Compact Ocean Wind Vector Radiometer (COWVR) Environmental Data Record (EDR) Quick-start Users Guide

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1. Introduction

1.1. Purpose and Scope

This user guide describes the Compact Ocean Wind Vector Radiometer (COWVR) environmental data record (EDR) and is intended to orient users to the file contents, provide recommendations for flagging and data quality control and highlight the idiosyncrasies of observations from the ISS.

1.2. Mission Description

The Compact Ocean Wind Vector Radiometer (COWVR) and Temporal Experiment for Storms and Tropical Systems (TEMPEST) were installed on the International Space Station (ISS) in January 2022, as part of the Space Test Program (STP-H8) mission sponsored by the US Space Force to demonstrate new low-cost microwave sensor technologies for weather applications, while maintaining the same performance as legacy sensors [1-6].

1.3. COWVR Instrument Description

The Compact Ocean Wind Vector Radiometer (COWVR) sensor is a fully polarimetric, conically imaging microwave radiometer, operating at 18.7 GHz, 23.8 GHz, and 33.9 GHz, for measuring ocean surface vector winds (OSVW), precipitable water vapor, and cloud liquid water. The instrument observing geometry—shown in Figure 1.3-1—is such that there is a fore and aft look. Consequently, two overlapping swaths of observations from COWVR can be used to estimate geophysical parameters and produce microwave imagery products. An example image of wind speed, wind direction and integrated liquid water is show in Figure 1.3-2 for a north Pacific storm on January 20, 2024. Figure 1.3-3 shows several examples of tropical cyclone imagery from COWVR along with a visible image taken from the ISS of COWVR over Hurricane Ian.

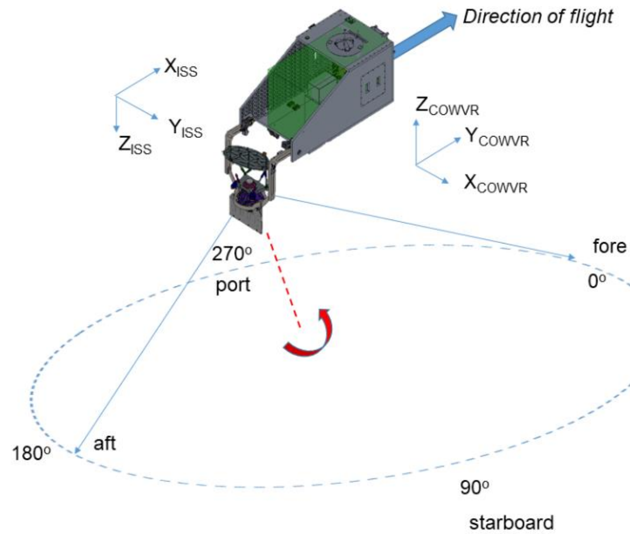

Figure 1.3-1: The observing geometry of COWVR, which scans conically 360 degrees for observations in the fore and aft directions of flight. The angles shown are the instrument scan angle in the EDR ('inst_scan_ang').

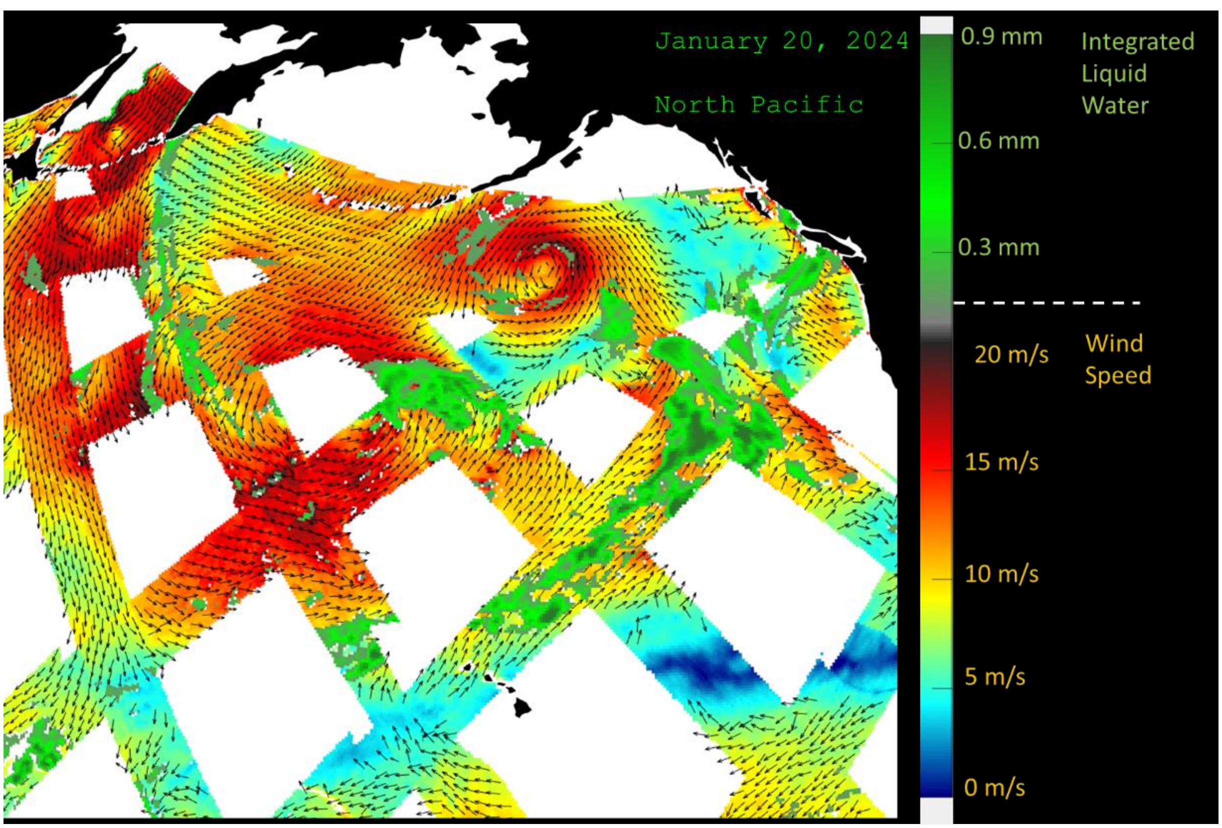

Figure 1.3-2: Example COWVR swath level EDR products for a north Pacific storm. The color scale shows wind speed in non-precipitating areas and integrated liquid water in areas of precipitation. Wind direction is shown as the quivers in non-precipitating areas.

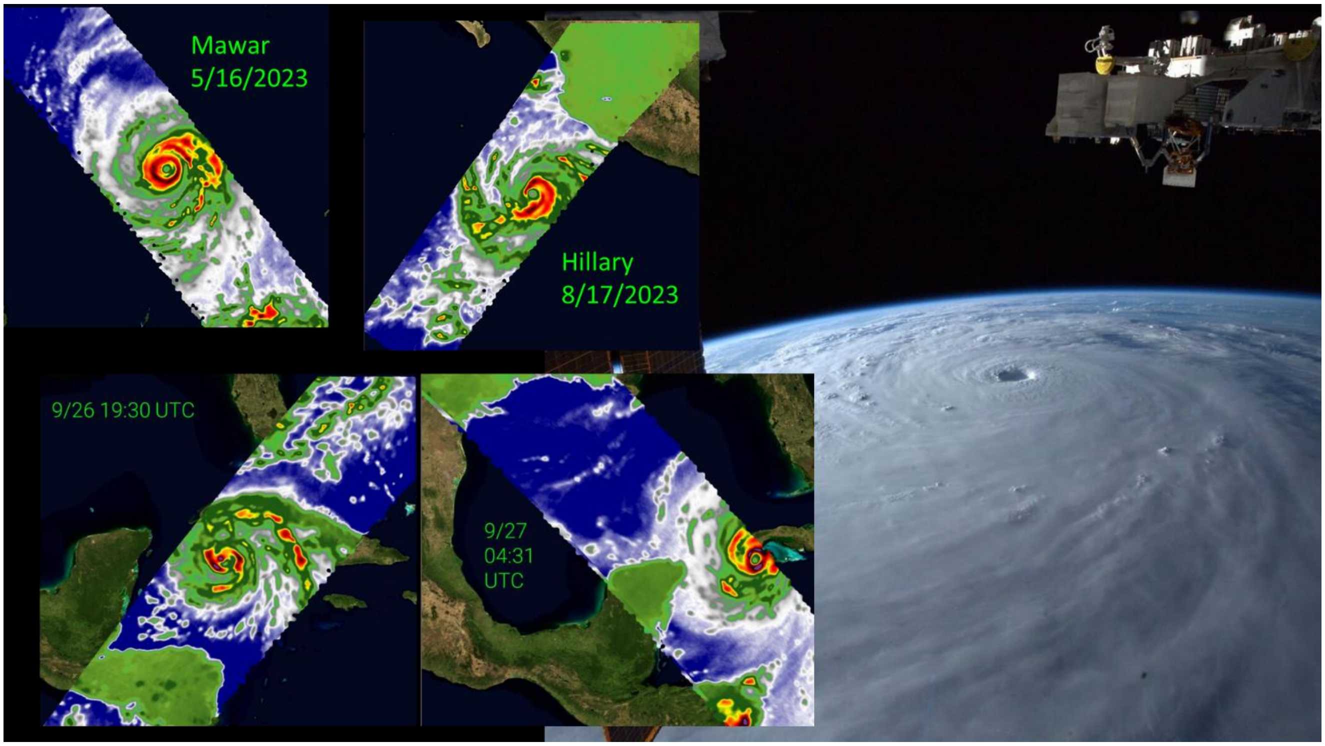

Figure 1.3-3: Example COWVR imagery of several tropical cyclones (Mawar, top left; Hillary, top right; and Ian, bottom). The right side shows an image of COWVR over Hurricane Ian.

1.4. COWVR EDR Description

1.4.1. Overview of Data Groups

The EDRs contain both ungridded and gridded variable groups, and flags to go with each type of data. The COWVR brightness temperature (TB) data are processed at two spatial resolutions; the Instantaneous Field of View (IFOV) is the native resolution of the sensor and the Composite Field of View (CFOV) is re-sampled to a common resolution at all frequencies. The IFOV resolution is nominally 30x19km, 23x15km and 16x10km for the 18.7, 23.8 and 33.9 GHz channels respectively. The CFOV resolution is a 30km circular footprint.

The brightness temperatures have 4 polarizations. The brightness temperature is reported as the modified Stokes vector,

$$\overline{T}_B = \begin{bmatrix} T_V \\ T_H \\ T_3 \\ T_4 \end{bmatrix} = \begin{bmatrix} T_V \\ T_H \\ T_{+45} - T_{-45} \\ T_{LCP} - T_{RCP} \end{bmatrix} = \frac{\lambda^2}{\eta k B} \begin{bmatrix} |E_V|^2 \\ |E_H|^2 \\ 2\,\mathrm{Re}|E_V E_H^*| \\ 2\,\mathrm{Im}|E_V E_H^*| \end{bmatrix} \tag{1}$$

where the vertical and horizontal polarizations are relative to the Earth normal

$$\hat{h} = \frac{\hat{k} \times \hat{n}}{\left|\hat{k} \times \hat{n}\right|} \tag{2a}$$

$$\hat{v} = \hat{h} \times \hat{k} \tag{2b}$$

where *k* is a vector pointing along the instrument boresight look direction. The array order is V-pol, H-pol, 3rd Stokes, 4th Stokes, in the Earth polarization frame.

The gridded data represent an average value of the observations that fall into a resolution cell of an Earth-fixed grid. Gridded data are available for both fore and aft looks and these grids match one another. There are two different types of gridded data: Gridded and FineGridded. All Gridded data use inputs at the CFOV resolution and the FineGridded data use inputs at the IFOV resolution. Both grids have a latitude range of $\pm$ 60 degrees and a longitude range of -180 to 180 degrees. The Gridded data have a resolution of 0.2 degrees and the FineGridded data have a resolution of 1/6 degrees. The regular Gridded groups have both the scene temperatures and geophysical data products, in addition to the relevant geolocation and flags. The FineGridded groups contain the scene temperatures and the relevant geolocation and flags that correspond with this group.

The data groups and a high-level description are given in the following table.

Group	Description
/CalibratedSceneTemperatures	1-dimensional brightness temperature arrays for the IFOV and CFOV resolutions for each polarization (V,H,3rd,4th) Dimensions: [4xN] – N is time dimension (variable length)
/GeolocationAndFlags	1-dimensional flags and geometry corresponding to the /CalibratedSceneTemperatures groups for the IFOV and CFOV resolutions Dimensions: [4xN] – N is time dimension (variable length)
/UngriddedEnvDataRecords	1-dimensional geophysical retrievals (note, wind vector requires 2-looks and is not performed for a single observation, only appears in gridded data) Dimensions: [4xN] – N is time dimension (variable length)
/GriddedSceneTemperatures	Gridded CFOV brightness temperatures Dimensions: [4x1801x601]
/GriddedGeolocationAndFlags	Gridded CFOV flags and geometry Dimensions: [1801x601]
/EnvDataRecords	Gridded geophysical retrievals from CFOV TBs Dimensions: [1801x601]
/GriddedAncillary	Gridded ancillary data used in retrieval Dimensions: [1801x601]

/FineGriddedSceneTemperatures	Gridded IFOV brightness temperatures Dimensions: [4x2161x721]
/FineGriddedGeolocationAndFlags	Gridded IFOV flags and geometry Dimensions: [2161x721]

1.4.2. Key Variable Descriptions

Scene Temperatures

The 0.2^{o} gridded scene temperatures can be found in the group called 'GriddedSceneTemperatures' and have the following naming convection:

grid_tbNN_LLL

where 'grid' indicates it is a gridded variable, 'tb' indicates it is a brightness temperature, NN indicates the frequency ('18','23','34'), and LLL is either 'fore' or 'aft' to denote whether it is the fore or aft swath. This variable is size 4 x 1801 x 601 as there are 4 polarizations and the size of the grid is 1801 x 601. The order of the polarization index is V, H, 3rd Stokes, and 4th Stokes. Variables with an additional affix 'stdev' are the standard deviation of the TB sampled that were averaged in that grid box.

The ungridded scene data are in the 'CalibratedSceneTemperatures' group. Each variable name is in the form

tbNN_AAA

where NN is the frequency ('18','23','34') and AAA will be either 'cfov', 'ifov', or 'stdev'. The 'cfov' variable contains brightness temperature (TB) at the CFOV resolution (Earth polarization frame). The 'ifov' variable contains brightness temperature at the IFOV resolution (Earth polarization frame). The ungridded data are size 4 x M because there are 4 polarizations and M is the number of observations. The order of the polarization index is V, H, 3rd Stokes, and 4th Stokes. The CFOV data should be used for any application where minimum noise or a consistent spatial resolution among the frequencies is important. The IFOV should be used where high-resolution is desired (e.g. imaging applications). The 'stdev' variable for a given sample is the standard deviation of a 7x7 neighboring set of IFOV TBs centered on the location of the given sample. The 'stdev' represents the scene inhomogeneity within a CFOV pixel (e.g. weather).

Environmental Data Records

The environmental data records are contained in the group EnvDataRecords. The precipitable water vapor (PWV) and cloud liquid water (CLW) are retrieved using the fore and aft scene individually. Most users will want to average these together to reduce noise. Wind direction estimates that are the closest to the ancillary wind vector (from the Navy NAVGEM model) are reported in 'wind_dir'. All of the wind direction solutions (ambiguities) available for a particular point are in the 'wind_dir_amb' variable, with the first column representing the first ranked solution (best fit to data). The wind direction is reported in the oceanographic convention; the direction wind is blowing toward, degrees clockwise from North. The 'wind_dir' variable is recommended for most users.

Geolocation

The COWVR geolocation uncertainty is estimated to be better than 2km. COWVR uses position information from a GPS receiver on the STP-H8 structure and attitude information from dedicated star trackers. The primary source of attitude information comes from two star trackers that are placed on the arms holding COWVR. Occasionally, one or both of these star trackers is blocked by a robotic arm. In this case, alternate sources are used. The next best source is a fixed star tracker placed on the STP-H8 structure. If all of the star trackers are blocked, then ISS provided attitude information is used (this is rare). There is a flag called 'att_source_flag' which indicates the attitude source used. These sources were all inter-calibrated and produce very similar quality geolocation. For most users, this flag can be ignored. For applications demanding the highest quality geolocation information, 'att_source_flag' of 1, 2 or 3 is recommended.

/GeolocationAndFlags/att_source_flag

- -1: unspecified
- 0: transition
- **1: flexcore nominal**
- 2: flexcore trac1 only
- 3: flexcore trac2 only
- 4: direct trac1
- 5: direct trac2
- 6: fixed tracker ← Body fixed (TEMPEST) star tracker
- 7: issbad sto ← ISS provided attitude (differential GPS)

(Flags 1–3: COWVR star trackers processed on-board; flags 4–5: COWVR star trackers processed on-ground)

Quality Flags

There are two general categories of flags. One set indicates the quality of the brightness temperatures (and carries over to retrieval products) and one set pertains only to the quality of the retrieval products (e.g. a rain flag or land flag). A ‘fill’ data value of -9999 indicates missing or bad data.

This group contains time and geolocation information, instrument geometry (e.g. scan and incidence angles) and quality flags. The ‘fill’ data value is -9999. There is a summary flag for the gridded data called ‘grid_summary_flags’, where 0 = unflagged over ocean, 1 = unflagged over land, 2 = flagged, 3 = unavailable.

Flags to be Applied to TBs and Retrieval Products

The main flags impacting the quality of the brightness temperature arise from field-of-view obstructions and from interfering radio sources (anthropogenic and solar). These flags should be applied to the TBs and retrieval products (0 = good). The flags appear as 1-D and gridded variables.

The arms holding COWVR partially block the antenna at the scan edges relative to the ground track (for nominal ISS attitude). Approximately twice per orbit, the large ISS solar arrays swing through part of the COWVR image. These two obstructions are illustrated in Figure 1.4-1 and are flagged using telemetry information (e.g. angle of solar array, scan angle). There are also obstructions from unknown origins which are identified by looking for anomalous TB values. These are often from visiting spacecraft or robotic arms. For the gridded flags, there is one set for the ‘fore’ observations and one set for the ‘aft’. The obstruction flags are listed in Table 1.4-1. Figure 1.4-2 shows the impact of the obstruction flags on the swath imagery.

Table 1.4-1: Field-of-view obstruction flags. For the gridded flags, there is one set for the ‘fore’ observations and one set for the ‘aft’.

Name	Description
solar_array_flag	COWVR solar array obstruction flag (0=unobstructed).
support_arm_flag	COWVR support arm obstruction flag (0=unobstructed).
ufo_obstruct_flag	COWVR unknown obstruction flag (0=unobstructed).

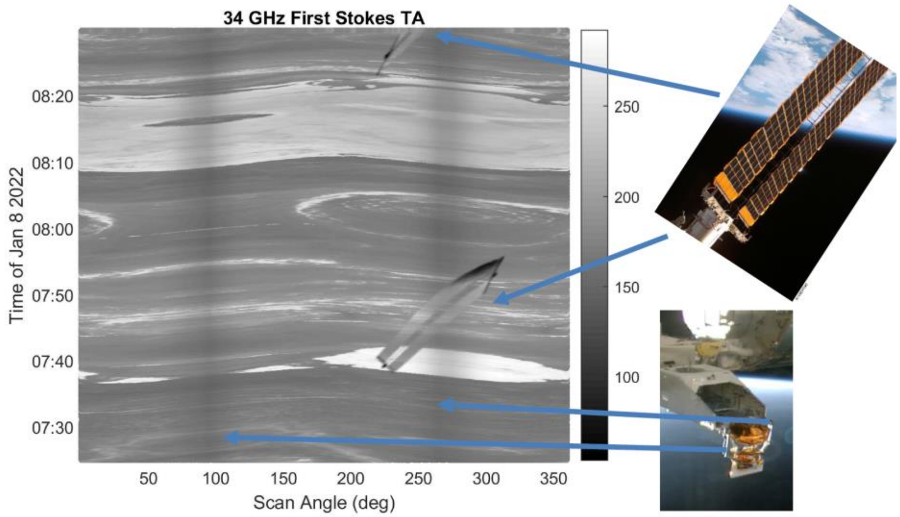

Figure 1.4-1: An example of imagery with artifacts from the ISS solar panels and COWVR's support arms.

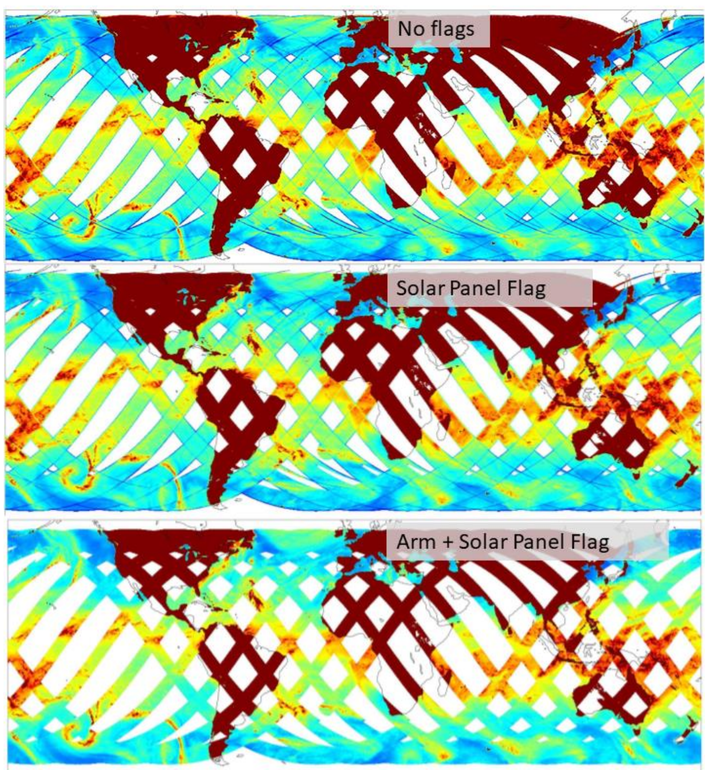

Figure 1.4-2: A series of maps with examples of view obstruction flags applied.

The COWVR TBs are also impacted by radio frequency interference (RFI) and solar emission reflecting off of the ocean surface (i.e. sun glint). The RFI can be direct (from ground to COWVR or from space to COWVR) or reflected off of the Earth's surface. In the case of reflected RFI, typically only one swath is impacted at a time (either fore or aft). Direct sun contamination is negligible. The radio interference flags are given in Table 1.4-2. For the gridded flags, there is one set for the 'fore' observations and one set for the 'aft'. Figure 1.4-3 shows a heat map for direct and reflected RFI. Reflected RFI (mostly 18.7 GHz) is predominately an issue around the coastlines of the United States, Europe and Australia. Direct RFI (mostly 33.9 GHz) is most prominent over China.

Table 1.4-2: Radio interference flags for ungridded data. Similar flags exist in gridded form.

Name	Description
rfi_flag	COWVR RFI flag (0=likely no reflected RFI)
sun_glint_flag	COWVR sun glint flag (0=limited sun glint)
direct_rfi_flag	COWVR direct RFI flag (0=likely no RFI)

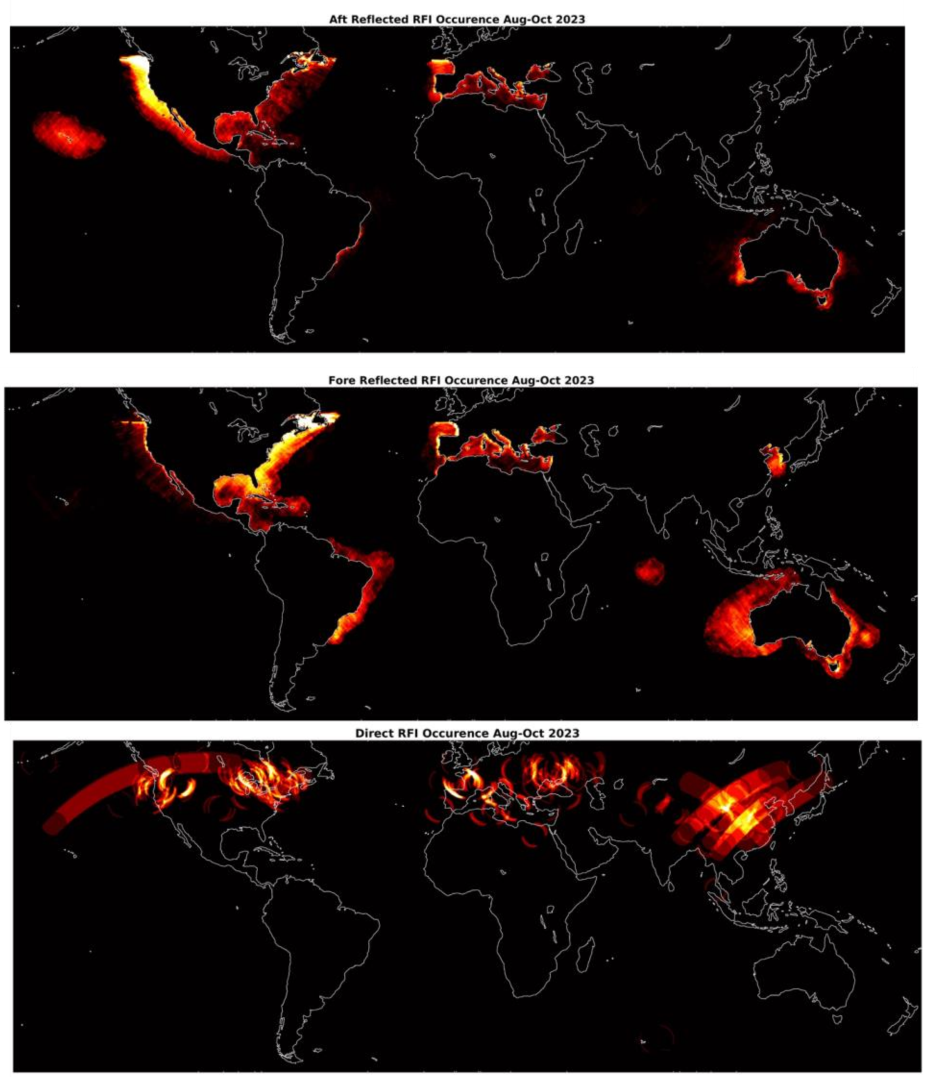

Figure 1.4-3. Typical locations of reflected RFI for the aft swath (top), forward swath (middle) and direct RFI for fore+aft (bottom). Yellow and white indicate the highest probability of seeing RFI in a particular location, black means it was not observed. These maps are for Aug-Oct 2023.

Flags to be applied only Retrieval Products

There are several quality flags that apply only to the geophysical retrieval products. The land flag and rain flag apply to all the geophysical retrievals and indicate conditions when a solution is possible. COWVR, as a demonstration mission, was not designed with the low-frequency channels needed to produce retrieval products in rainy conditions. The rain flag has 3-levels, no rain, possible or light rain and rain. There is only a minor degradation in the products in high-clouds/light rain, so a rain flag of 0 or 1 should be acceptable to most users. The land flag indicates ocean, coast or land. The coastal performance hasn't been independently validated to date, so for most applications (other than coastal), a land flag of 0 is recommended.

Table 1.4-3: Retrieval flags for land and rain. Similar flags exist in gridded form.

Name	Description
land_flag	0 – ocean, 1 – coast, 2 – land; -1: unknown
rain_flag	0: no rain, 1: possible rain, 2: rain, -1: unknown.

The wind vector retrieval also has specific quality flags. The nominal wind vector retrieval algorithm uses both the fore and aft observations in a so-called "2-look" retrieval algorithm. This dramatically improves the algorithm's skill (e.g. how often the lowest residual solution is the intended solution) and the algorithm's direction uncertainty. On occasion, one swath will be missing, flagged or degraded but the other swath is available. This situation occurs frequency in areas of reflected RFI. If one swath is degraded, the 2-look algorithm is used. If one swath is bad, it is ignored and a "1-look" algorithm is used with the good swath. The wind direction and wind speed quality flags, shown in Table 1.4-4, indicate which swath was used and why (degraded or bad). Note, the wind speed and direction flags should be applied independently to each. For example, the wind direction flag will indicate a degraded condition for low winds (< 3m/s) due to low signal level for direction, but produce an acceptable quality wind speed value.

Table 1.4-4: Retrieval flags wind retrieval. These should be applied independently to speed and direction.

Name	Description
wind_dir_flag	0: good, 1: fore good aft ignored, 2: aft good fore ignored, 3: fore and aft degraded, 4: fore degraded aft ignored, 5: aft degraded fore ignored, 6: bad, -1: unknown
wind_speed_flag	0: good, 1: fore good aft ignored, 2: aft good fore ignored, 3: fore and aft degraded, 4: fore degraded aft ignored, 5: aft degraded fore ignored, 6: bad, -1: unknown'

Other flags that may be useful for identifying off-nominal conditions are given in Table 1.4-5.

Table 1.4-5: Flags for off-nominal conditions. Generally, these are not needed to be used explicitly as they trigger other flags.

Name	Description
eph_source_flag	Ephemeris source; -1: unspecified, 0: transition, 1: gps, 2: issbad sto.

att_source_flag	Attitude source; -1: unspecified, 0: transition, 1: flexcore nominal, 2: flexcore trac1 only, 3: flexcore trac2 only, 4: direct trac1, 5: direct trac2, 6: fixed tracker, 7: issbad sto.
sc_att_flag	0 – nominal spacecraft attitude, 1 – off-nominal spacecraft attitude; -1: unknown
fore_aft_flag	0 – observation is forward scan, 1 – observation is aft scan; -1: unknown
asc_desc_flag	Satellite orbit node; 0: descending, 1: ascending, -1: unknown.

Geometry

It is important to note that the Earth incidence angle is not constant around the scan for COWVR due to the off-nominal pitch of the ISS. The range of incidence angles varies with time (due to ISS attitude changes) and is on average around 51.5^o. The incidence angle variation around the scan varies from a max of 46-57^o to a minimum of 51-52^o. A plot of how the min, mean and max incidence angle vary as a function of time is shown in Figure 1.4-5.

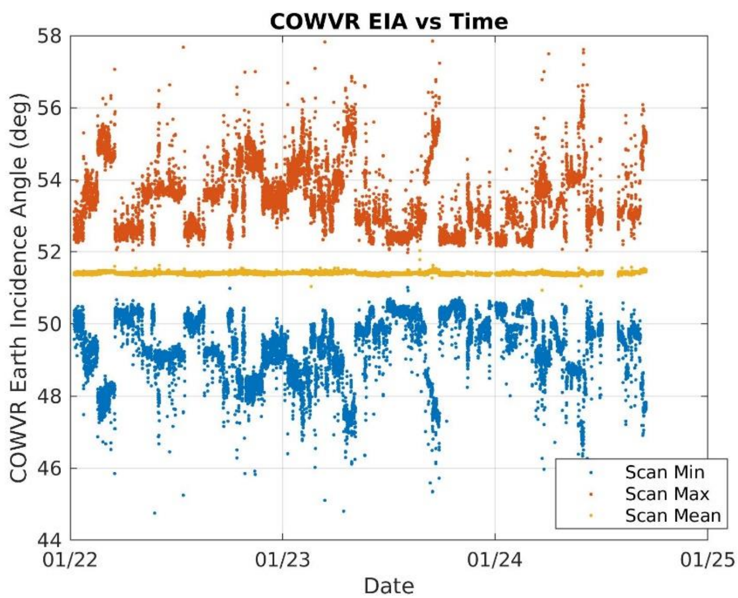

Figure 1.4-4. Incidence angle variation with time (min, max and mean over scan) related to ISS attitude changes.

The Earth azimuth angle (earth_az_ang) is the sensor azimuth angle with respect to Earth observation (0=pointing to north, 90=to east, 180=to south, 270=to west). This variable should be used when computing the relative wind direction. An example of the earth azimuth angle over the scan is shown in Figure 1.4-5. The instrument scan angle (instr_scan_ang) is the boresight scan angle in the instrument coordinate frame and remains fixed to the instrument.

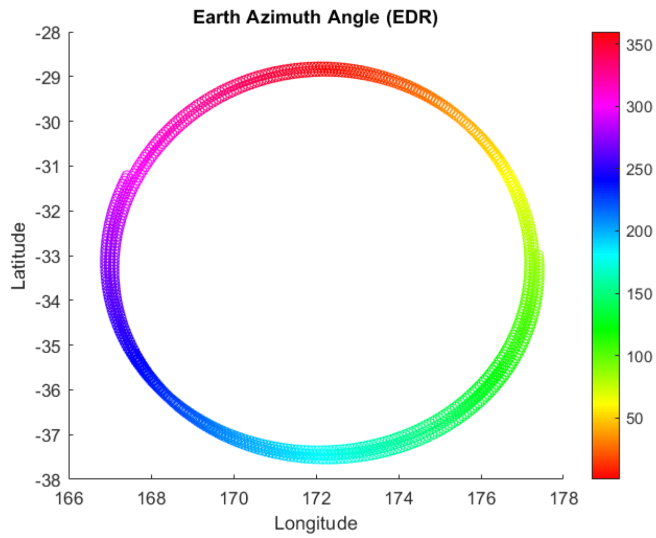

Figure 1.4-5: COWVR earth azimuth angle conventions for the EDR.

1.5. COWVR EDR Validation

The COWVR wind vectors products have been evaluated by the cal/val team. The wind speed and direction have been compared to ASCAT-B and ASCAT-C for co-incident observations made within 25km and ± 30 minutes of each other. The COWVR wind speed comparison to ASCAT is shown in Figure 1.5-1. The standard deviation of the difference (which includes errors from both sensors and spatial/temporal decorrelation error) is less than 1 m/s for wind speeds less than 10m/s The standard deviation grows to 1.5m/s for high winds, but some of this increase is due to the faster decorrelation times at higher winds.

The wind direction comparison is shown in Figure 1.5-2. The wind direction error is shown for both the closest ambiguity and the first rank solution, which are fairly similar due to the high algorithm skill (owing to the 2-look geometry). The algorithm skill exceeds 75% for wind speeds greater than 6m/s. The wind direction uncertainty is lower than WindSat retrievals which were made only with 1-look. The histogram of differences for select wind speed bins is shown in Figure 1.5-3 for the first rank and closest ambiguity solutions. This shows that ambiguities are minor for wind speeds greater than 6m/s and not minimal for all winds when using the closest ambiguity.

Figure 1.5-4 shows the wind direction difference statistics as a function of cloud liquid water and precipitable water vapor. The uncertainty changes very little with the amount of water vapor in the atmosphere. However, the uncertainty does grow slightly with larger values of integrated cloud liquid water, particularly above 0.18mm.

Figure 1.5-5 shows the mean and standard deviation of the COWVR-ASCAT wind speed and direction versus time showing temporally stable statistics. The wind direction statistics are for wind speeds greater than 6m/s.

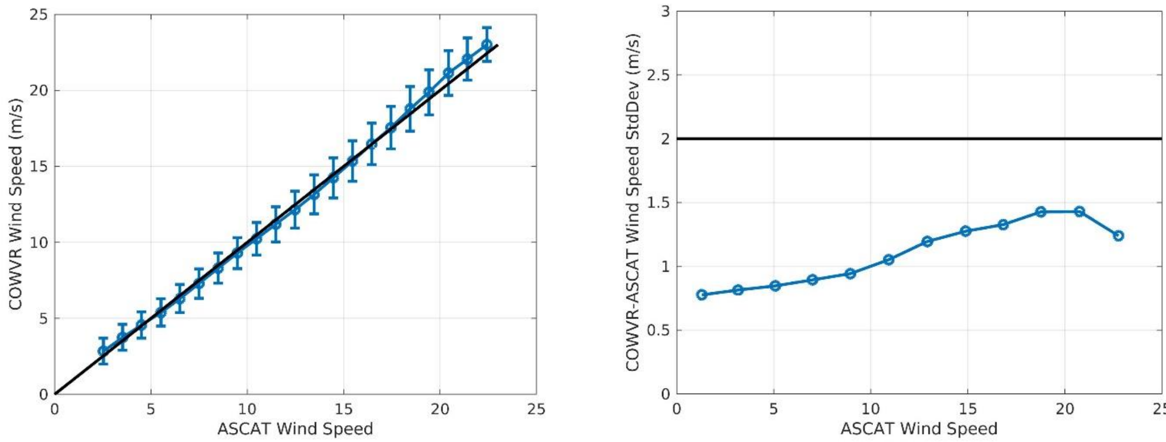

Figure 1.5-1. COWVR wind speed versus ASCAT wind speed (left) and standard deviation between COWVR and ASCAT wind speeds as a function of ASCAT wind speed (right).

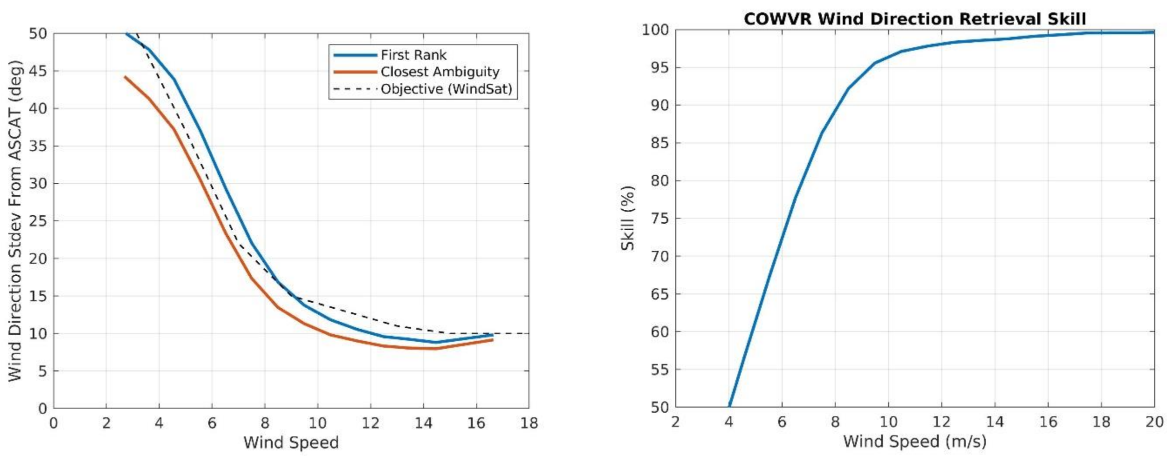

Figure 1.5-2. Standard deviation between COWVR and ASCAT wind direct as a function of ASCAT wind speed for both the closest ambiguity ('wind_dir') and the first rank solution ('wind_dir_amb(1)') (left). The algorithm skill (right) is the percentage of time the first rank solution is equal to the closest ambiguity.

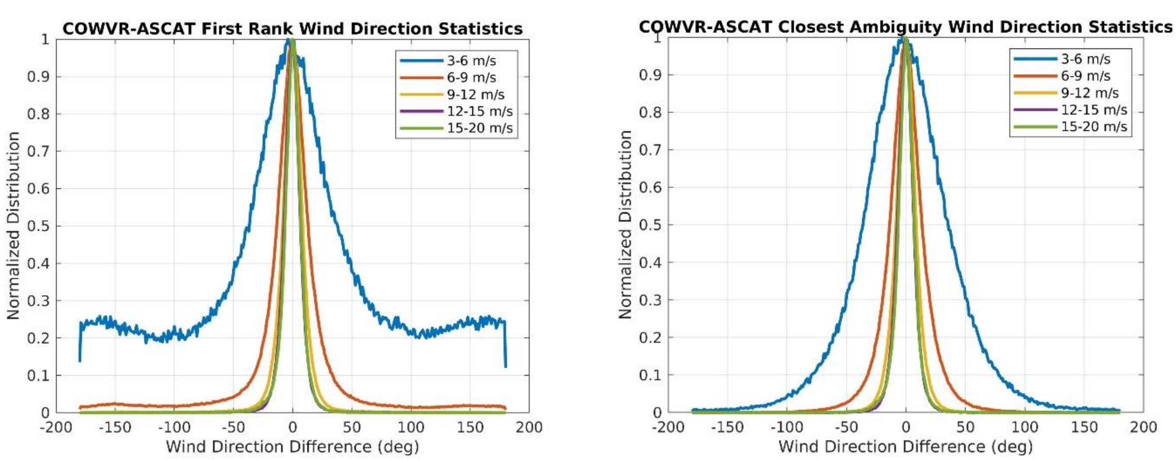

Figure 1.5-3. Histograms of COWVR-ASCAT wind direction for several wind speed ranges

for the first rank solution (left) and closest ambiguity solution (right).

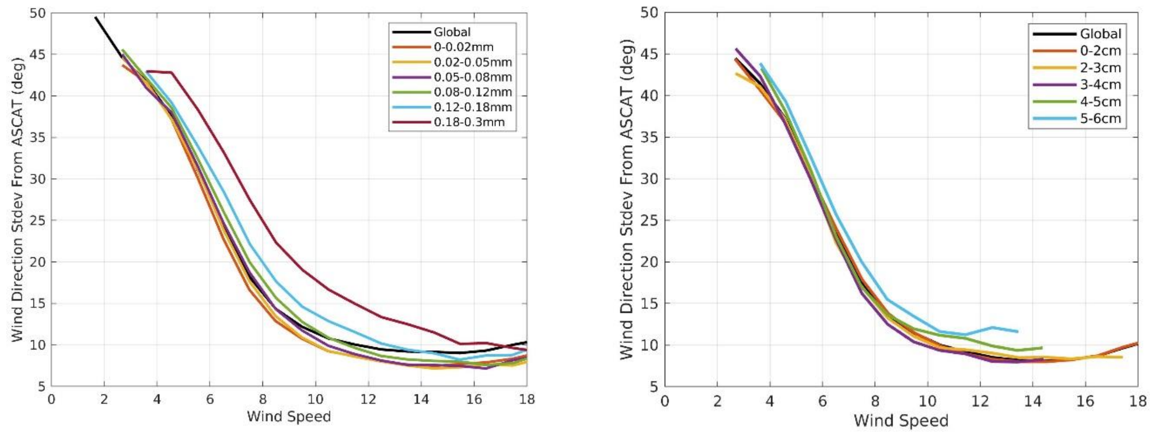

Figure 1.5-4. Standard deviation between COWVR and ASCAT wind direct as a function of ASCAT wind speed the closest ambiguity ('wind_dir') for ranges of cloud liquid water (left) and precipitable water vapor (right).

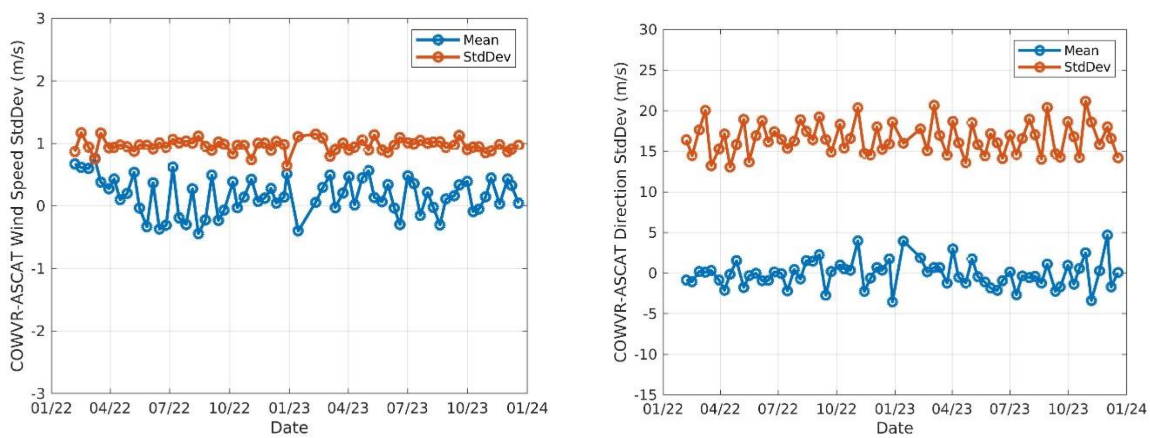

Figure 1.5-5. Mean and standard deviation of COWVR-ASCAT wind speed (left) and wind direction (right) (for wind speeds > 6m/s).

1.6. Data Access and Usage

1.6.1. NASA Earth Data Portal

On the NASA Earth Data search portal (https://search.earthdata.nasa.gov/) users can find the EDRs by looking at the dataset titled: COWVR STP-H8 Surface Wind Vector and Column-Integrated Atmospheric Water Measurements.

1.6.2. File Format

The EDRs are provided in '.h5' format. The files are provided in hourly granules. The filename format is as follows:

inst_typ.GID(SSSSSS).StartDateTime(YYYYMMDDThhmmss).EndDateTime(YYYYMMDD Tmmhhss).CollectionLabel(cv),LocationCode(C),ProductionTime(YYYYMMDDThhmmss).ext

where:

inst - Instrument: COWVR, TEMPEST
typ - Data type: TSDR, EDR
GID - Granule identification number (each granule is an hour); number of hours since defined epoch 2022-01-01
StartDateTime - Requested starting date and time of data
EndDateTime - Requested ending data and time of data
C – location code where data were produced ("J" is for JPL)
cv - Collection label (currently "v1001")

An example name for a Level 2 EDR file for granule 13822 is:

COWVR_EDR.013822.20230730T225845.20230731T000345.V1001.J.20240919T071016.h5

This file has data from 7/30/2023 22:58:45 UTC to 7/31/2023 00:03:45 UTC and was produced at JPL using V10.01 software on 9/19/2024 07:10:16 UTC.

1.7. Acknowledgement

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