Product handbook for the Airborne Precipitation Radar Second Generation (APR-2): GCPEX 4.0 and 2.0

Experiment: GPM Cold-Processes Experiment (GCPEX, Jan/Feb 2012, CARE site Canada, Great Lakes – Maine region)

Filename: APR2.yymmdd.hhmmss.40.HDF or APR2.yymmdd.hhmmss.20.HDF

Note: the yymmdd_hhmmss field in the filename indicates the UTC start time of the data.

Format: 4.X – Standard L1 product. Geolocated and calibrated radar reflectivity at Ku and Ka band, mean Doppler velocity and Linear Depolarization Ratio at Ku band, surface Normalized Radar Cross Section at Ku and Ka band.

Format: 2.X – Standard L1 product (see 4.X) + precalculated geodetic coordinates of every sample point.

Release: X.0

Change log:
X.0 – In field data, minor configuration and calibration changes applied during the experiment. **These data have passed preliminary QC and will be posted for the GPM, GCPEX team for beta testing. Users should be extremely cautious and contact the APR-2 team for any suspicious feature observed. Please read the known issues section.**

Data Format (version 4.x and 2.x)

APR-2 data are saved in HDF format.
The fileheader is stored as Vdata; the remaining items are Scientific Data Sets (SDSs).

Name	**format**	**size**	Units	Factor	**Notes**
fileheader	int32	18			See description in Table 2
scantime	int32	nscan x nray	s		Beginning of scan in seconds since 1 January 1970
scantimus	int32	nscan x nray	μs		Beginning of scan: microseconds past scantime
lat	float	nscan x nray	deg		From aircraft or MMS navigation files
lon	float	nscan x nray	deg		From aircraft or MMS navigation files
roll	float	nscan x nray	deg		From aircraft or MMS navigation files
pitch	float	nscan x nray	deg		From aircraft or MMS navigation files
drift	float	nscan x nray	deg		From aircraft or MMS navigation files
alt_nav	float	nscan x nray	m		From aircraft or MMS navigation files
alt_radar	float	nscan x nray	m		From APR-2 surface echo
look_vector	double	nscan x nray x 3			From P-3 navigation files
look_vector_radar	double	nscan x nray x 3			From APR-2 surface echo
range0	float	nscan x nray	Km		Distance of the first radar range bin from a/c
isurf	int32	nscan x nray			Index of radar range bin intersecting surface (starting from 0).
sequence	int32	nscan x nray			Ray number within the file
v_surfdc8	float	nscan x nray	m/s		Apparent surface Doppler velocity as estimated from P-3 navigation
v_surf	float	nscan x nray	m/s		APR-2 measured surface Doppler velocity
beamnum	float	nscan x nray			Ray number within a scan
surface_index	float	nscan x nray			Preliminary surface classification index

sigma_zero	float	nscan x nray x 2	dB		Surface NRCS (Ku and Ka band)
zhh14	int16	nscan x nray x nbin	dBZ	100	Radar Reflectivity at Ku band (scaled dBZ)
zhh35	int16	nscan x nray x nbin	dBZ	100	Radar Reflectivity at Ka band (scaled dBZ)
ldr14	int16	nscan x nray x nbin	dB	100	Linear Depolarization Ratio (scaled dB)
vel14	int16	nscan x nray x nbin	m/s	100	Doppler Velocity at Ku band (scaled m/s)

nscan is the number of scans in a file, nray is the number of rays, or beams, within a scan, and nbin is the number of range bins within a ray.

Missing data are replaced by –9999.

Altitude and Look Vector (i.e., the 3 components of the antenna relative to a global coordinate system with *x* being the aircraft ground track and *z* being vertical) are provided in two estimates: alt_nav and look_vector are calculated relying on the aircraft navigation information, instead alt_radar and look_vector_radar are calculated relying on the observed surface return in APR-2 data. The latter pair is reliable only when flying over ocean, and in this case it provides a more accurate geolocation than the navigation-based pair. See notes in the next section for specific recommendations with this data release.

The predicted (v_surf_nav) and observed (v_surf) surface Doppler velocities are provided: v_surf was corrected for occasional aliasing and, in turn, it was used to correct the Doppler measurements of precipitation for the bias introduced by the aircraft motion. This correction can be undone by the user by adding the value of v_surf from vel14 at all the range bins of every ray. The alternate correction using the Doppler estimated from navigation data can be then obtained by subtracting the value of v_surf_nav from vel14 at all the range bins of every ray. This alternate correction may be of interest for the minority of data collected over land where the v_surf estimate is more prone to errors, or for data collected during sharp maneuvers by the DC-8.

The surface index is estimated by analyzing APR-2 surface return (roughness, angle dependence of the surface normalized radar cross section, apparent surface inclination and LDR at nadir). It assumes one of 6 values (this classification is preliminary, see next section for known issues):

- 0 = Rough land
- 1 = Ocean (level flight)
- 2 = Ocean (roll maneuver)
- 3 = Flat land (level flight)
- 4 = Flat land (rolling maneuver)
- 5 = Antenna not scanning (unknown surface)

The file header contains information about the APR-2 data. These are parameters that are constant over the entire file. Table 4 shows the file header.
A sample Matlab routine is available for reading APR-2 HDF data. FORTRAN or C code can also be constructed using the HDF libraries available from NCSA.

File header

	Name	Format	Unit	Default	Description
1	PRF	Int 32	Hz	5000	Pulse repetition frequency in Hz
2	Pulse Length	Int 32	mus	3-20	Radar pulse length in 1 us units
3	Antenna Left	Int 32	deg	-25 or 0	Antenna scan left-limit in deg.
4	Antenna Right	Int 32	deg	+25 or 0	Antenna scan right-limit in deg.
5	Scan Duration	Int 32	ms	1200	Scan time for antenna in second * 100
6	Return Duration	Int 32	ms	600	Antenna retrace time in second * 100
7	Ncycle	Int 32		250	Number of pulse averaged by Wildstar board
8	AZ Average	Int 32		1	Number of blocks averaged in a beam or ray
9	Range average	Int 32		1	Number of 30m range cells averaged in a bin
10	Scan average	Int 32		1	Number of scans averaged
11	Number of Bins	Int 32		550	Number of range bins in the ray
12	Number of Beams	Int 32		24	Number of rays in each scan
13	Range Bin Size	Int 32	M	30	The vertical resolution of range bin
14	Z scale factor	Int 32		100	Factor multiplying reflectivity
15	V scale factor	Int 32		100	Factor multiplying Doppler
16	Valid Ka scan begin	Int 32			Scan number where the valid Ka data begin (obsolete)
17	Valid Ka scan end	Int 32			Scan number where the valid Ka data end (obsolete)
18	CalVersion	Int 32			Version number of the calibration table

List of flights: GCPEX

#	Date	Observation	Proces. level	GB (raw)	Notes
1	2012, Jan 11	Test Science Flight in California/Pacific Ocean	5.0	1.2	
2	2012, Jan 17	Transit Palmdale-Bangor	N/A		No Nav data available
3	2012, Jan 19	Light snowfall	5.0	4.6	
4	2012, Jan 21	Isolated light snow showers	5.0	3.2	
5	2012, Jan 27	Light rain and snowfall	5.0	6.5	
6	2012, Jan 28	Moderate snowfall over Maine, light snowfall over CARE	5.0	4.6	
7	2012, Jan 30/31	Light to moderate snowfall	5.0	4.0	
8	2012, Feb 4	Clear Air, Cloudy	5.0	1.6	
9	2012, Feb 7	Clear Air, Cloudy	5.0	1.0	
10	2012, Feb 12	Good lake effect	5.0	5.9	
11	2012, Feb 12/13	Very light snowfall,	5.0	0.9	APR-2 interrupted operations early
12	2012, Feb 16	Very light rain, shallow BB	5.0	4.4	
13	2012, Feb 20	Clear air over CARE	5.0	2.1	Configuration tests and changes may affect some of the files
14	2012, Feb 21	Snowfall and rain with extremely shallow BB	5.0	1.5	APR-2 operated only in the last portion of the flight
15	2012, Feb 24	Snowfall over CARE & Georgian Bay, mixed phase precip & heavy snowfall over Lake Ontario	5.0	8.0	
16	2012, Feb 25	Transit Bangor-Palmdale, snow showers south of the Great Lakes	5.0	2.0	

Known Problems, issues and other notes

This section lists all known problems with the APR-2 GCPEX v4.0 and v2.0 data.
Some of these problems are caused by problems in the raw data, while others are processing problems.

- In some files the Nbin field in the fileheader is set to 1. Ignore this field. Nbin = 550 for all products from GRIP.
- External calibration was used for all products. Reflectivity measurements should be considered reliable within ±2.0 dBZ in this release.
- The new APR-2 radome, Ka-band TWTA, and improved noise subtraction allowed to lower the Ka-band minimum detectable reflectivity to about -15dBZ at 10 km distance (-21 @ 5 km distance). Thresholding was kept just above the noise floor max to provide clean data and images, however, in some scenarios the warm background brought the noise floor above the threshold. In this release we chose to keep those occurrences visible as they are excellent markers of warm rain processes or land surface background. In the browse images they can be seen ‘wakes’ above the actual reflectivity; usually grey above ~5 km altitude, and purple below it, following the $10*\log10(r^2)$ shape of the noise floor.
- In the short range (usually 2 km, when the pulse length is set at 10 μs) the sensitivity is raised 6 dB to remove ringing artifacts.

- IMPORTANT: radar reflectivity factors are as measured – no correction for path attenuation is included in these products.
- The radar altitude and look_vector are occasionally affected by aircraft motion at a sub-scan timescale.
- IMPORTANT: This data version was produced using the 1Hz from DC-8 (iwg1). It is recommended to use look_vector and alt_nav for all processing as they are accurate in general.
- No data are available from the 24th ray of each scan (beamnum = 1). This ray was used for noise measurements (no pulse transmitted). The 24th ray was included in this dataset solely for compatibility with APR-2 datasets from previous experiments.
- LDR estimates are included in this release for the Ku-band channel. Users are cautioned in interpreting very low values of LDR (e.g., less than -20 dB) which are characterized by larger overall uncertainty.
- Antenna and range sidelobes show up as artifacts in data in some cases (i.e., thin feature at constant range appearing at large scan angles a few hundred m above the surface).
- Occasionally, high lateral winds caused the Doppler measurements to be aliased. Doppler measurements should be corrected accounting for a maximum unambiguous velocity of ±27.5 m/s. Also, correction for aircraft motion is less reliable when the aircraft was maneuvering or was affected by turbulence. Correction for aircraft motion over land is not reliable.
- The surface_index is estimated on a scan-by-scan basis. The most frequent misclassification is ocean being classified as flat land.
- The following data fields are present but are not used in the HDF files: ka_begin, ka_end. Users should ignore them.
- The isurf index is occasionally misdetected because of extreme attenuation in the rain profile.
- Ka-band TWTA had occasional faults, Ku-band TWTA had one fault; missing data are replaced by –9999. Listed in the table below.
- Occasional ‘locks’ in the antenna scanning occurred (or were commanded on purpose). They are indicated by the value 5 in surface index product.
- Occasional high surface reflectivity caused overflows in the Ku-band copolar channels causing data quality deterioration. Listed in the table below.
- Browse images are:
  - vertical slices below the aircraft. Effects of horizontal advection across the vertical plane are sometimes relevant to the interpretation of the images: users are invited to inspect the 3-D data fields for files of interest.
  - Swath views of horizontal sections or surface parameters, negative ordinate represents left of the track.

- Occasionally processing artifacts show up in the browse images but are not actually present in the data.

Known anomalous data periods, approximate times:

Outage Date	Outage start UTC	Duration [min]	Band
2012/01/19	17:10	19	Ku TWTA fault
2012/02/16	17:35	20	Processing artifacts in Ka
2012/02/20	17:04	4	Ka TWTA fault

Geolocation

Simplified logic steps to obtain the coordinates of every point in the 3-D dataset.

- **boldface indicates 3-D vectors**
- blue indicates parameters included in the HDF file

For each ray:

1. Aircraft position in geodetic coordinates: $\mathbf{G_a} = (lat, lon, alt\_nav);$
2. Aircraft position in GPS coordinates: $\mathbf{P_a}$ = *standard conversion of* $\mathbf{G_a}$
3. Aircraft instantaneous motion: $\mathbf{V_a} = \partial \mathbf{P_a} / \partial t$
4. Aircraft instantaneous direction: $\mathbf{D_a} = \mathbf{V_a} / |\mathbf{V_a}|$
5. Ray pointing direction in aircraft motion reference: ***look_vector***
6. Ray pointing direction in GPS reference: $\mathbf{D_{ray}}$ = *rotate* ***look_vector*** *on* ***Da*** *frame*
   - Look vector has x-axis along direction of motion, y axis to the left and z axis at zenith
7. Range of i-th range bin [m]: $r = range0 * 1000 + DR * i_{bin}$
8. Position of the i-th range bin: $\mathbf{p_i} = \mathbf{P_a} + r * \mathbf{D_{ray}}$
9. Position of the i-th range bin in geodetic coordinates: $\mathbf{g_i}$ = *standard conversion of* $\mathbf{p_i}$

Format 2.x

APR-2 data for release X.0 are distributed also in format 2.0 which includes the same fields included in Format 4.0 plus:

lat3D	int16	nscan x nray x nbin	deg	Latitude of each resolution bin
lon3D	int16	nscan x nray x nbin	deg	Longitude of each resolution bin
alt3D	int16	nscan x nray x nbin	m	Altitude of each resolution bin
lat3D_scale	Double	1		
lon3D_scale	Double	1		
alt3D_scale	Double	1		
lat3D_offset	double	1	deg	
lon3D_offset	Double	1	deg	
alt3D_offset	Double	1	m	

The value of coordinate *xxx* (*xxx = lat, lon or alt*) can be obtained as:
xxx = xxx3D / xxx3D_scale + xxx3D_offset

The precision is on 1/10000 degree for latitude and longitude, 1 m for altitude. Geolocation in this format is obtained using a local sphere approximation for Earth. Users in need of more accurate geolocation should follow the procedure described above with their own choices for the coordinate conversion process.

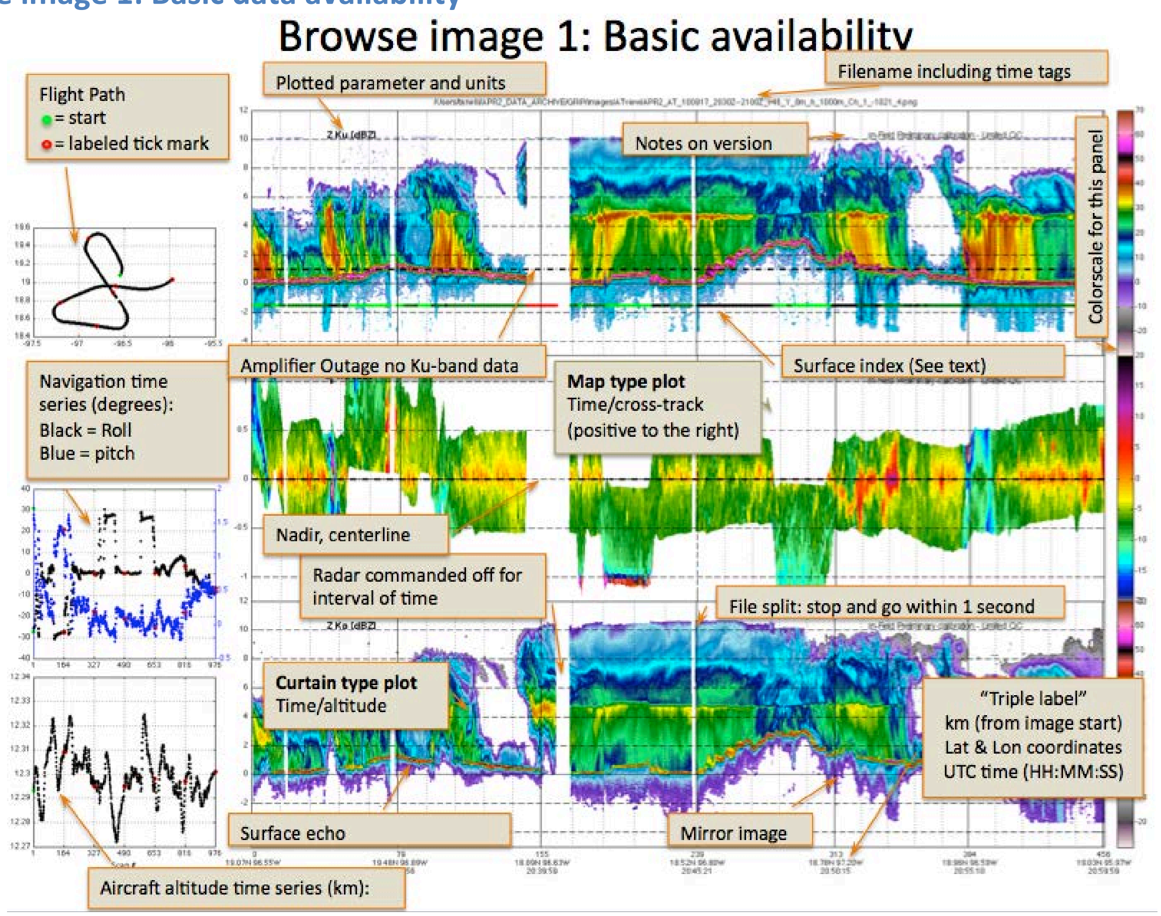
Browse images

Standard browse images are generated in 30 min intervals (less if at the beginning or end of a flight) starting on the hour and half-hour. 4 browse image files are generated for each interval. Each browse image includes navigation and a set of curtain plots and map plots:

Curtain plots: these are vertical sections below the aircraft. The closest beam to the nadir direction is used at every point. The section departs from vertical when the aircraft rolls more than the APR-2 scan angle. In the standard browse images the section is always at nadir (0 cross track displacement). Whenever a non-zero cross-track displacement is chosen (for custom made images) the cross-track displacement is shown in the first map plot by a dot-dash line.

Map plots: these are horizontal sections across the APR-2 swath. They include maps of surface properties (e.g., sigma_zero, v_surf etc.), or sections of volumetric properties (e.g., radar reflectivity at Ku or Ka band, mean Doppler velocity, etc.) at a predetermined altitude. The selected altitude is shown in the first curtain plot as a dot-dash thick line.

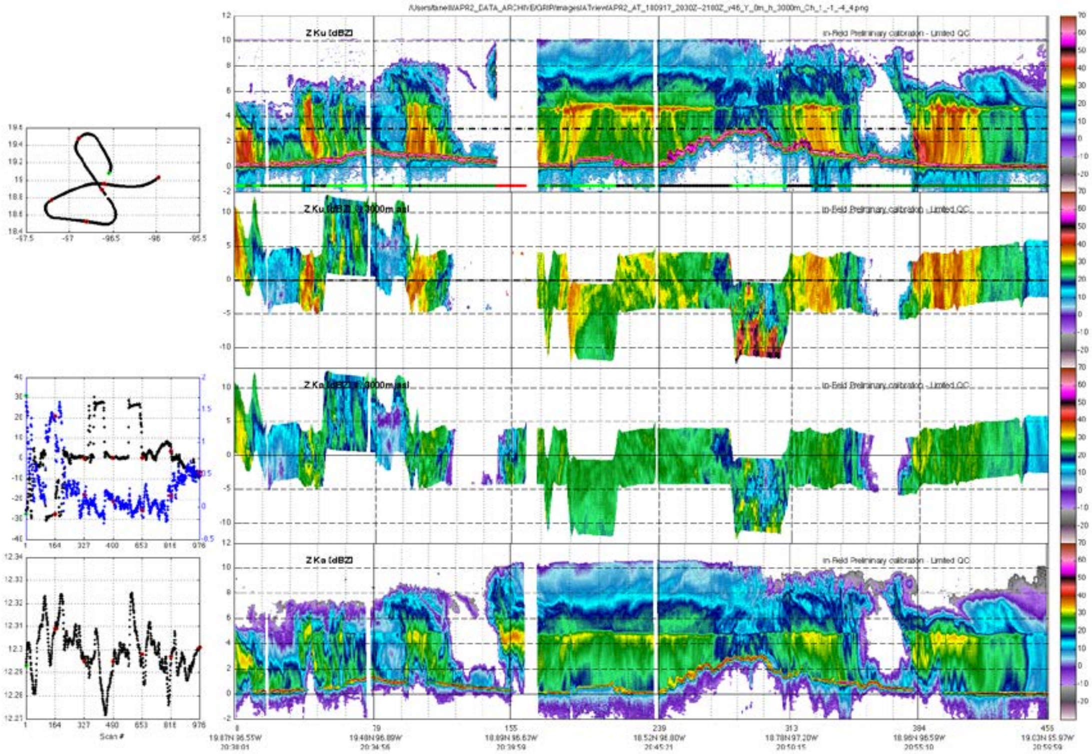
Browse image 1: Basic data availability



Top to bottom:

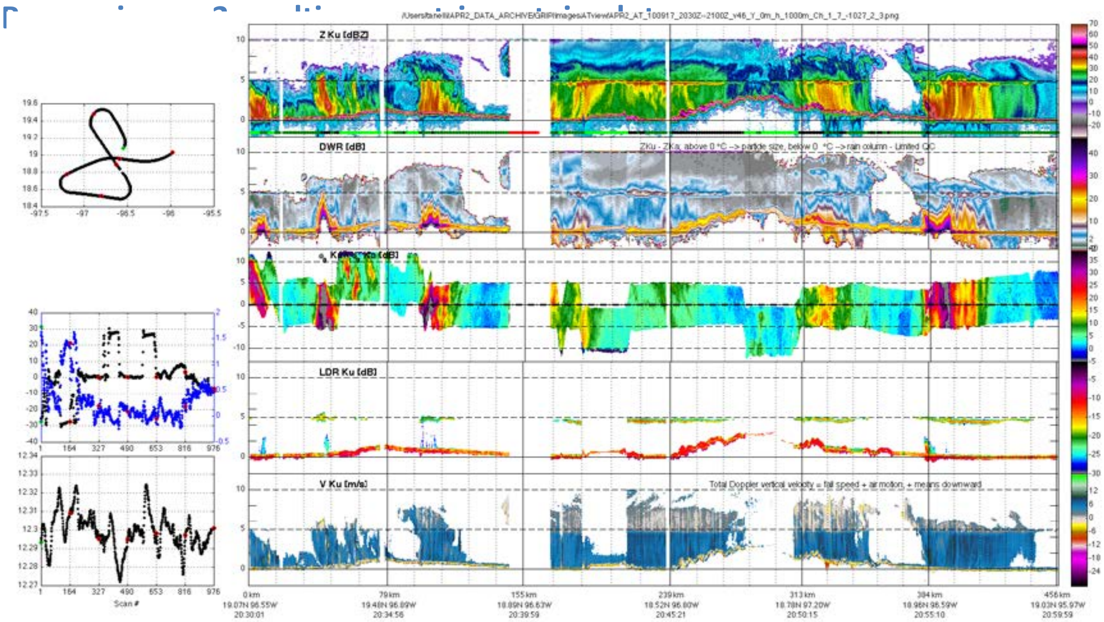
1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Swath of Normalized Radar Cross Section [dB].
3) Vertical curtain of measured Ka-band reflectivity [dBZ].

Browse image 2: Vertical and horizontal sections of reflectivity at both frequencies



Top to bottom:

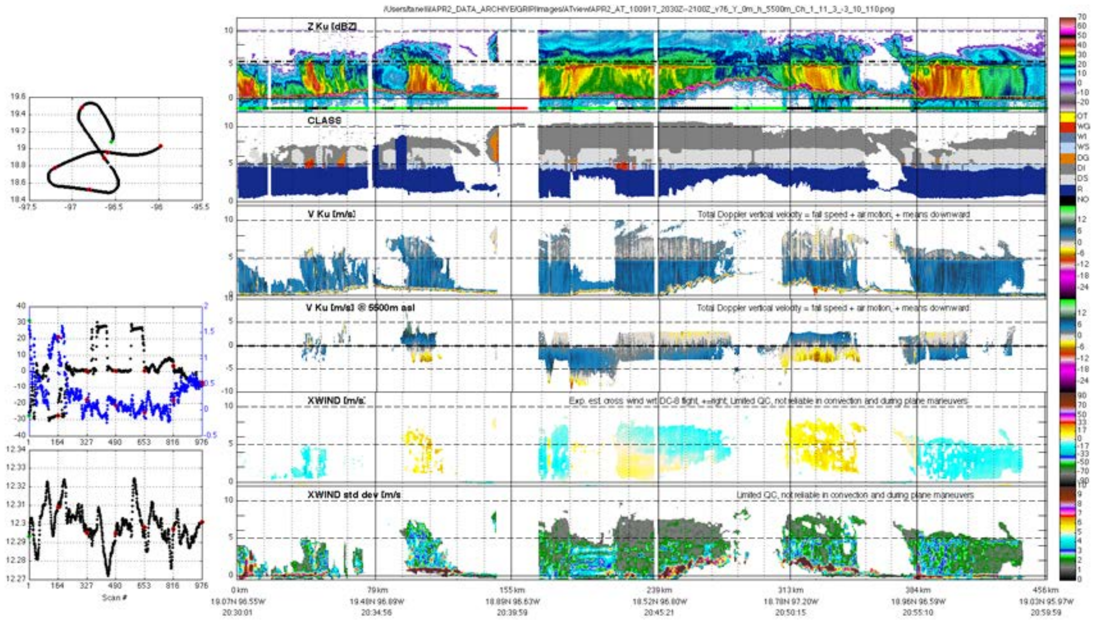
1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Horizontal section at 3 km asl of measured Ku-band reflectivity [dBZ].
3) Horizontal section at 3 km asl of measured Ka-band reflectivity [dBZ].
4) Vertical curtain of measured Ka-band reflectivity [dBZ].



Top to bottom:

1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Vertical curtain of measured DWR (Dual Wavelength Ratio: Ku-band reflectivity - Ka-band reflectivity) [dB].
3) Swath of Normalized Radar Cross Section difference (Ku-band – Ka-band) [dB].
4) Vertical curtain of measured Ku-band Linear Depolarization Ratio [dB].
5) Vertical curtain of measured Ku-band mean Doppler velocity [m/s] corrected for platform motion and aliasing.

Browse image 4: not validated experimental products



Top to bottom:

1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Vertical curtain of class (by predominant particle) *Not included in format 4.x and 2.x*:
   R = Rain, DS = Dry snow, DG = Dry Graupel, DM = Dry Mix Ice (undetermined ice), WS = Wet Snow (Melting Layer), WG = Wet Graupel, WM = Wet Mix Ice, OT = Other.
3) Vertical curtain of measured Ku-band mean Doppler velocity [m/s] corrected for platform motion and aliasing.
4) Horizontal section at 5.5km asl of measured Ku-band mean Doppler velocity [m/s] corrected for platform motion and aliasing.
5) Vertical curtain of horizontal wind component cross-track to the aircraft corrected for platform motion and aliasing [m/s]. Caution: the colorscale is adaptive and changes from plot to plot. *Not included in format 4.x and 2.x.*
6) Vertical curtain of the standard deviation from horizontal wind component in cross-track to the aircraft corrected for platform motion and aliasing [m/s]. This is a measure of confidence for the plot above: large values in this plot indicate less reliable cross-wind estimates. *Not included in format 4.x and 2.x.*

Contact Information

This data is intended for research rather than operational use, and users should contact the APR-2 team regarding its use, especially before publication or public presentation.
This is the first official release of APR-2 data from GCPEX 2012: these products that are still undergoing validation and quality control. Users are invited to address questions and provide feedback to the contact below.

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