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RAIN RADARS FOR EARTH SCIENCE GEOSTATIONARY PLATFORMS: SOME POSSIBILITIES

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ABSTRACT

This paper presents results of a feasibility study for a geostationary rain radar. A 2-cm wavelength radar with a 15- or 20-mm antenna will be useful for general scale meteorology. The transmitter power of 500 W with a pulse compression ratio of 200 will provide adequate signal-to-noise ratio for a rain rate of 1 mm/hour. Various problems associated with a geostationary radar and solutions are also discussed.

INTRODUCTION

The availability of large antennas and relatively potent power supplies for geostationary satellites suggests their use for radars to map rainfall in the tropical and temperate zones. Calculations presented here show that such systems are feasible, although far from perfect.

Two major problems are:

(a) The footprint one can feasibly achieve from geostationary orbits is much too large to identify individual rain cells. Thus these radars can map area rainfall, but cannot identify individual squalls.

(b) The time required to map the entire area of interest can be quite large, although ways around this limitation can be developed.

The inability to profile rains vertically is undesirable, but a necessary consequence of the combination of minimum feasible vertical beamwidths and long ranges.

Here we have developed some of the necessary parameters for such a radar. With a 500 W peak power and pulse-compression ratio (PCR) of 200, high signal-to-noise ratios (SNRs) are possible for single cells 5 km in diameter up to 60° latitude for 1 mm/hour rains with a 15-m diameter antenna. Actually significantly less power is needed if enough samples can be averaged. A 0 dB SNR only requires about 25 W with a PCR of 200. To obtain more averaging, however, one would normally increase the peak power and reduce the PCR.

CONCEPT

The geostationary rain radar would use a large electronically scanned antenna at a wavelength of about 2 cm. The antenna could be either an array or a reflector with scanned feed. It might also be scanned mechanically at a slow rate if complete 360° coverage were desired, since the electronic scan cannot cover such a wide angular range.

It would use a pencil beam, but even the best pencil beam cannot reduce the resolution cell to a size comparable with rain-cell sizes (typically about 5 km in diameter). Thus the scans would show areas of rainfall, but not individual cells. Sensitivity calculations presented here, however, assume only one cell within the beam at a time. More cells would increase the signal, but it would be difficult to determine whether the increased signal was due to heavier rain or more area covered by rain.

The transmitter would send pulses with a pulse-repetition frequency (PRF) such that no two pulses would be present in the rain at one time. Thus the interval in space between pulses would be at least 55 km. With a high PCR, this would have to be increased to allow for the long duration of the expanded pulse. This would reduce the PRF and the number of independent samples of the fading signal from rain that could be averaged, but with high SNR this number can be minimized. Nevertheless, to obtain reasonable measurement precision of the fading signal, one would have to average at least 25 samples. This tradeoff requires more study.

Because of the long time needed to scan a large area, simultaneous multiple beams might be needed. Since each beam would require the same power as every other one, this would make the power requirement proportional to the number of beams.

PROBLEMS

The largest antenna one can expect to make successfully would be about 1000 wavelengths across, resulting in a 1-mR beamwidth. At 2-cm wavelength this requires a very precise antenna 20 meters in diameter. Even with such a large antenna, the footprints get quite large. Fig. 1 shows the footprint dimensions for such an antenna as a function of distance from the satellite. If the beamwidth is β in both directions, the footprint is an ellipse with

$$(1)\ \text{Cell width} = \beta R \quad \text{(minor axis)}$$

and

$$(2)\ \text{Cell length} = \beta R/\cos\theta_i \quad \text{(major axis)},$$

where R is the slant range and θ_i is the angle of incidence. Because the angle of

CELL DIMENSIONS FOR GEOSTATIONARY RADAR
WAVELENGTH 2 cm ANTENNA DIAMETER 20 m

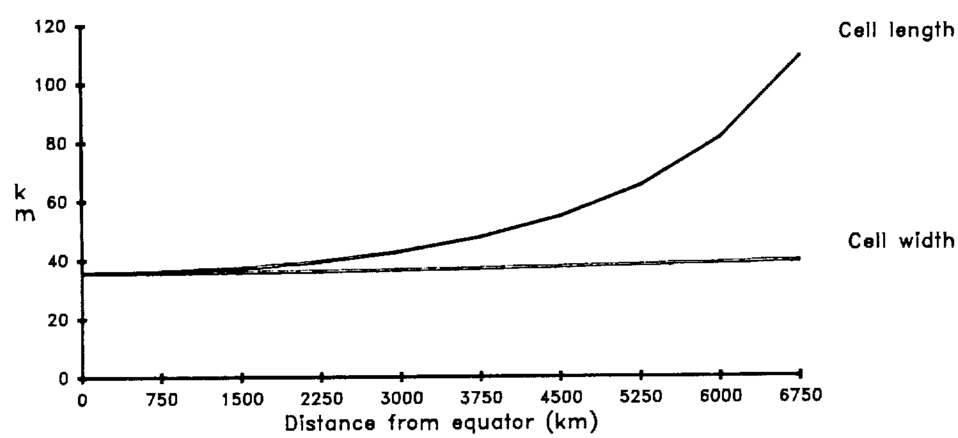

Figure 1

incidence becomes 60° at 6750 km from the satellite, this larger dimension becomes 109 km. The cell width is almost constant because the range changes little. It is on the order of 40 km. The angle of incidence and the much smaller pointing angle at the satellite are shown in Fig. 2.

When the antenna diameter is reduced to 10 m, the cell sizes double. These cells are so large that they have little meteorological significance. Calculations were also performed for a 5-m diameter antenna, but the cells are so large that this is only of value to illustrate the effect. Fig. 3 shows the cell sizes versus antenna diameter.

A major problem is the time required to map the area. Calculations have been performed for a 360° arc about the spacecraft, and these can be readily reduced if the coverage is reduced. The problem arises because the 1-mR beamwidth of the 20-m antenna has so many cells around a circle. The antenna must dwell on each of these long enough to permit averaging enough samples.

Moreover, the time required for the signal to travel round-trip to the surface is about 0.25 sec, so time must be allowed for the received signal to return to the satellite. This time is considerably larger than that required for integration, so steps should be taken to avoid the problem it creates. The most logical step is to have two separate beams, one for transmitting and one for receiving. The scanning of the receiving beam would lag that of the transmitting beam by 0.25 sec. Although this introduces major complications in the system, it appears necessary for timely coverage.

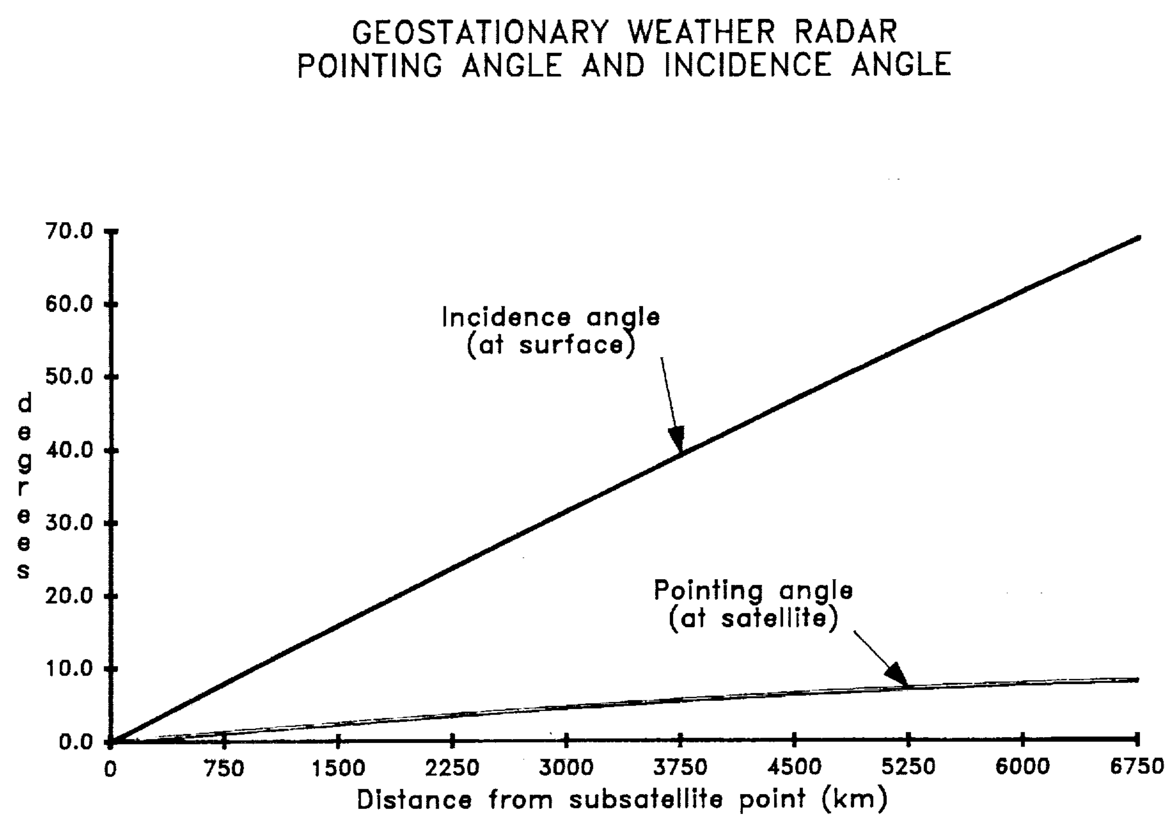

Figure 2

Table 1 illustrates the magnitude of this problem. For the table, we assume a PRF of 5000 (actually much too high for the PCR of 200 assumed later). This value assumes separate transmit and receive beams. In this case, we can integrate 100 samples (a reasonable number for reducing fading effects and allowing use of low values of SNR), while still observing 50 resolution cells per second.

TABLE 1
Calculations Regarding Coverage Time

Antenna diameter (m)	20	15	10	5
Beamwidth (mR)	1	1.33	2	4
Number of steps/circle	6283	4712	3142	1571
Number of circles (range)	142	107	71	36
Number of footprints (1000s)	892	502	223	56
Time for coverage at .26 s per cell (hours)	64	36	16	4
Time for coverage at 50 cells/sec (hours)	5.2	2.9	1.3	19 min

Clearly, the dual-beam system that allows 50 cells to be covered per second is preferable.

To achieve more adequate coverage in a short time, one should consider combining information from V-IR* scanners with the radar. There is no point in the

*Visible infrared (V-IR)

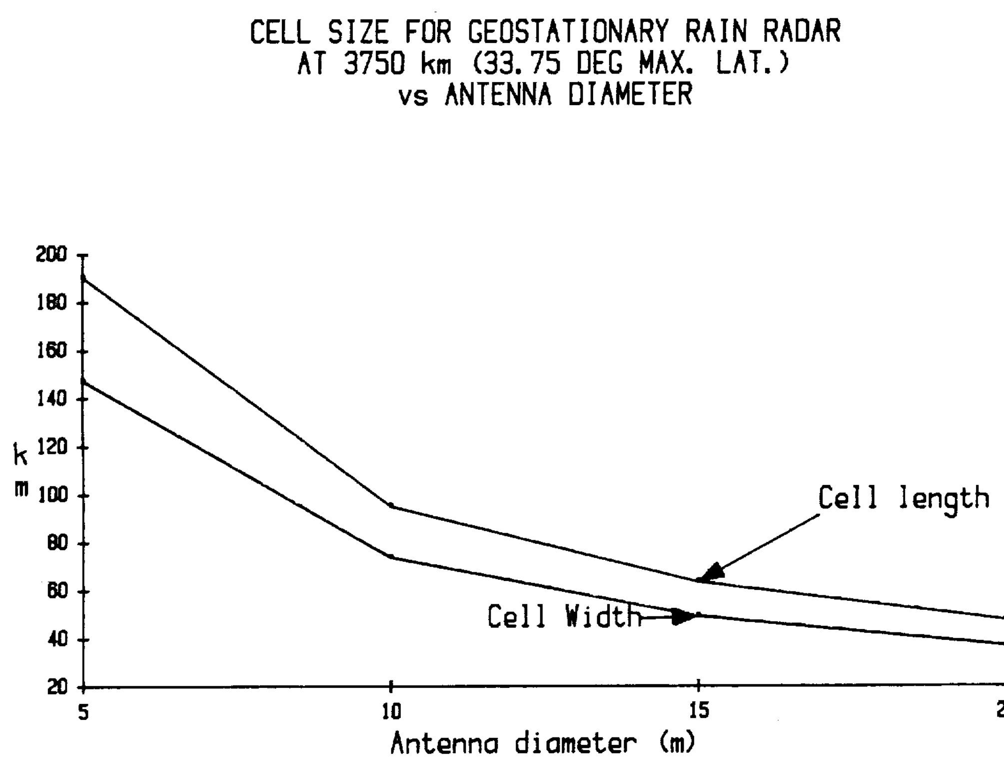

Figure 3

radar looking at areas where no clouds are present. The V-IR sensors can establish areas of clouds, and the radar can point only to these areas. Presumably this can make a major decrease in the required time for the radar to monitor the rain.

POWER CALCULATIONS

We calculated the power needed for a system such as this. The assumption is that one rain cell 5 km in diameter exists within a footprint and this cell extends from the ground to 5 km high. A further assumption (not justified for high rain rates) is that the scattering from the entire rain cell is received unattenuated at the satellite--except for spreading loss. The assumption of no attenuation was used for simplicity. We feel it was justified in this early-stage calculation, since the power limitation is set by the low rain rates where attenuation is small.

Figures 4, 5, and 6 show the SNR that can be achieved by a 500-W transmitter with a PCR of 200 for rain rates of 1 mm/hour to 20 mm/hour for antennas of different diameters. A standard Z-R relation for rain echoes was used. The SNR is 10 dB or better at all rain rates for a 15-m antenna. For a 10-m antenna the SNR at maximum range is only about 1 dB for 1 mm/hour, but this level is adequate if 100 samples are averaged. Moreover, the very large footprint of the 10-m antenna would almost certainly contain more than one rain cell, which would increase the SNR.

SNR FOR GEOSTATIONARY RADAR
20-m ANTENNA DIAMETER
ASSUMED RAIN CELL DIAMETER: 5 km
500 W TRANSMITTER - PULSE-COMPRESSION RATIO
200

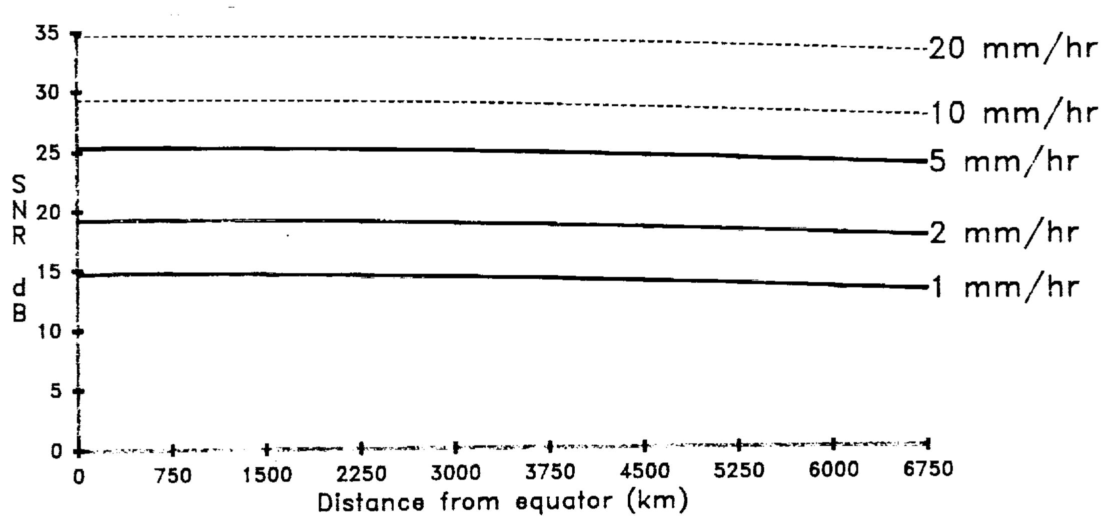

Figure 4

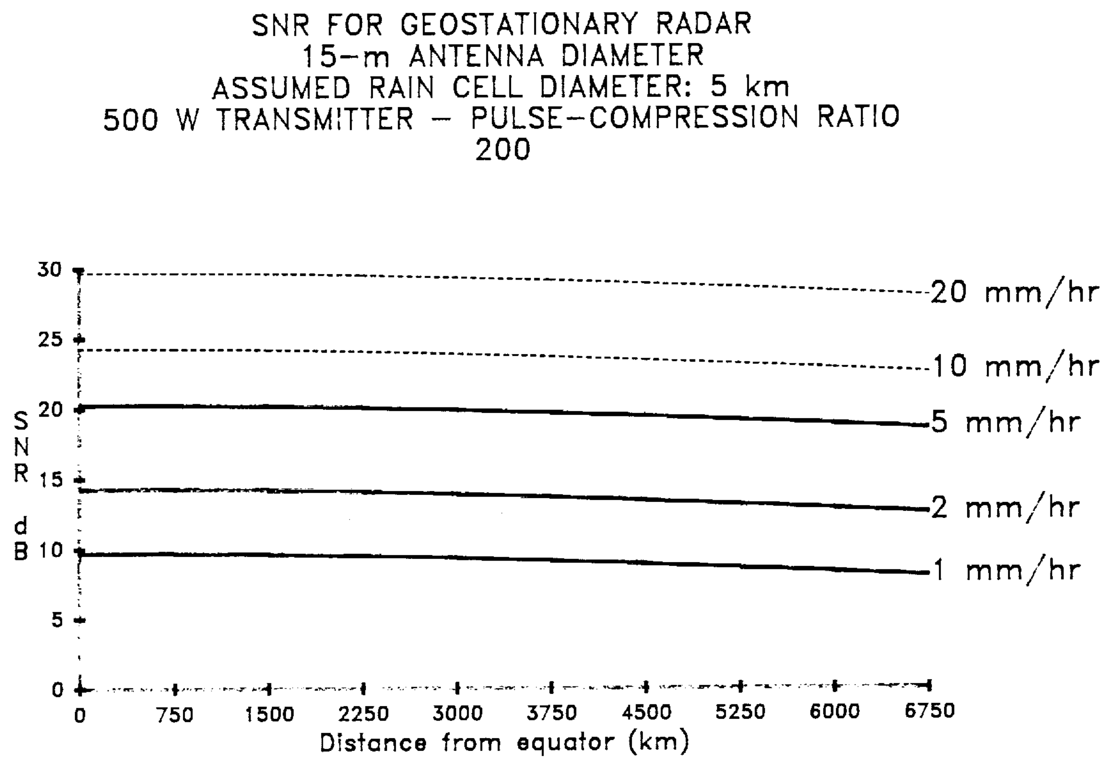

Figure 5

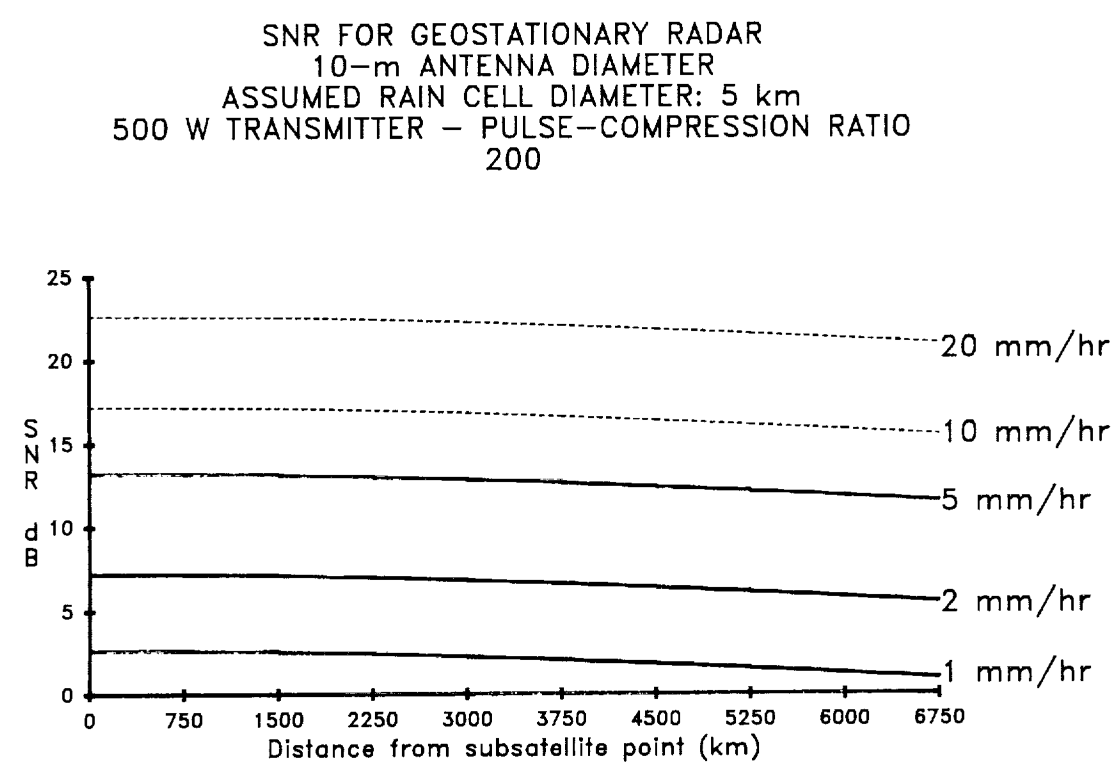

Figure 6

Fig. 7 plots the SNR at midrange (3750 km) versus antenna size for 1 mm/hour and 5 mm/hour. Clearly antenna size helps SNR, even though the resulting small footprints complicate the scanning.

In Fig. 8 we show the power required to achieve SNR=0 dB versus antenna diameter. The power levels are quite low for the larger antennas, but one must keep in mind that a PCR of 200 was assumed. Thus, without pulse compression, the powers would be higher by a factor of 200, making them totally unreasonable for the two smaller antenna sizes.

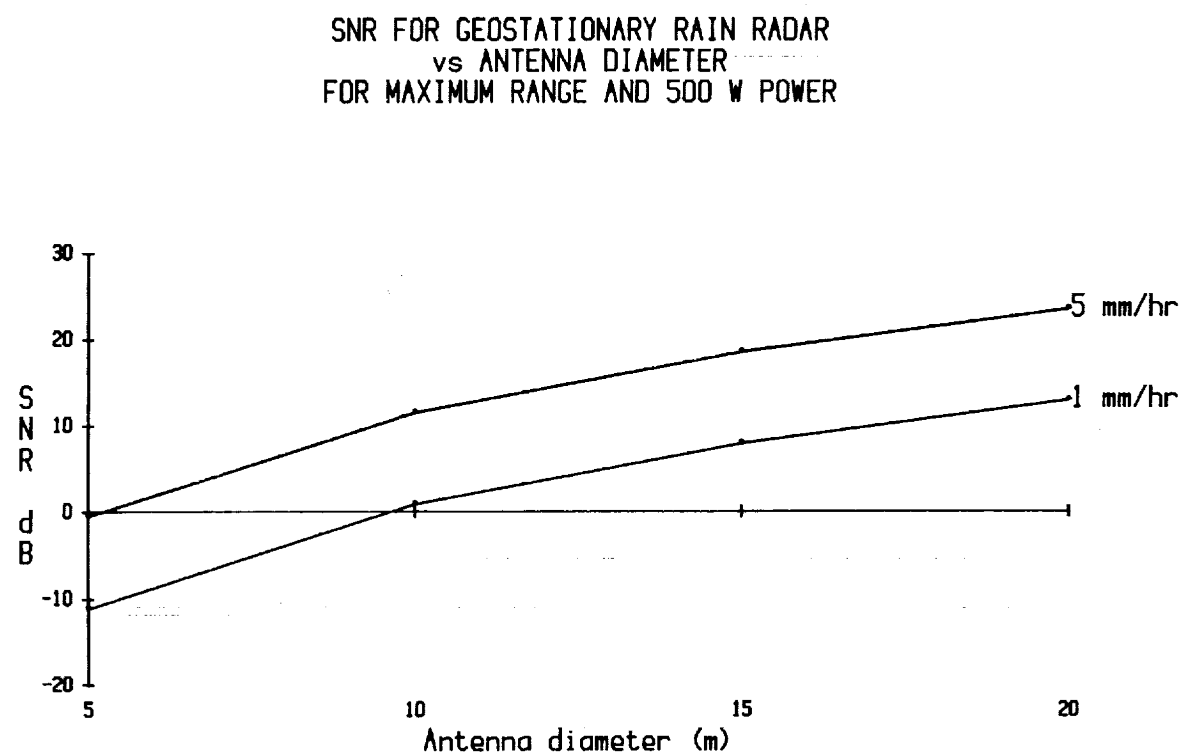

Figure 7

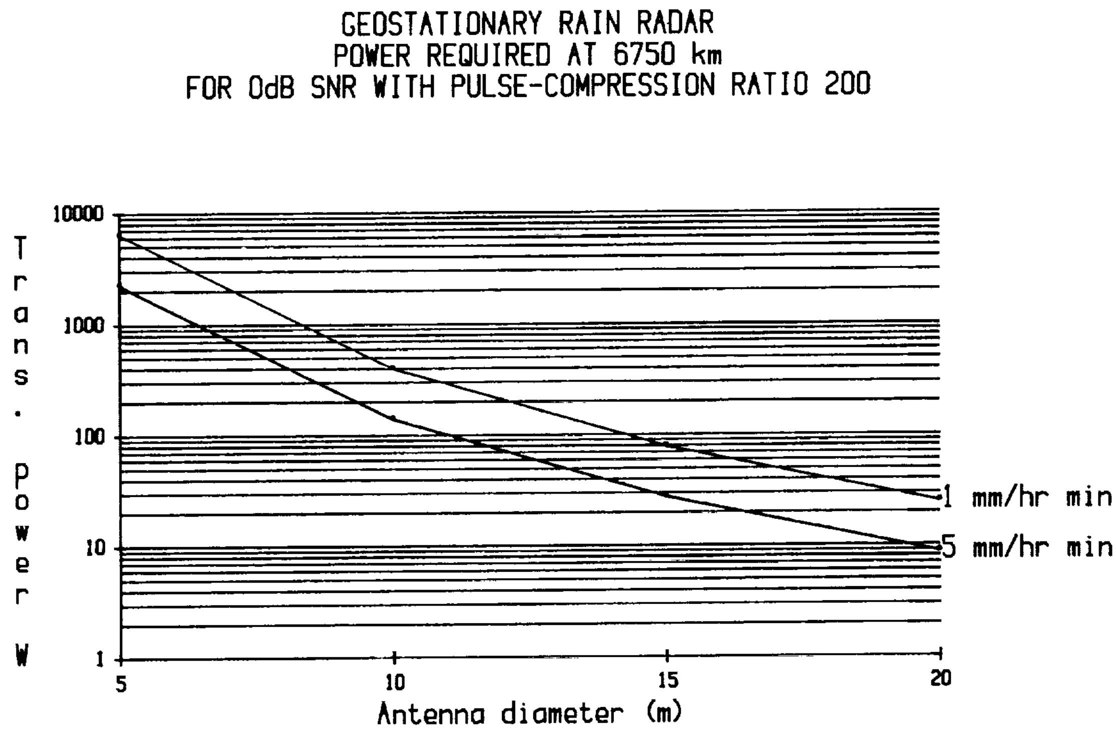
GEOSTATIONARY RAIN RADAR
POWER REQUIRED AT 6750 km
FOR 0dB SNR WITH PULSE-COMPRESSION RATIO 200
Trans. power W
10000
1000
100
10
1
5
10
15
20
Antenna diameter (m)
1 mm/hr min
5 mm/hr min

Figure 8

CONCLUSIONS

We have shown that a geostationary rain radar is feasible, though difficult. The biggest insoluble problem is the large footprint. However, the footprints for the 20-m and 15-m antennas considered should be useful for general-scale meteorology even if not for local scales. Scanning efficiency can be improved by using separately scanned beams for transmitting and receiving, so the long delay in receiving the echo does not slow down the scan. The situation can be further improved by using V-IR data to eliminate time wasted scanning clear areas.

This very preliminary study needs much refinement before we can be sure of the best design for a geostationary rain radar, as well as its cost and complexity. Nevertheless, this study is enough to show that the concept is a feasible one.