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Report on the Field Phase with Examples of Measurements

Edited by

Burghard Brümmer

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6.6. *Cloud particle measurements*

(R. Timm, S. Bakan, Max-Planck-Institut für Meteorologie, H. H. Brecht, Meteorologisches Institut der Universität Hamburg)

Each aircraft, FALCON-20 and DO-128, carried two probes for cloud particle measurements (see Figures 6.2.1 and 6.2.3, respectively): a Forward Scattering Spectrometer Probe (FSSP) manufactured by Particle Measuring Systems, Boulder, Colorado, and an Optical Array Probe from the same company.

6.6.1. *Function principle*

The FSSP-100 Forward Scattering Spectrometer Probe

The Forward Scattering Spectrometer Probe (FSSP) has been used to measure cloud particle between 2 - 47 µm diameter in 15 size channels with a resolution of 3 µm.

The optical arrangement of the probe is shown in Figure 6.6.1. The beam of a 5 mW He-Ne multimode laser is focused at the center of the sampling aperture. Just before the collecting optics there is a central dump spot which, in the absence of particles, totally shuts the laser beam. Particles crossing the beam in the focus (particle plane) scatter light into the optics. The intensity of the scattered light, which is a function of particle size and shape as well as of the laser mode and the way through the beam, is measured with a photodiode. In front of this detector photodiode there is a beam splitter with a central dump spot on the 90° prism transmitting face and a second photodiode behind. This annulus photodiode is used to control whether the passing particle was in the particle plane. Light scattered by particles in or very near the particle plane is masked by the dump spot, particles out of focus scatter light onto the annulus photodiode.

For spherical water droplets, *Mie* theory gives a relation between scattered energy and particle size as shown in Figure 6.6.2. Based on such calculations the measured intensities are interpreted as particle sizes by the probe electronics.

The sampling volume per time is given by the product of the particle velocity, i.e., the true air speed of the aircraft, and the effective sampling area. This sampling area is determined by the laser beam width (0.230 mm) and the depth-of-field (2.20mm) being 0.506 mm^2.

Due to this function principle the FSSP can give reliable results for particle sizes only in the case of pure water droplets. Ice particles with various shapes result in different scattering functions. So if there is ice among the measured particles the calculated size distribution and liquid water content may be wrong.

The OAP-2D Optical Array Probe

For measurement of cloud particles with more than 20 μm diameter Optical Array Probes were used.

The function principle of an Optical Array Probe is sketched in Figure 6.6.3. Particles cross the expanded beam of a He-Ne laser. The shadowgraph of the passing particle is sensed by a linear array of photodiodes. Reading the information of the photodiode array with a maximum repetition frequency of 5 MHz yields, in general, several one dimensional slices and in combination of these a two-dimensional image of the particle.

On board the FALCON-20 there was an OAP-2D2-C Optical Array Probe from the GKSS Forschungszentrum Geesthacht. This probe has an array of 32 photodiodes resulting in a measurement range of 25 - 800 μm and a resolution of 25 μm. The DO-128 carried an OAP-2D-GA2 Grey Probe. The main difference between these two probes is that a 2D2 gives one data bit for each photodiode while a Grey Probe distinguishes four light intensity levels resulting in two bits per pixel. In addition the Grey Probe has 64 photodiodes and a measurement range of 20 to 620 μm at a resolution of 10 μm.

The resolution in flight direction is given by the ratio of particle velocity, i.e., true air speed of the aircraft, and repetition frequency, called slice rate.

Only particles in a certain distance around the object plane are measured correctly. This so called depth of field itself increases with particle size up to a maximum given by the free distance between the mirrors of the probe (6.1 cm). The sampling area of the probe is the product of the effective array width and the depth of field and varies with particle size.

Calibration

The Optical Array Probes were calibrated before the experiment but not during the field phase.

The FSSP has to be cleaned and checked regularly. It can be calibrated with glass beads of known diameter blown through the sample area by compressed air. During the campaign the calibrations of both FSSP probes were compared several times and

were found in good agreement.

6.6.2. *Measurements and preliminary results*

Measurements with the probes described above were made during all flights of the two airplanes (see Section 6.3). Data acquisition on board the FALCON-20 was carried out by the DLR who will do the standard analysis of this data, too. Therefore in the following we will concentrate on the data from the DO-128. From 4 to 25 March 1993 the DO-128 flew nine missions in cold air outbreaks equipped with both cloud particle probes in each case.

The FSSP collected data of good quality during all flights. As a first example Figure 6.6.4 shows the liquid water content estimated by the FSSP data for each flight. These are only preliminary results calculated with a mean true air speed of 60 ms^{-1}. An exact determination under consideration of the variable air speed remains to be done.

It has to be remembered that a liquid water content calculated on the basis of FSSP data does not consider bigger particles and in addition is reliable only in the case of pure water droplets. Therefore, we will check and correct these results with Grey Probe data.

Grey Probe data were sampled on all flights except that on 19 March when a fuse blew at the start of the aircraft. The quality of the collected data is not as good as for the FSSP. Probably due to the extremely low temperatures or to electrostatic discharges, the electronics generated pseudo images of usually one slice length. These pseudo images dominated the record on 4 March. By keeping the probe warm until start and shielding the electronics it was possible to reduce the occurrence of pseudo images. Table 6.6.1 lists the duration of measurements with and without pseudo images for each flight.

Pseudo images have a typical form and can be removed from the data easily. The remaining valid images are not affected and can be used for studying the cloud particle structure qualitatively. However, a quantitative interpretation of the data is not possible for most parts of the flights until 17 March and even for short periods of the later missions where pseudo images simulate much to high particle number density.

References

R.G. Knollenberg (1981): Techniques for probing cloud microstructure. In: P.V. Hobbs and A. Deepak (Eds.): Clouds. Their Formation, Optical Properties and Effects. Academic Press, 15-91.

Particle Measuring Systems. Forward Scattering Spectrometer Probe PMS Model FSSP-100 Operating and Service Manual.

Particle Measuring Systems. Optical Array Grey Probe PMS Model OAP-2D-GA2 Operating Manual.

Table 6.6.1: Duration of Grey Probe measurements with and without pseudo images caused by electronics.

Date	Data OK	with pseudo images
04 March	2 min	211 min
10 March	128 min	93 min
11 March	183 min	23 min
17 March	219 min	22 min
20 March	207 min	2 min
23 March	119 min	1 min
24 March	189 min	12 min
25 March	247 min	2 min

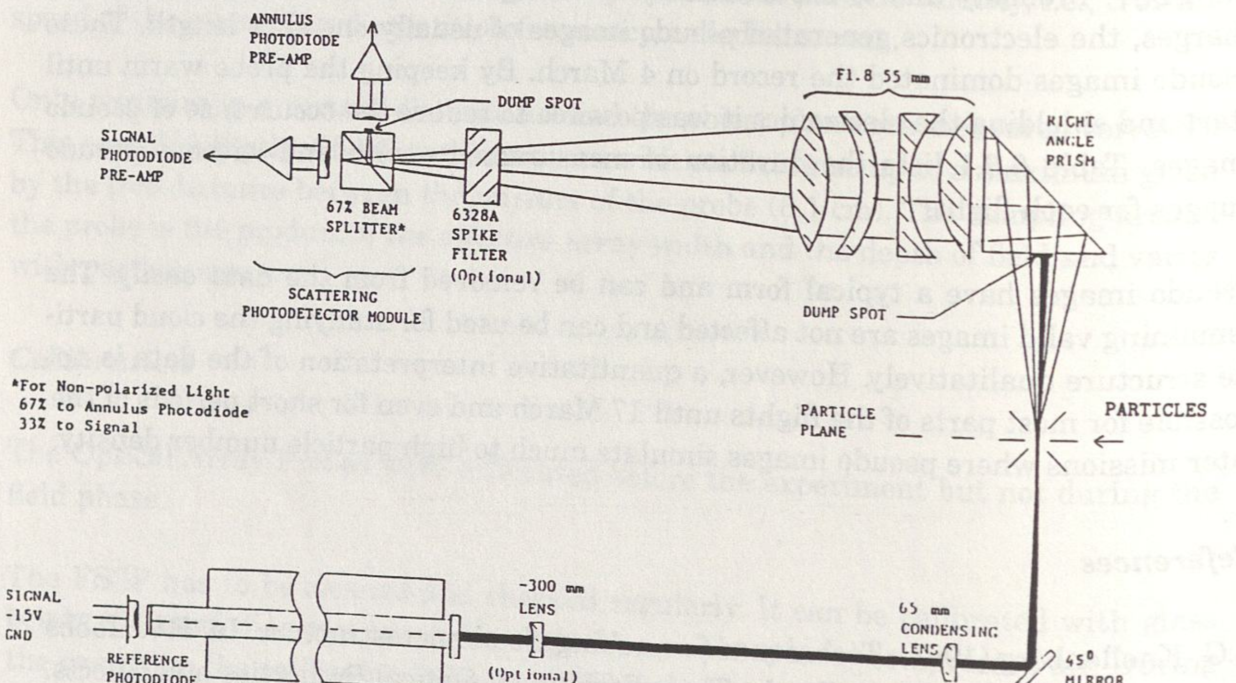

Figure 6.6.1: Optical system diagram of the Forward Scattering Spectrometer Probe (Particle Measuring Systems).

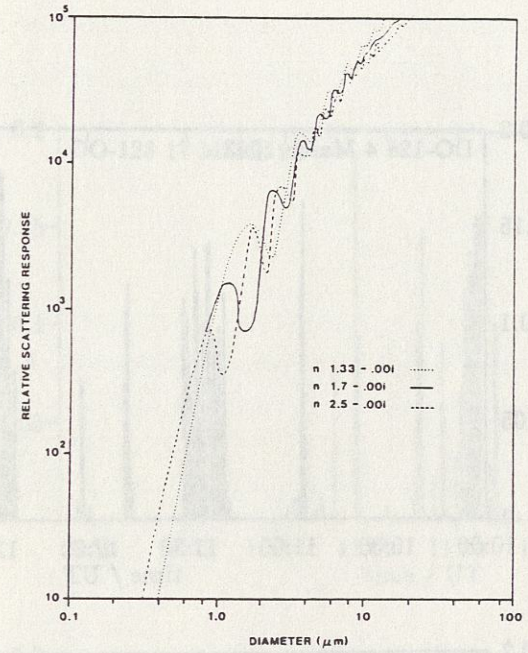

Figure 6.6.2: Scattered light intensity in a collecting angle of 4° to 22° as a function of diameter for different refractive indices computed for a wavelength of λ = 632.8 nm (Knollenberg, 1981).

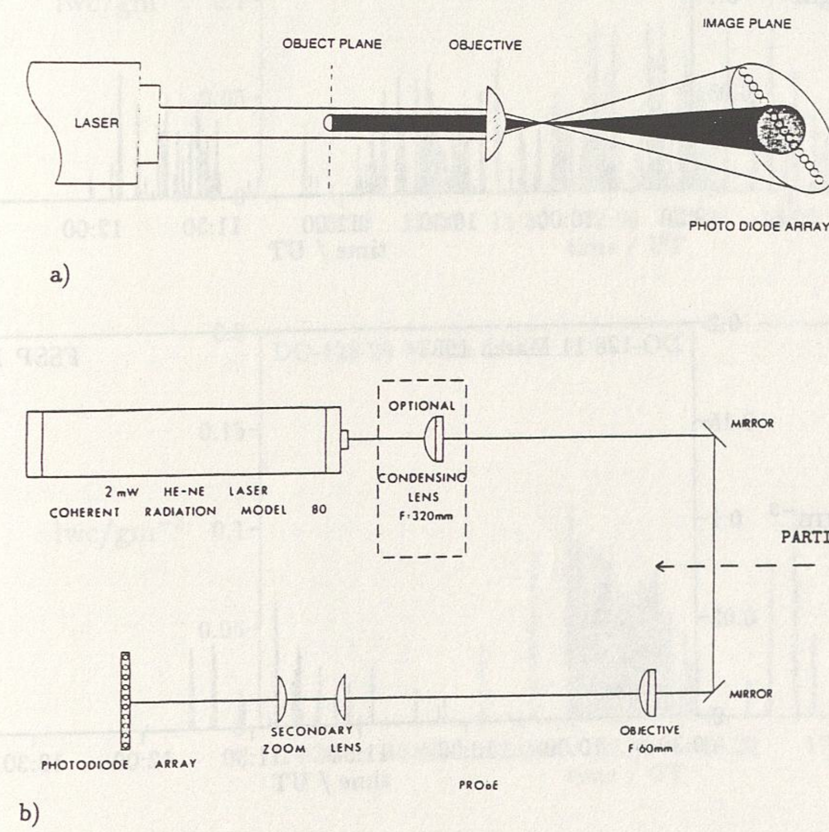

Figure 6.6.3: Scheme of the 2D Optical Array Probe (Knollenberg, 1981). a) Function principle. b) Optical arrangement.

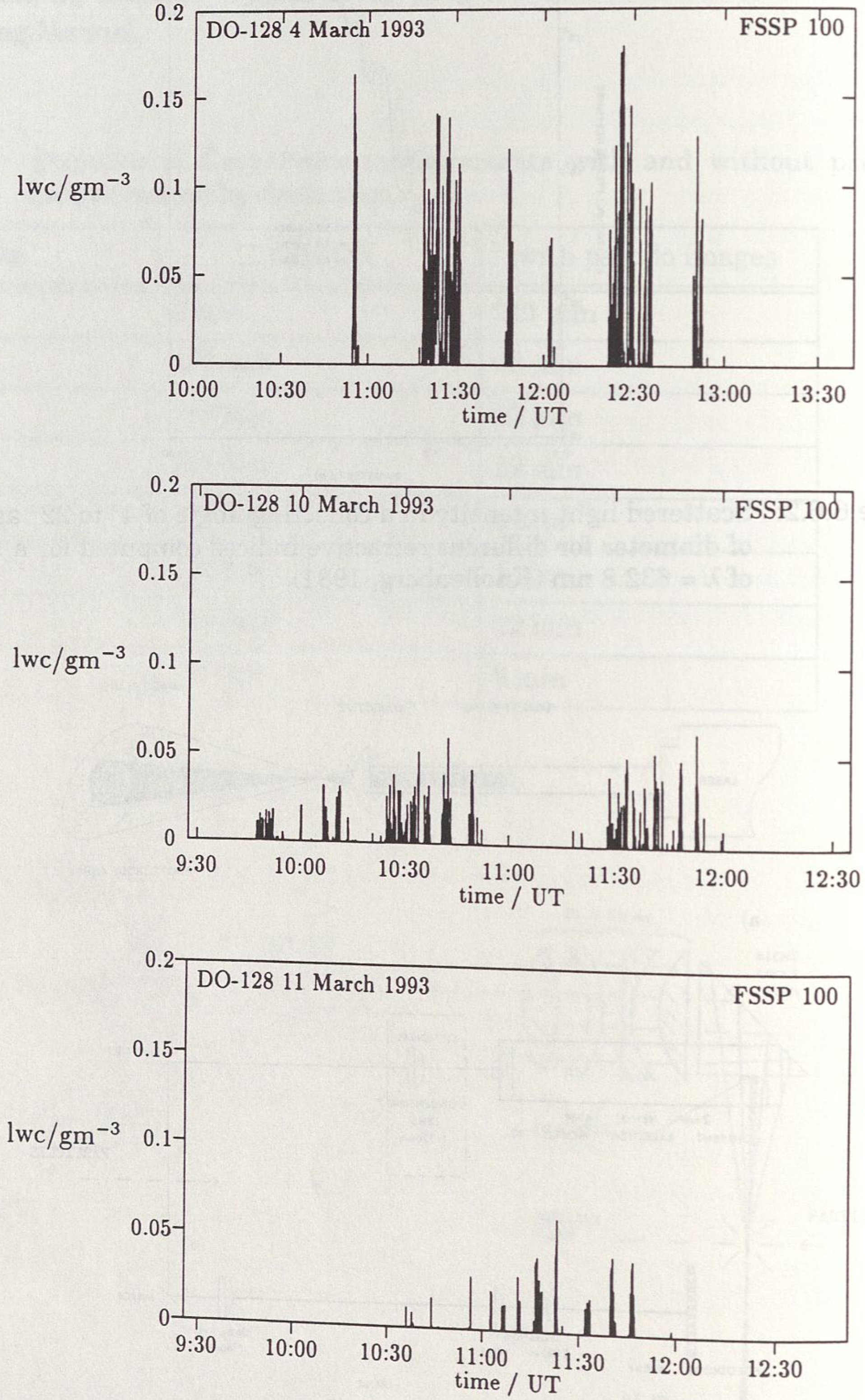

Figure 6.6.4: Liquid water content measured with the FSSP on board the DO-128 during all nine flight missions.

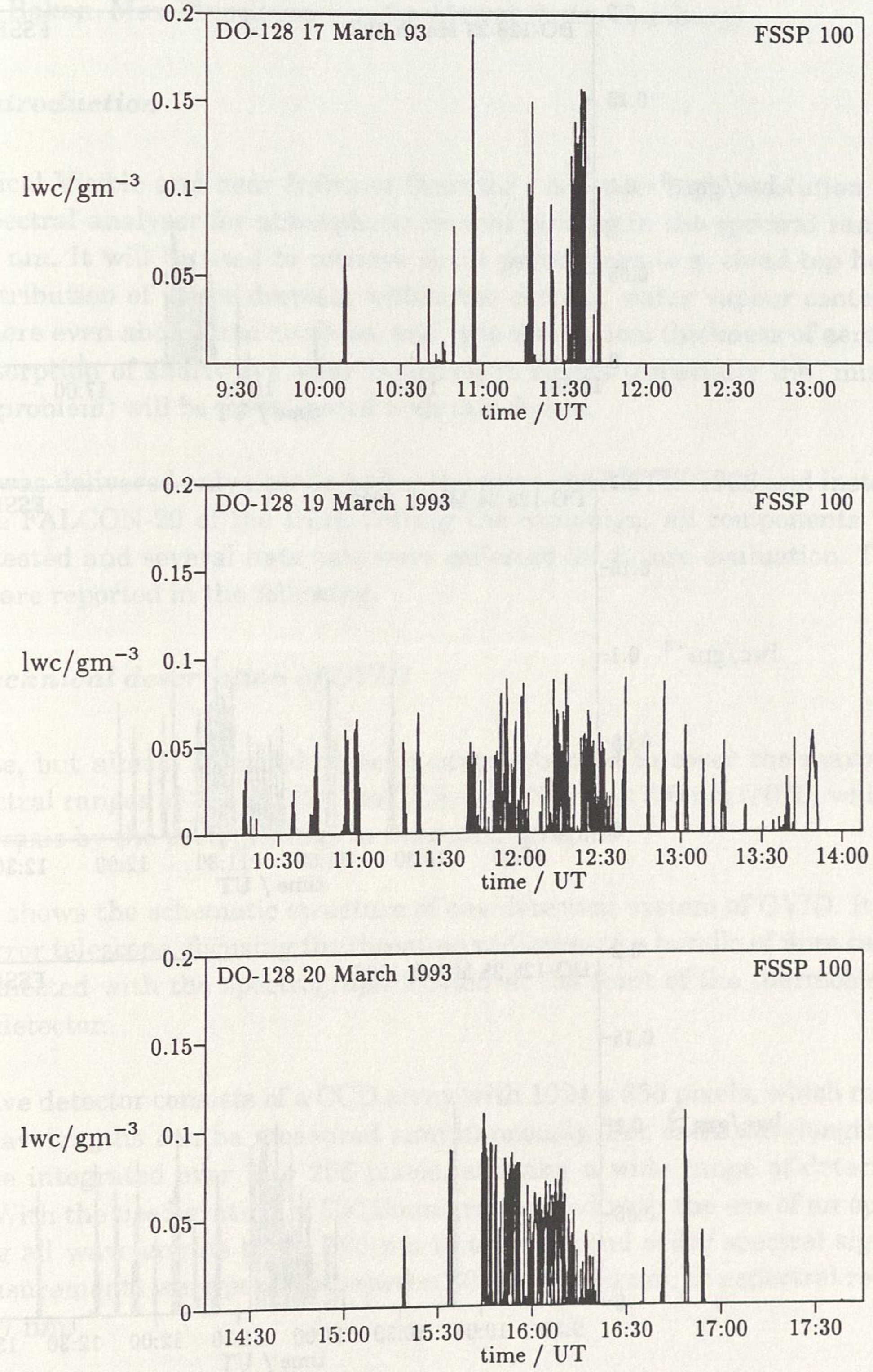

Figure 6.4.4: continued.

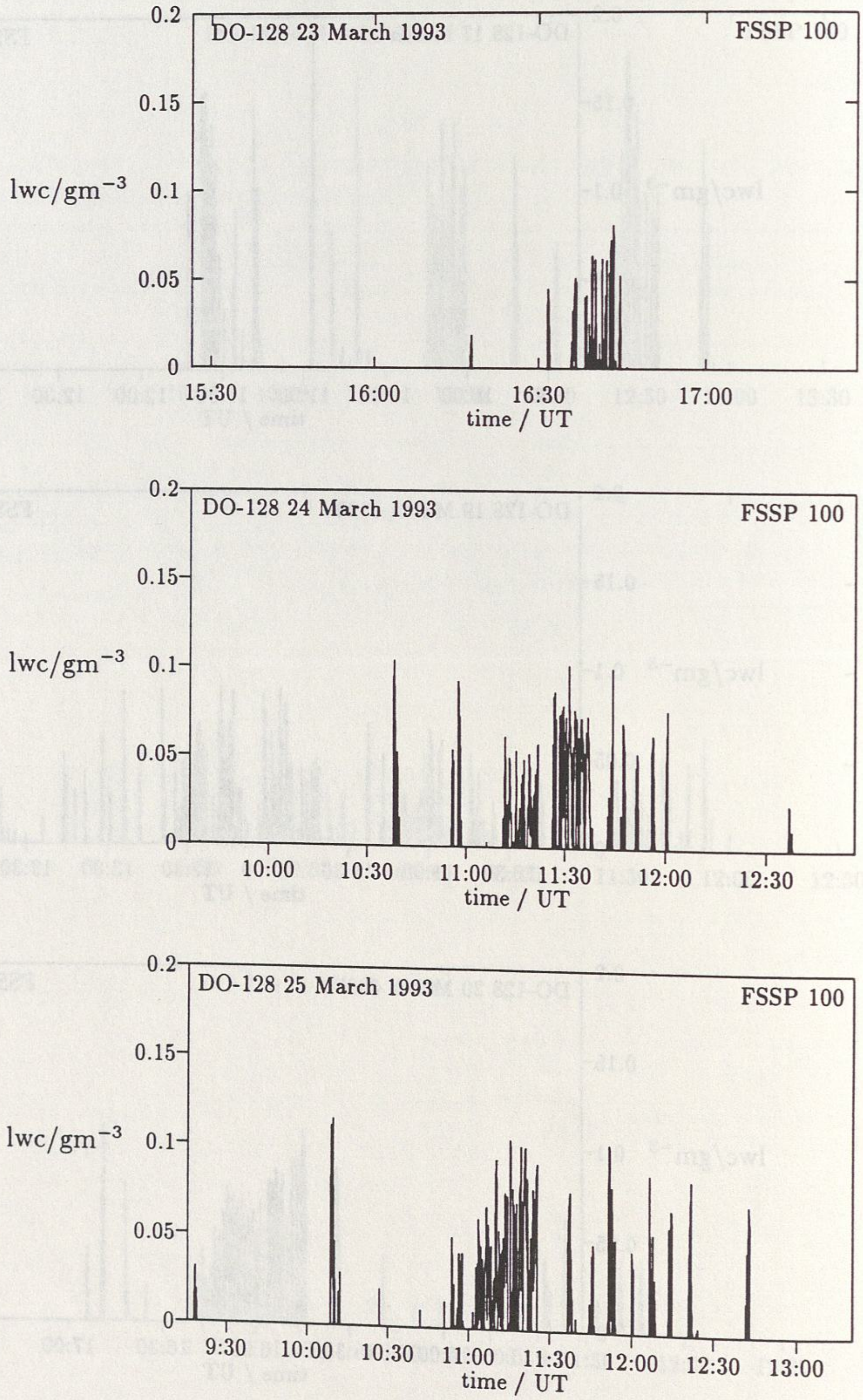

Figure 6.4.4: continued.