Product handbook for the Airborne Precipitation Radar Third Generation (APR3, nadir Z and σ^0): CAMP2EX 2.x

Experiment: CAMP2EX, Aug-Oct 2019, NW Pacific/Philippines, P3-Orion

Filename: standard: APR3_L2Znad_P3_YYMMDDhhmmss.Rx.h5,

CAMP2EX repository: *CAMP2Ex-APR3-L2Znad_P3B_20190824_R0_*

SYYMMDDahhmmss_EYYMMDDahhmmss_KUsKAsWn.h5

Note: SYYMMDDhhmmss and EYYMMDDhhmmss indicate the UTC start and end times of the data.

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

These simplified files contain only the radar reflectivity factors and surface NRCS (no Doppler, or LDR) seen from the nadir port (beam 13 of 25). Each file corresponds to a single flight (individual files concatenated into a single file).

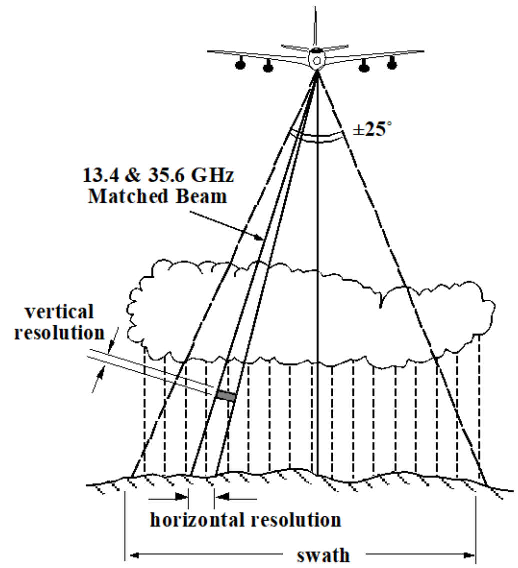
Release: 2.2 (data release to the CAMP2EX repository, March 2020)

Change log:
X.0 – In field data, configuration and calibration changes applied during the experiment.
X.1 – End of campaign reprocessing, full reprocessing with configuration control (Dec 2015). For internal QC only.
X.3 – First Science Team release of preliminary processing. Absolute calibration uncertainty 1-sigma estimated at 1 dB for Ku-band, 1.5 dB for Ka-band, 1.5 for W-band.
X.4 – Second science release. Uses HDF5. Improved Doppler processing and calibration. Absolute calibration uncertainty 1-sigma estimated at 1 dB for Ku-band, 1.5 dB for Ka-band, 1.5 for W-band.

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.

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.

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 *HDF5 files*. The elements of the fileheader are now defined explicitly in the sub-structures *params_KUKA and params_W*. All the variables are saved as doubles, and the HDF5 files are compressed.

Ns is the number of scans in a file 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 *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). These are parameters that are constant over the entire file.

Content of HDF5 files

The variables in the APR3 HDF files are listed in Tables 1 to 10. The file naming convention is

'CAMP2Ex-APR3-L2Znad_P3B_20190824_R0_StartUTC_EndUTC_c1.h5'.

The radar data consist of reflectivity factor Z and surface reflectivity σ^0 all at (Ku, Ka) from long pulse, W band scanning (HH) and nadir only (VV). The files also contain navigation and geolocation information. Every file contains all the available radar measurements from a given flight.

As described in Table 1, each file contains (a subset of) the following sub-structures

- *params_KUKA*: configuration parameters of Ku and Ka bands (see Table 2);
- *params_W*: configuration parameters of W band ACR (see Table 3),
- *postEng_cal*: Calibration shifts applied a posteriori to Z and σ^0 (see Table 6). To calibrate the radar channels, the NRCS measured over ocean are adjusted (constant shift) to match a simulated database of 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.
- *lores*: measurements at the lower along-track resolution of APR2 (see Table 7).
- *hi2lo:* ACR (hires) data *integrated along-track* to match the lower resolution of *lores* (see Table 10). In this case, the integrated data are saved in beam #13 of 3D arrays: for instance, the along-track integrated nadir-only reflectivity is saved as "hi2lo.z95n(:,13,:)".

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 files: Y(Yes), N(No);

All the variables are structures.

Ns (numbers of scans at low resolution, i.e. APR2).

Variable name (format = all structures)	**Size**	**Notes**
params_KUKA	1	APR2 operational mode: see Table 2
params_W	1	ACR operational mode: see Table 3
postEng_cal	1	Calibration shifts applied to Z and σ^0: see Table 4
lores	1	APR3 data at lower resolution: see Table 7
hi2lo	1	APR3 data at higher resolution: see Table 10

*Table 2: Parameters in "***params_KUKA***"*: APR2 operational mode

Variable name (format = all doubles)	size	Units	Notes
AntRetraceTime_s	1	s	Antenna retrace time
AntScanLeft_deg	1	deg	Antenna scan left-limit
AntScanRight_deg	1	deg	Antenna scan right-limit
AntScanTime_s	1	s	Scan time for antenna
NR	1		Number of range gates
Nbeams	1		Number of rays in each scan
Nbeams_data	1		Number of rays (per scan) with radar transmitting
Nbeams_noise	1		Number of rays (per scan) with radar NOT transmitting
Nbin_per_ray	1		Number of range bins in the ray
Npuls_avge	1		Number of pulse averaged by Wildstar board
Nscan	1		Number of scans in the file
PRF_Hz	1	Hz	APR2 pulse repetition frequency
Range_Size_m	1	m	Vertical resolution of range bin
ibeam_hires	1		Index of ray with hires (nadir) data (integrated to lores)
pulselen_us	1	us	APR2 pulse length

*Table 3: Parameters in "***params_W***"*: ACR operational mode

Variable name (format = all doubles)	size	Units	Notes
NR	1		Number of range gates
Nbeam	1		Number of rays (per scan) (=1 nadir if nadir only)
Nscan	1		Number of scans in the file
PRF_Hz	1	Hz	ACR pulse repetition frequency
Range_Size_m	1	m	Length of range bin (vertical sampling)
Range_res_m	1	m	Length of pulse (vertical resolution)
Vnyq	1	m/s	Nyquist velocity
date_beg	6		Start time [YYYY,MM,DD,hh,mm,ss]
integration_s	1	s	ACR integration time
pulselen_us	1	us	ACR pulse length
slave_mode	1		ACR operation mode (0 = stand-alone, 1= slaved mode)

*Table 4: Parameters in "***postEng_cal***"*: A posteriori calibration

Variable name (format = all doubles)	size	Units	Notes
Impose	1		Calibration constants manually imposed (1) or found automatically (0)
s0hh14, s0hh35	1	dB	Calibration correction applied to σ^0(Ku/Ka, Long pulse)
s0hh95	1	dB	Calibration correction applied to σ^0(W, scanning)
s0vv95	1	dB	Calibration correction applied to σ^0(W, nadir-only)
wsp_best	1	m/s	Wind speed retrieved from simulated look-up table during automatic calibration of surface reflectivity
zhh14, zhh35	1	dB	Calibration correction applied to Z (Ku/Ka, Long pulse)
zhh95	1	dB	Calibration correction applied to Z(W, scanning)
zvv95	1	dB	Calibration correction applied to Z(W, nadir-only)

*Table 5: list of parameters in "***lores***":* APR2 at low resolution
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.

Variable name (format = all doubles)	**size**	**Units**	**Notes**
Xat_km	Ns x 1	km	Distance traveled in km since beginning of file.
alt3D	Ns x 1 x Nr	m	Altitude of each resolution bin. For use with 'lores' data only
alt_nav	Ns x 1	m	Aircraft altitude [from MMS navigation files (recommended)]
lat	Ns x 1	deg	Latitude of the aircraft
lat3D	Ns x 1 x Nr	deg	Latitude of each resolution bin
lon	Ns x 1	deg	Longitude of the aircraft
lon3D	Ns x 1 x Nr	deg	Longitude of each resolution bin
pitch	Ns x 1	deg	From aircraft or MMS navigation files
roll	Ns x 1	deg	From aircraft or MMS navigation files
s0hh(14/35)	Ns x 1	dB	Surface NRCS at Ku/Ka band (long pulse)
timeM	Ns x 1	day	Time since 01/01/0000 in days (Matlab time)
zhh14, zhh35	Ns x 1 x Nr	dBZ	Radar Reflectivity at Ku/Ka band (long pulse)
s095s	Ns x 1	dB	Surface NRCS (W band, scanning)
z95s	Ns x 1 x Nr	dBZ	Reflectivity at W band, HH scanning channel

*Table 6: list of parameters in "***hi2lo***":* hires APR data integrated along-track to match APR2 (low) resolution
Ns: numbers of scans (along track), at low resolution;
Nb: number of beams
NrH: number of range bins at higher resolution:
= Nr (same as low-resolution vertical sampling), if Ku and Ka are present,
= native vertical sampling of ACR, otherwise.
Geolocation and attitude parameters (lat, lon, alt, roll, look_vector…) are down-sampled from the high-resolution navigation parameters to the lower resolution.
The integrated data from high-resolution mode are saved in beam 13 (of 25).

Variable name (format = doubles)	**size**	**Units**	**Notes**
Xat_km	Ns x 1	km	Distance traveled in km since beginning of file.
alt3D	Ns x 1 x NrH	m	Altitude of each resolution bin
lat3D	Ns x 1 x NrH	deg	Latitude of each resolution bin
lon3D	Ns x 1 x NrH	deg	Longitude of each resolution bin
s095n	Ns x 1	dB	surface NRCS (W band) nadir
timeM	Ns x 1	day	Time since 01/01/0000 (Matlab time)
z95n	Ns x 1 x NrH	dBZ	Radar Reflectivity at W band, nadir channel

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 (iwg1). It is recommended to use look_vector and alt_nav for all processing as they are accurate in general.
- 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).
- 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.

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* $\mathbf{p_i}$

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-3 data from CAMP2EX 2019: these products are still undergoing validation and quality control. Users are invited to address questions and provide feedback to the contact below.

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