Upgraded Capabilities of the Wyoming Cloud Radar and the Ka-band Probe Radar

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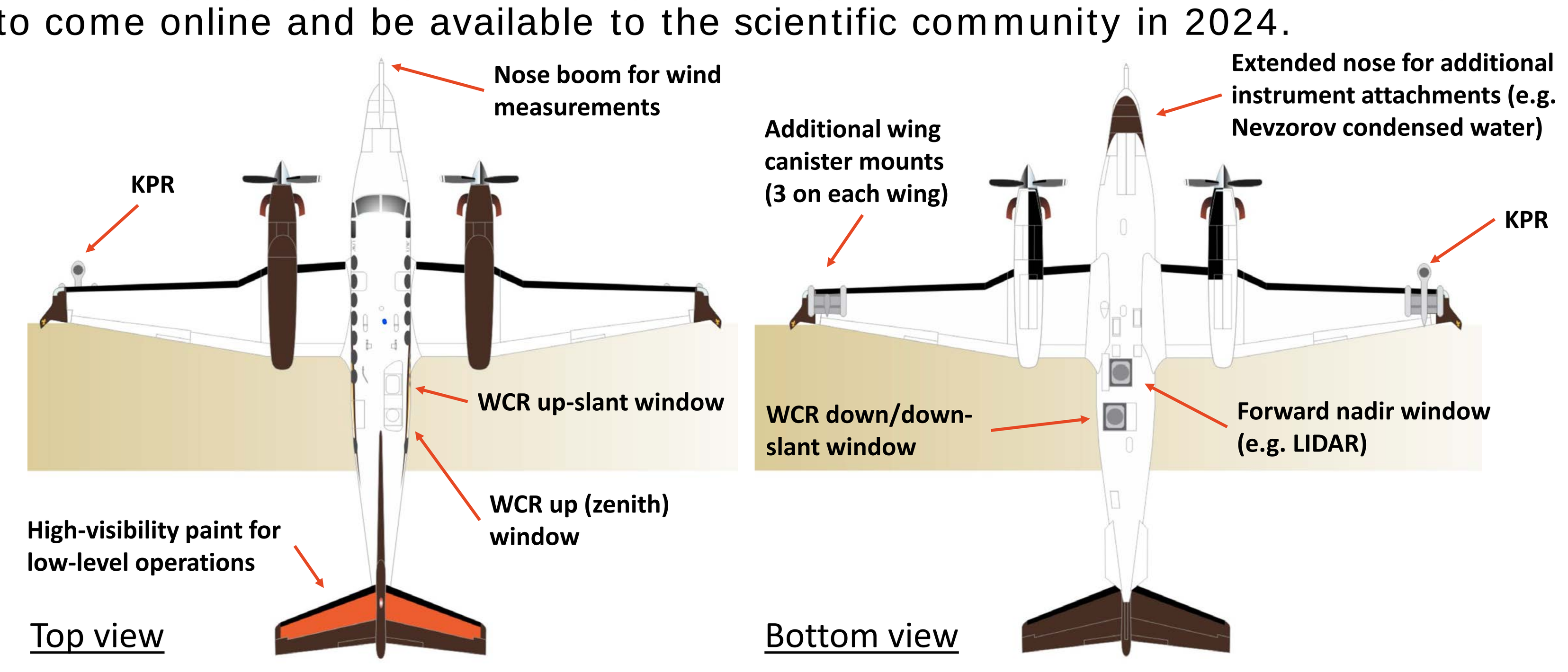
Next-Generation King Air

The University of Wyoming King Air Research Facility is undergoing major upgrades to infrastructure and measurement capabilities. At the core of the upgrades is the development of the Next Generation King Air (UWKA-2) research aircraft, a slightly larger more capable King Air 350. The new aircraft is expected to come online and be available to the scientific community in 2024.



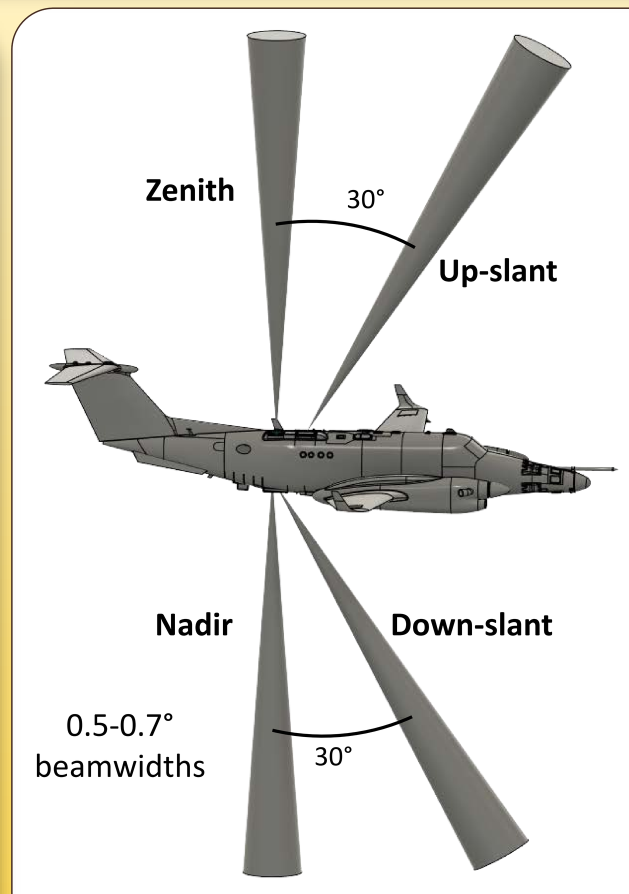
Modifications to the new aircraft include:

- Enhanced capabilities of in situ and remote sensing observations by incorporating a suite of current and new instrumentation, greater power capacity, higher ceiling (35k ft), and longer endurance (3.5-4.0 hours)
- Airframe modifications to the UWKA-2 to support a second upward-directed WCR antenna, pointing 30 degrees forward of zenith, and allow for dual-Doppler wind synthesis above and below the aircraft.
- improved investigator access

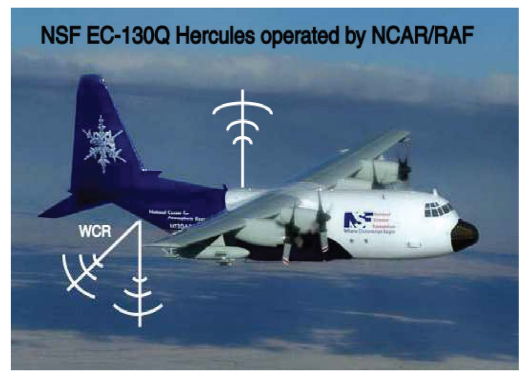
Scan to visit the King Air Webpage

The operation of the UWKA and WCR is funded under the Cooperative Agreement NSF-1917369

Wyoming Cloud Radar (WCR)



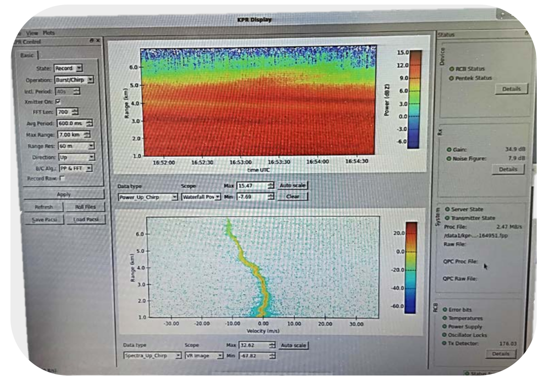
The WCR is a fixed-antenna W-band (95 GHz), polarimetric Doppler radar that is primarily installed on the UW King Air or the NCAR C-130. The airborne WCR can target research-specific clouds and precipitation to measure the fine-scale structure of reflectivity and radial velocity. With a typical range resolution of about 30 m and horizontal sampling of 4-7 m (depending on aircraft speed and dwell time), observations reveal features such as Kelvin-Helmholtz waves, convective up- and down-drafts, cloud-top generating cells, and other dynamics important for understanding cloud microphysics and precipitation.

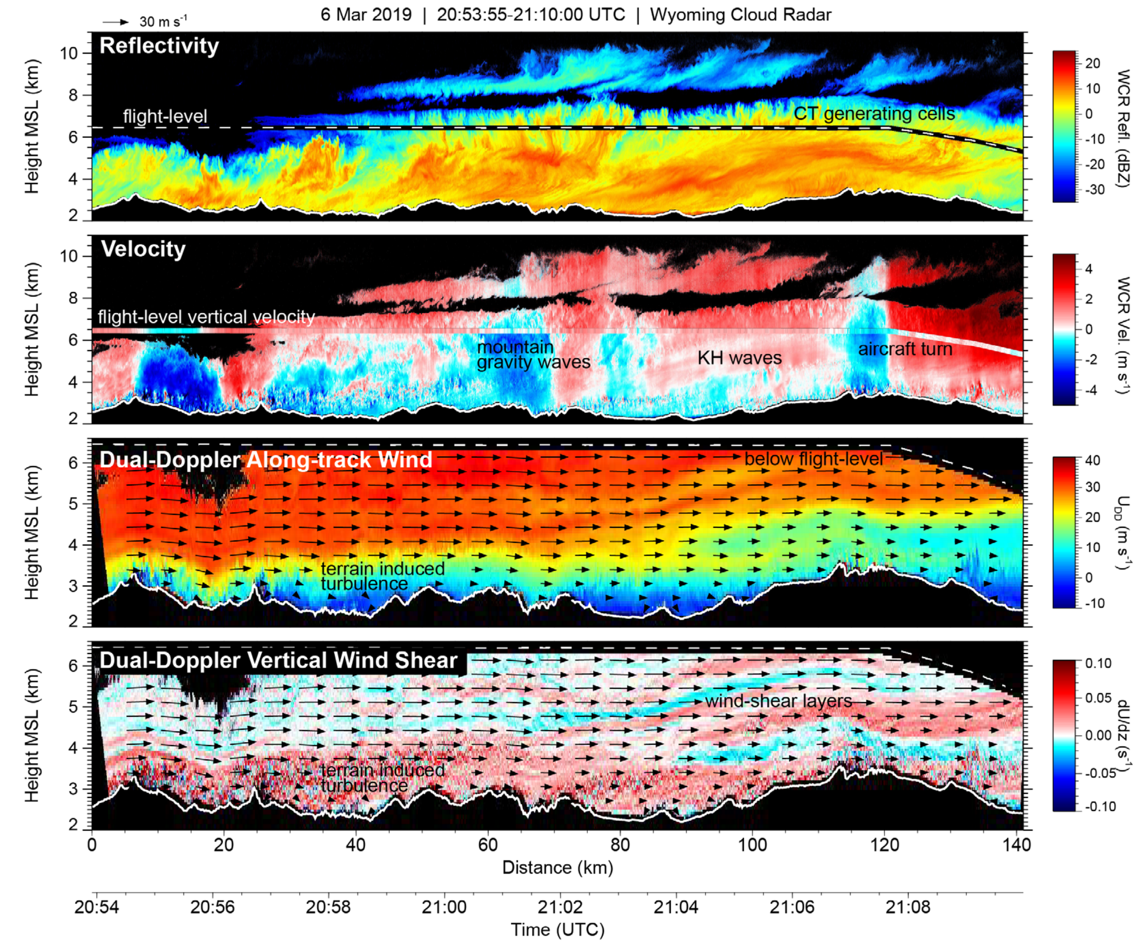


Upgrade to WCR4 in 2023

- New and improved components that increase the accuracy, reliability, and useability of the radar.
- A new real-time display and control GUI will make it easier for investigators to observe the live data and quickly adjust measurement parameters or research targets if necessary.

Scan to visit the WCR Webpage





WCR data showing, from top to bottom: WCR reflectivity, WCR velocity, dual-Doppler along track wind (below aircraft), and dual-Doppler vertical wind shear (below aircraft).

WCR Specifications

Wavelength | Frequency • Transmitted pulse packet	3.16 mm | 94.940 GHz (w-band) • 1-12 linearly polarized, sequenced pulses through up to 5 ports (antennas)
Peak Power | Duty Cycle	1.8 KW / 1%
Pulse length	100, 200, 250, 500 ns
Pulse Repetition Frequency (PRF)	1-20 KHz
Antenna Configuration (Currently supported): • UWKA • NCAR C-130	• Max of 4 antennas pointed near zenith (up), near nadir (down), 30° forward of zenith (up-fore), and 30° forward of nadir (down-fore) • Max of 3 antennas pointed near zenith (up), near nadir (down), 30° aft of nadir (down-aft)
Radar operational/acquisition modes: • Pulse-pair • Doppler spectrum (FFT) + pulse-pair	• 2 pulses per antenna, provides pp estimates of reflectivity, Dop. velocity, spectrum width • 16 – 512 spectrum bins, provides Doppler spectra and pp estimates of reflectivity, Dop. velocity, spectrum width
Receiver channels: • Receiver output • Dynamic range • Noise figure	2 (H/V) 16-bit magnitude and phase > 65 dB ~ 8 dB
Min dwell time | along-track sampling	45 ms | 4 – 7 m (typical)
Min detectable signal (expected): • One St. Dev. Above mean noise	For 200 ns pulse, 150 averaged pulses -40 dBZ at 1 km
Doppler radial velocity processor: ▪ pulse pair ▪ FFT spectrum	1st & 2nd moments 16 to 512 spectral lines
Maximum unambiguous Doppler **Unambiguous/useful range**	±15.8 m/s maximum (@ 20 KHz prf) 6 – 10 km (typical)
First usable radar range gate	~100 m

The WCR upgrade is funded under MSRI award NSF-1935930

Processing & CfRadial v2

Level 0

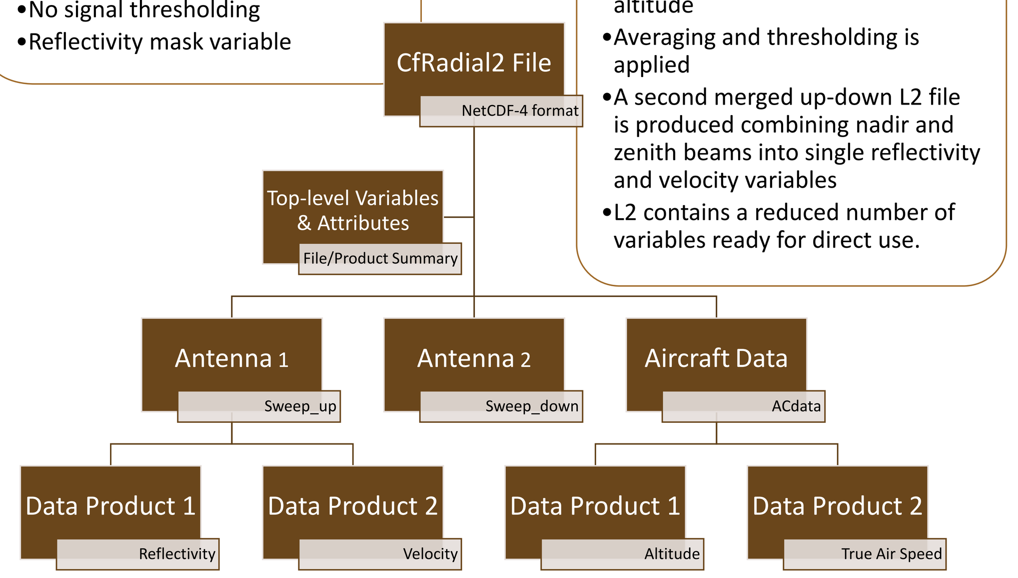
- Radar acquisition data is transferred to NetCDF CfRadial2 format
- Select aircraft data (e.g. attitude and position) are resampled and added to the file

Level 1

- Radar received power and phase measurements are processed into Reflectivity and Velocity
- Aircraft motion contribution is removed from Doppler velocity
- No signal thresholding
- Reflectivity mask variable

Level 2

- Averaging and thresholding is applied
- Data products are resampled into the vertical plane transforming the vertical coordinate from range to altitude
- Averaging and thresholding is applied
- A second merged up-down L2 file is produced combining nadir and zenith beams into single reflectivity and velocity variables
- L2 contains a reduced number of variables ready for direct use.



Beginning with WCR4, radar data is stored and shared in CfRadial v2 format. Variables and attributes are stored in groups with a hierarchical structure. We find it convenient and intuitive to use each sweep group to store the data fields for each antenna, for example: 'sweep_up'. Level 2 data offers an additional file with a single antenna group, 'sweep_up-down' with data merged from the up and down antennas into vertical profiles.

Scan to view the CfRadial v2 documentation

WCR4 data in Python

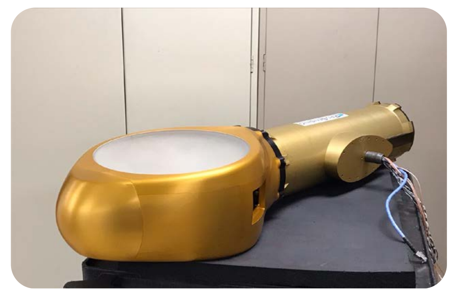
```python
# Required libraries ------------------------------------
from netCDF4 import Dataset
import numpy as np

# Open NetCDF file
wcr_root = Dataset("WCR_filePath")

# Choose group e.g. "sweep_up" for up antenna
sweep_group =wcr_root.groups["group_choice"]

# Identify the NetCDF variables wanted from each group
velocity = sweep_group.variables['velocity']
reflectivity =  sweep_group.variables['reflectivity']
time = sweep_group.variables['time']
altitude = sweep_group.variables['altitude']

# Convert to Numpy arrays  ---------------------------
time = np.array(time[:])
altitude = np.array(altitude[:])/1000. #change m to km
reflectivity = np.transpose(np.array(reflectivity[:]))
velocity = np.transpose(np.array(velocity[:]))

# Close file
wcr_root.close()
```

WCR4 data in IDL

```idl
;Open NetCDF file
ncid = ncdf_open("WCR_filePath")

;Choose group e.g.  "sweep_up-down" for merged up/down antennas
groupid = ncdf_ncidinq(ncid, "group_choice")

;Identify the NetCDF variable IDs
reflectivity_id = ncdf_varid(groupid,"reflectivity")
velocity_id = ncdf_varid(groupid,"velocity")
time_id = ncdf_varid(groupid,"time")
range_id = ncdf_varid(groupid,"range")

;Load data into arrays
ncdf_varget,groupid,reflectivity_id,reflectivity
ncdf_varget,groupid,velocity_id,velocity
ncdf_varget,groupid,time_id,time
ncdf_varget,groupid,range_id,range

;Close file
ncdf_close, ncid
```

KPR Specifications

Transmitter: Frequency | Wavelength ▪ solid state transmitter ▪ chirp, RF pulse, and Quadratic Phase Code waveforms	35.61-35.67 GHz | 8.4 mm
Peak Power | Duty Cycle	10 W | 5% - 45%
Chirp and RF Pulse length	2.5-6.2 µs and 250-620 ns
PRF	1-20 kHz
Antennas (fixed pointing): ▪ Up (near zenith) ▪ Down (near nadir)	aperture | beamwidth | polarization 0.279 m | 2.1° | single, linear 0.279 m | 2.1° | single, linear
Radar operational/acquisition modes: ▪ pulse-pair ▪ Doppler spectrum ▪ Quadratic Phase Code (QPC)	**Usage:** • allows combined pulse-pair & Doppler spectrum • single antenna or interleaving two antennas
Receiver channels: ▪ receiver outputs ▪ receiver dynamic range ▪ noise figure	1 Digital (16-bit), magnitude and phase 75 dB at 2 MHz bandwidth ~7 dB
Min. Dwell time | Along-track sampling	200 ms | 20 m (typical)
Min. detectable signal (expected): ▪ One Standard Deviation above mean noise	250 ns pulse, 2000 averaged pulses RF short pulse -10 dBZ at 1km compression chirp -20 dBZ at 1km
Resolution: ▪ in range | minimum range sampling ▪ volume@1 km, 5MHz IF filter	30, 60, 75 m | 7.5 m ~ 37 x 37 x 30 m (AZ x EL x range)
Doppler radial velocity processor: ▪ pulse pair ▪ FFT spectrum	• 1st & 2nd moments (lag 1 and lag 3 2nd moment) • 8 to 256 spectral lines (typical)
Maximum unambiguous Doppler **Maximum range**	±42.1 m s^{-1} (at 20 kHz PRF) ±6.5 km (typical)
First radar range gate for RF pulse | QPC	120 m | 45 m



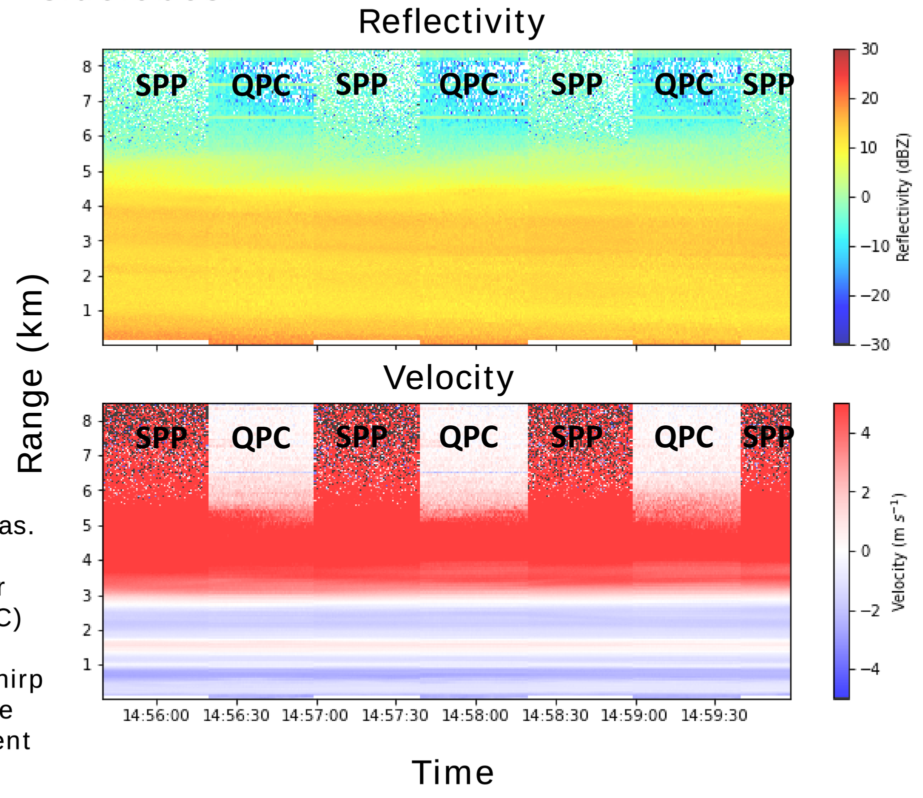
Left: KPR, canister, and new 11" antennas.

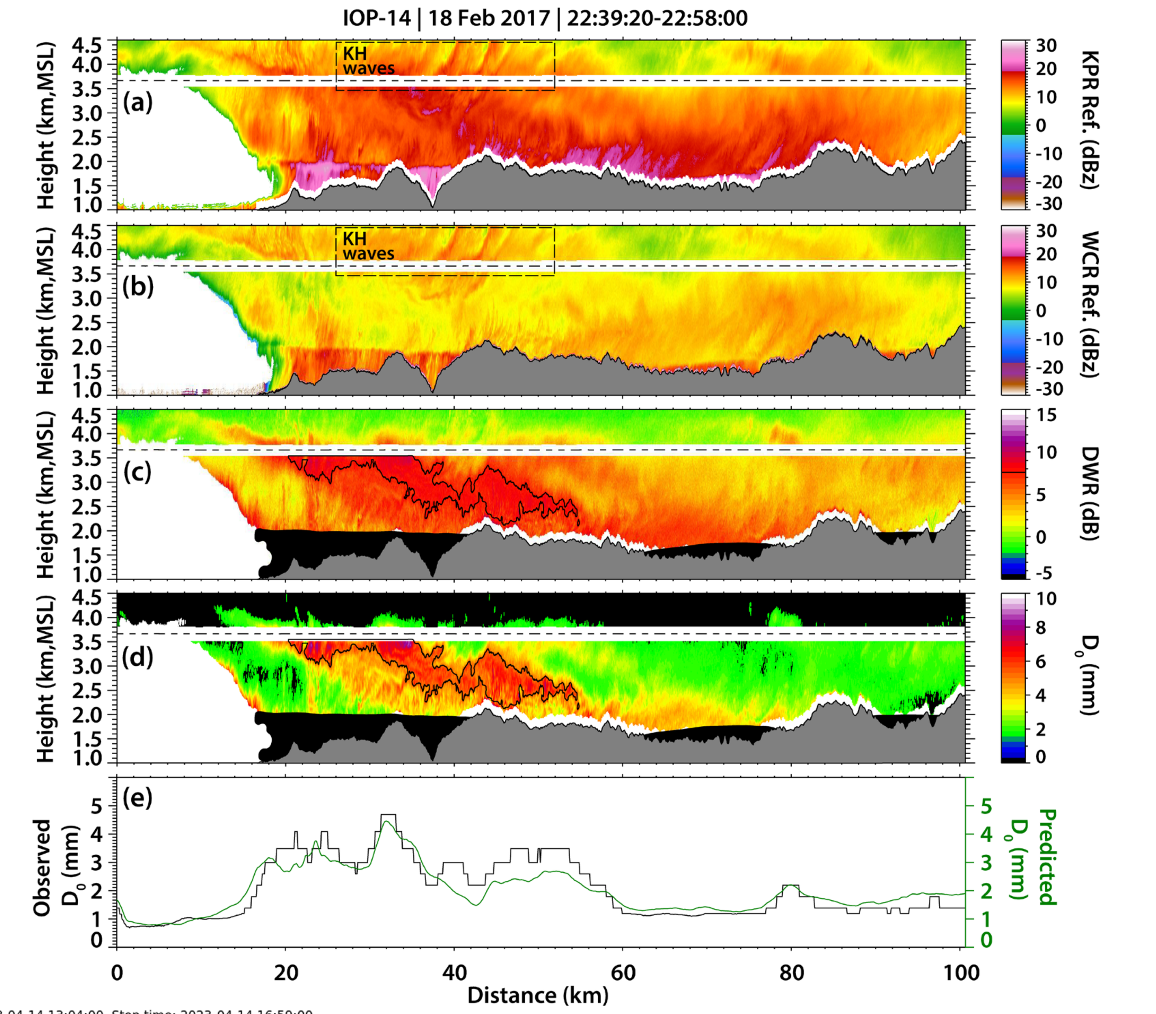
Right: Interleaved Standard Pulse Pair (SPP) and Quadratic Phase Coding (QPC) during a snow event. No thresholding applied. SPP is combined RF pulse and chirp data. The KPR is pointed 38° above the horizon and measuring a large component of horizontal wind.

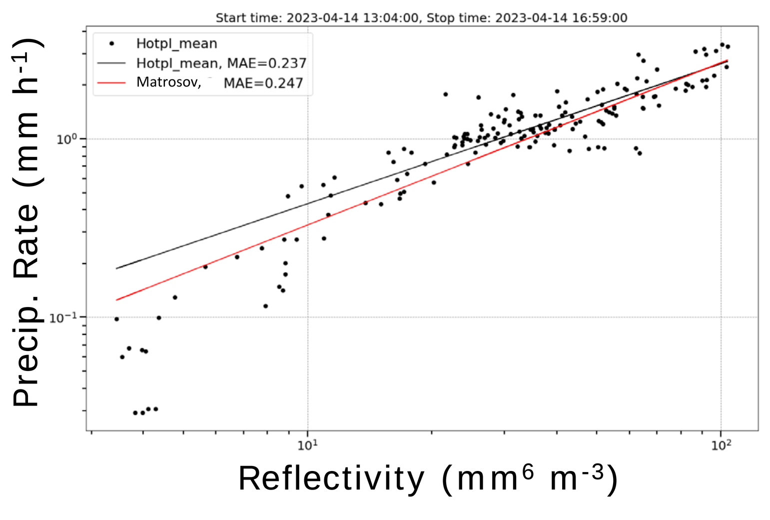
Ka-band Probe Radar (KPR)

After several successful deployments of the KPR since its acquisition in 2016 (e.g. SNOWIE, 2017), recent software and hardware upgrades were implemented by ProSensing Inc. to improve its capabilities when deployed on the UWKA-2.

- Larger 27.9 cm (11") antennas reduce the beamwidth to 2.1° to improve sensitivity and better match the sample volume of the WCR.
- Quadratic Phase Coding (QPC, being tested) improves sensitivity at all ranges by transmitting at up to 45% duty cycle.
- QPC allows for range gates closer to the aircraft (for in situ comparisons) and closer to the ground by having low range sidelobes.







Top: Dual-wavelength analysis with KPR reflectivity (a), WCR reflectivity (b), the DWR (c), est. median-volume diameter (D_0) of the ice size distribution (d), and near-gate D_0 comparison with flight-level (e) from IOP-14 in SNOWIE (Grasmick et al. 2022; © Copyright 2022 AMS)

Left: KPR reflectivity compared to precipitation rate from a hot plate during a snow-storm. The observed power-law fit (black) is compared to a theoretical fit (red) from Matrosov (2007).

The KPR upgrade is funded under MSRI award NSF-1935930