HIAPER Cloud Radar (HCR) data (CfRadial), Version 3.0

Changes from Version 2.1

Improvements to the ANTSTAT field were made.

A velocity de-aliasing scheme has been developed and was applied in the new VEL_UNFOLDED field. Data from times where HCR was in ANTSTAT modes other than zenith or nadir were masked out in VEL_UNFOLDED and the resulting field is available as VEL_MASKED. We recommend using VEL_MASKED as the standard radial velocity field for most purposes.

New experimental fields were added and we welcome feedback on their performance:

An echo type classification algorithm ECCO-V (Echo Classification from COnvectivity - Vertical pointing) was developed and applied. It adds a 2D (time, range) CONVECTIVITY field, which provides a quantitative measure of how convective each gridpoint is, with 0 indicating all stratiform and 1 indicating all convective echo. CONVECTIVITY is then translated into a 2D convective/stratiform partitioning field ECHO_TYPE_2D which provides several convective/stratiform echo classifications. The 2D field is composited into a 1D (time) ECHO_TYPE_1D field. Details can be found in Romatschke and Dixon (2022).

Particle IDentification (PID) was added with a newly developed algorithm which is based on a fuzzy logic scheme. It identifies different sizes of particles and in some cases provides particle phase (liquid/frozen). Details can be found in Romatschke and Vivekanandan (2022).

Overview

This dataset contains HIAPER Cloud Radar (HCR) data collected aboard the NSF/NCAR GV HIAPER (Gulfstream-V High-performance Instrumented Airborne Platform for Environmental Research, HIAPER) (N677F) during SOCRATES (Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study). The data were collected during 15 research flights which took place between January 15 and February 24, 2018, over the Southern Ocean south of Australia. For more information on SOCRATES, see www.eol.ucar.edu/field_projects/socrates.

Flight	Start date	Start time UTC	End date	End time UTC
RF01	20180115	21:50	20180116	05:30
RF02	20180119	00:00	20180119	07:15
RF03	20180122	19:25	20180123	03:45
RF04	20180123	21:20	20180124	06:10
RF05	20180125	21:55	20180126	05:30

RF06	20180128	21:25	20180129	06:10
RF07	20180130	23:30	20180131	07:50
RF08	20180203	21:40	20180204	06:45
RF09	20180204	22:10	20180205	06:55
RF10	20180207	19:25	20180208	05:00
RF11	20180216	23:35	20180217	06:20
RF12	20180217	22:10	20180218	07:45
RF13	20180219	21:25	20180220	06:25
RF14	20180221	22:10	20180222	06:40
RF15	20180224	01:50	20180224	08:35

Instrument description

HCR is an airborne, polarimetric, millimeter-wavelength (W-band) radar that serves the atmospheric science community by providing cloud remote sensing capabilities to the NSF/NCAR G-V (HIAPER) aircraft. HCR detects drizzle, and ice and liquid clouds, and collects Doppler radial velocity measurements, which at vertical incident include the vertical wind speed and particle fall speed.

In a pod-based design, a single lens antenna is used for both transmit and receive. The transceiver uses a two-stage up and down conversion superheterodyne design. The transmit waveform, from a waveform generator, passes through the two-stage up-conversion to the transmit frequency of 94.40 GHz. It is then amplified by an extended interaction klystron amplifier (EIKA) to 1.6 kW peak power. System performance on transmit and receive paths are closely monitored using a coupler and a noise source. Raw in-phase and quadrature information are archived in HCR. For more information, see Vivekanandan et al. (2015) and www.eol.ucar.edu/instruments/hiaper-cloud-radar-hcr

HIAPER Cloud Radar Specifications	
Parameter	**Specification**
Antenna	0.30 m, lens
Antenna gain	46.21 dB
Antenna 3 dB beam width	0.73°
Transmit Polarization	Linear (V)
Transmit frequency	94.40 GHz
Transmitter	Klystron
Peak transmit power	1.6 kW
Pulse width	0.2 – 1.0 μs

PRF	up to 10 kHz
System noise power	-101 dBm
Receiver noise figure	8.9 dB
Receiver Bandwidth	20 MHz
Receiver Dynamic Range	76 dB
First IF	156.25 MHz
Second IF	1406.25 MHz
Range resolution	20 - 180 m
Unambiguous range	15 km
Typical reflectivity uncertainty	0.4 dB
Sensitivity	-35.0 dBZ at 1 km and 256 ns pulse
Unambiguous velocity	±7.75 m/s
Typical radial velocity uncertainty	0.2 m/s at W=2 m/s
Dwell time	100 ms

Data description

The 10 Hz moments data described here are available at http://data.eol.ucar.edu/dataset/552.007 in CfRadial format. For more information on CfRadial see www.ral.ucar.edu/projects/titan/docs/radial_formats/CfRadialDoc.pdf. This data set contains all HCR variables at high resolution. A data set which contains only the primary HCR variables at 2Hz resolution combined with data from the High Spectral Resolution Lidar (HSRL) is available at http://data.eol.ucar.edu/dataset/552.034.

The primary data products for scientific use are listed in the table below.

Variable	**Dimensions**	**Unit**	**Long Name**
time	time	seconds	Time in seconds since volume start
range	time	meters	Range from instrument to center of gate
latitude	time	deg	Latitude
longitude	time	deg	Longitude
altitude	time	meters	Altitude of radar
DBZ	time, range	dBZ	Reflectivity
DBZ_MASKED	time, range	dBZ	Reflectivity of cloud echo only (DBZ(FLAG>1)=NAN, see

			FLAG below)
VEL_MASKED	time, range	m/s	Motion and bias corrected and de-aliased Doppler velocity
WIDTH	time, range	m/s	Spectral width
SNR	time, range	dB	Signal to noise ratio
DBMVC	time, range	dBm	Log power co-polar v transmit, v receive
DBMHX	time, range	dBm	Log power cross-polar v transmit, h receive
NCP	time, range		Normalized coherent power
LDR	time, range	dB	Linear depolarization ratio (V/H)
PRESS	time, range	hPa	Air pressure from ERA5
TEMP	time, range	C	Air temperature from ERA5
RH	time, range	%	Relative humidity from ERA5
SST	time	C	Sea surface temperature from ERA5 forecast
U_SURF	time	m/s	Surface U wind component from ERA5 forecast
V_SURF	time	m/s	Surface V wind component from ERA5 forecast
TOPO	time	m	Terrain elevation above mean sea level from GTOPO30
FLAG	time, range		See Romatschke et al. (2021) Flag field to classify reflectivity (to mask unwanted data): 1 Cloud 2 Speckle (contiguous 2D echo areas of < 100 pixels) 3 Extinct (signal completely attenuated) 4 Backlobe echo (reflection from the land/sea surface when zenith pointing and flying low) 5 Out of range (second trip echo from land/sea surface when flying too high) 6 Transmitter pulse (echo from within the radar itself) 7 Water surface echo 8 Land surface echo 9 Below the surface 10 Noise source calibration 11 Antenna in transition (e.g. from nadir to zenith or vice versa) 12 Missing (not transmitting)
ANTFLAG	time		Flag field to indicate the status of the antenna: 1 Down (nadir pointing) 2 Up (zenith pointing) 3 Pointing (pointing to an angle different from nadir or zenith) 4 Scanning (e.g. sea surface calibration) 5 Transition (e.g. from nadir to zenith) 6 Failure

MELTING_LAYER	time, range		See Romatschke (2021) 10 below icing level 11 ERA5 0 °C isotherm below icing level 12 detected melting layer below or at icing level 13 interpolated melting layer below or at icing level 14 estimated melting layer below or at icing level 20 above icing level 21 ERA5 0 °C isotherm above icing level 22 detected melting layer above icing level 23 interpolated melting layer above icing level 24 estimated melting layer above icing level
ICING_LEVEL	time	m	Icing level altitude, which is defined as the lowest melting layer
ECHO_TYPE_2D	time, range		See Romatschke and Dixon (2022) 14 stratiform low 16 stratiform mid 18 stratiform high 25 mixed 30 convective 32 convective elevated 34 convective shallow 36 convective mid 38 convective deep
ECHO_TYPE_1D	time		As ECHO_TYPE_2D
PID	time, range		See Romatschke and Vivekanandan (2022) 1 rain 2 supercooled rain 3 drizzle 4 supercooled drizzle 5 cloud liquid 6 supercooled cloud liquid 7 melting 8 large frozen 9 small frozen 10 precipitation 11 cloud

Data processing and quality control

A detailed description of the data processing and quality control procedures can be found in Romatschke et al. (2021).

Noise source calibration and temperature dependency correction

As an external, pod-mounted system, which is deployed in a wide range of altitudes, HCR experiences large temperature variations. To maintain good system calibration, it is essential to monitor the radar system performance versus temperature. In order to ensure operational accuracy, a number of noise source calibration (NSC) events were performed during research flights, and on the ground. During each NSC event, a known noise signal, which is invariant to temperature changes, is injected into the radar and then used to characterize the receiver gain changes by comparing the received power (DBMVC) to a temperature-corrected noise power.

As the low noise amplifiers (LNAs) dictate the receiver's performance, they are outfitted with heater circuits to maintain their temperatures between 37^0 and 40^0 C in the bench test environment. During deployment, as the heaters cycle on and off, the received power level (DBMVC) directly correlates to the temperature fluctuations, leading to a sinusoidal pattern when installed in the system. In some extreme cases, after flying at high altitudes and low temperatures for several hours, the heaters of the LNAs could not keep up with the heat loss to the environment, leading to a significant decline of the received power. Using the correlation between the LNA temperature and the received power level during the NSC events we calculated the correlation equation which we used (together with the calibration data obtained in the lab) to correct the power fields (DBMVC, DBMHX, and DBZ) for LNA temperature changes in the whole data set.

As mentioned above, the received power not only depends on the LNA temperatures but also on the pod temperature. After correcting for the LNA temperature changes we were able to establish a correlation between the pod temperature and the power output during the NSC events which was then again used to correct the whole data set. (Note that we define a mean of the Noise Source, EIK, Polarization Switch, and RF Detector temperatures as the "pod temperature".)

Sea surface calibration check

Based on the work of Li et al. (2005) we use the backscattering properties of the ocean surface to assess how well HCR reflectivity is calibrated. Sea surface calibration (SSC) events were performed during research flights, each consisting of a few minutes of cross-track scanning from 20° to -20° off-nadir. Again following Li et al. (2005) we used

$$\sigma_{0meas} = dBZ + 10log_{10}\left(\frac{\pi^5 c\tau\left|K\right|^2}{2\lambda^4 10^{18}}\right) + 2l_{a0} - 10log_{10}\left(cos\Theta\right)$$

to calculate the normalized radar cross section $\sigma_{0\,meas}$ of HCR in dB, where Z is the measured reflectivity, c is the speed of light m s^{-1}, τ is the pulse width s, $|K|^2$ is the radar dielectric factor, λ is the signal wavelength in m, l_{a0} is the nadir atmospheric attenuation in dB, and Θ is the elevation angle in degrees.

The measured $\sigma_{0\,meas}$ is then compared to theoretical values of the normalized ocean surface radar cross section $\sigma_{0\,theory}$ which were obtained from three models by Cox and Munk (1954), Freilich and Vanhoff (2003), and Wu (1972, 1990). $\sigma_{0\ theory}$ depends on the surface wind speed, and the sea surface temperature (SST). A weak dependency on ocean salinity is ignored. The wind speed and SST are obtained from ERA5 data.

The atmospheric attenuation was calculated using the methods of Liebe (1985) and the ITU Recommendation (2013). Both methods depend on atmospheric pressure, temperature, and relative humidity which are again obtained from ERA5 data. The attenuation results of the two methods differed by ~0.2 dB.

Comparison of $\sigma_{0\ meas}$ and $\sigma_{0\ theory}$ reveals a bias of $\sigma_{0\ meas}$ - $\sigma_{0\ theory}$ = ~1-2 dB depending on the model and the specific SSC event. That means that the HCR reflectivity data is likely biased high by between 1 and 2 dB.

Velocity correction

The radial velocity is corrected for platform motion using two different methods. The first corrects for platform motion using INS/GPS measurements. It is applied to all of the data. An additional correction is applied to the nadir-looking data only: The radial velocity of the surface, which is assumed to be 0 m/s, is used as a reference to correct the data with a running 3rd degree polynomial filter of length 20 seconds (Ellis et al., 2019).

Width correction

The radar has a 0.73 degree beam width. Therefore, when pointing nadir or zenith, the beam spread is about 0.36 degrees forward of vertical, and 0.36 degrees aft of the vertical. The sine of 0.36 degrees is 0.006, so at a ground speed of 200 m/s the velocity error at the forward edge of the beam is -0.006 x 200 = -1.2 m/s, since the motion is towards the radar. Similarly the velocity error at the aft edge of the beam is +1.2 m/s. These errors, across the width of the beam, increases the variance of the measured velocity, and hence increase the spectrum width. The computed width correction (delta below) is based on ground speed and beam width, and attempts to correct for this increase.

$$\delta = |(0.3 * speed * sin(elevation) * beamWidthRadians)|$$
$$corrected = \sqrt(measured^2 - \delta^2)$$

Known problems

Radial velocity

The surface based velocity correction worked well the majority of the time, however there are some regions in which problems were noted. These problems manifest themselves as columns of biased radial velocity at each range bin over several rays. We think these velocity pillars are caused by the filtering process over-smoothing surface velocity variations due to variable pointing error (Ellis et al. 2019).

Another problem that cannot be corrected is, that the radar, while it rotates 360˚ around the along-plane axis, has only limited range of motion along the cross-plane axis. This means, that when the plane has significant pitch, e.g. during steep climbs, the tilt angle correction of the radar is not sufficient, reports erroneous angles, and the first step of the velocity correction fails. In nadir pointing mode, this can partly be compensated with the second correction step but in zenith pointing mode the velocities are unreliable in these situations.

Backlobe echo in zenith pointing

When the HCR is pointing at zenith and the GV is near the surface, there is often an echo that results from the backlobe of the radar reflecting off of the surface. This backlobe contamination is typically characterized by a band of low reflectivity, highly variable radial velocity, and high spectrum width. The backlobe appears in the zenith data at a range equal to the altitude of the radar. So as the GV ascends or descends the backlobe contamination will recede and approach in range, respectively. An attempt was made to identify the backlobe echo and flag it in the FLAG field but the identification process does not always completely remove all backlobe echo.

Period in RF05 during which transmit was in H instead of V mode

During RF05, on 2018/01/26, from 01:50 to 02:15, the transmitter was transmitting in the H channel instead of the V channel. Care should be taken in using some of the data fields in this period:

- The reflectivity calibration is incorrect for H transmit
- The SNRVC, SNRHX, DBMVC and DBMHX fields will be missing during this period.
- The velocity and spectrum width are unaffected, as is NCP.

Periods during which the HCR transmitter was disabled

In the HCR data, there are some short periods during which the transmitter was disabled for safety reasons. These show up as gaps in the power fields.

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