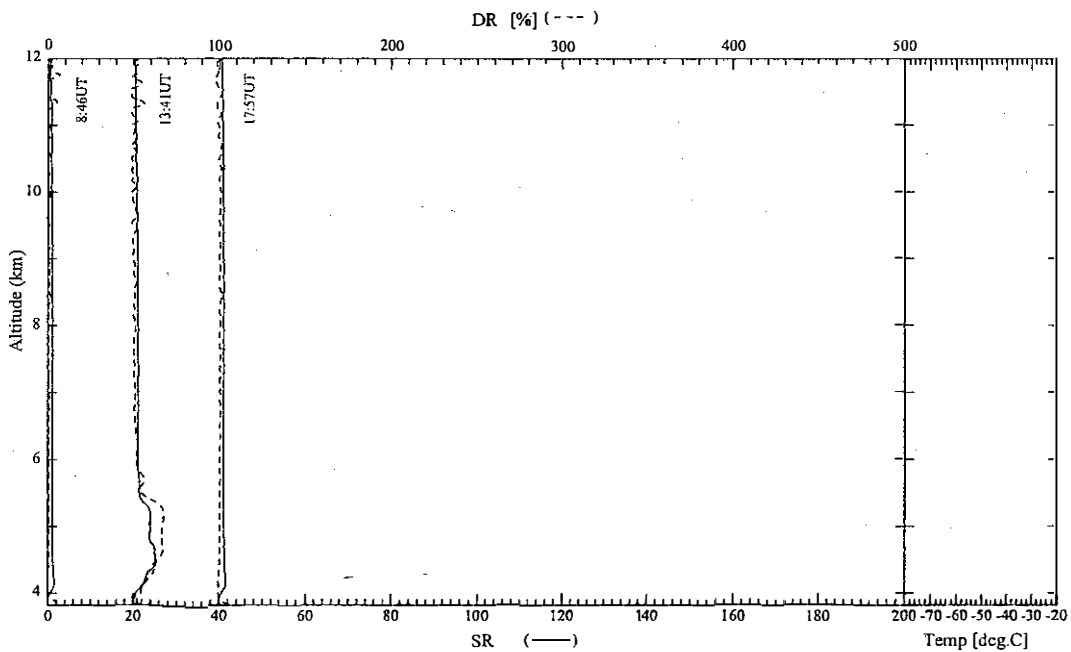
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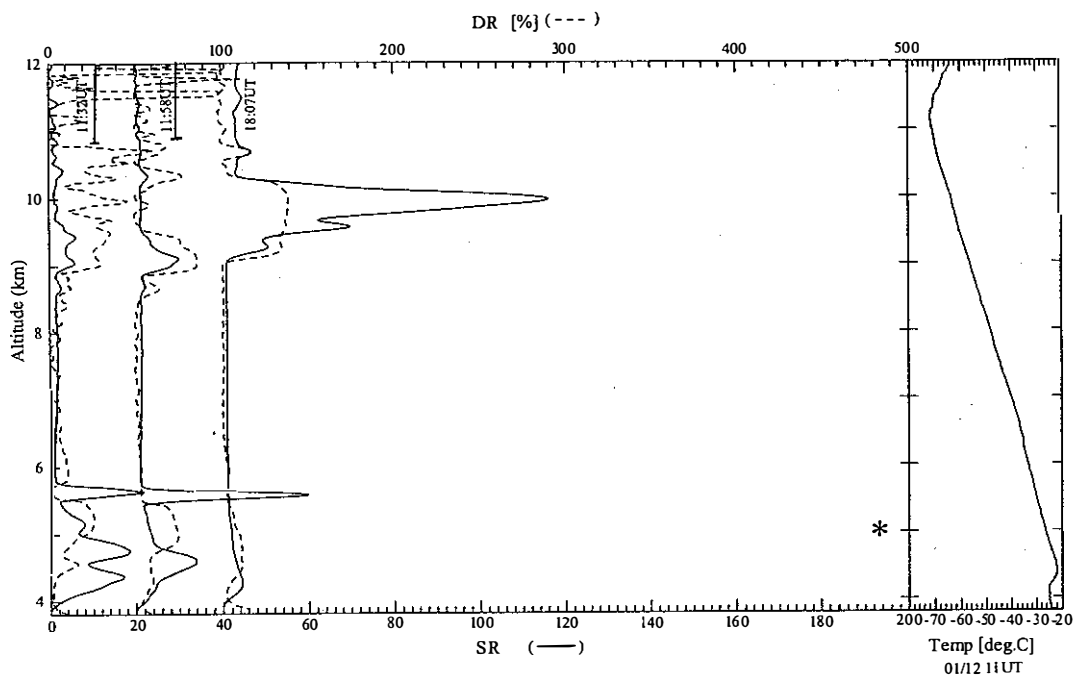
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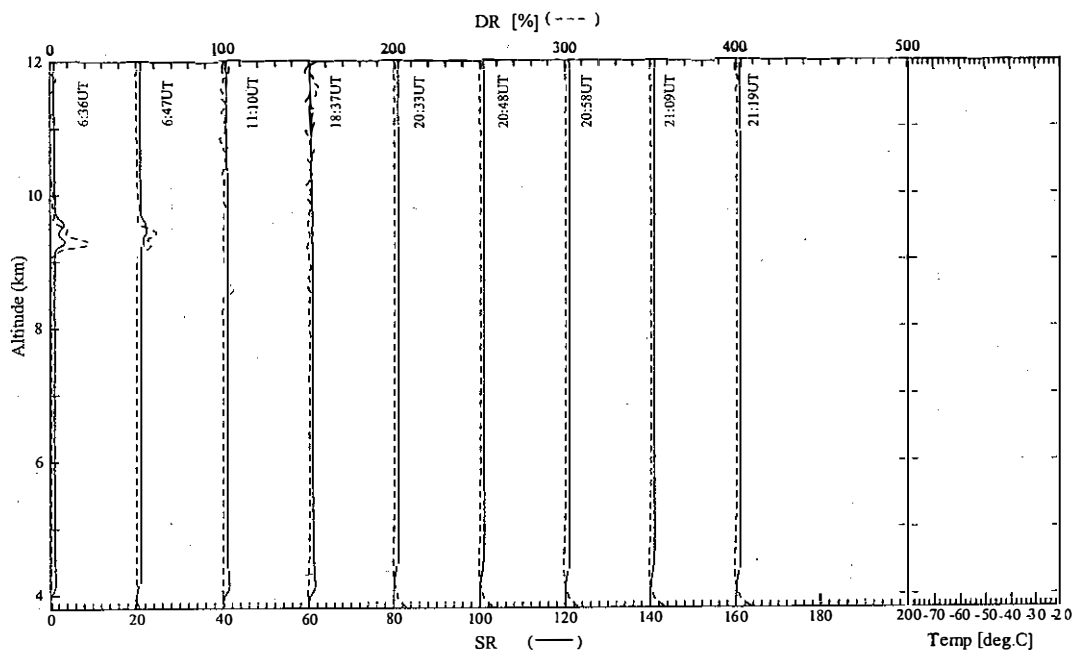
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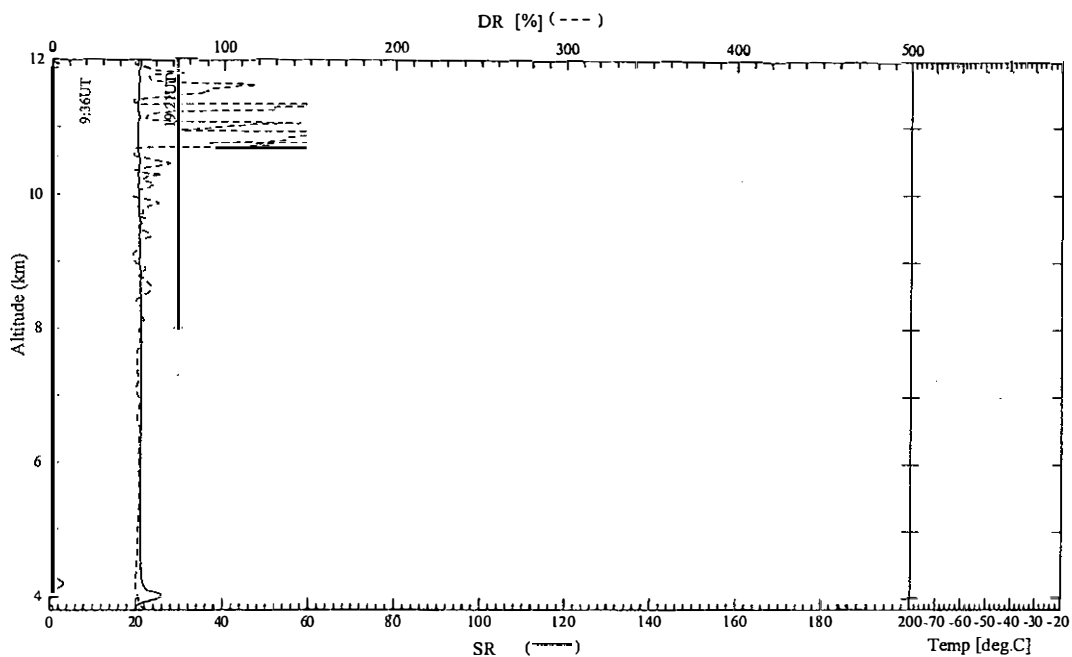
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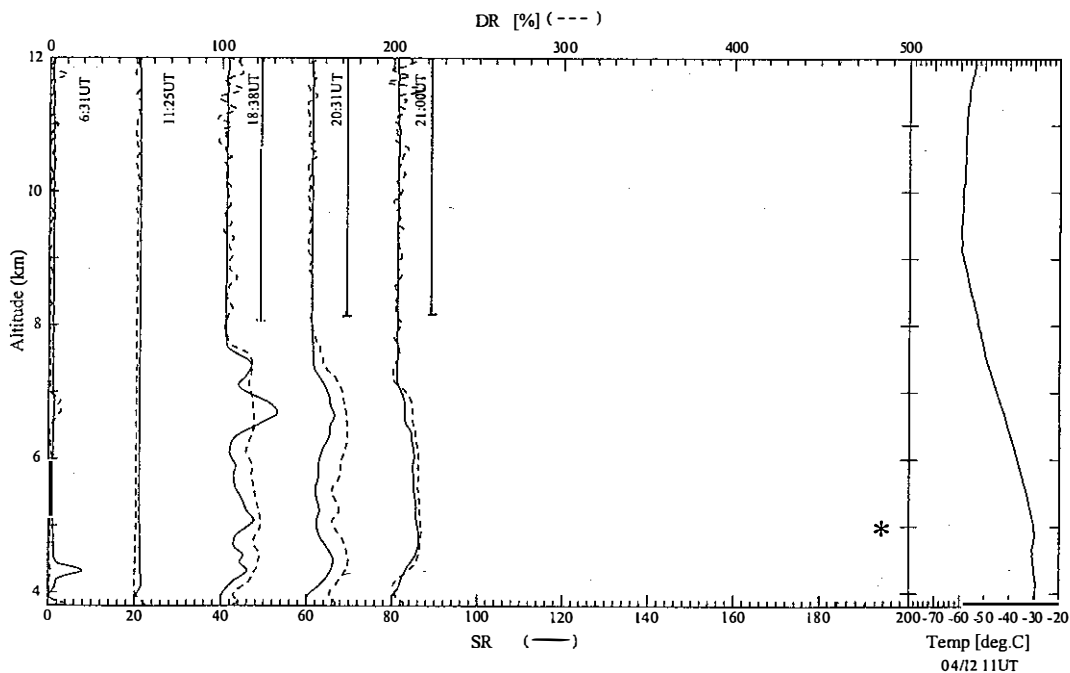
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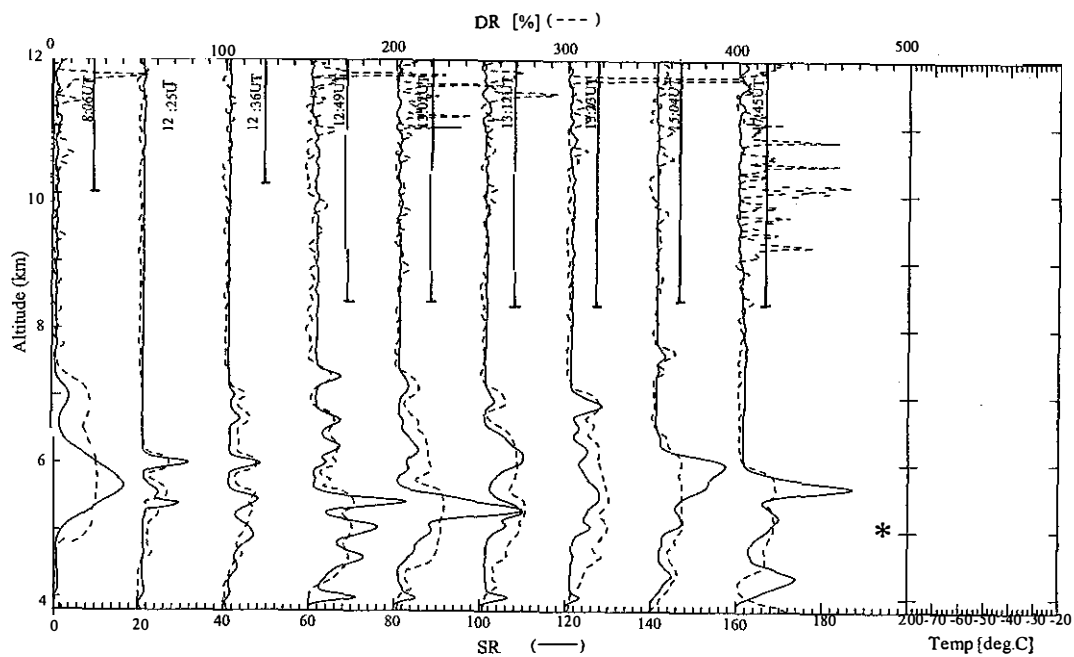
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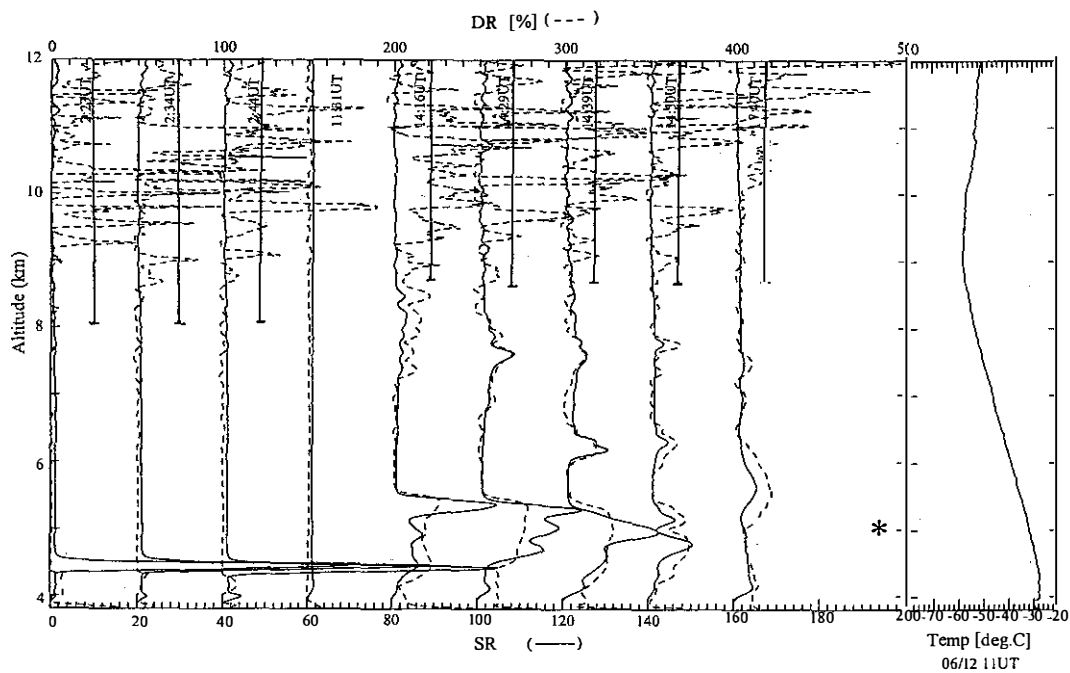
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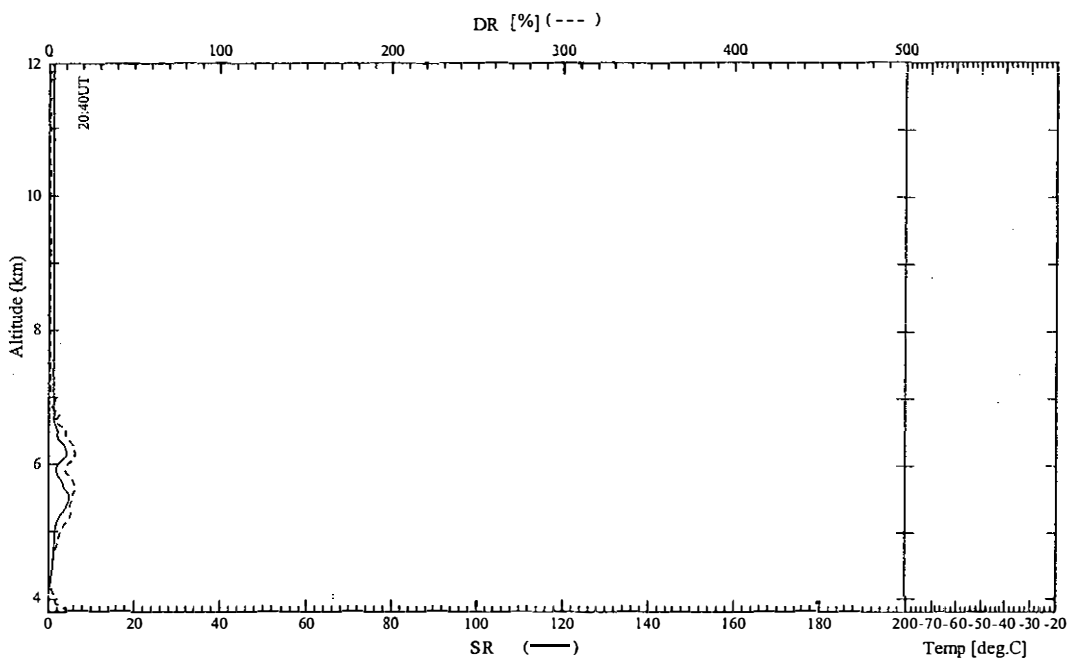
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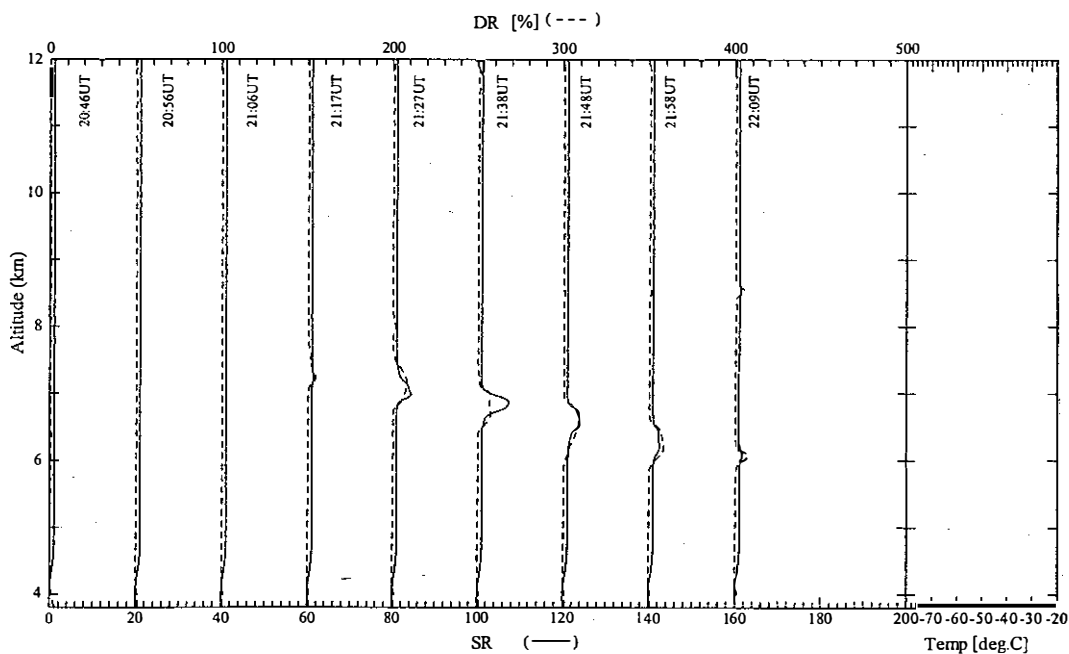
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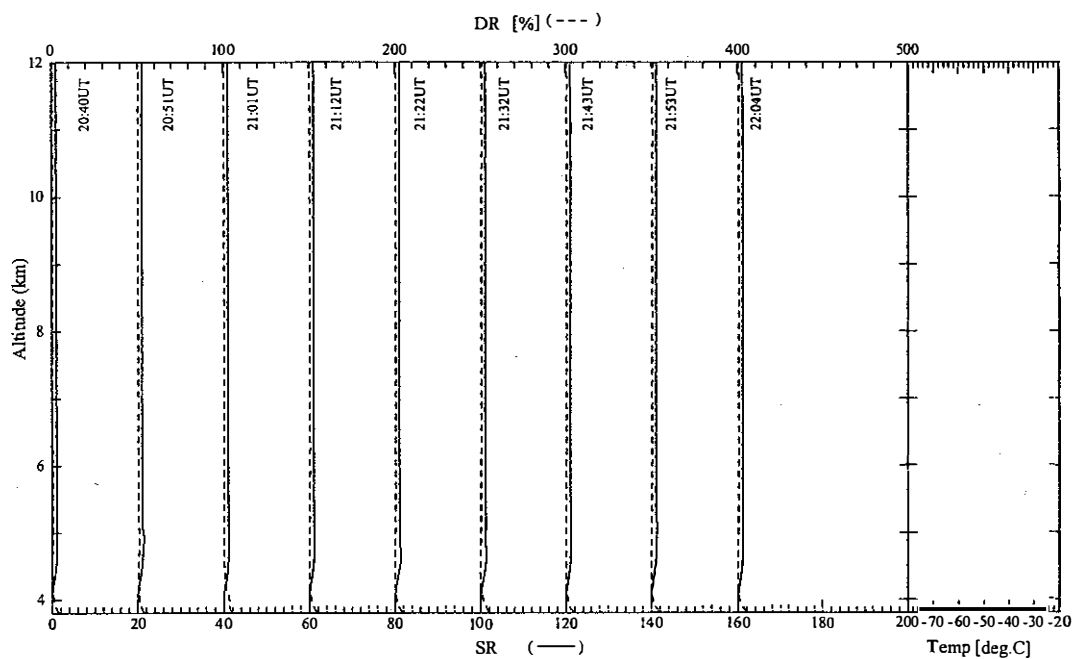
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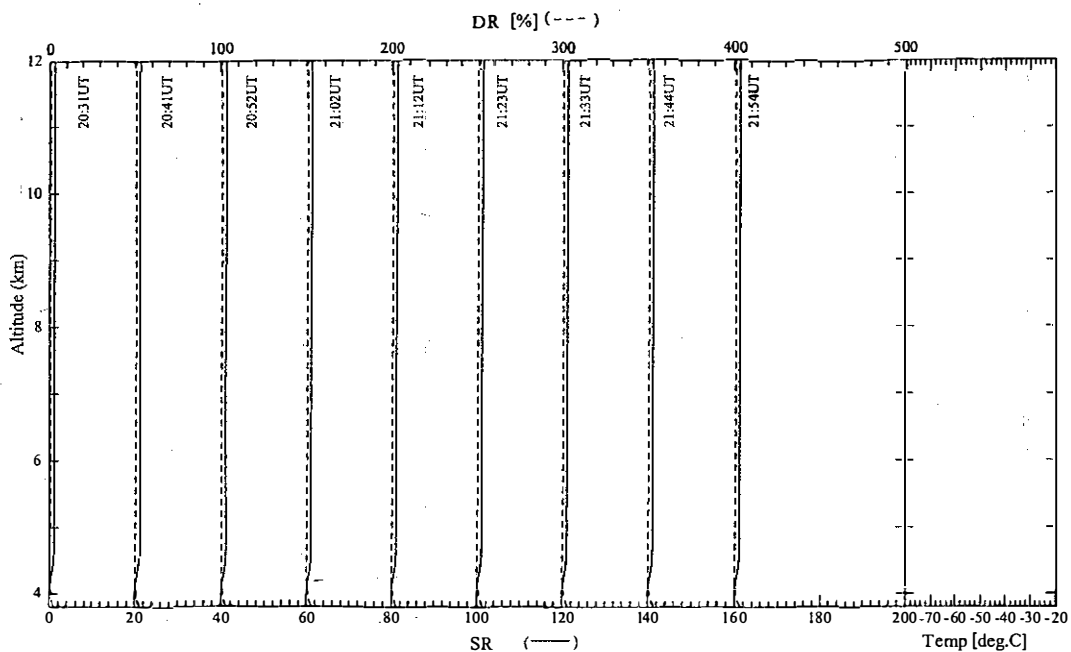
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12/12/1997



22/12/1997



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