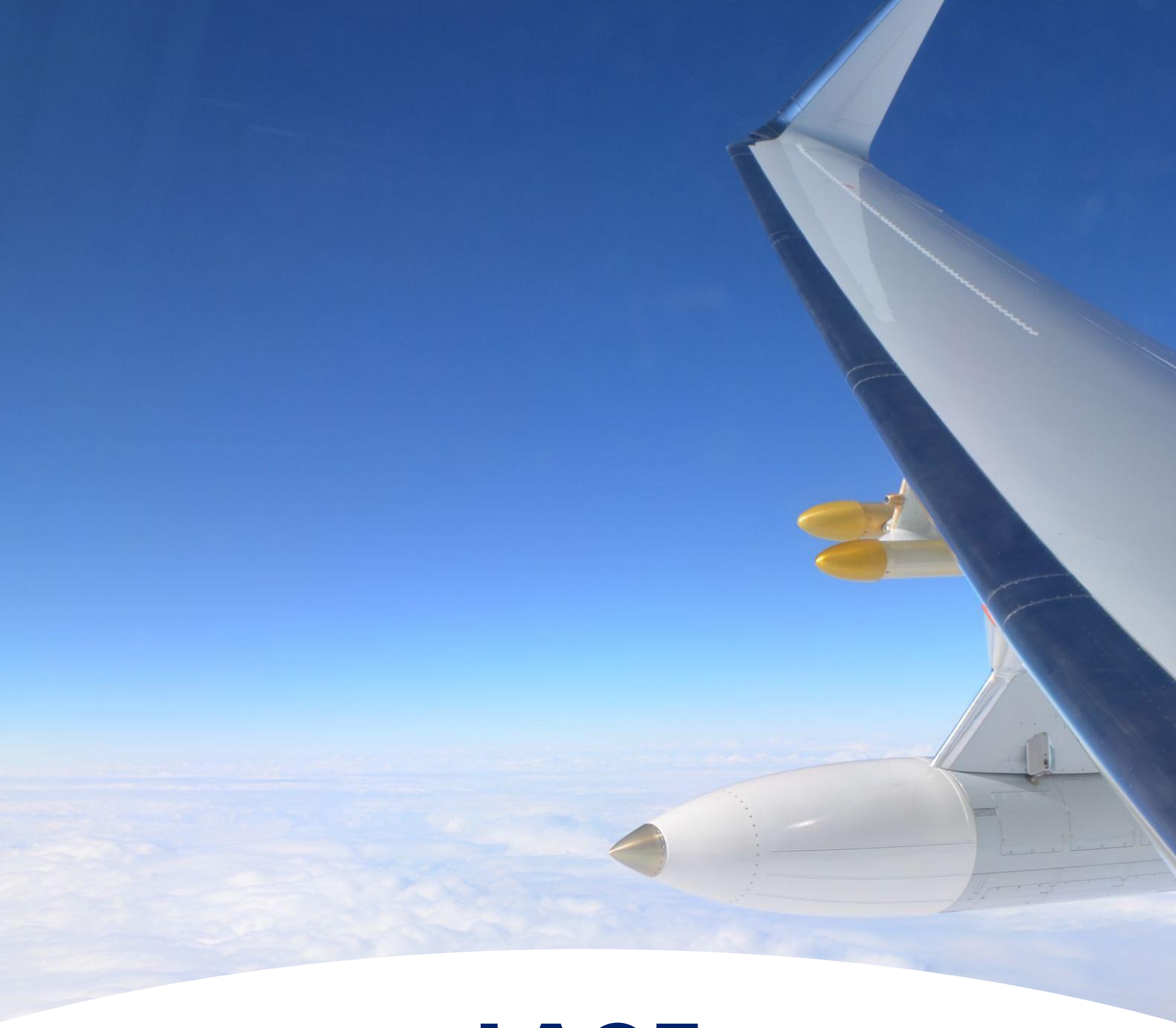
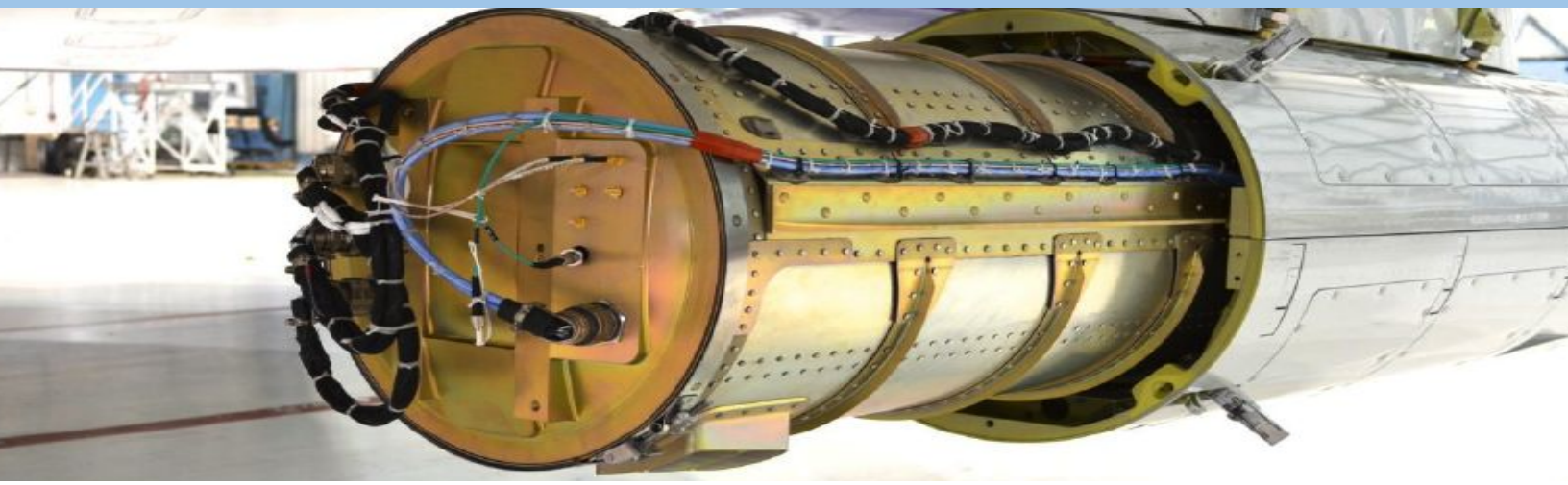


LAOF
AIRBORNE
INSTRUMENTATION

Overview

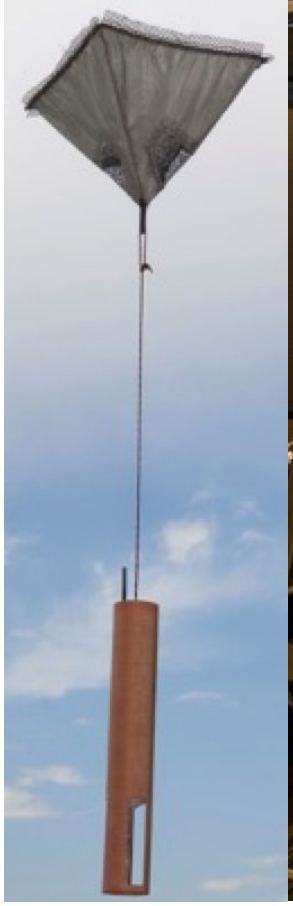


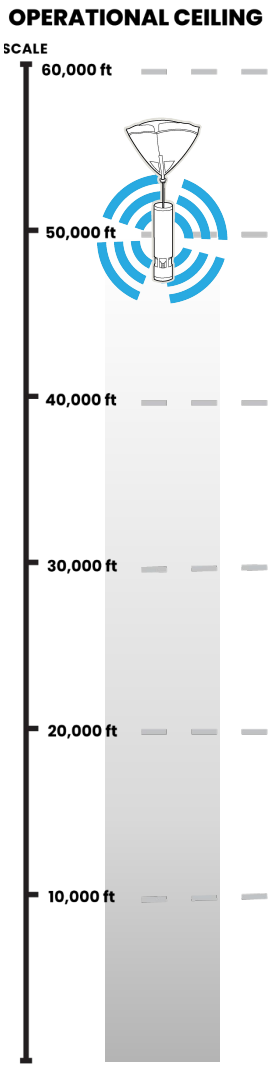
The NSF/NCAR and University of Wyoming aircraft can be outfitted with an extensive suite of airborne in-situ and remote sensing sensors that provides researchers with unparalleled observational capabilities.

The three airborne platforms are equipped with fuselage apertures of different shapes and sizes to accept optical windows or structural plates that serve as mounting locations for various instruments. Large, interchangeable instrumentation pods can carry optical particle probes, active and passive remote and in-situ sensors. Wingtip pylons can carry canister-mounted sensors. Structures at the fuselage top and bottom provide additional capacity for hemispheric radiometers and other sensors.

The main categories of airborne measurements include the following:

- Standard Instrumentation
- Cloud and Precipitation Measurements
- In-Situ Thermodynamic, Wind and Flux Measurements
- **Radar and Lidar** Vertical Profiling
- Radiative Measurements
- Aerosol Measurements
- Gas Measurements





NCAR AVAPS™

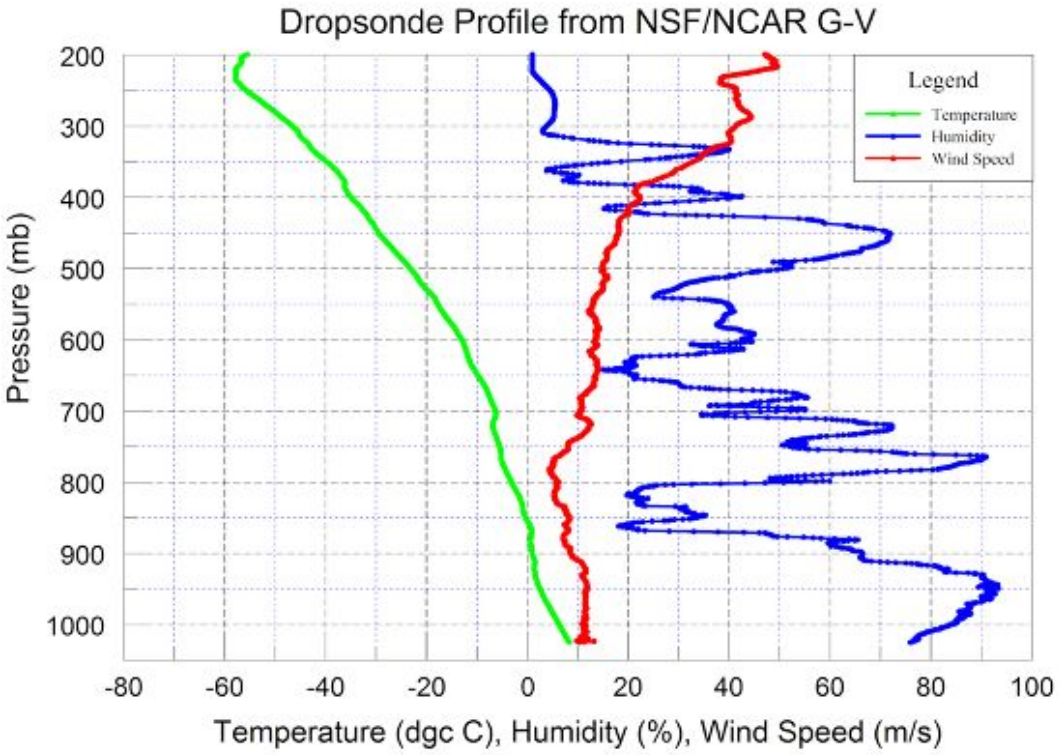
The **AVAPS™ Dropsonde System** is a critical atmospheric instrument that has dramatically extended the envelope of atmospheric profiling capabilities. Since its debut in 1996, it has flown on numerous missions on NSF, NOAA, NASA and USAF aircraft in support of operational weather forecasting and atmospheric research, with impressive results.

The AVAPS Dropsonde System measures high-resolution vertical profiles of ambient temperature, pressure, humidity, wind speed, and wind direction. Measurements are taken by a parachuted dropsonde as it descends to the surface. Dropsondes are either launched manually or from a fully-automated system from an aircraft..

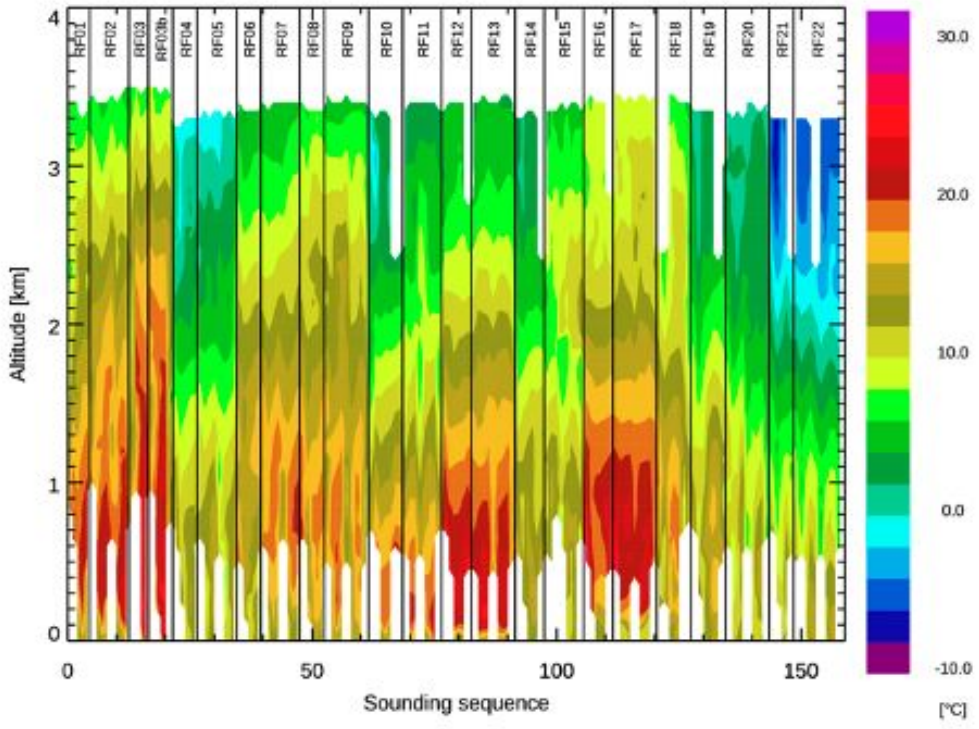
The dropsonde, which is composed of a small electronic circuit board, sensors, and a battery housed in a cardboard tube, collects in-situ data every half second, which provides a detailed profile of the atmosphere with high vertical resolution on the order of 5-20 meters. Data collected from the sonde's sensors are transmitted back in real time to an onboard aircraft data system via a radio link. Up to eight sondes can be rapidly released, providing a curtain of atmospheric profiles. Once the sonde has reached the surface, all data collected can be sent via satellite to the World Meteorological Organization's dedicated data centers as a BUFR message.

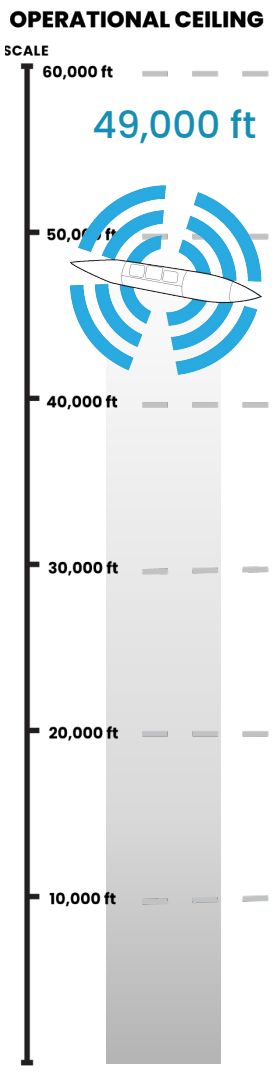
Atmospheric soundings from dropsondes provide the ability for targeted observations over remote areas such as the oceans, polar regions, and land masses; they also provide a means to obtain soundings in and around severe weather systems. Atmospheric soundings obtained from dropsondes during hurricane reconnaissance flights dramatically improve the accuracy of hurricane landfall forecasts.

UCAR has licensed Vaisala Inc. of Louisville, CO, to manufacture the NCAR GPS Dropsonde as Vaisala model RD41.



The data plot above shows the high-quality thermodynamic and wind data that the AVAPS Dropsonde System provides. The data plot below shows color contours of dropsonde temperature measurements taken during a sequence of 22 flights as part of the 2021 SWEX campaign.

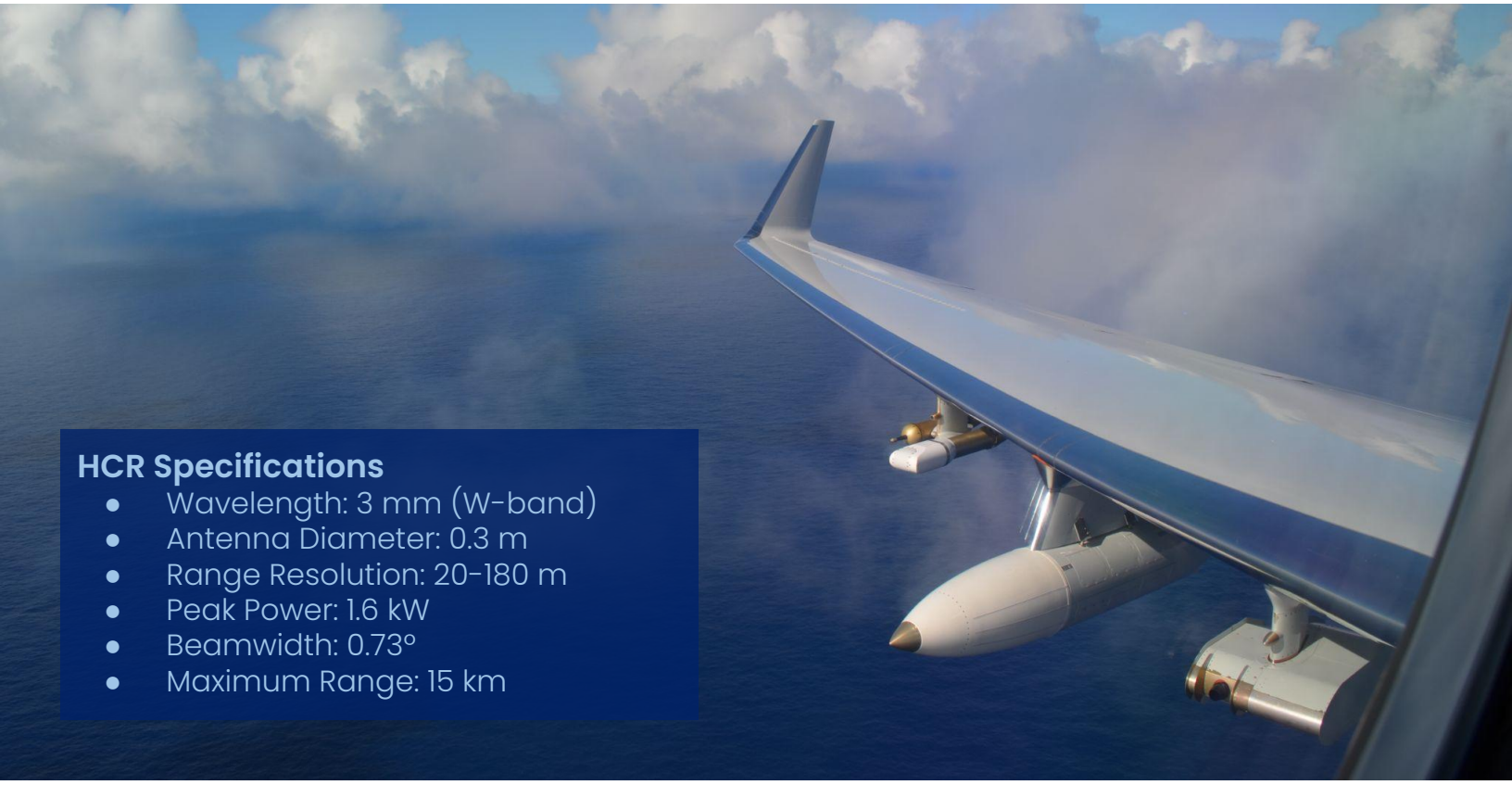




NCAR HCR

The **HIAPER Cloud Radar (HCR)** is an airborne, polarimetric, millimeter-wavelength Doppler radar that serves the atmospheric science community by providing cloud remote sensing capabilities on the NSF/NCAR HIAPER aircraft.

HCR provides unique observations of the formation and evolution of clouds. Its high sensitivity allows for the precise detection of liquid and ice clouds, aiding our understanding of the effects of clouds on the regional and global weather and climate. Derived scientific products, such as melting layer altitude, convective and stratiform echo type, or hydrometeor particle identification, provide additional information on the observed cloud and precipitation processes.

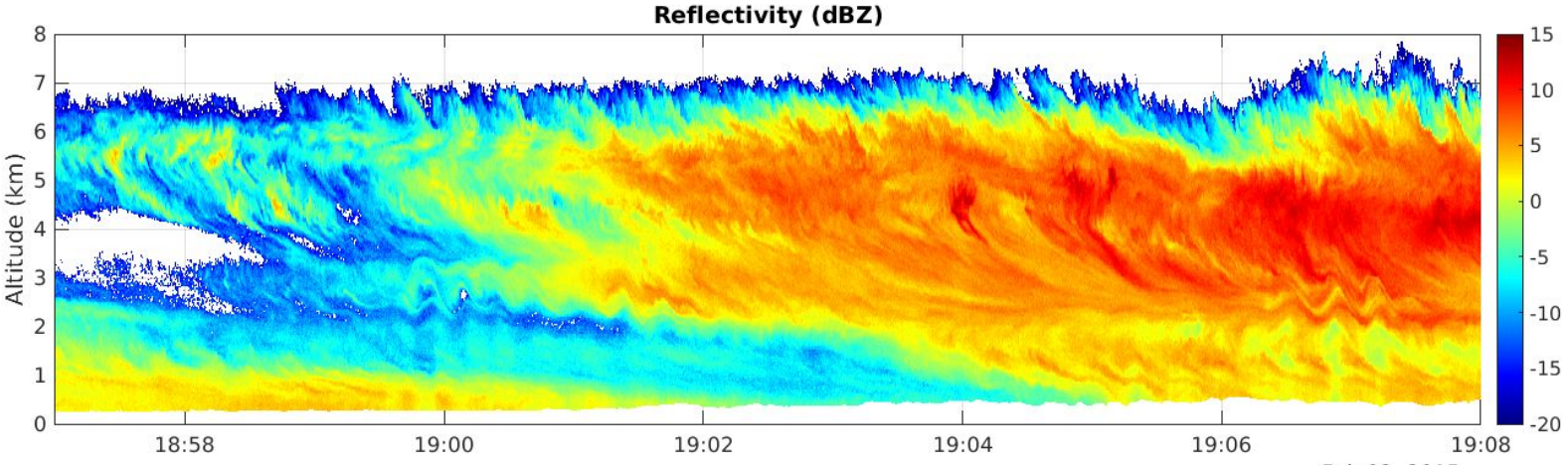


HCR Specifications

- Wavelength: 3 mm (W-band)
- Antenna Diameter: 0.3 m
- Range Resolution: 20-180 m
- Peak Power: 1.6 kW
- Beamwidth: 0.73°
- Maximum Range: 15 km

The HCR is mounted in the aircraft's underwing pod. A lens antenna illuminates a rotatable reflector, which allows for 240° cross-track scanning as well as staring, for example, at zenith or nadir. In staring mode, the beam is stabilized every 20 ms for changes in roll and pitch angles caused by platform motion. Measurements such as reflectivity, velocity, and dual-polarization variables are computed with a resolution of ~20 m in range and a temporal resolution of 10 Hz.

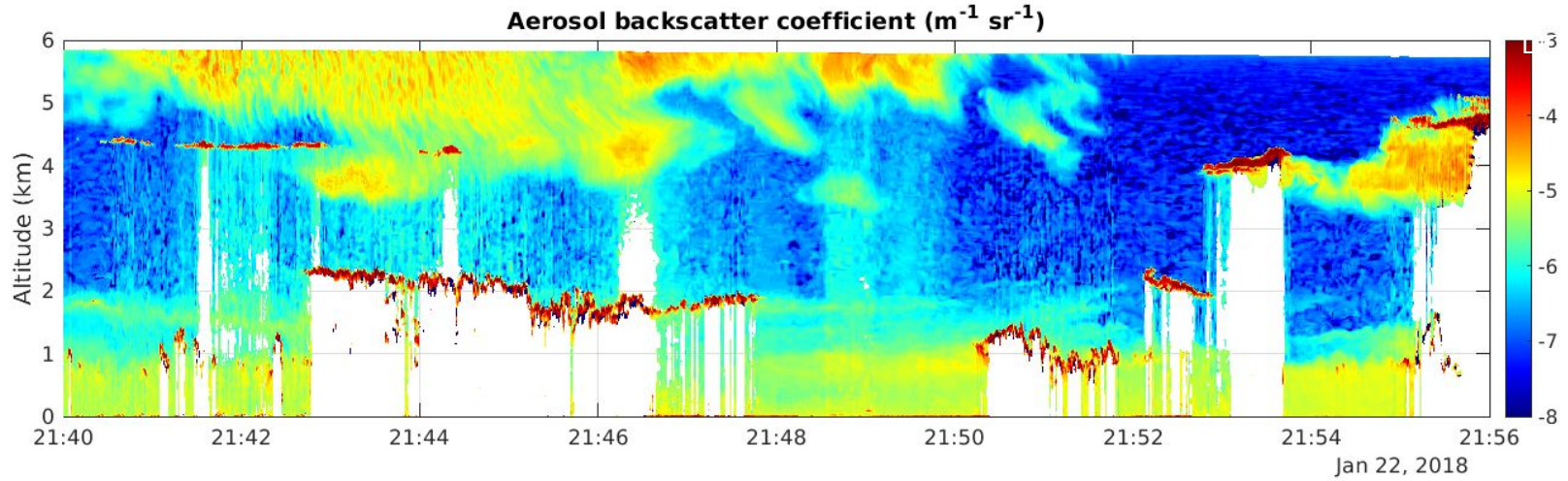
The data plot below illustrates some of the fine scale structural features observed by HCR during its maiden flight within a major Northeast US snow storm in February 2015.



NCAR High Spectral Resolution Lidar (HSRL)

The **NCAR GV High Spectral Resolution Lidar (GV-HSRL)** is an eye-safe, self-calibrated lidar that can measure backscatter coefficient, extinction coefficient, and depolarization properties of atmospheric aerosols and clouds. The system flies in the cabin of the NSF/NCAR HIAPER GV aircraft for upward and downward pointing observations.

HSRL is a self calibrating lidar technique that separates molecular backscattering from aerosol and cloud particle backscatter based on their Doppler spectrum widths. The molecular backscatter is used to calibrate the aerosol backscatter cross section from the ratio between the molecular signal and the aerosol signal. The aerosol extinction is calculated by comparing the expected molecular return to the actual molecular return signal. The instrument provides information used to characterize cloud and aerosol particles in order to create better models of the energy transfers in the atmosphere, and subsequently improve atmospheric and climate modeling for the planet.

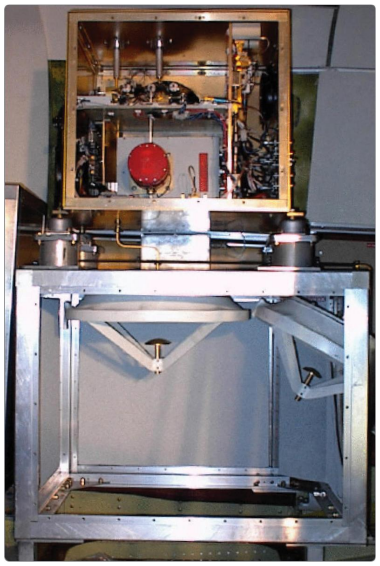


The GV-HSRL instrument provides real-time, calibrated vertical profiles along a single line of sight of various atmospheric parameters such as cloud optical depth, aerosol optical depth, backscatter coefficient, extinction coefficient, and particle depolarization (spherical irregularity).

The lidar is useful in determining atmospheric layers of interest and guiding the aircraft into these layers for in-situ measurements. The data plot above is an example of GV-HSRL airborne data collected during the SOCRATES campaign in 2018. The typical product resolution is 0.5s x 7.5 m with a range of 500 m to 12 km.

HSRL Specifications

- Wavelength: 532 nm
- Range Resolution: 7.5 m
- Temporal Resolution: 0.5 sec
- Vertical Resolution: 7.5 m



University of Wyoming Cloud Radar (WCR)

The **University of Wyoming Cloud Radar (WCR)** is an observational system for the study of cloud structure and composition. Principally paired with the UWKA-2, the WCR can also be installed on the NSF/NCAR C-130 or in the University of Wyoming Microwave Atmospheric Remote Sensing Mobile Laboratory (MARSF).

Operating at 95 GHz (3 mm wavelength), the radar provides high-resolution measurements of reflectivity, velocity, and polarization fields. The WCR provides continuous profiles of clouds and precipitation above and below the aircraft, from cloud top to the Earth surface, with a thin blind zone at flight level. Dual-Doppler synthesized winds can be obtained above and below flight level.

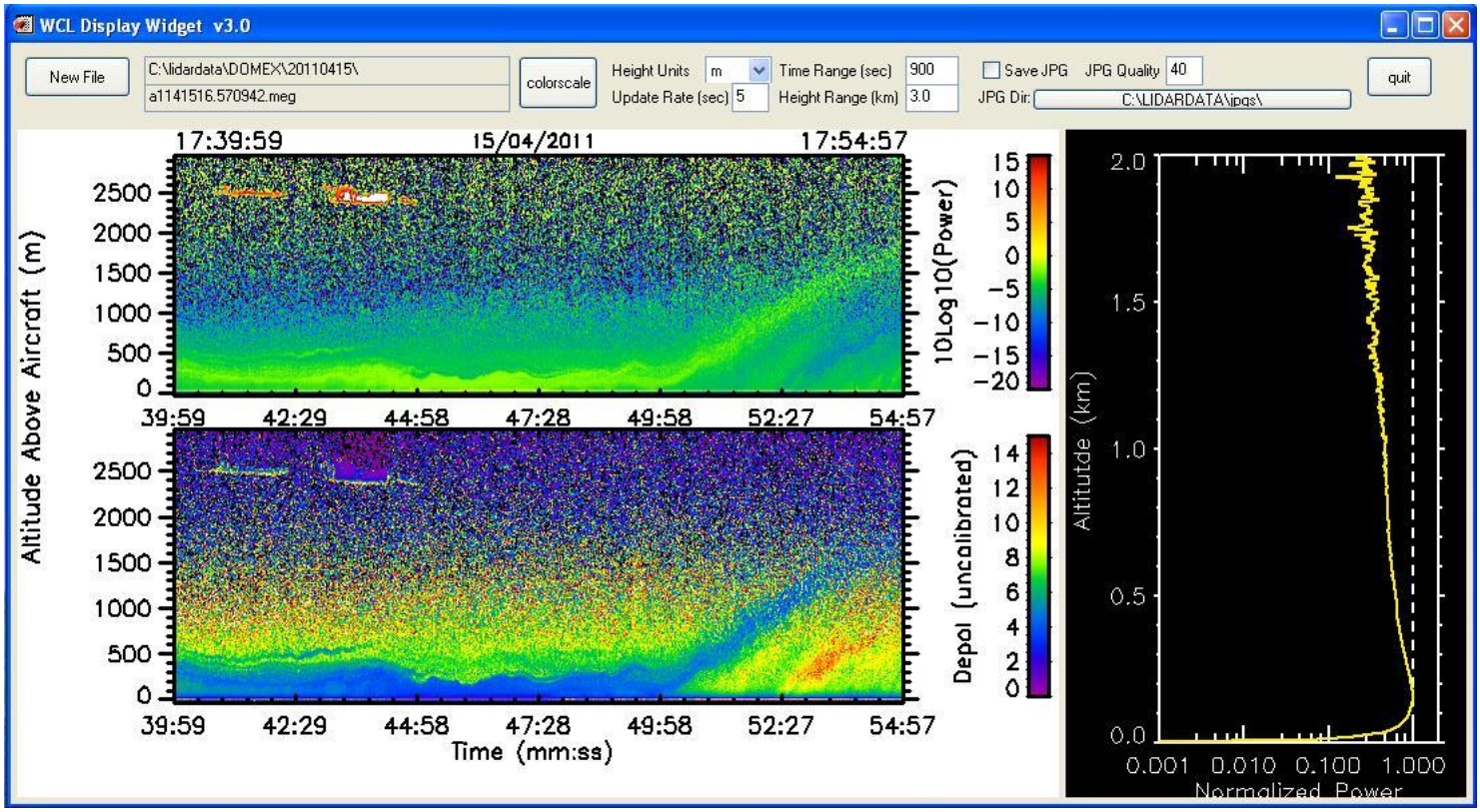
Coupled with the in-situ observations of hydrometeors and air motions from the same aircraft, these data yield unique information for analysis of cloud and precipitation processes.

Typical Research Applications

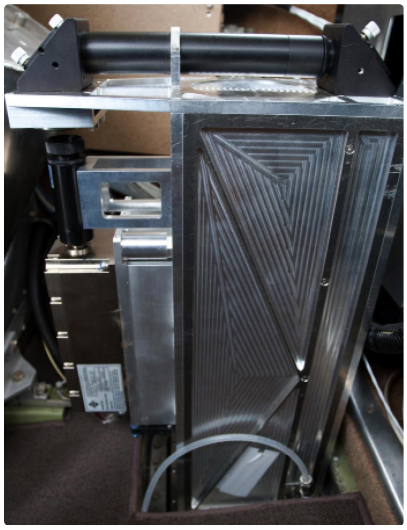
The WCR depicts reflectivity and velocity fields at a high spatial resolution and can collect data in situations for which traditional reflectivity would be too low. When the radar and lidar measurements are used together, researchers can obtain better cloud macrophysical and microphysical property characterizations than they have in the past.

Specifications

- Wavelength: 3 mm (W-band)
- Antenna Diameter: 0.30 to 0.46 m
- Range Resolution: 15 to 75 m
- Peak Power: 1.8 kW
- Beamwidth: 0.8° to 0.5°
- Maximum Range: 15 km



WCR reflectivity (top) and hydrometeor vertical velocity (bottom) from a January 2012 flight over the Sierra Madre in Wyoming during the ASCII field campaign. Note the mountain-induced wave and the hydraulic jump on the lee side of the mountain.



University of Wyoming Cloud Lidar (WCL)

The **Wyoming Cloud Lidar (WCL)** is an airborne observational system for the study of cloud structure and composition. It can be used as a ground-based facility, and the WCR and WCL can be used together on either the UWKA or the NSF/NCAR C-130 research aircraft.

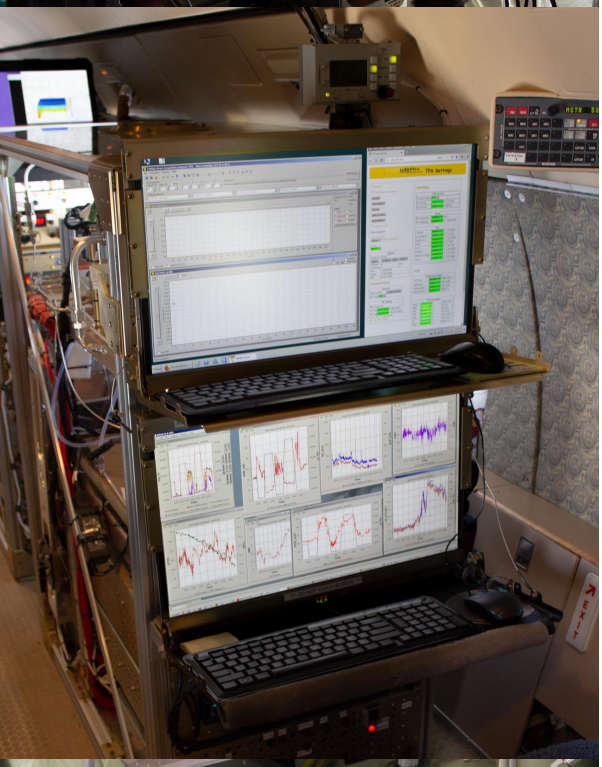
Operating at 355 nm (WCL-I) and 351 nm (WCL-II) wavelength, the lidar provides high spatial resolution cloud base measurements and depolarization profiles. Coupled with the in-situ observations of hydrometeors and air motions from the same aircraft, these data yield unique information for analysis of cloud and precipitation processes.

Typical Research Applications

The WCL depicts reflectivity and velocity fields at a high spatial resolution, and can collect data in situations for which traditional reflectivity would be too low. When the radar and lidar measurements are used together, researchers can obtain better cloud macrophysical and microphysical property characterizations than they have in the past.

Specifications for WCL-I and II

Wavelength	Upward 355 nm Downward 351 nm
Receiver Diameter	Upward 75 mm Downward 108 mm
Range Resolution	Upward 3.5 m and up Downward 1.5 m and up
Average Power	Upward 16 μJ Downward 200 μJ
Field of View	Upward 1-2 mrad Downward 1 mrad
Minimum Temporal Resolution	Upward 0.05 sec and up Downward 0.01 sec and up



TOGA: The Trace Organic Gas Analyzer

The NCAR Trace Organic Gas Analyzer (TOGA) is an *in-situ* instrument that provides near-continuous atmospheric mixing ratios of an extensive list of volatile organic compounds (VOCs). Since its debut in 2012, it has flown numerous missions on NSF and NASA aircraft in support of atmospheric research.

In 2019, the TOGA detector was upgraded to utilize a state-of-the-art TOFWERK high resolution electron ionization time-of-flight mass spectrometer (HR EI-TOF). The TOGA-TOF allows for greater selectivity and increased VOC separation in polluted and complex atmospheric mixtures providing more accurate measurements of a wider range of hard-to-measure gases.

The TOGA measures in the C_1-C_{10} molecular range including alkanes, alkenes, aromatic hydrocarbons, halocarbons, nitrates, nitriles, sulfides, alcohols, ketones, aldehydes, esters, and ethers. Trace gases are measured with sufficient sensitivity and dynamic range to provide VOC quantification from the remote background atmosphere to highly polluted air.

Detectable Species

Non-methane Hydrocarbons (NMHCs)	Oxidized Volatile Organic Compounds (OVOCs)	Halogenated VOCs
Propane Isobutane *n*-Butane Isopentane *n*-Pentane 2-Methylpentane 3-Methylpentane *n*-Hexane *n*-Heptane 2,2,4-Trimethylpentane *n*-Octane 1-Butene+Isobutene Benzene Toluene Ethylbenzene *p*-/*m*-xylene *o*-xylene Styrene Ethynylbenzene Trimethylbenzenes Ethyltoluenes	Formaldehyde Acetaldehyde Propanal Butanal Acrolein 2-Butenal (Crotonaldehyde) Acetone MEK 2,3-Butanedione Methanol Ethanol 2-Propanol Acrolein MTBE Ethylene Oxide Methyl formate Methyl acetate Ethyl acetate Furan Methylfurans Furfurals THF (Tetrahydrofuran) Dimethylfurans Ethylfurans	CFC-11 CFC-113 CFC-114 HFC-134a HCFC-22 HCFC-141b HCFC-142b PCBTF Methyl chloride Dichloromethane Chloroform Chloroethene Dichloroethenes Trichloroethene Tetrachloroethene Chlorobenzene Methyl bromide Dibromomethane Bromoform Methyl iodide Diiodomethane Ethyl iodide Bromodichloromethane Dibromochloromethane
Biogenic VOCs	**Nitrates, Nitriles, & Other Nitrogen-containing VOCs**	**Sulfur-containing VOCs**
Isoprene MVK Methacrolein MBO (2-Methyl-3-buten-2-ol) α-Pinene β-Pinene+Myrcene Camphene Limonene+3-Carene Tricyclene	HCN Acetonitrile Propanenitrile Acrylonitrile Methylacrylonitrile Nitromethane Methyl nitrate Ethyl nitrate Propyl nitrates Butyl nitrates	Carbonyl sulfide Carbon disulfide Methanethiol Dimethyl sulfide Carbon suboxide

Key Features

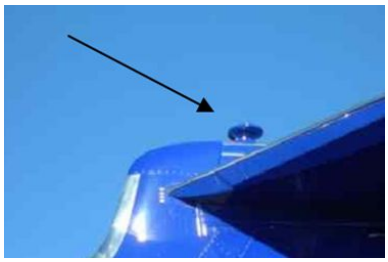
- Fast online GC-HTOF-MS
- Wide dynamic range
- Measures > 100 VOCs
- Operates from surface to 50,000 ft
- In-flight blanks and calibrations

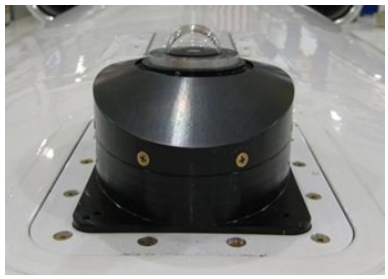
- Uncertainty (VOC specific): typically 20%
- Precision: 3%
- Detection limits: ppt to sub-ppt
- Response: 35-s samples on a 2-min cycle
- Power consumption: 1 kW

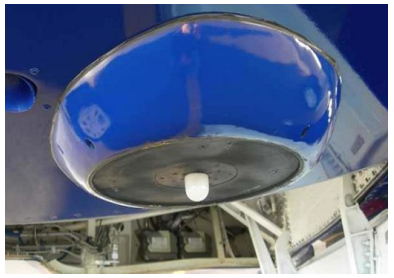
HIAPER Airborne Radiation Package (HARP)

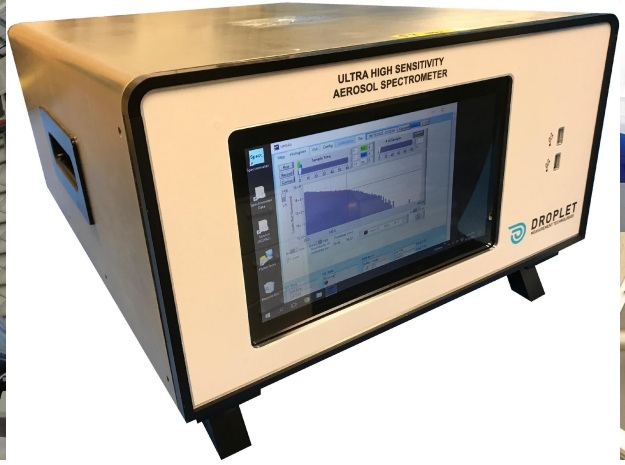
NCAR ACOM maintains and operates the **HIAPER Airborne Radiation Package (HARP)** for installation on the NSF/NCAR GV and C-130 aircraft. The HARP package consists of two components: upward and downward spectrally resolved actinic flux and spectral irradiance measurements. The actinic flux characterizes the photochemical radiation environment and is used for the calculation of photolysis rates. The irradiance provides surface, cloud, and aerosol properties and characterizes the energy distribution in the atmosphere related to climate.

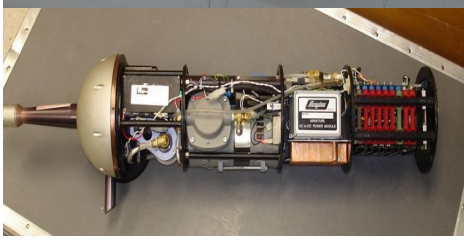
Airborne Radiation Measurements		
Actinic Flux	Irradiance SI	Irradiance InGcAs
Concentric domes	Integrating sphere	Integrating sphere
UV-VIS	VIS-NIR	NIR
280-680 nm	260–1090 nm	903-2217 nm
512 pixels	1024 pixels	256 pixels
0.8 nm sampling	0.8 nm sampling	5 nm sampling
1.7 FWHM @ 297 nm 2.4 FWHM @ 400 nm	3 FWHM	16 FWHM
4-6% uncertainty	3-5% uncertainty	
1 Hz response		
1% precision		











NCAR Aerosol Sensors

NCAR EOL operates and maintains various *in-situ* instruments and samplers which provide aerosol sensing capabilities on the NSF/NCAR GV and C-130 aircraft.

- **Ultra-High Sensitivity Aerosol Spectrometer (UHSAS-G)**

  Aerosol size distribution and concentration

- **Passive Cavity Aerosol Spectrometer Probe (PCASP)**

  Size distribution and concentration of aerosol particles

- **Condensation Nuclei (CN) Counter**

  Ambient concentration of aerosol particles larger than 11 nm in diameter that serve as condensation nuclei

- **Counterflow Virtual Impactor (CVI)**

  Samples cloud droplets or crystals > 8 µm

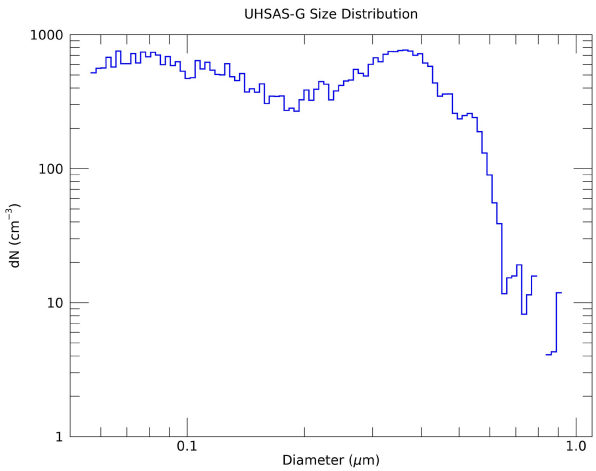
- **Solid Diffuser Inlet (SDI)**

  Aerosol inlet designed to create isokinetic flow conditions to minimize aerosol loss from sampling

Ultra-High Sensitivity Aerosol Spectrometer (UHSAS-G)

Size-resolved aerosol concentrations

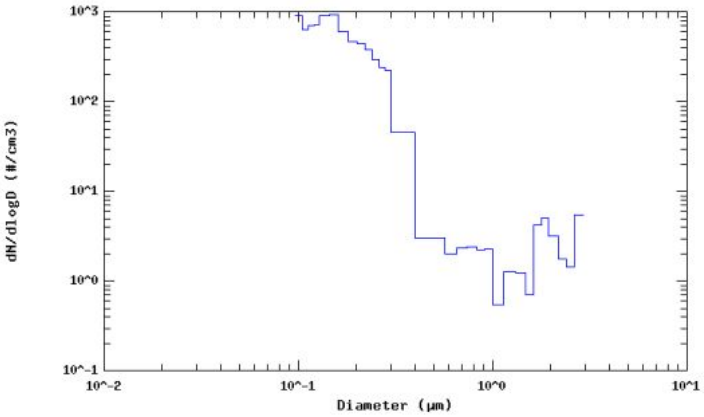
Diameter	0.055– 1 µm, 99 bins
Range of operation	Ground to 50,000 ft
Sampling rate	1-Hz



Passive Cavity Aerosol Spectrometer Probe (PCASP)

Size distribution and concentration of aerosol particles

Diameter	0.1– 3 µm, 30 bins
Range of operation	Ground to 26,000 ft
Sampling rate	10-Hz

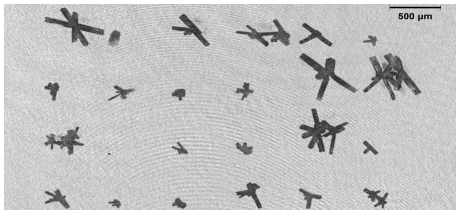


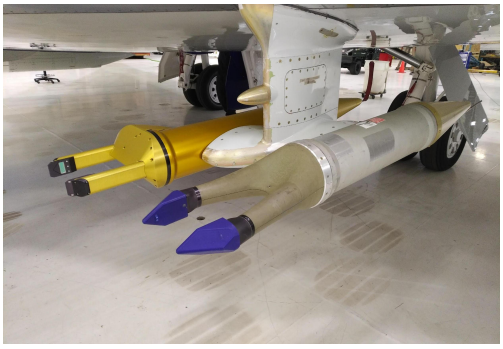
Condensation Nuclei (CN) counter

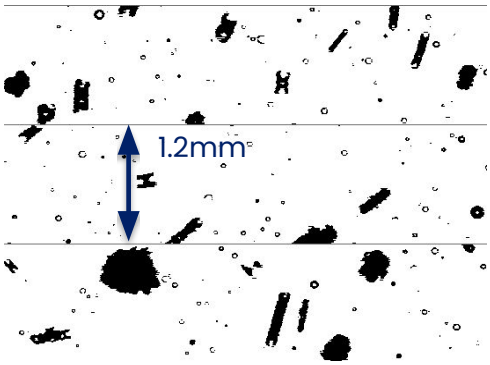
Ambient concentration of aerosols that serve as condensation nuclei

Uncertainty	< 10%
Concentration range, with coincidence Correction applied	up to 100,000 cm^{-3}
Sampling rate	10-Hz

Collectively, the NCAR aerosol sensor suite provides measurements of aerosol concentrations, size distribution, and abundance of condensation nuclei. These observations can be used to advance our knowledge of air quality, climate dynamics, and the complex interactions between aerosols and the atmosphere.







NCAR In-situ Cloud Measurements

The NSF/NCAR GV and C-130 aircraft can be fitted with an array of wing mountable sensors for in-situ cloud characterization:

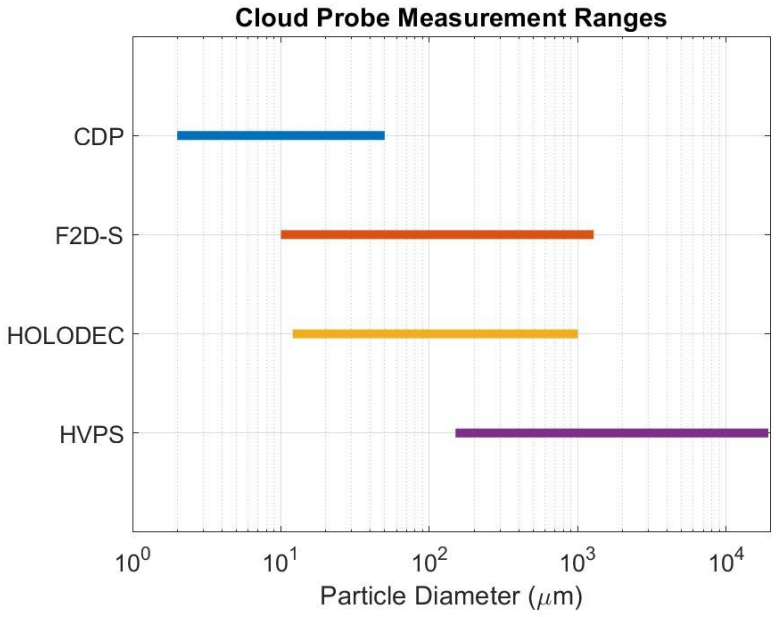
- King Liquid Water Probe
- Cloud Droplet Probe (CDP)
- Two-Dimensional Optical Array Cloud Probe (2D-C, 2D-P, 2D-S)
- Holographic Detector for Clouds (HOLODEC-II)
- High Volume Precipitation Sensor (HVPS-3)
- Rosemount Icing Probe (RICE)

Collectively, the RAF cloud probe suite of in-situ sensors observes cloud droplets, drops, precipitation, particles and ice habits. Together, this suite characterizes the cloud particle size, concentration, area, mass, phase (liquid/ice), as well as particle shape or habit.

Cloud Sensor Suite			
CDP	F2D-S	HVPS-3	HOLODEC-II
size, number, spectra			
	extinction, area, mass		extinction, area, mass, position
2-50 µm range	10-2000 µm range	150-19200 µm range	13-1000 µm range
2 µm resolution	10 µm resolution	150 µm resolution	1 µm resolution
25 Hz, 1 Hz	1 Hz		3 Hz
circular area assumed	Particle cross-sectional area is measured spectrally from particle images		
Liquid, mixed, ice clouds			

The NCAR in-situ cloud measurements facilitate the understanding of cloud physics, cloud formation processes, and their impact on atmospheric dynamics, weather, and climate.

Data provided from this array of sensors is valuable for improving weather forecasting, climate modeling, and our general understanding of Earth's atmosphere.



The range of particle diameters observed with the NCAR RAF in-situ cloud sensor suite. The full sensor suite can detect particles from 2 – 19200 µm

LAOF AIRBORNE INSTRUMENTATION	NSF/NCAR Aircraft	
Standard Instrumentation - NCAR (Provided on all projects)	**GV**	**C-130**
Static Pressure	✓	✓
Dynamic Pressure	✓	✓
Cabin Pressure	✓	✓
Ambient Temperature	✓	✓
Chilled Mirror Dew	✓	✓
Aircraft Position, Altitude, Ground Relative Speeds, Accelerations and Attitude Angles (IRU)	✓	✓

Standard Instrumentation - NCAR (cont'd) **(Provided on all projects)**	**GV**	**C-130**
GPS w/ TerraStar C accuracy	✓	✓
3-Dimensional Wind Fields	✓	✓
Icing Rate (presence of supercooled liquid water)		✓
King Probe Cloud Liquid Water Content	✓	✓
Remote (infrared) Surface Temperature		✓
Gas Dump Manifold Pressures	✓	
Forward Digital Video (GV - only with pylons installed)	✓	✓
SATCOM	✓	✓
XCHAT	✓	✓
Real-time Data Transfer to Ground	✓	✓
Real-time Display incl. maps, video, time series etc.	✓	✓

In-situ Vertical Profiling- NCAR **(Available by Request)**	**GV**	**C-130**
AVAPS® Dropsonde System*	✓	✓
*AVAPS can also be requested to operate on the UWY King Air and various NASA, NOAA and other research aircraft		

Cloud Measurements - NCAR **(Available by Request)**	**GV**	**C-130**
Cloud Droplet Probe (CDP) (2 – 50 µm range), water droplets, ice crystals	✓	✓
OAP 2DS Cloud Probe (2D-S stereo probe, 10 µm resolution, 128 bins), ice, water	✓	✓
OAP HVPS-3 Precipitation Probe (150 µm resolution, 128 bins)	✓	✓
HOLODEC-II Cloud Particle Imager	✓	✓
King Probe Cloud Liquid Water Content	✓	✓
Rosemount Icing Detector (RICE) (presence of supercooled liquid water)	✓	✓
Counterflow Virtual Impactor (CVI) (with water vapor TDL)	✓	✓
Counterflow Virtual Impactor (CVI) (with water vapor TDL and optional "add-on" CN counter)	✓	✓
OAP 2D-C 10 µm (2-D imaging spectrometer), 20 – 640 µm, ice, water	✓	✓
OAP 2D-C 25 µm (2-D imaging spectrometer), 50 – 1600 µm, ice, water	✓	✓
Gulfstream V High Spectral Resolution Lidar (GV-HSRL)	✓	
HIAPER Cloud Radar (HCR)	✓	
Cloud Measurements - University of Wyoming **(Available by Request)**	**UWKA -2**	**C-130**
Wyoming Cloud Radar (WCR) [UWyo]	✓	✓
Wyoming Cloud Lidar (WCL) [UWyo]	✓	✓

Radiative Measurements - NCAR **(Available by Request)**	**GV**	**C-130**
Remote (infrared) Sky Temperature (Heitronics KT19.85 radiation pyrometer)	✓	✓
Remote (infrared) Surface Temperature (Heitronics KT19.85 radiation pyrometer)	✓	✓
Radiometric Air Temperature	✓	✓
Shortwave (solar) irradiance (CMP22 Pyranometer - visible broadband radiometer), not stabilized	✓	
Shortwave (solar) irradiance (CMP22 Pyranometer - visible broadband radiometer), stabilized		✓
Infrared irradiance (CGR4 Pyrgeometer - infrared broadband radiometer), not stabilized	✓	
Infrared irradiance (CGR4 Pyrgeometer - infrared broadband radiometer), stabilized		✓
HIAPER Airborne Radiation Package (HARP), actinic flux [ACOM]	✓	✓
HIAPER Airborne Radiation Package (HARP), spectral irradiance [ACOM]	✓	✓
Microwave Temperature Profiler (MTP)	✓	

State Parameters & Wind Measurements- NCAR	GV	C-130
Heated Ambient Temperature Sensor	✓	✓
High Rate Ambient Temperature Sensor	✓	✓
Thermo-electronic Dew Point Sensor	✓	✓
Buck Instruments Model CR-2 Cryogenic Hygrometer	✓	✓
Ultraviolet Absorption Hygrometer		✓
Vertical Cavity Surface-Emitting Laser (VCSEL) Hygrometer	✓	✓
All-Weather Wind Gust Pod (anti-iced)	✓	
Ambient Static Pressure	✓	✓
Laser Air Motion Sensor (LAMS) [1, 3, and 4 (beam(s)]	✓	✓

Aerosol Measurements- NCAR **(Available by Request)**	**GV**	**C-130**
Condensation Nucleus (CN) Counter – (Butanol, low altitude only)	✓	✓
Counterflow Virtual Impactor (CVI) (water vapor TDL)	✓	✓
Counterflow Virtual Impactor (CVI) (with CN counter and water vapor TDL)	✓	✓
Gulfstream V High Spectral Resolution Lidar (GV-HSRL)	✓	
Ultra-High Sensitivity Aerosol Spectrometer (UHSAS), 0.06 - 1 µm, aerosols	✓	✓
Auto Giant Nuclei Impactor (GNI) (sea salt, 2-30 µm), 0.4 µm resolution, aerosols, salt	✓	
Manual GNI Giant Aerosol Impactor (sea-salt, 2 – 32 µm range)		✓
Passive Cavity Aerosol Spectrometer Probe (PCASP) (0.1 – 3 µm range)		✓
Condensation Nucleus (CN) Counter – (Butanol, low altitude only)	✓	✓

Gas Measurements- NCAR **(Available by Request)**		
Airborne Carbon Dioxide (CO_2), Methane (CH_4), Carbon Monoxide (CO), and Water Vapor [ACOM]	✓	✓
Aero-Laser Carbon Monoxide (CO) [ACOM]	✓	✓
QCL Carbon Monoxide (CO) and Nitrous Oxide (N_2O) [ACOM]	✓	✓
Water Vapor Isotopic Analyzer (WVISA) [EOL]	✓	✓
Fast Ozone (O3) [ACOM]	✓	✓
Total Organic Gas Analyzer (TOGA) (C2 - C10 organic range) [ACOM]	✓	✓
Airborne Whole Air Sampler (AWAS) [EOL]	✓	✓
Chemical Ionization Mass Spectrometer (CIMS) (SO2, HNO3, HNO4, HNO2 and others) [EOL]	✓	✓
Medusa Flask Sampler [EOL]	✓	✓
Airborne Oxygen Analyzer (AO2) [EOL]	✓	✓
NO and NO2 [ACOM]	✓	✓

Other Measurements- NCAR **(Available by Request)**		
Digital Video (forward, down, side) with optional date/time stamp	✓	✓
HIAPER Modular Inlets (HIMIL inlets)	✓	✓

NCAR
EOL

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