MARVELOUS Project Summary
Requesting PIs: Rachel Humphrey and Alan Srock
Requesting Institution: St. Cloud State University

Intended to run from 13 November through 3 December (but actually extending through 10 December), the **M**obile **A**tmospheric **R**esearch **V**ehicles for **E**nhanced **L**earning **O**pportunities for **U**ndergraduate **S**tudents (MARVELOUS) project offered undergraduate students at St. Cloud State University (SCSU) a unique chance to learn how to operate, collect data with and analyze data from state-of-the-art in-situ and remote sensing instrumentation. In addition, the project afforded students enrolled in the SCSU Atmospheric and Hydrologic Sciences (AHS) and STEM Education (STEM Ed) programs the opportunity to participate and lead multiple educational outreach events and activities, greatly expanding their exposure to applications and experiences well beyond the scope and confines of a traditional classroom setting. As a result, over 40 undergraduate students, 100 members of the general public, and more than 1000 K-12 students were directly impacted by this project, as detailed in the following project summary.

**On-Campus Student Preparation and Training:**

As proposed, one of the academic merits of MARVELOUS was that it was designed to bolster topics covered in AHS 468 (Radar and Satellite Meteorology) as well as other related AHS courses offered at SCSU. Three weeks prior to the start of the MARVELOUS project, students enrolled in AHS 468 (as well as five additional undergraduate AHS students) were trained by PI Humphrey[1] in how to use of SOLOII software for the visualization of Doppler On Wheels (DOW) radar data through a series of hands-on modules designed specifically for this project. In these modules, old datasets with winter-time meteorological conditions (lake-effect snow and nor'easters) were accessed, examined and analyzed by students. Beyond this, copies of "how-to" documents (provided by the Center for Severe Weather Research [CSWR]) were provided to the entire AHS department, ensuring any student who wanted to learn how to use the equipment would have the background knowledge beneficial to hands-on training. Students in AHS 468 were also trained how to use Microsoft Excel to plot the DOW mesonet and POD data in preparation for the multiple types of data they expected to collect during field operations.

Once the DOW and (four) in-situ PODs were physically on campus, students were divided up into small groups and instructed on the operation of both the DOW and the PODs during allotted 50-minute intervals[2]. (While this may seem like a very short amount of time for the groups, it should be noted that not only was prior instruction on safe/logical deployment practices and siting provided [and tested] in class, students were also given [and tested on] the instructional documents for both DOW and POD operations provided by CSWR.)

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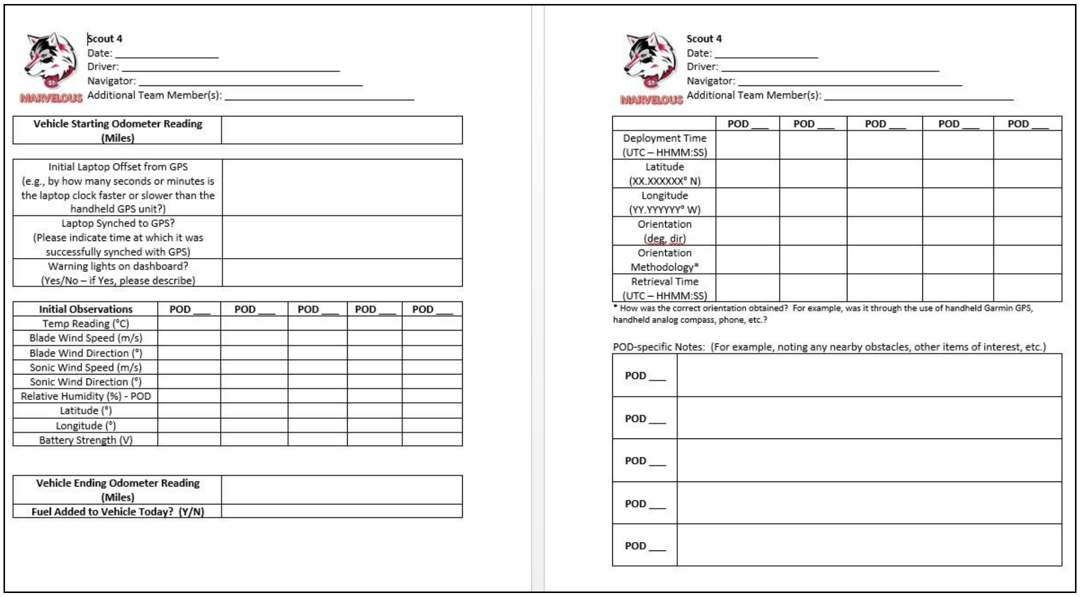
[1] No staff member from CSWR was present in St. Cloud during this educational project, as PI Humphrey was already an experienced DOW operator and POD technician.

[2] Admittedly, the necessity of staggering a group of 20 AHS 468 students (due to size limitations of the DOW interior and the number of PODs) initially presented a time-management challenge; in fact, the first opportunity for the class to go out into the field actually occurred before every student had "officially" received training on operations. However, as discussed below in the section detailing IOP I, this was met with very positive results, including students teaching each other "on the fly" during operations, and proved to be a boon to student learning and information retention for everyone involved.

Finally, in anticipation of the project, students were given sample DOW and POD deployment and field logs, and were instructed on filling them out properly and completely; examples provided to students appear in Figs. 1a and 1b.



MARVELOUS

**Scout 4**
Date: ______________
Driver: ______________________________
Navigator: ______________________________
Additional Team Member(s): __________________________

| **Vehicle Starting Odometer Reading (Miles)** | |
|---|---|

| | |
|---|---|
| Initial Laptop Offset from GPS (e.g., by how many seconds or minutes is the laptop clock faster or slower than the handheld GPS unit?) | |
| Laptop Synched to GPS? (Please indicate time at which it was successfully synched with GPS) | |
| Warning lights on dashboard? (Yes/No – if Yes, please describe) | |

| **Initial Observations** | **POD ___** | **POD ___** | **POD ___** | **POD ___** | **POD ___** |
|---|---|---|---|---|---|
| Temp Reading (°C) | | | | | |
| Blade Wind Speed (m/s) | | | | | |
| Blade Wind Direction (°) | | | | | |
| Sonic Wind Speed (m/s) | | | | | |
| Sonic Wind Direction (°) | | | | | |
| Relative Humidity (%) - POD | | | | | |
| Latitude (°) | | | | | |
| Longitude (°) | | | | | |
| Battery Strength (V) | | | | | |

| **Vehicle Ending Odometer Reading (Miles)** | |
|---|---|
| **Fuel Added to Vehicle Today? (Y/N)** | |

MARVELOUS

**Scout 4**
Date: ______________
Driver: ______________________________
Navigator: ______________________________
Additional Team Member(s): __________________________

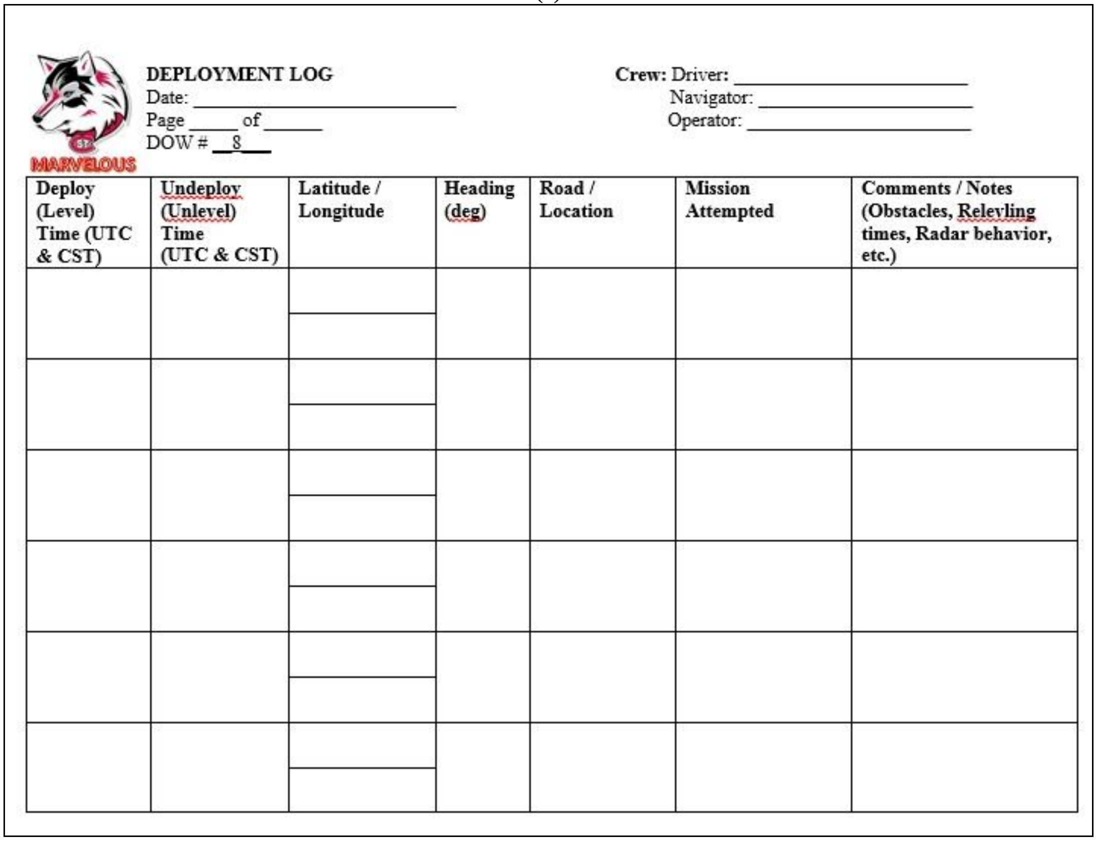
| | **POD ___** | **POD ___** | **POD ___** | **POD ___** | **POD ___** |
|---|---|---|---|---|---|
| Deployment Time (UTC – HHMM:SS) | | | | | |
| Latitude (XX.XXXXXX° N) | | | | | |
| Longitude (YY.YYYYYY° W) | | | | | |
| Orientation (deg, dir) | | | | | |
| Orientation Methodology* | | | | | |
| Retrieval Time (UTC – HHMM:SS) | | | | | |

* How was the correct orientation obtained? For example, was it through the use of handheld Garmin GPS, handheld analog compass, phone, etc.?

POD-specific Notes: (For example, noting any nearby obstacles, other items of interest, etc.)

| | |
|---|---|
| **POD ___** | |
| **POD ___** | |
| **POD ___** | |
| **POD ___** | |
| **POD ___** | |

(a)



MARVELOUS

**DEPLOYMENT LOG**
Date: ______________________
Page _____ of ______
DOW # __8__

**Crew:** Driver: ______________________
Navigator: ______________________
Operator: ______________________

| **Deploy (Level) Time (UTC & CST)** | **Undeploy (Unlevel) Time (UTC & CST)** | **Latitude / Longitude** | **Heading (deg)** | **Road / Location** | **Mission Attempted** | **Comments / Notes (Obstacles, Relevling times, Radar behavior, etc.)** |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

(b)

Fig. 1. Sample field logs for (a) POD deployments and (b) DOW deployments.

**Meteorological Operations (IOPs):**

As with many educational projects, longer-duration off-site field operations were constrained by observable weather as well as the availability of students during times above and beyond regularly-scheduled class periods. However, a rather “unusually quiet and mild” start to the MN autumn gave way to a more active weather pattern by the time the DOW arrived in St. Cloud; fortuitously, the weather and students’ schedules occasionally aligned. As a result, there were two main opportunities for Intensive Operation Periods (IOPs), where students intercepted, observed and collected data on inclement winter weather. The first took place in Sauk Centre, MN on 18 November (UTC) and the second took place along the SW shores of Mille Lacs Lake on 6-7 December (UTC). Table 1 and Fig. 2 show deployment characteristics of IOPs I and II.

| Date (UTC) / IOP ID | Deployment Duration (UTC) | Deployment Location (Lat/Lon) | Mission Attempted | # of Participating Undergraduates |
|---|---|---|---|---|
| 18 Nov. 2016, IOP-I | 1000 – 1650 | 45.71897/ -94.95112 | Interception of transitioning precipitation (liquid-to-frozen) in approaching winter storm | 15 |
| 6-7 Dec. 2016, IOP-II | 2200 - 0330 | 46.1225/ -93.6606 | Lake-effect snow band initiation over Mille Lacs Lake | 7 |

Table 1. Description of IOPs during MARVELOUS.

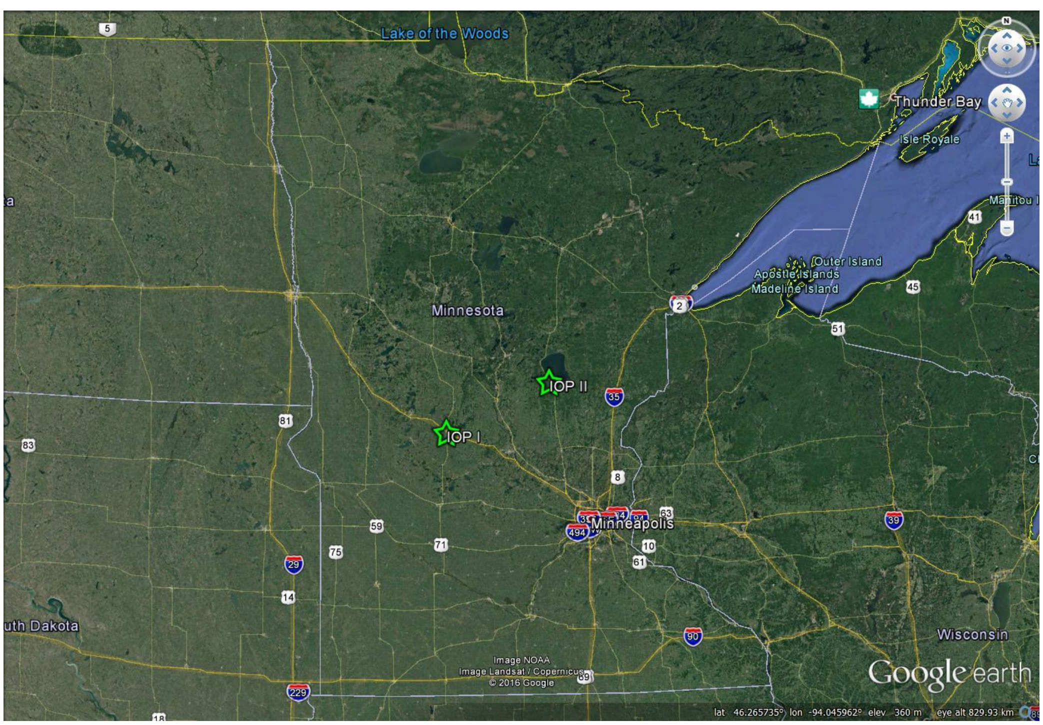



Fig. 2. Above, the deployment sites for the two main IOPs of the MARVELOUS project.

Prior to each deployment, undergraduate students enrolled in AHS 468 as well as other students from the AHS department conducted discussions pertaining to the small and large-scale meteorological setups of each event as well as the deployment sites most likely to result in the best datasets possible for the given conditions. Students and PIs Humphrey and Srock met the day before each event to get a "baseline" or feeling for what conditions were to be expected. During the discussion, students shared their insights as to what thermodynamic and dynamic forcings would be causing the event, where the best deployment site(s) would be, and the most effective scanning and transmission strategies to employ during the deployments. (This all built upon prior concepts discussed earlier in the semester in AHS 468.) Students and PIs subsequently met 12- and 6-hours prior to expected departure time, with a "final call" being given about an hour prior to leaving for each IOP's destination. Descriptions of each IOP appear below.

*IOP-I: 18 November 2016 – Transitioning precipitation intercept*

In the afternoon (~1200 Local Time, LT) and evening (~1800 LT) of 17 November, student-led weather forecast discussions (for an event due to impact the region on 18 November) were held with minimal instructor/PI input. In each discussion, students forecasted the meteorology behind the event and selected a target deployment region in order to be in position to capture a transition line between frozen and liquid precipitation. In their discussions, students utilized Google Earth to pick out appropriate deployment sites and discussed at great lengths where the best deployment site would be. Although there were a few students who wished to go further NW, it was preliminarily decided that, to ensure that the maximum number of students could participate in the IOP (multiple vehicles were employed due to the sheer volume of student interest), the target region would be in Sauk Centre (Fig. 2). At 0200 LT on 18 November, a "final call" decision was made to go forward with the deployment, and the students and PI Humphrey met at the SCSU campus, departing by 0300 LT and arriving to the deployment site by 0400 LT.


Fig. 3. Deployment location of DOW 8 and the four PODs (G-J) utilized during IOP I in Sauk Centre, MN.

The DOW was operational and collecting data shortly after 0400 LT, and all PODs (four in total) were deployed within about an hour of site arrival (Fig. 3). This was the first IOP of the project, and, as a result fact, not all of the participants had completed training on DOW operations yet. However, this IOP provided a “learn-on-the-go” environment in which they could ask questions in real-time as they learned and implemented the proper sequence for bringing the radar up, selected various configuration files, etc.  It also presented numerous opportunities for peer-to-peer teaching moments, as students who had already been trained on equipment usage and programming were encouraged to share and demonstrate their knowledge with the students who had not yet “officially” learned the operational methodology in a “hands-on” capacity.

In addition, the changing weather conditions throughout the deployment (from liquid to semi-frozen to all-frozen precipitation) afforded students the ability make concrete connections between what had been discussed during the prior weeks and in the textbook with what they were, quite literally, seeing directly in front of them on the screen.  Furthermore, they were able to build upon their prior knowledge as well as their in-field conditions to adjust their scanning strategies accordingly.  Several students noticed a large amount of ground clutter was blocking the radar beam, while another noticed that the higher elevation angles weren’t allowing them to see the development of the lower-level jet, and so discussions were had “on the fly” to remedy that and ensured a useful dataset was obtained.  The ability (and willingness) of students to make such decisions while immediately seeing the results of their decisions in real-time was something to which they definitely responded positively and enthusiastically (see Figs. 4 and 5).

Fig. 4. Top left: Students worked in small groups to deploy PODs during the first IOP. Having previously learned about the importance of proper POD alignment/orientation, students employed their skills in the dark early-morning hours of 18 November.
Bottom left:  During the daylight hours, students periodically went out to the POD sites to ensure proper data collection.
Bottom right: Students monitored conditions in real-time and adjusted scan strategies when needed.

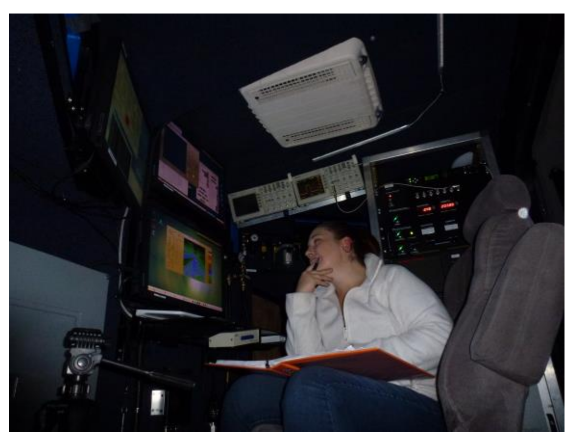
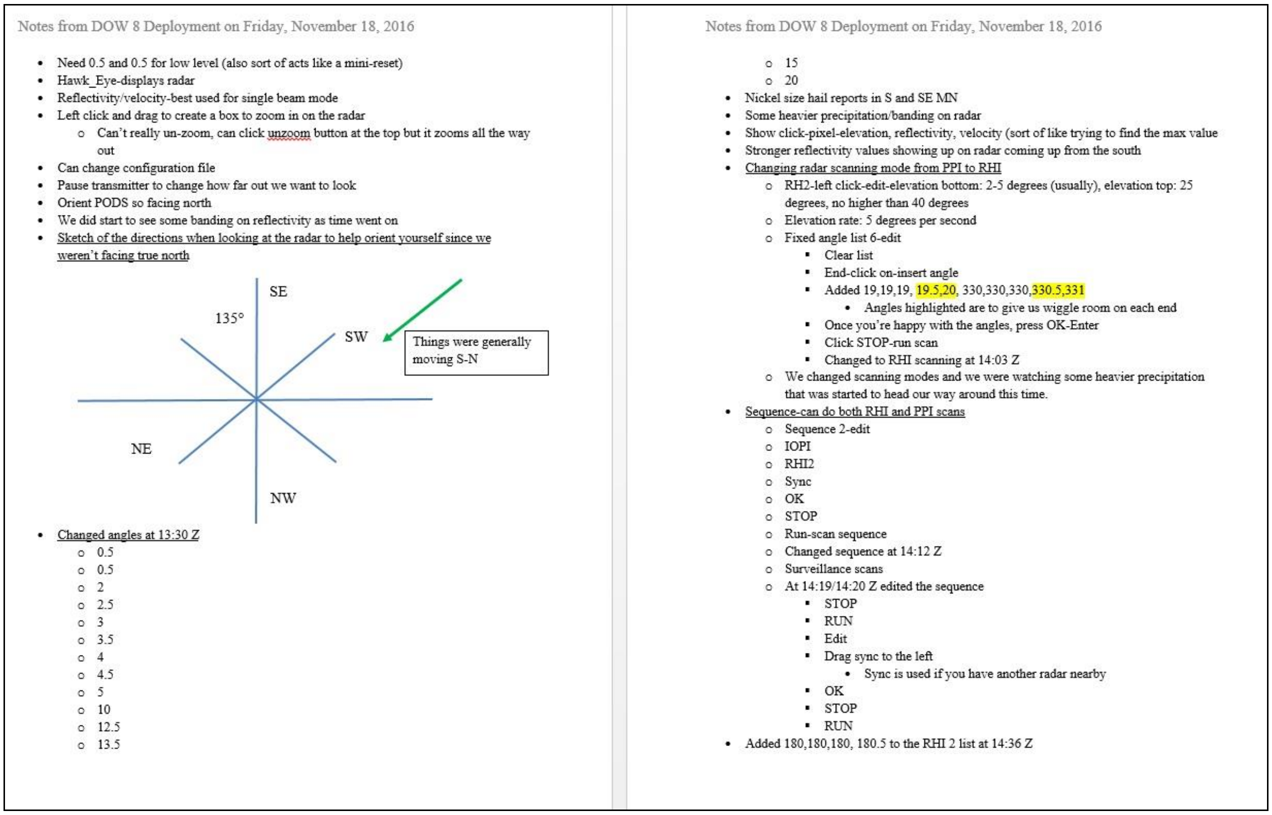



Fig. 5. Above (top), AHS 468 students examine the radar data during IOP-I deployment and (bottom) the AHS students just prior to departure from the deployment site.

In addition to the prescribed field logs, students were encouraged to take notes on their own throughout the deployment. Though they were allowed to take notes in any format they wished, many opted to take notes electronically, a sample of which appears in Figure 6.



Notes from DOW 8 Deployment on Friday, November 18, 2016

- Need 0.5 and 0.5 for low level (also sort of acts like a mini-reset)
- Hawk_Eye-displays radar
- Reflectivity/velocity-best used for single beam mode
- Left click and drag to create a box to zoom in on the radar
  - Can't really un-zoom, can click unzoom button at the top but it zooms all the way out
- Can change configuration file
- Pause transmitter to change how far out we want to look
- Orient PODS so facing north
- We did start to see some banding on reflectivity as time went on
- Sketch of the directions when looking at the radar to help orient yourself since we weren't facing true north



- Changed angles at 13:30 Z
  - 0.5
  - 0.5
  - 2
  - 2.5
  - 3
  - 3.5
  - 4
  - 4.5
  - 5
  - 10
  - 12.5
  - 13.5

Notes from DOW 8 Deployment on Friday, November 18, 2016

  - 15
  - 20
- Nickel size hail reports in S and SE MN
- Some heavier precipitation/banding on radar
- Show click-pixel-elevation, reflectivity, velocity (sort of like trying to find the max value
- Stronger reflectivity values showing up on radar coming up from the south
- Changing radar scanning mode from PPI to RHI
  - RH2-left click-edit-elevation bottom: 2-5 degrees (usually), elevation top: 25 degrees, no higher than 40 degrees
  - Elevation rate: 5 degrees per second
  - Fixed angle list 6-edit
    - Clear list
    - End-click on-insert angle
    - Added 19,19,19, 19.5,20, 330,330,330,330.5,331
      - Angles highlighted are to give us wiggle room on each end
    - Once you're happy with the angles, press OK-Enter
    - Click STOP-run scan
    - Changed to RHI scanning at 14:03 Z
  - We changed scanning modes and we were watching some heavier precipitation that was started to head our way around this time.
- Sequence-can do both RHI and PPI scans
  - Sequence 2-edit
  - IOPI
  - RHI2
  - Sync
  - OK
  - STOP
  - Run-scan sequence
  - Changed sequence at 14:12 Z
  - Surveillance scans
  - At 14:19/14:20 Z edited the sequence
    - STOP
    - RUN
    - Edit
    - Drag sync to the left
      - Sync is used if you have another radar nearby
    - OK
    - STOP
    - RUN
- Added 180,180,180, 180.5 to the RHI 2 list at 14:36 Z

Fig. 6. A sample of "ancillary" notes taken by an AHS 468 student during IOP I.

With no direct guidance[3] provided for individualized student note-taking, when it came time to analyze the first IOP's data, students worked in conjunction with one another to cobble together bits of incomplete or "solitary" information in the form of notes. It was quickly observed that as a direct benefit of having students fill out prescribed logs as well as taking their own notes (without reminders as to the pertinent information to record in their own notes), students began to understand and realize the importance of thorough note-taking during fieldwork. (Perhaps unsurprisingly, as a result of the first "cobbling" activity, the students' individualized notes taken during the second IOP were more complete than in those taken during the first IOP.)

Though IOP-I was initially intended to go through 1200 LT on 18 November, deteriorating weather and road conditions – observed, monitored and analyzed by the SCSU students throughout the deployment – resulted in a truncated deployment, with the entire crew leaving the site around 1030 LT. The caravan of the DOW, Scout vehicle and a handful of student vehicles

[3] This was intentional; a prior lecture/activity in class stressed the challenge and importance of taking notes in the field. This "hands-off" approach by the PI was a way to gauge student understanding of individual "off-the-cuff" note recording in conjunction with prescribed templates, the latter of which were provided in order to ensure students at least recorded very basic information essential for radar data navigation and editing in the lab after the IOP was over.

traveled together back to St. Cloud and arrived safely. During the next class period, the dataset was disseminated to the entire class (as well as additional AHS students) for analysis. Some results of the students' data analysis appear in a later section within this report.

*IOP-II: 6-7 December 2016 – Lake-effect snow initiation*

During the afternoon of 6 December, PI Humphrey was approached by AHS 468 students who said they had been holding informal weather discussions on their own and were interested in attempting a mission to intercept lake-effect snow over Mille Lacs Lake in east-central MN. They also informed the PI that they had selected appropriate deployment sites for both the DOW and the PODs during the deployment. At approximately 1700 LT, the decision was made to depart to the deployment site, which is shown in Fig. 7.

Fig. 7. A map of the deployment site for the DOW and PODs (labeled accordingly within the image) during IOP II.

Throughout the deployment, students opted to run sector scans instead of full 360° scans, due to the instrument positioning along the lake shore resulting in approximately 210 degrees of blockage. As the deployment occurred during the evening (dark) hours, students relied heavily on the live radar imagery to calculate the most effective scanning strategies to ensure a beneficial dataset. (Extreme caution was also employed for the POD deployments, as the selected locations were along a road shoulder which sat atop a steep drop-off directly over the lake.)

During the course of the deployment, students observed (and, as a result, augmented their scanning rates, elevation angles and selected configuration files for the transmitter) the development of a weak lake-effect banding of snow was observed. Though not a particularly strong or long-lived event, the students responded positively to the IOP, expressing interest in analyzing the data. Due to the time constraints of the MARVELOUS project (the end of which coincided with the end of the Fall 2016 semester at SCSU), students were given copies of the dataset from the second IOP, but did not have time to do in-class analysis of the data. Thus, at the time of this report, students have not had a chance to generate IOP II-derived plots in SOLOII or Excel; such analysis is expected to continue into the upcoming semester and beyond.

In addition to the two main IOPs, students also collected radar and POD data on the SCSU campus during two "transitioning precipitation" events (both occurring on 4 December). Although the on-campus deployment sites were far from ideal for radar line-of-sight limitations, the atmosphere provided enough variable weather on this day to warrant student interest. This also afforded the opportunity for additional students in the AHS department (as well as one very interested father of an AHS student) to learn how to level, operate, and collect data with the DOW as well as deploy PODs and analyze the data collected by the various instrumentation. Again, due to the end-of-semester time limitations, students will be analyzing the data next semester.

**Undergraduate Research, Analysis and Presentations:**
Prior to the MARVELOUS project, students were informed that they would be working in small groups (3-4 students) to generate a final project relating to and analyzing one or more aspects of the radar *and* POD data collected[4] during the project. The final project would entail writing up a synopsis of the weather event, summarizing the main features of interest (what their group found to "stand out" to them) in both the radar and POD data, and presenting their findings to a group of their peers.

The findings of the groups were highly variable, not the least of which came from two astute groups who, early on in the project (right after the first IOP, and prior to the next class meeting), discovered (1) that the DOW velocity data, although it had been displaying correctly in the truck, appeared to be "reversed" in sign for the entire deployment and (2) that some of the POD data was showing incorrect timestamps. These were significant discoveries; ones that prevented erroneous analyses for the entire class; thankfully, there were "quick fix" solutions to remedy the situation. However, the fact that students were able to compare their own recollections/observations of being out in the field with readings they had obtained with handheld anemometers in the field *and* the POD data *and* the DOW data allowed them to see that even the high-tech instruments used in the field of meteorology are not without errors; it was a highly valuable lesson regarding data analysis as well as data integrity.

[4] Since the project was weather-dependent, had there been no weather to collect with the DOW or the POD, the students were informed that they would be given an alternate dataset to analyze. Fortunately, this was not an issue during this project.

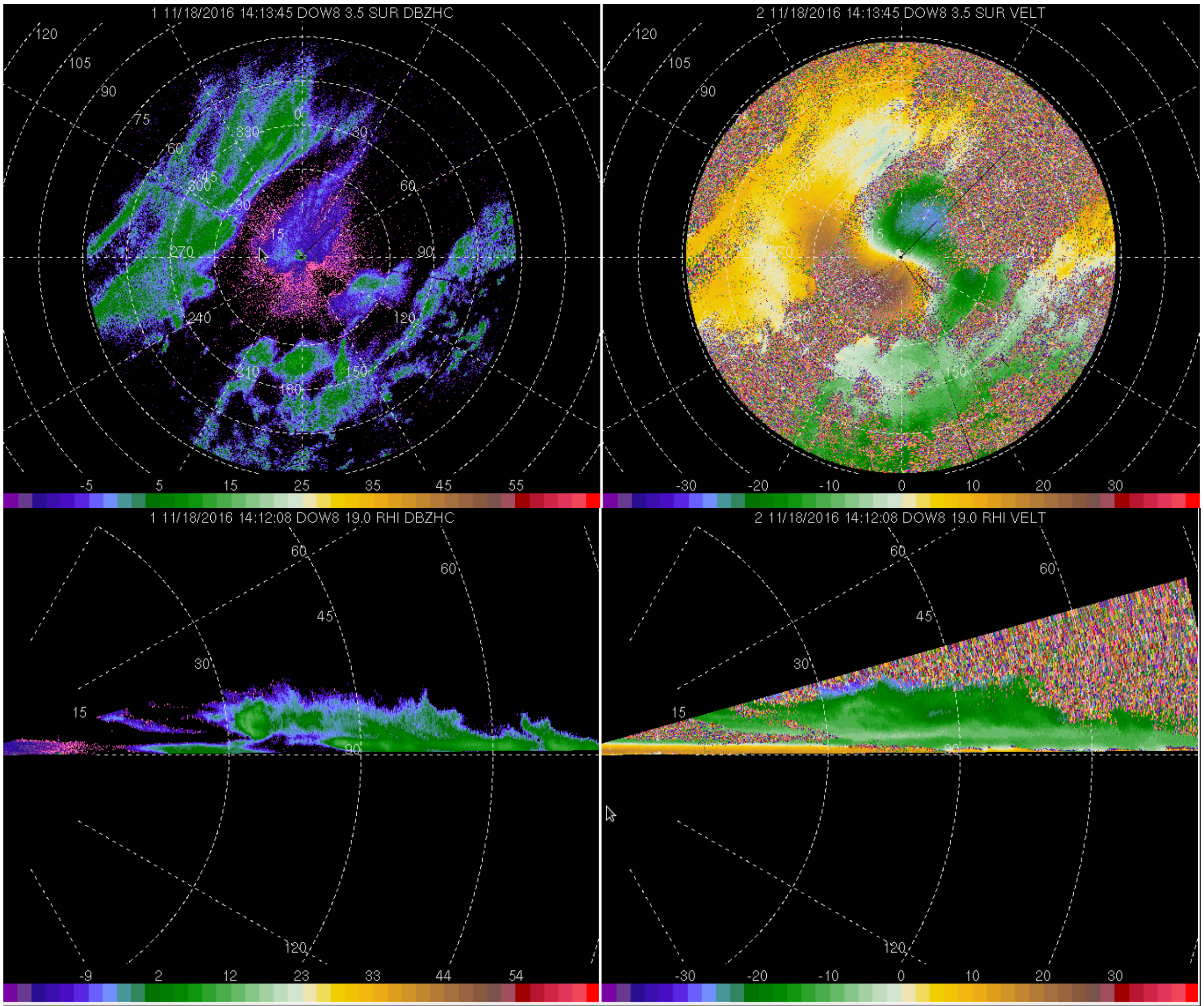
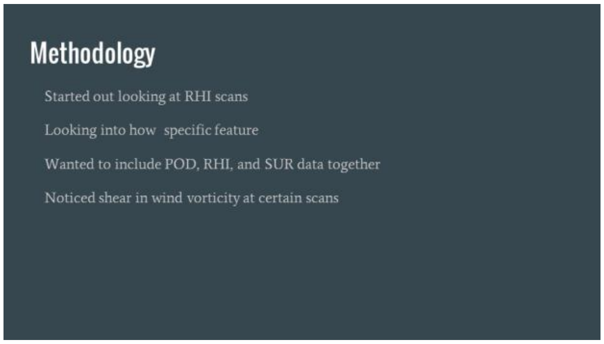


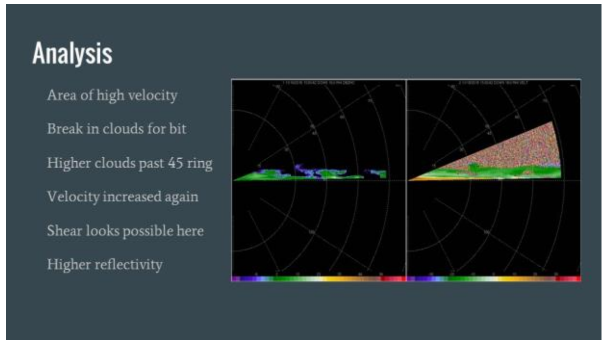
Fig. 8. A sample of a plot included in a presentation by a group of AHS 468 students who opted to examine (left panels) reflectivity and (right panels) radial velocity fields of (top) PPI and (bottom) RHI scans for their particular feature(s) of interest.

Once the quality control issues were fixed, and because it was by no means accidental that the deployment time span captured a period of noticeable intensification of the precipitation event[5], there were many routes of analysis from which the student groups could choose. Analysis of the data by the student groups included the investigation of the development of a low-level jet during IOP I, comparisons between the POD readings, comparisons of the POD/DOW mesonet readings and those of local NWS observations (specifically, comparing ASOS station readings to those of the PODs and the DOW mesonet), the evolution of conditions experienced throughout the deployment in the context of the larger synoptic setup, and the comparison of DOW multi-elevation angle measurements with atmospheric soundings. A sample of some student presentation slides appears in Figures 8, 9a-d, 10a-f, and 11a-d.

[5] The student forecasters did an excellent job predicting this event, and there was also very helpful input provided to them by Dr. Robert Weisman (from AHS) during their weekly weather discussion course.




(a)

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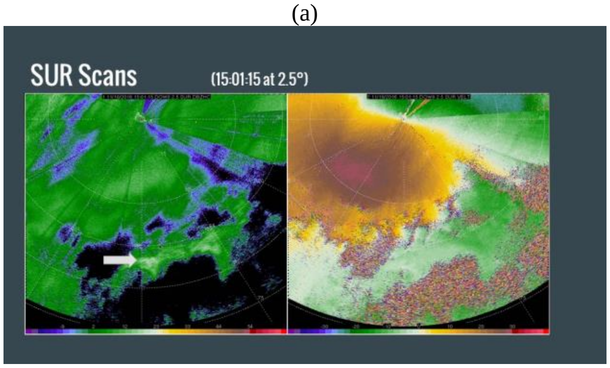
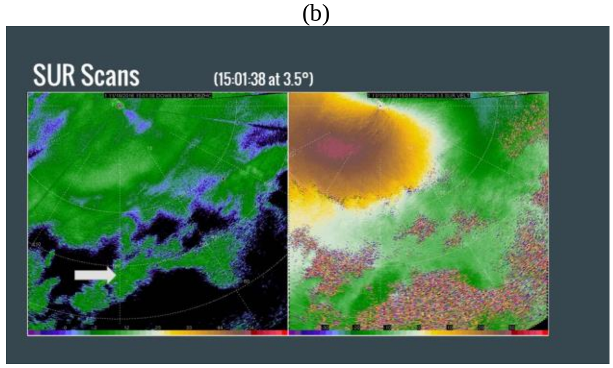



(c)




(d)

Fig. 9. (a) Methodology of student analysis of visible features in (left panels) reflectivity and (right panels) radial velocity fields from (b) RHI and (c, d) SUR scans during IOP I.

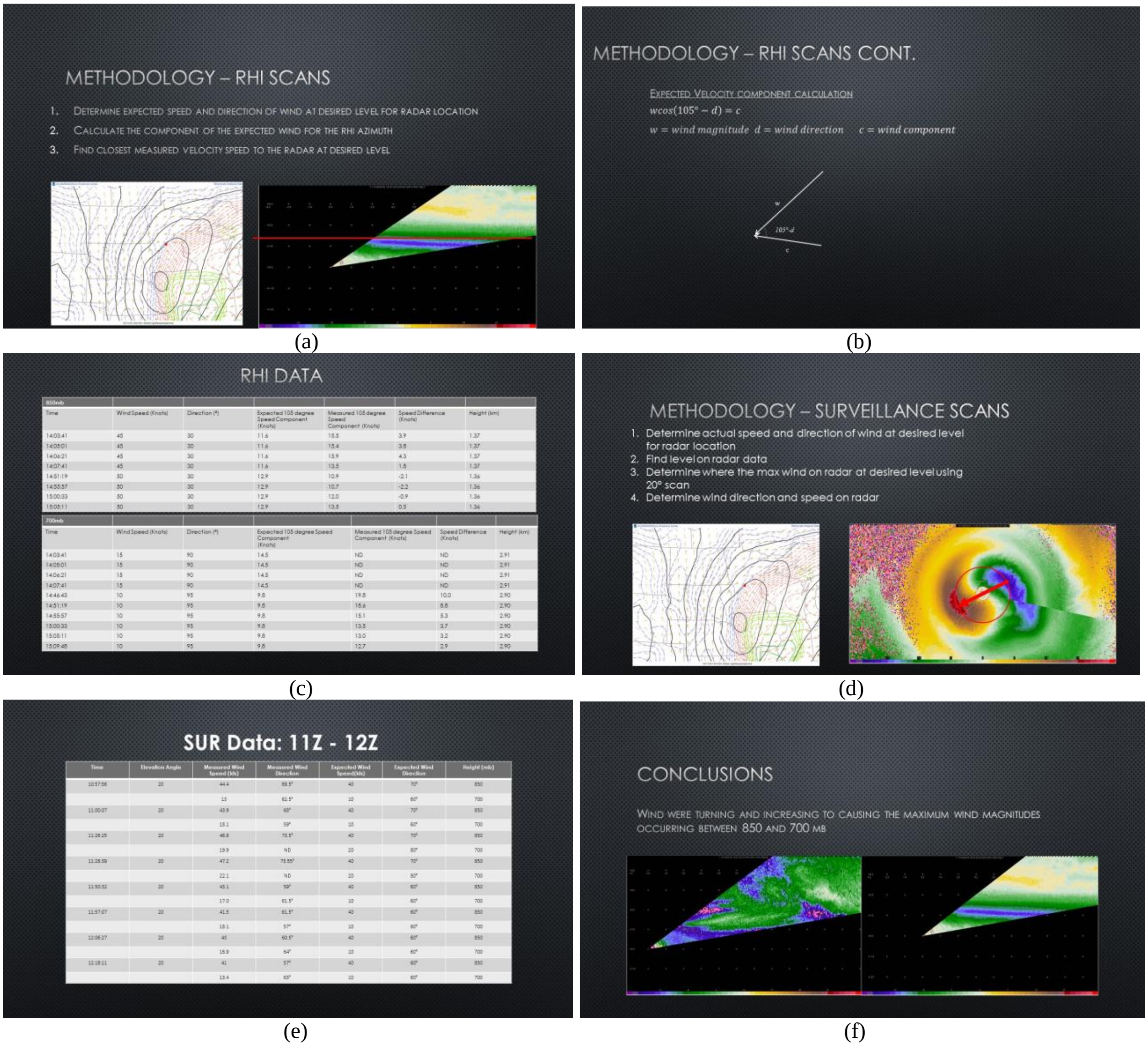
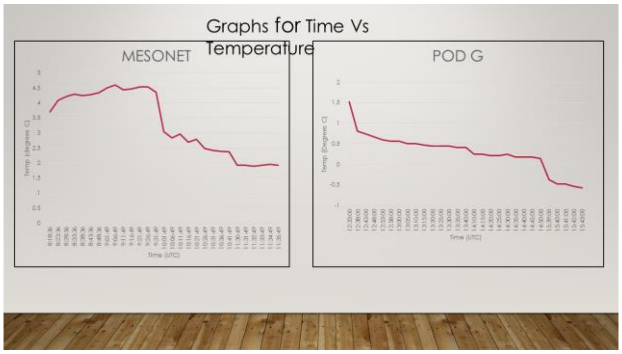
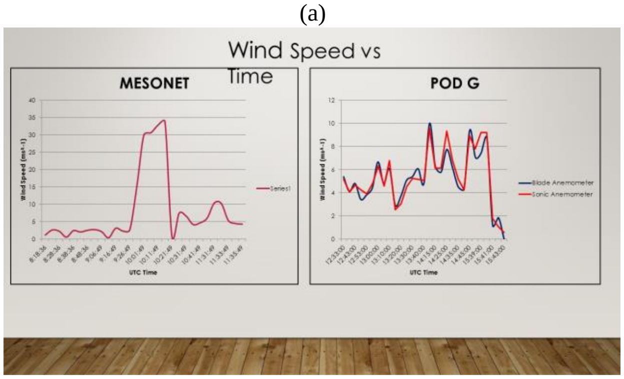


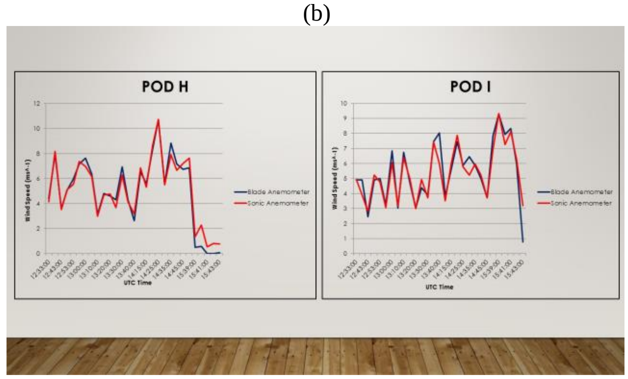

Fig. 10. Student analysis of (a-c) RHI and (d-e) PPI scans depicting the development of an 850-hPa jet during IOP I and (f) a sample conclusion slide.





(a) (b)




(c) (d)

Fig. 11. Student comparisons of POD and DOW mesonet measurements of (a, b) ambient temperature and (c, d) wind speed during IOP I.

Student groups were responsible for the write-ups and presentations as mentioned earlier, and they presented their findings to their peers. Each group, since they chose a different aspect of the deployment to examine, fielded a host of questions from their peers as well as PI Humphrey. Overall grades for the final project (including reports, field logs, pictures, notes, presentations, etc.) ranged from B- to A+.

In addition to the final projects, students were alerted to the fact that they can collaborate with PI Humphrey on radar analysis during future semesters. As of this report, she has had three students who have expressed interest in continuing with radar analysis (from IOPs I and II, as well as additional DOW data) as contributing to and being incorporated into their Senior Research projects.

At the end of the project, students were given an informal questionnaire meant to gauge the effectiveness and impact of MARVELOUS on contributing to meaningful student learning, performance and interest in the AHS 468 course. Results of the questionnaire (as well as additional feedback on the project from other interested/impacted parties) are discussed later in this report.

**Outreach and Impacted K-12 Students:**
Also integral to the MARVELOUS project was the goal to conduct educational outreach events to historically under-represented (in the field of atmospheric science) K-12 students as well as the general public. Though it was initially proposed that there would be five K-12 outreach events organized and implemented during MARVELOUS, undergrads from both the AHS and STEM Ed programs participated in events occurring at eight local K-12 schools, one large regional library (the Great River Regional Library), the Science Museum of Minnesota, an SCSU campus-wide "Open House" for the AHS department, and the Northern Plains Winter Weather Workshop. With the exception of two outreach events, every event involved at least one undergraduate student enrolled in either the AHS or STEM-education programs. In all, 15 different undergraduate students participated in the education outreach events during the MARVELOUS project. A table of completed educational outreach event metrics appears in Table 2.

| Date (All dates 2016) | Location / School (All locations in MN) | Event type | Impacted K-12 Students | # of SCSU Undergraduates Involved and/or Impacted | # Impacted females (K-12 or other) | # Impacted minorities (K-12 or other and excluding females) |
|---|---|---|---|---|---|---|
| 14 Nov | Northern Plains Winter Weather Workshop (St. Cloud) | DOW / POD Show n' Tell | 1 | 30 | 10 | 4 |
| 15 Nov | St. Cloud Tech High School (St. Cloud) | DOW / POD Show n' Tell | 32 | N/A | 17 | 4 |
| 17 Nov | Kennedy Community School (St. Joseph) | DOW / POD Show n' Tell | 347 | 5 | 179 | 123 |
| 17 Nov | Discovery Elementary School (Waite Park) | DOW / POD Show n' Tell | 60 | 5 | 35 | 16 |
| 19 Nov | Great River Regional Library (St. Cloud) | DOW / POD Show n' Tell | 15 | 5 | 10 | 5 |
| 22 Nov | Clearview Elementary (Clear Lake) | DOW / POD Show n' Tell | 84 | 2 | 54 | 15 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 Dec | AHS Open House (SCSU) | DOW / POD Show n' Tell | 0 | 77 | 38 | 24 |
| 1 Dec | Trinity Lutheran Church – Girl Scout Troop (Sauk Rapids) | DOW / POD Show n' Tell | 4 | N/A | 6 | 0 |
| 2 Dec | Chaska Elementary School (Chaska) | DOW / POD Show n' Tell | 201 | 3 | 123 | 45 |
| 2 Dec | Victoria Elementary School (Victoria) | DOW / POD Show n' Tell | 153 | 3 | 88 | 42 |
| 3 Dec | Science Museum of Minnesota (St. Paul) | DOW / POD Show n' Tell and Presentation | 79 | 7 | 87 | 64 |
| 6 Dec | St. Francis K-8 School (Buffalo) | DOW / POD Show n' Tell | 51 | 1 | 30 | 3 |

Table 2. Educational outreach events during MARVELOUS. In addition to the outreach events listed above, formal training sessions for undergraduate students in AHS as well as STEM Ed (none of whom were officially enrolled in AHS 468) were also conducted. In all, through the training, 43 undergraduates were trained to use the DOW and/or PODs. In the interest of space, not shown are the tallies of "general public impacts", which did not include K-12 students. Such metrics are available upon request, however.

During MARVELOUS, outreach events consisted of primarily student-led “Show n’ Tells” of the DOW and PODs, demonstrations of POD deployments and tours of the DOW (replete with archived data loops from tornadoes and hurricanes, but also displaying data that was collected by the SCSU students during IOP I.) Students were also given the opportunity to speak with and present to many members of the public and K-12 population regarding their experiences in the field of atmospheric science research as well as science education. Sample images of typical educational outreach deployments appear below in Figs. 12, 13, and 14.


Fig. 12. Educational outreach events at local K-12 schools benefited not only the K-12 students, but also the undergraduate SCSU students; both student populations learned from one another.


Fig 13. Students met with members of the general public at the Great River Regional Library outreach event on 19 November.

Fig. 14. The final large outreach for the MARVELOUS project took place at the Science Museum of Minnesota in St. Paul on 3 December.

The social impact of the MARVELOUS project's outreach was significant. During the four-week project, 1031 K-12 students were impacted (primarily at the grades 2-8 level); of those, roughly half (497) were female and a little over one-quarter (271) were minority (and non-female) K-12 students. At the non-K-12 school events, over 300 students and members of the general public were impacted.

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**Local media coverage and advertising**

It was initially anticipated that one of the biggest challenges of the MARVELOUS project would be advertising the outreach events. However, there were ample opportunities for the word to be spread.

The SCSU University Chronicle featured an article, "Students get unique opportunity with DOW", http://universitychron.com/students-get-unique-opportunity-dow/, which summarized the early phase of the MARVELOUS project. (The author of the article was a SCSU journalism major who participated in the field for IOP I.)

The Science Museum of Minnesota advertised the DOW exhibit/outreach event prominently on their website: https://www.smm.org/doppler

A local radio station for St. Cloud, WJON, featured a story on the educational outreach that was done during the early phase of the MARVELOUS project: http://wjon.com/doppler-on-wheels-stops-at-discovery-community-school-video/ (Additional advertising of subsequent outreach events was also done through WJON.)

Drs. Robert Weisman and Tony Hansen sent out specific campus-wide emails (via the scsu-announce email list) to encourage students and faculty of SCSU to come out and explore the DOW during the AHS "Open House" on 4 December.

The Great River Regional Library advertised an educational outreach event which took place on 19 November: https://griver.org/event/saint-cloud/doppler-on-wheels/2016-11-19/31503

UTVS, a local television station, featured two stories about the MARVELOUS project. (The reporter from UTVS was also enrolled in AHS 468, and these reports were designed to explain to the viewing audience the basics of the MARVELOUS project, as well as interview participating students.)

Overall, the Public Relations aspect of MARVELOUS turned out to be executed very well, and contributed to large attendance numbers at many of the outreach events.

**Student Impact and Feedback:**
Students in both the AHS and STEM Ed programs responded to informal questionnaires / prompts asking them to summarize their reactions to the MARVELOUS project and experiences relating to it. Feedback was overwhelmingly positive, largely due to the fact that students not only had the opportunity to go out into the field during inclement weather, but also because they were able to participate in a wide array of outreach events as well as operations/data collection events. Several representative undergraduate student responses appear below, separated by intended major:

*AHS majors***:**
"It was great having the DOW here. It tied in really nicely with the items we've talked about in class, and it was so cool to be able to program in our own scanning elevations, rotation rates and the like. It really made me excited to know that the data I was analyzing came from a project in which I participated."

"Thanks so much for having the DOW and PODs here! Working in a group was challenging, but it forced us to work together to plan out how we were going to deploy the instruments, and we really had to think about a lot of different factors that we hadn't thought of before. It encouraged us to think outside of the box, and that was really beneficial."

"Being in this field, we don't get a chance to go out to other schools all that much, and really not at all at the elementary level. It was so neat to see kids getting psyched about science! I loved going to the schools with the DOW and the PODs!"

"This was a great opportunity for us; thanks so much for having the instruments here! I learned a lot!"

"Using the DOW and the PODs really got me thinking about how it's not all about one type of data or another. It's often important to think about multiple levels of data and each one is interesting."

"I never thought I would get a chance to operate a DOW; that was a dream come true! I enjoyed looking at the data and trying to make sense of it as well, even with SOLOII crashing as often as it did."

*STEM Ed majors:*
"What a cool way to get out into the field and see 2nd graders really excited about science! I loved being able to answer their questions and ask them; they knew a lot. I really enjoyed this opportunity."

"I found the opportunity to go out into the schools with the DOW and the PODs really enlightening as to how kids respond to cool gadgets. It makes me think about how important it is to have multiple ways of getting information across. Having something they can climb into or twirl around made them ask more questions, which they may not have gotten just from looking at pictures in a book or on a website. I really enjoyed interacting with them – they're so smart! It really helped me see what it's like to have a classful of smart, engaged students!"

"I liked the fact that the students and the teachers were able to see 'science up close', like we've talked about in class. It helps to have the methodologies we're learning about in our classrooms play out in front of our eyes. I learned a lot about how to manage large groups of (sometimes very excited) kids in a variety of ways."

*Feedback from the local K-12 teachers and students was overwhelmingly (though perhaps unsurprisingly) positive, as well:*
"The Doppler truck was really cool! I liked seeing the videos and pictures up close." (AW, 2nd grade student)

"I got to deploy a POD, and I didn't put it on my foot. It was really neat, though. I want to study weather when I am a grown-up." (SW, 4th grade student)

"Science is awesome! I love weather! The truck was loud and the fumes were bad, but I want to go on it and look at snow and tornadoes when I get older." (TK, 2nd grade student)

"The students and I really appreciated you all taking the time to come and teach us some things about the radar. We all thought it was very cool and appreciated the opportunity to go and look inside it. It's nice to know more about how our weather is detected, since it's so crucial and important." (JD, 9th grade teacher)

"Thank you so much for coming; the kids and I loved it!" (JP, 4th grade teacher)

**Summary, Lessons Learned, Conclusions and Future Goals:**
In total, MARVELOUS was a success for the student body of the AHS and STEM Ed departments and for the general public. The interdisciplinary nature of involving students from both the AHS department as well as the STEM Ed department in the project lent itself very nicely for multiple learning opportunities for K-12 students *and* the undergraduate students in a unique educational setting and atmosphere. This is an aspect of MARVELOUS which was anticipated to be an eye-opening experience for many involved, and it was met with very positive results, as demonstrated in the student, faculty and public feedback given to the PIs.

In future educational projects, it is anticipated that there will be even more student, faculty and public interest in both the meteorological *and* educational outreach opportunities that MARVELOUS offered. For example, the National Weather Service office in Duluth, MN, has expressed interest in working with the students in the AHS department on future deployments, as having a mobile Doppler radar would provide coverage in areas not well sampled by the stationary WSR-88D; this in and of itself would be a wonderful collaboration between budding and seasoned meteorologists.

As the need for meaningful and long-lasting science- and inquiry-based education and experiences for K-12 *and* college-aged students inevitably increases, we look forward to developing and organizing more projects like MARVELOUS at SCSU in the future.

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