P3.5 **NOAA/ETL's POLARIZATION-UPGRADED X-BAND "HYDRO" RADAR**

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1. INTRODUCTION

NOAA/ETL has long operated a pair of transportable X-band Doppler radars for observing storm kinematics, boundary layer airflow, ocean surface features, and tracking air parcels with chaff. One of these radars was outfitted in 1985 for circular dual-polarization measurements. More recently, that radar has been retired while the other, named NOAA/D (Fig. 1), has become the focus of extensive hardware and data system upgrades. This newly upgraded radar serves double duty as an atmospheric and an ocean surface observation system. Of special interest are new polarization capabilities that make it suitable for high-resolution quantitative measurements of rainfall and snowfall, hence the "hydro" radar nickname.

Traditionally, X-band has been a poor choice for quantitative estimates of rainfall by radar because rain attenuates signals strongly at these frequencies. However, recent theoretical and experimental work at NOAA/ETL has demonstrated that X-band measurements using specific differential phase (K_{DP}) offer a way around this limitation by relying on the radar's phase measurements in place of, or in addition to, the attenuation-prone reflectivity-based measurements. In fact, differential phase estimates of light rainfall are more promising at X-band than at longer wavelengths, which are better suited for use in heavy rain. The NOAA/ETL radar is one of the first X-band systems to be equipped with K_{DP} capability, and its usefulness has now been illustrated in a number of recent rain projects (see Section 5).

2. BASIC CAPABILITIES

Basic characteristics of the radar are listed in Table 1. It is a Doppler, polarization diversity system with excellent scanning capabilities using a 3.1-m antenna on a missile tracking mount. It is transported to locations in North America on its 16-m flatbed trailer or can be disassembled and transported overseas in three standard 6.1-m sea containers. The radar is normally powered by three-phase line power, but a 60-kW diesel generator is also available for operations in locations where commercial power

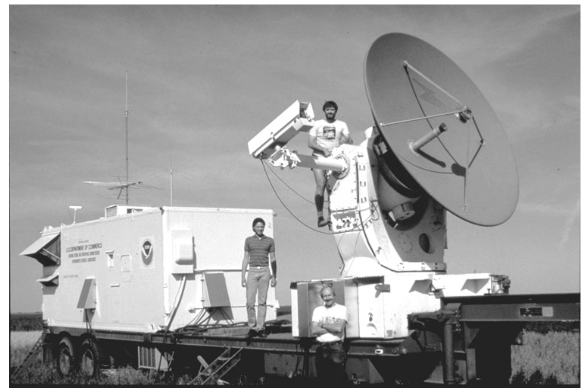

Figure 1. The NOAA/ETL X-band radar.

Table 1. NOAA/D Radar Characteristics

Major Capabilities: transportable,
scanning,
Doppler,
polarization diversity.
Primary Uses: measurements of precipitation,
boundary layer airflow, and
ocean surface features.
Frequency: 9.34 GHz (λ = 3.2 cm)
Peak Transmit Power: 30 kW
Antenna: 3.1 m diameter, 44 dB gain
Beam width: 0.9 deg., circular
Pulse Length: selectable from 0.05 to 1.0 μs
(resolution = 7.5 to 150 m)
PRF: selectable (2000 typical),
double pulse method to extend Nyquist
Scans: PPI, RHI, sector, fixed beam, all with
elevations through zenith and below horizon;
scan rates up to 30 deg/s
Sensitivity: approx. 0 dBZ at 25 km range
Polarizations: pulse-to-pulse HV switching, or
simultaneous equal HV; or circular.
Doppler processing: pulse pairs or time series
Data System: VME-based with DSP & SPARC
Platform: 16-m flatbed trailer, or 3 seatainers

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is unavailable or unreliable. Overall system calibration is checked using a trihedral corner reflector mounted atop a 25-m wooden pole at the radar's home base in Colorado.

Most aspects of the radar have been designed and built at NOAA/ETL, with continual upgrades and refinements over the years, including the installation of a completely new processor described in the next section. The recent polarization and processor upgrades endow the radar with greater flexibility to obtain measurements that were previously unavailable, such as rainfall intensity estimates using K_{DP}, ocean surface current observations using delta-K methods, and greatly expanded Doppler spectra recording capability.

Although pre-programmed scan sequences allow some unattended operation, the radar is normally attended in the field by an engineer and a scientist. However, an ongoing engineering effort is making the system operations more automated and robust, with the eventual goal of fully unattended and remotely controlled operations. Remote near-realtime display of data on the worldwide web has already been demonstrated with the NOAA/ETL radars.

3. DATA SYSTEM

A programmable realtime data processing and display system, known as the Radar Acquisition and Display System (RADS) controls the radar's scan and signal characteristics and processes, displays and records the data (Campbell and Gibson 1997). It consists of a VME bus with an UltraSPARC-10 processor and DSP, A/D, timing generator, and synchro/digital cards. The programmable DSP allows the flexibility to incorporate new and revised algorithms for the data processing. Pulse pairs, time series, Doppler spectrum, delta-K, and differential phase modes have been programmed and demonstrated with this system. The RADS realtime color display includes PPI, RHI, time-height, VAD profile, and amplitude-range ("A-scope") displays of the various fields. Data are currently recorded on a pair of 8-mm tape drives; one tape typically covers 12 h or longer, depending on the operating mode.

4. POLARIZATION UPGRADES

Dual-polarization capability is available in the hydro radar in different configurations, including: HV transmit switching, simultaneous HV transmission, and circular. The desired configuration must be chosen well in advance of a field deployment to allow time for hardware restructuring. The switching mode uses a fast ferrite switch to alternate between the transmission of horizontally and vertically polarized pairs of pulses. The simultaneous HV mode transmits pairs of pulses with equal power simultaneously in horizontal and vertical polarizations resulting in linearly polarized waves with a 45-degree tilt. This is the same scheme recommended for future polarization upgrades to NEXRAD (Doviak et al. 2000). Polarization measurables from this mode include differential reflectivity (Z_{DR}), propagation differential phase shift (ϕ_{DP}) and its range derivative, specific differential phase (K_{DP}), and polarization correlation magnitude at zero lag (ρ_{HV}). These fields and linear depolarization ratio (LDR) are available in the switching mode. These polarimetric parameters are used to estimate precipitation rates and/or hydrometeor types.

5. DEMONSTRATIONS IN RAINFALL

Traditional estimates of rainfall, R, from radar reflectivity factor, Z, suffer from numerous well-documented problems that often severely limit resulting accuracies. Many of these Z-R method problems are avoided or minimized in the newer K_{DP} method based on measurements of the propagation differential phase shift using suitably equipped polarimetric radar (Zrnic and Ryzhkov 1996).

Most K_{DP} rainfall estimation research has been conducted at S-band (~10-cm-wavelength), but a study by Matrosov et al. (1999a) concludes that the method can also be usefully applied at X-band to rain rates below about 15 mm/h. The magnitude of the differential phase effect for a given rain rate is inversely proportional to wavelength, a factor which favors X-band.

The K_{DP} capability was installed on the NOAA/ETL X-band radar in 1997 and subsequently tested in Texas, Colorado, and Virginia. Both the HV switching and simultaneous equal-HV transmit modes of operation (Section 4) have been used. In these experiments K_{DP} estimates of rain intensity and accumulation were tested against high-resolution rain gage measurements and compared with Z-R algorithms. Agreement with the gage data was consistently better using K_{DP} than the attenuationdegraded Z-R equations. Even better accuracy was obtained with an extension of the technique that uses a combination of the K_{DP}, Z, and Z_{DR} values measured by the radar (Matrosov et al. 2001). In this refinement, the Z and Z_{DR} estimates are corrected for attenuation effects using the observed differential phase values. Figure 2 from that study shows that this combined parameter method gave good rain estimates for rates up to about 50 mm/h, well beyond the rainfall range expected for X-band estimates based on K_{DP} alone.

Accurate estimates of raindrop size (*e.g.* median volume diameter) are also obtained using the radar's Z_{DR} measurements when a correction for differential attenuation is applied using the ϕ_{DP} data (Matrosov et al. 1999b). Figure 3 shows an example of good agreement of these Z_{DR}-based size estimates with raindrop disdrometer observations at the surface.

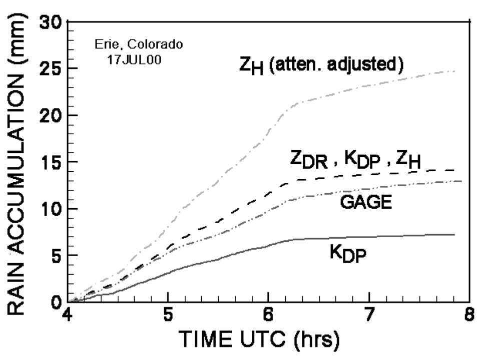

Figure 2. Rain accumulation in Colorado from gage measurements and radar estimators.

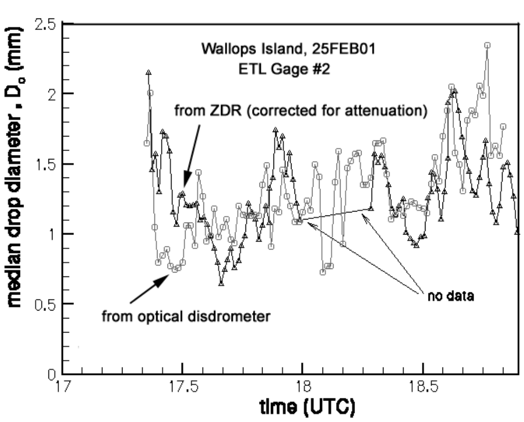

Figure 3. Median volume raindrop diameter in a Virginia storm from disdrometer and radar Z_{DR}.

6. HYDROLOGICAL APPLICATIONS

These findings open new avenues for the NOAA/ETL X-band radar to participate in hydro-meteorology studies by making accurate quantitative observations of light to moderate rain. These rain rates, characteristic of stratiform precipitation regions, are believed to cover a sizeable and important fraction of the global total rainfall. The smaller size, better portability, finer-scale spatial resolution, and lower cost of X-band radars compared to large operational and research S-band radars, are attractive features for some applications, other than wide-area thunderstorm surveillance. In research projects, they can provide complementary fine-scale observations within the wider, coarser coverage of the operational NEXRAD network or can fill holes in NEXRAD coverage. The upgraded NOAA/ETL X-band radar is now well suited to make detailed observations of rain and snow across small to mid-size watersheds, including mountain and urban basins.

Acknowledgments

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