Wyoming Cloud Radar (WCR) and Ka-band Profiling Radar (KPR)

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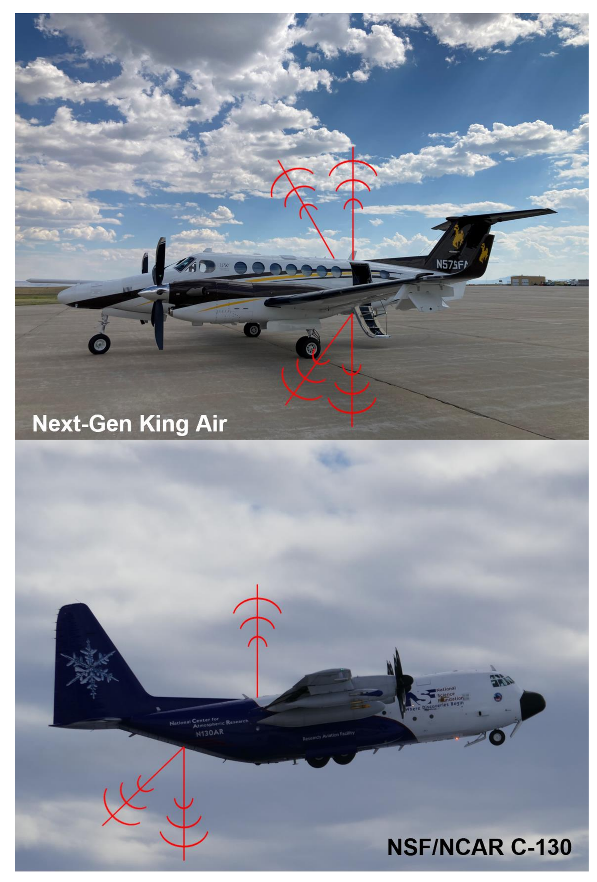
Wyoming Cloud Radar (WCR)

The WCR is a fixed-antenna W-band (95 GHz), Doppler radar that is primarily installed on the NSF UW King Air or the NSF 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.

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 ns
Pulse Repetition Frequency (PRF)	1-20 KHz
Antenna Configurations: ▪ UWKA ▪ NCAR C-130 ▪ Beamwidth	• 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) • 0.5° - 0.75°
Radar 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: ▪ Receiver output ▪ Dynamic range ▪ Noise figure	2 (H/V) 16-bit magnitude and phase > 65 dB < 8 dB
Min detectable signal: ▪ One St. Dev. above mean noise	For 250 ns pulse, 100 averaged pulses -35 dBZ at 1 km
Dwell time | along-track sampling	50 ms | 4 – 7 m (typical)
Resolution: ▪ Range | min. range sampling ▪ Beam diameter @ 1; 5 km	15, 30, 37.5 m | 3.7 m 8.7 – 13.1 m; 43.6 – 65.5 m
Maximum unambiguous Doppler **Maximum range**	±15.8 m/s maximum (@ 20 KHz prf) 6 – 10 km (typical)
First usable radar range gate	~110 m

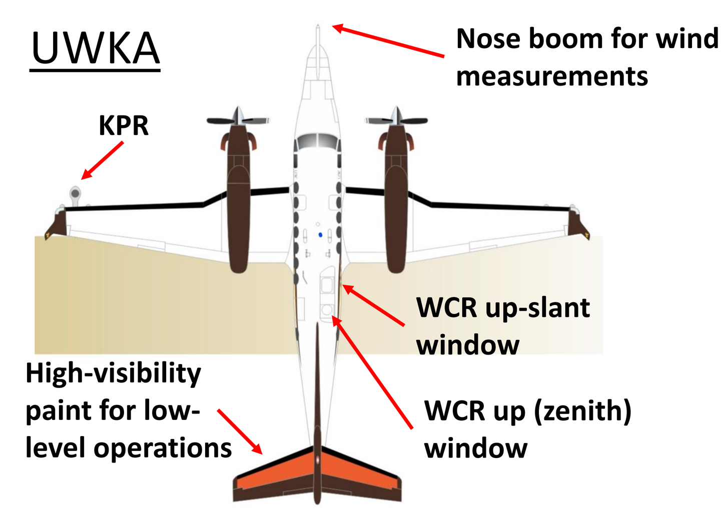


The operation of the UWKA and WCR is funded under the Cooperative Agreement NSF-1917369

The new NSF UW King Air (UWKA) modifications include WCR ports for up to four antennas – nadir, zenith, 30° forward nadir, and 30° forward zenith. This setup enables full-vertical profile, dual-Doppler synthesis. Together, with a suite of microphysics instrumentation, and a near-match with KPR profiles, the UWKA is an optimal platform for studying cloud and precipitation physics. The aircraft and instrumentation are accessible through the NSF Facility and Instrumentation Request Process (FIRP).

Ka-band Profiling Radar (KPR)

The KPR is a Ka-band (35 GHz) Doppler radar with a solid-state transmitter. It operates quazi-simultaneously two 2.1° beamwidth antennas pointing at near nadir and zenith. KPR utilizes conventional short pulse transmission, linear frequency pulse-compression, and Quadratic Phase Coding (QPC) to improve sensitivity. The antennas and the transceiver fit in an under-wing PMS-style canister.



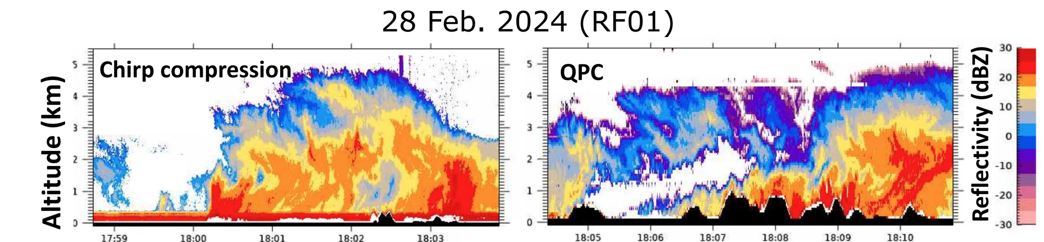
C-130

KPR Specifications

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 acquisition modes: ▪ Pulse-pair ▪ Doppler spectrum ▪ Quadratic Phase Code (QPC)	• Lag 1 and Lag 3 • Allows combined pulse-pair & Doppler spectrum, 8-256 spectral bins, 1st & 2nd moments (lag 1 and lag 3 2nd moment) • Single antenna or interleaving
Receiver: ▪ 2 receiver channels output ▪ receiver dynamic range ▪ noise figure	• Digital (16-bit), magnitude and phase • 75 dB at 2 MHz bandwidth • <8 dB
Min. detectable signal: ▪ One Std. Dev. above mean noise	200 ns pulse, 1500 averaged pulses RF short pulse -6 dBZ at 1km compression chirp -18 dBZ at 1km
Dwell time | Along-track sampling	150 ms | 15 m (typical)
Resolution: ▪ Range | min. range sampling ▪ Beam diameter @ 1; 5 km	30, 60, 75 m | 7.5 m 36.7 m; 183.3 m
Maximum unambiguous Doppler **Maximum range**	± 42.1 m s^{-1} (at 20 kHz PRF) ± 6.5 km (typical)
First range gate for RF pulse | QPC	120 m | 45 m

The WCR and KPR upgrades were funded under MSRI award NSF-1935930

28 Feb. 2024 (RF01)



Comparison of KPR's chirp and QPC reflectivity products for consecutive regions during CAESAR. Both signals are thresholded using 3 standard deviations of the noise.

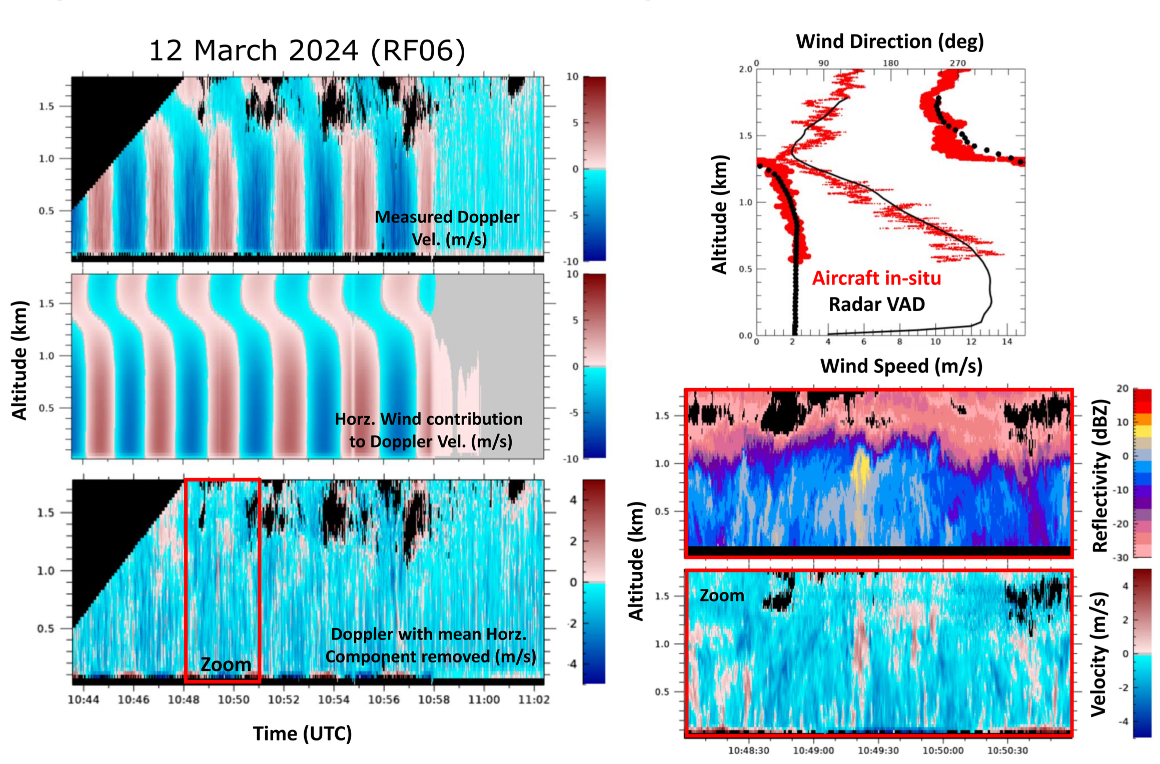
Radar Observations and Applications from CAESAR

The WCR and KPR were recently installed on the NSF NCAR C-130 as part of the Cold Air outbreak Experiment in the Sub-Arctic Region (CAESAR) based out of Kiruna, Sweden. In early Spring 2024, over the Norwegian Sea, the radars observed mixed-phase, shallow-convection driven by extreme heat and moisture fluxes into the arctic-sourced air. WCR operated three antennas: zenith, nadir, and aft-nadir (for below aircraft dual-Doppler), while KPR operated the nadir antenna only.

Airborne VAD

Velocity Azimuth Display (VAD) can be applied to spiral ascents/descents for horizontal wind retrieval (Leon and Vali, 1998) and the recovery of hydrometeor vertical velocity.

12 March 2024 (RF06)



Operation of the WCR and KPR in CAESAR was funded by NSF-2151329

Damiani, R. and S. Haimov, 2006: A High-Resolution Dual-Doppler Technique for Fixed Multiantenna Airborne Radar. *IEEE TGRS*, **44**, 3475-3489.
Grasmick, C., B. Geerts, J. R. French, S. Haimov, and R. M. Rauber, 2022: Estimating Microphysics Properties in Ice-Dominated Clouds from Airborne Ka–W-band Dual-Wavelength Ratio Reflectivity Factor in Close Proximity to In Situ Probes. *J. Atmos. Oceanic Technol.*, **39**, 1815–1833.
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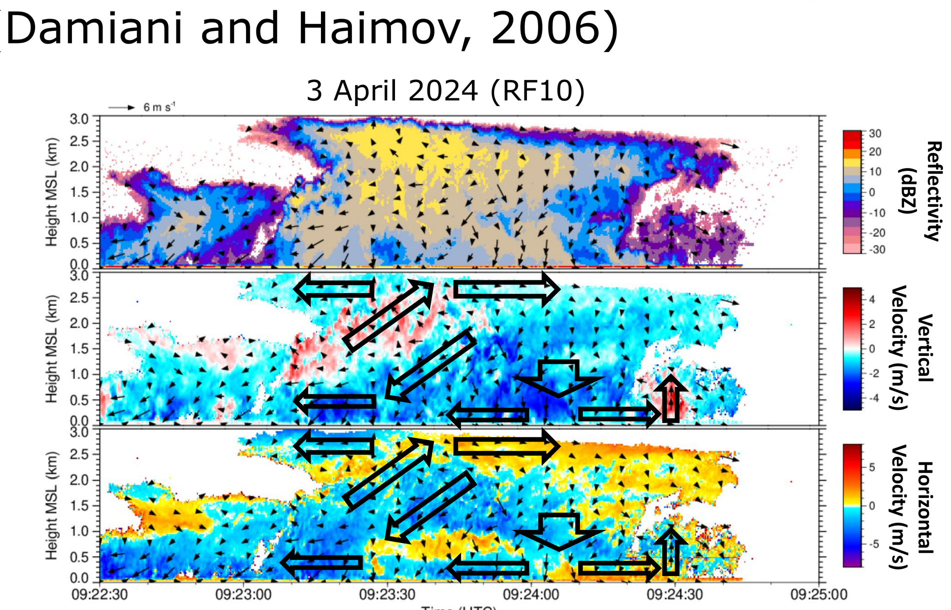
WCR dual-Doppler Synthesis

With multiple WCR antennas, the different Doppler wind components can be combined in airborne dual-Doppler synthesis to provide the 2D wind field along the aircraft track. (Damiani and Haimov, 2006)

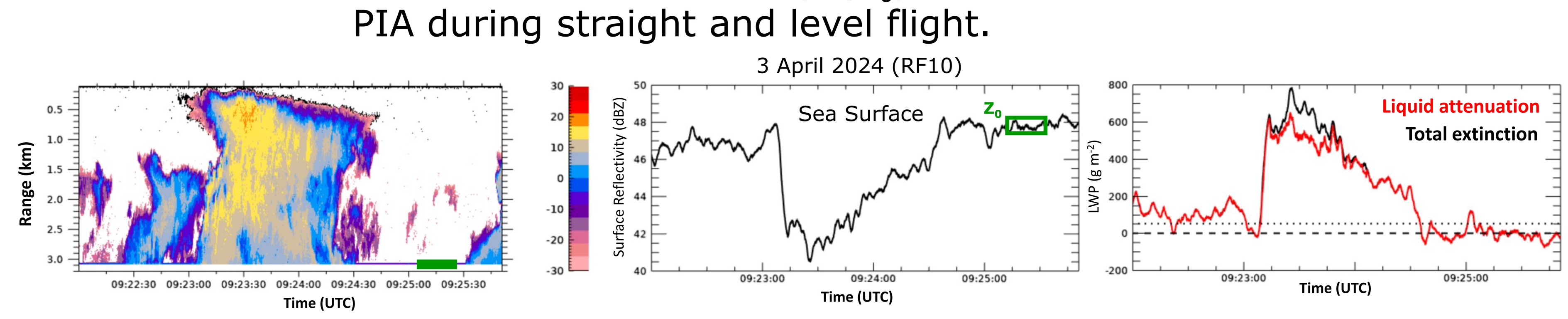
3 April 2024 (RF10)



WCR Liquid Water Path

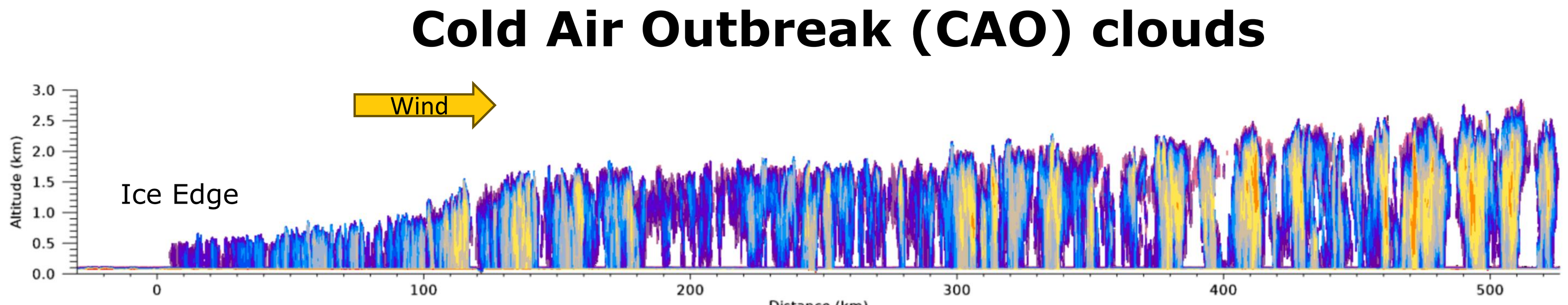
When Path-Integrated-Attenuation (PIA) or differential attenuation are known, they can be used to retrieve estimates of liquid water path (LWP). In this case, the ocean surface reflectivity (Z_0) can be used to estimate PIA during straight and level flight.

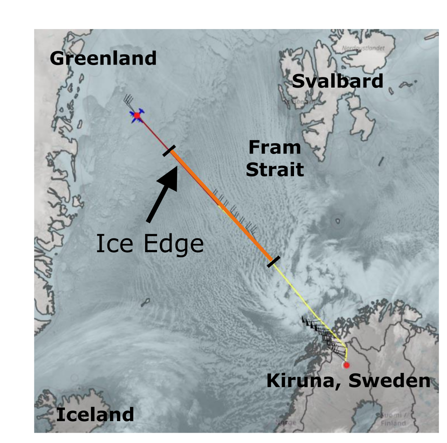
3 April 2024 (RF10)



PIA is estimated after determining the sea-surface reflectivity (Z_0) where no cloud exists. PIA is converted to LWP using a W-band liquid attenuation coef. of 4.6 dB km^{-1} (g m^{-3})$^{-1}$. 0.5 dB km^{-1} is removed for ice extinction where Z>13 dBZ (Protat et al. 2019).

Cold Air Outbreak (CAO) clouds

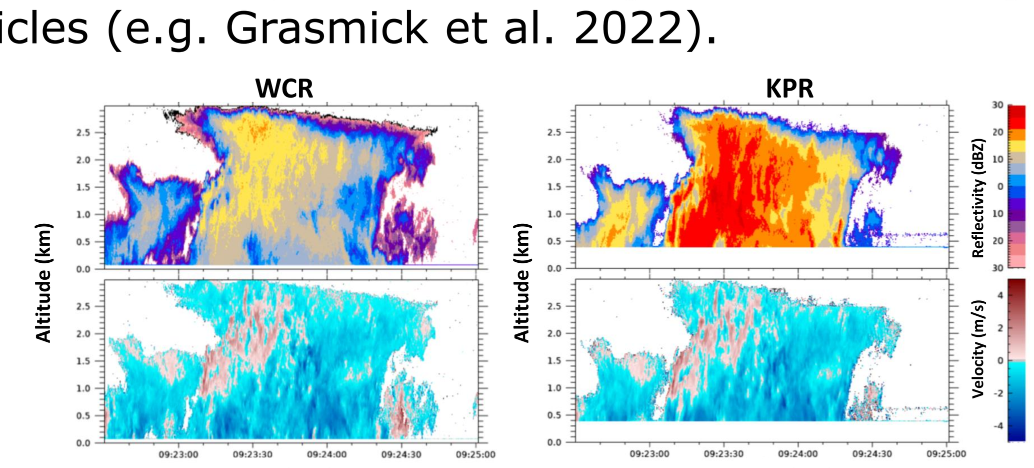


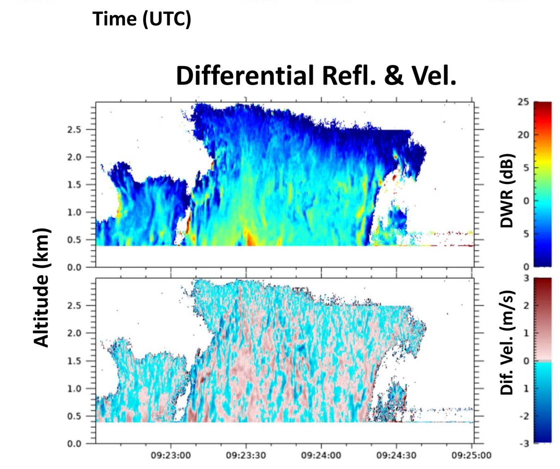


WCR reflectivity (above) from the nadir antenna along the orange flight track in the satellite image (right) on 16 March 2024 (RF07). The 550-kilometer section stretches from the sea ice near Greenland, across the Fram Strait, and to the edge of a polar low. The reflectivity reveals the growth of the marine boundary layer and deepening convection as the arctic air streams southward.

KPR-WCR Dual-Wavelength Ratio

The difference between Ka-band and W-band reflectivity can provide information about differential extinction and quantities of large, Mie-scattering ice particles (e.g. Grasmick et al. 2022).





3 April 2024 (RF10)

The Dual-Wavelength Ratio (DWR) is the combined effect of PIA (see LWP section) and differences in particle backscatter at the two wavelengths.

Differential velocity can be related to the size of particles (via terminal velocity) w/o contributions from PIA (Matrosov 2011). In this case, differences may be due to the size of eddies due to a beam offset of ~14 m.