Dual-Frequency Precipitation Radar Observations in CAMEX-4 and Wakasa Bay Experiments

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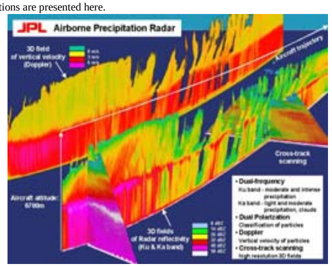
A new airborne rain profiling radar, known as the **Dual-Frequency Airborne Precipitation Radar (APR-2)**, has been developed as a prototype of the second-generation rain radar instruments for future spaceborne precipitation measurement missions. APR-2 is capable of making simultaneous measurements of multiple rainfall parameters, including **co-polarized** and **cross-polarized reflectivities** and **vertical Doppler velocities of rainfall and snowfall** at both **14** and **35 GHz**. It also features several other advanced technologies for performance improvement, including **real-time data processing**, **low-sidelobe pulse compression**, and **dual-frequency scanning antenna**. It is different from the **Dual-frequency Precipitation Radar (DPR)** in the **Global Precipitation Measurements (GPM)** Mission in that DPR is physically consisting of two separate radars while APR-2 is a single radar with two frequency channels.

Since August 2001, APR-2 has been deployed on the NASA P3 and DC8 aircrafts in several experiments, including **CAMEX-4** and the **Wakasa Bay** (**AQUA AMSR-E** validation) experiments. During these experiments APR-2 has acquired more than 50 hours of data covering rainfall and snowfall systems, both over ocean and land, from the tropics to mid-latitude. Raw radar data are first processed to obtain reflectivity, LDR (linear depolarization ratio), and Doppler velocity measurements. The dataset is then processed iteratively to accurately estimate the true aircraft navigation parameters and to classify the surface return. These intermediate products are then used to refine precipitation reflectivity and LDR calibrations (by analyzing clear air ocean surface returns), and to correct for aircraft motion. Precipitation melting layer is then characterized at the APR-2 range resolution of 30m. A multiparametric algorithm is used to classify the radar returns as either stratiform rain, convection, melting layer, cloud, snowfall or 'other'. The resulting 3D dataset is being used for studying precipitation microphysics and processes, supporting advanced retrieval technique development, and validating spaceborne measurements. Some examples of these science applications are presented here.

APR-2 Parameters	Ku-band	Ka-band
Frequency	13.4 GHz	35.6 GHz
Polarization	HH, HV	HH, HV
Antenna effective diameter	0.4 m	0.14 m
Antenna gain	34 dBi	33 dBi
Antenna sidelobe	-30 dB	-30 dB
Antenna scan angle	±25˚	±25˚
Polarization isolation	-25 dB	-17dB
Peak power	200 W	100 W
Bandwidth	4 MHz	4 MHz
Pulse width	10 - 40 µs	10 - 40 µs
Pulse Repetition Frequency	5 kHz	5 kHz
Vertical resolution	60 m	60 m
Horiz resolution:		
At 9 km (30,000 ft) altitude	600 m	600 m
At 6 km (20,000 ft) altitude	400 m	400 m
Ground Swath		
At 9 km altitude	8.5 km	8.5 km
At 6 km altitude	5.6 km	5.6 km
Sensitivity:		
At 7 km range	10 dBZ	7 dBZ
Doppler precision	0.5 m/s	1 m/s

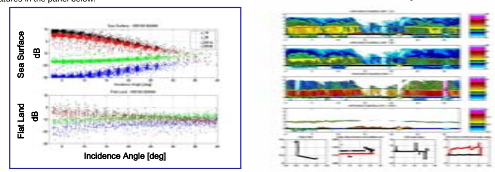


APR-2 Surface Classification

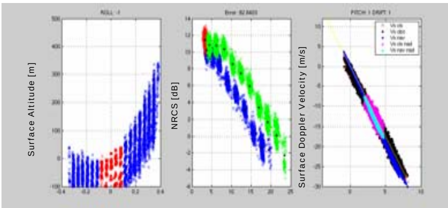
- Preliminary Screening is performed through the Z14 channel alone: the cross-track profile of the apparent height of the surface is is used to discriminate flat surface, rough surface (hills & mountains) and whether the aircraft was rolling or the antenna was not scanning.
- Cross-track scans classified as flat surface are further classified into Sea Surface or Flat Land by using Z14, Z35, LDR14 and LDR35 channels. See the different signatures in the panel below.

A surface classification index is assigned to each cross track scan

- 0 - Rough Land - **BLACK**
- 1 - Sea Surface - **BLUE**
- 2 - Sea Surface (a/c rolling) - **CYAN**
- 3 - Flat Land - **GREEN**
- 4 - Flat Land (a/c rolling) - **YELLOW**
- 5 - Antenna Not Scanning - **RED**



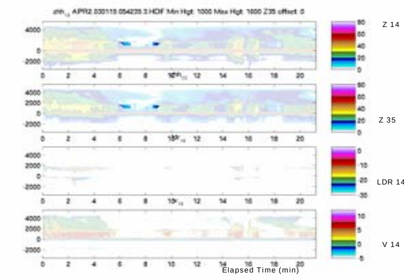
APR-2 Navigation Correction



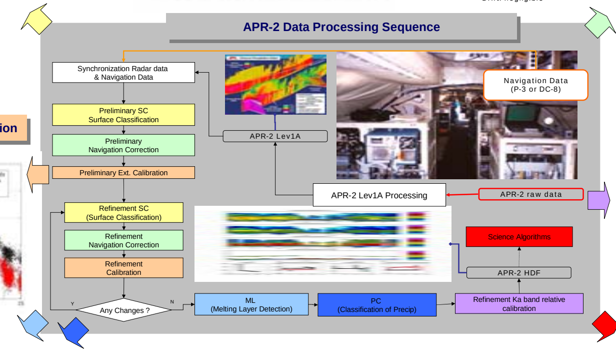
sensitivity to: Roll: highest, Pitch: minor, Drift: negligible

Sensitivity to: Roll: high, Pitch: minor, Drift: negligible

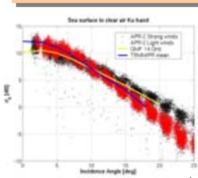
Sensitivity to: Roll: minor, Pitch: high Drift: high



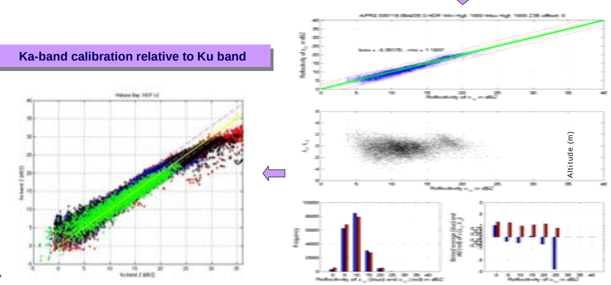
APR-2 Data Processing Sequence



Ku-band External Calibration



Ka-band calibration relative to Ku band

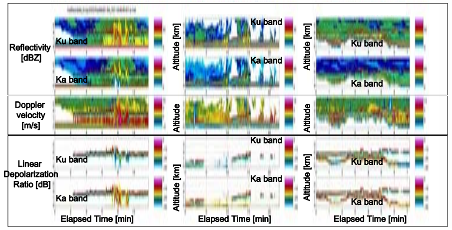


Melting Layer Detection – ML1 Results

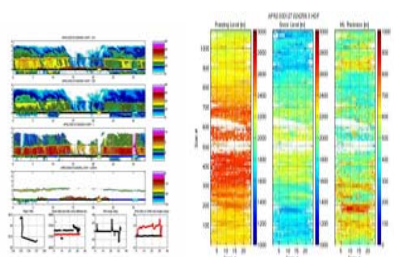
Wakasa Bay – Stratiform system with embedded convection

Wakasa Bay – Changing Freezing Level

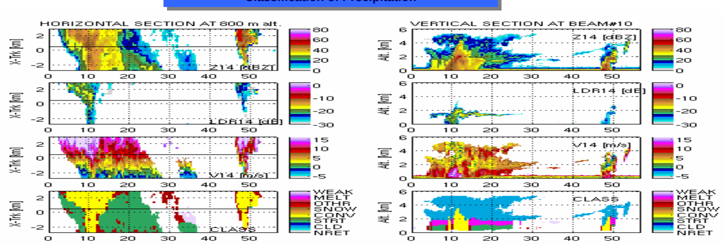
Wakasa Bay – Stratiform system over mountains



Melting Layer Detection – 2D extension (ML2)

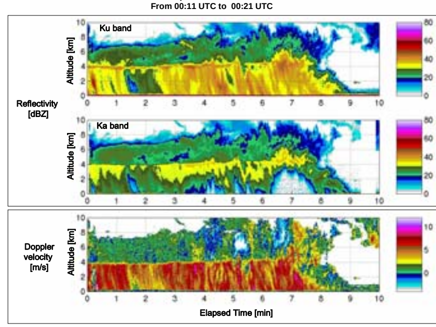


Classification of Precipitation



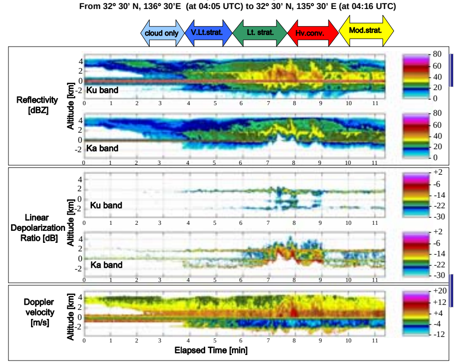
CAMEX 4 – Hurricane Humberto

September 25th 2001
From 00:11 UTC to 00:21 UTC

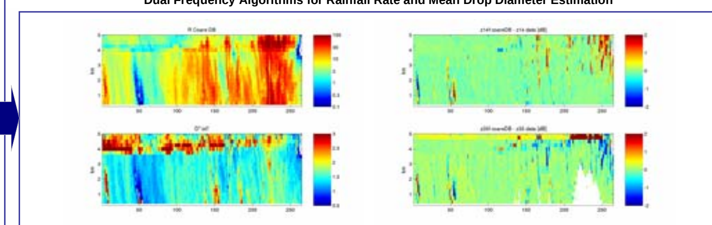


Wakasa Bay – Stratiform system with embedded convection

January 19th 2003 – Flight #3
From 32° 30' N, 136° 30'E (at 04:05 UTC) to 32° 30' N, 135° 30' E (at 04:16 UTC)



Dual Frequency Algorithms for Rainfall Rate and Mean Drop Diameter Estimation

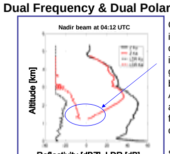


We have recently developed algorithms that use a probabilistic framework

Two approaches to calculate the mean or the boundaries of Rain Rate and Mean Drop Diameter (Mass Weighted)

- Particle filter Monte Carlo method
- Bayesian (see poster by Z.S. Haddad et al.)

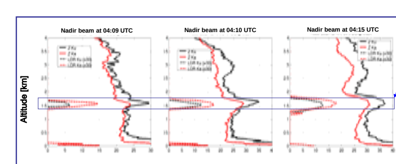
Dual Frequency & Dual Polarization Analysis of Multiple Scattering Contribution to Ka band Reflectivity measurements



Convective cell – The Ku band LDR return shows a peak at 2.2 km altitude (corresponding to the melting layer altitude in the surrounding stratiform rain system) and slowly decreases below it. Such profile indicates the possible presence of mixed phase hydrometeors below the freezing level due to convection. On the other hand, the Ka LDR return increases linearly below the melting layer altitude. Such profile indicates the effect of multiple scattering at Ka band. In general, multiple scattering affects Ka band reflectivity measurements when large attenuations occur (in fact, at Ka band, a significant amount of the extinction cross section is due to scattering).
APR-2 measurements are in excellent agreement with previously reported observations. They confirm the validity of the approximation to the second order for the multiply scattered signal. The ratio of cross-polar vs. co-polar contributions from multiple scattering is estimated accordingly. Therefore, LDR measurements can be used to quantify the contribution of multiple scattering to the measured reflectivity and remove the corresponding bias in rain rate estimates.

S. Kobayashi, S. Tanelli and E. Im, Second-order multiple scattering theory associated with backscattering enhancement for a millimeter-wavelength weather radar with a finite beam width, *Radio Science*, in press.

Multiparametric Analysis of the Melting Layer



- LDR peaks indicate maximum average eccentricity of hydrometeors and/or decrease of number drop density due to increase in vertical velocity
- Z peaks indicate maximum average size of hydrometeors

APR-2 Observations

- Inside the Brightband the altitudes of the peaks of LDR are 0 to 300m below the corresponding peaks of Z.
- The relative offset between LDR and Z peaks is more evident at Ku band than at Ka band.
- Ku band LDR peak is strongly correlated with the region of increase in Doppler velocity.

Goal: test and refine existing Melting Layer models see Poster by S.L. Durden et al.

ACKNOWLEDGEMENT

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