CHEESEHEAD 2019

SODAR-RASS Data Report

NCAR/EOL Integrated Sounding System

William Brown

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Earth Observing Laboratory
In situ Sensing Facility

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
P.O. Box 3000
BOULDER, COLORADO 80307-3000

OVERVIEW

This document describes data from the NCAR / EOL SODAR-RASS at the CHEESEHEAD 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. (2020): CHEESEHEAD 2019 NCAR/EOL ISS SODAR-RASS Data Report.*

CHEESEHEAD Principal Investigators:

PI: Ankur Desai (University of Wisconsin-Madison)
Co-PIs: Mark Schwartz (Uni.WI), Matthias Mauder (KIT), Stefan Metzger (NEON)

EOL Staff:

ISS Lead Scientist and Contact: William Brown *wbrown@ucar.edu*
Lead Engineer: John Sobtzak
Technicians: Lou Verstraete, Liz Bernhardt
Software Engineers: Gary Granger, Isabel Suhr
Data Managers: Jacquie Witte, Matt Paulus

NCAR / Earth Observing Laboratory
P.O. Box 3000
3090 Center Green Drive
Boulder, CO 80301, USA

Websites:

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

Citations:

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

- NCAR Integrated Sounding System. 2020. NCAR/EOL ISS SODAR-RASS Data. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/23RE-6PBF-X10F. *Access date should be included in the citation.*

INTRODUCTION

NCAR/EOL deployed the SODAR-RASS to the CHEESEHEAD (Chequamegon Heterogeneous Ecosystem Energy-balance Study Enabled by a High-density Extensive Array of Detectors) field campaign in June - October, 2019 [1]. The sodar was operated as part of the Integrated Sounding Systems (ISS) [2] at a site in Price County, northern Wisconsin, approximately 12 km east of the town of Park Falls and 1.6 km west of the WLEF tall tower. The site was a farmers field on the corner of route 182 and East Rd. As discussed in this document, the sodar measures wind and virtual temperatures. The virtual temperature measurements look very good (despite a small altitude bias), however the winds suffered due to partial speaker failures resulting in an underestimation in speeds of about 20%.

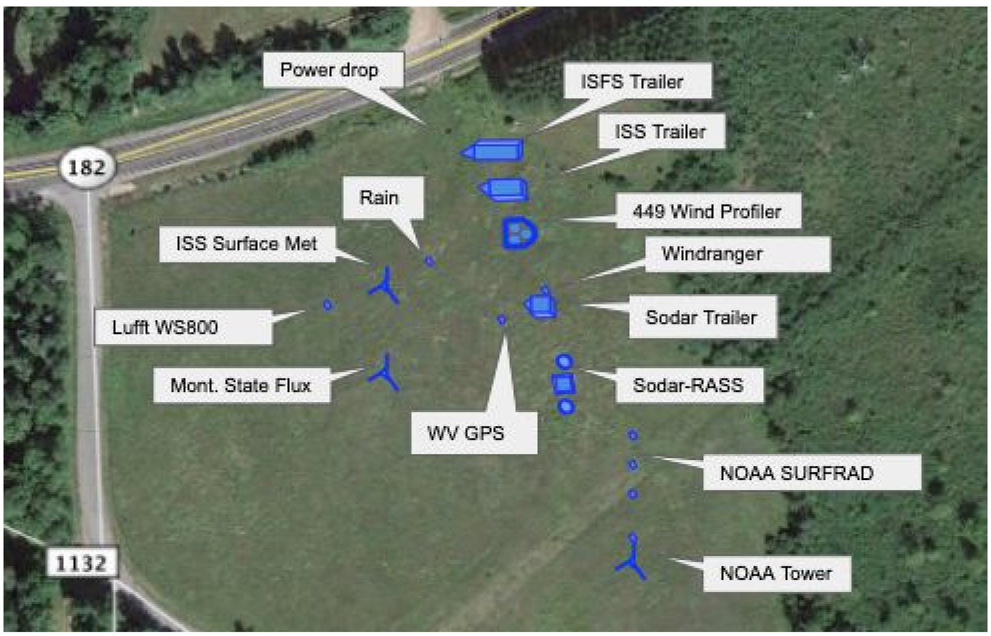

Figure 1: Approximate layout of the ISS site at CHEESEHEAD. The area shown is about 300 x 200 meters. The sodar-RASS is approximately 60 meters from the ISS trailer where radiosonde soundings were launched.

SODAR-RASS

The sodar used was a Metek DSDPA.90-24 mini-sodar which is a smaller version of the DSDPA.90-64 described in Engelbart, et al (1999) [3]. The sodar uses the Doppler beam swinging technique to measure winds, by steering an acoustic beam through 3 directions over a 20-second cycle. Virtual temperatures were measured using the Radio Acoustic Sounding System (RASS) technique via a CW radar attached to the sodar. Winds and virtual temperature products were generated every 10 minutes. The operating parameters for CHEESEHEAD are summarized in Table 1.

SODAR-RASS	Metek DSDPA.90-24 mini-Doppler SODAR-RASS
Location	45.945354°N, 90.293457°W, 463 m MSL
Acoustic Antenna	24 speaker phased array (however 2 speakers disabled) steered vertically and to 16° off zenith at azimuth 48° & 318° Transmitted chirp pulses around 2 kHz
RASS	25 W, CW radar at 915 MHz driving two vertically pointing 2-meter parabolic dish antennas, 5.6m apart
Time Sampling	Raw spectra and moments approx every 20 seconds Wind and virtual temperate profile every 10 minutes
Range sampling	20m sampling 40 - 400 m, noise only at 500m

Table 1: Typical operating characteristics of the SODAR-RASS as configured for CHEESEHEAD.

SODAR-RASS Data

Winds and virtual temperatures were calculated using Metek standard processing software which generates daily ascii raw Doppler moment data with ~ 20 second sampling and 10-minute averaged product files. These 10-minute average files are then processed by IDL code at NCAR to generate the netcdf files that make up this data set. The netCDF format [4] is self-documented and the CDL (header information with variable names) is in Table 2.

The data are mainly in 2-dimensional arrays corresponding to time, height coordinates. The most useful variables to many users are likely to be fWindSpeed, fWindDirection, fRassTV and fRassPTV corresponding to wind speed and direction, RASS virtual temperature and RASS potential virtual temperature. The first letter of each variable indicates the variable type (e.g. “f” indicates float).

Time is recorded in the 1-dimensional variable fTime_vec and is the number of seconds since the beginning of the file (recorded in variables fTime_begin and strTime_begin, both in UTC). Note that the time stamp is at the end of the averaging time and since fTime_vec[0] is typically zero seconds after 0 UTC, the first sample is typically the average of the last 10 seconds of the previous day. Heights are in meters AGL in the fHeight variable.

```
netcdf sodar_20181001.avg {
dimensions:
        dim_time = 144 ;
        dim_string = 256 ;
        dim_heights = 21 ;
        dim_beams = 4 ;
        dim_fTime = 6 ;
        dim_MixFreqs = 5 ;
        dim_SpFreqs = 1 ;
variables:
        char strProject(dim_string) ;
        char strSite(dim_string) ;
        char strName(dim_string) ;
        char strOperator(dim_string) ;
        float fLatitude ;
                fLatitude:long_name = "North of equator" ;
                fLatitude:units = "degrees" ;
        float fLongitude ;
                fLongitude:long_name = "East of Greenwich" ;
                fLongitude:units = "degrees" ;
        float fAltitude ;
                fAltitude:long_name = "Above mean sea level" ;
                fAltitude:units = "metres" ;
        int lAverageTime(dim_time) ;
                lAverageTime:long_name = "Averaging Time" ;
                lAverageTime:units = "s" ;
        float fMinHeight(dim_time) ;
                fMinHeight:long_name = "Minimum Height" ;
                fMinHeight:units = "m" ;
        float fMaxHeight(dim_time) ;
                fMaxHeight:long_name = "Maximum Height" ;
                fMaxHeight:units = "m" ;
        int fNoise(dim_time) ;
                fNoise:long_name = "Noise" ;
                fNoise:units = " " ;
        int fStep(dim_time) ;
                fStep:long_name = "Step" ;
        float fVolume(dim_time, dim_beams) ;
                fVolume:long_name = "Volume" ;
                fVolume:units = " " ;
        int fTXFreq(dim_time) ;
                fTXFreq:long_name = "Transmitter Frequency" ;
                fTXFreq:units = "Hz" ;
        float fMixFreqs(dim_time, dim_MixFreqs) ;
                fMixFreqs:long_name = "Transmitted Freqs" ;
                fMixFreqs:units = "Hz" ;
        float fSampleFreq(dim_time) ;
                fSampleFreq:long_name = "Sampling Frequency" ;
                fSampleFreq:units = "Hz" ;
        float fAzimuth(dim_time, dim_beams) ;
                fAzimuth:long_name = "Azimuth angle of beams"
                fAzimuth:units = "Deg" ;
        float fZenith(dim_time, dim_beams) ;
                fZenith:long_name = "Zenith angle of beams" ;
                fZenith:units = "Deg" ;
        float fGndTemp(dim_time) ;
                fGndTemp:long_name = "Ground Temperature" ;
                fGndTemp:units = "C" ;
        float fCrossTalk(dim_time) ;
                fCrossTalk:long_name = "RASS Cross Talk" ;
                fCrossTalk:units = "V" ;
        char strTime_begin(dim_string) ;
                strTime_begin:long_name = "Start time" ;
        float fTime_begin(dim_fTime) ;
        char strTime_end(dim_string) ;
                strTime_end:long_name = "End time" ;
        float fTime_end(dim_fTime) ;
        float fUtc_offset ;
                fUtc_offset:long_name = "Offset from UTC" ;
        float fTime_vec(dim_time) ;
                fTime_vec:long_name = "Since start time" ;
                fTime_vec:units = "seconds" ;
        float fHeight(dim_time, dim_heights) ;
```

```
        float fPower(dim_time, dim_heights, dim_beams) ;
                fPower:long_name = "Power" ;
                fPower:units = "dB" ;
                fPower:_FillValue = -999.f ;
        float fReflectivity(dim_time, dim_heights, dim_beams)
                fReflectivity:long_name = "Reflectivity" ;
                fReflectivity:units = "dB" ;
                fReflectivity:_FillValue = -999.f ;
        float fRadialVel(dim_time, dim_heights, dim_beams) ;
                fRadialVel:long_name = "Radial Vel along beam"
                fRadialVel:units = "dB" ;
                fRadialVel:_FillValue = -999.f ;
        float fU(dim_time, dim_heights) ;
                fU:long_name = "Eastward (U) Wind Vel" ;
                fU:units = "m/s" ;
                fU:_FillValue = -999.f ;
        float fV(dim_time, dim_heights) ;
                fV:long_name = "Northward (V) Wind Vel" ;
                fV:units = "m/s" ;
                fV:_FillValue = -999.f ;
        float fW(dim_time, dim_heights) ;
                fW:long_name = "Vertical (W) Wind Vel" ;
                fW:units = "m/s" ;
                fW:_FillValue = -999.f ;
        float fWindSpeed(dim_time, dim_heights) ;
                fWindSpeed:long_name = "Wind Speed" ;
                fWindSpeed:units = "m/s" ;
                fWindSpeed:_FillValue = -999.f ;
        float fWindDirection(dim_time, dim_heights) ;
                fWindDirection:long_name = "Wind Direction" ;
                fWindDirection:units = "degrees" ;
                fWindDirection:_FillValue = -999.f ;
        float fWindSpeedCL(dim_time, dim_heights) ;
                fWindSpeedCL:long_name = "Wind Speed Cluste" ;
                fWindSpeedCL:units = "m/s" ;
                fWindSpeedCL:_FillValue = -999.f ;
        float fWindDirectionCL(dim_time, dim_heights) ;
                fWindDirectionCL:long_name = "Wind Dirn Clust"
                fWindDirectionCL:units = "degrees" ;
                fWindDirectionCL:_FillValue = -999.f ;
        float fRadVelSigma(dim_time, dim_heights, dim_beams) ;
                fRadVelSigma:long_name = "Std dev radial vel"
                fRadVelSigma:units = "m/s" ;
                fRadVelSigma:_FillValue = -999.f ;
        float fWindPhiSigma(dim_time, dim_heights) ;
                fWindPhiSigma:long_name = "Std dev wind incl"
                fWindPhiSigma:units = "deg" ;
                fWindPhiSigma:_FillValue = -999.f ;
        char fDiffusionClass(dim_time, dim_heights) ;
                fDiffusionClass:long_name = "Diffusion Class"
        float fRassTV(dim_time, dim_heights) ;
                fRassTV:long_name = "RASS Virtual Temperature"
                fRassTV:units = "C" ;
                fRassTV:_FillValue = -999.f ;
        float fRassPTV(dim_time, dim_heights) ;
                fRassPTV:long_name = "RASS Potential Virtual
Temperature dry adiabatic" ;
                fRassPTV:units = "C" ;
                fRassPTV:_FillValue = -999.f ;
        short nDataAvailability(dim_time,dim_heights,dim_beams
                nDataAvailability:long_name = "Data Avail" ;
                nDataAvailability:units = "%" ;
        float fSNR(dim_time, dim_heights, dim_beams) ;
                fSNR:long_name = "Signal to Noise Ratio" ;
                fSNR:units = "dB" ;
                fSNR:_FillValue = -999.f ;
        int lPlausibility(dim_time, dim_heights, dim_beams) ;
                lPlausibility:long_name = "Data Plausibility"
                lPlausibility:note = "Converted from octal to
base10" ;
```

Table 2: Sample header information in the averaged netCDF files (abbreviated). Key data are in the variables fWindSpeed, fWindDirection (or fU, fV) for winds, fRassTV and fRassPTV for RASS virtual temperature and potential virtual temperature variables. It is suggested that data with corresponding fSNR >= 3 dB and lPlausibility code <= 2 be used in analyses.

Note that the wind 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). The eastward and northward winds are also available in variables fU and fV. There is an alternate method of measuring wind using a cluster average technique (variables fWindSpeedCL and fWindDirectionCL), however comparisons with soundings and tower measurements determined that the default winds (variables fWindSpeed and fWindDirection) were more accurate. The RASS potential virtual temperature (variable fRassPTV) is derived directly from the virtual temperature assuming a dry adiabatic height correction.

Two other variables that should be examined when using this data are the signal to noise ratio and Metek's plausibility code (variables fSNR and lPlausibility). Based on comparisons with soundings and the WLEF tower, it is found that samples with fSNR greater than or equal to 3 dB, and lPlausibility code 2 or less, are likely to be more accurate than samples outside those limits. The lPlausibility code is derived from Metek's plausibility bit code sequence for each beam. The lPlausibility limit of 2 means that either no problems were found (all bits are zero), bit 0 is set (saturation found in some samples but those were not used in the analysis), or bit 1 is set (noise was found in some samples but those were not used in the analysis). All other issues (such as excessive noise, spikes in the Doppler spectra, low SNR, statistical issues and a range of other problems) result in the sample being rejected.

The SNR and lPlausibility limits can be relaxed if a particular case is being examined and measurements are found to be sparse, however the user should be aware that some measurements may be erroneous.

Other data such as reflectivity, radial velocity, sigma of radial velocity and wind direction and others are also available. Some of these are available for each beam direction. Three beam directions were used: vertical and two oblique beams (directed 16° off zenith to azimuths 48° and 318° clockwise from north) used to measure winds using the Doppler beam swinging technique. In the data files four beam directions are listed, the extra beam is for RASS however this is also vertical. The convention in the netCDF files is that beam 0 is for RASS, while the other beams are for wind measurements. In the ascii files beams 1, 2, & 3 are the wind measurement beams and the RASS beam is labeled with the letter "R".

Other files from the sodar that are available on request are:

- 10 minute average ascii files
- Raw moment data ascii files
- Plots of the data (also at https://www.eol.ucar.edu/content/iss-operations-cheesehead)

Comparison with Soundings and Performance

Radiosonde soundings were also launched from the ISS site. Soundings were launched daily at 18 UTC (1pm local time), and during the Intensive Observation Periods (IOP) additional soundings were launched from sunrise to sunset. Figures 2 and 3 compare wind and virtual temperature measurements from the sodar and the 169 soundings. Figure 2 shows times series plots for the whole campaign, and figure 3 shows scatter plots comparing the sodar and soundings.

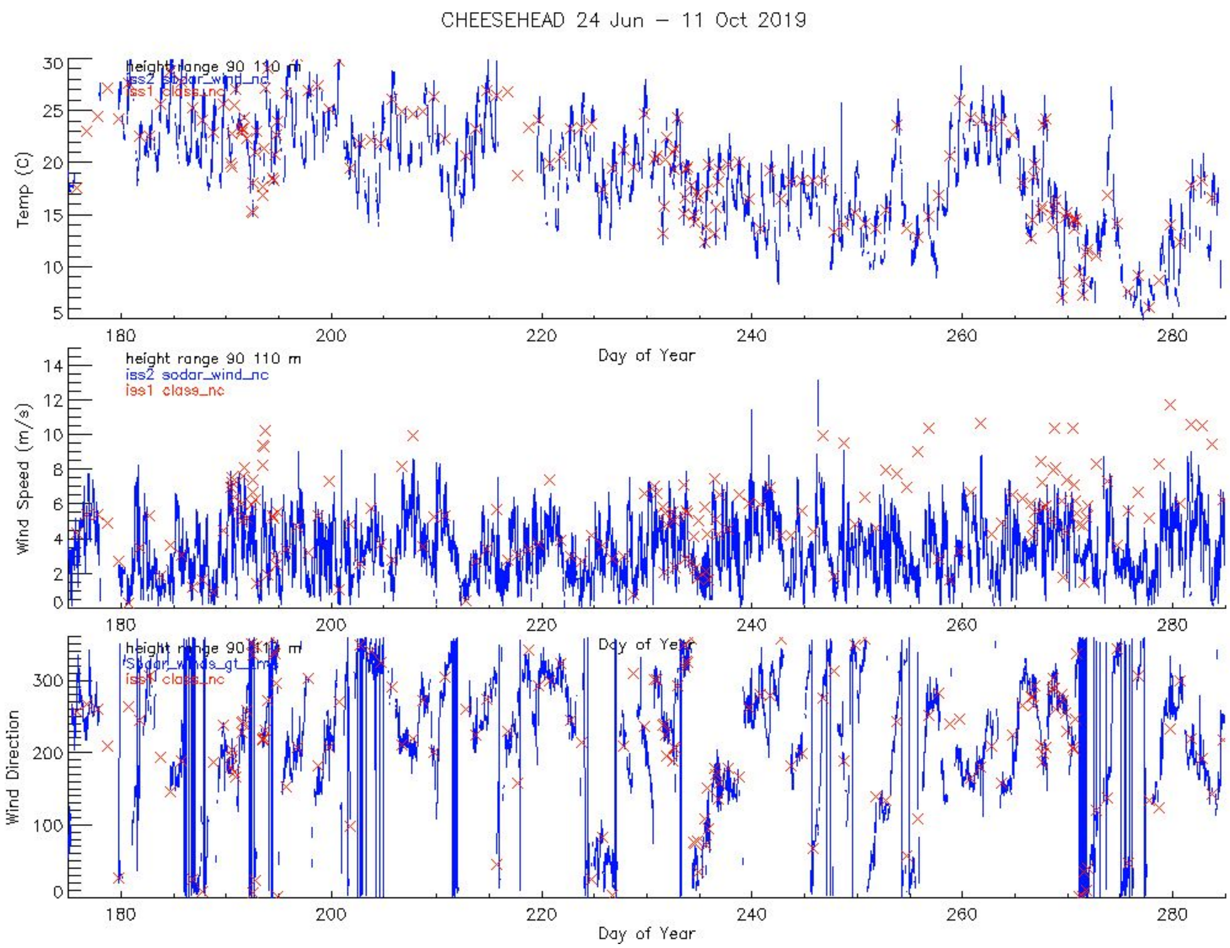

Figure 2: Time series of virtual temperatures from the Sodar-RASS and soundings at the 100 meter level. The sodar data are the blue lines, and the soundings are the red crosses.

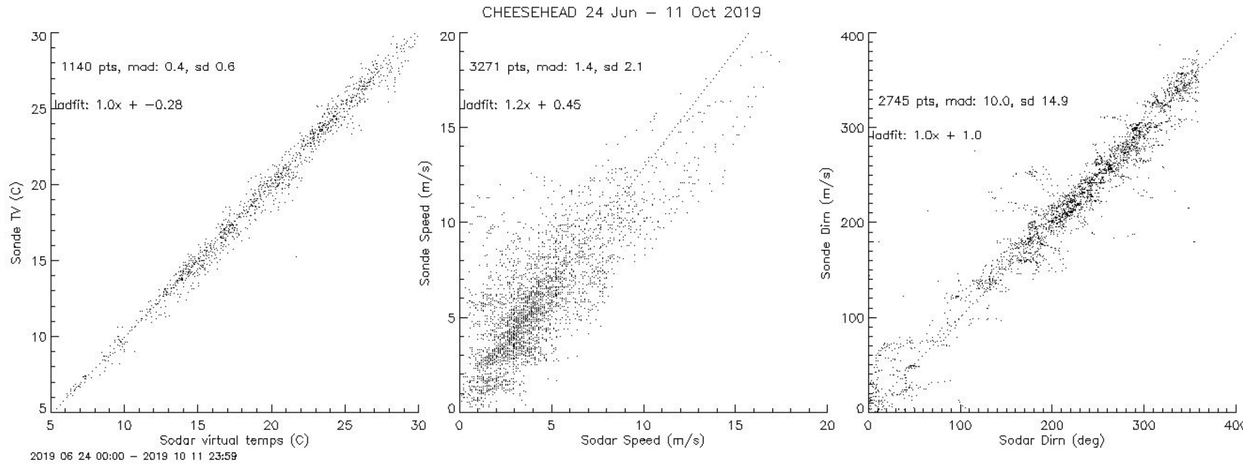

Figure 3: Scatter plot comparisons between the Sodar-RASS and radiosonde soundings over the 40 - 400 meter height range. The left panel shows the virtual temperature comparison, the center panel the wind speeds and the right panel the wind directions. All 169 soundings launched during the campaign were included.

Overall the agreements were good, with wind speeds and directions having standard deviations of 2 m/s and 15° respectively, and the virtual temperatures agreed with a standard deviation of 0.6 C. The slopes of best fits were very close to 1 for wind directions and temperatures, however is about 1.2 for wind speeds, indicating that the sodar was underestimating speeds by around 20%. Further statistics are summarized in Table 3. Comparisons with the WLEF tower (1.6 km to the east) and the co-located 449 MHz Modular Wind Profiler show similar relationships. As discussed in the next section, it is suspected that the wind speed bias is caused by an issue with the sodar speakers. There also appears to be an altitude bias to the temperature data.

The maximum height of reliable measurement depends on many factors such as background noise, atmospheric conditions, and even the wind speed. For CHEESEHEAD, wind measurements were available 90% of the time at the 120 meter level and virtual temperature measurements were available 90% of the time at the 40 meter level. The virtual temperature availability falls off fairly rapidly with altitude, being available 50% of the time at 110 meters. The winds data is available to higher altitudes, being available 50% of the time at the 250 meter level. Height coverage was about 10 - 20% better during the day than at night. Further details on the height coverage are shown in the lower section of Table 3.

	Median Abs Dev	***Std Deviation***	***Correlation Coef***	***Best fit slope***
Wind Speed comparison	1.4 m/s	2.1 m/s	0.79	1.24
Wind Direction comparison	10^o	15^o	0.96	0.996
Virtual Temperature	0.40C	0.59C	0.97	1.02
Height	***50 m***	***100 m***	***150 m***	***200m***
Night time (0-12Z) availability wind/TV	50% / 90%	90% / 55%	85% / 10%	65% / 5%
Day time (12-24Z) availability wind/TV	60% / 90%	90% / 60%	90% / 15%	85% / 5%

Table 3: Overall statistics of the sodar-RASS for the entire campaign. The upper section shows the results of comparison of sodar winds and virtual temperature with soundings over all range gates. The lower section shows the availability for winds and virtual temperature (TV) at the 50m, 100m, 150m & 200m levels. Peak availability was at the 120m level for winds (90% of the time) and 40m for virtual temperature (90% of the time). Measurements were available 50% of the time up to 250m for winds and 110m for virtual temperature.

Known Data Issues

As discussed above, wind speeds from the sodar appear to be underestimated by about 20%. This was probably related to problems discovered with the speaker system. The acoustic array consists of 24 speakers, however early in the campaign it was found that two of the speakers had faults and were likely damaged by nearby lightning. Unfortunately these speciality speakers (which act as transmitters and receivers) are no longer in production and could not be replaced or repaired. These problems would not have significantly affected the virtual temperature measurements, however appear to have contributed to some distortion in the wind measurements.

Examination of the virtual temperature data shows that there were a small percentage of points that had extreme values (as low as -30C and as high as 50C), even with the SNR > 3 dB and IPlausibility < 2 restrictions mentioned above. A filter of -5 C to +35 C was imposed for the netCDF files that make up this data set and this removed around 0.3% of the data. Note that these points remain in the original ASCII data sets.

There appears to be an altitude bias to the virtual temperature data. This was uncovered in the virtual temperature measurements by NOAA Affiliate James Duncan and is illustrated in the right panel of Figure 4. The profiles show the difference in virtual temperature between the sodar and soundings as a function of altitude (the three profiles show the lower quartile, median and upper quartile of the differences). The difference is most pronounced at the 40 meter level (the lowest level measured) where the median difference was -0.4 C (negative indicating that the sodar temperatures were 0.4 C too cool), however given that is the first range gate there may be sampling errors.   Above about 70 m the bias is the other way (ie, the sodar measuring too warm) with the median difference reaching about 0.2 C at the 100 m level.

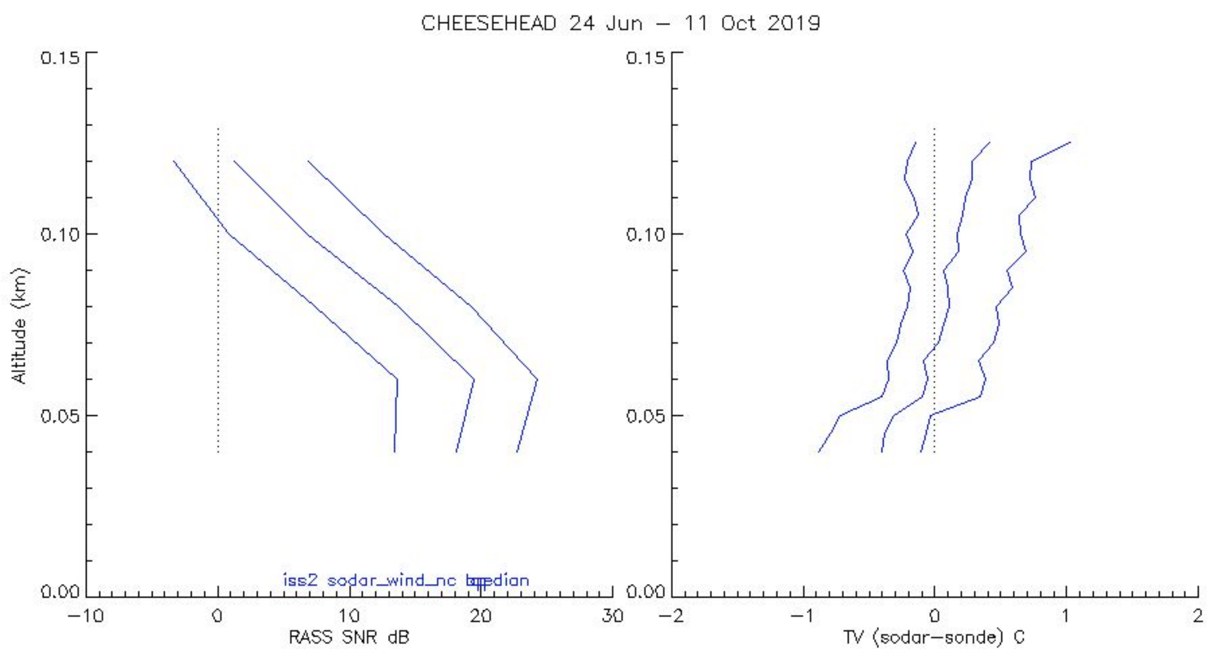

Figure 4 Profiles of RASS SNR and virtual temperature differences between the sodar and radiosonde soundings. The three profiles in each plot represent the lower quartile, median and upper quartiles of the RASS SNR in the left plot and virtual temperature differences on the right plot. Above about 120 m, there is too little data to reliably estimate the bias.

The SNR profiles on the right panel of Figure 4 hint at a possible cause. The SNR has a peak at about 60 m, below that level the SNR gradually increases with altitude and above that level significantly SNR decreases with altitude. The altitude of a particular measurement can be biased by this SNR profile. The sampling profile is a convolution of the range gate sampling and the signal profile; if there is a strong SNR gradient then the actual sampling could be skewed in the direction of increasing SNR. Measurements below the SNR peak may be skewed a little high, and measurements above the peak may be skewed a little low. Most soundings were during the day and if the boundary layer follows a typical moist adiabatic lapse rate of 5 K/km, this might imply that measurements around 100 m level might be 40 m too high. However because the sampling characteristics of the radiosonde and sodar are very different, caution should be exercised in drawing such conclusions. Nonetheless it is reasonable to assume that the altitudes in the sodar may be off by one or two range gates. A similar bias has been reported in radar wind profiler RASS by Görsdorf and Lehmann (2000) [3]. In principle it is possible to apply their corrections to the data, although these have not been tested in sodar-RASS data. Note there does not appear to be a significant bias in winds with altitude.

Table 4 summarizes major events during the campaign, data interruptions and days with significant issues. The most significant interruptions were during the June 24 - 26 period when a truck blocked the RASS signal; June 27 - 28 when the sodar suffered lightning damage; and August 3 - 7 when the RASS receiver failed. There were shorter outages due to power interruptions due to storms and to carry out maintenance.

June 18 - 23	Setup period, some data available however various interruptions for testing and calibration
June 24	First day of operations
June 24 - June 26	Limited RASS measurements due to truck blockage
June 27 1 UTC - June 28 19 UTC	Electronics failure due to nearby lightning
July 8	Electronics overheating, occasional outages
July 9 - 12	IOP 1
July 15 03 - 18 UTC	Power failure due to storms
July 17 19 - 20 UTC	Down briefly for repairs
July 20 0 - 5 UTC	Power failure due to storms
Aug 3 19 UTC - Aug 7 13 UTC	RASS receiver fault, repaired Aug 7
Aug 19 - 24	IOP 2
Sept 3 10 - 15 UTC	Power failure due to storms
Sept 13 0 - 14 UTC	Power failure due to storms
Sept 23 - 28	IOP 3
Oct 11	Last day of operations

Table 4: Notable events and data interruptions

Acknowledgements:

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References:

[1] CHEESEHEAD

Brian Butterworth, Ankur Desai, et.al., 2020: "Connecting Land-Atmosphere Interactions to Surface Heterogeneity in CHEESEHEAD 2019", (in preparation for submission to BAMS)

Homepage: https://www.eol.ucar.edu/field_projects/cheesehead
ISS page: https://www.eol.ucar.edu/content/iss-operations-cheesehead
Data Archive: https://data.eol.ucar.edu/master_lists/generated/cheesehead/

[2] ISS Integrated Sounding System

Website:https://www.eol.ucar.edu/observing_facilities/iss
DOI: http://dx.doi.org/10.5065/D6348HF9
Reference: Parsons, D., W. Dabberdt, H. Cole, T. Hock, C. Martin, A-L. Barrett, E. Miller, M. Spowart, M. Howard, W. Ecklund, D. Carter, K. Gage and J. Wilson, 1994: "The Integrated Sounding System: Description and preliminary observations from TOGA COARE". *Bull. Amer. Meteor. Soc.,* 75, 553–567, doi:10.1175/1520-0477(1994)075<0553:TISSDA>2.0.CO;2.

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

CONTACT:

William Brown, NCAR/EOL
PO Box 3000, Boulder, CO 80307
wbrown@ucar.edu, Ph: 303-497-8774