Remote Sensing Systems

COWVR Calibration to GMI & Wind Direction Performance

Richard Lindsley*, Katherine Nelson, Frank Wentz, Thomas Meissner

*Corresponding author: lindsley@remss.com

Remote Sensing Systems

Funded by: NASA Ocean Vector Winds Science Team

Compact Ocean Wind Vector Radiometer (COWVR) Key Features:

1. Measures Wind Speed and Direction Using 18.7, 23.8, 33.9 GHz Fully Polarimetric Channels, 2. Full 360° Scan with Fore and Aft Look, 3. Low-Cost Design: Stationary Feed Bench While Antenna Rotates, 4. Hosted on the ISS, 5. Data Available from 2022-01-08 to 2025-07-27 (TSDR from PO.DAAC, Winds from PO.DAAC and Remote Sensing Systems) at https://www.remss.com/missions/cowvr/

We calibrated COWVR measurements to the absolutely calibrated brightness temperatures (TBs) from GMI in order to adjust for average, along-scan, and time-varying biases.

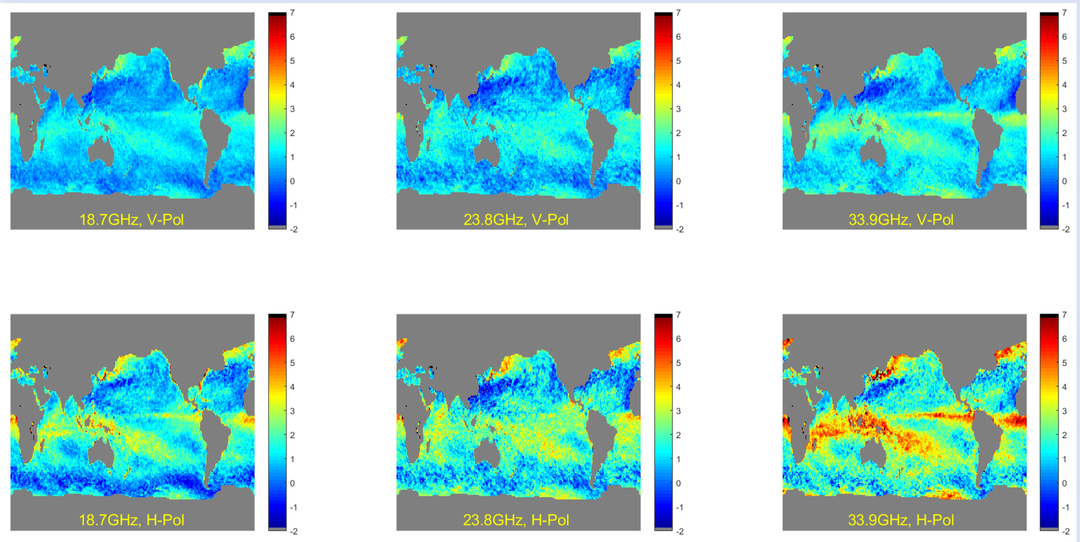

Fig 1. Monthly 1° latitude/longitude maps of $T_{B,GMI} - T_{B,GDAS}$ for COWVR 18.7, 23.8, and 33.9 GHz frequencies. GMI 37 GHz data is adjusted to the 34 GHz COWVR band.

$$T'_{B,\mathrm{GDAS}} = T_{B,\mathrm{GDAS}} + \left\langle T_{B,GMI} - T_{B,GDAS} \right\rangle$$

$$\Delta T_{B.COWVR} = T_{B,\mathrm{COWVR}} - T'_{B,\mathrm{GDAS}}$$

Table 1. Derived values for calibration parameters.

	18.7 GHz	23.8 GHz	33.9 GHz
Spillover Factor u_j	0.99062	0.99708	0.99806
Cross-Polarization Factor v_j	1.00644	1.00293	1.02799
Non-Linearity Coef. A_j	0.048	0.079	0.040

We use a GMI-based calibration reference for every COWVR measurement because COWVR does not have external calibration targets. This method relies on an RTM with NCEP GDAS input data that has been calibrated to GMI ($T'_{B,GDAS}$). We use the RTM instead of directly using GMI because COWVR and GMI are in different orbital planes with different ascending node time. Thus, near-simultaneous measurements (i.e., within one hour) are infrequent and limited to specific geographical regions. We derive the calibration parameters (Table 1) by comparing V1001 COWVR TBs with RTM TBs ($\Delta T_{B,COWVR}$).

Calibration Step 1: Cold Space Spillover

The spillover correction factors u_j are derived from COWVR observations over the Amazon Rainforest (Fig. 2).

Calibration Step 2: Cross-Polarization

We found the values for the cross-polarization correction factors v_j that remove the ocean along-scan biases that remain after the spillover correction. This applies mostly to the 2nd and 3rd Stokes, which show a difference between green and black curves in Fig. 3.

Calibration Step 3: Non-Linearity

The overall bias is greatly reduced by the application of u_j and v_j, and is close to negligible (<0.1 K). We remove this remaining bias by applying a small correction to the non-linearity (A_j) of the COWVR receiver for the 1st Stokes.

Calibration Step 4: Along-Scan Bias

After correcting for spillover, cross-polarization, and non-linearity, we generated tables of the along-scan biases over the ocean, averaged into 1° bins. The table offsets were used to subtract out these residual biases from the COWVR measurements over the ocean (Fig. 4).

Calibration Step 5: Time-Varying Bias

The final step is to correct for time-varying biases. We smooth the residual timeseries biases using a ±30-day moving time window (Fig. 5, left). The biases were put into tables and removed from the COWVR measurements over the ocean and Amazon rainforest (1st Stokes only) (Fig. 5, right).

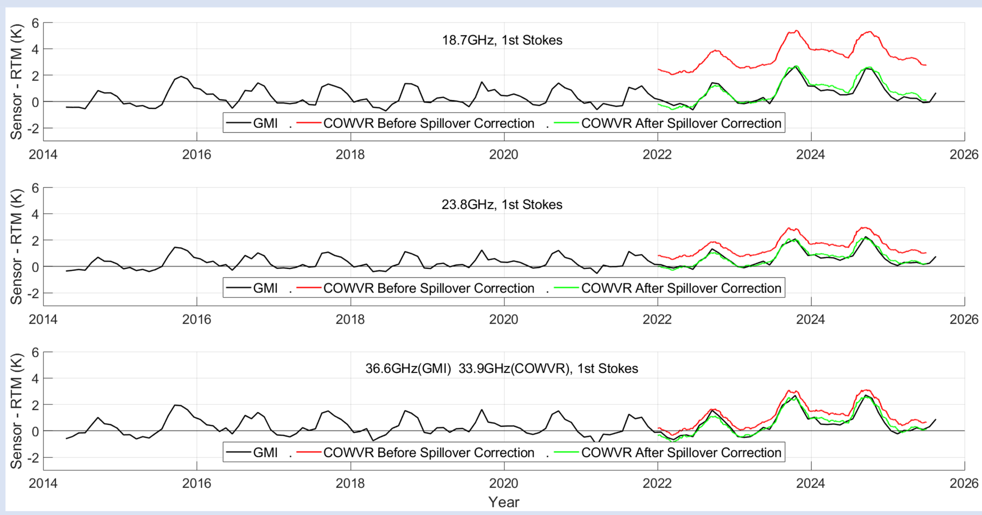

Fig 2. Timeseries of $\Delta T_{B,COWVR}$ over the Amazon rainforest before (red) and after (green) spillover correction. $\Delta T_{B,GMI}$ (black) is shown for comparison.

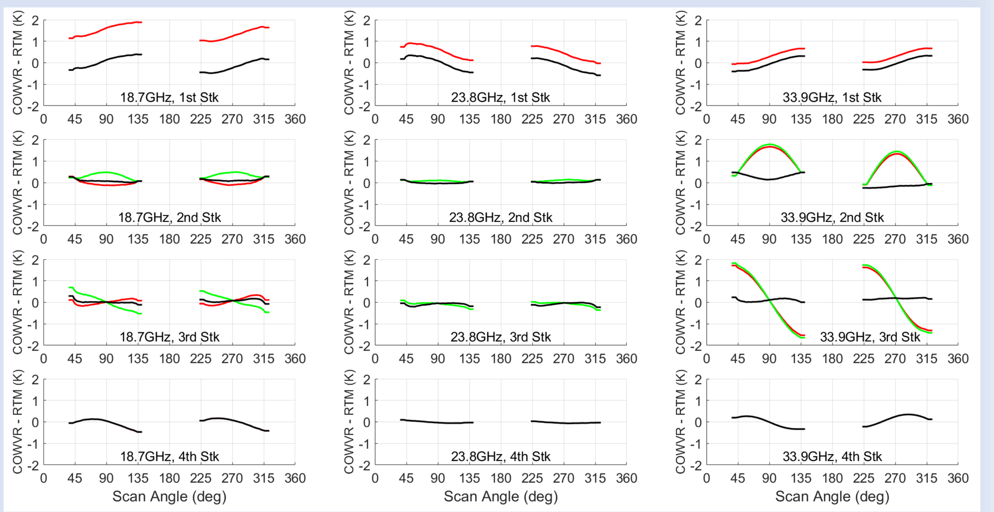

Fig 3. Along-scan $\Delta T_{B,COWVR}$ over the ocean before (red) and after spillover (green) plus cross-polarization (black) corrections.

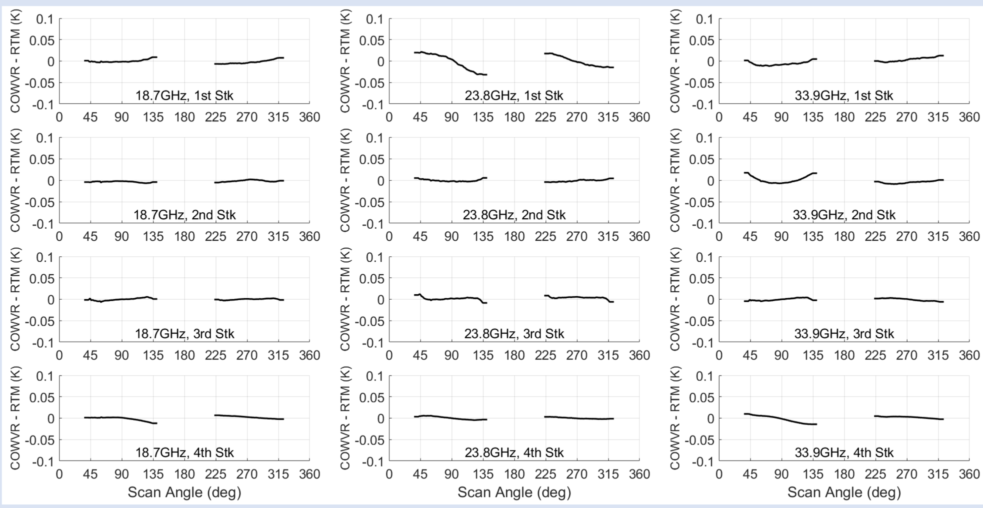

Fig 4. Along-scan $\Delta T_{B,COWVR}$ over the ocean after spillover and cross-polarization adjustments.

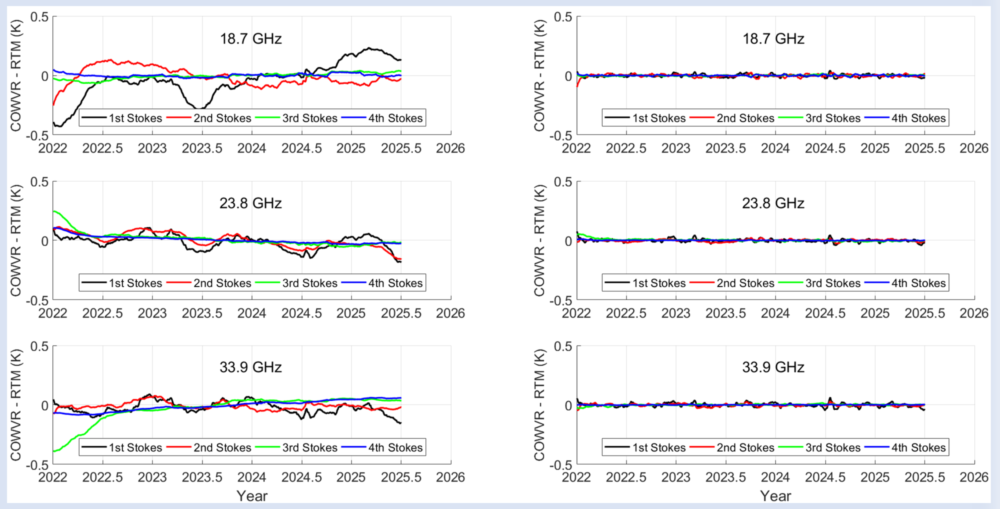

Fig 5. Timeseries of $\Delta T_{B,COWVR}$ over the ocean before (left) and after (right) the time-varying bias correction.

Wentz, Lindsley, and Nelson (in review). "Using GMI as a Calibration Reference for COWVR." AMS JTECH.

The COWVR two-look wind direction retrievals do not need to be nudged with an ancillary dataset because a second look resolves the errors caused by low-sensitivity points in the wind direction model (i.e., E_ϕ extrema and downwinds near 180°) that would otherwise reduce the skill and increase the RMSE of the one-look retrievals.

There are up to four wind direction (ϕ) ambiguities that correspond to the local chi-squared (χ^2) minima. Two methods are used to choose the wind direction among the four: (1) the ambiguity with the lowest χ^2 value, and (2) the ambiguity closest in value to ancillary data (e.g. ERA5 wind direction).

$$\chi^2 = \sum_{p,f,l} \frac{\left(T_{B,\mathrm{meas},p,f,l} - T_{B,\mathrm{rtm},p,f}(W,\boxed{\phi})\right)^2}{\mathrm{var}(T_{B,\mathrm{meas},p,f})}$$

p: V-pol, H-pol, 3rd Stokes (S3), 4th Stokes (S4)
f: 18.7, 23.8, 33.9 GHz
l: fore/aft look

The following emissivity model as a function of relative wind direction is used within the RTM.

$$E_\phi = \begin{cases} A_1\cos(\phi_r) + A_2\cos(2\phi_r), & p = v, h \\ A_1\sin(\phi_r) + A_2\sin(2\phi_r), & p = \mathrm{S3}, \mathrm{S4} \end{cases}$$
$$\text{where } \phi_r = \phi_a - \boxed{\phi}$$

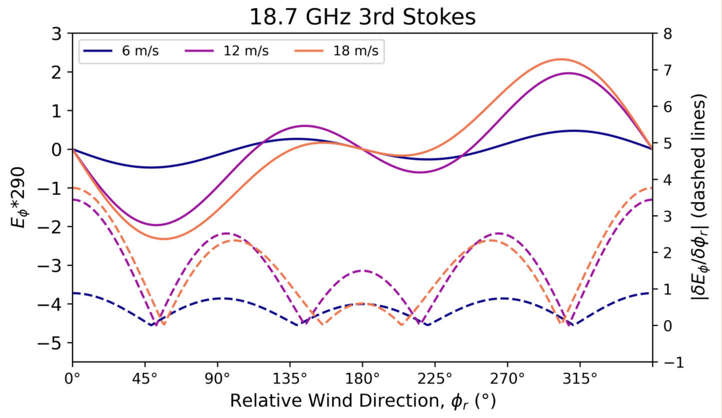

Fig 6. E_ϕ relative wind direction (ϕ_r) model for one polarimetric channel.

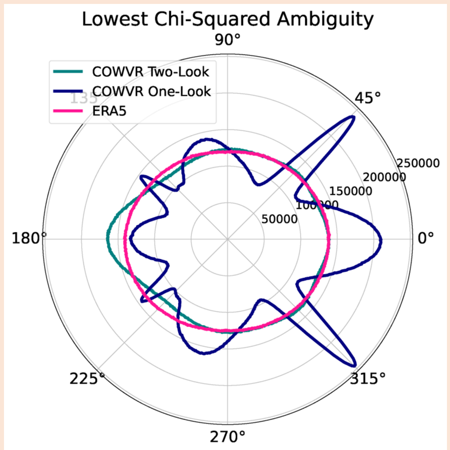

Fig 7. Distribution of retrieved relative wind directions.

One-Look Sensitivity to E_ϕ Extrema

The dominant signal for retrieving wind direction is the 3rd Stokes. Fig. 7 represents the relative wind direction distribution for COWVR one-look and two-look retrievals. COWVR one-look retrievals show spikes and dips because the 3rd Stokes signal is a harmonic function with local extrema. Noisy TBs result in more relative wind directions at the E_ϕ extrema and fewer relative wind directions adjacent to the extrema. Two-look retrievals avoid this problem and yield a more uniform angular distribution, similar to ERA5.

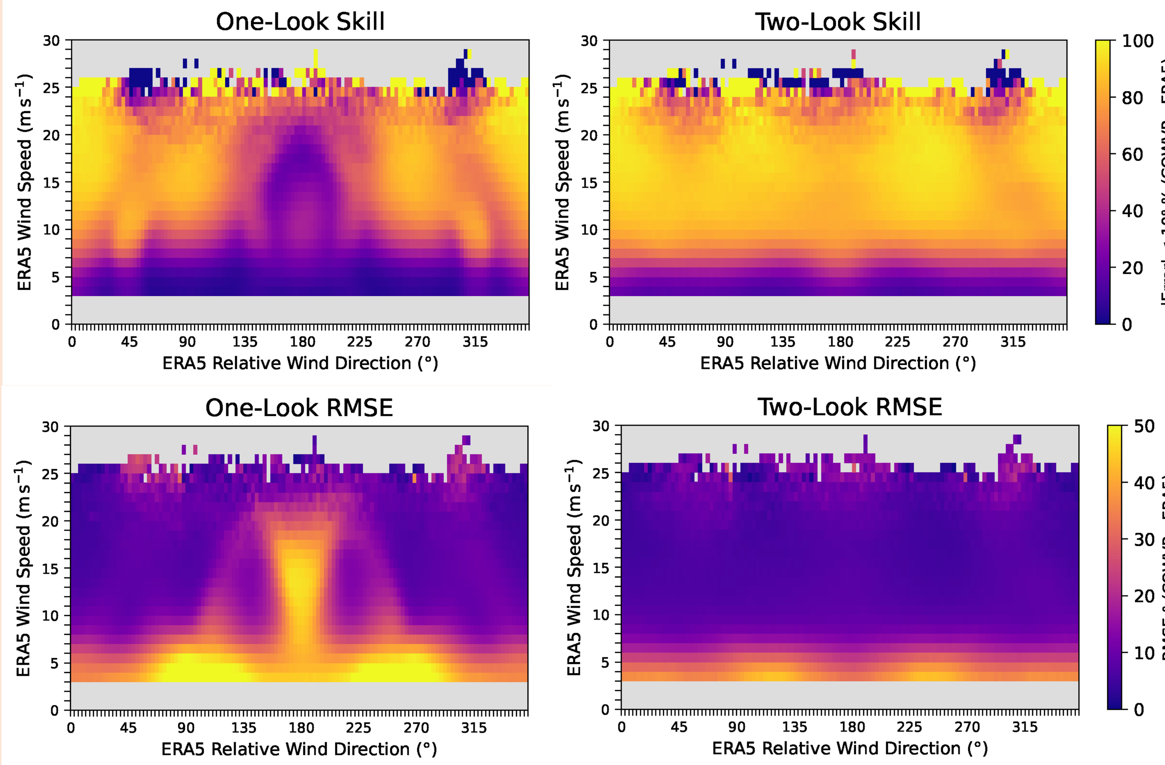

Fig 8. COWVR one-look and two-look skill and RMSE for various wind speeds and relative wind directions.

One-Look Sensitivity to Downwind Observations

In one-look downwind observations, the skill rate is 20 % to 40 % (Fig. 8, top left) and the RMSE is > 40° (Fig. 8, bottom left). For two-look wind direction retrievals above 7 m/s, the skill rate exceeds 80 % and the RMSE < 10°. The same is true for upwind and crosswind observations in the one-look retrievals.

COWVR One-Look vs. Two-Look Wind Direction Performance

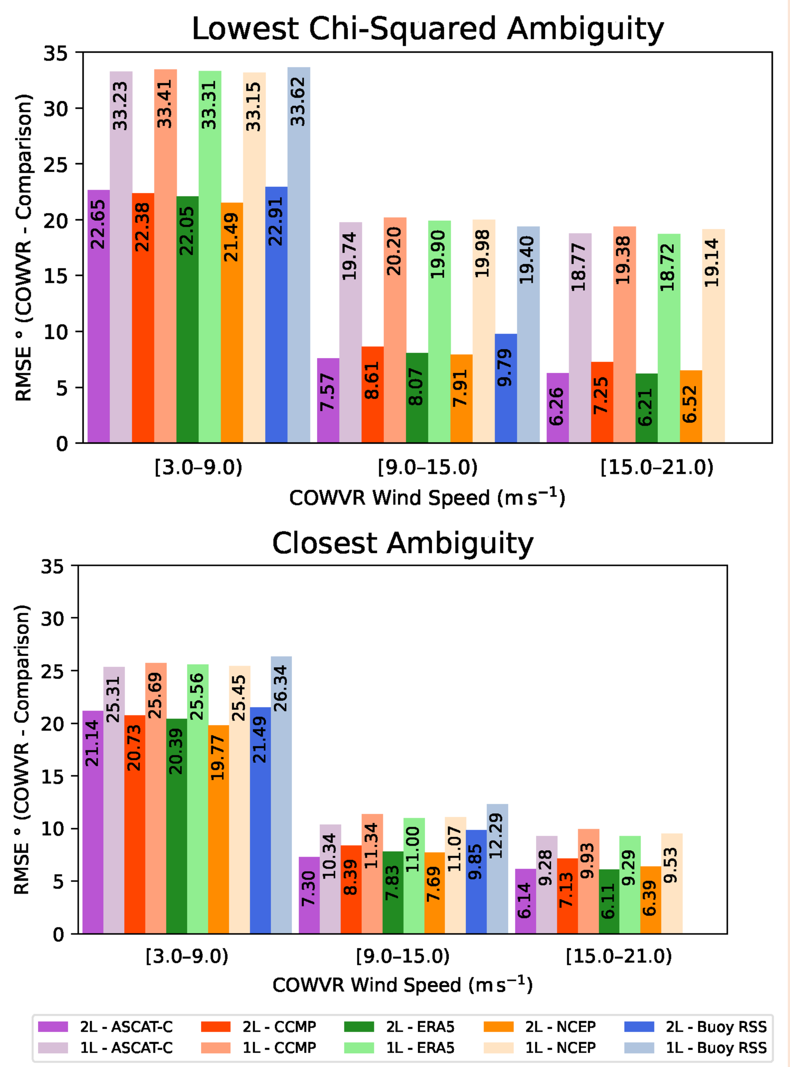

Fig 9. RMSE of COWVR versus comparison datasets for one-look (light bars) and two-look (dark bars) retrievals from the lowest chi-squared ambiguity (top) and the closest ambiguity (bottom).

(1) The two-look lowest chi-squared ambiguity (Fig. 9, top dark bars) and closest ambiguity (Fig. 9, bottom dark bars) wind direction RMSE are within 2° of one another, which indicates that the two-look algorithm does not require an ancillary wind direction dataset to select the appropriate COWVR ambiguity.

(2) The lowest chi-squared wind direction RMSE of the two-look retrieval (Fig. 9, top dark bars) is about 3° lower than the closest RMSE of the one-look retrieval (Fig. 9, bottom light bars). Even though using the closest ambiguity decreases differences between the one-look and two-look algorithms, the two-look lowest chi-squared wind direction retrieval still performs better than the one-look closest ambiguity.

Nelson, Lindsley, Meissner, and Mears (in review). "COWVR Wind Direction Performance for One-Look Versus Two-Look Viewing Geometry." IEEE JSTARS.