2022 HIWC III Flight Campaign
-Radar Datasets

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Purpose

This document provides a basic description the radar datasets collected by NASA during the 2022 HIWC III Flight Campaign, which is now archived and provided to the research community by NCAR. The radar measurements contained in this dataset have been processed to remove the instrument properties from the airborne radar data and thereby produce scientific measures of the atmosphere and the High Ice Water Concentration (HIWC) conditions and the surrounding meteorological environment.

Users of this radar dataset may also make use of datasets from the other instruments installed on the aircraft and archived by NCAR as part of the 2022 HIWC III Flight Campaign. This document is intended to assist users of the 2022 NASA HIWC III Flight Campaign datasets by providing general descriptions, data format, and instructions on how to read the radar dataset.

Background info

High Ice Water Content (HIWC) has been identified as a hazard to modern commercial aircraft operations and it is characterized by high concentrations of ice crystals often associated with strong, deep convection distributed over horizontal scales of tens to hundreds of kilometers. The radar objective of the 2015 HIWC I Radar Flight Campaign was to collect radar measurements of these conditions in order to ascertain radar observables and correlate these observations with in-situ measurements. The 2018 HIWC II Radar Flight Campaign sought to assess the performance of candidate radar measures and techniques that locate and estimate IWC levels. The objective of the 2022 HIWC III Flight Campaign was to assess the dependence of HIWC on aerosol concentrations, whether the 99th percentile needed further refinement, and whether the radar algorithm that predicts ice crystal concentrations needed to account for aerosol concentrations.

The 4-week flight campaign was conducted in July 2022 using the NASA AFRC DC-8 aircraft operating from Cecil Field (VQQ) in Jacksonville, FL. Flight operations traversed the Atlantic seaboard from Florida up to Delaware (see Figure 1), as well as two flights through the Gulf of Mexico (one focused on an area south of Louisiana and the other that focused on an area east of the Yucatan Peninsula).

The NASA DC-8 was equipped with a variety of instruments needed to measure ice concentrations, particle size, and atmospheric conditions in which the aircraft flew. In addition to these in situ instruments, remotely sensed measurements were recorded using a modified commercial, airborne, Doppler weather radar mounted in the nose of the DC-8 aircraft. Using these instruments, the aircraft flew into and measured HIWC atmospheric conditions associated with oceanic mesoscale convection systems, tropical storms, and hurricanes.

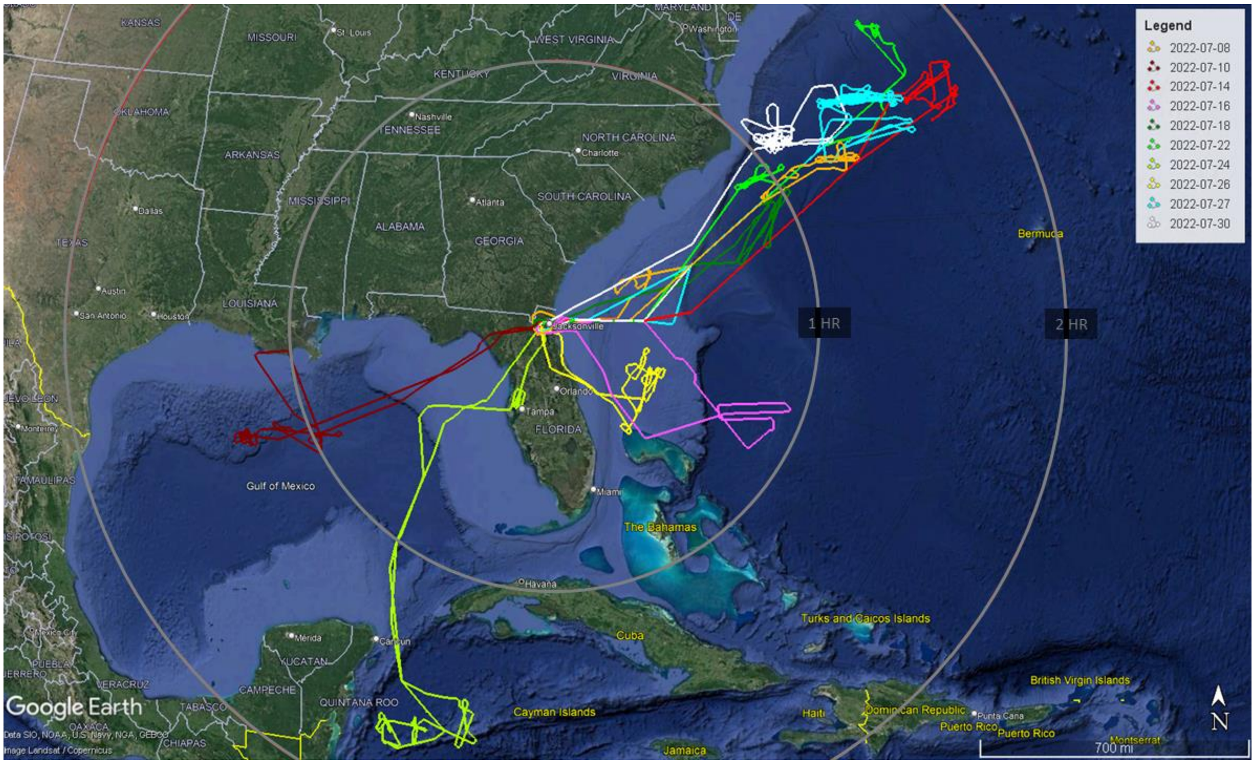

Figure 1 Flight Tracks July 08-30, 2022

Radar Data Collected

The airborne radar used for this flight campaign was a Honeywell RDR-4000 and had been modified to allow recording of In-phase/Quadrature-voltage measurements while the DC-8 aircraft was in flight. In order to assess the radar's performance, a variety of meteorological instruments were also installed, including: a pitot probe, a Total Air Temperature (TAT) probe and an ICD/Robust probe on the nose of the aircraft and four other probes that were installed on wing pods. The wing pod instruments included: a Precipitation Imaging Probe (PIP), an optical imaging (2D-S) probe, a Cloud Droplet Probe (CDP) and an Iso-Kinetic Probe (IKP). Additionally, aircraft state variables were recorded and are available from the archive. Several video cameras were installed and recorded during the flight but the video is too large (800GB) for NCAR's archive – however requests for short time segments will be provided (if possible) and should be requested using the contact info at the end of this document. The balance of this document describes data and data formatting related to the radar instrument/files.

Flight Summary

The Table below provides a summary of the flights, their dominate flight location, and indicates the start and stop times for radar recordings.

Flight Number	Date	Radar Data UTC Times (hh:mm)		General Description
		Start	Stop	
1405	07/08/2022	15:35	20:17	N. Carolina & S. Carolina Coasts
1406	07/10/2022	20:01	22:04	Gulf of Mexico (S of LA)
1407	07/14/2022	14:01	20:24	Virginia Coast
1408	07/16/2022	14:10	18:16	Florida Coast
1409	07/18/2022	16:16	20:46	Carolina Coasts
1410	07/22/2022	12:11	18:14	N. Carolina & Delaware Coasts
1411	07/24/2022	12:21	18:55	Gulf of Mexico (E of Yucatan)
1412	07/26/2022	11:40	15:13	Florida Coast
1413	07/27/2022	10:34	18:42	Virginia & N. Carolina Coasts
1414	07/30/2022	17:42	20:29	N. Carolina Coast

Data Processing

In-phase and quadrature voltage measurements were recorded during the flight. During post-flight analysis, and in order to produce the accompanying datasets, a suite of signal and data processing algorithms/techniques were used to reduce spurious signals and de-aliasing artifacts. This dataset represents a consistent, scientific measure of the atmosphere within 60 nautical miles of the aircraft, ±60° of heading, and from the surface up to approximately 45,000 feet. The data in this dataset includes radar reflectivity factor (RRF), Index of Dispersion for RRF measures, Doppler velocity, spectral width, and radar estimated ice water content (RIWC) for regions above about 0dBZ RRF. The velocity and spectral width measurements were obtained using pulse pair processing techniques. The sign convention used for radial velocity defines positive velocities along increasing range (i.e. away from the radar antenna).

Available Data

There are several types of files containing radar measurements in this dataset, specifically:

- *List* – contains specific *RadProd* values associated with IKP measurement locations,
- *RadProd* – contains all the radar products – bin-by-bin for each azimuth/vertical orientation,
- *bitmap* – contains captured PPI images for each *RadProd* for several temperature altitudes,
- *KMZ* – contains aircraft and radar data/imagery suitable for visualization using Google Earth.

The balance of this section describes each of these files types in more detail along with information relevant to electronic reading and utilization of that data.

List files

Ice-Water-Content (IWC) is the metric to be compared, and the preferred IWC measurement is produced from 5-second running-averages from the IKP instrument. So once IKP data are released, the radar team uses those 4D locations to produce radar products at the same location and over the same spatial extent as those embodied in the IKP measurements. The *List* files provide this tabularized data and aircraft state measurements. The following table specifies the measurements and column order for this ASCII file.

Measurements Name:
Time
AC Latitude
AC Longitude
AC Altitude
AC Heading
AC Airspeed (original)
AC Airspeed (fixed)
AC Groundspeed
AC Vertical Velocity
Wind Speed
Wind Direction
Vertical Winds
Normal Acceleration
Normal Acceleration (stddev)
RRF
Index of Dispersion
Velocity
Spectral Width
RIWC
SAT

A single, Comma Separated Variable (*csv*), file is provided for each flight (day) with filenames that conform to the following:

summary_**YYYYMMDD**_**####**.csv

where **YYYYMMDD** are the year month day characters and **####** are the numerical characters for that particular flight (redundant information to date that allows either nomenclature to be used).

The source of the data items in blue are from the **IKP**, in green from the **AC_systems (note: Vertical Winds were not available for this 2022 flight campaign)**, and in red from the **radar**. These files provide the variables at a 1 Hertz sample rate and are synchronized using recorded GPS time. Previous tests allowed validation of these times as a common reference. It should also be noted that **two** airspeeds are provided: the original (containing anomalies during HIWC encounters) and fixed (restored estimates based upon multiple inputs).

RadProd files

A single binary file is provided for each flight (day) with filenames that conform to the following:

YYYYMMDD_**####**.prd

where **YYYYMMDD** are the year month day characters and **####** are the numerical characters for that particular flight (redundant information to date that allows either nomenclature to be used).

These files were created by processing the radar data collected during the flight campaign. Note: some prd files contain time gaps due to stopping and restarting the recording; these gaps may be: small (eg, 1-5 seconds) due to a change in radar/recorder configuration, or large gaps (10's of minutes) due to long transits in clear air without any observable clouds. The time parameter will exhibit this gap and the KMZ graphics shows it pictorially.

Figure 3 graphically shows the format of a prd file and is produced for each Coherent Processing Interval (CPI) of radar data. It consists of 32 bytes of **Header**, then 225 bytes of **Reflectivity** (1 byte per range bin, for each 225 range bins), then 225 bytes of **Index of Dispersion**, then 225 bytes of **Velocity**, then 225 bytes of **Spectral Width** (ie, measure of turbulence), and 225 bytes of **Radar estimated IWC**.

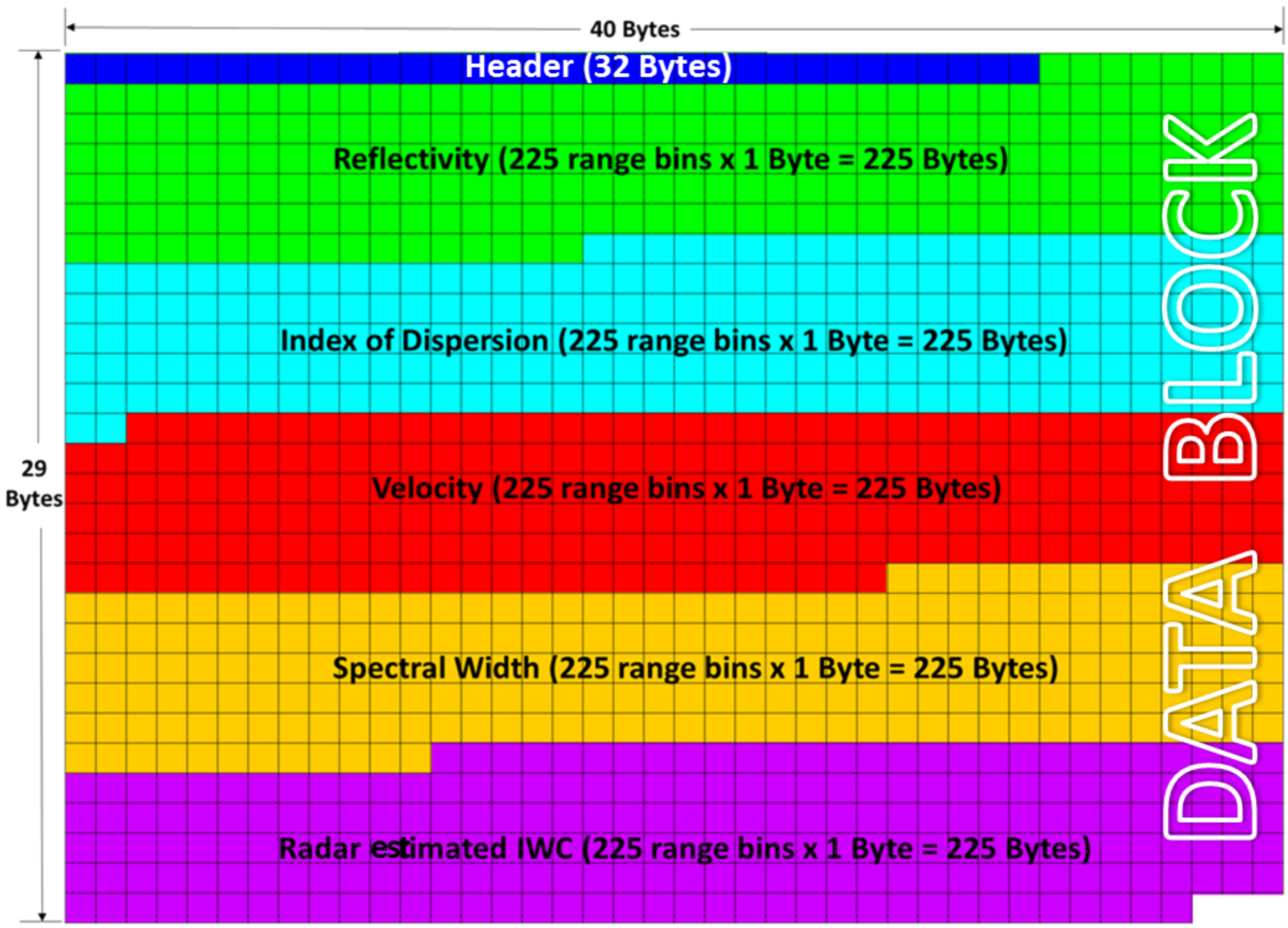

Figure 2: Graphical Representation of the prd format consisting of one CPI of data

Header Block – The header block of each CPI contains 12 variables, each variable has been scaled to allow integer representation within this file. The following table defines the variables contained in the Header, their order, the scaling applied, and the number of bytes that are used to convey this value. The subsequent graphic also conveys the same formatting information.

Table of Header information/format

#	Variable Name and description	Units	Bytes
1	Time (coarse)	Seconds since midnight	4
2	Time (fine)	10^{-4} seconds	2
3	Latitude	10^{-4} degrees	4
4	Longitude	10^{-4}degrees	4
5	Altitude	meters	4
6	Heading	10^{-2} degree	2
7	Groundspeed	10^{-2} meter/second	2
8	True Air Speed	10^{-2} meter/second	2
9	Antenna Azimuth	10^{-2} degrees	2
10	Antenna Elevation	10^{-2} degrees	2
11	Resolution size of bin	meters	2
12	Number of range bins	#	2

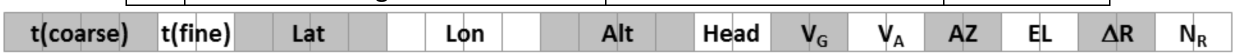

Figure 3: Depiction of Header - each square represents 1 Byte (8 bits)

<u>Data Block</u> – (As previously depicted in Figure 2) After the header, the radar products for each of the 225 range bins are represented by 1-byte signed integers with valid data in the range of ±127. If no valid measurement was made, "no data" is represented as a value of -128. Reflectivity values are provided in units of dBZ, Index of Dispersion for RRF measures are provided in units of one-quarter dBZ with an offset of 12 dBZ (i.e. ID = X/4 + 12 where X is the 1-byte signed integer value), velocity values are provided in units of meters per second (m/s), spectral width values are provided in units of meters per second (m/s), and radar estimated IWC values are provided in units of one-tenth gram per cubic meter (1/10 g/m^3) (i.e. RIWC = X/10 where X is the 1-byte signed integer value).

Bitmap files

Periodic images of the radar scans (ie, Plan Position Indicator (PPI)) were captured and are provided as a quick view of the radar observations. These images were captured approximately every minute and without any annotation, so it is important to know that each image is 80Nmi (vertical image dimension) by 160Nmi (horizontal image dimension); the aircraft is positioned at the center of the bottom edge of the image; and the image center-vertical is oriented according to the aircraft heading (true) reported at the time of the image. Where no radar measurements were made, the image pixels are set to transparent (alpha channel value of zero), so the full 80x160Nmi extent may not be visible depending on how the image is viewed.

At each of these aircraft positions, PPI images for four radar products (eg, RRF(dBZ), Radial Velocity(m/s), spectral width(m/s), and RIWC (g/m^3)) were captured at each of the following altitudes: current FL, FL330 (representative of -50°C), FL230 (-30°C), FL130 (-10°C), & FL050 (+5°C). These images are produced as a composite of multiple scans, at multiple elevation angles, and multiple aircraft positions, so a variety of radar and sampling artifacts may be present; consequently, these images should be used for qualitative assessments of the storm and measurements collected. Detailed analyses including all quantitative results should be produced from the *RadProd* files rather than this imagery.

In order to facilitate the widest possible compatibility, these images are stored as bitmaps and should be readily accessible/viewable by all users and on all computing platforms. The *bmp* directory has subdirectories for each day containing zip archives of *bmp* image files in the following format:

YYYYMMDD_####_alt_type.zip

where **YYYY** is the year,
MM is the month,
DD is the day,
is flight number,
alt is the altitude of the measurements (MSL in ft OR FL for ownship altitude),
type is the type of radar data (eg, reflectivity (RRF), Velocity (Vel), spectral width (SW), and radar estimated IWC (RIWC)).

Each zip archive contains multiple bmp image files with file names in the following format:

type_altHHMMSS.bmp

where **type** is the type of radar data (eg, reflectivity (RRF), Velocity (Vel), spectral width (SW), and radar estimated IWC (RIWC)),
alt is the altitude of the measurements (MSL in ft OR FL for ownship altitude),
HHMMSS is UTC time (HH is hours, MM is minutes, and SS is seconds).

Google™ Earth files (aka KMZ files)

Analyzing HIWC data is challenging, as radar measurements are made in front of the aircraft and all other instruments measure in situ. Efforts were made to synchronize time recorded in these files; however, even with this synchronization it is often difficult to "see" the spatial correlation of these records.

To facilitate this process we have adapted our output files into a set of KMZ formatted files that enable rendering of the data within the Google™ Earth application (freely obtainable at https://www.google.com/earth/). This process enables video-like rendering of multiple, independent, spatio-temporal datasets from multiple sources into a single visualization space/tool. For details on how to operate Google™ Earth (in general) consult their help page(s) (https://support.google.com/earth) found within Google™ Earth – for help with the video rendering process search their help page(s) for "time slider".

Within this *KMZ* archive, there are two sets of files: PPI and Satellite images. In order to render these files all that needs to occur is to open them with Google™ Earth (in Windows environments with Google™ Earth already installed this may accomplished by simply double-clicking the KMZ file icon).

PPI Images

The *PPI_Images* contained in these *KMZ* files are the same ones depicted in the *bitmap* flies (as previously described) with the addition of meta-data to support it's rendering within Google™ Earth.

The *KMZ* directory has subdirectories for each day and the individual *KMZ* files adhere to the following filename format:

YYYYMMDD_####_alt_type.kmz

where **YYYY** is the year
MM is the month
DD is the day
is flight number
alt is the altitude of the measurements (MSL in ft OR FL for ownship altitude)
type is the type of radar data (eg, reflectivity (RRF), Velocity (Vel), spectral width (SW), and radar estimated IWC (RIWC))

Satellite Imagery

In prior HIWC Flight Campaigns, we also provided the satellite data used during the flight campaign but formatted to work in Google™ Earth alongside the radar imagery. However, this format was not created for this flight campaign, but the satellite imagery is available at the NCAR archive. Additionally, the satellite imagery comes from GOES-16 and GOES-17 high resolution imagery that was obtained from the NASA Langley Science Directorate archive, and maybe accessible at: HIWC III Satellite Imagery.

Support

Any questions regarding the 2022 HIWC III Flight Campaign; specifically, the radar dataset should be addressed to:

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