SAVANT 2018

449 MHz Radar Wind Profiler Data Report

NCAR/EOL Integrated Sounding System

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Earth Observing Laboratory
In situ Sensing Facility

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OVERVIEW

This document describes data from the NCAR / EOL 449 MHz Modular Wind Profiler radar at the SAVANT 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): SAVANT 2019 NCAR/EOL ISS 449 MHz Radar Wind Profiler Data Report.*

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ISS Operations and quicklook plots: https://www.eol.ucar.edu/content/iss-savant
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 In-situ Sensing Facility. 2020. NCAR/EOL ISS 449 MHz Modular Wind Profiler Products, 5 and 30 minute Winds. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/K6J3-MJG4-RG0D.

- NCAR/EOL In-situ Sensing Facility. 2020. NCAR/EOL ISS 449 MHz Modular Wind Profiler Moments. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/GPV8-089T-HB0H.

INTRODUCTION

NCAR/EOL deployed the 449 MHz Modular Wind Profiler radar for the SAVANT (Stable Atmospheric Variability and Transport) field campaign between September 15 and November 15, 2018 [1]. The profiler was operated as part of the Integrated Sounding Systems (ISS) [2] at a site in Champaign County, Illinois, near the town of Mahomet, IL. The ISS was split between the main study area in a field about 1 km north of Mahomet (with the ISFS tower array, ISS sodar-RASS and other instruments) and a farm homestead approx 4km to the northwest. The Modular Profiler was located at this northwest location, along with a radiosonde sounding, a 10 meter surface meteorological tower system and the ISFS base trailer.

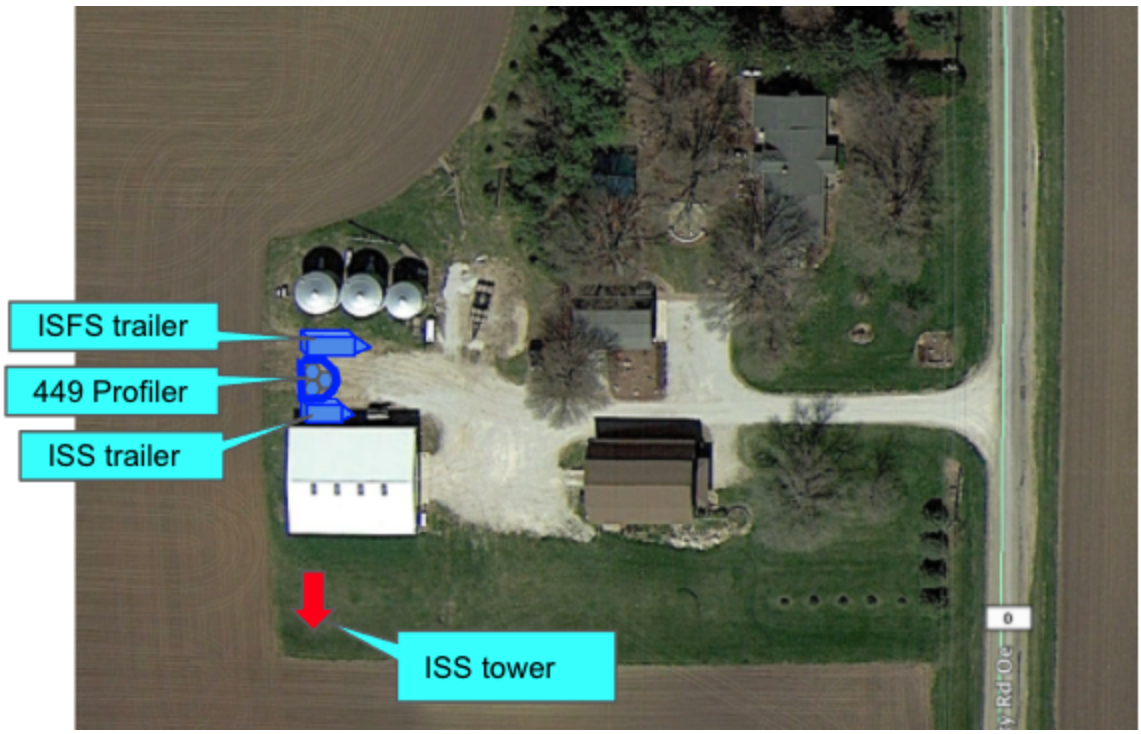

Figure 1: Approximate layout of the ISS1 site at SAVANT.

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 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). SAVANT focused on the planetary boundary layer so the profiler was deployed in a three antenna module configuration.

The wind profiler's operating parameters for SAVANT are summarized in Table 1. The profiler was driven using a Delta Sigma 2 kW power amplifier, typically at 8% duty cycle. Approx 20% of power was lost to cable and other component inefficiencies. A clutter fence was designed to reduce clutter echoes from a highway (I-74, 1.4 km to the south) and nearby trees, and also reduce the effects of radio frequency radiation on passersby.

Wind Profiler	449 MHz Modular Wind Profiler operating as a Spaced Antenna Radar
Location	40.2254°N, 88.46198°W, 239 m MSL
Antennas	3 vertically pointing 18-element phased array modules with antenna pair 0-1 orientated at 300°, approx 10° beamwidth
Power Amp	2 kW peak, 8% duty cycle, 150 W average
Time Sampling	Raw IQ: 165 Hz (IPP 50 μs, NCI 30, 4 channels) Correlations and Spectra: 30 second averages Moments: 30 second averages Winds: 5 minute and 30 minute averages
Range sampling	1 μs pulse with 4 bit complementary phase code 150 m resolution from 200 m to up 4 km AGL

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

Wind Profiler 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 signals 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, Cohn et. al. 2001). Raw (IQ) data from the receivers sampled at 165 Hz were retained for the entire campaign, totaling over 4 TB of data. 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 correlation files are then analysed to generate the daily winds and moment files that make up this archive.

Two analysis techniques were applied to the correlation files to determine winds, "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. A range of parameters such as the Signal to Noise Ratio (SNR), spectral width, magnitude and variability of the cross correlation between different receivers, phase differences between receivers, and other parameters were

considered in a series of statistical tests. Those samples that passed these tests in a pseudo fuzzy logic approach were included in consensus averaging analyses to produce the 30-minute and 5-minute wind data files in this archive.

The data files are in netCDF format [6]. There are two product file types, wind measurements (files with extension *.winds.*.nc) and spectral moments data (extension *.mom.nc). The winds files total around 14 MB and the moment files around 400 MB. 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 ("time" and "x" dimensions in the netCDF files, Table 2). 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 variables containing Signal to Noise Ratio (SNR, related to backscatter signal strength and reflectivity), vertical velocity (positive is upwards) and Doppler spectral width (can be used to estimate turbulence with lots of caveats). We generally recommend that only experienced profiler users analyze these data. These data are also in the moments data files, derived from zeroth, first, and second moments of the Doppler spectra at approx 30 second intervals. 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.

```
netcdf prof449.20181018.winds.30 {
dimensions:
    time = UNLIMITED ; // (48 currently)
    x = 25 ;
variables:
    int base_time ;
        base_time:string = "18-Oct-2018,
00:00:00 GMT" ;
        base_time:long_name = "Base time in
Epoch" ;
        base_time:units = "seconds since
1970-1-1 0:00:00" ;
        base_time:day_of_year = 291 ;
    float lat ;
        lat:long_name = "Site latitude; north is
positive" ;
        lat:units = "Degrees" ;
    float lon ;
        lon:long_name = "Site longitude; east is
positive" ;
        lon:units = "Degrees" ;
    float alt ;
        alt:long_name = "Site Altitude" ;
        alt:units = "Meters, ASL" ;
    float frequency ;
        frequency:long_name = "Transmitter
Frequency" ;
        frequency:units = "MHz" ;
    float x_spacing ;
        x_spacing:long_name = "grid spacing" ;
        x_spacing:string =
        "x for Zeb compatibility, actually height
dimension" ;
        x_spacing:units = "meters" ;
    double time_offset(time) ;
        time_offset:long_name = "Time offset
    float wspd(time, x) ;
        wspd:long_name = "Wind Speed" ;
        wspd:_FillValue = -999.f ;
        wspd:units = "meters/second" ;
    float wdir(time, x) ;
        wdir:long_name = "Wind Direction
(from direction)" ;
        wdir:_FillValue = -999.f ;
        wdir:units = "degrees (east of north)" ;
    float wvert(time, x) ;
        wvert:long_name = "Vertical Wind" ;
        wvert:_FillValue = -999.f ;
        wvert:units = "meters/second" ;
    float snrw(time, x) ;
        snrw:long_name = "Signal to Noise
Ratio" ;
        snrw:description =
            "Average of consensing wvert
samples" ;
        snrw:_FillValue = -999.f ;
        snrw:units = "dB" ;
    float specWid(time, x) ;
        specWid:long_name = "Doppler
Spectral Width, HPHW" ;
        specWid:_FillValue = -999.f ;
        specWid:units = "meters/second" ;
        specWid:description =
            "Average of consensing wvert
samples" ;

// global attributes:
    :description = "Modular Profiler
consensus winds" ;
    :Processing-Method = "30 minute
consensus averages" ;
    :history = "write_cons_4.pro" ;
```

from base_time" ; time_offset:description = "Time at center of averaging period" ; time_offset:units = "seconds since 18-Oct-2018, 00:00:00 GMT" ; float height(time, x) ; height:long_name = "Height of measured value, MSL" ; height:units = "meters" ; height:valid_range = 125.f, 3775.f ;	:File-Start-Time = 1539820800. ; :File-End-Time = 1539907199.00001 ; :beg_dt = 2018.f, 10.f, 18.f, 0.f, 0.f, 0.f ; :end_dt = 2018.f, 10.f, 18.f, 23.f, 59.f, 59.f ; :project = "SAVANT" ; :site = "Mahomet, IL" ; :missing_value = -999.f ; :zebra_platform = "MAPR/449 winds" ;

Table 2: Sample header information in the QC'ed winds netCDF files. Wind speed and direction are in the wspd and wdir variables. Note that the "x" dimension is actually the height coordinate.

Performance and Comparison with Soundings

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 SAVANT, the primary unwanted signals were echo clutters from birds, particularly at night in the fall when large numbers of song birds migrate to their winter resting grounds.

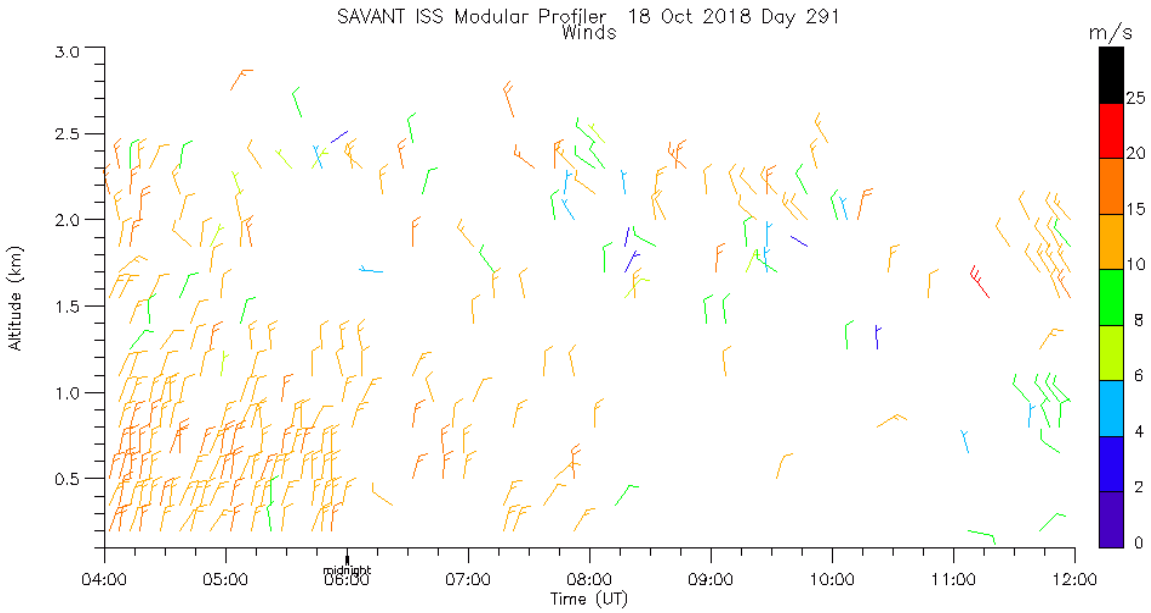

Figure 2: 449 MHz Modular Profiler wind measurements during IOP 5 at SAVANT.

An example of the typical QC'ed 5-minute wind measurements during an IOP IIntensive Operating Procedures) are shown in Figure 2. This is IOP 5 on a night with much bird activity. Some measurements are likely biased by the bird clutter echoes, however overall the winds are consistent with soundings, particularly at lower levels. The atmospheric signal weakened during the night so fewer measurements are available after midnight.

The QC processing had some success in removing the bird echoes, however there are sure to be some remaining in the final data set. The birds tend to fly with the wind and during migration nights are almost constantly in the radar beam so it can be difficult to separate their echos from atmospheric backscatter. It appears that the conditions that favored migration (clear with light winds, typically northerlies) were also those favored for IOPs, so on most IOP nights there was interference by birds (summarized in Table 4 below). Compounding the issue, atmospheric backscatter tends to be weaker during these conditions than during typical daytime convective boundary layer conditions.

Despite these factors the overall QC'ed profiler winds compared well with the radiosonde soundings as can be seen in Figures 3 and 4. The overall statistics are summarized in Table 3. The standard deviation between the 30-minute winds from the profiler and soundings was speed was around 2.1 m/s and in direction was 12^{o}. These numbers are similar to those seen in other campaigns. There are some gaps when the processed data failed the QC procedures due to either weak signal or samples being rejected (frequently because they were identified as being biased by birds) resulting in winds being available at the 1 km level 80% of the time during the day and 60% of the time during the night. The approximate availability of wind measurements for each IOP is listed in Table 3.

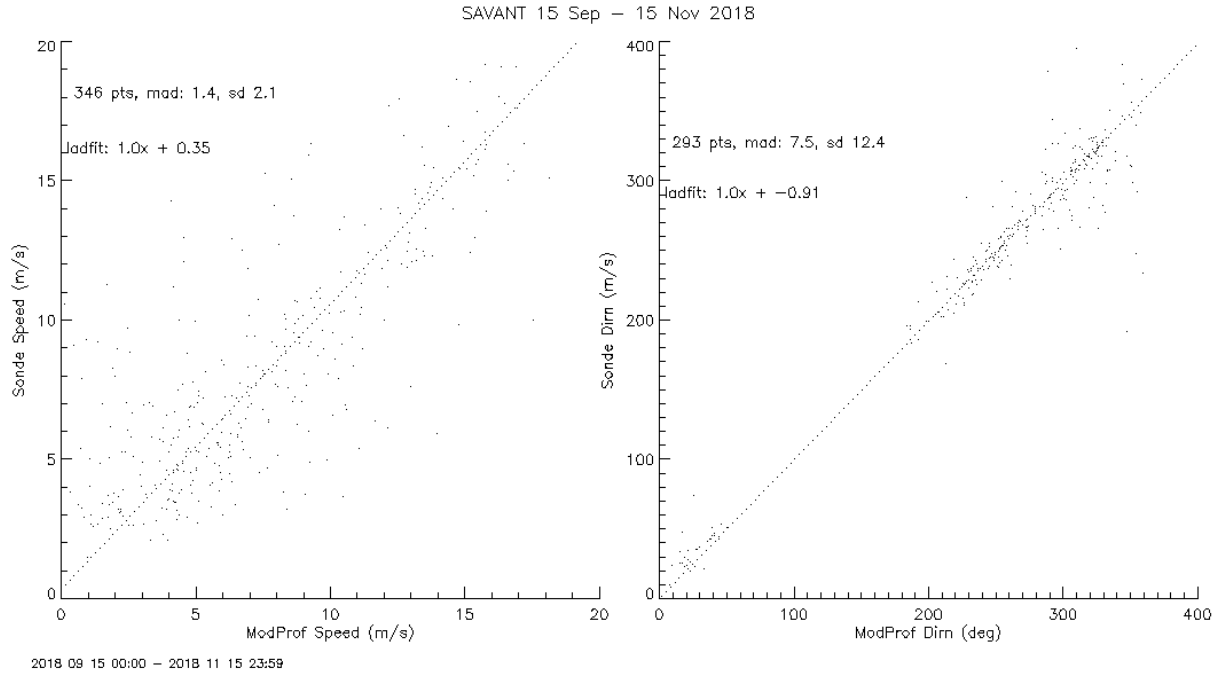

Figure 3: Comparison between the Modular Wind Profiler 30-minute averaged winds and soundings over all range gates. All 41 soundings launched during the campaign were included.

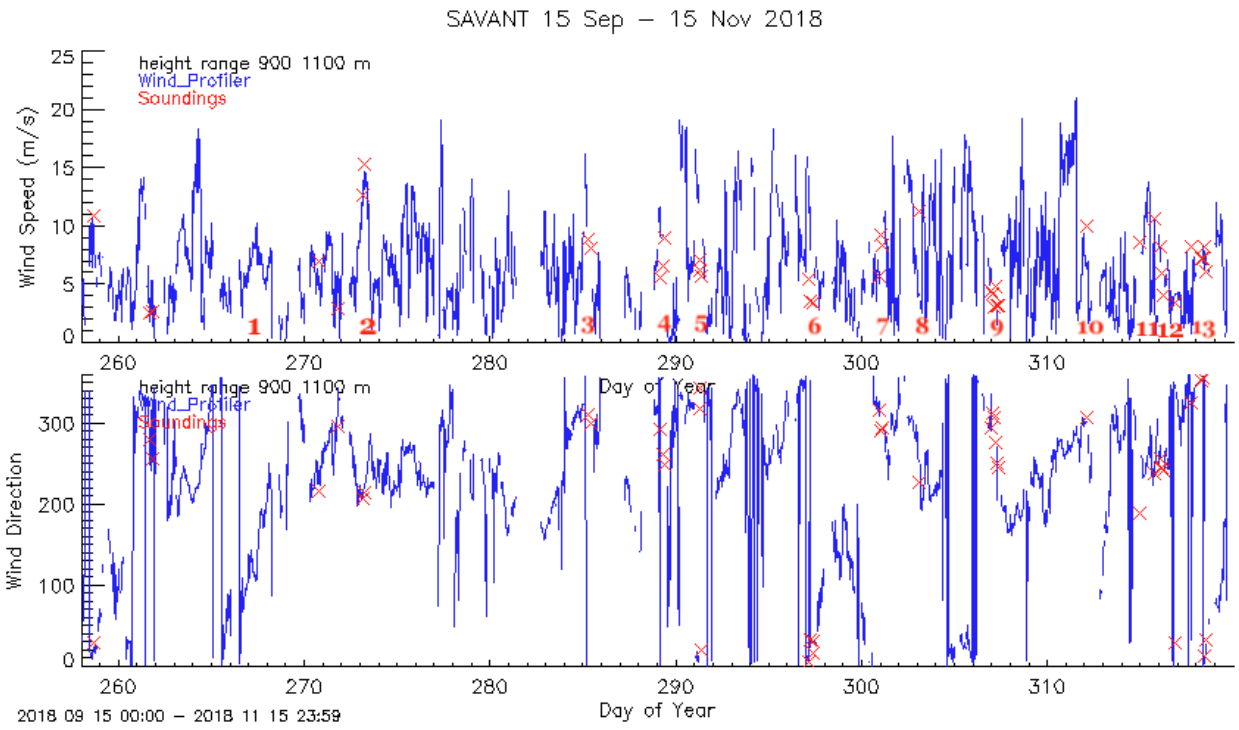

Figure 4: Time series plots of wind speed (upper panel) and direction (lower panel) from the wind profiler (blue line) and radiosonde soundings (red crosses) at the 1 km level for the entire SAVANT campaign. The red numbers indicate the times of the 13 IOPs.

	Median Abs Dev	*Std Deviation*	*Correlation Coef*
Wind Speed compared with soundings	1.4 m/s	2.1 m/s	0.81
Wind Direction compared with soundings	7^{o}	12^{o}	0.96
	1 km	*2 km*	*3 km*
Night time (0-12Z) availability	60%	50%	30%
Day time (12-24Z) availability	80%	60%	35%

Table 3: Overall statistics of the QC'ed wind profiler data set for the entire campaign.

Known Data Issues

As noted above, birds were a significant problem particularly on IOP nights. Other less significant issues were the occasional build up of rain water and ice on the antenna, both of which can attenuate and distort the signals. Most of this drained or melted off prior to IOPs, however there may be periods during, and for some hours after, precipitation when signals are weaker than they would otherwise have been. In addition, during heavy rain events the

profiler wind speeds tend to be underestimated by 10 to 40%. No corrections for this biasing have been applied for this data set.

Another possible issue is potential biasing of the range bins related to reflectivity gradients and pulse coding. The range resolution is nominally 150 meters, 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.

Table 4 summarizes major events including IOPs, data interruptions and days with significant issues. For each IOP there is a comment on the effect of birds and an estimate of the percentage of the time during the IOP that wind estimates were available at least two range gates.

Sep 12 - 14	Setup, some data available (with interruptions)
Sep 15 - 16	Operations began Sept 15 with brief interruptions for further testing and calibration on the 15 & 16th.
Sep 24: 0230 - 0730 UTC	IOP 1: few birds, good atmospheric signal; winds available for more than 90% of IOP
Sep 30: 0300 - 0630 UTC	IOP 2: few birds, good signal, however failure from 3-4 UTC. Winds available for the remainder of IOP.
Oct 8: 0900 - Oct 9: 1700	Receiver channel 1 failure, signal and vertical vel available but no wind measurements
Oct 12: 0600 - 1200 UTC	IOP 3: many birds, much atmospheric signal blocked, winds available approx 50% of IOP
Oct 16: 0423 - 1130 UTC	IOP 4: many birds, much atmospheric signal blocked, winds available approx 50% of IOP
Oct 18: 0400 - 1200 UTC	IOP 5: many birds, much atmospheric signal blocked, winds available approx 50% of IOP
Oct 24: 0400 - 1200 UTC	IOP 6: many birds, much atmospheric signal blocked, winds available approx 50% of IOP
Oct 28: 0100 - 0400 UTC	IOP 7: many birds, much atmospheric signal blocked, winds available approx 60% of IOP
Oct 29: 2230 - Oct 30: 0600	IOP 8: some birds, atmospheric signal partly blocked, winds available approx 90% of IOP
Nov 3: 0000 - 1300 UTC	IOP 9: many birds, most atmospheric signal blocked, winds available approx 60% of IOP
Nov 8: 0100 - 0500 UTC	IOP 10: few birds, little atmospheric signal blocked, winds available more than 90% of IOP

Nov 10 - 12	Ice on antenna, mostly melted prior to IOPs 11 & 12 although signals may be weakened
Nov 10: 2300 - Nov 11: 0500	IOP 11: few birds, little atmospheric signal blocked, winds available more than 90% of IOP
Nov 12: 0000 - 0600 UTC	IOP 12: some birds, weak atmospheric signal blocked, winds available approx 70% of IOP
Nov 14: 0400 - 1300 UTC	IOP 13: some birds, some atmospheric signal blocked, winds available approx 80% of IOP
Nov 15	Last day of operations

Table 4: Notable events and data interruptions. The IOP times are based on those in Field Catalog. The winds availability is a simple estimate of the percentage of time for which wind measurements are available at two or more range gates for the duration of each IOP.

References

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Field Catalog: http://catalog.eol.ucar.edu/savant
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[6] NetCDF: UCAR/Unidata netcdf web site:
http://www.unidata.ucar.edu/content/software/netcdf/

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