SCIENTIFIC AND ENGINEERING OVERVIEW OF THE NASA DUAL-FREQUENCY DUAL-POLARIZED DOPPLER RADAR (D3R) SYSTEM FOR GPM GROUND VALIDATION

V. Chandrasekar[1]*, Mathew Schwaller*[2]*, Manuel Vega*[1, 2]*, James Carswell*[3]*, Kumar Vijay Mishra*[1]*,*
Robert Meneghini[2]*, Cuong Nguyen*[1]

[1]Colorado State University, [2]NASA Goddard Space Flight Center, [3]Remote Sensing Solutions

1. INTRODUCTION

The successful introduction of single-frequency (Ku-Band: 13.8 GHz) weather radar onboard the Tropical Rain Measuring Mission (TRMM) satellite in 1997 facilitated improved understanding of the spatial distribution, variability, intensity of rainfall and its role in climate. However, the mission's inherent limitations of spatiotemporal coverage and limited sensitivity to frozen precipitation hindered knowledge of the role of precipitation in climate and hydrological cycles. The Global Precipitation Measurement (GPM) mission will attempt to advance further the goal of making global scale precipitation observations by deploying the next generation of satellite-borne weather radars. The GPM satellite will carry a Ka-Ku band Dual-frequency Precipitation Radar (DPR) that can make measurements of parameters directly related to the microphysics of precipitation (such as raindrop size distribution). While the Ku-band radar is an updated version of the TRMM precipitation radar, the Ka-band radar would provide higher sensitivity which can prove useful in the measurement of snow and light rain. The Dual-Frequency Dual-Polarized Doppler Radar (D3R) is a ground validation radar, proposed as a part of the GPM Ground Validation (GV) program, to enable both physical validation support in terms of understanding the microphysical description of the observations as well as algorithm retrieval implications. This paper provides a scientific and technical overview of the D3R system as well as major challenges.

2. SCIENTIFIC OVERVIEW OF D3R

The preferred frequency bands of operation for precipitation surveillance in ground radar systems have been nearly non-attenuating frequencies (such as S-, C-band) or short-range measurements of attenuating frequencies (as in X band). Moving to higher frequencies to observe precipitation offers two challenges namely, attenuation due to precipitation and reduced Doppler velocity Nyquist limits. However, it is not practical to use traditional ground radar frequencies for precipitation observation (such as S- or C-band) for space-borne observations of precipitation. Following the success of TRMM, the GPM mission has embarked on a dual-frequency approach at Ku- and Ka-band for characterizing precipitation. While extensive ground radar observations of precipitation are available at S- and C- band, such measurements do not exist at Ku- and Ka-band. Ground radar measurements enjoy the advantage of coincident microphysical observations available to interpret radar signatures. An important broader science goal of the NASA D3R is to enhance the database of dual-frequency radar observations on the ground, in conjunction with existing observations, in order to provide a dataset for physical validation basis.

Another major advantage of the ground radar observations is the ability to use dual-polarization techniques to yield enhanced microphysical characterization similar to what has been done at lower frequencies. In addition, self-consistency of dual-polarization and dual-frequency observations presents an enhanced level of interpretation, while also providing independent rainfall estimates on the ground. With the ground-based D3R, an independent estimation of hydrometeor classification and drop size distribution retrievals can be done to understand the error structure of retrievals. Thus, the radar also offers an insight into the physics of the retrieval processes and the associated measurement errors. While the GPM DPR radar presents a global picture of precipitation through observations at Ku- and Ka-band, the ground-based D3R yields detailed fine-scale local statistics of the microphysical interpretation. This can provide anchor points for the global retrieval algorithms used in GPM DPR.

3. ENGINEERING OVERVIEW

The dual-frequency ground-based radar provides for various options, including polarimetry and Doppler capabilities. Polarimetry is critical for understanding the microphysics and Doppler measurements can be useful for linking the dynamics with the microphysics of precipitation structure, which is missing in the space-borne measurements available today. Thus, as a value-added validation instrument, it is very useful to have both dual-polarization and Doppler measurement. Hence, the name D3R or Dual-frequency Dual-polarized Doppler Radar. D3R is being developed as a fully polarimetric, scanning weather radar system operating at the nominal frequencies of 13.9 GHz and 35.5 GHz covering a maximum range of 30 km. The frequencies chosen allow close compatibility with the GPM DPR system. The sensitivity of the system at both frequencies is pegged at -10 dBZ at 15 km to enable snow measurements, which can document the “missing tail” in the current snow observations from GPM DPR.

Another important engineering aspect of a dual-frequency system is the level of “integration”. This can range from a design where two separate radar units operate independently to the one that employs a common reference system for dual transmitters on a single dual-frequency aperture. The first generation version of the D3R falls somewhere in the middle, i.e., a common platform transmitter illuminating two distinct but aligned antennas. There are future plans to migrate to a single aperture system.

Most of the engineering challenges stem from making precipitation measurements on the ground at a highly attenuating frequency. In order to support the development, extensive numerical evaluations have been carried out to document the extinction statistics of propagation through precipitation. These results will be presented in this paper. Furthermore, this radar is meant for deployment at different climactic locations. One of the novel aspects of this system is that it employs a solid-state transceiver which supports the above-mentioned deployment scenarios. Thirdly, the dual-frequency dual-polarization operation at higher frequencies involves non-Rayleigh scattering mechanisms and presents different precipitation signatures compared to the conventional S- or C- band observations. The expected observations for this radar based on such scattering and precipitation models are also presented in this paper.

Table 1 lists the technical specifications for the D3R system, along with the different data products. A separate paper in this conference discusses the technical details of the realization of the solid-state transmitter/receiver system. In summary, this paper will provide the scientific and engineering overview of the radar system, placing it in the broader context of precipitation observations from ground, as well as in the particular science context of the NASA GPM project. The discussion on radar is also placed in a microphysical context targeted towards the microphysical measurements of precipitation.

4. REFERENCES

[1] T. Iguchi, H. Hanado, N. Takahashi, S. Kobayashi, S. Satoh, "The Dual Frequency Precipitation Radar For The GPM Core Satellite," *IGARSS 2003*, Toulouse, France.

System	
Ku-Band center-frequency	13.91GHz ± 25MHz
Ka-Band center frequency	35.56GHz ± 25MHz
Minimum detectable signal (Ku, Ka)	-10dBZ at 15 km in clear air for a single pulse at 150 m range resolution
Minimum operational range	450 m
Minimum range resolution	30 m
Selectable range resolution	0.2 µs-1.8 µs in 0.2 µs steps
Maximum range	30 km
Angular coverage	0-360° Az, -0.5-90° El
Angular resolution	≤ 0.1° Az, ≤ 0.1° El
Angular uncertainty	≤ 0.2° Az, ≤ 0.2° El
Antenna	
Size (diameter)	6 ft (72 in.) (Ku), 28 in. (Ka)
Gain	44.5 dB
HPBW (Ku, Ka)	≤1°
Maximum return loss	18dB (VSWR <1.3)
Polarization (Ku, Ka)	Dual linear orthogonal (H and V)
Matched H and V Antenna Patterns (Ku, Ka)	Within 5% integrated over main lobe
Maximum sidelobe level (Ku, Ka)	-25 dB
Cross-polarization isolation	32 dB
Ka-Ku beam alignment	Within 1/10th of 3dB BW
Scan rates	0-24°/s Az, 0.5-12°/s El
Transceiver	
P_t	180 W (Ku), 45 W (Ka)
Noise figure	4.6 (Ku), 5.5 (Ka)
Receiver dynamic range (Ku, Ka)	≥90 dB
Transceiver channel isolation	≥45 dB
Transceiver operating bandwidth	50 MHz
Phase noise (Ku, Ka)	0.5°
Data Products	
Standard products	- Equivalent reflectivity factor (Z_h, Z_v) (Ku, Ka) - Doppler radial velocity (unambiguous: 25 m/s) - Uncertainty in radial velocity: ± 1 m/s
Dual-pol products	- Differential reflectivity (Z_{dr}) accuracy (Ku, Ka) - Differential propagation phase (φ_{dp}) (Ku, Ka) - Copolar correlation coefficient (ρ_{hv}) (Ku, Ka) - Linear depolarization ratio (LDR_h, LDR_v) (Ku, Ka)
Derived products	- Specific differential phase (K_{dp}) (Ku, Ka) - Liquid water content profiles - Hydrometeor classification - Median drop diameter (D_0) - Instantaneous rain rate - Number concentration per unit volume

Table 1. Technical Specifications of D3R. Unless otherwise noted, the specification is the same for both Ku and Ka band.