NOAA/ETL'S VERTICAL-PROFILING CLOUD RADAR AND RADIOMETER PACKAGE

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1. INTRODUCTION

Clouds play vitally important roles in climate and water resources by virtue of their ability to transform radiant energy and water phase in the atmosphere. Research on climate change in the 1990s was a major motivation for accelerated development of remote sensing technologies to observe cloud properties from land, sea, air and space. NOAA/ETL has been a major contributor to these advances in the areas of millimeter-wave "cloud" radar and the use of microwave and infrared radiometers for ground-based cloud observations.

NOAA/ETL began designing and operating dual-frequency microwave radiometers and K_a-band cloud radars around 1980. More recently, it also designed the unattended cloud-profiling K_a-band radars, known as the Millimeter-wave Cloud Radar (MMCR), for the U.S. Department of Energy's Cloud and Radiation Test-bed sites (Stokes and Schwartz 1994). These radars are intended to operate for at least a decade at remote locations. A nearly identical radar is also operated by NOAA/ETL for field experiments of shorter duration on land and ships. This radar is joined in the same sea container by a dual-channel microwave radiometer (MWR) and a narrow-band infrared radiometer (IRR).

Figure 1. Photo of the MMCR Package showing the radar antenna (roof) and MWR reflector (right side).

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2. BASIC CAPABILITIES

Simultaneous data from these instruments provide the input for retrieving microphysical features of the overlying tropospheric clouds. These include estimates of the profiles of cloud particle median size, total concentration, and mass content for ice clouds and liquid water clouds. Combining the instruments in a single container (Fig. 1) provides a powerful, self-contained cloud research system. Basic characteristics of this package are listed in Table 1.

Table 1. Instrument Package Characteristics

----- Combined System -----

Major Capabilities: Multi-wavelength remote sensing, unattended operations, transportable.
Primary Uses: Monitoring cloud layer heights and thicknesses, water vapor and liquid water path, cloud base temperature, and retrievals of profiles of hydrometeor median size, total concentration, and mass content.
Platform: 6.1-m sea container.

----- Cloud Radar (MMCR) -----

Major Capabilities: Ultra-high sensitivity, Doppler.
Primary Uses: vertical profiles of clouds, drizzle, snowfall and very light rain.
Frequency: 34.86 GHz (λ= 8.6 mm)
Transmit Power: 100 W peak, with up to 25 W avg.
Transmitter: Traveling Wave Tube (>20,000 h life)
Antenna: 1.8-m diameter; tilted flat radome.
Beam Width: 0.3 deg., circular.
Height Coverage/ Resolutions: ~20 km / 45 & 90 m; (255 and 495-m resolutions also available).
Polarization: transmit and receive H.
Sensitivity: approx. -40 dBZ at height of 10 km.
Doppler Processing: FFT.
Data System: wind profiler POP with 2 computers.

----- Microwave Radiometer (MWR) -----

Primary Uses: Monitoring vertical water vapor path and liquid water path.
Frequencies: 20.6, 31.65, and 90.0 (optional) GHz.
Beam Width: 5 deg.

----- IR Radiometer (IRR) -----

Primary Uses: Sensing presence of cloud overhead, estimating base temp. of optically thick clouds.
Wavelength: 9.9-11.4 µm or 10.6-11.3 µm.
Field of View: 2 deg.

Collectively, the instruments are called the "MMCR Package". Each observes the zenith and does not scan. Hence, the system is a vertical profiler.

The MMCR, described by Moran et al. (1998), is the heart of the system. Many of the radar operating characteristics are computer-selectable. Although it transmits only 100 W of peak power, the radar can detect extremely weak tropospheric clouds overhead, including multiple layer and optically thick cloud situations that optical sensors usually cannot penetrate. It achieves its excellent sensitivity (-40 dBZ at 10 km) through the use of a high duty cycle, large antenna (for this wavelength), long sample times (~1 s), and pulse compression techniques. The radar normally cycles through four operating modes that have different sensitivities, height resolutions and coverages, and susceptibilities to various artifacts, such as range side lobe clutter, 2nd-trip echoes, and folded velocities. Data from the four modes are merged in post-processing using algorithms developed at Penn State University (Clothiaux et al. 2000). The resolutions of the merged data are 45 m and 10 s. Full Doppler spectra can be recorded at each gate, but generally only the Doppler moments (reflectivity, mean velocity, and spectral width) computed from the spectra are recorded to reduce data rates. The radar data are recorded in netCDF format on optical disks.

Insects are also readily detected by the radar in the lower altitudes at continental locations in spring, summer and fall. These echoes are very difficult to discern from those of stratus clouds. Various methods to discriminate droplets from insects are being investigated, including adding dual-polarization capability to the radar (Martner and Moran 2001). However, the insect echoes are useful for observing turbulence conditions in the clear boundary layer.

The dual-frequency MWR design is described by Guiraud et al. (1979). Real-time conversion of the measured down-welling brightness temperatures to water vapor path (precipitable water vapor) and liquid water path is made using algorithms that incorporate site-specific climatological radiosonde data. The radiometer's view periodically switches between the sky and a reference calibration source. An external reflector plate spins continuously to centrifuge rainwater, condensation and slush away. Either of two commercial IRRs (Barnes or Heitronics) is available with the Package. The measured IRR brightness temperature approximates the physical temperature of cloud base for optically dense clouds. Temporal resolutions of 30-60 s are typical for data from the radiometers, as used in the MMCR package.

3. CLOUD PROFILING AND RETRIEVALS

Figure 2 shows a 24-h segment of data collected with the MMCR Package near Boston. Cloud heights, thicknesses, internal structure and vertical motions measured by the radar, and the evolving nature of the radiometer data are revealed with excellent detail. These graphical products from the Package have been posted on the worldwide web in near realtime from project field sites.

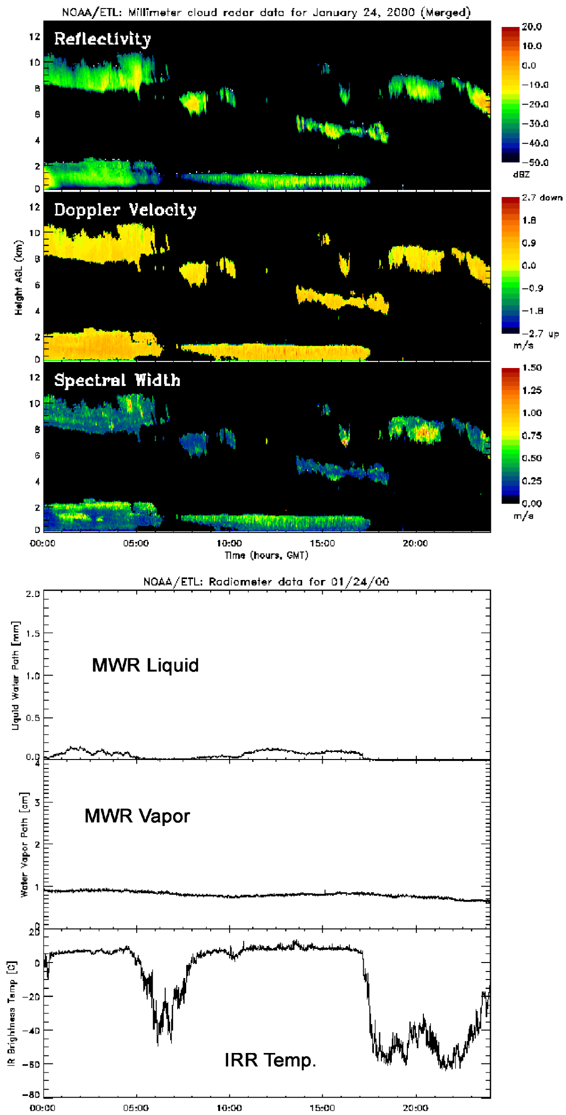

Figure 2. An example of MMCR-Package data for a 24-h period with high, middle, and low clouds. The upper three panels are time-height displays of Doppler moments from the radar; the lower three panels are time series plots from the radiometers.

In addition to observing cloud macro-features, the radar and radiometer data are combined in post-processing to retrieve microphysical parameters of the clouds. In the case of liquid clouds, such as stratus, the MWR data are used, following the technique developed by Frisch et. al. (1995). The IRR data are used for optically thin cirrus clouds, following variations of the technique originally developed by Matrosov et al. (1992). Vertical profiles of estimated mean particle size, total concentration and mass content mixing ratio are computed. The accuracy and applicability of these radar/radiometer retrievals is a subject of ongoing research, but early comparisons for single-phase clouds with in-situ samples from research aircraft have shown very good agreement (Matrosov et al. 1998, Frisch et al. 2000).

4. APPLICATIONS

Numerous applications of cloud radar, with and without radiometers, are described by Kropfli and Kelly (1996). Perhaps, foremost among these are continuous ground-based cloud measurements that contribute to knowledge of how clouds impact climate through their effects on radiative transfer. Another major application involves using continuous data from ground-based instruments, such as the MMCR Package, for calibrating and validating cloud retrievals from satellites. The satellites' radiometer-based retrievals provide estimates and inventories of global cloud conditions, while the ground-based data provide independent anchor points for checking and improving the space-borne observations. Applications in the areas of aviation safety, radio communications, and cloud seeding experiments are also progressing.

During its first four years of existence, the MMCR Package has been operated in Colorado and Massachusetts and on research ships in the Arctic, Pacific, and Indian Oceans. (The Arctic work utilized external radiometers). Specific research topics of these projects have included assessing of the nature of Arctic clouds and their role in climate, calibration and validation of satellite-based cloud retrievals, investigating the impact of clouds on high-frequency radio communications links, and basic studies of cloud and precipitation processes.

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