Hawaiian Educational Radar Opportunity (HERO) Final Report

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Summary

A three-week educational deployment of a polarimetric Doppler on Wheels (DOW) radar was conducted at the University of Hawai'i at Manoa (UHM) from 22 October - 13 November 2013. The educational deployment of a mobile radar was the first of its kind in Hawai'i and on the island of O'ahu. The central focus of the Hawaiian Educational Radar Opportunity (HERO) was to give undergraduate and graduate students at UHM an opportunity for an intensive, hands-on radar education period. The deployment coincided with the first UHM offering of MET 628 "Radar Meteorology", which had an enrollment of 12 graduate students who led 16 intensive observing periods (IOPs) with the DOW. A total of approximately 50 participants including graduate students, undergraduate students, and National Weather Service (NWS) forecasters participated in radar training, forecasting, weather balloon launches, and radar deployments around the island. Three special course lectures and two Department seminars from renowned radar experts helped to augment the educational impact of the project. Extensive outreach to the community was also conducted, including a School of Ocean Earth Science and Technology (SOEST) Open House event with over 7,500 visitors from local K-12 schools and the public, a deployment visit from a school for students with learning disabilities, and positive radio, television, and newspaper media coverage.

1 Introduction

The Hawaiian Islands have frequent tropical rain events, ranging from light trade wind showers to heavy orographic and synoptically forced rain and flash-flooding. O'ahu is a relatively small (71 x 48 km) island in the state, but has significant mesoscale variability in rainfall due to the complex terrain of the Ko'olau and Wai'anae mountains. Doppler radar is one of the only meteorological tools available that can probe the three-dimensional precipitation and wind structure of tropical clouds, showers, thunderstorms and tropical cyclones with adequate spatial and temporal resolution to observe this variability. The island is located between two NWS Weather Surveillance Doppler (WSR-88D) radars located on Kaua'i and Moloka'i, but the distance from those islands limits the ability to observe precipitation below 1 km altitude and at sufficiently high spatial resolution for some research purposes. There is no permanent Doppler radar on O'ahu, despite the rainfall variability over a population of nearly one million people. Research radars also do not routinely visit the Hawaiian islands due to the distance from the mainland United States.

The importance of radar technology to both research and operational weather forecasting has continued to grow over the years, especially with the recent polarimetric upgrade of the WSR-88Ds completed in Spring 2013. While radar observations are included in many courses at UHM, a dedicated course on this principles and application of this technology was not available until Fall

2013 with the advent of MET 628 "Radar Meteorology". As part of the inaugural offering of MET 628, a National Science Foundation (NSF) Educational Deployment of the DOW was requested in order to maximize the educational value of the course. The deployment also offered an opportunity to provide field and forecasting experience for interested undergraduate students, and allowed for broad exposure for the NSF facility to the public, including non-major UHM students and K-12 students. Native Hawaiians and Pacific Islanders are underrepresented in the atmospheric sciences, and the chance to tour a high-tech weather radar was an exciting experience for several thousand Hawaii residents.

This report summarizes the main activities conducted during the HERO project. The integration with MET 628 and other UHM educational activities are described in Section 2. A description of the SOEST Open House and other outreach events are presented in Section 3. Section 4 summarizes the field operations, including the number of participants in each IOP. Lessons learned during the deployment and concluding remarks are presented in Section 5.

2 Education Integration

The HERO Educational Deployment featured three main avenues to integrate the hands-on experience provided by the DOW radar visit: 1) Strong integration with MET 628 for graduate students, 2) Field planning, deployment, and forecast experience for graduate and undergraduate students, and 3) public education and outreach.

2.1 MET 628 Radar Meteorology

"Radar Meteorology" is a new graduate level course at UHM to teach students the history, theory, hardware, and practical use of radar for meteorological applications. During this course students developed skills in understanding, interpreting, and using radar observations for meteorological research and operational forecasting. MET 628 is an elective 3-credit course, and had 12 enrolled students during the Fall 2013 semester. An additional 3 students audited the course. The MET 628 students were principal investigators (PIs) for HERO, and handled all radar operations and deployments under the advisement of the lead PI/Professor Michael Bell.

The first 8 weeks of class were dedicated to foundational material designed to prepare the students for the arrival of the DOW. This material covered weather radar hardware and technology, the theory of polarimetric electromagnetic wave propagation, scattering, and attenuation, the radar equation for distributed targets, and introduction to polarimetric variables. Weekly radar labs were conducted for practical experience performing radar calculations and using past DOW data in radar software such as the NCAR Solo program. The course also coincided with the biannual American Meteorological Society Conference on Radar Meteorology, which allowed the students to read extended abstracts covering the latest in radar research. A mid-term exam was given just prior to the arrival of the DOW and the start of the HERO project.

Once the DOW arrived on 21 October, the material shifted to present more specialized material relevant to the project, including mobile radar applications, quantitative precipitation estimation, and single Doppler wind retrieval techniques. A DOW training day was conducted on 22 October for MET 628 students at a public park near the UHM campus. The students each received a 1.5 hour hands-on training session from Karen Kosiba and Ab Pfeiffer in separate groups of 3. Course lectures continued during the HERO project, with several guest lectures during that time.

Dr. Wen-Chau Lee, Senior Scientist and Manager of NCAR/EOL's Remote Sensing Facility, visited UHM from 22 October - 14 November. Dr. Lee's visit to share his expertise in radar and tropical meteorology was of great benefit to HERO. He participated in the SOEST Open House

educational outreach activities and in all aspects of HERO, including data collection during several IOPs. In addition, his expertise in radar data processing was used to help train local students and maximize the utility of the HERO dataset. Dr. Lee gave a Departmental seminar and two lectures on single Doppler wind retrieval techniques in MET 628, and participated in a course lab period. He also was part of a live radio show on Hawaii Public Radio discussed in the outreach section below. His visit was primarily supported by the UCAR University Visits in Scientific Interaction and Teaching (UVISIT) program, with cost-sharing from the PI.

Dr. Jeff Keeler, Senior Radar Engineer formerly at NCAR and currently at Advanced Radar Corporation, visited UHM from 30 October - 4 November. Dr. Keeler participated in a HERO IOP, and gave a guest lecture on antenna patterns in MET 628. He had meetings with students interested in more technical details of radar meteorology.

Dr. Karen Kosiba and Dr. Josh Wurman from the Center for Severe Weather Research (CSWR) visited during the HERO project. Dr. Kosiba helped train the MET 628 students on radar operations, assisted in the first site survey on the windward coast, and helped with the first two IOPs. Dr. Wurman assisted in the second site survey in the central valley and helped with the second IOP. The CSWR scientists also gave a joint seminar on the use of DOW data in tornados and hurricane research. Photos of the visiting scientists are shown in Fig. 1.

After the HERO project was over, additional course material on dual-Doppler techniques, radar data assimilation, satellite radars, and clear air, thunderstorm, and hurricane applications was presented. The students turned their attention to the exceptional dataset collected for their final research papers and class presentations. A wide variety of research topics were selected from the different IOPs, with the titles for each project listed in the appendix. The timing of the HERO deployment during the middle part of the semester proved to be advantageous for both weather and the course layout. Students had received enough of the radar fundamentals to be prepared for the DOW arrival, and had enough time at the end of the semester to conduct preliminary analyses using the collected dataset.

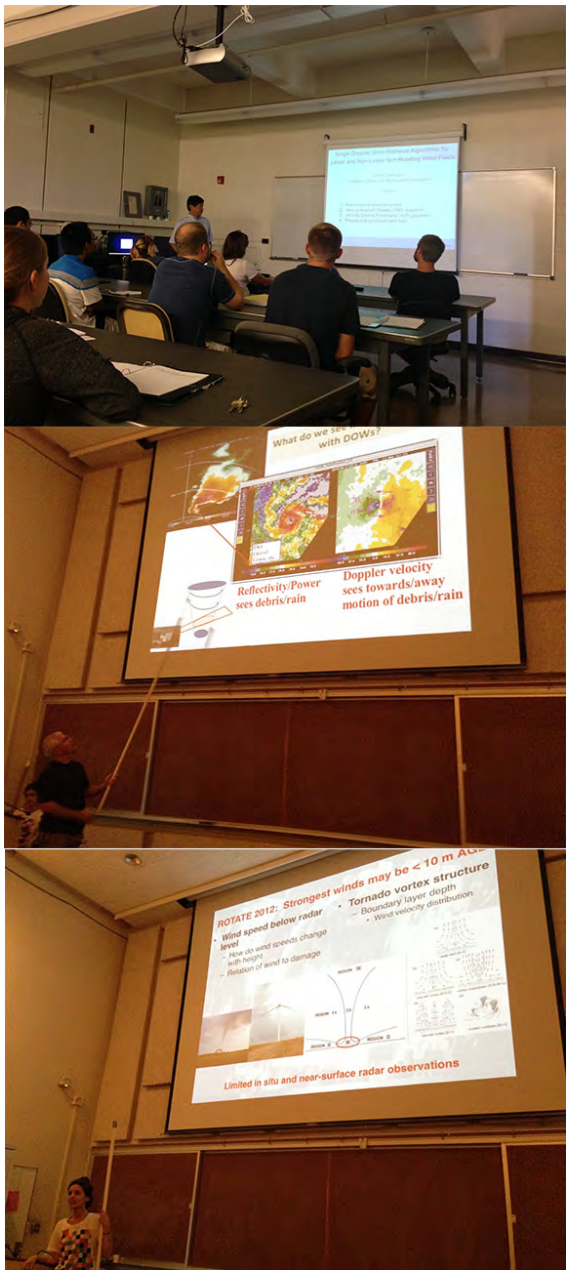

Figure 1: *Photos of (a) Dr. Wen-Chau Lee in MET 628, (b) Dr. Joshua Wurman, and (c) Dr. Karen Kosiba in a Department Seminar.*

2.2 Weather Forecasting

A key component of HERO was accurate forecasting of the weather conditions and targeted precipitation forecasts. The University of Hawai'i is a unique institution that has both a graduate and undergraduate Meteorology program, and has the local NWS Weather Forecast Office (WFO) collocated on campus. The Central Pacific Hurricane Center is also collocated in the NWS Honolulu office. One of the successes of HERO was the opportunity for students to improve their tropical forecasting skills under the guidance of skilled NWS forecasters.

A daily forecast briefing and operations meeting was conducted in the Meteorology Department classroom at 9:00 am local time. Four person forecast teams were organized prior to the project for 6-day shifts each. A list of the forecast participants is shown Table 1, with an approximately equal number of undergraduate and graduate students. The 6-day shifts enabled continuity and learning in the forecasts without overburdening the students for the whole project. Each team would meet at 8:00 am to prepare the forecast, and would be joined by a NWS forecaster at 8:30 for advice. This arrangement worked very well, and both the student and NWS forecasters spoke highly of the positive benefits of the collaboration.

Each daily meeting started with a 15-minute weather briefing for rainfall placement on or near Oahu during the next 48 hours, with an outlook for any potential major events out to approximately 5 days. After the weather briefing, a discussion on operations was conducted amongst the PI, students, and NWS personnel. Despite the prevailing notion that the weather is always the same in the tropics, the weather variability and forecast difficulties proved both enlightening and challenging. The timing of precipitation proved to be especially challenging due to mesoscale variability that was not captured by numerical weather prediction models in our data sparse region. The ability to have real assets like the DOW to deploy added a significant value to the forecast discussions. Unlike typical student exercises where there is a low penalty for a busted forecast, the decision to call for a real mission at 4 am local time was not taken lightly by the students. The variety of weather observed ultimately turned out to be quite exceptional for the project period, and allowed for a good range of forecast conditions and testing of numerical model skill in Hawai'i.

10/21-10/26	Danny (U)	Anthony (U)	Vanessa (G)	Andre (G)
10/27-11/01	Magnus (U)	Brandon (G)	Yu (G)	
11/02-11/07	Naufal (U)	Rachel L. (U)	Xiaomin (G)	Annette (G)
11/08-11/13	Rachel J. (G)	Kelly (U)	Liye (G)	Tom (G)

Table 1: *Student forecast teams. 'U' and 'G" indicate undergraduate and graduate students, respectively.*

3 Public Education and Outreach

Another key aspect of HERO was public education and outreach for the local people of O'ahu. Like most places in the U.S. the weather is a common topic of conversation and plays an important role in daily life. Even though the tropical weather in Hawai'i is usually benign, the conditions can quickly change due to the potential for flooding or severe weather any time of the year. Hurricanes such as Iniki (1992), while uncommon in the islands, have also caused significant damage in the past. It was important to showcase the DOW and NSF facilities, and their role in improving our understanding of severe weather, to the local K-12 students and their families.

The timing of the HERO project was adjusted in order to take advantage of a significant Open House outreach event conducted on the UHM campus biannually. The SOEST Open House consisted of a two day Friday and Saturday event, with the first day primarily for K-12 students, and the second primarily for families. The event has grown every two years, and the 2013 event was no exception. Exciting science booths, exhibits, and games from across the geosciences were on display, ranging from Oceanography, Geology, Space Science, to Meteorology.

An estimated 5,300 visitors attended the event on the first day, consisting mostly of organized K-12 school groups from around the island. The DOW was parked near the center of the exhibits, and had a phenomenal attendance from the visiting groups. A steady stream of young students toured the DOW as the monitors displayed data from previous tornado and hurricane deployments. The local newspaper and television media also visited the DOW. The PI, Dr. Lee, graduate student volunteers, and CSWR staff answered questions from 8 am - 2 pm on Friday.

On Saturday, an estimated 2,300 visitors attended the event, consisting mostly of families with school-aged children. The HERO team answered more detailed questions from the groups and families who were able to stay longer at the exhibit on this day. Many of the young students asked insightful questions about the radar, the weather pod, and weather balloons on display. A total of 7,600 visitors attended the two-day event, and it was estimated that most of them visited the DOW to at least stop for a moment and take a picture. A significant fraction of the visitors spoke with one of the HERO representatives, and most of those visitors went inside the truck for a quick tour. The response from the University and SOEST was very positive, and it was clear that the DOW was one of the showcase exhibits. It is hoped that the exhibit encouraged some young students to pursue careers in atmospheric science, geoscience, or other science and technology field.

Figure 2: *(a) Photo of students waiting to tour the DOW at the SOEST Open House and (b) photo from the Honolulu Star-Advertiser*

In addition to the Open House, the PI did several media interviews during the project. Links to the media coverage are listed below. In particular, both the Hawaii Public Radio interview with the PI and Dr. Lee, and the Hawaii News Now television story on the DOW and weather balloon launch were well done. Photos of the Open House event are shown in Fig. 2, including a picture from the Hawaii Star Advertiser newspaper. As will be discussed further in the lessons learned, positive media coverage turned out to be crucial to gaining support of the locals for weather operations in public areas.

An additional outreach event was conducted during one of the IOPs for visiting students from the Variety School of Hawaii that educates children with learning disabilities, attention deficit disorder, and autism. 8 middle school students and 2 teachers visited the radar at Manoa Park

to ask questions and help launch the weather balloon. The experience was great for the students, and they built a "weather wall of thunder" with drawings and pictures at their school after the event.

Hawaii News Now:
http://www.hawaiinewsnow.com/story/24046540/high-tech-doppler-radar-cruises-islands
Hawaii Public Radio:
http://www.bytemarkscafe.org/2013/11/13/episode-274-doppler-on-wheels-nov-13-2013/
KITV:
http://www.kitv.com/news/hawaii/mobile-weather-radar-in-hawaii-for-1st-time/-/8905354/22663592/-/vacd2pz/-/index.html
UH News:
http://www.hawaii.edu/news/article.php?aId=6078
Hawaii Star-Advertiser newspaper:
http://www.staradvertiser.com/multimedia/photo_galleries/Island_Images_Oct_2013.html?photo=10

4 Field Operations

IOPs were targeted to be centered on 1800 or 0000 UTC for approximately 6 hours on station. On station times therefore typically started at 5 am or 11 am local. There were 4 DOW radar teams named after radar variables: KDP, Doppler, dBZ, and ZDR, shown in Fig. 3a. Teams were assigned on a rotating schedule based on availability, such that all MET 628 participants had at least 3 missions with the DOW. Support teams accompanied the truck in private vehicles to assist with radiosonde launches, and to observe and learn the DOW radar operations. The support teams consisted of a combination of undergraduate and graduate students and NWS personnel. 17 sites around O'ahu were identified to observe different types of weather conditions as part of a course lab assignment on radar beam height. These sites were then refined based on site surveys conducted with CSWR personnel to ensure adequate clearance for the DOW and limited ground clutter, shown in Fig. 3b. The primary area of operations was on the windward side of O'ahu to observe trade wind showers, with scientific interests on orographic forcing and warm rain precipitation processes. The Manoa Valley Park site was used for training and to document the changes in trade wind showers as they cross the Ko'olau range. Investigation of which clouds survive and continue to rain on the leeward side or dissipate was of interest. The

HERO Deployment Summary

		KDP	Doppler	ZDR	dBZ	Teams Available
Sunday	Morning	KDP	Doppler			2
	Afternoon	KDP	Doppler	ZDR		3
Monday	Morning		Doppler	ZDR		2
	Afternoon		Doppler			1
Tuesday	Morning	KDP			dBZ	2
	Afternoon	KDP		ZDR	dBZ	3
Wednesday	Morning		Doppler	ZDR		2
	Afternoon		Doppler	ZDR		2
Thursday	Morning	KDP			dBZ	2
	Afternoon	KDP			dBZ	2
Friday	Morning		Doppler	ZDR	dBZ	3
	Afternoon		Doppler		dBZ	2
Saturday	Morning	KDP		ZDR	dBZ	3
	Afternoon	KDP		ZDR	dBZ	3
		Mark	Gary	Alyssa	Tom	
		Andre	Andrew	Feng	Liye	
		Annette	Shannon	Bob	Vanessa	
		Kavina (Backup)	Yu-Du (backup)	Brandon (back-up)		

Figure 3: *HERO Deployment teams and schedule used for IOP*

primary site in the Central Valley was near Wahiawa for terrain and diurnally induced circulations, particularly those that led to heavy thunderstorms over the Waianae and Ko'olau ranges. That site was preferred on weak trade wind days when a sea breeze and inland convection were expected.

A decision on the operations site was made one day in advance at the daily meeting. The radar operations team was also selected, along with volunteers for the support team. Typically the support team would arrive one hour after the DOW, and begin sounding procedures.

Radiosondes, balloons, and helium for use with the Department's InterMet sounding system were purchased by the PI for the project. A total of 14 radiosondes were launched during the 16 IOPs. The soundings were a critical component of the deployment to provide thermodynamic context for the radar observations, since operational soundings are not launched on O'ahu. The weather balloon launches were also an important part of the educational integration, since they allowed undergraduate students to productively contribute to each IOP. Radiosonde data was also sent in real time to the WFO at the NWS, and to the National Center for Environmental Prediction (NCEP) in the latter part of the project. Since operational soundings are only launched twice a day from neighbor islands, the local soundings provided valuable information for the forecasters to aid in decision making and weather watches and warnings.

Figure 4: *Photos of (a) students collecting data at Kahalu'u and (b) launching a radiosonde at Kualoa Ranch*

A combination of PPI and RHI scans were used to observe clouds and precipitation. A variety of different scan modes were used depending on the desired range, velocity, and spatial resolution. A "playbook" in the Operations Manual contained the different scan modes, with selection of the appropriate mode guided by the PI, Dr. Lee, and CSWR staff during the project. However, the ultimate decision on which mode to use, and the angles used in the PPIs and RHIs, rested with the MET 628 students. The ability, and responsibility, to make choices about the scan strategy proved to be a powerful teaching tool. Photos of the students from two of the deployments are shown in Fig. 4, and a summary of the IOPs is shown in Table 2. A description of each IOP is given below, with additional details available in the mission reports at `http://www.soest.hawaii.edu/MET/Faculty/mmbell/HERO`

4.1 IOP 1: Kahalu'u Wet Trade Wind Showers

Number of participants: 8
Start of Mission: 24 October 2013 1510 UTC
End of Mission: 24 October 2013 2040 UTC

The first mission forecast called for weak trade wind regime with little synoptic forcing and

IOP	Date	Start	End (UTC)	Event	Participants
1	24 Oct.	1510	2040	Kahalu'u Wet Trade Wind Showers	8
2	27 Oct.	1952	0130	Wahiawa Sea-breeze Thunderstorms	9
3	29 Oct.	1514	2017	Kahalu'u Weak Trade Wind Showers	9
4	30 Oct.	1824	2255	Fishpond Moderate Trade Wind Showers	9
5	31 Oct.	1519	2228	Kahalu'u Tropical Squall Lline	6
6	1 Nov.	1513	2011	Makapu'u Offshore Trade Wind Showers	8
7	3 Nov.	1514	2017	Kahalu'u Orographic Showers	10
8	4. Nov.	1550	2204	Kahalu'u Cold Air Aloft	5
9	5 Nov.	1521	1818	Pali Lookout Weak Trade Winds	3
10	7 Nov.	200	0200	Wahiawa Sea-breeze Convection	6
11	8 Nov.	1527	2116	Kualoa Ranch Weak Trade Winds	8
12a	10 Nov.	0400	1200	Wahiawa Cold Frontal Passage "A"	8
12b	10 Nov.	1200	1949	Wahiawa Cold Frontal Passage "B"	9
12c	10 Nov.	1949	0153	Wahiawa Cold Frontal Passage "C"	8
13	12 Nov.	1615	2119	Manoa Valley Post-frontal	3 + 10
14	13 Nov.	1535	1803	Kualoa Ranch Cumulus Clouds	4

Table 2: HERO Deployment Summary

lower than average boundary layer moisture. Chances for precipitation were best early morning and would most likely result from topographical forcing on the windward coast with a chance of land breeze trade wind convergence resulting in showers off shore. The DOW Radar was deployed to Kahalu'u Regional Park on the windward coast. Upon arrival there was a band of precipitation offshore of Kaneohe and Kailua with overcast skies along the windward coast and shallow trade cumulus further offshore. The wind direction from the mast showed westerly winds suggesting downslope flow.

Despite the marginal forecast, showers developed anchored to the mountain summits producing locally heavy rain early on. Shower intensity abated and then became scattered, with a rain band near Kaneohe that remained stationary for some time. Near the end of the mission, some isolated echoes from the central valley appeared. Problems with the laptop used for soundings prohibited a radiosonde launch. The abundant echoes allowed for an interesting time-mean composite used to investigate orographic wind enhancements by Ms. Foerster (see Appendix for student project titles).

4.2 IOP 2: Wahiawa Sea-breeze Thunderstorms

Number of participants: 9
Start of Mission: 27 October 2013 1952 UTC
End of Mission: 27 October 2013 0130 UTC

The dominant feature for this IOP was forecast to be a surface ridge over the main Hawaiian Islands, with a cold pool aloft associated with a nearby upper level low. Southerly flow over the island the day before had advected higher than normal boundary layer moisture over the island, also contributing to the higher than normal instability. Deep convection was expected to develop over the central valley of Oahu during the afternoon due to a combination of sea breeze convergence and upslope flow in a light synoptic flow pattern, and a moist boundary layer. Colder than normal temperatures in the middle levels of the atmosphere due to the upper low also contributed to the instability. The Central Valley location was chosen as the deployment site based upon the tendency for sea breeze convergence to incite convection in the surrounding region.

The DOW was deployed in a dirt parking lot off of Kaukonahua Road in Wahiawa, just east of

the Schofield Barracks. Towering cumulus accompanied by showers were already occurring at the site upon arrival time. During the late morning hours several cells of deep convection developed near the radar site, with thunder being heard at the site by 2208 UTC. At 2211 UTC, outflow from the thunderstorm to the west of the radar reached the DOW wind instruments, with a wind speed of 8.4 m s^{-1}. Short-lived ordinary-cell deep convection continued to develop and dissipate over the central valley and nearby mountains throughout the afternoon.

Despite the weak synoptic forcing, this day produced the deepest convection of the HERO project. The radiosonde launch was successful, although no humidity data was obtained due to a failed sensor. Mr. Ballard investigated the differences between the electrified convection on this day and weaker sea-breeze driven convection on 4 November. Mr. Frambach performed a hydrometeor classification on the thunderstorms from this day.

4.3 IOP 3: Kahalu'u Weak Trade Wind Showers

Number of participants: 9
Start of Mission: 29 October 2013 1514 UTC
End of Mission: 29 October 2013 2017 UTC

Forecasting products showed a transition from southerly flow into a trade wind shower regime. Remnant moisture from Sunday's storm provided for a forecast of moist trade showers, especially on the windward and Mauka side of Oahu. The best chance of precipitation was early in the morning as the diurnal radiation tends to favor convection at that time.

The radar was deployed at the Kahalu'u Regional Park. Upon arrival at the site location there were a few tradewind cumulus clouds offshore and some clouds forming over the mountain ranges. Winds were very light, and the clouds over the area cleared out for a bit. A few sprinkles did occur around 8 am but other than that the tradewind showers that were expected were very light and showers were scarce.

The radiosonde was successfully launched at 1645. The launch ended around 1840 and captured a trade wind inversion around 850 mb, weak winds, and a lack of moisture in the upper levels that helped explain why the trade wind showers did not develop as much as anticipated.

4.4 IOP 4: Fishpond Moderate Trade Wind Showers

Number of participants: 9
Start of Mission: 30 October 2013 1824 UTC
End of Mission: 30 October 2013 2255 UTC

The mission forecast called for weak to moderate trade wind shower activity, with conditions favoring precipitation more likely to occur during the morning hours. These showers were expected to gradually dry up as the mission progressed. In actuality, the trade winds continued throughout the deployment but the sky later cleared, with a brief but notable shower passing over at 2015 UTC. The radar was deployed on the windward coast at the Waikalua Lo'ko fish pond with the truck facing almost due east. The shallow trade wind cumulus that were present over the land at and around the mission site gradually decreased in coverage offshore throughout the morning. Some light showers were already existing while others formed nearby.

The launch of the radiosonde was initially delayed as we were waiting for the news crew to arrive, but was successfully launched at approximately 2100. Due to failure of the humidity sensor, however, no moisture data was able to be recorded throughout the entire flight. Data was retrieved

up to a height of about 19 km before the recording was ended as the mission was complete and the sonde was already well into the stratosphere.

A Hawaii News Now television crew visited the radar and filmed the radiosonde launch. More details on the news coverage are listed in the outreach section.

4.5 IOP 5: Kahalu'u Tropical Squall Line

Number of participants: 6
Start of Mission: 31 October 2013 1519 UTC
End of Mission: 31 October 2013 2228 UTC

The forecast was for enhanced convection overnight along the Ko'olaus, and a slight chance for trade wind convection through the day in a weak trade wind regime. The radar was deployed to Kahalu'u Regional Park on the windward coast. Upon arrival there was a short period of heavy precipitation, which was not recorded because it ceased before operations began. When operations began there were showers along the Ko'olaus as well as cells of convection offshore. Shower activity decreased through sunrise at which point the radiosonde was launched, which recorded good data up to 7 km altitude. Quiescent conditions followed until an area of scattered convection moved into range north of Moloka'i. This area was tracked for the remainder of the mission as it approached O'ahu and organized itself into a squall line. Mr. Pattantyus performed a dual Doppler analysis on this squall line to investigate the structure.

4.6 IOP 6: Makapu'u Offshore Trade Wind Showers

Number of participants: 8
Start of Mission: 1 November 2013 1513 UTC
End of Mission: 1 November 2013 2011 UTC

The mission forecast called for a relatively weak pattern of trade wind showers, with moderate trade winds resulting in some orographic lift over a shallow layer. Limited moisture and a relatively low inversion would limit the vertical depth and coverage of the activity. A weak trough aloft was over the islands but did not do much to enhance shower activity in the morning. Additional showers, associated with a weak trough in the low level flow, approached the site during the afternoon, but this was after the completion of this IOP. The DOW was deployed to Makapu'u Beach Park on the windward shore, an area good for looking at undisturbed trade wind conditions offshore. Upon arrival there were scattered showers offshore, mostly beyond 60 km from the radar. Most of the showers dissipated during the course of the morning with only brief very light rain occurring at the DOW during this IOP. The vast majority of the time, it was rain-free near the DOW site. After an initial launch error, a second good sounding was released that recorded data up to 20 km altitude.

4.7 IOP 7: Kahalu'u Orographic Showers

Number of participants: 10
Start of Mission: 03 November 1514 UTC
End of Mission: 03 November 2017 UTC

There was an upper level low with a cold pool forecasted to move close to the northwest region of the Hawaiian Islands. Moisture forecasts showed some pockets of moisture coinciding with this cold pool giving way to unstable conditions favorable for convective rain on the windward areas of

O'ahu. Inland areas were also favorable for some convection, however, the 1200 sounding did not show as much moisture available to deploy inland to the Wahiawa site. The radar had a planned deployment to the fish pond but was redirected to the Kahalu'u Regional Park because we were unable to unlock the outer gate on the weekend. A different location in the park was chosen to minimize generator noise for the locals on the weekend. A few short lived trade showers came through, and some orographically anchored clouds were seen along the mountains. Later there were some showers observed offshore to the northeast, followed by a more sensitive scanning strategy was used to capture the orographic lifting and nearby showers in higher detail. A good sounding was launched, with the balloon released by a local middle school student. Mr. Robinson investigated the orographic enhancement by the concave mountain cirques using this dataset.

4.8 IOP 8: Kahalu'u Cold Air Aloft

Number of participants: 5
Start of Mission: 4 November 2013 1550 UTC
End of Mission: 4 November 2013 2204 UTC

The forecast for this IOP was moderate trade winds with increased instability due to a cold pool aloft. An upper level low was approaching the islands from the northeast and was expected to allow for some increased convection. Deep trade showers were expected on the Windward coast and in the Ko'olau. There was a brief shower at the site at 1645 UTC and again at 1813 UTC. Most of the morning had small scattered showers offshore with some building as they approached the mountains. Conditions became increasingly dry as the day went on. Although the upper-levels were colder than usual, the instability and moisture was not enough to allow for deep convection as was hoped for. A sounding with a failed humidity sensor collected data up to 26 km altitude.

4.9 IOP 9: Pali Lookout Weak Trade Winds

Number of participants: 3
Start of Mission: 05 November 2013 1521 UTC
End of Mission: 05 November 2013 1818 UTC

The mission forecast called for weak instability persisting from the weekend with weak trade winds. The DOW radar was deployed to Pali Highway Lookout on the windward side of the Pali tunnels. The extremely close proximity to the Ko'olaus limited viewing to the west. No support team was deployed due to the early morning start time and limited space at the Pali Lookout location. Initially, there was isolated convection offshore, and new cells began to develop over the coast of Kailua and Waimanalo and moved inland near 1600 UTC. Showers developed along the Ko'olaus as rainband movement was blocked by the terrain. While adjusting the scan strategy to look further offshore, the transmitter failed and the mission ended abruptly at 1818 UTC.

4.10 IOP 10: Wahiawa Sea-breeze Convection

Number of participants: 6
Start of Mission: 7 November 2013 2000 UTC
End of Mission: 8 November 2013 0200 UTC

This mission occurred during a moderately vigorous afternoon convective pattern. A light southerly synoptic background flow allowed moderately deep convection to develop over the interior

and north shore of O'ahu. While no thunder was reported on Oahu this day, several team members did note possible rotation near cloud base to the northeast of the site during the mission. It is not uncommon for funnel clouds to form at the base of vigorous deep convection on days with light winds and strong sea breeze convergence over central O'ahu. The radiosonde was successfully released at the site at 2034 UTC. However, there appeared to be problems with the data below about 950 meters before the data quality appears to improve, and the radiosonde data stopped at a height of 6.6 km.

4.11 IOP 11: Kualoa Ranch Weak Trade Winds

Number of participants: 8
Start of Mission: 8 November 2013 1527 UTC
End of Mission: 8 November 2013 2116 UTC

A shallow trough aloft and to the east of Hawaii island chain along with low level moisture transported through the trade wind inversion layer created some instability in the 1200 UTC Lihue sounding. Synoptically the potential for convection was favorable but the level of free convection was near 800 m above ground due to some dry air being advected near the surface. It was expected during the course of the morning this convective inhibition would give way or the trade winds would be strong enough to produce some orographic enhanced convection on the windward side. The radar site was located at the Kualoa ranch, with the truck parked on horse pasture which provided an open area. The truck faced to the north into the mountain range ahead of us. Upon arrival and generally throughout the day cloud development was observed over the Ko'olaus with a few quick showers over Kaneohe. The sounding reported data to the tropopause, and skies during the launch were clear enough to see the balloon rise to nearly 500 mb.

4.12 IOP 12a: Wahiawa Cold Frontal Passage "A"

Number of participants: 8
Start of Mission: 10 November 2013 0400 UTC
End of Mission: 10 November 2013 1200 UTC

The forecast for this IOP was heavy rain with increased instability due to a cold pool aloft. A cold front was approaching the islands from the north and expected to bring unsettled weather with the chance for thunderstorms. The timing of the front was uncertain, but a line of convection ahead of the front approached the islands from the north. Similar lines of convection could be seen on the eastern side of almost all main Hawaiian islands, associated with lee-side convergence. The DOW was deployed at the Wahiawa site just east of the Schofield Barracks. The radiosonde release was delayed due to rain until there was a break at 0955 UTC. The temperature sounding revealed a lack of inversion and cold air aloft, and the humidity profile revealed a very deep moist layer with high relative humidities up to 250 mb.

During the IOP O'ahu was under a Flash Flood Watch, then Warning as heavy rain showers stationed themselves over the South and Windward coasts. This was the first part of the mission which consisted of three consecutive shifts until the cold front passed. Eventually the Manoa Stream reached its flood stage during the IOP. Ms. Almanza used the radar data from this IOP to perform a dual-Doppler analysis of a large mesoscale convective system.

4.13 IOP 12b: Wahiawa Cold Frontal Passage "B"

Number of participants: 9
Start of Mission: 10 November 2013 1200 UTC
End of Mission: 10 November 2013 1949 UTC

The operations teams transitioned at 2 am local to continue the extended IOP. Over the southern shores there was wide-spread precipitation which caused flood advisories to be issued for much of the island. There was also precipitation anchored to the Ko'olaus. Shortly after arrival a band of precipitation moved through from the northwest, followed by a period of clearing before another band moved through. A third, narrow band formed north of the coast but never passed over the radar site. The last hours of the mission consisted of showers over the Ko'olaus and scattered precipitation in the central valley. A radiosonde launched at 1727 UTC during a period of strong winds that only reached a height of 1.5 km before the balloon burst. A second radiosonde was launched that ascended successfully to 27 km and showed very different atmospheric conditions from the previous launch. Mr. Bauman analyzed the convective to stratiform transition during one of the rainband passages. Ms. Li compared the quantitative precipitation estimate from the radar with the local rain gauge data.

4.14 IOP 12c: Wahiawa Cold Frontal Passage "C"

Number of participants: 8
Start of Mission: 10 November 2013 1949 UTC
End of Mission: 10 November 2013 0153 UTC

This mission began on the tail end of a day long deployment at the Wahiawa site. Prefrontal heavy showers had moved over the IOP site the night before. A diffuse band of showers, associated with weakening convergence along the cold front itself, were affecting site during the midday and afternoon hours. A general increase in northeasterly winds were noted during this IOP, and a 13.2 m s^{-1} wind gust was recorded on the mast instrumentation at 2139 UTC. The radiosonde was launched successfully, despite strong winds of over 10 m s^{-1} during preparation, with data recorded up to 500 hPa. Mr. Grunseich compared Doppler velocities from the DOW with those obtained from radiosondes, including the sonde from this IOP, to assess data quality. Mr. Hsiao assimilated DOW radar data into the Weather Research and Forecasting (WRF) model to improve predictions of the cold frontal passage. Ms. Sockol calculated statistics of the radar variables over the 24 hour extended IOP to examine the change in precipitation during the event.

4.15 IOP 13: Manoa Valley Post-frontal

Number of participants: 3 + 10 middle school students and teachers
Start of Mission: 12 November 2013 1615 UTC
End of Mission: 12 November 2013 2119 UTC

After a frontal passage on Sunday 10 November and with a high building in from the northwest, the forecast called for calm conditions with a chance for weak trade wind convection. The purpose of the mission was to record data of trade wind showers on the leeward side of the mountain range. The radar was deployed to the southern parking lot of Manoa Valley Park on the mauka side of the Ko'olaus. At arrival, there was a sky full of stars, but no clouds. It was an exceptionally clear day where not even the mountain tops were overcast. During the IOP, a few small non-precipitating

clouds could be identified visually, but detection on the radar scope was difficult because of the weak returns and the large fraction of non-weather echoes. At around 2000 UTC a group of students from the Variety School of Hawaii came to visit the truck and helped launch a sounding.

4.16 IOP 14: Kualoa Ranch Cumulus Clouds

Number of participants: 4
Start of Mission: 13 November 2013 1535 UTC
End of Mission: 13 November 2013 1803 UTC

The forecast for this IOP was light trade winds with little moisture. The cold front had gone through on Sunday and dry cool weather set in on the islands. Since it was the last day of HERO one last mission to Kualoa Ranch was conducted in hopes of catching some morning trade wind showers. Three cumulus clouds were tracked closely. The first was a sizeable cloud which was followed in by continuous RHIs to capture it's approach. The whole life-cycle of a short-lived small developing cumulus was also captured. The third cloud was a persistent one at slightly greater range. A solar scan in clear conditions was done at 1803 UTC that was used by Ms. McElhinney to calculate antenna gain and beam patterns.

5 Lessons Learned

The HERO project was extremely successful. The deep integration with MET 628 "Radar Meteorology" contributed to both a successful course and educational deployment by giving the students a true hands-on learning experience. The arrival of the DOW in the middle of the semester was an ideal time for maximizing both the pre-deployment learning and post-deployment analysis. Incorporating weather balloon launches into the project and having dedicated forecast teams helped to involve undergraduate students directly so that they were active participants in the project. The radiosondes also provided valuable scientific information that helped improve the educational value of the radar data collection. HERO was the first field project for several of the students, and the feedback from all students has been very positive.

The close collaboration with the National Weather Service also proved to be an important part of the project which contributed greatly to student forecasting skill and experience, and also provided data for operational weather forecasts and warnings. The willingness of the NWS forecasters to volunteer their time and expertise was greatly appreciated. Collaborative student and NWS radiosonde launches and forecast discussions will continue at UHM as a result of the HERO project.

Capitalizing on the exceptional organization of the SOEST Open House helped the DOW showcase be a very large public outreach event reaching over 7,500 people. In addition, positive media coverage of the DOW also reached a large percentage of the local population. The outreach and media coverage ended up being important for operating in public areas. Most of the people who came by the DOW with positive comments had heard about the radar from one of those sources. A small percentage of people were confused or troubled by the radar's presence around the island, with most of them changing their minds after talking with the PI or UHM students.

One of the difficulties operating on O'ahu was the lack of space in the congested urban environment. Unlike most mainland deployments where the DOW can park and operate freely, the parking and deployment locations were strongly constrained. There was no secure, 24-hour access parking on campus, such that the overnight storage was instead at the nearby UH Marine Center. The

location was not ideal since it added to the pre- and post-deployment time, but it was a safe, easily accessible location. Other options would be investigated for any future DOW project on O'ahu.

There were few side-of-the-road spots where the DOW could operate, such that public parks were a primary IOP option. Many public parks did not open early enough to operate during the nocturnal convective maxima, therefore night-time operations were limited. Later in the day, the parks became crowded with both locals and tourists who had mixed reactions to the radar and associated generator noise. Three privately owned locations identified during the project proved to be the best places to operate, and it is planned to more actively involve local landowners for any future DOW project. Many thanks to the Waikalua Loko Board of Directors and David Morgan at Kualoa Ranch for allowing use of their land.

Despite some of the difficulties with the O'ahu operations environment, the meteorological situation proved ideal for an educational deployment. The DOW radar worked very well in the tropics, with only one small exception due to a transmitter failure that was fixed quickly. The dedication and hard work of the CSWR staff contributed greatly to the success of the project. The abundance of clouds and rain in the tropics helped to keep the project exciting for the entire duration, and there were a few uncommon events such as thunderstorms and frontal passage. An exceptional dataset was collected and valuable insights into tropical weather processes are expected upon further analysis. The data will be made freely available to other interested researchers.

A journal article for the Bulletin of the American Meteorological Society describing the project and some of the highlights of the collected data is in preparation. Mahalo Nui Loa to CSWR and NSF for supporting the Hawaiian Educational Radar Opportunity. With the success of HERO, it is expected that a request for a future deployment will be made. Aloha!

Figure 5: *HERO project participants*

A List of Student Research Projects from HERO

- Almanza, V., "Dual-Doppler Analysis During a Sub-tropical Rainfall Event"
- Bauman, M., "Comparing Mobile Doppler Radar Characteristics of Convective and Stratiform Regions of a Tropical Line of Convection"
- Ballard, R., "Mobile Polarimetric Radar Observations of Sea Breeze Convection on Oahu"
- Foerster, A., "Trade wind flow interaction with the Ko'olaus"
- Frambach, A., "Hydrometeor Classification in Hawaii Using the DOW7 X-Band Dual-Polarization Mobile Radar During the HERO Project"
- Grunseich, G., "Validation of Doppler Velocities gathered during the Hawaiian Educational Radar Opportunity (HERO) under different weather regimes"
- Hsiao, F., "Assimilation of Radar data with SAMURAI for a Cold Front Case in Oahu, Hawaii"
- Li, L., "Z-R relationship for a cold frontal precipitation in Hawaii"
- McElhinney, S., "Solar Calibration and Antenna Patterns of the DOW 7"
- Pattantyus, A., "Tropical squall line features and characteristics observed with the Doppler on Wheels during the Hawaii Educational Radar Opportunity"
- Robinson, T., "Radar Validation of Orographic Shape Vertical Motion Model"
- Sockol, A., "A Statistical Analysis of the November 10th, 2013 Storm on the Island of Oahu"