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RADAR-MEASUREMENTS IN THE TROPO, STRATO- AND MESOSPHERE

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ABSTRACT

An experiment was performed using the large 50 MHz-radar at Jicamarca/Peru to observe waves, winds and clear air turbulence (CAT) at tropospheric and stratospheric heights. The antenna was used as an interferometer in order to measure the scale size of the turbulent inhomogeneities and to obtain velocities in an alternative way (other than Doppler). The scale size of the inhomogeneities is one of the important parameters in designing the Harz-VHF-radar facility. The various measurements, the data evaluation as well as first results are discussed.

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1. INTRODUCTION

The investigation of the dynamics of the middle atmosphere (15-90 km), which includes, of course, processes in the adjacent troposphere and thermosphere, is the scientific goal of the SOUSY-group at the Max-Planck-Institut (MPI) in Lindau/Germany. One of the main objects are the coupling mechanisms between the different layers (SOUSY-Report, 1974). The most suitable tools for observing the relevant atmospheric parameters as a function of time and space are groundbased measurements (Woodman and Guillen, 1974). One experiment of the planned sounding system (SOUSY) is a VHF-radar, which is described in detail in the previous paper of this issue by Czechowsky et.al. (1976). In designing this facility, the MPI carried out some special measurements at the Jicamarca Observatory in Peru using its large 50 MHz radar. The potential and possibilities of using low VHF frequencies for the remote sensing of the middle atmosphere have been pointed out by Woodman and Guillen (1974) and have been recently exploited by Rastogi and Woodman (1974), Rastogi and Bowhill (1975), VanZandt (1975), Green et.al. (1975), Cunnold (1975). The purpose of this paper is to describe the measurements and to report the progress made on the analysis of the data.

2. MOTIVATION AND SCIENTIFIC GOALS

The motivation for the experiment is twofold: a) to provide answers to some of the design problems presented by the SOUSY-VHF-Radar project of the MPI obtaining information about the different time and spatial scales of the turbulent processes responsible for the radar backscattering, b) to obtain a better understanding of the same turbulence phenomena in the middle atmosphere.

Since the projected MPI antenna in the Harz mountains near Lindau is going to be of a smaller size than the Jicamarca antenna for economic as well as spatial limitations, the performance of the projected radar had to be obtained by proper scaling of the previous results at Jicamarca. This scaling depends on the spatial homogeneity of the turbulent layers. The radar equation would go from a r^{-2} to a r^{-4} dependence, if the layer is turbulent throughout the crossection of the beam pattern instead of consisting of many blobs with various scale sizes not filling the entire volume illuminated by the beam. In order to investigate this problem the Jicamarca antenna was subdivided into quarters, and two quarters at a time were used as a crosscorrelation interferometer (e.g. Wohlleben und Mattes, 1973). The amplitude of the estimate of the complex crosscorrelation function is a measure of the angular size of the scattering medium and the phase a measure of angular position of the center of a blob.

Using the antenna as an interferometer it is possible to measure alternatively the velocity of the layer with respect to the observing point, and therefore, the horizontal velocity of the layer, since the range is known. The technique is expected to work best if the turbulent layer is nonhomogeneous within horizontal scale sizes of the order of the beam width, which correspond to a crossection of about 120 m in tropospheric and about 500 m in stratospheric heights. In such a case the phase of the crosscorrelation function would correspond to the center of gravity of the turbulence strength, and would change in time as the center moves with the background velocity of the medium. The phase variation with time then is a measure of the wind velocity in direction of the interferometer baseline for the particular height in observation. If the turbulence of the layer is homogeneous, however, the average center of the backscatter direction would correspond to the center of the illuminating and receiving antennas and would contain no velocity information. The evaluation of this technique was another goal of the present experiment.

Since the SOUSY-VHF-Radar is planned to be used to investigate tropospheric heights, too, it was intended to evaluate beforehand signals from these heights at Jicamarca. This facility, on the other hand, was built mainly for investigating processes at ionospheric heights. In order to extend the Jicamarca results to as low heights as possible a different antenna had to be used for transmission and for reception avoiding the use of a transmit-receive-switch and the associated problems of spark-gap recovery and receiver saturation. Ground clutter was subtracted during processing by frequency notching whereever the signal strength was within the dynamic range of the receiver and digital converters.

Another important goal of the experiment is the investigation of the spati[illegible]ion between different heights. The que[illegible] if the possible correlation is due to similar physical processes (as e.g. wave-motions) at different altitudes or due to a common scattering volume not resolved by the pulse width. This problem could be solved by comparing the crosscorrelation function of the raw signals from different altitudes with the crosscorrelation function of the autocorrelation functions derived from the raw signals.

If the process in question is assumed to be Gaussian and stationary, it is fully characterized by its correlation function or its frequency spectrum. It is known from previous experiments (e.g. Woodman and Guillen, 1974) that the radar returns from the stratosphere and mesosphere show rapid time-variations. Whenever this occurs it is possible that interesting events with characteristic times shorter than the integration time are lost in the process of coherent integration. This was one motivation to perform the experiment by recording the complete raw data after the analog to digital conversion on magnetic tape and do the processing off-line. The disadvantages, on the other hand, are that only 4 or 8 heights could be recorded at a time because of the limited information rate the tape units could handle, and that the experiment produces a large number of tapes for a few hours of observation. This procedure, however, makes it possible to plot the raw data time series (after proper data filtering) and from it to deduce optimum times for coherent (filtering) and incoherent integration. It will allow also a more sophisticated processing which would not be possible on-line because of computing time limitation.

3. THE JICAMARCA RADAR FACILITY

The radio observatory of Jicamarca near Lima/Peru started work in 1962 with measurements of properties of the ionosphere and exosphere by means of the incoherent scatter technique. The radar facility in Jicamarca operates at 50 MHz with a pulse peak power of about 4 MW. The antenna array of 290 x 290 m consists of 18,432 dipoles. The antenna gain of 42 dB corresponds to a half power beam width of about 1°. The antenna direction is steerable by a few degrees out of the zenith. Apart from investigations of the equatorial ionosphere in 1972 radar echoes from stratospheric and mesospheric heights have been observed (Woodman and Guillen, 1974).

4. EXPERIMENTAL SET-UP

The measurements have been carried out using the Jicamarca radar with the following special experimental arrangements (Fig. 1). The whole antenna was divided into quarters, one of which

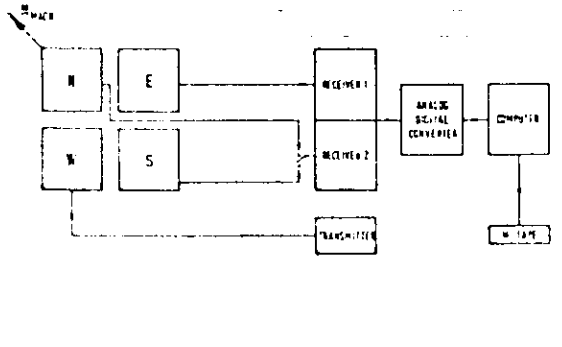

Figure 1. Block diagram of the experimental set-up at Jicamarca/Peru.

was used as the transmitting antenna and two other quarters as the two receiving antennas of the interferometer. The complex outputs of the receivers with a bandwidth of 30 kHz were digitized (1 real word = 8 bits) and fed to a computer for possible processing and recording. The base-line of the interferometer was 145 m and the half power beam width of one quarter was 1.4°. The tilt of the antenna field in S-E-direction is 1.05°. The pulse periods were 1 or 2 ms, the pulse length 16.6 μs. Resulting from the limited transfer rate of the magnetic tape, 4 or 8 heights, depending on the pulse-period, were sampled at a time and recorded on tape without any preprocessing.

5. PROCESSING SCHEME

The raw data, which are recorded on tape, are processed off-line in several sequential steps. Firstly the data are compressed by a coherent integration, which is equivalent to a digital filtering (Woodman and Guillen, 1974). One of the reasons for recording raw data is the possibility of investigating to which extent the final results depend on the coherent integration time which can be a function of height and time. Since the observed signals are time-varying, the data, before any further statistical processing, are plotted in order to get information about the characteristic times of the variations. Figures 2, 3 and 4 show

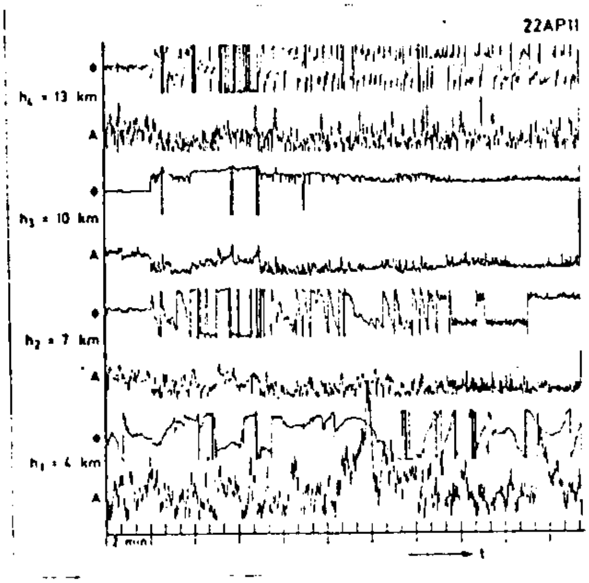

Figure 2. Amplitude and phase (modulo 4 π) of complex signals (raw data coherently integrated over 0.25 s) backscattered from 4 tropospheric heights as a function of time.

examples of plotted compressed data, which are raw data, coherently integrated over 0.25 s. The amplitude and the phase (modulo 4 π) of the complex signals for different heights are plotted as a function of time. The amplitude A is related to the intensity of the backscattered signal, whereas the time derivative of the phase Φ is proportional to the line-of-sight velocity component of

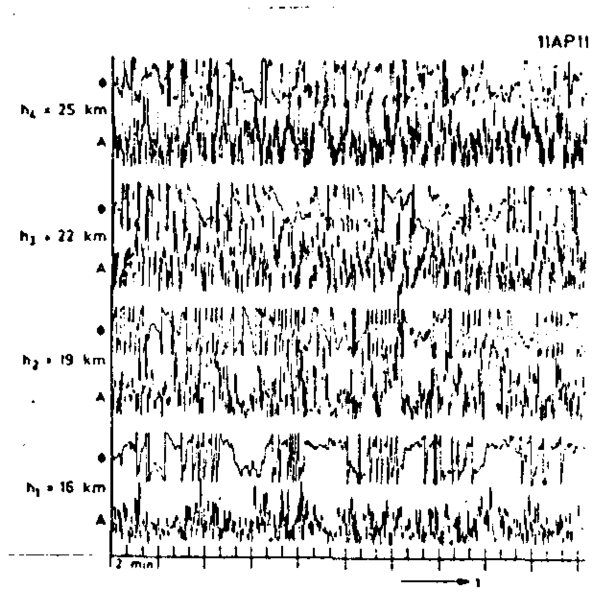

Figure 3. Amplitude and phase (modulo 4 π) of complex signals (raw data coherently integrated over 0.25 s) backscattered from 4 stratospheric heights as a function of time.

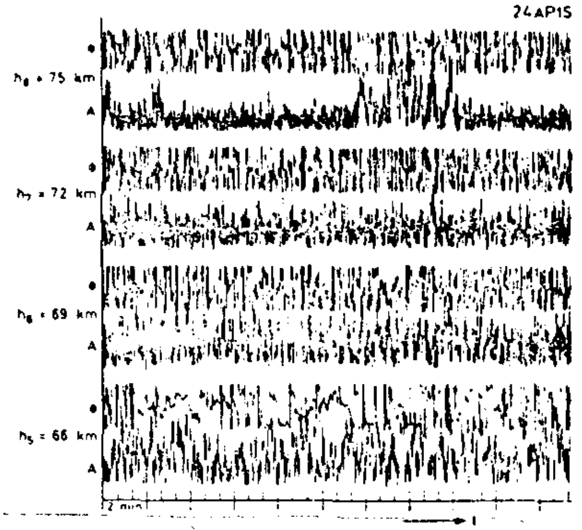

Figure 4. Amplitude and phase (modulo 4 π) of complex signals (raw data coherently integrated over 0.25 s) backscattered from 4 mesospheric heights as a function of time.

the scattering volume. The time-variation of the signals can easily be seen as well as the different respective time-scales. The transition from slow to fast fading can occur very suddenly (Fig. 3). The high signal-to-noise ratio is shown in figures 2 and 3. Noise is equivalent to the width of the lines, which is first detectable at about 22 km. In the next step of processing the constant parts of the signals are eliminated. These constant parts can result from two different sources: a) instrumental biases (DC) or b) non-moving objects (ground clutter). If the two channels of the complex signal have been differently amplified or the quadrature detector showed phase-errors, this is corrected in the next step of the signal processing.

At this stage statistical methods are applied to the processed signals to obtain the line-of-sight velocity v and the power P, which is a measure of the intensity of the backscattered signal.

6. RESULTS AND DISCUSSION

Figures 2, 3 and 4 show plots of the compressed raw data obtained from measurements in the tropo-, strato- and mesosphere. Problems in the lower tropospheric heights (Fig. 2) are caused by saturation of the receiver, which could result in wrong amplitudes. This problem can be avoided by increasing the dynamic range of the receiver. Fig. 3 presenting stratospheric results shows clearly the rapid time-variation of the received signals. The phases for all heights undergo periodic variations between fast and slow changes.

It is interesting to note the very noisy and bursty nature of the signals returned from mesospheric heights (Fig. 4). Only when the received signal power is high the signal-to-noise ratio of the phase increases.

From these data-plots the appropriate integration times for auto- or crosscorrelation analysis are obtained. Applying simple autocorrelation analysis with an integration time of about 10 s to the data of Figure 3, signal power P without an r^{-2}-correction and velocity v are determined as a function of time for four heights. P is proportional to the turbulence intensity in the scattering volume and v is the radial or line-of-sight velocity of the scattering volume. The results are shown in Figure 5. Very stable oscillations of the line-of-sight velocity v with a period of about 4 min are observed at all four heights. The amplitude of the oscillations, which has a maximum of about 40 cm/s and is greatest at 16 km, shows a height dependence and the period T is in quite good agreement with the Väisälä-Brunt period. It should be pointed out that the mean square of the statistical variations which are superimposed are only of the order of a few cm/s. Figure 6 shows similar atmospheric oscillations at a height of 16 km, which, however, seem to be confined to a much smaller height range of only about 3 km. This result gives a good example for investigating not only temporal but also spatial variations. The mean square deviation of v at 16 km is about 10 cm/s.

Figure 7 presents the respective results of an autocorrelation analysis which was applied to the mesospheric data shown in Figure 4. The statistical fluctuations are highly reduced during special events, when the signal strength increases for a limited period of time.

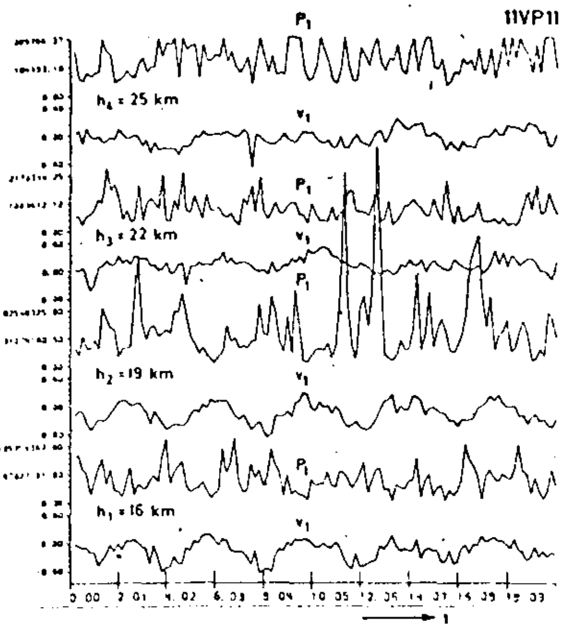

Figure 5. Power and line-of-sight velocity at 4 stratospheric heights obtained from an autocorrelation analysis of the radar backscatter echoes shown in Fig. 3 as a function of time (min). (The scale for P is linear in arbitrary units, the one for v is m/s.)

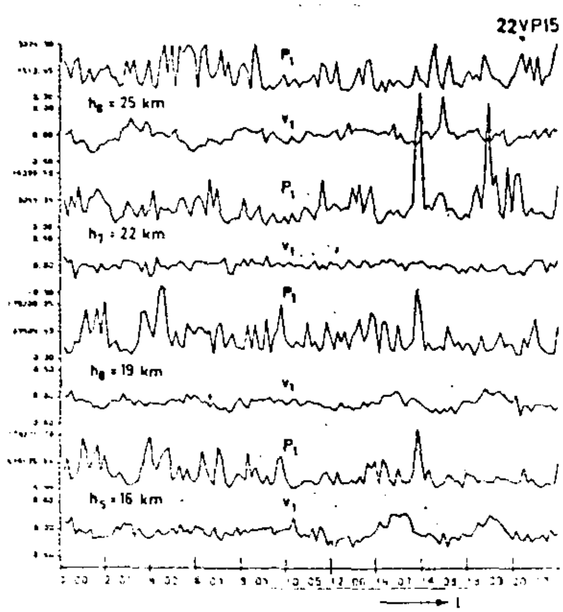

Figure 6. Power and line-of-sight velocity at 4 stratospheric heights obtained from an autocorrelation analysis of radar backscatter echoes. (The scale for P is linear in arbitrary units, the one for v is m/s.)

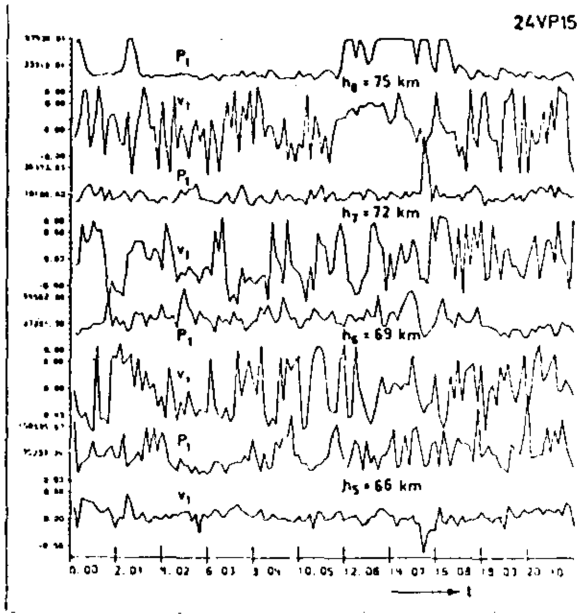

Figure 7. Power and line-of-sight velocity at 4 mesospheric heights obtained from an autocorrelation analysis of the radar backscatter echoes shown in Fig. 4. (The scale for P is linear in arbitrary units, the one for v is m/s.)

The antenna was used as an interferometer in order to measure the scale size of the turbulent inhomogeneities. The cross-correlation results of many measurements show mainly random phase variations. If there are inhomogeneities, then they are larger than the scattering volume, which has a horizontal size of about 120 m in tropospheric and about 500 m in stratospheric heights. A more sophisticated data processing, therefore, is necessary to answer special questions about these inhomogeneities. A fourth moment correlation scheme could be an alternative way to determine velocities.

(At the closing date for submission of papers to be published in this conference proceedings, the software developed for the processing of the data had just started to produce information. It is expected that at the time of the conference considerably more material will be analysed. We limited ourselves here, therefore, to present the motivation for the experiment, the experimental set-up, some of the processing techniques, some preliminary results and conclusions.)

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