5.10A CAPABILITIES AND LIMITATIONS OF THE SONDRESTROM RADAR FOR ST OBSERVATIONS

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INTRODUCTION

The Sondrestrom radar is located on the western side of Greenland (67°N, 51°W) near the U.S. air base and Danish community at Sondre Stromfjord. The radar was previously located at Chatanika, Alaska where its primary role was incoherent-scatter studies of the auroral ionosphere. Stratosphere/troposphere studies have occupied a very small portion of the radar observing schedule. Ionospheric research is still the radar's primary function and was the reason for its re-location from Alaska to a very high magnetic latitude. The radar was moved from Alaska during the second half of 1982 and was first operational in Greenland in January 1983 and commenced regular operations in April 1983. It is managed and operated by SRI International although there are users from other institutions.

The high operating frequency (1290 MHz) implies that the radar may only be used for turbulence-scatter studies in the troposphere and lower stratosphere. While the inner scale sizes of turbulence imply that the radar should be able to obtain data up to at least 20 km, in practice about 15 km seems to be the usual limit, due to lack of system sensitivity. However, this upper height limit varies from day to day and data have been obtained up to 23 km when a long (50 μsec) pulse has been used (BALSLEY et al., 1977). At high latitudes the tropopause is typically about 8-11 km altitude, therefore the radar is particularly suited to studies at tropopause heights.

Figure 1 shows the antenna and buildings. The surrounding terrain provides relatively little protection from ground clutter echoes compared to the previous Alaskan site. The stronger ground clutter may compromise experiments when the turbulence signals have a small Doppler shift; this occurs, for example, when the antenna is directed vertically.

HARDWARE

Transmitter

The radar transmitter operates at 1290 MHz and uses a single Litton L3938 Klystrom as its final power amplifier. It was originally designed for incoherent-scatter ionospheric research. With the longer pulses and lower pulse repetition frequency (PRF) used for ionospheric studies (up to 320 μsec pulses and PRF < 75 Hz) the peak pulse power is typically 4 MW. However, this is reduced to 3 MW with the short (5 μsec) pulses and higher PRF (250 Hz) used for ST studies. As will be discussed later, the maximum 250 Hz PRF value is too low; it compromises the signal detectability and may result in spectral aliasing. Other priorities have precluded any modifications to the transmitter.

No hardware is presently available to support phase-coded pulses, and only uncoded 5 or 10 μsec pulses have so far been used. There is also a limitation with the receiver analog-to-digital (A/D) converters that precludes the use of transmitter pulses less than 2 μsec long. The maximum A/D sample rate is 500 kHz.

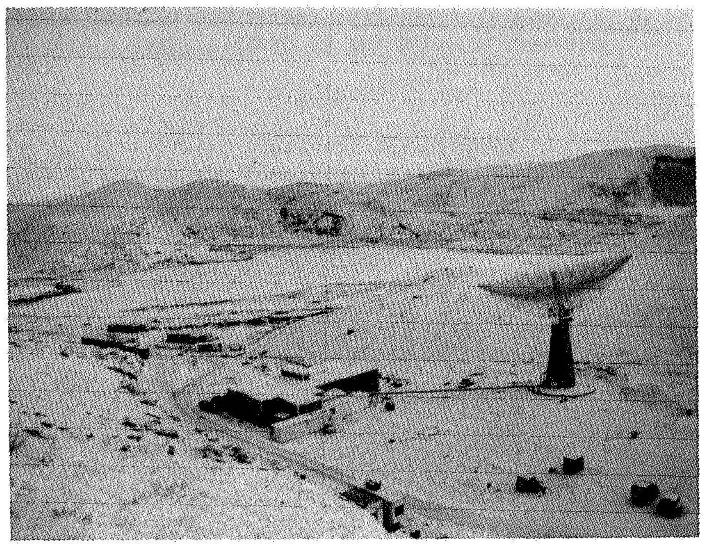

Figure 1. The Sondrestrom radar.

Receiver

The first receiver stage is a GaAs FET amplifier located in the antenna mount just behind the antenna surface. Following this, the first mixer produces a 30 MHz IF (10 MHz bandwidth) that is amplified and directed to the receiver room. A directional coupler which is located just before the parametric amplifier is used to inject a calibrated noise source into the received signal. The noise source is pulsed on briefly near the end of each interpulse period; it permits an accurate calibration of the received signals and hence turbulence intensities.

The 30-MHz IF is subsequently filtered, coherently demodulated and then digitally sampled.

Antenna

The antenna is a fully steerable dish of 32 meters diameter. After relocating the radar to Sondrestrom the antenna was increased in diameter from

Table 1. Sondrestrom radar parameters

Frequency	1290 MHz
Peak pulse power*	3 MW
Pulse repetition frequency*	250 Hz
Pulse length*	5-10 μsec
Maximum duty cycle	3 %
Polarization	Circular
Antenna diameter	32 m
Antenna gain	49.6 dB
Antenna efficiency	52 %
System temperature	100° K

*Typical values for ST observations

its original 26 meters and the efficiency has been increased from 43 to 52%. The effective aperture is now 418 m^2 which is almost a factor of 2 increase which should aid future ST observations.

The antenna can be slewed rapidly at 5°/second and elevation scans are permitted over a range of 120 degrees and possibly more in the future.

SOFTWARE

Real-Time Program

The real-time data-acquisition program was written by C. Dawson at SRII for the on-site Harris computer. It is capable of determining power spectra with up to 512 point FFTs; we have usually used either 256 or 512 points. No dc clutter subtraction is performed before the FFT calculations, therefore a central clutter spike is evident in our spectra, especially the lower heights.

The program is limited to a maximum of 24 range gates. Due to memory limitations some disk accesses have been necessary thereby slowing the effective processing rate.

While the program has so far performed well for simple wind measurements, the program efficiency is very low. There is too much time used in processing for the worst case of 512 point spectra and four coherent integrations (the maximum allowed by the program) only about 20% of the radar pulses are used and the signal returns from the remainder are discarded while processing takes place. This limitation lies with the computer which has too little available memory and is too slow. An array processor with a large amount of memory would significantly enhance the programming speed and increase the effective signal/noise ratio because more spectra could be averaged in a given time.

The real-time program is also responsible for controlling the antenna motion and providing graphics output of spectra on an HP-2648A CRT terminal. Data may be gathered either with the antenna moving, or stationary in a sequence of fixed directions. We prefer to take data with the antenna stationary because it avoids spectral spreading of signals and clutter. The antenna can be moved quickly to the next position while the computer is doing the processing and writing data to tape.

Off-line Analysis Programs

The off-line analysis programs have been written by this author to run on the Geophysical Institute's VAX 11/780 computer. Programs are available to analyze and plot power spectra. As well as the usual wind and power measurements, we can analyze complex multi-peaked spectra. The Doppler velocity, power and width of several individual peaks in a spectrum can be determined.

Other programs have been written to plot these spectral parameters as a function of height or time.

MEASUREMENT CAPABILITIES AND LIMITATIONS

The ST measurements have so far focussed on wind measurements using azimuth and elevation scans (BALSLEY and PETERSON, 1981; CHANG, 1980). Recent observations in Alaska just prior to the relocation to Greenland involved data comparisons with the nearby Poker Flat MST radar.

The steerable dish antenna can be moved rapidly (5 degrees per second) so that an azimuth or elevation scan can be quickly completed (e.g. Figure 2). This is important for wave studies. The ability to direct the antenna to low elevation angles (minimum of 30 degrees) can be useful for reducing clutter because the range to a given height can be increased so that clutter is minimal. Low antenna elevations permit experiments similar to that performed by CRANE (1980) who studied the horizontal extent of turbulent structures.

Another feature of the radar we are beginning to exploit is its ability to easily derive Doppler spectra with high frequency resolution. We have used 512 point FFTs with 4 coherent integrations to obtain a frequency resolution of 1.4 cm/sec. An example of one of these spectra is shown in Figure 3. With high frequency resolution data we have been able to accurately determine the small vertical wind motions (WATKINS and JAYAWEERA, 1983) with the antenna directed vertically.

The radar is also capable of incoherent-scatter studies of the ionosphere (80 - 600 km). It should be feasible to operate the radar in both incoherent-scatter and turbulence-scatter modes simultaneously. This would probably require alternately switching rapidly between modes. It may be useful for investigating possible coupling between the two height regions but has not so far been attempted.

There are several limitations of the radar when used for ST studies. A major intrinsic limitation is its inability to receive usable signals much higher than about 15 km. However, if long pulses ($\geq$ 50 μsec) are used (BALSLEY et al., 1977) the upper height limit can be extended to about 25 km.

The present use of 5 μsec pulses gives a range resolution of 750 meters. This is inadequate for resolving individual turbulent layers. It would be desirable to obtain at least 150 - 200 meter resolution by phase-coding. It is not practical to use an uncoded pulse shorter than the present 5 μsec because the radar is already sensitivity limited.

The relatively low transmitter PRF can pose a problem of spectral aliasing for some experiments and it needs to be increased. The Nyquist frequency for the spectra is given by (PRF/2) Hz which corresponds to ($1/4\ \lambda$ PRF) = 14.4 m/s Doppler velocity. The horizontal wind speed is often greater than this value. Thus experiments with low antenna elevations often produce aliasing of the turbulence-scattered signals, and this makes it difficult to determine the real wind velocity. Increasing the PRF would also aid system sensitivity because of higher average power.

An associated minor problem is that it is usually not feasible to perform coherent integration because the narrow spectral bandwidth is further reduced by N_C, the number of coherent integrations. However, for experiments with the antenna near vertical we have successfully used up to four coherent integrations.

The major limitation at present is the data-acquisition computer which is too slow and cannot process spectra fast enough in real time. For simple wind measurements where time resolution is unimportant, this is not a problem. However, if vector wind data are to be acquired quickly enough to resolve gravity waves, improvements need to be made.

While the full potential of the radar has yet to be exploited, the system can provide very good wind data up to about 24 km. If phase-coding and an upgraded data-acquisition system can be implemented it will be possible to take advantage of the antenna steerability to study wave and turbulence structures with good spatial and temporal resolution.

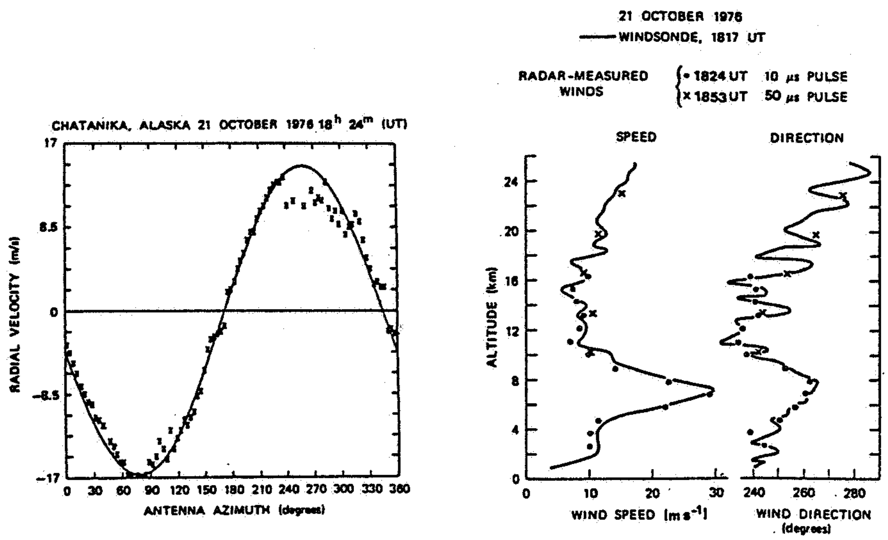

Figure 2. Left: An example of data from an azimuth scan at constant elevation (45 deg). The crosses are data points and the continuous curve is a best-fit sine function. The amplitude of the sine curve gives the horizontal wind speed, the phase gives the horizontal direction, and the vertical offset gives the vertical wind component. Right: Wind profiles (dots and crosses) obtained from a radar azimuth scan. For comparative purposes, radiosonde-measured winds are shown as the continuous curve (from BALSLEY et al., 1977).

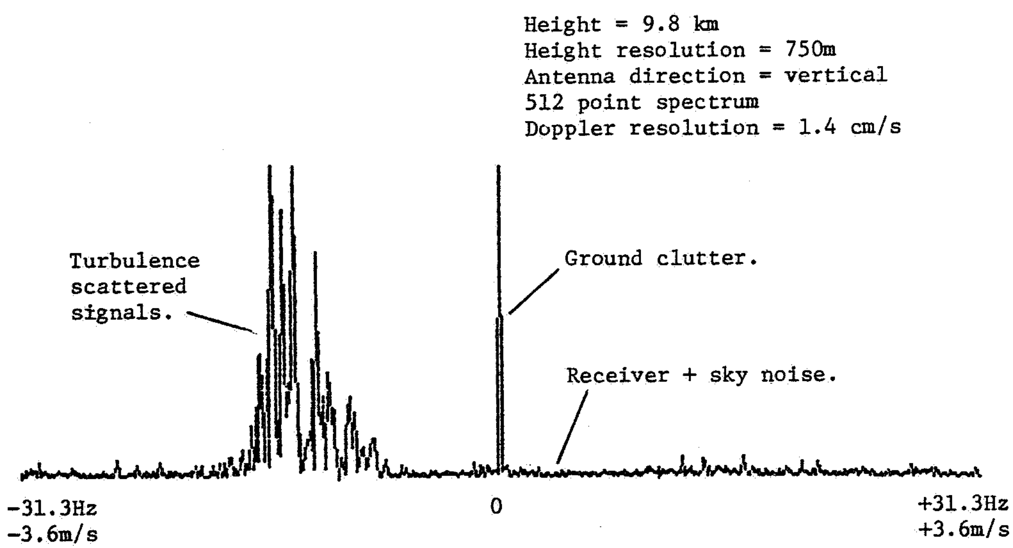

Figure 3. Example of a high resolution spectrum. The width of the turbulence signals is about 0.9 m/s. The mean (vertical component) is about 1.5 m/s downward.

In summary, the major advantages and limitations are listed below:

ADVANTAGES

1. Fast steerable dish antenna
2. Good Doppler resolution easily attained
3. Possibility of "simultaneous" incoherent-scatter operation.

LIMITATIONS

1. ST operation only - low maximum height for stratospheric returns (15-20 km) due to short wavelength.
2. Long runs (> 24 hours) generally not possible. This limits radar's usefulness for synoptic type studies.
3. Slow data processing capability. This limits the usefulness of the steerable antenna.
4. Average transmitter power is too low thereby reducing sensitivity. Implementation of phase-coding would increase sensitivity and also permit better range resolution.
5. Maximum transmitter pulse repetition frequency (250 Hz) is too low.

It should be noted that the limitations 3, 4, 5 could all be corrected with an appropriate investment in money and manpower.

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