NSF Facilities for Education: 'TOM: Teaching flow Over Mountains'

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Summary
The rapid-scan Doppler on Wheels (DOW) radar was requested between 1 March – 15 April 2011 to be deployed in two snow storms occurring along the Colorado foothills in the vicinity of Boulder, CO. The month of March 2011 was unusually dry with no major snow storm in Boulder (Fig. 1). Only one weak storm passed over the area before the experiment ended. As a result, the rapid-scan DOW was only deployed on Sunday 3 April 2011 for 9 hours between 3pm and midnight.

This activity was a collaborative effort between the Dept. of Atmospheric and Oceanic Science (ATOC) at the U. of Colorado (CU) and the Dept. of Marine, Earth, and Atmospheric Sciences (MEAS) at North Carolina State University (NCSU). The instrument was used in the CU undergraduate courses ATOC 1050 (*Weather and the Atmosphere*) and ATOC 4500 (*Weather Analysis and Forecasting*). We had planned to use the data in the aforementioned CU courses and the NCSU course MEA511 (*Introduction to Meteorological Remote Sensing*). The light snow event obtained on 3 April was marginal so these data were not incorporated into the NCSU class. The goal of this activity was to enhance undergraduate and graduate student learning in the atmospheric sciences by providing hands-on instrument experience and data analysis for CU students, and a practical application of scan strategy design and data analysis for NCSU students.

The educational activity consisted of several parts:
- Outreach presentations giving by Drs. Kosiba and Wurman to graduate and undergraduate students at CU,
- Survey potential deployment sites, define scan strategy, forecasting weather, and organizing logistics accomplished by the PIs and CU and NCSU graduate students,
- Teaching fundamentals of "flow over mountains" and radar principles at introductory (ATOC1050) and advanced levels (ATOC4500, MEA511),
- DOW deployment on 3 April including 30 undergraduate students,
- Student projects during the deployment and homework assignments based on the fundamental concepts of flow over mountains and data collected during the TOM experiment, and
- Testing of NCAR's visualization software JAZZ using DOW radar data.

More information and material related to the TOM experiment are posted at http://rain.colorado.edu.

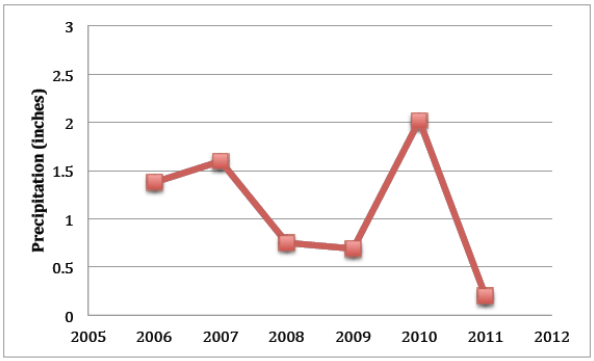

Fig. 1 Accumulated precipitation in inches in March between 2006 and 2011 observed at the CU Boulder campus.

1. Outreach presentations

One outreach presentation was given by Dr. Kosiba entitled "Doppler on Wheels observations in hurricanes and thunderstorms" on 21 February to ~300 undergraduate students in Dr. Friedrich's introductory class for non-science majors "*ATOC1050: Weather and the Atmosphere*". The talk was advertised across campus with students attending from other undergraduate ATOC classes such as Dr. Lundquist course "*ATOC4500: Weather Analysis and Forecasting*". The presentation was recorded and can be downloaded at (http://atoc.colorado.edu/~friedrik/TOM/ATOC_1050_DrKosiba_21Feb.zip).

The TOM experiment was also featured in two local Colorado newspaper articles (Daily Camera and the Colorado Daily) including interviews with CU students. The articles can be found at http://rain.colorado.edu/TOM-news.

2. Site survey, scan strategy, weather forecasting, and logistics

Surveying deployment sites and defining the scan strategy were conducted by the PIs together with the graduate students. We choose two sites, which are easily accessible from the CU Boulder campus. The graduate student Evan Kalina developed an IDL program merging scan strategy and radar beam blockage based on scan strategy. The CU undergraduate student, Carol Helfenbein, maintained the TOM website and uploaded the images and data. For her it was a great experience to see how field experiments are planned and conducted.

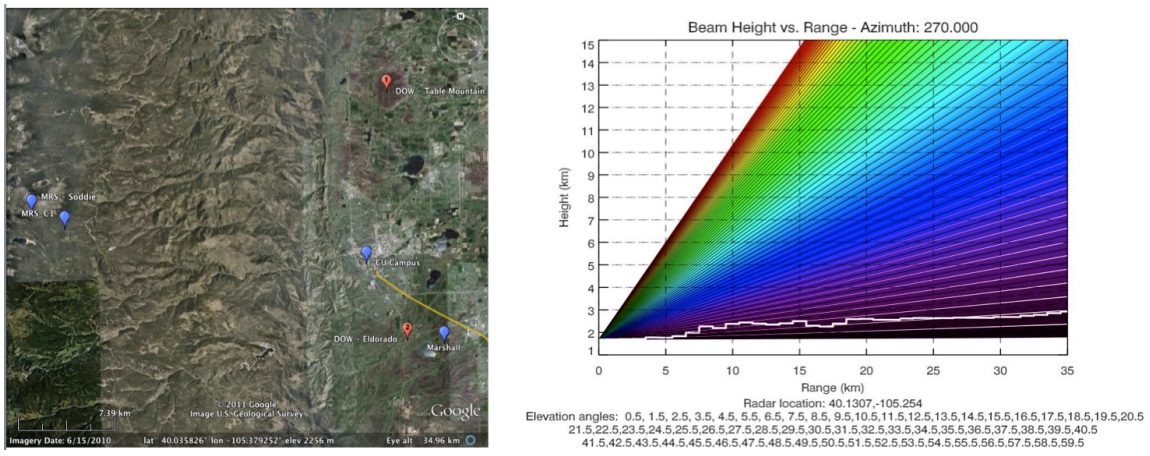

Fig. 2: Left: Google map of the potential deployment sites north (DOW-Table Mountain) and south (DOW-Eldorado) of Boulder. Location of additional instrumentation at the Mountain Research Site, CU Campus and the NCAR Marshall Field site are indicated. Right: Range-height cross-section towards the west indicating beam heights for the scan strategy LOWresTALL. Topography is indicated as white line.

The most challenging part of the TOM experiment was to forecast the location and onset of the snow storm and organize ~150 students. The students were supposed to sign up at the beginning of the semester and regularly check the web site for weather updates and announcements. Once we announced an IOP (~24 hrs prior), an email was send out and students had to sign up for a particular time slot on the Doodle calendar on a first come first serve basis. We also organized a shuttle car, which would drive students back and forth between the deployment site and the CU campus.

The snow storm forecasting was conducted by John L'Heureux, a NCSU graduate student, who sent out regular emails to the PIs. Weather forecasting was also part of the ATOC4500 course taught by Dr. Lundquist.

3. Teaching principles on flow over mountains and radar observations

ATOC1050 (lower-division undergraduate course populated by non-science majors mainly from the School of Arts and Sciences and the Business School: Radar principles and how to interpret radar observations (reflectivity and Doppler velocity) were taught as part of ATOC1050 at the beginning of the semester. Mountain meteorology and the principle of upslope snow storms in Boulder was taught in the second half of the semester. The weather situation prior to the experiment and after the experiment was discussed in class and weather maps related to the 3-April snow event were analyzed. Students' personal in-situ observations were related to weather maps and the rapid-scan DOW observations in a lecture shortly after the experiment. Slides and the online lecture can be downloaded.

ATOC4500 (upper-division undergraduate course populated by ATOC minors (Environmental Studies majors, Geography majors, Engineering majors, a Journalism student, and a Business Major): The ATOC 4500 curriculum presents principles of radar, as well as providing extensive practice in interpreting radar reflectivity and Doppler velocity. Two class periods were devoted to radar, as well as two homework assignments and one in-class exercise. The possibility of "go" conditions for the TOM experiment was discussed during the weekly weather discussion, prepared by the students.

4. Rapid-scan DOW deployment

Fig. 3: Rapid-scan DOW at the southern deployment site close to Eldorado Canyon (DOW-Eldorado in Fig. 2).

The rapid-scan DOW radar was deployed on Sunday 3 April between 3pm and midnight for nine hours during the passage of a cold front with weak upslope flow very weak snow storms. Nine groups of 3-4 CU students (total of 30 students) were responsible for taking measurements for one hour each with the Rapid Scan DOW. Originally, students were supposed to operate the radar for 2 hours. Since the TOM experiment consisted of only relatively short event, we wanted to give many students the possibility to visit the rapid-scan

DOW, and therefore maximized the number of students and minimized the time at the radar.

Dr. Kosiba and Mr. Robinson of CSWR operated the rapid-scan DOW during the deployment and were available to answer specific questions and help the students to master the assignment. The assignment which the students were to finish at the radar site consists of problems related to radar observations and scanning strategy, e.g., reflectivity and velocity signatures of ground-clutter versus weather signal, height of radar beam and radar resolution. The assignment and an instruction sheet can be downloaded from the TOM web site (http://rain.colorado.edu/TOM-teaching). Links are located at the bottom of the page under attachments (see TOM-worksheet.pdf and Instructions-TOM-worksheet.pdf).

Fig. 4: Dr. Kosiba and CU undergraduate students inside the radar truck during the deployment on 3 April.

5. Student projects and homework assignments

ATOC1050 (lower-division undergraduate course designed for non-science students): An extra credit homework was offered to the students who could not participate in the radar deployment. Out of ~260 students about 110 students submitted the extra credit homework assignment. The homework covered topics related to signatures of ground clutter and weather in the reflectivity and Doppler velocity field, interpreting radar observations, principles of upslope storms in Boulder, radar resolution, and relating the rapid-scan DOW observation to other instruments (surface observations, Denver NSR radar, Denver sounding). The homework assignment and an instruction sheet can be downloaded from the TOM web site (http://rain.colorado.edu/TOM-teaching). Links are located at the bottom of the page under attachments (see Exercise-TOM-ATOC1050-SS2011.pdf and Exercise-TOM-ATCO1050_SS2011_key.pdf).

6. Uploading data and visualizing radar data using JAZZ

The data collected during the TOM experiment are available online at http://rain.colorado.edu/TOM-data. The data include DOW radar observations and auxiliary data from instruments in the vicinity (Fig. 2). The auxiliary data consists of observations from the WSR-88D at Denver, Denver sounding, microwave rain radar, radiometer, ceilometer, surface stations, and disdrometers. Images and raw data files are posted on the website and were used in the classes.

A key requirement for NCSU participation was the availability of web-based data perusal images containing individual elevation angle PPIs and individual azimuth angle RHIs within 24 hours

after data collection. Prior to the radar deployment, a chain of how the large amount of rapid-scan data can be efficiently downloaded, navigated and quality-controlled, uploaded onto a web server, and visualized by using the NCAR's JAZZ software was developed by Dr. Wurman (CSWR) and Michael Dixon (NCAR) together with the PIs.

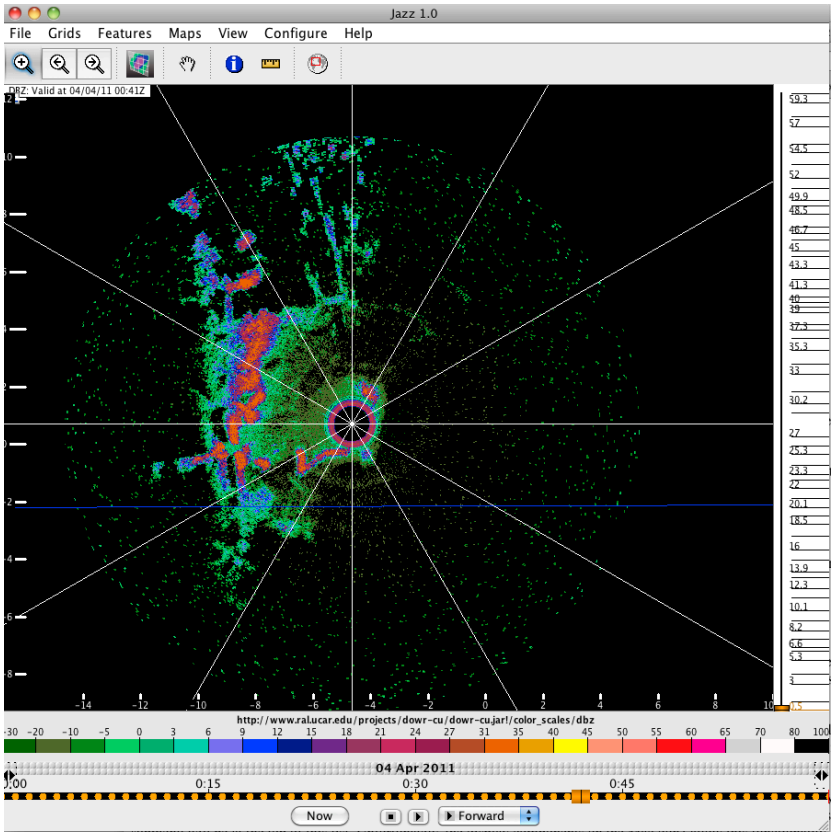

Fig. 5: NCAR's JAZZ radar display showing the TOM radar reflectivity at 0030 UTC on 4 April 2011.

After the deployement, CSWR downloaded and navigated the data, which were uploaded within 2 days onto the NCAR server. The radar data were available for the students ~3 days after the experiment. The JAZZ software is easy to use with little training needed. To launch Jazz for the TOM experiment go to http://www.rap.ucar.edu/projects/dowr-cu/. While the PIs like the JAZZ visualization software, we feel that the JAZZ software runs relatively slow especially when displaying time series of reflectivity and Doppler velocity.

7. Lessons learned and student comments

- We found the radar deployment very beneficial of any kind of student such as non-science and atmospheric science graduate and lower and upper undergraduate students. It is a great opportunity.
- CSWR was very helpful in assisting with the site survey and radar operations. Although, the facility request stated operations only to be conducted Monday through Friday during university hours, CSWR staff was very support to operate the radar during the only possible case which occurred on Sunday afternoon until midnight. CSWR was very efficient in downloading the large amount of data and navigated and quality controlled the data within a few days. They did an amazing job educating the students during the deployment.
- Running the education project for the first time beside the regular teaching responsibilities is very time consuming. Since the several major components (e.g., site survey, scan strategies, and logistics) are in place, we would like to repeat the experiment.
- Most of the non-science and non-meteorology undergraduate students know the DOW radars and Dr. Wurman from his television appearance. Students were very excited to

learn that Dr. Wurman and the radars are stationed in Boulder and that the students have the possibility to visit the radars.

- Students liked the extra credit especially with a real-life application. They enjoyed gaining additional knowledge in specific field.
- JAZZ software is very easy to operate and suitable for students. Data are uploaded on an NCAR server and can be used anyone.

Recommendations:

- To would be nice to have a central NSF education facility web site where PIs can get help and ideas about deployments, student projects, homework assignments etc.
- In order to better assess the gained knowledge a standardized set of survey questions could be developed to assess general learning goals for various levels.
- JAZZ is a great tool to visualize radar data at a very basic level. We would recommend that NCAR support the software development and maintenance.

Student comments:

John L'Heureux (NCSU): "Even though I have previous experience forecasting snow events for the southern Appalachian Mountains, forecasting snow events for the eastern Rockies proved to be very challenging. During this project, I learned the importance of atmospheric stability (east of the Rocky Mountains) and the importance of moisture flow approaching the eastern slopes of the Rocky Mountains."

Courtney Stafford (ATOC1050, CU): "I really enjoyed the TOM experiment, and I think it really gave me a much better perspective on how the processes work. I'm definitely a hands on learner, and it really gave me a much better understanding, rather than just sitting in a classroom learning it off of a powerpoint. I'd definitely recommend that it be used again if possible! "