Second-Generation Spaceborne Precipitation Radar

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ABSTRACT

The Global Precipitation Mission is currently being planned as a follow-on to the Tropical Rainfall Measuring Mission. One of the key components of the GPM science instrumentation is an advanced, dual-frequency rain mapping radar. In this paper, we present a potential system concept for this second-generation spaceborne precipitation radar. This proposed design incorporates several advanced features, including 13.6/35-GHz dual frequency radar channels; a dual-frequency, wide-swath scanning, deployable antenna; digital chirp generation and the corresponding on-board pulse compression scheme; and adaptively antenna scanning.

INTRODUCTION

Atmospheric latent heating field is fundamental to all modes of atmospheric circulation and upper mixed layer circulations of the ocean. The key to understanding the atmospheric heating process is understanding how and where precipitation occurs. It is well-known that surface and near-surface rainfall are two of the key forcing functions on a number of geophysical parameters at the surface-air interface, including the water salinity, sea surface temperature, fresh water supply, and marine biology and eco-system, rainforest ecology and chemistry, land hydrology and surface runoff. Precipitation has also been closely linked to a number of atmospheric anomalies and natural hazards that occur at various time scales, including hurricanes, cyclones, tropical depressions, flash floods, droughts, and most noticeable of all, the El Ninos.

These and many other science applications require the knowledge of, on a global basis, the vertical rain structures, including vertical motion, rain intensity, differentiation of the hydrometeors' phase state, and the classification of mesoscale physical structure of the rain systems. The launch of the Tropical Rainfall Measuring Mission (TRMM) satellite [1] in late 1997 has made a great stride towards this ultimate goal. The Precipitation Radar (PR) aboard the satellite is the first-ever spaceborne radar dedicated to three-dimensional, global precipitation measurements over the tropics and the subtropics. The measurements collected by the PR, together with those collected by other science instruments abroad the satellite, have provided unprecedented insights into the rainfall process.

Because of the TRMM success, a follow-on mission, called the Global Precipitation Mission (GPM), is currently being planned to extend the TRMM's instrument capability in such a way to fully address the key science questions from microphysical to climatic time scale. The baseline GPM configuration consists of a constellation of 8 micro-satellites each carries a 3-frequency scanning radiometer, and a core satellite which carries a 5-frequency scanning radiometer, and a high-resolution, Doppler-enabled, wide-swath scanning, dual-frequency radar. In this paper, a potential system concept for this second-generation precipitation radar (PR-2) will be described.

SYSTEM CONCEPT

The current plan calls for the PR-2 to operate at an orbital altitude of 400 km. PR-2 will operate in two modes: Wide-Swath Mode and Nadir Doppler Mode. During Wide-Swath mode operations, the antenna will scan ±37° cross-track with the corresponding ground swaths of 600 km. The Nadir Doppler mode will acquire the "vertical" Doppler profiles of precipitation at nadir if precipitation is detected in such regions. The radar antenna is planned to be 5.3 m in size, and will be fully illuminated at 13.6 GHz and under-illuminated at 35 GHz in order to obtain the matched beams at 2-km horizontal resolution. The vertical resolution will be set at 250 m at all altitudes of operation, but the chirp bandwidth will be 5 MHz to allow an 8-fold increase in the number of independent samples.

Wide Swath Mode: In this mode, rain reflectivity profiles will be measured over a 600-km cross-track swath using the so-called 'adaptive scan' scheme. As shown in the GATE and other experimental results (e.g., [2]), the probability of rain occurrence over a specific location is < 20%. For this reason, and to effectively utilize the limited observation time, each PR-2 observation sequence will be divided into two periods: a Quick-Scan Period to determine the location and vertical extent of the rain cells within the entire swath, and a Dwell Period at which detailed precipitation measurements of the identified rain cells will be made. At an altitude of 400 km, a nominal observation sequence will last ~0.3 sec, the Quick-Scan Period will occupy the first 0.1 sec and the Dwell Period will use the remaining available time (0.2 sec). During the Quick-Scan Period the radar will make a complete cross-track scan through the entire swath, transmit and receive only 1 pulse at each 2-km ground resolution cell at a nominal pulse repetition frequency (PRF) of 2700. The radar backscatter measurements at each resolution cell will be averaged on-board over a vertical column of 2 km (~64 samples) and will be compared with a set of thresholds and ranked according to their respective backscatter strength. The ranked results will then be used to develop the subsequent antenna scan pattern for the Dwell Period. In the Dwell Period, the radar will measure the detailed rain backscatter profile over areas with significant rainfall. The nominal swath covered in the Dwell Period is ~200 km, which should be sufficient to cover most of the rain areas within the swath. In the event that there is pervasive rainfall covering areas >200 km across the track, our proposed dwell pattern would allow observations over cells with the most intense rainfall, thus covering a significant portion of the total rainfall in those areas.

Nadir Doppler Mode: When the Quick-Scan results indicate rain occurrence at or near nadir, the Nadir Doppler Mode will be exercised. In this mode, the radar antenna will be pointed at this small region for a total time of ~0.05 sec. A higher pulse repetition frequency (~5000) will be used to accommodate the anticipated Doppler spread. Multiple rain echoes obtained in each resolution cell will be used to estimate the Doppler shift caused by the mean rainfall motion. Conventional pulse-pair technique to estimate the mean Doppler will work well only in uniform rain. However, a new algorithm recently developed [3] has shown satisfactory vertical rain velocity even with the highly inhomogenuous rain cells. With the PR-2's operating parameters, the vertical rainfall velocity can be measured to an accuracy of between 1 and 1.5 m/s.

Detection Sensitivity: Figure 1 shows the signal-to-noise ratios (SNRs) of the rain echoes as a function of the rain rate for the PR-2 system. Notice the significant sensitivity improvement, as compared to the TRMM PR, in detecting both very light rain (< 0.1 mm/hr) and very intense rain (~90 mm/hr) systems. At rain rates below ~15 mm/hr, measurements from both frequencies can be combined to measure the entire rain rate profile. At rain rates between 15 and 35 mm/hr, the dual-frequency measurements can be used to retrieve at least the upper half of the rain clouds.

RADAR ANTENNA

The large swath coverage and fine horizontal resolution desired for detailed rain profiling lead to the use of a large, dual-frequency, scanning antenna. While the TRMM PR's slotted waveguide antenna design can be extended to a larger scan range and to two frequencies, it is heavy and can only be accommodated by large, and often more expensive, satellite buses and launch vehicles. The PR-2 antenna, therefore, is designed to achieve the goals of low mass and small stowage volume. Our proposed design is a 5.3m x 5.3m cylindrical/ parabolic inflatable antenna offset-fed by a linear array with T/R modules (see Figure 2). In order to achieve the required matched beams for the two frequencies, the 35-GHz feed will under-illuminate the reflector and will be less than half the length of the 13.6-GHz feed. Representative antenna patterns, together with the required sidelobe levels (green curves) are given in Figure 3.

The mechanical design of the PR-2 antenna comprises a reflective membrane surface. The parabola has a linear (projected) span of 5.3 m originating at the apex, and a focal location at 1.89 m from the apex. A set of two inflatable and rigidizable tubes will be used to deploy, pre-tension, and maintain the desired parabolic-cylindrical shape of the reflective membrane. These space-rigidizable tubes are cantilevered from the spacecraft interface and interconnected at their free ends by a rigid cross-member. At launch, each inflatable tube is rolled up around a rigid mandrel, and the thin-film reflective membrane in turn, around the rigid cross-member; thus forming a cylindrical bundle with a launch volume no greater than a square cross section of 1.3m x 1.3m and 5.5 m in length. This antenna design is expected to have a mass density of less than 2.0 kg/m^2. In order to meet the low sidelobe requirement, the antenna's RMS surface accuracy should be better than 0.17 mm. To maintain such accuracy, the inflatable tube must be rigidized, and the reflective membrane must be dimensionally stable in the expected space environment. Preliminary analyses have been performed which indicate that these goals are achievable.

SUMMARY

A design for the second-generation spaceborne precipitation radars was presented in this paper. In this design, several innovative features are being incorporated to enhance the rain measurement capability. These include: 13.6/35-GHz dual-frequency operations, a large, shared-aperture, deployable, scanning antenna, nadir Doppler measurements, and pulse compression. It is anticipated that such instrument concept can provide significant data for advancing our understanding on rain processes, latent heating, climate variability, and atmospheric anomalies.

ACKNOWLEDGMENTS

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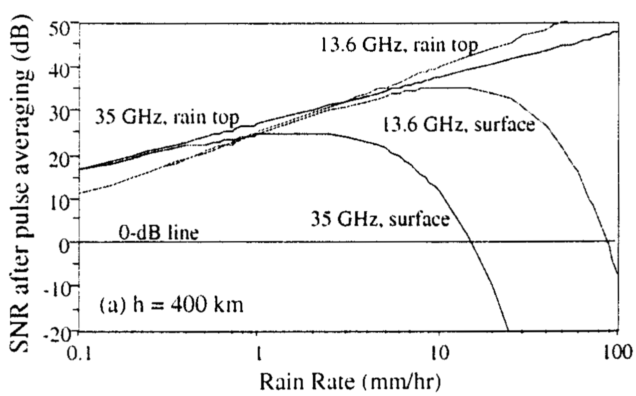

Figure 1. Expected signal-to-noise ratios for the PR-2 system at 400-km altitude.

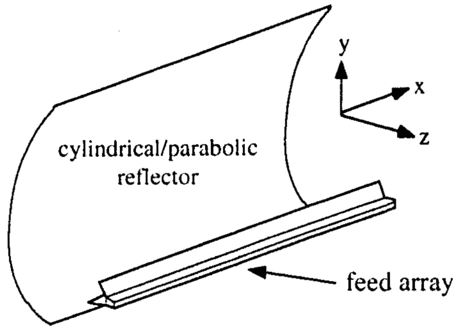

Figure 2. Configuration of a cylindrical/parabolic reflector illuminated by a linear array.

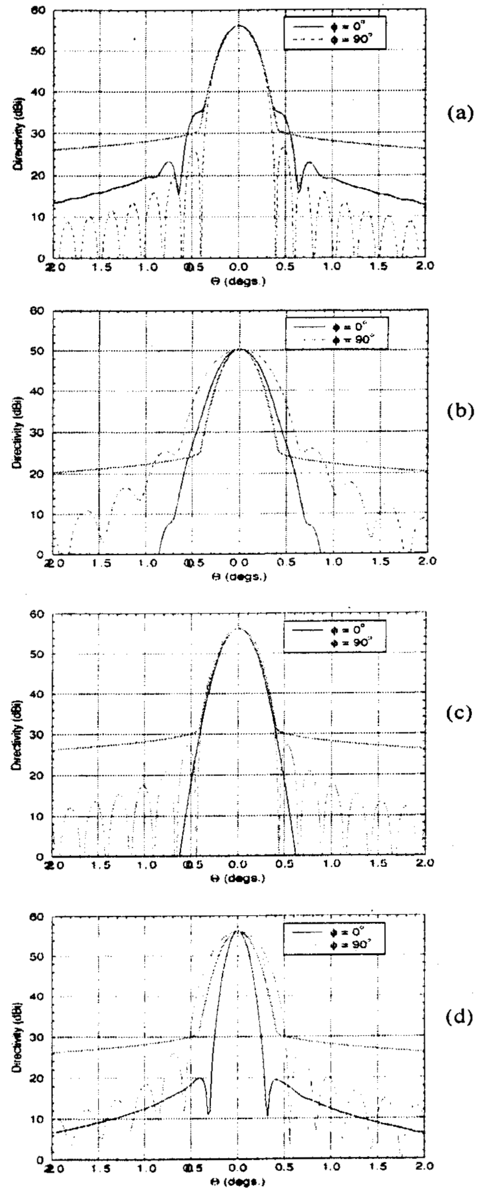

Figure 3. PR-2's far-field antenna patterns: (a) 13.6 GHz, beam at boresight. (b) 13.6 GHz, beam tilt to 37°. (c) 35 GHz, beam at boresight. (d) 35 GHz, beam tilt to 37°. The desired sidelobe envelope template is also shown in green curves.