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*Scientific note*

# Observations of the Arctic troposphere and lower stratosphere with the SOUSY Svalbard Radar

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***Abstract:*** The SOUSY Svalbard Radar was operated in the ST (stratosphere-troposphere) mode during tests and several campaigns since September 1998. Here we describe the configuration used for this purpose. We present results of wind and reflectivity profiles, showing layered structures during passage of synoptic-scale disturbances and tropopause variations. It is also reported that lee wave activity is frequently quite pronounced over Svalbard.

## 1. Introduction

Continuous observations of the structure and dynamics of the Arctic troposphere and stratosphere are of particular interest to obtain information on the climatology of atmospheric waves and turbulence in the high latitudes. Investigations of the variability of the polar vortex and the propagation of synoptic scale disturbances into high latitudes are also essential phenomena of polar meteorology, which require continuous observations. Stratosphere-troposphere (ST) wind profiler radars are proper tools for such studies, although they cover only one location and are limited to altitudes up to about 20–25 km. Measurements with these radars can also provide estimates on transport by turbulence or mean velocity. Röttger and Larsen (1990) have described these systems and summarized their capabilities, and Röttger and Tsuda (1995) have presented particular suggestions for radar studies of the polar middle and lower atmosphere.

The SOUSY Svalbard Radar is a mesosphere-stratosphere-troposphere (MST) radar operated for studies of Polar Mesosphere Summer Echoes (Czechowsky *et al*., 1998; Röttger, 2001), of coupling processes in the middle and the lower atmosphere and the structure and dynamics of the troposphere and lower stratosphere (Röttger, 2000a). We introduce here first results of observations of small-scale gravity waves, mountain lee waves, and passages of synoptic- and meso-scale disturbances as well as the structure of the tropopause over Svalbard at the high latitude of 78°N.

## 2. The SOUSY Svalbard Radar

In the year 1998 the Max-Planck-Institut für Aeronomie has constructed the SOUSY Svalbard Radar (SSR (Czechowsky *et al*., 1998)) near Longyearbyen (78°N, 16°E) on the island Spitzbergen, which is part of the archipelago of Svalbard. The SSR is an MST VHF

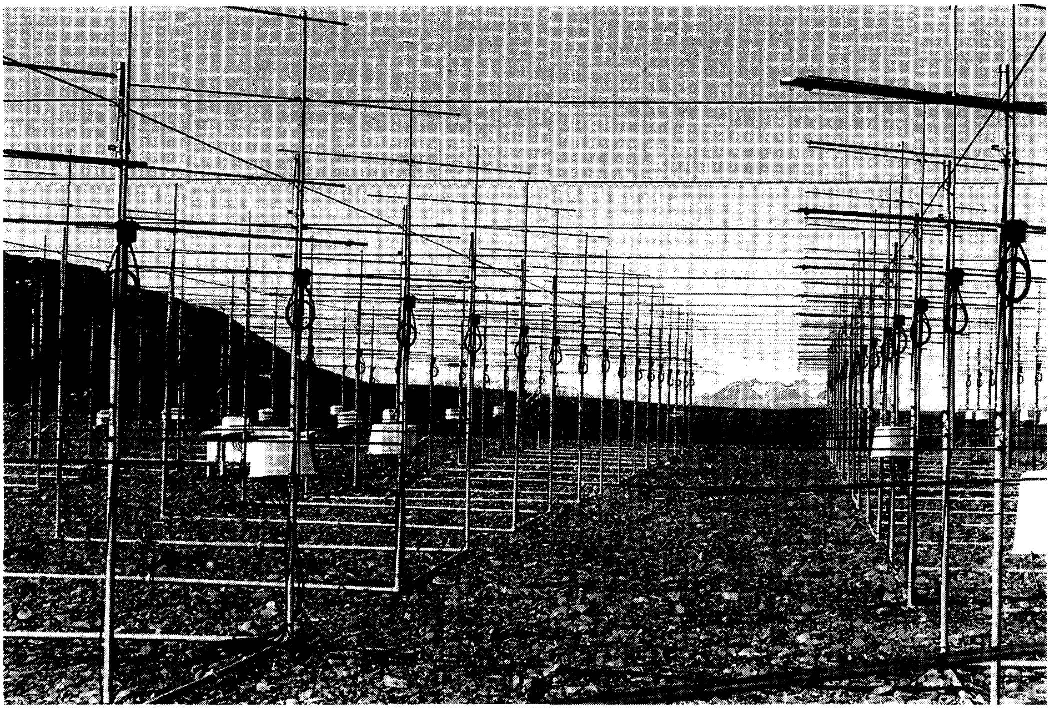


*Fig. 1. Part of the phased-array antenna of the SOUSY Svalbard Radar located near Longyearbyen (78° N, 16° E), which consists of 356 four-element Yagis in total (July 1999).*

radar and operates on 53.5 MHz with 70 kW peak power, applying a hybrid modulation of single and complementary pulse coding for ST applications, and a phased antenna array of 356 Yagis (Fig. 1). The antenna has a beam width of 4 degrees and is steerable into the zenith direction, and at 5 degrees zenith angle in four azimuths NE, SE, SW and NW. It is being separated into four receiving sub-arrays (4×36 Yagis) for spaced antenna and interferometer measurements. These sub-arrays are indicated by gray shading in Fig. 2. In the initial troposphere and lower stratosphere observations, which are briefly described here, only a sub-module of 4 Yagis was used for reception to allow recording of signals from lower tropospheric heights down to about 1 km. Since the beam width of the receiving modules (with vertical pointing direction) is wider than the steering angle of the full array antenna, the vertical pointing receiving beams need not to be steered.

## 3. Observations

It is common to display height-time-intensity plots of the measured parameters, such as the received power, and the wind velocity components in horizontal and vertical direction etc. The received power is a measure of the reflectivity of layers in the atmosphere and in particular indicates vertical humidity gradients in the lower troposphere and temperature gradients in the upper troposphere and stratosphere. The reflectivity of such layers is also affected by turbulence, which can be deduced from measured velocity fluctuations.

In Figs. 3 and 4 we present such typical plots obtained from measurements between

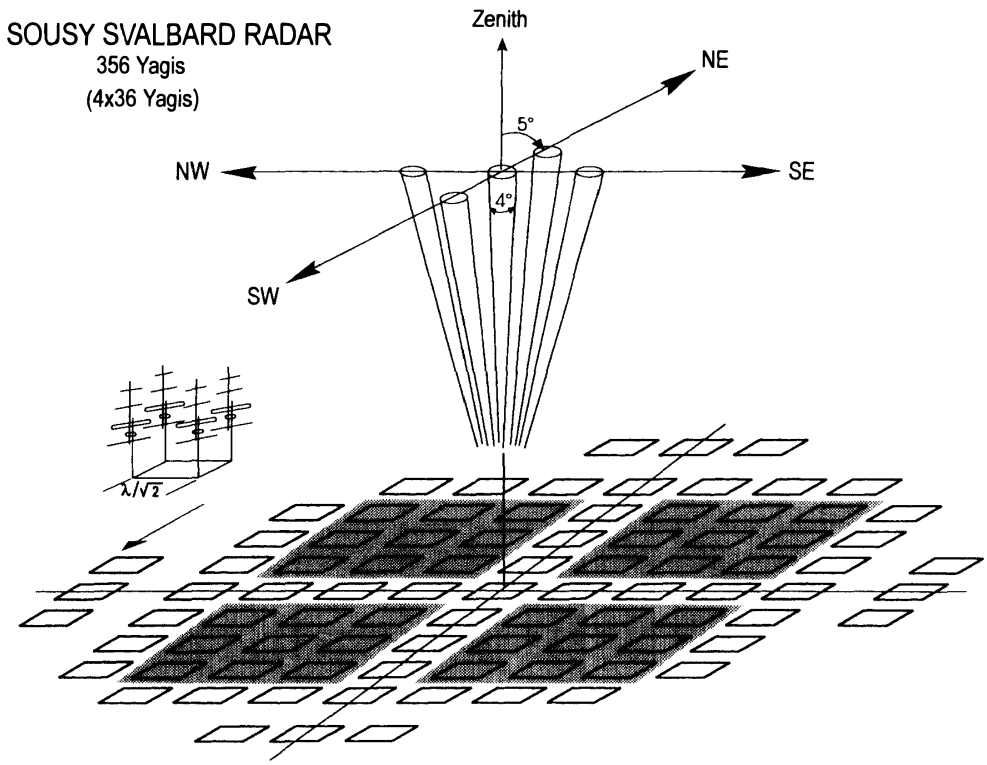



*Fig. 2. Layout of the antenna array of the SOUSY Svalbard Radar, showing the five possible beam directions. Each small square represents a subset of 4 Yagis. The four shaded areas comprise the modules taken out by passive transmit-receive switches for spaced-antenna reception.*

13 and 15 November 1999. The lower panels show the power variation, and the upper panels the variation of velocity as function of height and time. These observations were during a passage of a warm front over Svalbard, which is clearly seen in the downward sloping structure in the lower left-hand panel of Fig. 3. These detach from a strong structure around 10 km, which is an indicator of the tropopause. Larsen and Röttger (1985) have shown the relevance of ST radar investigations of frontal zone and tropopause structures. Downward slopes of radar-detected structures, as seen in Fig. 3, correspond to warm front passages. The lower right-hand side plot of Fig. 3 shows the power received in the NE beam at 5 degrees angle off-zenith. The power level 0 dB (light-yellow color) corresponds to the noise level. The reduced power at this angle, as compared to those measured with the vertical beam (lower left-hand panel of Fig. 3) determines the aspect sensitivity of the atmospheric structures detected by VHF radars. The aspect sensitivity is a measure for the stability of the atmospheric region in which this structure is embedded. The frontal structure is separated into 3–4 meso-scale substructures. The high power received from the altitudes below 4–6 km is likely due to increased humidity. Following the detachment of the frontal structure the tropopause is lifted significantly and also separates into a multiple tropopause. Following the warm front we find the increase of velocity in the altitudes between 6 and 10 km, which is the jet stream concurring with the frontal passage. The zonal ($u$) and meridional ($v$) velocities are shown in the upper panels of Fig. 3. The blank parts in these

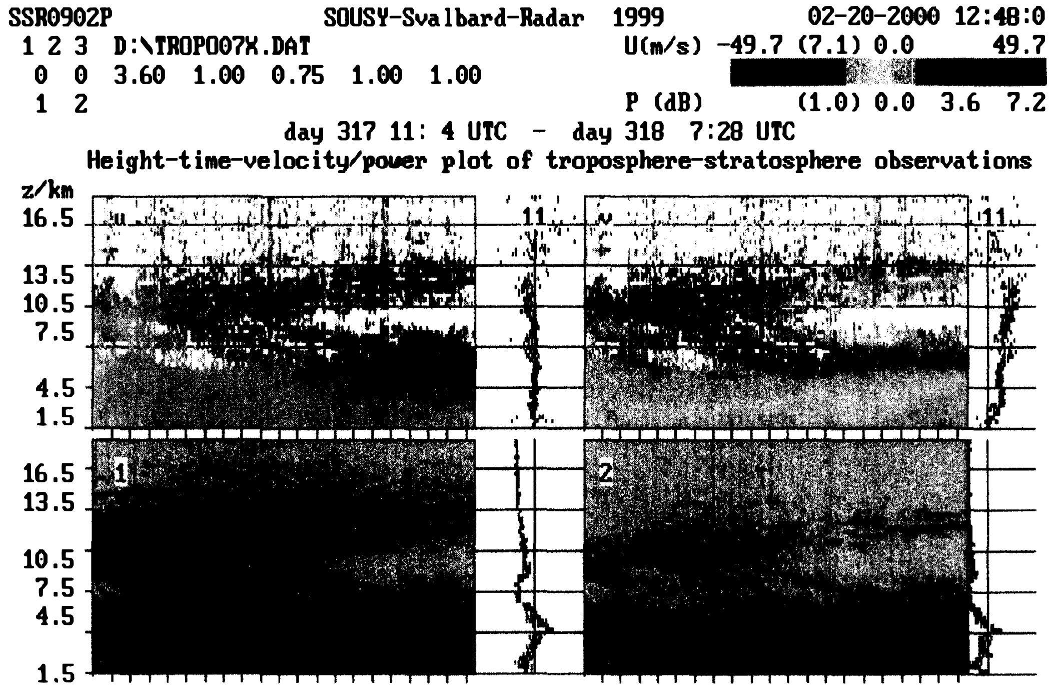
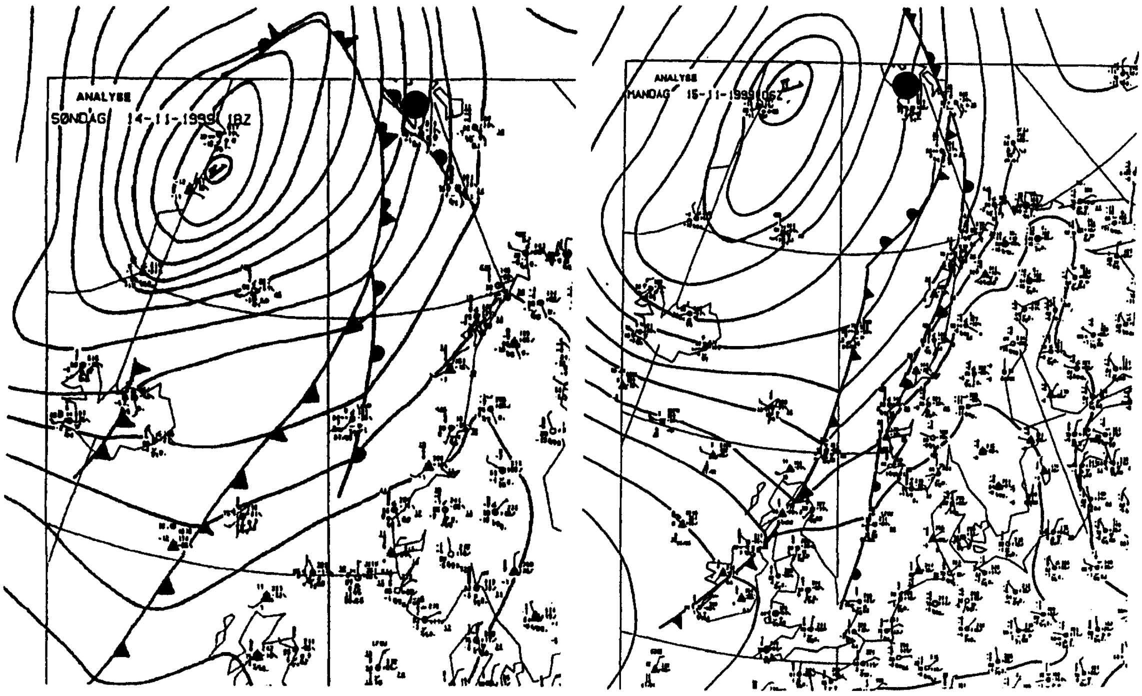



*Fig. 3. Height-time-intensity plots of eastward velocity u (upper left panel), northward velocity v (upper right), power received in the vertical beam (lower left) and in the NE beam (lower right), recorded between 1104 UT on 13 November 1999 and 0728 UT on 14 November 1999 (day 318). The color scales define $\pm 49.7$ m $s^{-1}$ for velocities and 0 dB to 7.2 dB in the relative power scales. The scatter profiles in the center and the right margin are the corresponding velocity components of 11–12 UT on 13 November (upper plots) and the averages of the radar power in the lower panels.*

velocity plots result from lacking signal in this region.

These observations are basically equivalent to the observations with radiosondes performed every day at 11 UT at Ny-Ålesund (operated by the Alfred Wegener Institut für Polar und Meeresforschung), which is about 100 km north of the SSR. The surface weather maps (Fig. 4) show the warm front passage at Svalbard around 18 UT on 14 November, which is a few hours later than we extrapolate from the latter down-sloping structure detected by the SSR in Longyearbyen (Fig. 3).

In the following period, 15–16 November 1999, relatively extreme variations of the quasi-vertical velocity were observed with the SOUSY Svalbard Radar. These are presented in Fig. 5, where we show, in addition to the height-time-intensity plot of the power, the velocities deduced from the Doppler shift of the signals received in the vertical beam and in the opposite NE and SW field beams (*e.g.* Röttger and Larsen, 1990). The latter can be combined to yield an additional estimate of the quasi-vertical velocity. In homogeneous and horizontally stratified reflectivity and velocity fields these two velocity estimates should be equal, yielding the correct vertical velocity component. We notice some equivalence of these two velocity estimates in the beginning of this period whereas they deviate significantly in the latter part of this period. We also see a change of direction of these velocities with height and with time. These are clear signs of a non-homogeneous wind



14.11.99 (318), 18 UTC                15.11.99 (319), 06 UTC

*Fig. 4.* *Weather maps (sea level) of 14 November (18 UT) and 15 November 1999 (06 UT). The location of Longyearbyen, Svalbard, is marked by the filled circle in the upper part of the maps (provided by courtesy of Longyearbyen airport).*

field. The periodicity at vertical scales of a few kilometers and time scales of hours, which are observed after about 12 UT point to quasi-stationary mountain lee waves. In the beginning of the period some shorter period oscillations at some 10 to 20 min are noted, which are likely due to small-scale gravity waves. These long- and short-period wave disturbances are superimposed on the mean background wind field.

It is apparent from the shown combination of the vertical beam and the NE and SW beams, that the horizontal wavelength of the lee waves, observed after about 18 UT, is much less than a few kilometers, resulting from the separation of the radar beam pointing directions. This has a non-negligible effect on the determination of mean vertical and horizontal winds, and requires a very careful consideration. This potential effect can be ameliorated by including the spatial interferometer technique (*e.g.,* Röttger *et al*., 1990). The SOUSY Svalbard Radar is, thus, being extended to allow such interferometer measurements with the spaced antenna configuration (see Fig. 2).

Svalbard is an archipelago with high mountains, steeply extending from the ocean surface. Strong surface winds can, thus, easily generate mountain lee waves, which propagate into the lower atmosphere. Our observations with the SSR show that these wave disturbances are frequently occurring in the troposphere over Svalbard. Their amplitudes can be up to 2-3 m $s^{-1}$. This corresponds to high tubulence intensity, if encountered by aircraft. When these waves break, also smaller scale turbulence is created, which we may see in the highly variable power received from the middle and lower troposphere (Fig. 5). We

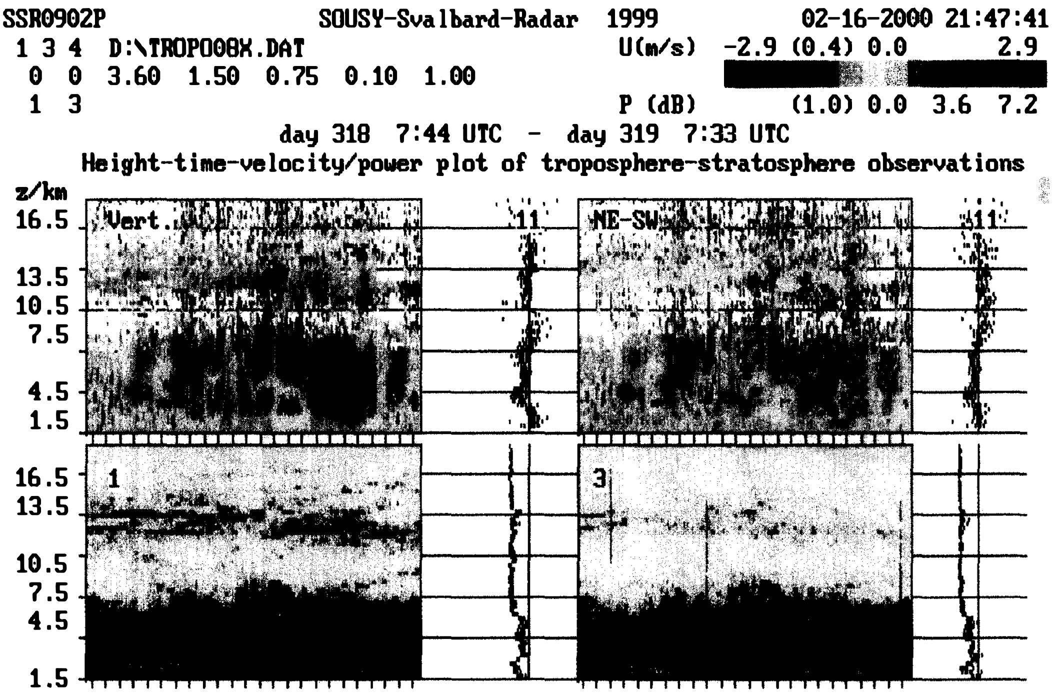



*Fig. 5. Same as Fig. 3 but for the following time period 0744 UT on 14 November to 0733 UT on 15 November 1999 (day 319). The right-hand lower plot shows the power in the SE beam. The upper plots show the velocity in the vertical beam (left panel) and the quasi-vertical velocity composed from the NE and SW beam (right). The scatter plots in the center and the right are displaying averages of the corresponding parameters on their left between 11 UT and 12 UT. The color scales cover $\pm 2.9$ m $s^{-1}$ for the velocity and 0 dB to 7.2 dB in the relative power scales.*

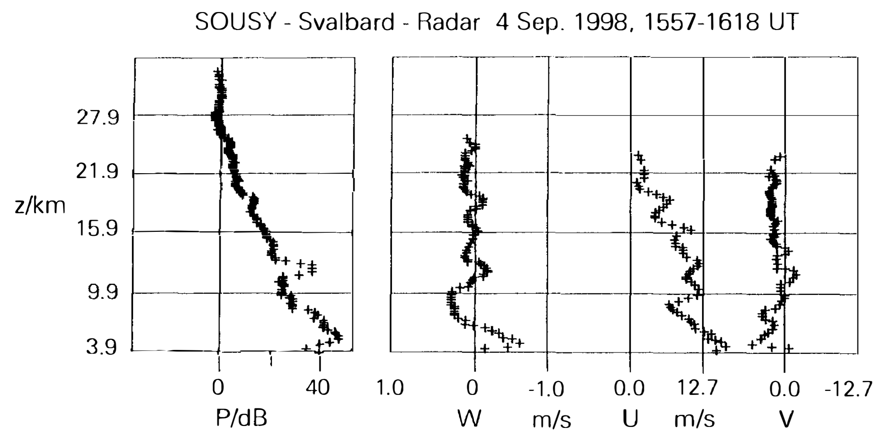



*Fig. 6. Profiles of relative power P, quasi-vertical velocity w, zonal velocity u and meridional velocity v, measured during test-operation on 4 September 1998, using the full antenna array for transmission and reception as well.*

also notice in Fig. 5 that the quasi-vertical velocities occasionally change direction within short time periods. This can only be explained by either changes in the source activity, or by variations of the wind and/or temperature profiles aloft. In Fig. 6 mean profiles (average over 20 min) of power and the three wind velocity components, *u*, *v*, and *w*, are shown. We note the periodic variations of the velocity components with height. The horizontal velocity components are significantly out of phase by 180 degrees, which supports the view that these variations are due to a lee wave.

Röttger (2000b) has reviewed the VHF radar investigations of atmospheric waves over mountainous areas. It appears to us that the intensity of lee wave activity over Svalbard is very pronounced as compared to other sites. We need to analyze these mountain wave effects over Svalbard quite carefully and more intensely in future investigations.

## 4. Conclusion

Initial results of troposphere and stratosphere observations with the SOUSY Svalbard Radar (SSR) have been presented. These show that this radar can substantially contribute to the investigations of high polar latitude meteorology by observing tropospheric and lower stratospheric structures and wind fields, including strong lee wave activity. The SSR has subsequently been operated in a continuous mode during the ASTAR-2000 campaign in March and April 2000. Figure 7 shows a copy of a real-time plot of three main measurement parameters, namely the zonal ($u$) and the meridional ($v$) wind components, and the power ($P_t$), which is a measure of the radar reflectivity and shows the layered structure of the troposphere and the tropopause. The presented display shows the passage of an occlusion, combined with a tropopause folding event between 20 UT and 24 UT on

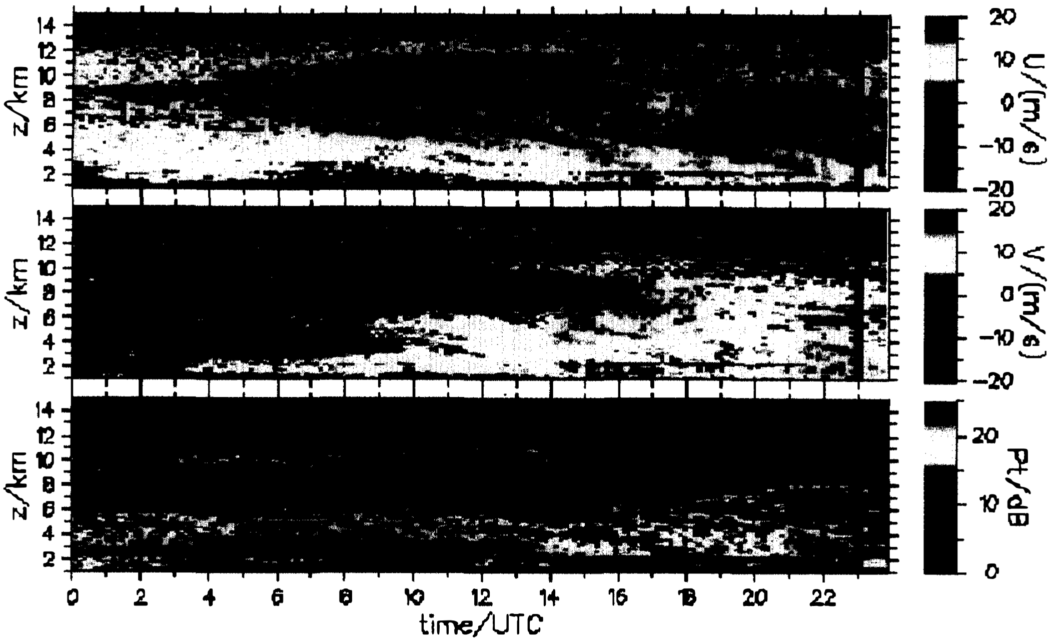



*Fig. 7. Height-time-intensity plots of provisional real-time estimates of zonal velocity u, meridional velocity v and relative total power $P_t$ (noise + signal) recorded over a 24-hour period on 8 April 2000 during the ASTAR-2000 campaign.*

8 April 2000. These plots are available in real time on the home page of the MPAe. We expect the SOUSY Svalbard Radar to attend several future campaigns of this kind.

## Acknowledgments

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