Spaceborne Doppler Atmospheric Radar: an overview for measuring atmospheric dynamics

Simone Tanelli
Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, USA
E-mail: simone.tanelli@jpl.nasa.gov ; Tel: +1-818-354-0195; Fax: +1-818-393-6440

Knowledge of the global distribution of the vertical velocity of precipitation and cloud constituents is important in estimating latent heat fluxes, and therefore in the study of energy transport in the atmosphere, the climate and weather. Such knowledge can only be directly acquired with the use of spaceborne Doppler Atmospheric Radars (DARs). A Doppler Atmospheric Radar (DAR) is a spaceborne coherent radar designed to detect hydrometeors and their motion. Two main subcategories of atmospheric radars can be roughly demarcated by their operating frequency, the Precipitation Radars (PR, at 35 GHz or lower) and Cloud Profiling Radars (CPR, at 35 GHz or higher).

The use of coherent systems is well established in the ground and airborne weather radar community and the advantages brought by the Doppler capability (i.e., direct measurement of the speed of the hydrometeors relative to the radar) are widely recognized. Although, the use of Doppler systems from space to measure atmospheric targets is hindered by the high orbiting velocity of the radar (which introduces issues and effects otherwise negligible for slower platforms), the average vertical velocity can be measured to acceptable accuracy levels. Such results can be obtained only by appropriate selection of radar parameters and data processing algorithms, and by recognizing some general trade-off considerations in the radar system design.

1. Radar Advantages & TRMM’s Heritage

- Function of all precipitating and non-precipitating clouds, relative to standard GOES cloud imagery
- Characterization precipitating system structure and evolution in the local climate
- Estimation of vertical and horizontal velocity of cloud parameters and dynamics which control and modulate the formation and evolution of atmospheric events
- - Rain intensity
- - Vertical motion
- - Cloud phase
- - Latent heat release
- - Provide such data for NWP improved forecast and understanding of current and extreme events

Jacobian Determinant $J_{Z14/V-R/D}$
Jacobian Determinant $J_{Z35/Z-35/R/D}$

Latent Heating for Hurricane Bonnie from Vertical Derivative of Rain Mass Flux

2. Why Doppler?

| Type | Potential of Doppler | Measurement Improvement for retrieving cloud and storm parameters | Contribution of Tanelli and/or TRMM knowledge |
|---------------------------------|---------------------------------------------------------------|--------------------------------------------------|
| Measurements of Vertical Air Motion and Characterization of Convection | - Direct measurement of the speed of the hydrometeors relative to the radar | Enhanced precipitation parameters and dynamics over a global scale | - Improvement in characterization of convection | - Vertical profiling and temporal resolution | - Improved assimilation for characterizing convection | - Contribution to Weather and Climate knowledge |
| Hydrometeor Classification | - Single-polarization sensor | Non-Doppler multi-frequency sensors | - Improved hydrometeor classification | - Lidar in clear air | - Vertical Air Motion | - Improvement in Latent Heating global maps |
| Estimation of Precipitation and DSD parameters | - Improved characterization of precipitation and DSD | - Improved precipitation and DSD measurement over the tropics (TRMM) | - Improvement in rainfall rate estimates | - Improvement in radiation budget studies | - Improvement in rainfall rate estimates | - Improvement in rainfall rate estimates |
| Convective-Mean Doppler Classification | - Improved characterization of precipitation and DSD | - Improved precipitation and DSD measurement over the tropics (TRMM) | - Improvement in rainfall rate estimates | - Improvement in radiation budget studies | - Improvement in rainfall rate estimates | - Improvement in rainfall rate estimates |
| Latent Heat | - Improved characterization of precipitation and DSD | - Improved precipitation and DSD measurement over the tropics (TRMM) | - Improvement in rainfall rate estimates | - Improvement in radiation budget studies | - Improvement in rainfall rate estimates | - Improvement in rainfall rate estimates |

3. Airborne and Spaceborne Doppler Radars

JPL Airborne Precipitation Radars

- The 3-D high resolution data obtained by the two JPL airborne radars are the primary dataset used in this investigation.

ARMAR: Ka-band, dual-polar, Doppler, scanning radar
APE-2: Sea trata below and displays to the right

Dual-Frequency Doppler Spaceborne Radar for Hurricane Monitoring (Dr. Eastwood In)

- 14 GHz (Ku-band) and 35 GHz (Ka-band) dual-frequency radar
- Deployable antenna reflector with standard horns (can ± 45° x ± 3° panels)
- Horizontal resolution: 2.5 km @ 380 km
- W-band coverage using adaptive scanning ± 43 km (45° x 100 km)
- High-resolution scanning
- On-board, real-time pulse compression: 150° resolution
- Compass peak power (440 W, 14 GHz; 260 W, 35 GHz)
- Enhanced minimum detectable Z: 4 dB (4 GHz); 2.8 dB (35 GHz)
- 16 GHz vertical Doppler mean, ± 1 m/s precision
- On-board processing: Doppler, averaging

Nexrad-In-Space (Dr. Eastwood In)

- Monitoring time evolution of rain and cloud from GEO (alt. ~ 36,000 km)
- 350-km, 4° spatial scanning radar to cover 550-km diameter earth disk (equivalent to coverage of 48° latitude and 40° longitude)
- Deployable spherical aperture antenna to obtain 12 to 14 km horizontal resolution
- Variable or automated antenna scan strategy
- 1 transmit feed and 1 receive feed with fixed spacing to compensate for pulse delay
- Scan by motion of 2 feeds in spiral path
- Advantage over 2-D electronic scan, which requires millions of phase shifts
- Advantage over mechanical rotation of entire antenna, which creates unacceptable scope
- Advantage over X-band station, which requires expensive antenna, usually very expensive S/C
- Vertical resolution of 900 m using pulse compression
- Radar detection sensitivity: ~ 1 dB (after 100 sample averaging)
- ~ 12 dB more sensitive than the TRMM radar
- More robust in all-weather conditions
- One 2-D full-scan image per hour
- Real-time processing to reduce downlink data volume

ACKNOWLEDGEMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
4. DAR performance in Doppler measurements

The observed Doppler velocity spectrum of rain is
- Mean Doppler velocity
- Spatial variability on the 1-5 m range
- Mean rainfall intensity on the 0.25 and
- Mean rain intensity signal measurement functions
- Signal power fluctuation on the horizontal direction.

The mean Doppler velocity is the integral of the

When the Doppler broadening is induced by the

The standard deviation of the

5. 3D Doppler Radar Simulator

ARMAR and APR-2
3D HiRes fields of
reflectivity and Doppler vel.
from TOGA/CORE
KWAEJEX CAMEX-3
CAMEX-4 and WAKASA
BAY campaigns.

HiRes Cartesian grid:
\( \Delta x = 200 \text{m (along-track)} \)
\( \Delta y = 60 \text{m (cross-track)} \)
\( \Delta z = 250 \text{m (vertical)} \)

6. Correction of NUBF effects

ARMAR and APR-2
3D HiRes fields of
reflectivity and Doppler vel.
from TOGA/CORE
KWAEJEX CAMEX-3
CAMEX-4 and WAKASA
BAY campaigns.

HiRes Cartesian grid:
\( \Delta x = 200 \text{m (along-track)} \)
\( \Delta y = 60 \text{m (cross-track)} \)
\( \Delta z = 250 \text{m (vertical)} \)
10. Classification of Precipitation (APR-2 Algorithm, S. Tanelli)

Melting Layer Detection - 3D Algorithm Results

Wakasa Bay – Stratiform rain over ocean (V. Light to Heavy)

January 29th 2003 – Flight #9 – Line 1

From 36°30'N 135°30'E (at 03:32 UTC) to 32°30'N 135°30'E (at 03:52 UTC)

11. Analysis of impact of Multiple Scattering

(Dr. Satoru Kobayashi)

Time-resolved analytical model includes effects of multiple scattering as modeled by radiative transfer theory, and of backscattering enhancement as well as multiple scattering.

Normalized footprint radius = 0.1

Layer thickness / mean free path (Optical Thickness)

LATENT HEATING

Frequency : 94 GHz

Diameter : 1 mm

Analytical wave theory (AT) and radiative transfer theory (RT)

Condensation

Frequency : 94 GHz

Diameter : 1 mm

Number density : 5x10^3 cm^-3

Layer Thickness : 100 m

Increment in reflectivity (dB)

Scattering angle

k_i

θ_s

k_s

T

EB

EA

TR

EB

θ

s

θ

s

k

s

Optical thickness

Second order reflectivity (dB)

CFT Estimated vp (color) [m/s]

Estimated through Doppler measurements

True vp (color) [m/s], F (AT)

Diameter : 1 mm

Number density : 5x10^3 cm^-3

Layer Thickness : 100 m

Estimated through CFT measurements

Copolarization

Doppler velocity [m/s]

Rainfall Rate (RR) Mean Diameter (D*)

Comparison of Rainfall estimation between dual-frequency (DF) and dual-frequency + Doppler (DFV) Bayesian algorithm.

• DFV produces higher RR and smaller D*

• DFV retrievals show lower retrieval standard deviation especially for low RR and low D*.