CFACT 2022

449 MHz Radar Wind Profiler Data Report

NCAR/EOL Integrated Sounding System

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OVERVIEW

This document describes data from the NCAR/EOL 449 MHz Modular Wind Profiler radar at the CFACT field project. In the event that information from this document are used for publication or presentation purposes, please provide appropriate acknowledgement to NSF and NCAR/EOL and make reference to *Brown, W.O.J. (2022): CFACT 2022 NCAR/EOL ISS 449 MHz Radar Wind Profiler Data Report*

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CFACT data archive: https://data.eol.ucar.edu/master_lists/generated/cfact/
ISS Operations and quicklook plots: https://www.eol.ucar.edu/content/iss-operations-cfact
ISS Homepage: https://www.eol.ucar.edu/observing_facilities/iss

CITATIONS

If data from the EOL wind profilers are used for research resulting in publication, please acknowledge EOL and NSF and include the following citations in your paper as appropriate:

- NCAR/EOL ISS Team. 2022. CFACT: NCAR/EOL ISS 449 MHz Modular Wind Profiler Products. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/XZ8P-3FWE-JP0E. Accessed 02 Feb 2023.

INTRODUCTION

NCAR/EOL deployed the 449 MHz Modular Wind Profiler radar for the CFACT (Cold Fog Amongst Complex Terrain) field campaign in January - February, 2022 [1]. The profiler was operated as part of the Integrated Sounding Systems (ISS) [2] at a site in Wasatch County, Utah, approximately 1 km southwest of Heber City, UT. The site was on Southfield Rd (S 1200 W St) approximately 0.9 km north of its intersection with highway 189. The location was an irrigated farm field belonging to the Heber Valley Special Services District, the local wastewater treatment agency. We referred to this site as the North Pivot site. A second ISS was operated near the Deer Creek supersite 3km to the west, and radiosonde soundings were launched from that site.

Testing the power amplifiers during the setup of the Modular Wind Profiler at CFACT.

Modular Wind Profiler

The Modular Wind Profiler has a unique modular design enabling the system to be scaled to suit the phenomena being observed. The hexagonal antenna modules are designed to be separated into multiple small radars if just boundary layer observations are required. Alternatively they can be combined into a large array if measurements are required higher into the atmosphere [3] (Brown et.al. 2007, Cohn et.al, 2009, Lindseth et.al., 2012). CFACT focused on the planetary boundary layer so the profiler was deployed in a three antenna module configuration. A clutter fence was erected around the profiler to reduce clutter echoes from the nearby power lines and trees, and also reduce the effects of radio frequency interference and radiation on passersby (Sobtzak and Wislinsky, 2019).

Wind Profiler	449 MHz Modular Wind Profiler operating as a Spaced Antenna Radar with RASS
Location	40.488176°N, 111.432897°W, 1700 m MSL
Antennas	3 vertically pointing 18-element phased array modules, approx 10° beamwidth
Power Amp	~4 kW peak, 4-5% duty cycle, 150-200 W average power
Time Sampling	Winds Mode: Raw IQ: 120 Hz (IPP 50μs, NCI 40, 4 RIM channels) Correlations and Spectra: 30 second averages Moments: 30 second average dwell Winds products: 5 minute and 30 minute averages RASS mode: Raw IQ: 2 kHz (IPP 2.4μs, NCI 4, 4 RIM channels) Correlations and Spectra: 30 second averages Moments: 15-20 second average dwell RASS products: 5 minute consensus every 30 minutes
Range sampling	Winds Mode: 0.7 μs pulse, 4 bit complementary phase code, 100 m resolution from 400 m to up 5 km RASS mode: 1 μs pulse with no phase coding, 150 m resolution from 200 m to up 2 km

Table 1: Typical operating characteristics of the Modular Profiler radar as configured for CFACT.

The radar was run in two modes, winds mode with sampling optimized for making wind measurements, and RASS mode with sampling optimized for virtual temperature measurements. The operating parameters for CFACT are summarized in table 1. The radar was driven using radio frequency power amplifiers developed at NCAR. Three 1.5 kW amplifier modules were run at 4-5% duty cycle driven in parallel to feed the three antennas. Each of the three antennas were also connected to receivers with a Pentek 7142 DSP (Digital Signal Processor) which digitized the data at rates in the MHz range. The data was coherently averaged on the DSP to generate 120 Hz data for winds mode and 2 kHz for RASS mode, then streamed to the linux host computer for further processing.

Wind Mode Data

The Modular Profiler is operated as a Spaced Antenna profiler with three receiving antennas. As reflecting targets (e.g., clear-air turbulence eddies) are advected over the array by the wind, backscattered patterns are received on the upwind side slightly before being detected on the downwind side, enabling a measurement of wind speed and direction to be made (eg, Lehmann and Brown, 2021; Cohn et. al. 2001). Raw IQ data were retained for the entire operations period, totaling around 4TB of data. The nominal operating frequency of the radar is 449 MHz, although it continuously adjusted by stepping through four frequencies 333 kHz apart to reduce the effects of radio frequency interference and for frequency domain interferometry.

Auto and cross correlation function files were generated at 30 second averaging time using the ICRA intermittent clutter filtering algorithm to reduce the effect of transient targets such as birds. The winds correlation files are then analyzed to generate the daily winds and moment files that make up this archive. The winds product files total around 40 MB and the moment files around 300 MB.

Two winds analysis techniques were applied to the correlation files to calculate winds products, “Full Correlation Analysis” (FCA, Briggs, 1984) and the “Slope at Zero Lag” (Holloway et.al., 1997) [3] techniques. A series of tests were applied to the data during the QC process to identify samples contaminated with unwanted signals (particularly clutter and bird echoes), and exclude those samples from the averages. The parameters for these tests were determined using a combination of comparisons with soundings and visual inspection. For example, the Signal to Noise Ratio (SNR) of samples that agree with soundings was generally higher than those that disagree (see figure 1). The agreeing population distribution peaked at around -4 dB, with 90% of the agreeing population being above -13 dB and this was the level chosen for the SNR test. Similar analyses were carried out for a range of parameters such as the spectral width, magnitude and variability of the cross correlation between different receivers, phase differences between receivers, and other parameters. Samples were scored on whether they passed a series of these tests. Those that passed a certain threshold in a pseudo fuzzy logic approach were included in consensus averaging analyses to produce the final 30-minute and 5-minute wind data files in this archive.

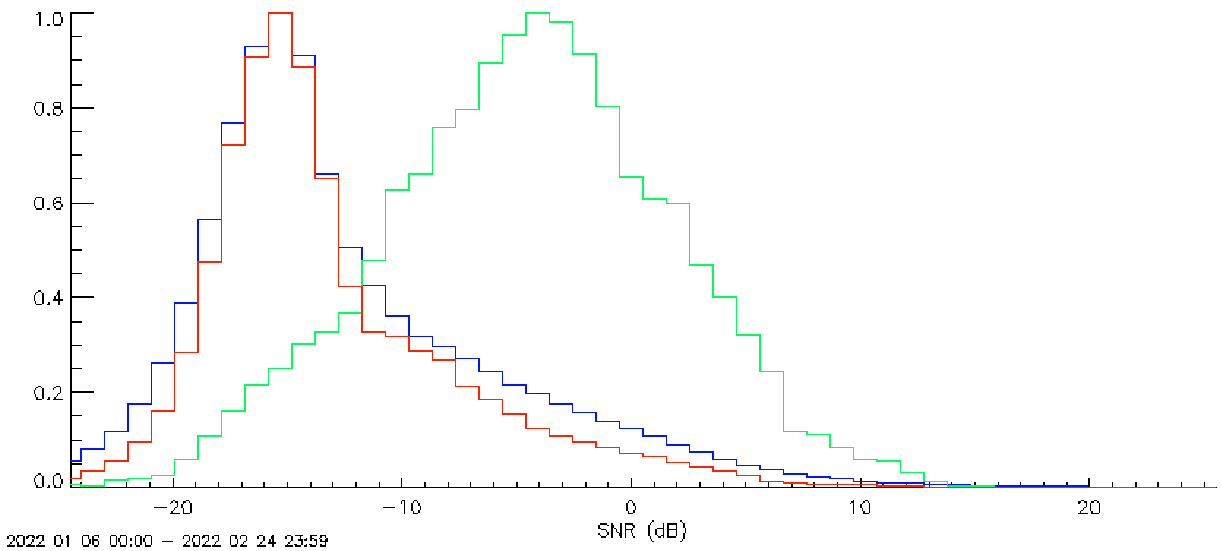

Figure 1: Examples of Signal to Noise (SNR) distributions for samples with wind estimates that agree with soundings (within 2 m/s and 30 degrees in speed and direction) indicated by the green histogram, disagree (red histogram) and the entire population of samples (blue histogram). The analysis includes all 120 soundings launched during the campaign.

The data files are all in netCDF format [6] and the various types of these files are listed in Table 2. There are two product file types in the EOL archive from the winds mode: the wind measurements (files with extension *.winds.*.nc) and spectral moments data (extension *.mom.nc).   The *.winds.05.nc and *.winds.30.nc files correspond to the 5 and 30 minute average winds respectively. The data is arranged in time, height coordinates. The wind speed and direction data are contained in the wspd and wdir variables and these are the data that would be used by most users. The direction data follows the usual meteorological convention in that it is the direction the winds are coming from (ie, clockwise from north, with northerlies being 0, 90 being easterlies, 180 being southerlies, and 270 being westerly).

There are also snrw, wvert, spectWid, u, v, u_dispersion, and v_dispersion variables containing Signal to Noise Ratio (SNR, related to backscatter signal strength and reflectivity), vertical velocity (positive is upwards), Doppler spectral width (can be used to estimate turbulence with lots of caveats, e.g. see Lehmann and Brown, 2021), eastward and northward winds, and the dispersion of the winds (spread as defined by the standard deviation of the winds).   We generally recommend that only experienced profiler users analyze these data. The SNR, w, and spectral width for each 30 second dwell are in the moments files ("moments" refers to their derivation from zeroth, first, and second moments of the Doppler spectra). The moments files have confidence indicators. Use only those data points for which the corresponding confidence level exceeds the chosen threshold confidence level.   Usually we use a threshold confidence level of 0.5. A variety of plots are also produced and these are available on the field catalog and ISS web pages [1].

Data Product	Definition	Availability
Raw IQ data (*.tms.nc)	Collected in both winds and RASS modes, this is the high-rate raw data (100 Hz in winds mode, 2 kHz in RASS mode) directly from the DSP. Files are produced every 5 - 15 minutes, totals around 3.5 TB.	By request only
Correlation and spectral data (*.cor.nc and *.spc.nc)	Collected in both winds and RASS modes, these are intermediate products with 15-30 second averages. Files are produced every 5 - 15 minutes and total around 200 GB.	By request only
Raw winds products (*.mapr.nc)	These are intermediate winds products containing unfiltered FCA and SZL winds and raw moment products, calculated from the correlation files every 30 seconds. Files are produced every 15 minutes and total around 1.2 GB .	By request only
Winds product files (*.winds.05.nc and *.winds.30.nc)	These are the final wind product files that have gone through the QC processing described in this document. These are daily files with 5 minute and 30 minute averaged winds. Total around 40 MB.	EOL data archive. See citation.
Moment files (*.mom.nc)	These files contain the first 3 moments of the Doppler spectra (mean SNR, vertical velocity and spectral width) every 30 seconds. These are daily files and total around 300 MB.	EOL data archive. See citation.
RASS product files (*.rass.nc)	These are the RASS product files with consensus averaged virtual temperature data. They are produced for each 5-minute RASS mode sampling period and total around 20 MB.	EOL data archive. See citation

Table 2: The various data files produced by the Modular Wind Profiler.

Performance and Comparisons

Wind profilers detect scattering from precipitation and from clear-air refractivity gradients (such as those due to turbulence and inversions). The strength of the scattering (reflectivity) and thus ability to measure wind is a complicated function of temperature, humidity, turbulence, precipitation, and the presence of unwanted signals (radio interference, clutter echoes from the vehicles, trees, power lines, birds, etc). At CFACT, the primary unwanted signals were radio interference signals coming from other radio transmitters in the valley.

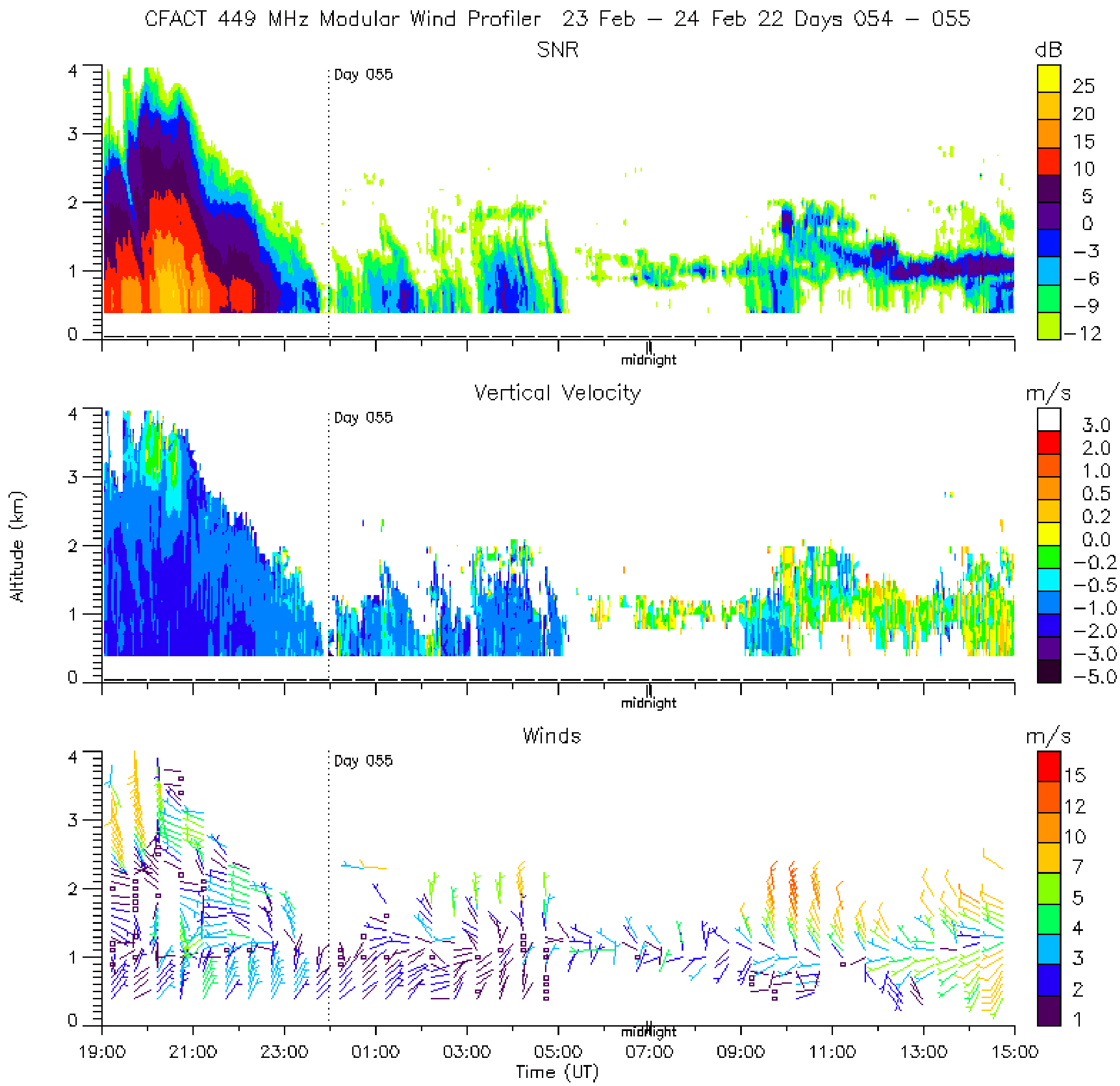

Figure 2: Example of 449 MHz Modular Profiler measurements at CFACT during IOP 9. The panels show time-height plots of Signal to Noise Ratio, Vertical Velocity, and 30-minute Winds.

Much of the time, the atmosphere in the valley was cold and stable with little turbulence, so the clear-air reflectivity was very low resulting in weak signal for the wind profiler. There were periods of snow, and since any precipitation is highly reflective for UHF radars, the profiler performed very well during those periods.

Figure 2 shows Modular Profiler measurements during IOP 9. The Signal to Noise Ratio (SNR, upper panel) shows strong signals during a period of snow at the beginning of the IOP. The vertical velocity (middle panel) shows the fall speed of the snow is in the 1 - 2 m/s range. The bulk of the snow has mostly ended by about 23 UT, although there are some much shallower and lighter snow showers until about 5 UT and briefly again 9 - 10 UT. The SNR is much weaker during non-snow periods since the atmosphere in the valley is very cold with little reflectivity for the profiler to detect. There is an enhanced signal layer around the 1 km level later in the IOP, and that may be due to a combination of the relative humidity gradient (evident in soundings) and the wind shear generating turbulence. Winds (lower panel) are from the northeast at low levels during the snow, but are initially from the south at upper levels, then switch around to the northwest around 21 UT. Towards the end of the IOP winds are from the southeast at low levels and northwest aloft.

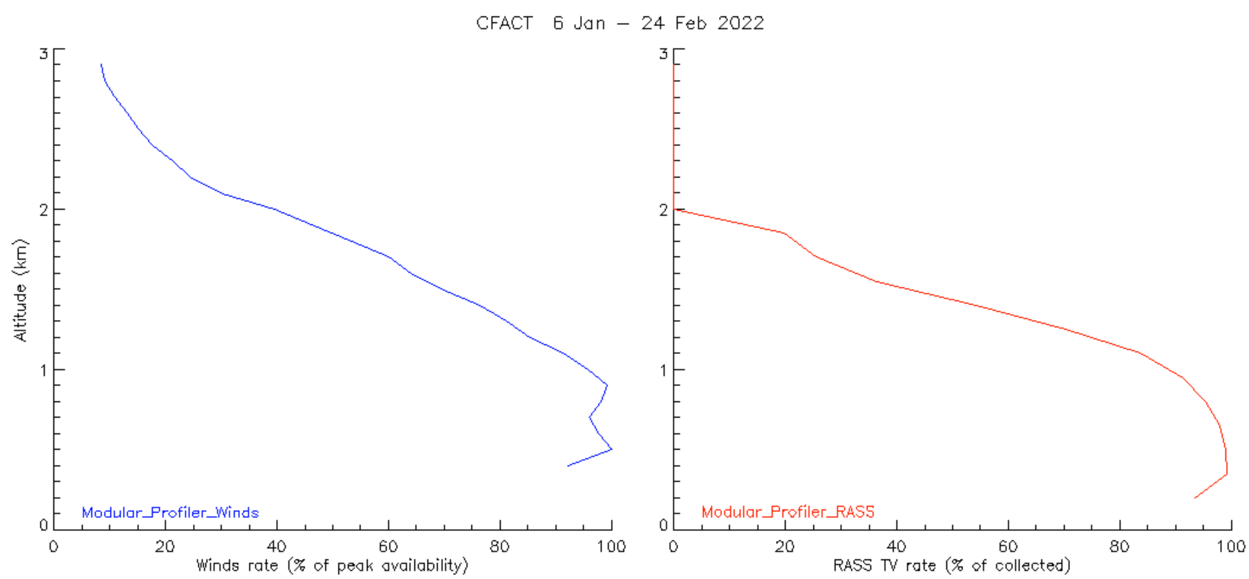

Figure 3: Wind and RASS measurement availability as a function of altitude above ground.

The Modular Profiler reported winds and RASS virtual temperature measurements over 90% of the time. Figure 3 shows the measurement availability as a function of height and time that the profiler was operating. Wind measurements are available up to about 1.4 km about 75% of the time and virtual temperature measurements were available up to 1.2 km about 75% of the time.

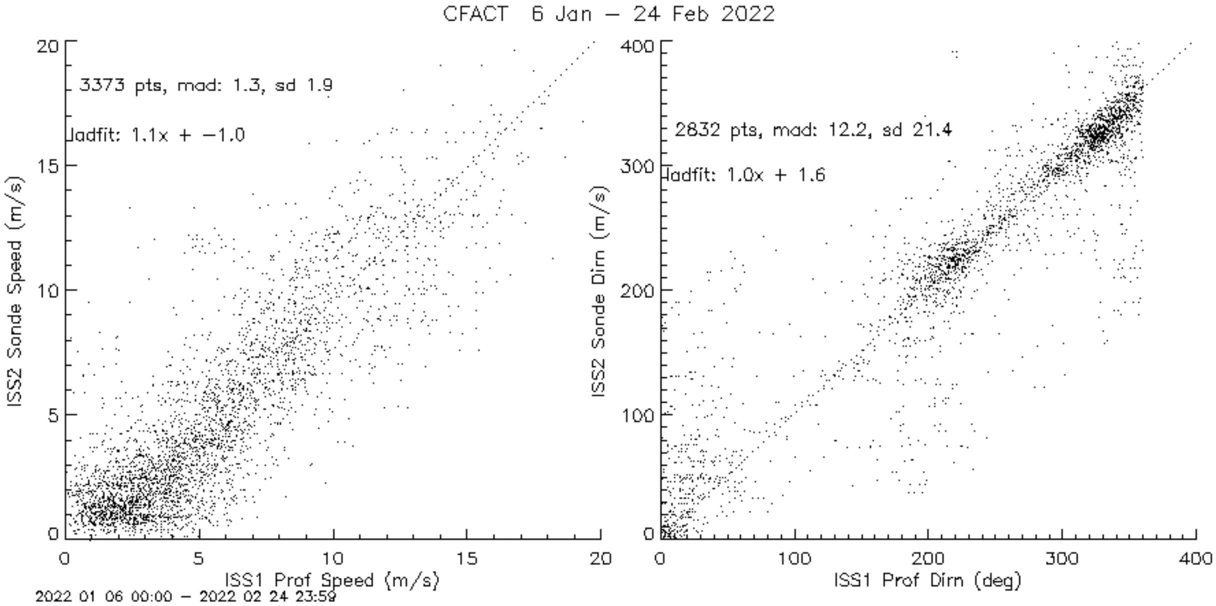

Figure 4: Comparison between the Modular Wind Profiler 30-minute consensus winds and sounding winds over the 500 m to 2 km height range. All 120 soundings launched during the campaign were included. The profiler and sounding sites were separated by about 3 km.

The profiler winds compared well with sounding winds (Figure 4), with a median absolute deviation of 1.32 m/s in speed and 12.2° in direction (standard deviation of 1.88 m/s and 21.4° respectively). The best fit lines have slopes of 1.06 and 0.99 for speed and direction respectively. Note that the soundings were launched approximately 3 km from the Modular Profiler so some differences are to be expected.

RASS (Radio Acoustic Sounding System)

The profiler was operated in RASS mode for 5 minutes every half hour for much of the campaign. RASS enables virtual temperature profiling using a vertically pointing loud acoustic source to generate sound waves that propagate up into the atmosphere. The acoustic waves perturb the radio refractive index of the air sufficiently to be detectable by the profiler. Since the speed of sound is related to virtual temperature, a virtual temperature profile can be determined. There is some uncertainty to the measurement and the resolution is low (around 150 meters) and the range limited to the 200 m to 1.5 km region. In general the measurements are better used qualitatively rather than quantitatively (without rigorous analysis), however they can be a useful indicator of inversions in the detection region.

Following convention for RASS data, the files include two virtual temperature estimates, TV (which is the data we recommend using for CFACT) and TVC. TVC includes a correction for vertical air motion derived from the clear-air part of the Doppler spectrum. However the TVC estimate is mainly intended to be used in the warm season convective boundary layer where the clear-air motion can be strong and variable.   The analysis does not do a good job of separating precipitation and clear-air echoes. During CFACT we did observe periods of light precipitation and in general the clear-air vertical motion was very weak, so it is recommended that the TV estimates be used instead of the TVC estimates.

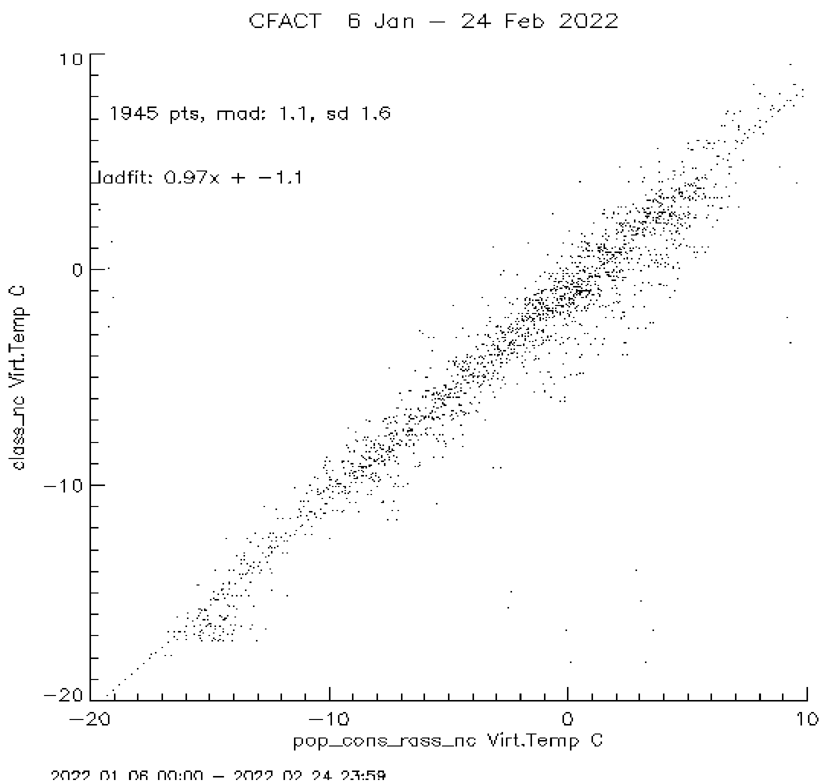

Figure 5: Comparison between soundings and Modular Wind Profiler RASS consensus virtual temperatures (TV) over the campaign.   The profiler and sounding sites are about 3 km apart.

Figure 5 shows a scatter plot comparing the RASS TV estimates and sounding derived virtual temperatures. The median deviation from soundings was about 1.09 C and the standard deviation was about 1.58 C. (For TVC the agreements were fractionally lower with median and standard deviations of about 1.21 C and 1.85 C respectively).

Further analysis of comparisons between RASS virtual temperatures and soundings such as the rate of agreement and disagreement as a function of parameters such as SNR did not reveal the clear relationships that were seen in the winds analysis. Instead it is recommended that users visually examine time-height plots of virtual temperature and be suspicious of regions that appear to be outliners. For example, in figure 6 below, the data from 3 to 5 UTC above the 1.5 km level differs from the surrounding samples so may be erroneous, although it should be noted that a sounding at 0215 UTC did show a clear inversion above the 1 km level.

Note that during significant snow events, RASS was turned off and the acoustic speaker dishes were covered up to prevent the dishes being buried in snow.

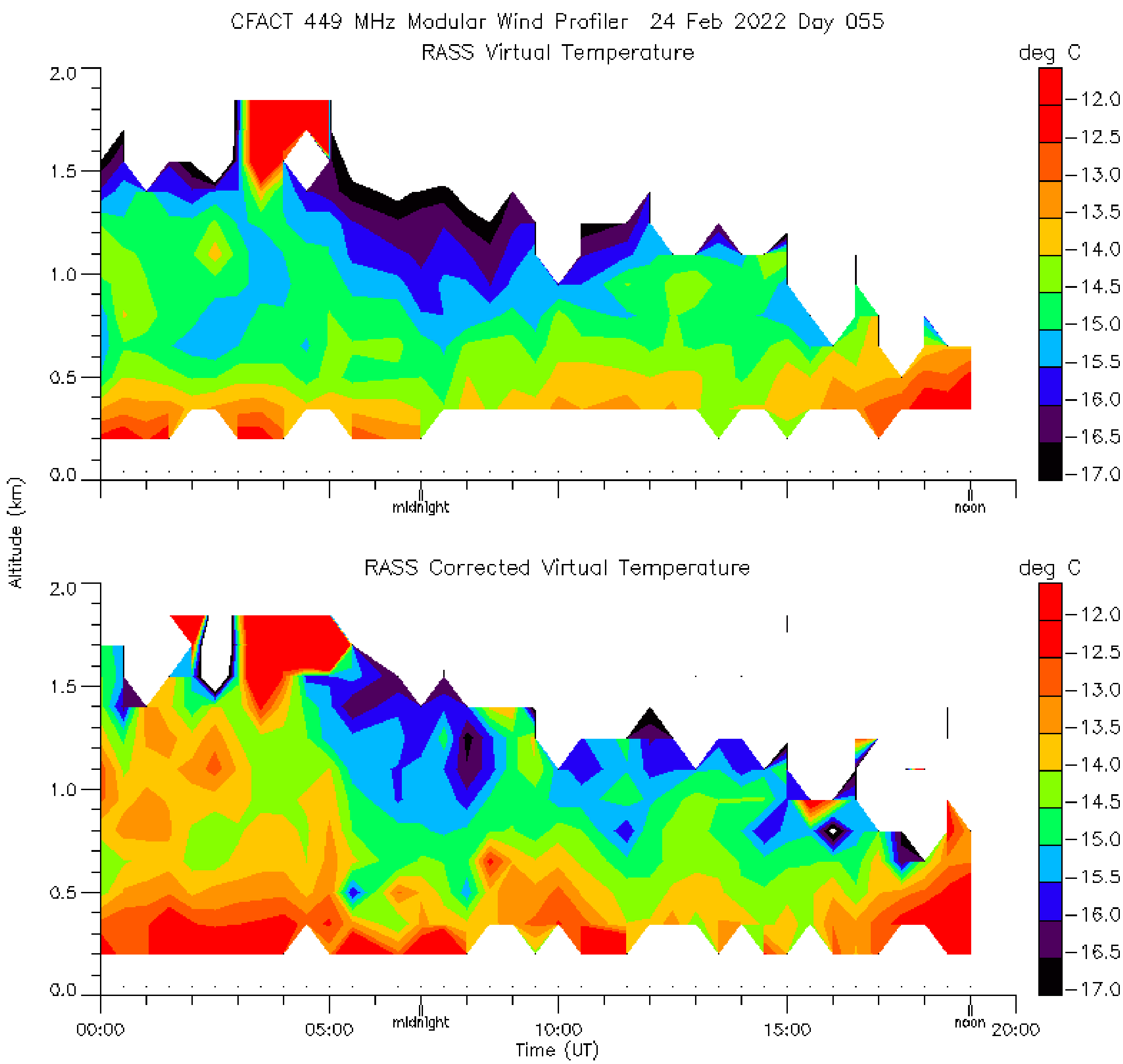

Figure 6: Modular Profiler RASS virtual temperatures for Feb 24, 2022.

Known Data Issues

Table 3 summarizes significant events and data interruptions. Detailed ISS staff notes for these items are available upon request.

Dec 3 - Jan 5	ISS Setup and testing. Profiler operated intermittently in test modes
Jan 6	First day of CFACT operations
Jan 8	Maintenance work, started RASS ~ 17 UTC
Jan 16	Adjustments to power levels ~ 17 UTC
Jan 18	Profiler down, repairs ~ 20 UTC
Jan 21	Profiler down to remove snow ~ 16 UTC
Jan 22	RASS sound distortion, repairs to cables ~ 17 UTC
Jan 24	Down to remove water and ice ~ 16 UTC
Jan 25	Profiler down for repairs to cabling 20 UT - 1 UTC
Feb 15	Profiler down for RASS repair ~ 18 UTC
Feb 20	Profiler down for maintenance 18 and 21 UTC
Feb 21	Profiler down to clear 2 inches of snow ~ 18 UTC
Feb 22	Profiler down to clear 2 inches of snow ~ 18 UTC
Feb 23	Profiler down 18-19 UTC for maintenance work
Feb 24	Last day of operations

Table 3: Notable events and data interruptions

Clutter: Clutter was not a significant issue for the Modular Profiler at the CFACT campaign. There were hints of echoes from nearby power lines in the lowest 800 meters, so caution should be exercised when using data at these low levels however most data appears to be unaffected by clutter. The ICRA routine and other filtering removed most intermittent clutter signals such as that due to birds, aircraft and traffic.

Data Gaps: The Modular Profiler operated continuously, however there were occasional gaps for equipment tests, maintenance and snow removal. These are noted in Table 3.

Vertical resolution: The range resolution for winds is nominally 100 meters (and 150 m for RASS), however if there are sharp vertical gradients in reflectivity (such as with an inversion layer, or at the top of the boundary layer), there may be some smearing or biasing of the measurements in adjacent range gates.

Snow: There was occasional snow buildup on the antennas and in the RASS dishes which did affect the performance of the profiler. Snow was removed periodically as noted in Table 3. Typically it appeared that the snow absorbed 2 or 3 dB of signal, suppressing the range of the profiler by 100 or 200 meters.

Clearing snow from the Modular Wind Profiler antennas and RASS dishes.

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[6] NetCDF: UCAR/Unidata netcdf web site:
http://www.unidata.ucar.edu/content/software/netcdf/

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