Product handbook for the Airborne Precipitation Radar Third Generation (APR3, all products): CPEX-CV 2022 2.x

Experiment: CPEX-CV, Aug-Sept 2023, E Atlantic/Cabo Verde, DC8

Filename on CPEX-CV repository:

- Files with **Full 3D APR3** data (Ku, Ka, W):

  *cpexcv-**APR3**_DC8_20220907_R0_
  SYYMMDDahhmmss_EYYMMDDahhmmss_KUsKAsWn.nc*

  SYYMMDDhhmmss/EYYMMDDhhmmss are UTC start/end times of data.

- Files with 2D **NADIR-ONLY APR3** data (Ku, Ka, W):

  *cpexcv-**APR3nad**_DC8_20220907_R0_
  SYYMMDDahhmmss_EYYMMDDahhmmss_KUsKAsWn.nc*

- Files with **NADIR-ONLY APR3 and CloudCube** data
  (Ku & Ka from APR, W from CloudCube):

  *cpexcv-**APCLD3nad**_DC8_20220907_R0_
  SYYMMDDahhmmss_EYYMMDDahhmmss_KUsKAsWn.nc*

Format: 2.X– Standard L1 product. Geolocated and calibrated radar reflectivity at Ku/Ka/W band, mean Doppler velocity and spectral width, Linear Depolarization Ratio at Ku band, surface Normalized Radar Cross Section at Ku, Ka and W band, pre-calculated geodetic coordinates of every sample point.

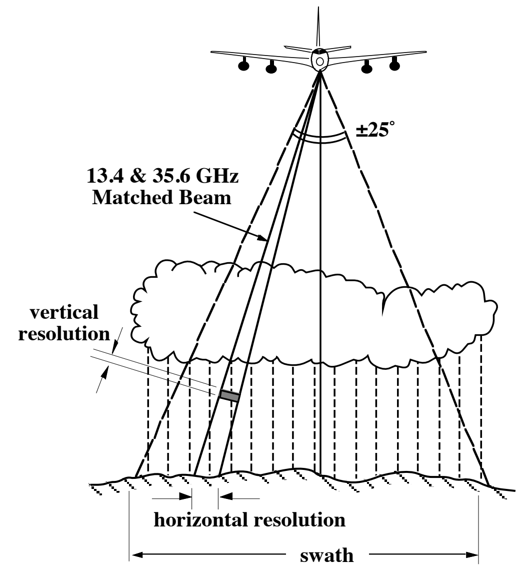
Release: 2.2 (data release to the CPEX-CV repository, April 2023)

Change log:
X.0 – In field data, configuration and calibration changes applied during the experiment.
X.1 – End of campaign reprocessing, full reprocessing. For internal QC only.
X.2 – First release. Absolute calibration uncertainty 1-sigma estimated at 1 dB for Ku-band, 1.5 dB for Ka-band, 1.5 for W-band.
Uses netCDF. Improved noise-floor detection, Doppler processing and calibration.

APR3 Instrument Overview

APR3 is an enhanced version of the APR2 radar, which has successfully acquired data in a number of field campaigns since 2001. Features of APR2 are:

- simultaneous dual-frequency, matched beam operation at 13.4 and 35.6 GHz (same as GPM Dual-Frequency Precipitation Radar)
- simultaneous measurement of both like- and cross-polarized signals at both frequencies
- Doppler operation
- cross-track scanning (same as GPM/DPR)



APR-2 operational geometry

The APR2 operational geometry is shown in Figure 1; it looks downward and scans its beam across-track, with each scan beginning at 25 degrees to the left of nadir and ending at 25 degrees to the right. Sadowy et al. (2003) provides a full description of the APR2 radar system. Calibration of the radar reflectivity products is verified at Ku-band by using the ocean surface and at Ka-band by comparing with the Ku-band reflectivity in light precipitation (Tanelli et al. 2006). Doppler velocities are corrected for aircraft motion using surface return.

APR3 refers to the version of APR2 with a W-band channel (Durden et al. 2020). It allows two types of W-band data to be collected. For precipitation, the existing Ku/Ka feed was modified to allow operation at W-band, in addition to Ku and Ka bands. This allowed acquisition of W-band data with the same cross-track scanning geometry as used for Ku and Ka-bands, these data are denoted HH, due to historical use of the port in the W-band hardware. A second W-band antenna was installed to provide higher sensitivity for cloud sensing goals. This antenna has a larger aperture than that achieved by the three-frequency feed at W-band. Also, it only looks at nadir, allowing more pulses to be integrated. For historical reasons data on this channel are denoted VV. Data were acquired with one or the other or sometime both antennas (simultaneous scanning and nadir). APR2 data (Ku, Ka) were acquired using a long and a short pulse signal, whih are then merged together into 1 product, with a shorter blind range. Since 2021, APR3 also radiates at Ka band through the zenith port, which allows to measure clouds/precipitation above the aircraft.
In CPEX-CV, W-band radar measurements were also acquired by the CloudCube radar (*Rodriguez-Monje et al. 2020*). These are reflectivity factor measurements at nadir.

References:

G. A. Sadowy, A. C. Berkun, W. Chun, E. Im, and S. L. Durden, “Development of an advanced airborne precipitation radar," *Microwave J.*, vol. 46, no. 1, pp. 84-98, Jan 2003.
S. Tanelli, S. L. Durden, and E. Im, “Simultaneous Measurements of Ku- and Ka-band Sea Surface Cross-Sections by an Airborne Radar,” *IEEE Geosci. Remote Sens. Lett.*, vol. 3, no. 3, pp. 359-363, July 2006.

S. L. Durden, S. Tanelli and O. O. Sy, "Comparison of GPM DPR and Airborne Radar Observations in OLYMPEX," *IEEE Geosci. Remote Sens. Lett*., pp. 1-5, November 2020
R. Rodriguez-Monje, R. M. Beauchamp, K. B. Cooper, S. Joshi and S. Tanelli, "A compact W-band breadboard radar for Atmospheric Measurements," *2020 IEEE Radar Conference (RadarConf20)*, Florence, Italy, 2020, doi:10.1109/RadarConf2043947.2020.9266363.

Data Format (version 2.x)

The format for APR3 data (i.e. data with W-band) is an expansion of version 2.x data from previous field experiments with APR2. As used here, APR2 refers to the Ku/Ka-band system. The data are provided in *netCDF files*. The elements of the fileheader are now defined explicitly in the sub-structures *params_KUKA and params_W,* which are included in the global attributes of the files, as well as the calibration adjustments applied to the various channels. All the variables are saved as doubles, and the netCDF files are compressed.

Ns is the number of scans in a file, *Nb* is the number of rays (aka: beams) within a scan, and *Nr* is the number of range bins within a ray.

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 Ku/Ka 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 mean Doppler velocities provided are estimated by pulse-pair processing. As such they can be affected by aliasing in the presence of large velocities. Furthermore, the measurement are also affected by the aircraft motion.
The observed surface Doppler velocity (*v_surf*) is provided. Over land or during sharp maneuvers by the DC8, the v_surf estimate is more prone to errors.

The *surface index* is estimated by analyzing Ku/Ka 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 information about the radar configuration and data is provided in the sub-structures *params_KuKa* (for APR-2 data) and *params_W* (for W-band data), which are now included in the global attributes of the files. These parameters are constant over the entire file.

Content of NETCDFfiles

A. Files with full 3D variables (*cpexcv-APR3_DC8*_YYYYmmDD_R0)

The variables in the APR3 NETCDF files are listed in Tables 1 to 10. The type of radar data is specified by the file suffix modeID, with the naming convention
'*cpexcv* -APR3_ *DC8*_FlightDate_R0_StartUTC_EndUTC_',modeID,'.nc'

where, e.g., modeID = "KUsKAsWsn" indicates that the file contains

- "KUsKAs": Ku- and Ka-band radar data obtained in scanning mode, via long and short pulses;
- "Wsn": W-band data obtained via scanning ("Ws") and nadir-only ("Wn") modes.

The radar data consist mainly of a reflectivity factor Z, linear depolarization ratio (LDR), mean Doppler velocity V and spectral width S, and surface reflectivity σ^0 all at Ku, Ka and W bands. The files also contain navigation and geolocation information.

As described in Table 1, each file contains (a subset of) the following datasets.

- ***Global attributes:***
  - General information about the file format and summary of geolocation;
  - configuration parameters of Ku and Ka bands (with prefix *paramsKUKA*, e.g. *paramsKUKA_Nbeams* is the number of cross-track beams per scan);
  - configuration parameters of W band (with prefix *paramsW*, e.g. *paramsW_PRF_Hz* is the pulse repetition frequency of W-band in Hertz);
  - Calibration corrections applied to each channel (with prefix *postCalib*, e.g. *postCalib_zhh35* is the correction applied to Ka and reflectivity. To calibrate the radar channels, the NRCS measured over ocean are adjusted (constant shift) to match a simulated database of ocean NRCS for various surface wind speeds. This adjustment provides a retrieved wind speed. Next the reflectivity factors from the cloud tops are adjusted relative to one another under the assumption that smaller particles are subjected to Rayleigh scattering.
  - Description of the file suffix: for instance *file_suffix_KUsKAs* describes that the files with suffix *KUsKAs* containing Ku/Ka Doppler data obtained in scanning mode.
  - Spatial resolutions of the data: with prefix *radar_data_resolution*, e.g. *radar_data_resolution_lores* describes how the *"lores"*: data (Ku,Ka,W bands) are acquired in a cross-track scanning mode.
- ***Data resolutions:***
  APR3 can measure radar data in two primary modes ("lores" scanning for Ku/Ka/W bands, and "hires" nadir-only mode for W-band only).
  - ***lores***: measurements in cross-track scanning mode of radar data at Ku, Ka, W bands on a common 3D grid . Because of the scanning, fewer data are measured at "nadir". In this group, the 3D arrays like the altitude of the bins *alt3D* have dimensions *Ns x Nb x Nr*, with *Ns*: numbers of scans (along track); *Nb*: number of rays (cross track); *Nr*: number of range bins.
  - ***Hires:*** measurements only at NADIR (i.e. at the vertical below the aircraft, which is nadir if flying straight and level). In this mode only W-band data

are measured. The along-track sampling is much finer (~25 times) than the along-track sampling of "lores" (where APR3 must spend time scanning). In this group, the 2D arrays like the altitude of the bins *alt3D* have dimensions *NsH x NrH*, with *NsH*: numbers of scans (along track at higher resolution); *NrH*: number of range bins.

However, we also provide two hybrid modes with data at nadir only

- *lo2hi:* nadir data (Ku/Ka/W) from *lores* are *interpolated along-track* to the higher resolution of *hires*. This allows for comparisons between Ku/Ka/W (lores) and W (hires) on the common "hires" grid (nadir only, but fine sampling) for calibration and scientific purposes. In this group, the 2D arrays like the altitude of the bins *alt3D* have dimensions *NsH x NrH*.
- *hi2lo:* nadir data (W band) from hires *integrated along-track* to the lower resolution of *lores*'s nadir. In this group, the 3D arrays like the altitude of the bins *alt3D* have dimensions *Ns x Nb x Nr*, with data only in the central beam (of Nb=25, then the central beam is #13).

The variables (described in Table 1) in each resolution subgroup are written with the prefix of the resolution: for instance, *hi2lo_alt3D* is the altitude of the radar bins at the *hi2lo* resolution.

Important note: *For each of the data subgroups (lores, hires, lo2hi, hi2lo), it is important to use the corresponding geolocation and attitude parameters (e.g. alt3D, lookvector, etc.). Otherwise, this can lead to odd features, especially when the aircraft is not flying straight and level.*

*Table 1: **list of parameters in each APR3 file***

label to indicate presence in APR3 file type defined by given suffix: Y(Yes), N(No

Ns: numbers of scans (along track), at low resolution;

Nb: number of rays (cross track) in scanning mode at low resolution;

Nr: number of range bins at low resolution.

NsH: numbers of scans (along track), at high resolution;

NrH: number of range bins (= *Nr* (same as low-resolution vertical sampling), if Ku and Ka are present, otherwise = W-band native vertical sampling, otherwise.

Variables present only in the full3D files highlighted in yellow. Variables present only in the nadir-only files highlighted in blue. Variables present in all files are not highlighted.

Variable name (format = all doubles)	size	Units	Notes
alt	Ns x 1	m	Altitude of the aircraft.
alt_ac	Ns x 1	m	Altitude of the aircraft.
alt_nav	Ns x Nb	m	Aircraft altitude [from MMS navigation files (recommended)]
alt_radar	Ns x Nb	m	Aircraft altitude [From APR-2 surface echo (alternate)]
alt_range	Ns x 1	m	Altitude of each resolution bin below the aircraft, i.e. seen through the nadir ports. Constant vector between [-1,12] km [only present in nadir-only files]
alt3D	Ns x Nb x Nr	m	Altitude of each resolution bin below the aircraft.
alt3DZN	Ns x Nb x Nr	m	Altitude of each resolution bin above the aircraft (zenith port).
altsurf14	Ns x Nb	m	Surface altitude from Ku reflectivity (peak echo)
altsurf35	Ns x Nb	m	Surface altitude from Ka reflectivity (peak echo)
azimuth	Ns x Nb	deg	APR antenna azimuth angle
beamnum	Ns x Nb		Ray number within a scan
drift	Ns x Nb	deg	From aircraft or MMS navigation files
elevation	Ns x Nb	deg	APR antenna elevation angle
gsp_mps	Ns x Nb	m/s	Aircraft ground speed
ibeam_hires	Ns x Nb		beam index for comparison to integrated hires data (= ib_cent)
ipc14	Ns x Nb		Bin number at the edge of Tx pulse clutter in Ku reflectivity
Ipc35	Ns x Nb		Bin number at the edge of Tx pulse clutter in Ka reflectivity
isc14	Ns x Nb		Bin number at the edge of surface clutter in Ku reflectivity
isc35	Ns x Nb		Bin number at the edge of surface clutter in Ka reflectivity
isurf	Ns x Nb		Index of radar range bin intersecting surface (in Ku and Ka).
isurf_95n	NsH x 1		Surface bin estimated from z95n
Isurf14	Ns x Nb		Index of radar range bin intersecting surface (in Ku).
Isurf35	Ns x Nb		Index of radar range bin intersecting surface (in Ka).

Table 1 (Continued): ***list of parameters in each APR3 file***

Variable name (format = all doubles)	size	Units	Notes
lat	Ns x Nb	deg	Latitude of the aircraft
lat_ac	Ns x 1	deg	Latitude of the aircraft
lat3D	Ns x Nb x Nr	deg	Latitude of each resolution bin
ldrhh14	Ns x Nb x Nr	dB	Linear Depolarization Ratio at Ku band
lon	Ns x Nb	deg	Longitude of the aircraft
lon_ac	Ns x 1	deg	Longitude of the aircraft
lon3D	Ns x Nb x Nr	deg	Longitude of each resolution bin
look_vector	Ns x Nb x 3		From navigation files (recommended): 3 components of unit vector in the antenna's pointing direction
look_vector_95n	NsH x3		Ray unit vector in local surface coordinates '3 components of unit vector along antenna pointing direction: From W-band Nadir surface echo (alternate)
look_vector_nadir	Ns x Nb x 3		From APR-2 surface echo in nadir-only mode (alternate)
look_vector_radar	Ns x Nb x 3		From APR-2 surface echo in scanning channels (alternate)
mask	NsH x1xNrH		Cloud mask: If = 5: radar transmit-pulse clutter (6): sub-surface and surface clutter (11): boundary between cloud and surface clutter (15): other (default value) (20) noise based on SNR (30) if low SNR cloud/rain (40) if high SNR cloud/rain
pitch	Ns x Nb	deg	From aircraft or MMS navigation files
roll	Ns x Nb	deg	From aircraft or MMS navigation files

*Table 1 (Continued): **list of parameters in each APR3 file***

Variable name (format = all doubles)	size	Units	Notes
s095n	NsH	dB	surface NRCS (W band) nadir
s095s	Ns x Nb	dB	Surface NRCS (W band, scanning)
s0hh14	Ns x Nb	dB	Surface NRCS at Ku band
s0hh35	Ns x Nb	dB	Surface NRCS at Ka band
scantime	Ns x Nb	s	Beginning of scan since 1 Jan. 1970.
sequence	Ns x Nb		Ray number within the file
sfc_alt	Ns x Nb	m	Altitude of radar bins intersecting the surface
sfc_lat	Ns x Nb	deg	Latitude of radar bins intersecting the surface
sfc_lon	Ns x Nb	deg	Longitude of radar bins intersecting the surface
sfc_mask	Ns x Nb		Surface mask (ocean:0, land:1)
Sig14	Ns x Nb x Nr	m/s	Spread of Doppler Velocity at Ku band
Sig35	Ns x Nb x Nr	m/s	Spread of Doppler Velocity at Ka band
sig95n	NsH x1xNrH	m/s	Doppler Width at W band nadir
sig95s	Ns x Nb x Nr	m/s	Spread of Doppler Velocity at W band scanning
surface_index	Ns x Nb		Preliminary surface classification index
Topo_Hm	Ns x Nb	m	Topographic surface height.
time	Ns x 1	s	Time of scan, since midnight UTC of flight date
timeM	Ns x 1	days	Time of scan, since 1 Jan. 0000, i.e. Matlab convention in function datenum.

Table 1 (Continued): ***list of parameters in each APR3 file***

Variable name (format = all doubles)	size	Units	Notes
v_surf14	Ns x Nb	m/s	APR-measured surface Doppler velocity at Ku band
Vel14	Ns x Nb x Nr	m/s	Mean Doppler Velocity at Ku band (UNCORRECTED affected by platform motion and aliasing).
vel14c	Ns x Nb x Nr	m/s	Mean Doppler Velocity at Ku corrected by subtraction of surface Doppler velocity (recommended)
vel35	Ns x Nb x Nr	m/s	Mean Doppler Velocity at Ka band (UNCORRECTED affected by platform motion and aliasing).
vel35c	Ns x Nb x Nr	m/s	Mean Doppler Velocity at Ka corrected by subtraction of surface Doppler velocity and experimental dealiasing (not recommended, very noisy)
vel95n	NsH x1xNrH	m/s	Mean Doppler Velocity at W band nadir channel (UNCORRECTED affected by platform motion and aliasing).
vel95nc	NsH x1xNrH	m/s	mean Doppler Velocity at W band nadir channel. CORRECTED by surface-reference technique and experimental dealiasing
vel95s	Ns x Nb x Nr	m/s	Mean Doppler Velocity at W band scanning (UNCORRECTED affected by platform motion and aliasing).
vel95sc	Ns x Nb x Nr	m/s	Doppler Velocity at W band scanning (CORRECTED by surface-reference technique and experimental dealiasing. Caution: the dealiasing is not perfect so there may still be residual aliasing)
velZN35	NsH x1xNrH	m/s	Mean Doppler Velocity at Ka band from zenith port (UNCORRECTED affected by platform motion and aliasing).
velZN35c	NsH x1xNrH	m/s	Mean Doppler Velocity at Ka band from zenith port (CORRECTED by surface-reference technique).
Xat_km	Ns x Nb	km	Distance traveled in km since beginning of file.
z95s	Ns x Nb x Nr	dBZ	Reflectivity at W band, HH scanning channel
z95n	NsH x1xNrH	dBZ	Radar Reflectivity at W band, nadir channel
Zcld_Ka	Ns x Nb	dBZ	Reflectivity factor at Ka-band measured below the aircraft, vertically averaged omitting the surface.
zhh14	Ns x Nb x Nr	dBZ	Radar Reflectivity at Ku band
zhh35	Ns x Nb x Nr	dBZ	Radar Reflectivity at Ka band from nadir port (below aircraft)
zZN35	Ns x Nb x Nr	dBZ	Radar Reflectivity at Ka band from zenith port (above aircraft)

B. Files with full nadir only APR3 data (*cpexcv-APR3nad_DC8*)

The nadir-only files, contain APR3 radar data measured at the vertical of the aircraft (with respect to the aircraft's wings): for an aircraft that flies straight and level, this corresponds to nadir.

The variable names are the same as the ones reported in Table 1. The only difference is that all the parameters that depend on the cross-track dimension (Nb in the tables), become independent of the Nb (because we're only measuring data at Nadir). For instance, *zhh14* has as dimensions *Ns* x *Nr*, whereas *s0hh14* has as dimensions *Ns* x *1*. Each nadir-only file contains the content of an entire flight. To do so, we use only the "lores" and "hi2lo" data and interpolate them in range onto a fixed-altitude grid (between -1km and 12km by steps of 100m).

Quicklooks of the APR3 data

The various field of the APR3 measurements are plotted in quicklooks that can be used to get a sense of the radar measurements.

Figures ending in

- '3DKHLoLP' correspond the (Ku,Ka,W) band data with the W-band from the scanning mode (example shown in Fig.2).
- '3DKVLoLP' correspond the (Ku,Ka,W) band data with the W-band from the nadir-only mode.

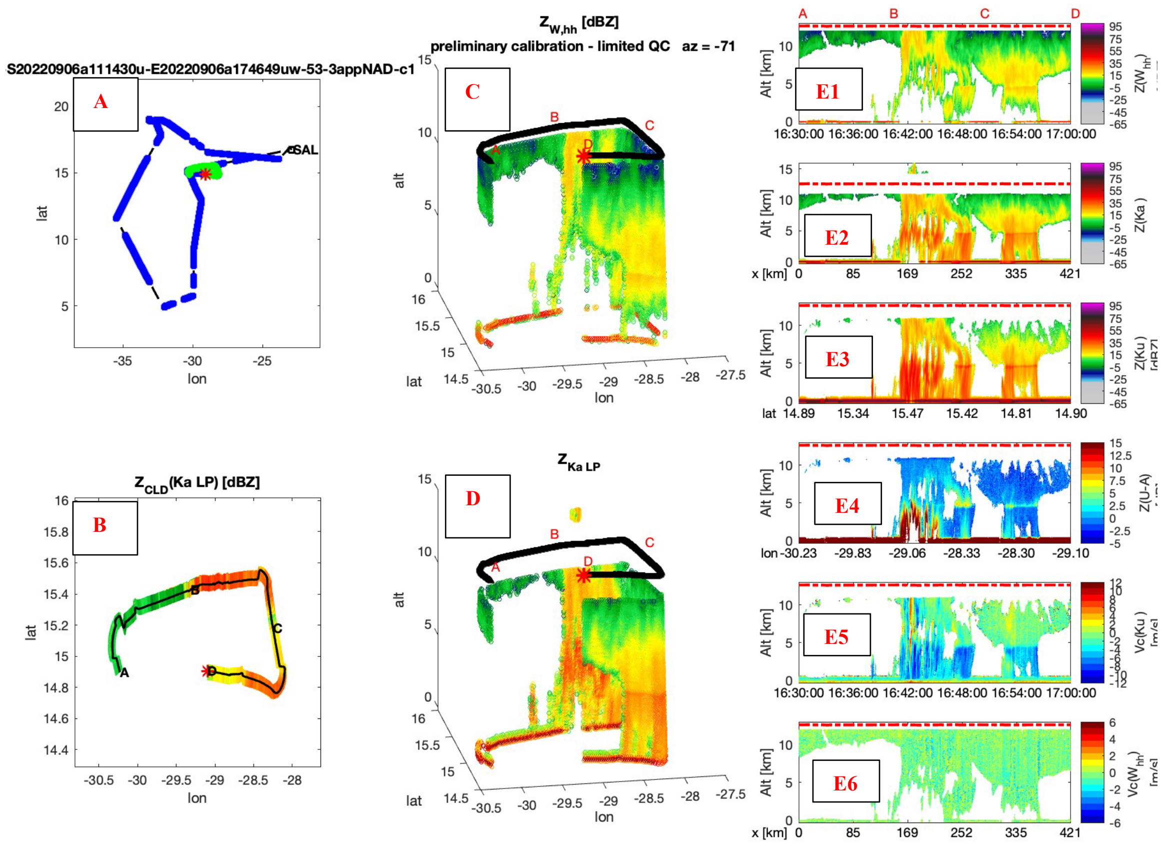


Fig.2: Example of APR3 measurements from 2022/09/06, with W-band from scanning mode: Panel A (top-left) shows a map of the entire flight track (blue) and the portion of the flight (green, with last position of DC8 as red star)that tis displayed in the other panels. Panel B (Bottom left): map of vertical average of Ka-band reflectivity (downward looking), without surface return. Panel C shows the W-band reflectivity as a function of the 3 spatial coordinates, with the location of the DC8 in black and its latest position as a red star. Panel D showx the same as Panel C, but for the Ka-band reflectivities measured through the zenith and nadir ports. Panels E show curtain plots of the reflectivity at W-band scanning (E1), Ka band zenith and nadir (E2), Ku band (E3), dual-wavelength ratio Z(Ku) – Z(Ka) (Panel E4), mean velocity at Ku (E5) and W (E6) bands.

Known Problems, issues and other notes

This section lists all known problems with the APR3 CAMP2EX v2.3 data. Some of these problems are caused by problems in the raw data, while others are processing problems.

- External calibration was used for all products. Reflectivity measurements should be considered reliable within ±3 sigma as reported in the change log for this release.
- The radar sensitivity was not constant (mainly dependent on the pulse length). Users not familiar with the weather radar equation and APR3 data should contact the APR3 team to support data interpretation.
- In the short range (that is the first 5 bins after the blanked transmit window) the reported value of reflectivity is underestimated. This region should be used only for detection purposes, and not quantitative estimation.
- 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.
- This data version was produced using the 1Hz from the P3-Orion (iwg1). It is recommended to use *look_vector* and *alt_nav* as they are accurate in general.
- 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 may cause the Doppler measurements to be aliased. Doppler measurements should be corrected accounting for a maximum unambiguous velocity (±27.5 m/s at Ku, ~4 m/s at W band). Also, correct for aircraft motion.
- The *surface_index* is estimated on a scan-by-scan basis. The most frequent misclassification is ocean being classified as flat land.
- The *isurf* index is occasionally misdetected because of extreme attenuation in the rain profile.
- Occasional intermittent changes in the overall calibration may not be properly accounted for.

- The Doppler velocities were corrected by surface-reference technique. This produces reliable results in the Ku-band Doppler velocity (recommended product), which is also free of aliasing.
- The mean velocities at Ka and W band are affected by the platform motion and by aliasing, i.e. folding of the velocities with amplitudes that exceed the Nyquist limit (about 8m/s at Ka, and 4 m/s at W band)). We have applied the surface-reference correction, and an experimental dealiasing algorithm.
  As a result, the Ka band velocity is very noisy and we are investigating the origins of this problem (the user is cautioned about using this product; and in many instance we have blanked this product instead of providing a bad velocity). The W-band product is generally reliable.
- The dealiasing of the Ka- and W-band velocity may lead to conservative results: some real updrafts may be falsely labelled as aliasing and unfolded into negative velocities. For this reason, we strongly recommend the use of the Ku-band velocity.

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 NETCDF 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* $\mathbf{p}_i$

For APR3 data in format 2.x one can use the following:

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.

Contact Information

This data is intended for research rather than operational use, and users should contact the APR-3 team regarding its use, especially before publication or public presentation. This is the first official release of APR-2/3 data from CAMP2EX 2015: 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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