MULTI-INSTITUTIONAL COLLABORATIVE STUDENT EXPERIENCE IN AIRBORNE RESEARCH IN THE MID-ATLANTIC REGION ***(SEAR-MAR)***

A National Science Foundation Educational Deployment of the University of Wyoming King Air Aircraft

PROJECT PARTICIPANTS

Millersville University
Richard D. Clark
Todd D. Sikora
Brian Billings

Pennsylvania State University
Kenneth Davis
Paul Markowski

University of Maryland – Baltimore County
Belay Demoz
Zhibo Zhang

Rutgers University
Mark Miller

And over 100 undergraduate and graduate students from partnering universities

20 February 2018

SEAR_MAR
Table of Contents

Public Relations Overview

MULTI-INSTITUTIONAL COLLABORATIVE STUDENT EXPERIENCE IN AIRBORNE RESEARCH IN THE MID-ATLANTIC REGION (SEAR-MAR)

Over 100 undergraduate and graduate students and eight scientists-educators from four partnering mid-Atlantic universities (logos above) participated in a two-week, 40 flight-hour deployment of the University of Wyoming King Air airborne platform funded by the National Science Foundation. The project, dubbed the *Student Experience in Airborne Research: Mid-Atlantic Region* (SEAR-MAR), provided the opportunity for research and research training, including ground-based activities such as forecasting, instrument installation and operation, upper-air soundings, flight plan design, and pre-flight planning. In addition, students were involved in outreach activities to local schools, such as the 58 6th-graders at a local elementary school who saw the King Air fly over and then launched a radiosonde. We also provided opportunities for 40+ freshmen meteorology majors to tour the hangar and get an overview of the aircraft by the Wyoming crew, and hosted a half-dozen female *STEM Sisters*, a program sponsored by the North Museum of Nature and Science designed to excite and engage middle and high school girls in the STEM fields.

The scientific objectives and the experimental plans were designed to optimize educational activities and student engagement. The intention was to fly every day except hard down days and take advantage of the airborne platform for outreach activities when not flying. We were able to study the fine structure of frontal systems, post-frontal mountain waves, cold pools in Appalachian valleys, cold-air damming, methane emissions from mines, PBL evolution in the mid-Atlantic coastal zone, and instrument comparison and calibration. Each day consisted of a 5-day forecast released by 14 UTC (9:00 EST) with emphasis on the next-day's flight operations, pre-flight update three hours before take-off, and a noon-time update. All meetings were conducted via video conference.

In all, 45 students flew on 15 science missions. Many of the students have already begun to analyze the aircraft and ground-based data, and some have already presented preliminary results

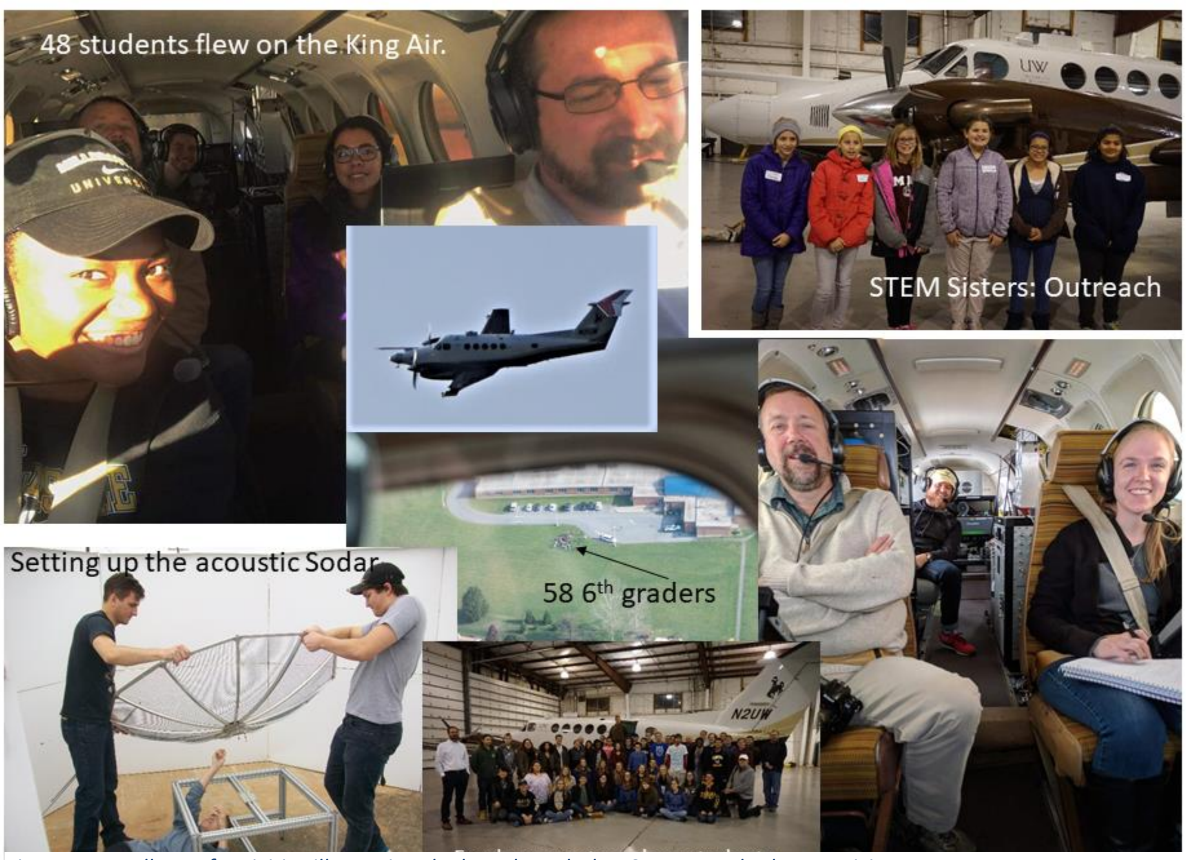


Figure 1: A collage of activities illustrating the broad reach that SEAR-MAR had on participants.

at the American Meteorological Society's 98th Annual Meeting in Austin, TX. The logistics of managing a comprehensive multi-institutional collaborative project while classes are in session, participating in three video conference each day, maintaining a ground-based facility, mentoring students, arranging outreach activities and public relations with the regional news media, demanded a marathon effort on the part of students and professors, but one that everyone would agree was nothing short of an exceptional authentic experience in research and research training for so many students.

Figure 2: A subset of the 62 Millersville University undergraduate students posing with the flight crew from the University of Wyoming and Millersville faculty.

I. Introduction

The ***Multi-Institution Collaborative: Student Experience in Airborne Research in the Mid-Atlantic Region*** (SEAR-MAR), was an educational field deployment of the University of Wyoming King Air aircraft (UWKA) in the period 4-18 November 2017. The participating universities were Millersville University (MU), Pennsylvania State University (PSU), Rutgers, The State University of New Jersey - Rutgers (RU), and the University of Maryland, Baltimore County (UMBC). Figure 3 shows the location of the four universities in relation to the project domain. The domain outlined in white represents the area within which the Wyoming Cloud Lidar (WCL) could be safely operated, although some missions where the WCL was not essential included transects there were outside this domain.

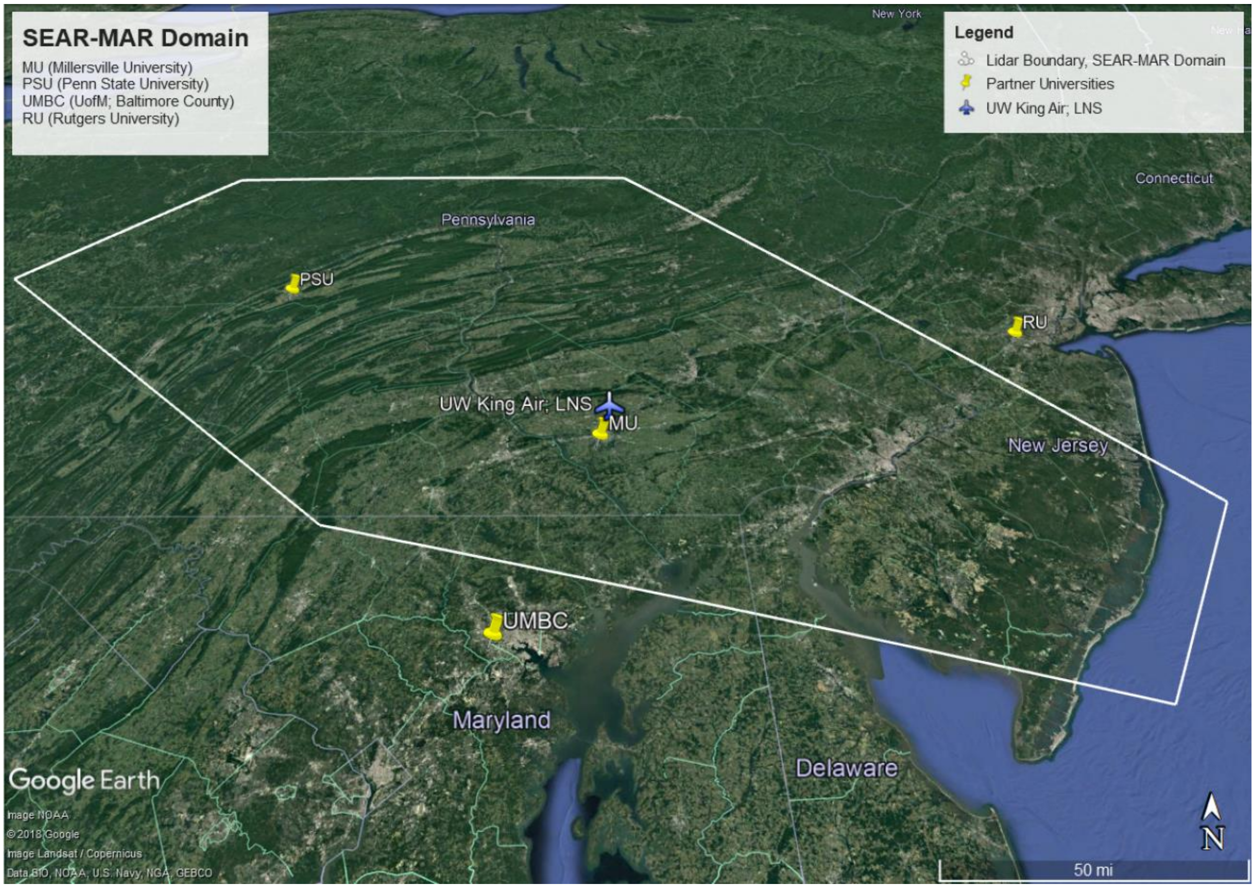


Figure 3: Primary SEAR-MAR domain outlining the area within which the Wyoming Cloud Lidar could be operated and showing the location of the four partner universities.

The geographic domain was centered roughly on Lancaster, PA, so it made sense to have the UWKA and Wyoming operations center located at the Lancaster Airport (KLNS), about 12 miles from the Millersville University campus.

As an educational deployment, the purpose of SEAR-MAR provided the locus for undergraduate and graduate student participation in airborne research. The scientific objectives were selected from the atmospheric phenomena that were likely to be observed based on November climatology in the mid-Atlantic region and were experimentally feasible for study by an instrumented airborne platform. While each scientific mission was designed around the use of the UWKA as the primary facility, each of the participating universities contributed their own ground-based and/or upper air instruments for *in situ* and remote sensing measurements, which further enhanced and expanded the overall capability. In several cases, these additional facilities provided much-needed coupling to the surface. The National Science Foundation (NSF) also provided funding for 90 radiosondes (60 Vaisala® RS41-SGP; 30 Windsonds®). Not only were the students active participants in research using an instrumented research aircraft, they also had rich exposure to the supporting instrumentation provided by the university partners, which afforded them the opportunity to develop competencies in assembling, operating, maintaining, calibrating, and analyzing data from multiple sensors.

Figure 4: In addition to the UWKA, partner universities deployed a variety of instrumentation. Here is a collage showing Millersville University students installing the flux tower components and assembling the MFAS SoDAR with RASS extension.

The atmospheric phenomena in the mid-Atlantic region that drew our combined interests spanned the synoptic, mesoscale, microscale, atmospheric chemistry, and even aircraft instrument calibration. The table below provides a list of the IOPs dedicated to SEAR-MAR.

Table 1: List of Intensive Operating Periods Involving the UWKA during SEAR-MAR

Date	Flight # (*.kml)	Status	Times (UTC)	Hours
17 Nov 2017	RF14	Clear air profiling near Rutgers' PAM site and Millersville's ground site.	1751-1932	1.8
16 Nov 2017	RF13b	Second of two paired flights, sampling emissions downwind of Philadelphia.	2113-2254	1.8
16 Nov 2017	RF13a	First of two paired flights, sampling background emissions upwind of Philadelphia.	1845-2001	1.3
16 Nov 2017	RF12	Sampling boundary layer across coastal transition (UMBC cold-frontal track).	1349-1601	2.3
15 Nov 2017	RF11	Rutgers PAM site overflight & coastal boundary layer sampling.	1803-2006	2.2
14 Nov 2017	RF10	Calibration maneuvers - static pressure profile.	1750-1854	1.1
11 Nov 2017	RF09	Ocean-bay-land boundary layer characterization.	1245-2004	2.5
11 Nov 2017	RF08	Cold Pool and Northerly LLJ	1209-1514	3.1
10 Nov 2017	RF07	Mountain Waves	1424-1625	2.1
9 Nov 2017	RF06	Emissions profiles around Enlow & Cumberland coal mines.	1759-2150	3.9
8 Nov 2017	RF05	Emissions profile, Sugar Run-Salt Springs track.	1656-2008	3.3
7 Nov 2017	RF04	Mid-level frontogenesis.	1656-2022	3.6
6 Nov 2017	RF03	Fine structure of fronts.	1935-2228	3.0
6 Nov 2017	RF02	Fine structure of fronts.	1400-1753	3.9
4 Nov 2017	RF01	Cold air damming flight profile.	1155-1551	4.1

In all, SEAR-MAR consisted of 15 research intensive operating periods (IOPs) employing a total of 40 flight hours, and five test flights. Given the breadth of research topics, it should not be surprising that all 40 hours of UWKA flight time allocated to the project were used. Select IOP missions are discussed in section III.

While it was relatively easy to develop a list of interesting and relevant science objectives, recall that the purpose of SEAR-MAR was to provide a conduit for learning by doing. Indeed, SEAR-MAR involved over 100 students from the partner universities, many of whom were able to directly connect their SEAR-MAR involvement to concurrent coursework and/or research. Section IV addresses that outcome in detail. Forty-five students flew on 15 UWKA flights accumulating 40 flight hours over a 12-day deployment. In addition to its standard *in situ* instrumentation, the UWKA was outfitted with the upward and downward pointing cloud lidar, and a Picarro. Students from MU, PSU, and UMBC launched 60 rawinsondes over the course of SEAR-MAR. Moreover, scores of MU students were directly involved with the transport, assembly, and maintenance of MU's ground-based instruments, which were deployed at Frey Farm Landfill, which is about 10 km west of MU. Those ground-based instruments included an MFAS SODAR with RASS extension, an MPL-111 SigmaSpace Lidar, and 10 m flux tower with instruments at 2 and 8.5 meters.

In addition to flying on the UWKA and taking lead roles with the other instrument platforms, several students were also involved in the planning of certain missions from the ground-up. As described in section III, examples of such are the 04 November cold air damming IOP and the 11 November cold pool IOP. As discussed below in section 2, students from MU also took a lead role in mission forecasting providing forecasts for the determination of the next-day's science mission and forecast updates for the Wyoming crew three hours before take-off using video conferencing with the partners. In addition, prior to the start of the project, one MU undergraduate student (R. Capella) spent part of summer 2017 initializing the WRF model using gridded GFS output from legacy systems that affected the mid-Atlantic region. His 36-hour simulations provided a usual set of products to help investigators diagnose the salient characteristics of atmospheric conditions and develop flight patterns that would best achieve useful results for each mission.

II. Operational Logistics

Each research flight of the King Air required: i) selection of a scientific mission based on the expected weather conditions, ii) determination of the flight's takeoff and landing times and flight plan, iii) requests for any required radiosonde support with launch times and locations, and iv) the ability to make changes in this plan as the flight developed. Since the project involved the Wyoming flight crew and universities in four different cities, special methods of communication were needed to accomplish these requirements. Different approaches were used prior to, during, and after a daily noon planning meeting.

The process began with a forecast. Due to time spent on other aspects of the project leading up to the start of operations on 4 NOV (e.g. ground equipment installation), the first meeting with prospective student forecasters did not occur until 31 OCT. It had previously been decided that Millersville University students would develop the forecasts and host the video conference. The call for forecasters was distributed to all Millersville meteorology students with a requirement of one-semester participation in the Campus Weather Service, which would provide students with the practical experience and knowledge of products useful in creating forecasts.

To further leverage the Campus Weather Service, SEAR-MAR students prepared a 5-day forecast each day after the normal 0730 LST weather briefing used to develop a local forecast for Millersville University. With guidance from faculty, the forecasters wrote a summary of the expected weather conditions each day and identified the most favorable scientific mission based on a description of the relevant flight plan and approximate flight times. This was the first document distributed to an e-mail list, which included lead scientists, research associates, the Wyoming crew, and over 100 students at the four institutions. The one-line summaries were also kept on a whiteboard in the Millersville University Weather Information Center (MUWIC) as shown in Figure 5.

Figure 5: Blaik Thompson (senior, MU Meteorology) discusses the five-day forecast with Ryan Lees (sophomore, MU Meteorology) in the MU Weather Information Center. The five-day forecast and 3-hour update were routine responsibilities for students during SEAR-MAR

On the day before a potential flight, an additional forecast was prepared one hour before the daily planning meeting to confirm the best mission and add additional information from higher resolution models. This was also distributed by e-mail to the same listserv. While the forecasts were intended to be guides to research mission selection, and were occasionally superseded by other participants' analysis, they ended up having great weight in determining the flight was chosen, so that the students involved in the forecasting were also effectively gaining experience field experiment operations.

The most important communication between partners was the planning meeting, which was held at noon every day of the project until the flight hours were expended. This meeting was used to formally declare the mission and its parameters, including when radiosondes would be launched and from which site. Other announcements of relevance to the project could also be made. While a classroom on the Millersville campus allowed many students from that campus to attend (Fig. 6), any participant could easily join by phone or video conference. The latter made for a more familiar meeting situation and could even be used to provide live weather updates during IOPs. It was also beneficial that the Wyoming crew could join from the airport in close proximity to takeoff and landing times.

Figure 6: Amber Liggett (senior, MU Meteorology) presents the daily forecast to other students and faculty for a particular mission.

For subsequent changes to the mission plan there was first a pre-flight forecast update, which was prepared by that day's student forecasters and delivered by one of them using video conferencing three hours before the declared takeoff time. This allowed observations and the highest-resolution model runs to be incorporated into the outlook, while also allowing enough time to train those students who were to fly that day. While the start time could not be moved forward after the pre-flight update, it could be pushed back for more favorable conditions or to accommodate slight modifications to the flight plan.

After the flight was airborne, communication was still possible using chat software available on the King Air and to any interested participants on the ground. An important ground station was MUWIC where there was always one or more people following the progress of the mission. If data from early legs was not as expected, mission scientists on the ground could suggest or approve changes to improve the results, such as shifting legs laterally or to a higher altitude. On occasion, chat was also used at Millersville's ground site if that was involved in the mission, or to communicate with the mobile radiosonde crew.

III. Select Mission Summaries

Mission identification in this section follows that employed by the UWKA staff, and found at, http://flights.uwyo.edu/projects/searmar17/.

a. Fine Structure of Cold Fronts – RF02

On 6 November 2017, a mission was flown (RF02) in support of the first science objective to investigate the fine structure of cold fronts. The UWKA departed KLNS at 1400 UTC and returned at 1753 UTC. The mission was to ascend to and maintain constant altitude at 1500 m AGL). Fig. 7 shows the UWKA flight track created using Google Earth.®

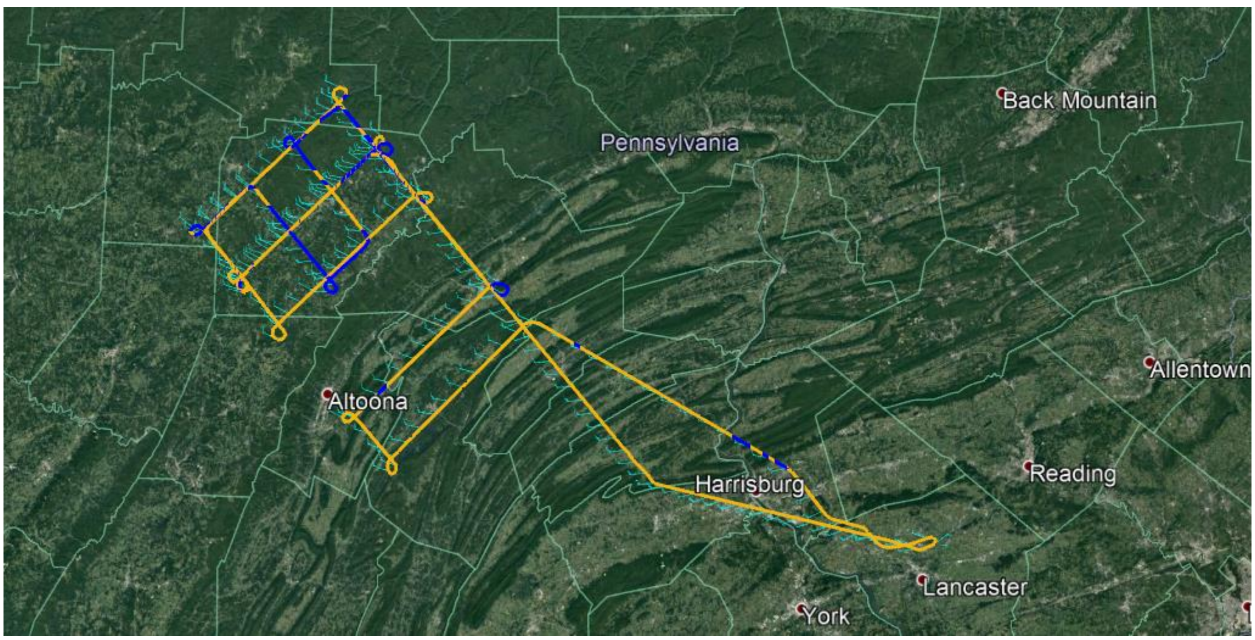


Figure 7: UWKA flight track for RF02 - fine structure of a cold front.

The UWKA transited first to the Allegheny Plateau, where a series off lawnmower tracks were flown in the vicinity of the analyzed surface front in Figure 8. The lawnmower pattern was selected to investigate the terrain-induced influence on frontal ebb and surge, discrete propagation of fronts, frontal width, and narrow cold-frontal rainband passage.

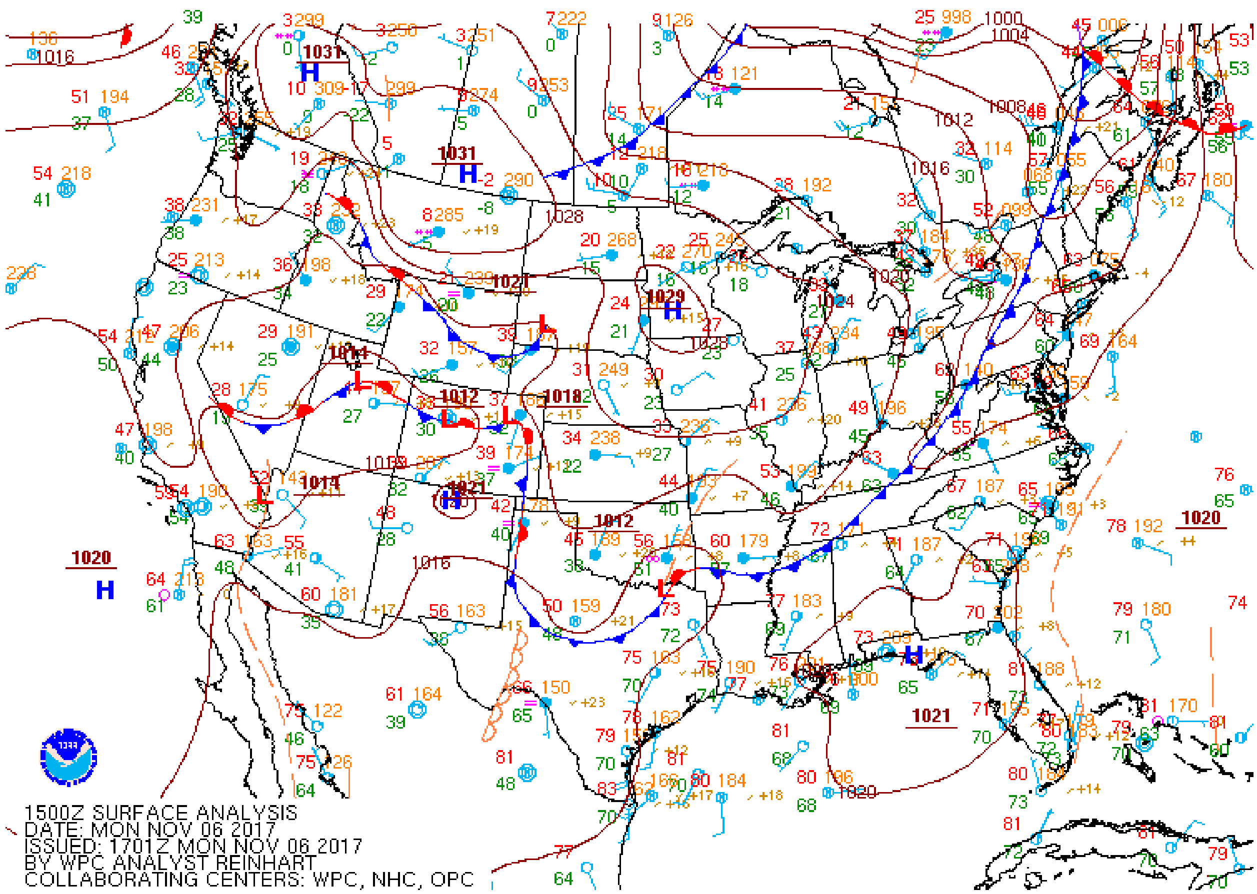


Figure 8: WPC surface analysis for 1500 UTC 6 November 2017 depicting the cold front over PA that was the focus of the mission RF02.

That cold front moved quickly to the southeast during the mission, being located near Philadelphia, PA by 1800 UTC 5 November 2017 WPC surface analysis (not shown). An attempt was made to sample the cold front after it moved from the Allegheny Plateau to the convoluted ridge and valley system southwest of State College, PA. Hence, the UWKA flew a second truncated southern lawnmower pattern before returning to KLNS.

Radiosondes were launched in support of the RF02 mission by PSU at University Park, PA at 1200 UTC, 1500 UTC, and 1800 UTC (all 6 November 2017). Radiosondes were also launched by MU at 1800 UTC, 2100 UTC, (both on 6 November 2017) and at 00000 UTC on 7 November 2017.

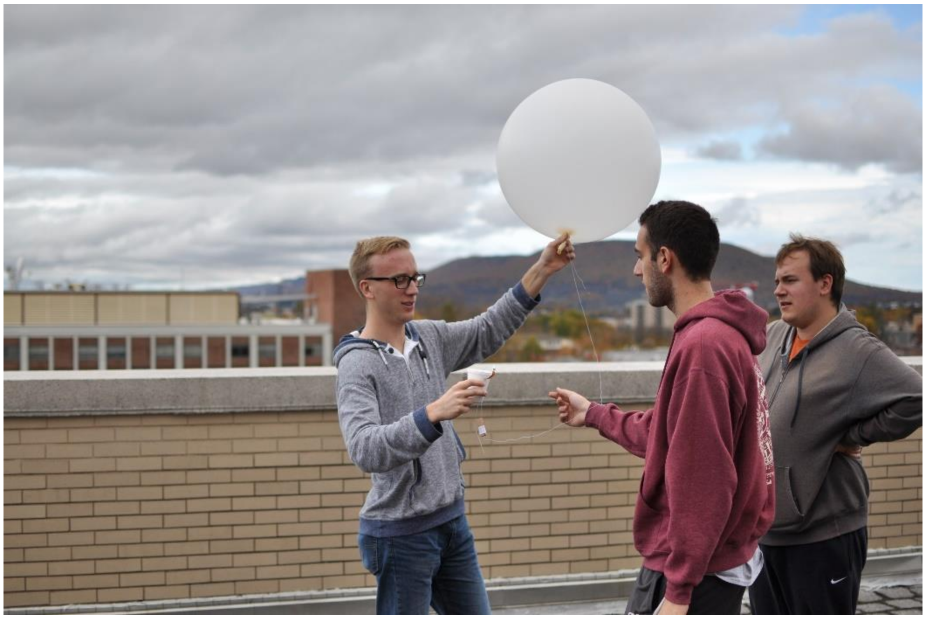


Figure 9: Trio of PSU students in Dr. Markowski's Mesoscale Meteorology course preparing to launch a Windsond to obtain upper air wind and thermodynamic profiles.

As of the time of this writing, data from the UWKA for this mission as not been analyzed in detail. Erin Jones, senior MU meteorology major, Honors College Scholar, and Hollings Scholar, is using SEAR-MAR data obtained during this science mission for her Honors thesis, entitled the *"Impact of local radiosonde observations in high-resolution WRF simulations."*

b. Cold Air Damming – RF01

Another mission with high student involvement was based on a larger research project proposed by a group of Millersville students independent of SEAR-MAR or any meteorology course. Their goal over a two-year period is to perform the research, present the preliminary results at a series of conferences (the first being the annual Made in Millersville student conference; Dellandre et al. 2018), and ultimately author a journal article. The work involves a case study comparison of two cold air damming (CAD) events, and with the availability of the UWKA the second event could be supported by a unique dataset (see RF01 in Table 1).

These students made an initial attempt to design a flight path over the valleys near Altoona, PA, the site of a significant historical CAD event. However, due to the King Air's minimum altitude, these tracks turned out to be beneath the local crestline of the Appalachians. Therefore, the study area was shifted southward to the Cumberland Valley and downwind of the Blue Ridge Mountains (Fig. 10) with two flight altitudes and slow climbs and descents in between. There were also three missed approaches planned at small airports in Carrol County, MD and Franklin County, PA. Three MU students flew on the UWKA during this mission.

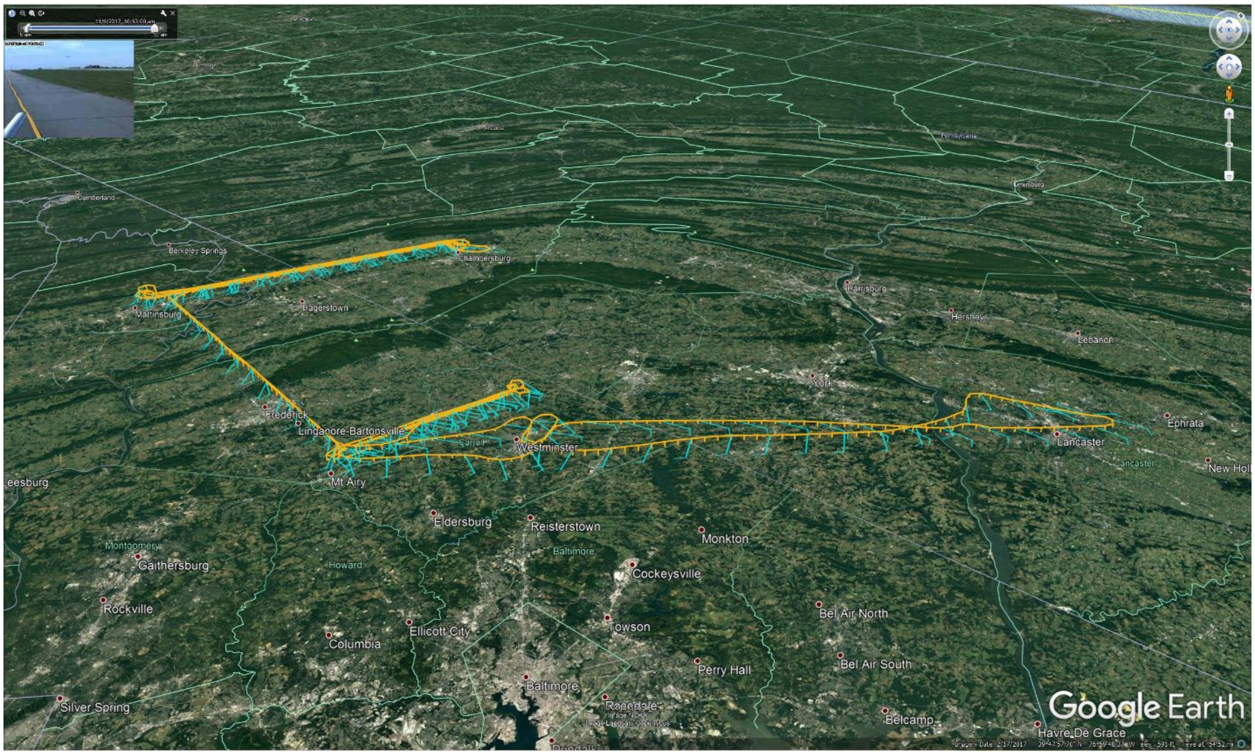


Figure 10: UWKA flight pattern designed to capture a cold-air damming event, for which favorable conditions occurred on 4 NOV 2017, marking the first IOP of SEAR-MAR.

The ideal synoptic conditions occurred on the first day of the deployment (4 Nov) with a closed high forecast over the Ontario-Manitoba border and ridging isobars extending southward to Virginia (Fig. 11). While daylight conditions were required to fly the minimum altitudes, the mission was otherwise scheduled as early as possible to minimize the amount of heating and surface erosion of the cold air, so that takeoff was at 12 UTC (08 LST).

The rest of the student research team provided additional ground support by launching two Windsonds along the flight path. They first traveled to the Sharpsburg, MD area at 1230 UTC to obtain a sounding in the Cumberland Valley directly under the ferry leg. This was timed to coincide with the King Air's overpass by communicating with students in Millersville's Weather Center who were following the flight on NCAR Mission Coordinator. Moving north, students launched a second balloon. Both sondes were recovered after the second launch. To capture additional horizontal variation in the vertical structure, radiosondes were also used from the Millersville base site at 1230 UTC and by PSU at Bedford, PA at 1130 UTC.

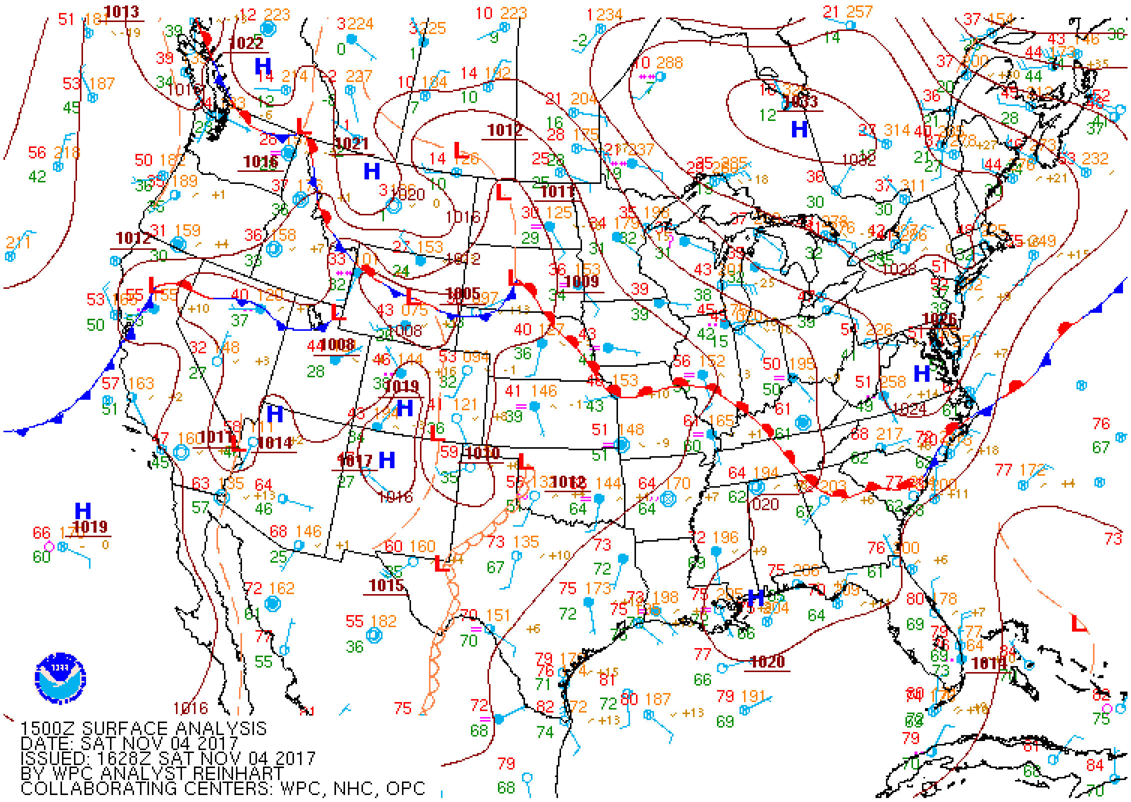


Figure 11: WPC surface analysis for 1500 UTC 4 November 2017 depicting the region of high pressure in Canada contributed to the cold-air-damming event of mission RF01.

During the first missed approach and mountain parallel flight legs, it was found that temperature was higher nearer to the surface. However, as the King Air was ferrying westward, the plane was forced to climb to 4000’ to pass ATC at Frederick, MD. At this level, the warmer temperatures of the inversion were discovered. After discussion among the flight team and with participants in the Weather Center, it was agreed to add an additional flight level at a higher elevation along both sets of ridges. This new altitude and the one beneath it were used to map out the horizontal structure of the inversion, which is shown in Fig. 12. Moreover, the students reported visually observing fanning smokestack plumes during the flight. The inversion was also captured in all of the morning radiosonde launches. While the earlier soundings from Bedford and Sharpsburg, MD (Fig. 4a) have second surface-based inversions, the later profile from Waynesboro, PA (Fig. 4b) had the same decreasing temperatures seen in the King Air data. On returning from their trip, students made particular note of this dramatic difference in surface temperature between the two launch locations. While the extra hour of solar heating would have an obvious impact, it is also possible this is due to horizontal variations between up- and down-valley locations, as the King Air observed horizontal temperature variations along its valley legs.

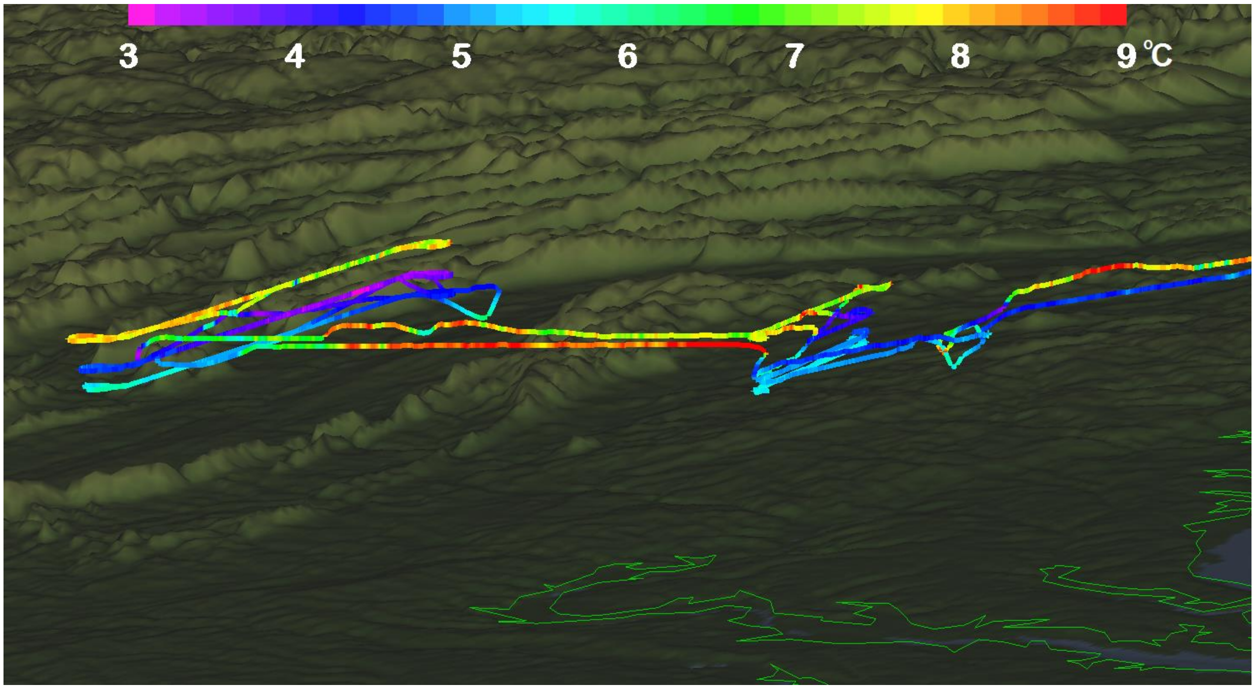


Figure 12: Flight tracks during RF02 colored with temperature. Deep cold pools are relatively common in the PA valleys under high pressure, clear sky conditions.

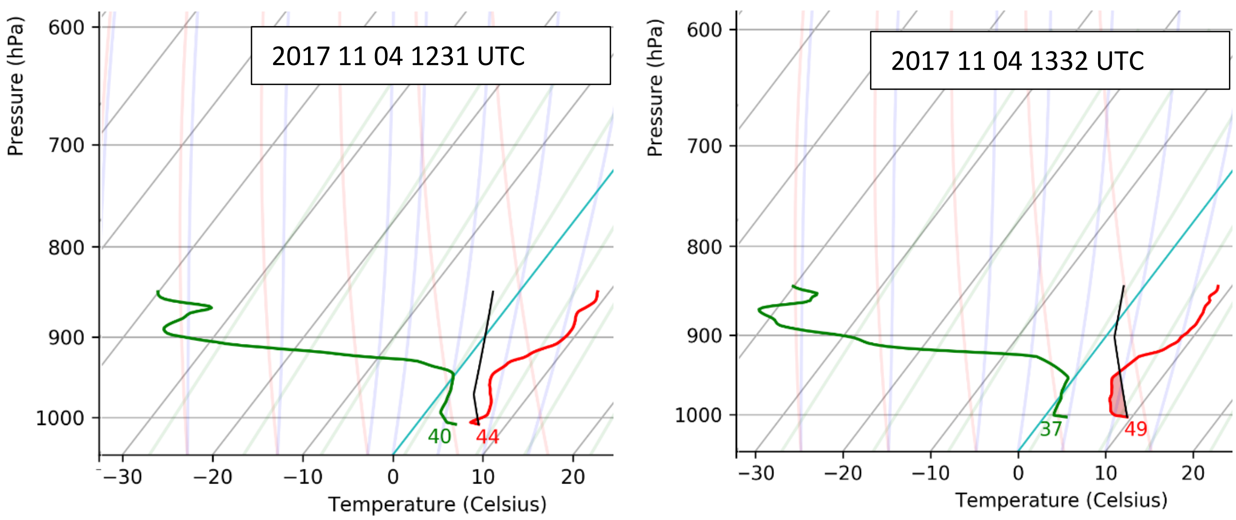


Figure 13: Vertical profiles of temperature (red) and dew-point temperature (green) for Sharpsburg, MD at 1231 UTC (left) and Waynesboro, PA at 1332 UTC (right) during a cold-air damming event (RF01)

c. Mountain Lee Waves – RF07

After the passage of a cold front, the Appalachians often experience an extended period of strong flow with a westerly and/or northerly component. In cooler, more stable air this results in the formation of trapped lee waves with trains that may propagate across the mid-Atlantic Piedmont and through the SEAR-MAR domain. Since the mountains have a sharp clockwise bend in the study area, both eastward and southward traveling waves can be triggered, and there is a possibility of interference between the two.

Forecast teams identified 10 Nov, after an overnight cold front passage and ahead of an advancing 1040 hPa high pressure system (Fig. 14), as an ideal mountain wave day. Short-term model guidance suggested a midday transition from wave trains to convective cloud streets, so takeoff was scheduled for 1430 UTC.

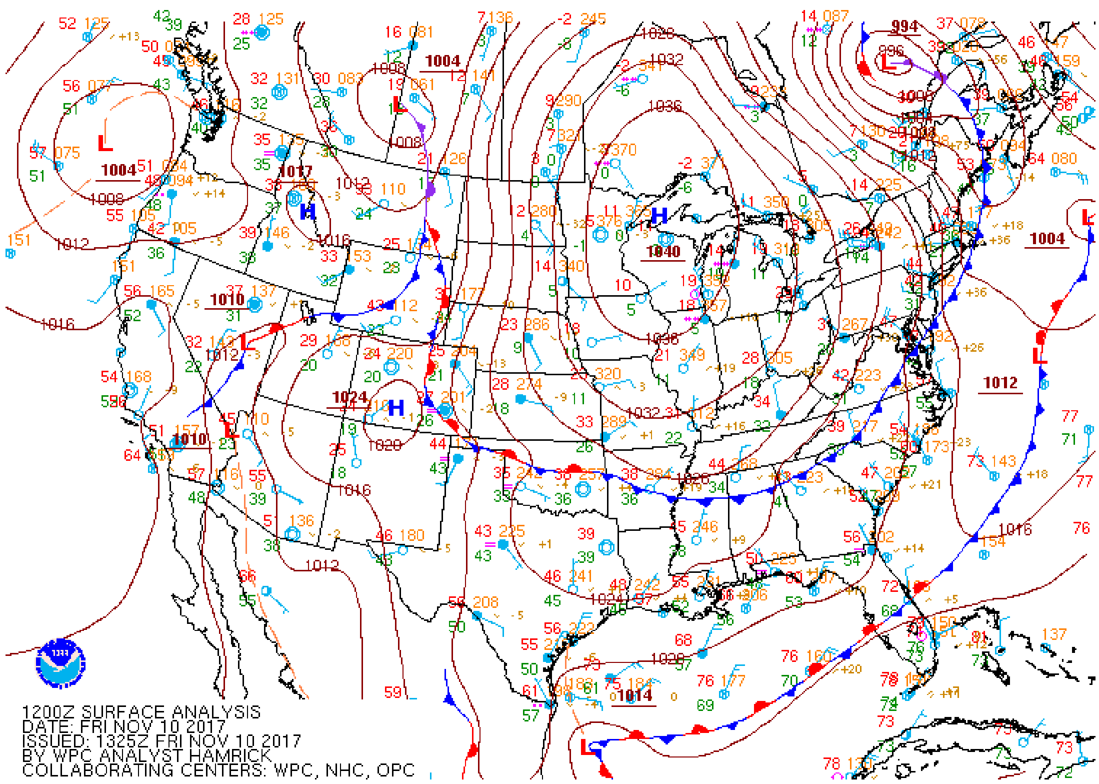


Figure 14: WPC surface analysis for 1200 UTC 10 November 2017 showing the advancing high pressure system making for favorable conditions for the mountain wave mission RF07.

To study this phenomenon, a flight path was developed that included four vertically-stacked levels in both an N-S direction and an E-W direction (Fig. 15). Between these two stacks, in the area NE of Gettysburg, PA, a sequence of ascending legs crisscrossing the line of inflection through the Appalachians was planned, followed by a set of similar descending legs.

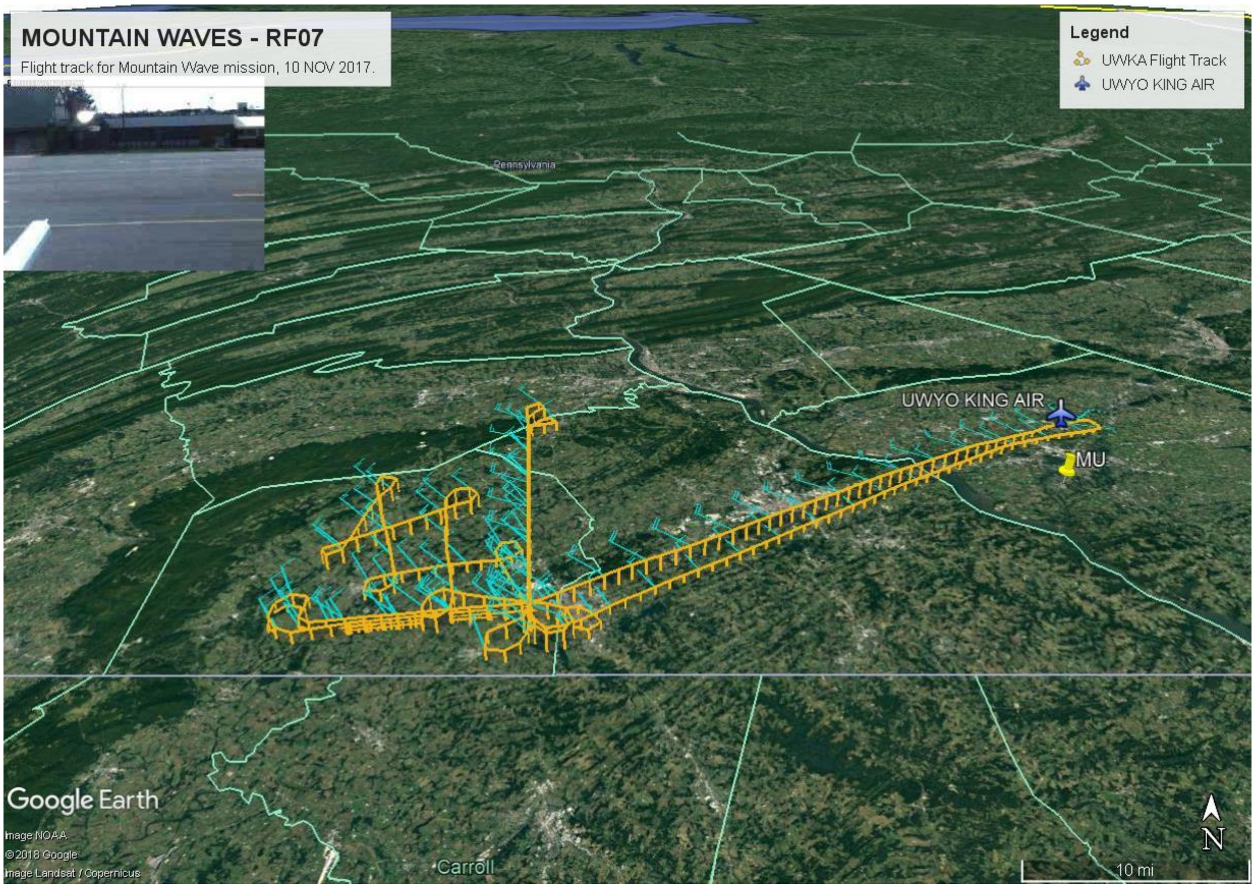


Figure 15: Flight path for Mountain Wave study RF07.

The N-S stacks had a well-defined wave structure at 6250' AGL, but the lower three legs were found to all be within the turbulent boundary layer. For this reason, the flight plan was changed so that after the ascending zigzag, the return pattern was made at a constant 6250' elevation. Then, one of the lower E-W legs was replaced by a higher one at 7750' resulting in additional mountain wave transits.

Figure 16 is from a student presentation showing the inflight vertical velocities for the entire track. There are obvious differences between the irregular fluctuations in the lower transects and the smoother, periodic undulations along the transects at higher altitudes where the mountain waves reside.

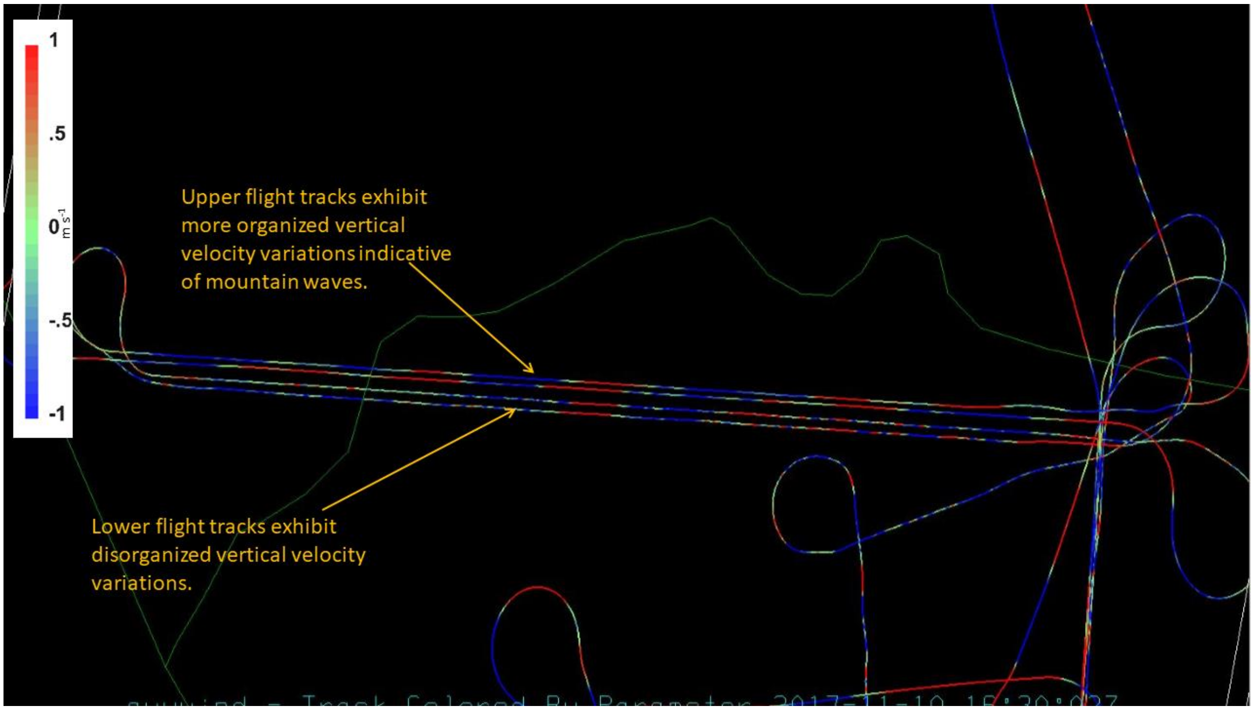


Figure 16: Flight tracks colored with vertical velocities. The four east-west stacks are indicative of regular mountain wave undulations residing on top of a turbulent boundary layer during RF07.

d. Cold Pool and Northerly Low-Level Jet – RF08

The Cold Pool experiment aimed to characterize the lowest levels of the stable boundary layer across valleys of varying widths to understand terrain influences on cold pool development and dissipation in the Pennsylvanian Appalachian Mountains. All observational resources available to Millersville University SEAR-MAR participants were used, including the University of Wyoming King Air (UWKA) Research Aircraft, LiDAR, SoDAR, 10-meter flux tower, and radiosonde systems.

A climatological study of frontal passage types indicated that approximately two frontal systems would be observed during the active SEAR-MAR project phase. With similar frequency, high pressure centers or cold air damming signatures were expected to occur. The ideal synoptic requirements for the Cold Pool experiment included a weak surface pressure gradient, ideal radiational cooling the evening prior, and calm surface winds. Two of three conditions were met (Fig. 17): light winds existed in the Susquehanna Valley (KMDT, KLNS) but frequently ceased in the nearby valleys, including at Selinsgrove (KSEG), Altoona (KAOO), and even Muir Army Airfield (KMUI).

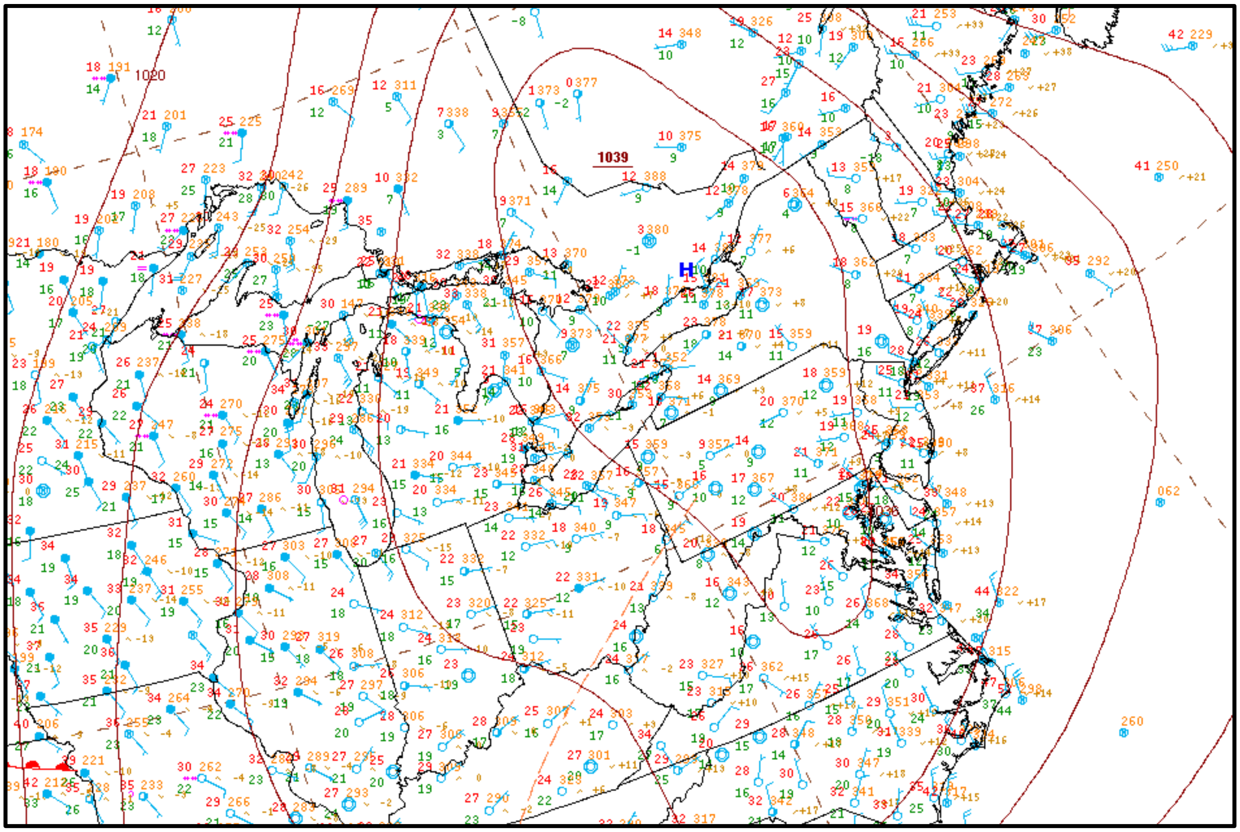


Figure 17: WPC surface analysis for 12 UTC 11 Nov 2017 showing high pressure over the SEAR-MAR domain making conditions right for the cold-pool mission RF08.

The Cold Pool experiment design revolved around the capabilities of the UWKA. The objective was to explore the boundary layer in a wide valley and narrow valley case. To observe below the 1,000 ft. AGL flight minimum, regional airport accessibility was a major factor in valley selection. Therefore, the Cumberland Valley (Franklin County Regional Airport (N68)) and the valley containing Bendigo Airport (74N) were chosen. The flight path is shown in Figure 18. Meanwhile, a Windsond launch team launched two radiosondes: one in an intermediate width valley (near Pine Grove, PA) and one in conjunction with the Schuylkill County Airport (KZER) missed approach.

Also, the flux tower, LiDAR and SoDAR measurements were to be used to describe the relatively flat environment to the south and east of the target valleys.

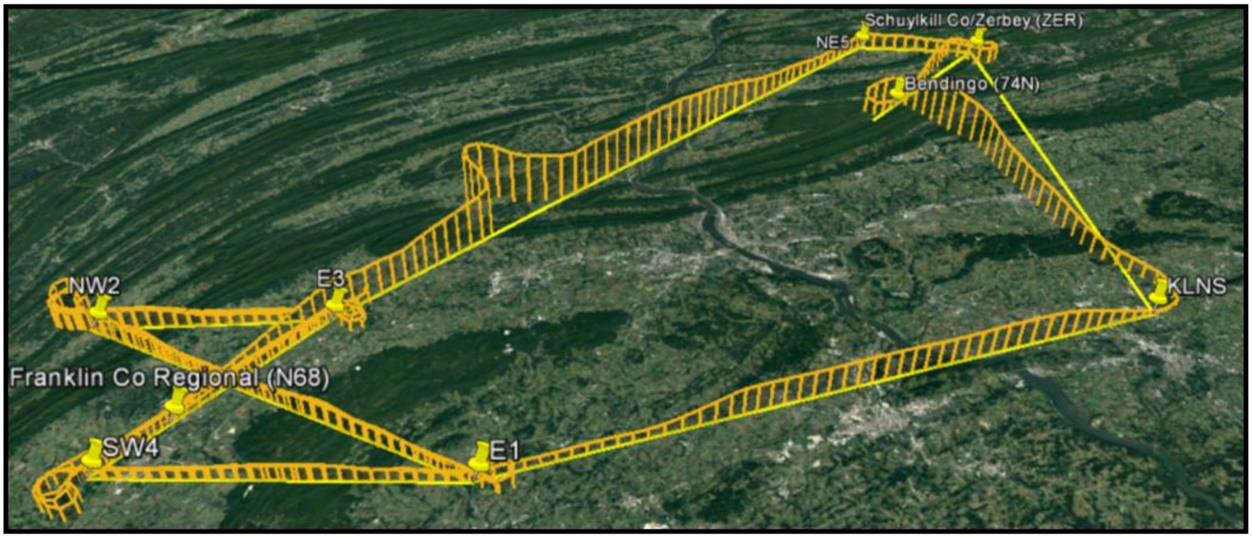


Figure 18: Flight track for RF08, the SEAR-MAR Cold-Pool mission on 11 NOV 2017. Yellow line represents the proposed flight pattern; the orange line the actual flight track.

The Cumberland Valley was interrogated with the UWKA using an hourglass pattern to obtain along-valley and cross-valley characteristics at various altitudes (1,000, 1,300 and 1,600 ft. AGL). Along the entering and exiting along-valley tracks, a missed approach was included to measure the near-surface environment down to 50 ft. AGL. Upon exiting the Cumberland Valley, in transit to Bendigo, an aircraft sounding to 7,000 ft. was executed.

Two missed approaches were incorporated into exploring the Bendigo Valley. KZER presented an opportunity to measure the ridgeline near Bendigo Airport as it lies overlooking a steep slope of a similarly sized valley approximately 24 km (15 miles) to the northeast. The second Windsond launch was executed from the valley floor beneath KZER concurrently with the missed approach. From KZER, the UWKA proceeded to complete a missed approach of the narrow valley floor at Bendigo Airport followed by a sounding up to 7,000 ft. The aircraft then returned to base.

Some preliminary findings were extracted from the sounding data. The lowest portions of the boundary layer in the valley appear to have mixed by the interrogation period. However, a stable, supergeostrophic wind maximum (Fig. 19) – a northerly valley-parallel low-level jet was observed along the ridgeline above the cold pools. The structure, formation and evolution of this wind maximum has excited interest in the student group and the subject of investigation.

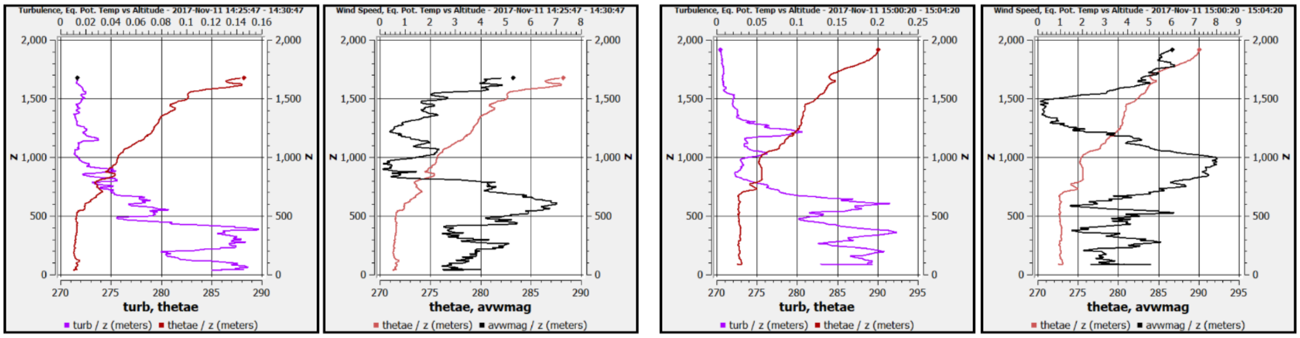


Figure 19: Vertical profiles from Cumberland, MD (left two) and Bendigo, PA (right two) on 11 NOV 2017 showing equivalent potential temperature (red), turbulence intensity (magenta), and wind speed (black) during an Appalachian cold-pool event.

e. Ocean-Bay-Land PBL Height Variability – RF09 and RF12

The planetary boundary layer (PBL) is the lowest layer of the atmosphere, encompassing surface interactions and most of the weather that affects daily life. The depth of the PBL starts at the Earth's surface and extends anywhere from a few hundred meters to a few kilometers above the surface depending on environmental conditions. This variability in PBL height is important for air quality, atmospheric chemistry, and weather. For example, most atmospheric constituents within the PBL mix homogeneously, thus a shallow PBL confines pollutants to a small volume, whereas a deeper PBL would spread those pollutants over a larger volume thus lowering concentration and potential health risks.

While some aspects of PBL height are understood (such as the diurnal growth and decay cycle forced by solar heating), height variability over diverse surface types is not very well understood and is a valuable topic for research. In general, urban areas produce more heat and thus the PBL tends to be taller over cities. Oceans are typically cooler than land, and thus have lower PBL heights. Transitions away from these regions towards rural or coastal areas are not well characterized, in part because most PBL studies utilize fixed ground-based or radio sounding measurements that observe points, rather than spatial variation. Aircraft measurements are a great opportunity to observe this spatial variability in PBL height.

Research flight 09 (RF09) was designed to investigate the PBL height changes along a track that included urban or suburban areas, a river, rural land, forest, coast, and ocean. This track is shown in Figure 20. The flight track of interest was repeated four times to build up a robust data set. The first and fourth legs were sawtooth altitude patterns flying in and out of the PBL to measure PBL height via in situ instruments and served the purpose of characterizing the atmospheric conditions in and above the PBL. The sawtooth patterns only provide six point-measurements of PBL height along the track. Flight legs two and three provided continuous PBL height observations along the track by flying at constant altitude above the PBL, using the downward-pointing backscatter lidar onboard the aircraft to retrieve PBL heights. RF09 was conducted around 1 to 3 PM local time, when the PBL is expected to be near its maximum height for the day.

Figure 20: Flight track for the RF09 PBL Height Variation science mission on the afternoon of 11 NOV 2017. The PBL in the mid-Atlantic region is uniquely complicated by the convolutions created by land, rivers, large bays, and ocean. The repeated leg was flown four times between Elkton, MD on the west end and 10 miles off the NJ coast on the east end.

The flight was successful as planned. In situ measurements during the sawtooth pattern legs showed clear distinction between the PBL and free troposphere above it. The Wyoming Cloud Lidar (WCL) measurements during the constant altitude legs captured PBL heights with good data quality for most of the flight. A section of the third leg lidar data is shown in Figure 21; PBL height differences of 400m or more were observed along the flight path.

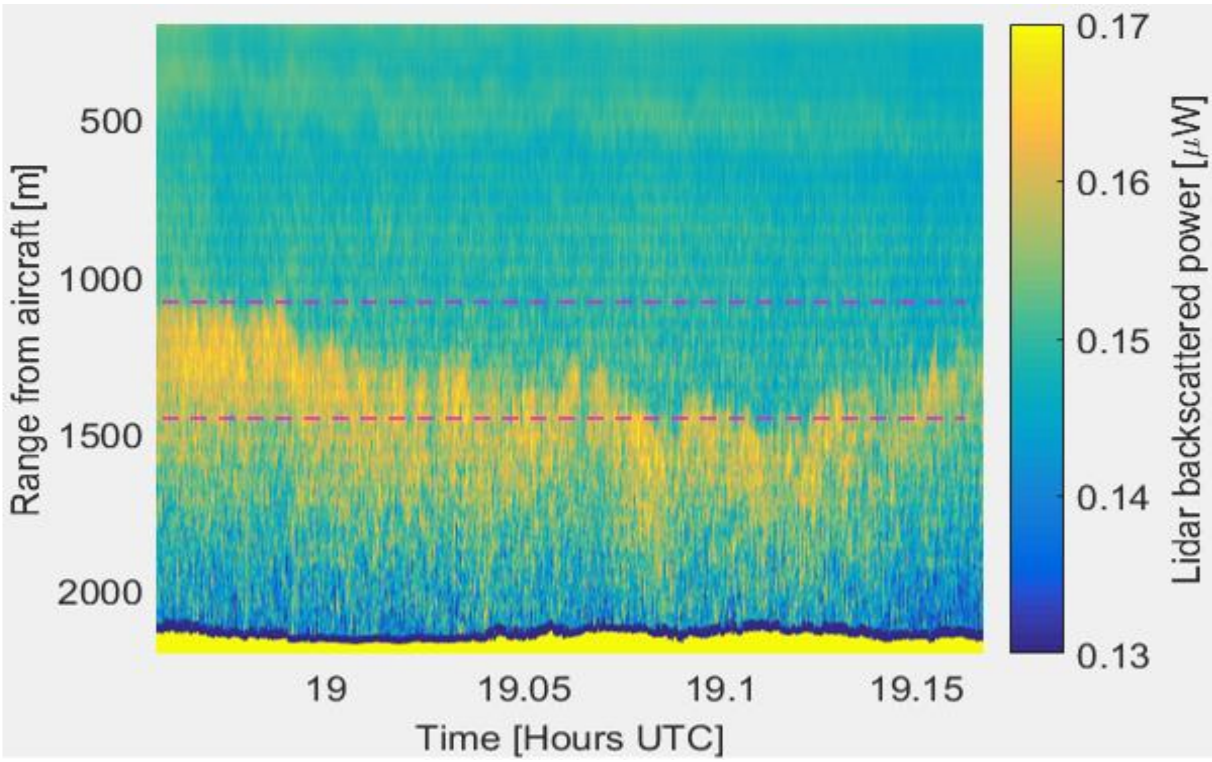


Figure 21: Downward-pointing lidar backscatter along an eastbound constant altitude flight leg for the RF09 PBL mission. Saturated signal at the bottom of the plot is the ground; high return above that is backscatter from well-mixed aerosols within the PBL, and hence the change from that high return to the uniform low signal above marks the PBL height. The two magenta lines highlight a PBL height change of ~400 m, from a maximum over urban/suburban land (left edge of plot) to lower values over rural land (right half of plot).

This analysis is still in preliminary stages. Future steps will improve data visualization and draw conclusions about PBL heights over different surface types. The impacts of the unavoidably coupled daily meteorology on this case study must also be considered. Extending beyond RF09, a similar flight path was flown for RF12 collecting PBL data shortly after sunrise. The RF12 dataset may corroborate the results of RF09, or provide new information about PBL spatial variability during the morning transition period. In the coming year, several graduate and undergraduate students will be using the data together with operational models for their research rotation work and some have expressed interest to use part of the data as a motivation in their master's thesis study.

f. Methane – RF05, RF06, RF13a, RF13b

The PSU science objectives focused on measuring methane emissions from coal mines and a watershed where methane leaks associated with gas drilling has been identified, and measuring carbon dioxide emissions from a high density metropolitan area (Philadelphia). One project sought to quantify emissions of methane from coal mines in southwestern Pennsylvania (RF06, 09 NOV 2017). Coal mines are reported to be the largest single point sources of methane emissions in the state of Pennsylvania. Figure 22 shows a strong plume of methane emanating from the location of the coal mine.

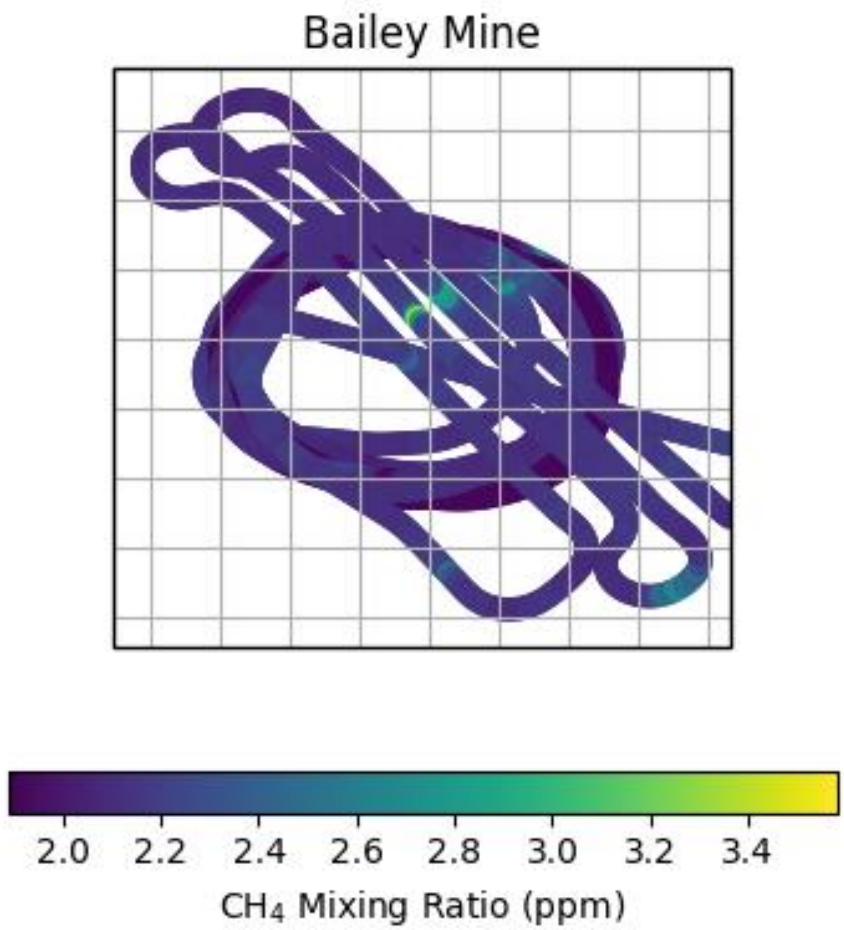


Figure 22: Methane mole fractions in a small circle (3 km radius) around the Bailey coal mine in southwestern Pennsylvania during SEAR-MAR RF06 on 9 NOV 2017. Most of the data are within the atmospheric boundary layer. Flight time is midday. Figure courtesy D. Wesloh.

Figure 23 shows data from the same flight segments, illustrating their position with altitude. The flight levels span the entire atmospheric boundary layer (ABL) and show methane mole fractions that are elevated as much as 1.5 ppm above the upwind ABL mole fractions of about 2.1 ppm. ABL depth is about 1 km, and lower, free tropospheric mole fractions of about 1.9 ppm are observed aloft. Emission were estimates from two coal mines using a mass balance approach (Karion et al, 2015). Uncertainties in the emission rates were large due to a complex and probably polluted background in one case, and limited vertical mixing (Figure 23) in the second case. A more sophisticated analysis approach would be needed to derive a more precise estimate of emissions.

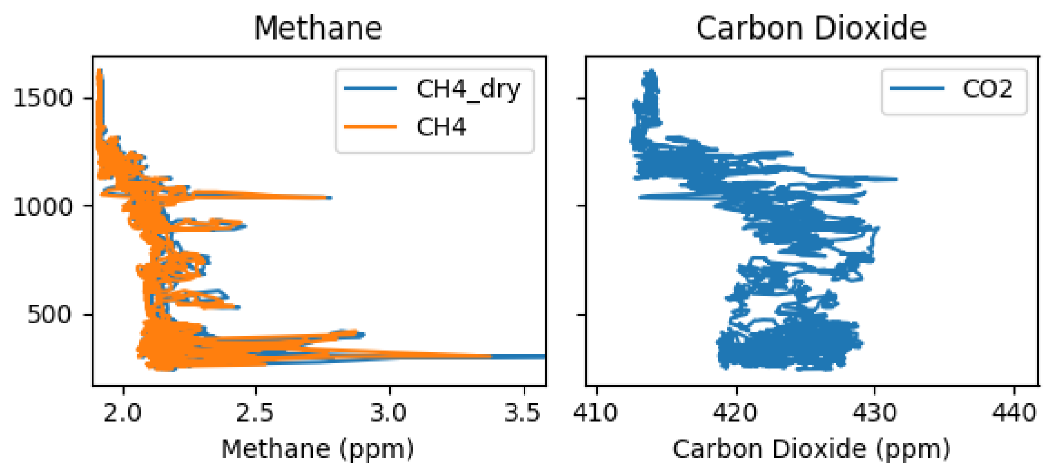


Figure 23: Carbon dioxide and methane mole fractions vs. altitude collected on spiral flights around the Bailey coal mine in southwestern Pennsylvania. Flight time is midday. Figure courtesy D. Wesloh.

A second effort aimed to quantify carbon dioxide (CO_2) emissions from Philadelphia (RF13a, RF13b). Upwind and downwind flights within the ABL (Figure 24) showed slightly elevated emissions downwind of the city, as well as heterogeneous upwind background conditions. The ABL on that day was surprisingly deep, and the flight was not high enough to locate the ABL top, leaving uncertainty concerning the depth of mixing. Emissions of CO_2 were estimated (2.9×10^2 tons C hr^{-1}) and were similar to the values available from a bottom-up inventory, albeit within fairly large uncertainty bounds in the airborne estimate.

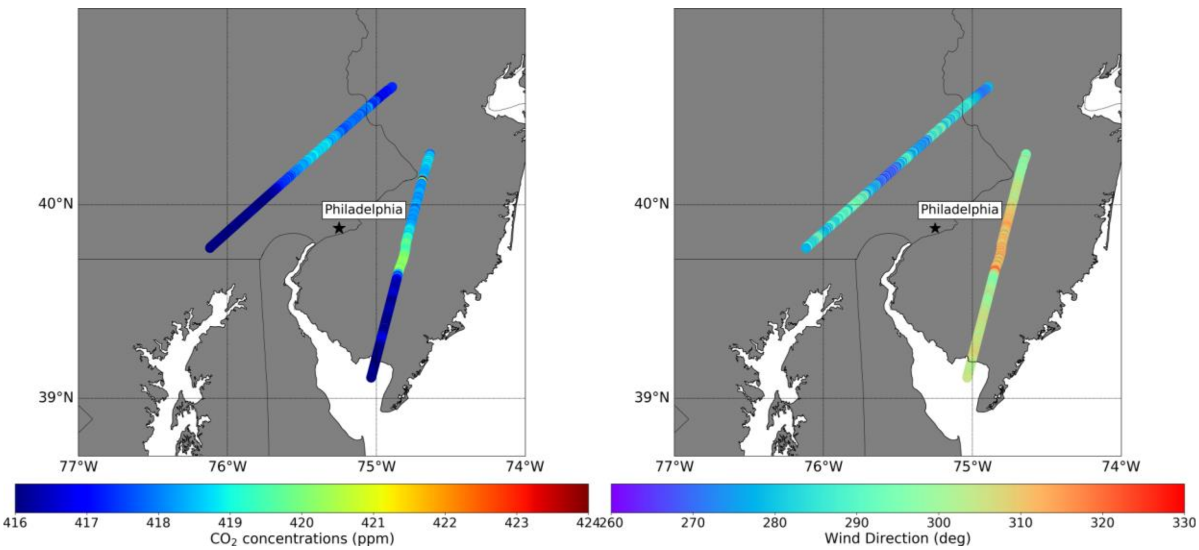


Figure 24: Wind direction and carbon dioxide mole fractions in the atmospheric boundary layer upwind and downwind of the city of Philadelphia. Flight time is midday. The star indicates the Philadelphia International Airport. Figure courtesy A. Samaddar.

The third research flight searched for emissions from a watershed where a natural gas well is suspected to be leaking (RF05-Sugar Run-Salt Springs). Very high methane mole fractions have been measured from the ground, but no quantification of emissions into the atmosphere exists. A grid of data was collected within the ABL over the region of the suspected well failure (Figure 25). Significant, heterogeneous enhancements of 50-100 ppb of methane were observed very close to the watershed and may be associated with the emissions from the watershed. The plume structure, however, was complex and difficult to attribute to a single source location.

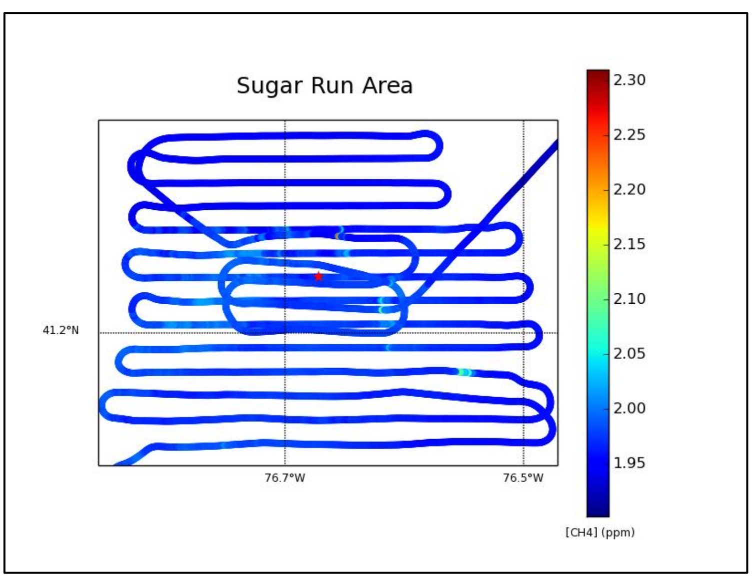


Figure 25: Methane mole fractions observed during a gridded flight over the Sugar Run watershed, east of Williamsport, Pennsylvania. Gridded flights were conducted at approximately 300 meters AGL, and at midday. A red star indicates the Sugar Run watershed.

g. PAM – RF11 and RF14

Rutgers' involvement with the SEAR-MAR aircraft research dealt primarily with gathering information to verify the accuracy of ground-based measurements of the lower atmosphere. Specifically, the wind speed and direction measurements from a 915 MHz Wind Profiler located on Rutgers Horticulture Research Farm 3 in East Brunswick, NJ. The instrument measures wind speed/direction and virtual temperature up to about 5,000 and 1,200 meters above ground level, respectively. The research aircraft made trips to the site on two different days and provided our first ever glimpse into just how well the ground-based instrument is performing. Figure 26 shows the flight track on 15 NOV 2017, RF11, and two days later on 17 NOV 2017, RF14 was used to perform a second aircraft pass over the PAM site and the Millersville MARAF site for instrument comparison as the final flight hours were expended (Figure 27).

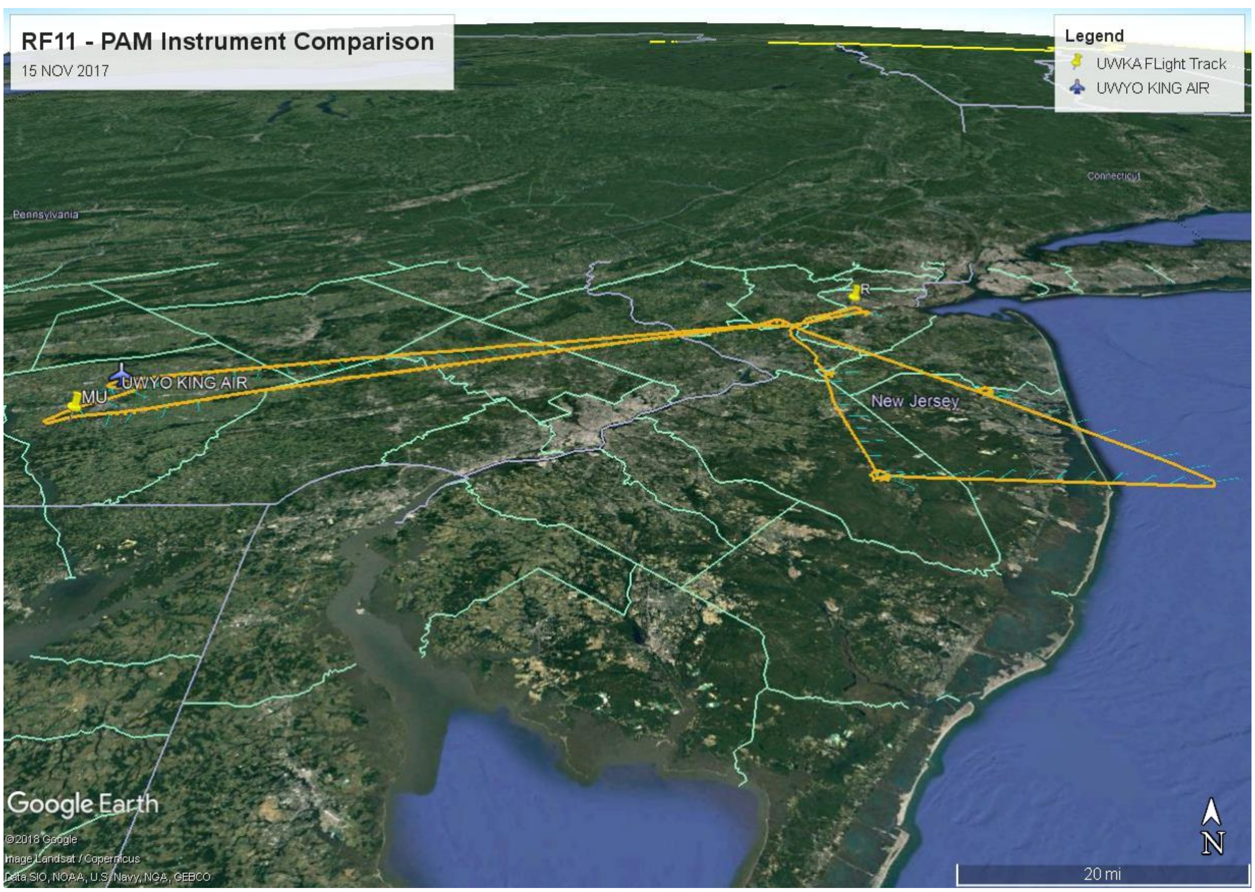


Figure 26: Flight track performed during the RF11 15 NOV 2017 mission to conduct an instrument comparison at the Rutgers PAM site and investigate the coastal PBL..

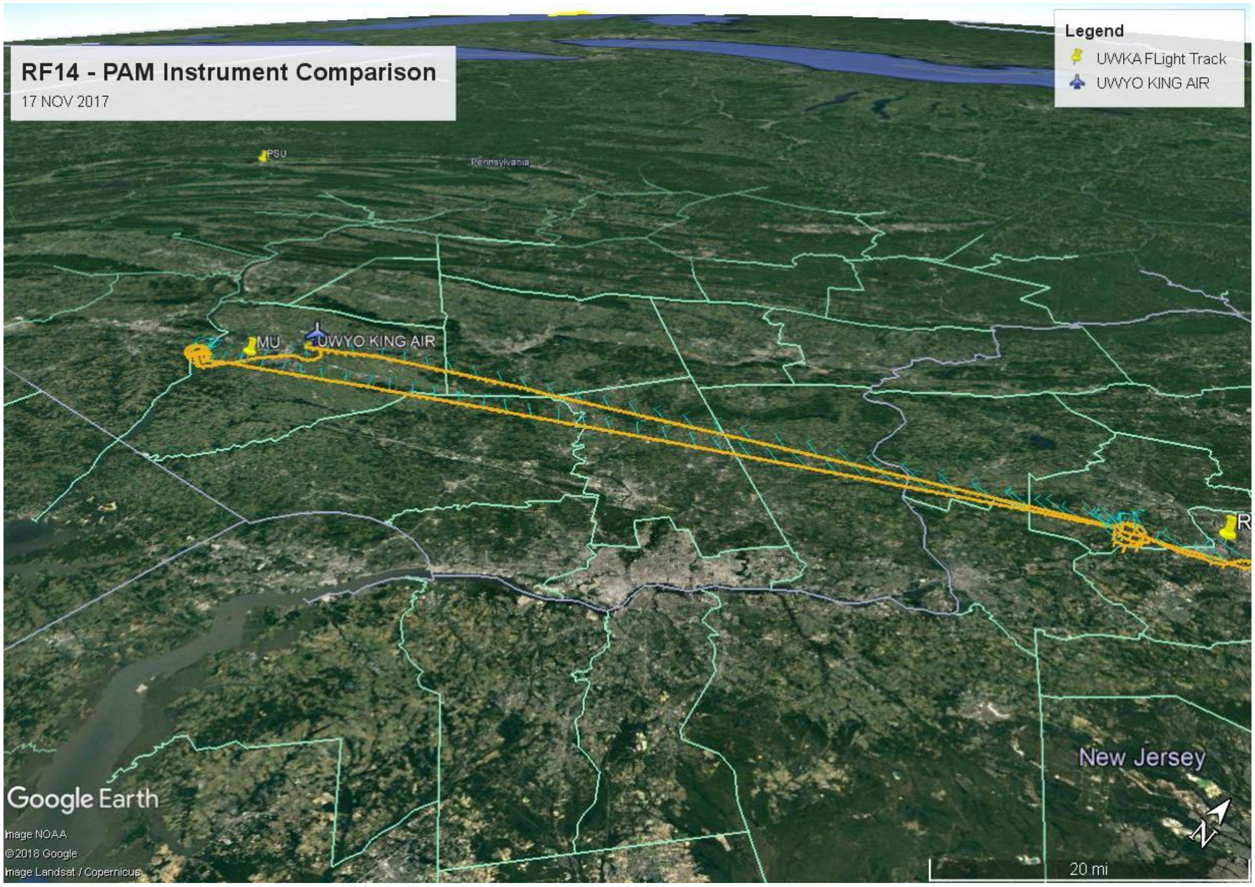


Figure 27: On 17 NOV 2017 the UWKA flew the last of the 40 flight hours allocated to the project. The mission was primarily to conduct an instrument comparison between the aircraft and two instrumented ground sites, the Rutgers PAM site and the Millersville MARAF.

It is important that this instrument, first installed in 1993, is still working accurately, as the data from this profiler will not only be used in my master's thesis which will be analyzing the longer-term trends at the site, but also because it is part of an official PAMS (Photochemical Assessment Monitoring Station) for the state of New Jersey. The profiler's data is used by the New Jersey Department of Environmental Protection's Air Monitoring Group to make crucial decisions about issuing air quality alerts and determining the causes of unexpected poor air quality events, so it must be accurate. As the site is situated over 'final approach' for Newark Liberty International Airport, launching radiosondes at the site is understandably impractical due to FAA regulations, so the aircraft flyovers were an excellent solution.

The other part of the PAMS aircraft flights were related to assessing boundary layer development over the state of New Jersey, both overland and just off the coast. The plane flew in a spiral over some set locations taking measurements to determine the boundary layer depth and dynamics.

Boundary layer measurements are an important component of many plume dispersion and behavior models, and therefore also play an important role in understanding and predicting air quality in the state. Not only that, but the comparison of the boundary layer development on land versus offshore is a valuable data set to have for future student projects.

Figure 28: Matthew Drews, Graduate Student, Rutgers University.

"My flight was one of the most exciting experiences of my academic career so far. I'd known about research aircraft and the vital purpose they served, but I never thought I would get the opportunity to fly in one and have the flight be related to my research so soon in my academic career. It was a tremendous learning experience and one that I would happily participate in again in the future. I look forward to incorporating the data from the flights into my master's thesis research."

Matthew Drews
Department of Environmental Sciences
Rutgers, The State University of New Jersey
Masters, Atmospheric Science, class of 2018

It was also a very helpful and interesting learning experience to see and participate in the logistics behind how field campaigns operate. It's something I don't think very many people know about unless they're directly involved with it. Working in the meteorology and atmospheric science field, this may not be the last field campaign I will be a part of. This campaign serving primarily as an educational and teaching deployment was a unique opportunity I feel fortunate to have been a part of. It will hopefully prepare me for future campaigns where a more basic understanding of the logistics might be assumed of the participants.

h. Static Pressure Defect – RF10

Aircraft rely on a static pressure sensor to determine airspeed and altitude from measured pressure outside the aircraft. Figure 29 shows two students identifying the location of the static pressure port on the King Air before the RF10 mission on 14 NOV 2017. The dynamic (ram) pressure data is obtained from the pressure transducer on the tip on the gust probe on the nose boom as illustrated in Fig. 30. There are static pressure ports on the nose boom as well (see Fig. 30), but they are not used in this analysis.

Figure 29: Two MU students point out the location of the static pressure port in the aft section of the fuselage of the King Air.

The static pressure measurements contain an inherent error or defect due to the turbulence fluctuations that impact the static pressure ports. Using data obtained during a specialized series of flight maneuvers of the UWKA, mathematical algorithms are being developed that will model the relationship between the variability in static pressure measured at the static port as a function of aircraft parameters pitch, roll, yaw, and airspeed. Statistical methods will be employed to quantify and reduce the uncertainty to a minimum. An algorithm can be used as an alternative in place of more expensive and time-consuming methods of static defect determination such as the

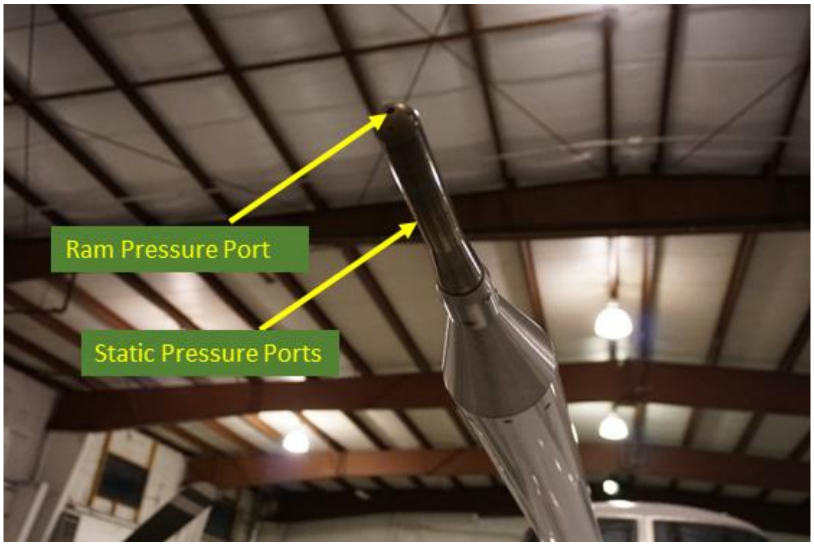


Figure 30: Close-up of the tip of the gust probe of the UWKA showing the ports used to measure ram (dynamic) and static pressure. Bernoulli's Principle for a compressible fluid is used to determine the true air speed.

trailing cone or tower fly-bys. The flight pattern was designed by the students, project scientists, and the UWKA crew, including the pilot (Fig. 31). The flight pattern is one of the more arduous and taxing on the crew. Students were informed before flying that in all likelihood they would experience some degree of motion sickness, and they did, but they deplaned smiling and enthusiastic.

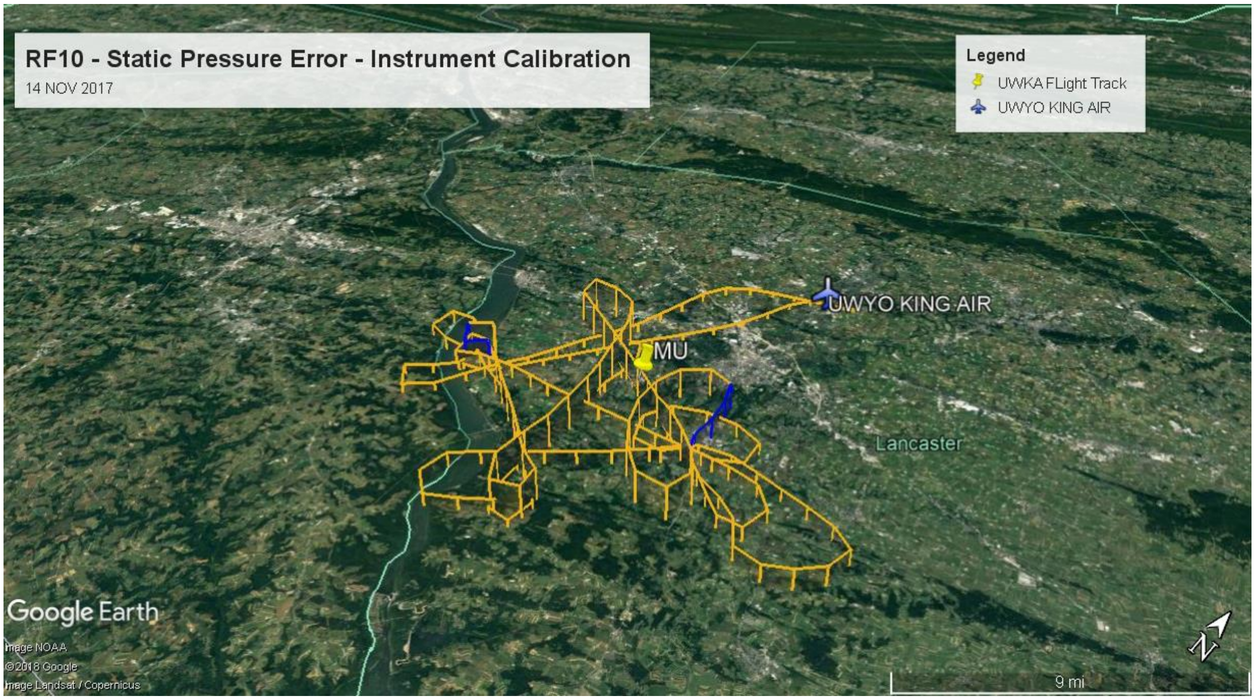


Figure 31: Flight pattern used for the determination of the aircraft static pressure error. The pattern was designed to maximize the variation in aircraft parameters (pitch, roll, yaw, airspeed, etc.) and to gather a sufficiently long data set to provide a statistically robust algorithm with which to estimate the error in static pressure measured at the static ports.

One student created a 3-D spatial plot of the UWKA track that highlights the various maneuvers accomplished during the RF10 mission (Fig. 33). Fortunately, because the sampling rates are high (100 and 25 Hz), it does not take long to generate a robust data set (~15 minutes; SEAR-MAR was extended to about 30 minutes of maneuvers.

Figure 32: Three MU students volunteered to crew the RF10 mission to fly a set of aircraft maneuvers where it was hard to avoid feeling some degree of motion sickness (clockwise from front left; Tim Keebler, Shelby Fuller, Amanda Fritz, and pilot, Tom Drew). Photo by T. Keebler.

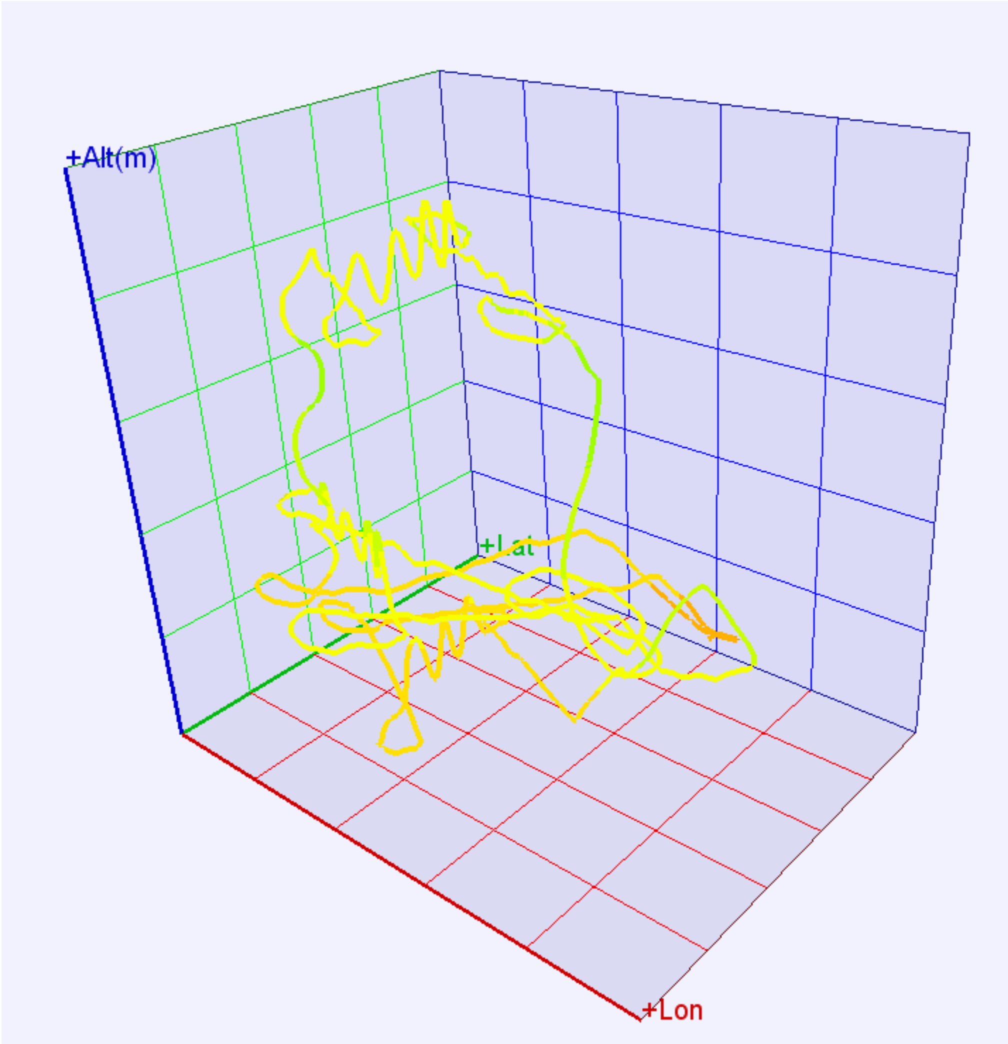


Figure 33: Three-dimensional flight volume plotted using AEROS software. Created by Timothy Keebler.

To determine fluctuations in static pressure defect, the UWKA research aircraft performed a series of variations in aircraft parameters along three spatial axes to isolate the effects of each maneuver. Pitch, yaw (heading), and airspeed were varied through a full range of aircraft motion for two minutes each at three different altitudes. The aircraft measures static pressure using two independent Rosemount 1501 High Accuracy Digital Sensing (HADS) pressure ports, two each for pilot and copilot systems, and a Weston digital vibrating cylinder pressure system. Static pressure ports are mounted aft of the wings on the fuselage (Fig. 29) and on the gust probe (Fig. 30), with each system having a static pressure port on each side of the aircraft. Data was collected at 100 Hz temporal resolution.

Time series of aircraft parameters pitch (Fig. 34), yaw or heading (Fig. 35), and true airspeed (Fig. 36).

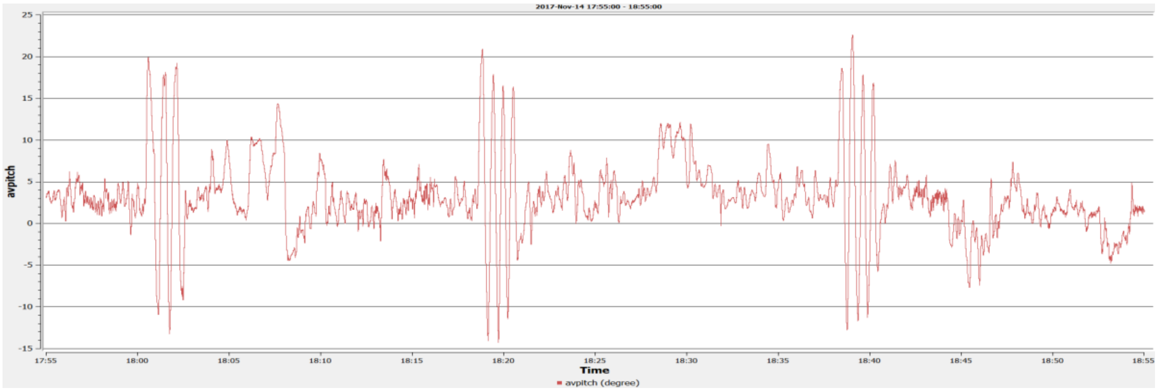


Figure 34: King Air aircraft pitch measurements. Note the three periods of regular variation that represent a series of porpoising maneuvers.

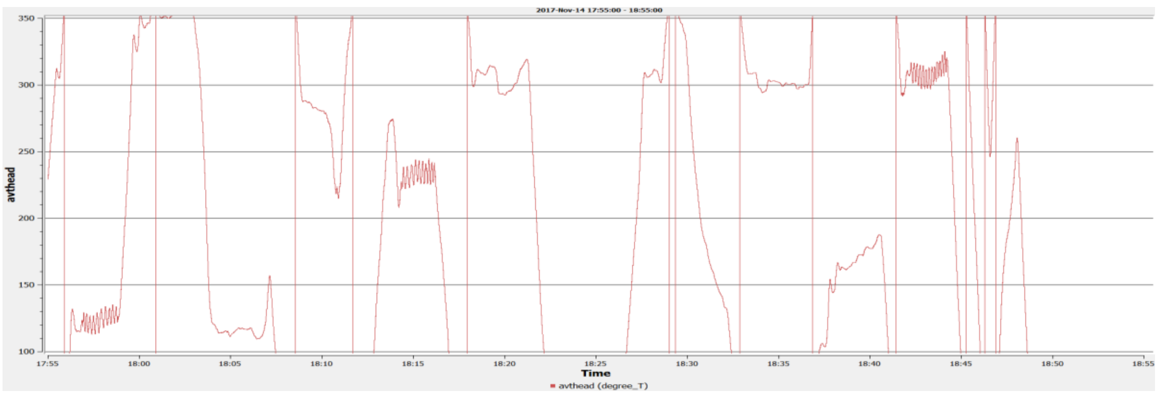


Figure 30: King Air aircraft true aircraft heading measurements. Note the three periods of regular variation that represent a series of maneuvers to vary yaw via the rudder.

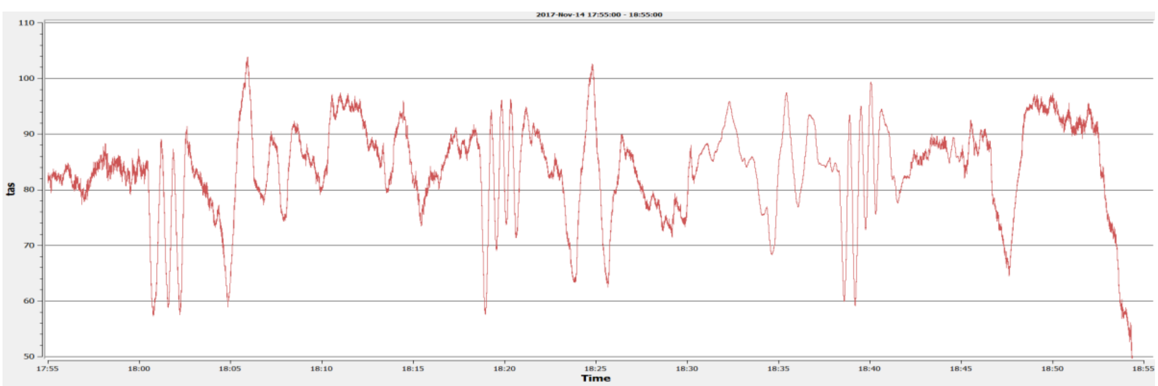


Figure 31: King Air aircraft true airspeed measurements. Note the three periods of regular variation that represent a series of maneuvers to vary airspeed.

Atmospheric conditions during the flight were stable, featuring light winds and a thin stratus layer with a ceiling of 4000 ft. Each aircraft parameter was varied according to the flight plan at

1000 ft, 3000 ft, and 7000 ft AGL, and with different headings to capture variability caused by wind direction and altitude. The flight pattern followed a diamond shape with orthogonal bisecting flight legs and 270° turns at each vertex, with only minor deviations due to conflicting air traffic. The next step in this study will be to use the data collected during RF10 to develop an empirical model of the static pressure defect using a multidimensional polynomial and regress the coefficients.

IV. Classroom Integration

MILLERSVILLE UNIVERSITY METEOROLOGY COURSES

Meteorological Instrumentation, Measurement, and Observing Systems (ESCI 447, Clark).
Synoptic Meteorology Lecture-Laboratory (ESCI 441, Sikora)
Mountain Meteorology (ESCI 390, Billings)
Atmospheric Thermodynamics (ESCI 341, Clark)
Atmospheric Dynamics (ESCI 342, Sikora)

SEAR-MAR took place in mid-semester (4-18 NOV) and can be defined by three characteristics: disruptive, challenging, and exhilarating. A typical project day started early and continued between classes, and for the flight crew, sometimes did not end until late in the day. For the 20 students enrolled in ESCI 447, *Meteorological Instruments, Measurement, and Observing Systems*, not only were they expected to complete the mission preparation tasks (e.g., preparing forecasts, flight updates, sounding deployments across the SEAR-MAR domain), but they also

Figure 37: Students attach instruments to the 10 m flux tower (left) and anchor the RASS dish on the SoDAR (right). In addition, students were required to learn the theory of operation of all the sensors on each platform.

had the course expectations since ESCI 447 was inextricably integrated into SEAR-MAR. The most significant of these responsibilities was the set-up our ground measurement site located about six miles from campus. The Millersville Atmospheric Research and Aerostat Facility (MARAF) was a significant component of SEAR-MAR research and research training in which students installed, operated, and dismantled a 10 m flux tower used for eddy-covariance measurements, ScinTec MFAS SoDAR with RASS extension for time-height profiles of wind, virtual temperature and turbulence statistics, MPL-111 Micropulse LiDAR for backscatter, PBL height, and cloud height, and two upper-air sounding systems for fixed and mobile atmospheric profiling. PSU and UMBC each had their own upper air sounding systems: 1) UMBC with the Vaisala RS41-SGP radiosonde, which was identical to the MU profiling system, and 2) the PSU Windsond identical to the MU mobile system. As part of the integrated course work, students were required to select an instrument that would be their primary responsibility, although as part of the lecture every student was taught the theory of operation of each instrument platform. ESCI 447 is a 3-credit/4 contact-hour a "writing intensive" course requiring students to complete a 2500 paper with revised prose on their instrument/sensor of choice. To take advantage of the concurrent educational deployment, students were required to write about half the paper on the instrument/sensor itself, including specifications and operational theory, one-quarter on how it complimented and integrated into the observing system that it comprised, and finally what was its value as part of the SEAR-MAR scientific mission. Coincidentally, the class was also exposed to a new set of MetEd learning modules being developed as a collaborative project between MU, the COMET program, and NCAR/Earth Observing Laboratory and with funding from the NSF (NSF Award # 1642643, PI: Clark). The module on *Instrument Performance Characteristics* was particularly relevant and useful to the class and its involvement in SEAR-MAR because students could relate the learning exercises to the authentic experience that SEAR-MAR provided. (see https://www.meted.ucar.edu/training_module.php?id=1349#.WosNF6gbPZs, registration and login required).

While the Instrumentation class was given preferred access to the King Air and other SEAR-MAR activities, the ability to perform field research in complex terrain with a research aircraft was a great opportunity for students in a special elective course titled ESCI 390 *Mountain*

Meteorology. The course was offered specifically for students taking part in those SEAR-MAR scientific missions that focused on the influence of complex terrain on the lower troposphere. The first integration of SEAR-MAR into class for these eight students was after a site visit by the Wyoming flight crew on 13 Sept 2017. Using information they provided, the evening lecture began with some guidance on how to prepare a flight path using Google Earth. Students were then encouraged to submit their own missions over the next two weeks. While only two students chose to attempt this, these plans did become the CAD and cold pool missions discussed previously. Later in the semester, there were two required project assignments related to SEAR-MAR. First was a participation project, which simply required that students involve themselves during the two-week deployment. To increase engagement, they had to participate in two out of four defined areas. One was to volunteer for the student forecasting team described in Section XX. Another was to assist with a radiosonde launch, which occurred both with Vaisala sondes at the base site and the Windsonds during the CAD and cold pool missions. A third possibility was to serve as a ground-based flight tracker. These individuals remained in the Weather Center for the duration of the flight following its progress using Aeros and NCAR Mission Coordinator and communicating using chat. They would pass any requested weather information to the aircraft, note any required deviations from the original flight path, and help to coordinate any changes to the mission plan. Three students would volunteer as flight trackers, and in each case, aspects of the operations plan were modified after takeoff. The fourth assignment object was to be attendance at any SEAR-MAR based classroom lectures or seminars, but when none of these occurred, this was replaced by a night where the Mountain Meteorology class was moved to the Lancaster Airport to coordinate with an aircraft visit by the department's freshman orientation course.

The second SEAR-MAR project in the Mountain Meteorology course was after the operations had ended. Students worked in pairs, and the four groups were required to analyze and give a short oral presentation on one of the four flights related to complex terrain processes (CAD, cold pool, mountain waves, and leeside cold front). Due to other course requirements near the end of the semester, this project was not done outside of class but instead occupied the final three-hour meeting before finals week. Despite the short time frame, groups were still able to pick out a significant finding in their track data. They also created interesting and personalized presentations with good use of images, such as Aeros and IDV track output, King Air camera stills, and supplemental operational weather data. Some students would later state that the Aeros experience for this project helped with later construction of posters for the AMS Annual Meeting in Austin.

ESCI 441 *Synoptic Meteorology* (LECT/LAB) is a 3 credit, 6 contact-hour required course in the major. Synoptic Meteorology covers the application of atmospheric dynamics and atmospheric physics to the theoretical and empirical investigation of mid-latitude synoptic-scale meteorological processes. Topics include the diagnosis of synoptic-scale vertical motions, the circulation at fronts and the life cycle of the extratropical cyclone and was nicely aligned with the many of the scientific missions, in particular, the fine structure of fronts and cold air damming. However, it could be that the greatest value that ESCI 441 was its forecast preparation for students involved in SEAR-MAR. Students, with instructor supervisor, prepared three forecasts each day for SEAR-MAR: 1) the 5-day forecast, 2) 24-hour forecast, and 3) the 3-hour-prior pilot/crew briefing. These forecasts required considerable time gathering, analyzing, and interpreting model output, imagery, and surface and upper air data to produce a reliable forecast and guidance for all missions, including for flight operations from other partner schools. In addition to SEAR-MAR offering unique integrated experience for students in this course, the forecasting component elevated the competency levels of students and better prepared them for what they are encountering in the spring semester in a special skills course that we offer, ESCI 442, Advanced Weather Analysis and Forecasting.

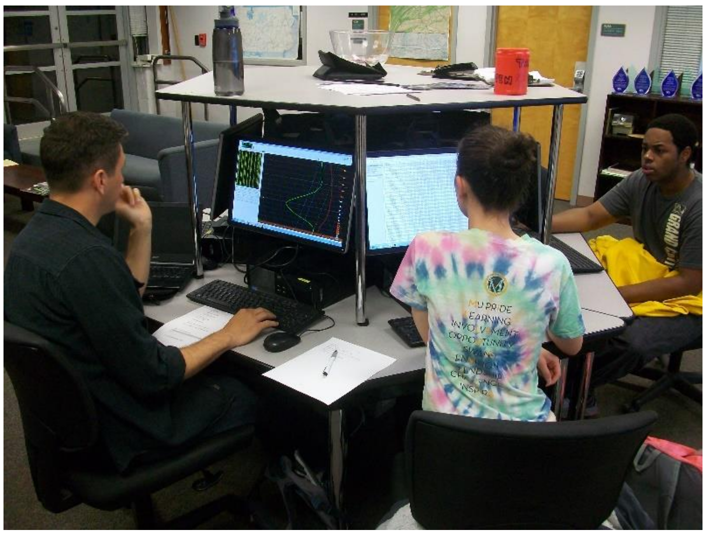


Figure 32: Students preparing the pre-flight update for the first IOP on 4 NOV 2017. Teamwork was critical in producing a useful and reliable forecast.

At Penn State, six enrolled and four auditing graduate students in Penn State’s Meteorology 597, *The Global Carbon Cycle*, planned and analyzed three research flights as part of the SEAR-

MAR project. The students were in the process of learning about the pools and fluxes of carbon in the earth system, focusing especially on the processes governing the atmospheric pool of these greenhouse gases. Early in the course students are introduced to a variety of atmospheric methods used to study sources and sinks, both natural and anthropogenic, to the atmosphere. Students were divided into three groups of three students, and asked to plan a research flight that would address a research problem in the field of carbon cycle science. Students were asked to write a brief scientific justification for the flight, including references to current research literature, and to design and submit flight plans that could accomplish their research objectives.

After modest feedback from the course instructor, Prof. Kenneth Davis, the students were invited to submit the flight plans to SEAR-MAR PI, Prof. Richard Clark, and to take part in flight planning discussions. The graduate students self-organized such that representatives cognitive of the group's three flight plans attended planning meetings before and during the flight campaign. All three flight plans were conducted during the course of the field campaign. One student flew on the King Air as a scientific observer for the research flight that his group designed.

Students were invited to analyze their flight data as a final project for the course. Five of the six enrolled students chose to analyze SEAR-MAR flight data for their final course project, and three of the five chose to apply a simple atmospheric boundary layer (ABL) mass-balance approach to quantifying greenhouse gas emissions from anthropogenic sources. A few of their findings are summarized here.

Also at PSU, undergraduate meteorology majors enrolled in Dr. P. Markowski's *Mesoscale Meteorology* course were actively involved in supporting each scientific missions and collaborated with MU on several mesoscale events. In particular, the PSU undergraduates deployed their Windsond upper air sounding system to support frontal fine structure, cold-air damming, cold pools, and others.

Rutgers and UMBC used SEAR-MAR for special studies and Honors College capstone projects. Rutgers integrated SEAR-MAR into *Physical Meteorology*, exposing 20-30 students to aircraft operations while conducting a first-ever inter-comparison of its PAM site. Three (3) Honors

Scholars doing research in cloud physics in the marine BL were took advantage of SEAR-MAR to study stratus/nimbostratus moving on-shore in the mid-Atlantic region.

UMBC engaged 20-30 students who took their experiences back to present a series of seminars for undergraduates, and to integrate their courses in graduate level atmospheric physics.

V. Outreach

The four partner institutions were committed to leveraging SEAR-MAR for outreach to the public, academic, and scientific communities. This took on several different forms depending on the institution and the logistics of engaging their communities. UMBC and Millersville created PR media overviews for SEAR-MAR, which bookmark this final report at the beginning and end, and/or were interviewed for the local news media distribution with articles appearing in local newspapers and online media or as video segments on local TV stations. The photos in Fig. 39 below of a Millersville undergraduate (left) and a UMBC Ph.D. student (right) are example of the interaction with media.

Figure 33: Engaging the media was one form of successful outreach during SEAR-MAR. Left: Tim Keebler (MU, undergraduate meteorology) is interviewed by the NBC news affiliate WGAL TV8, Lancaster, PA during an open house at the UWKA hangar. Right: Zhifeng Yang (UMBC, Ph.D. atmospheric physics) describes his participation in SEAR-MAR before one of the boundary layer missions.

More substantive outreach had many tentacles including a special Millersville University Weather Watch segment produced by students who took part in SEAR-MAR (https://www.youtube.com/watch?v=XlQxwsfX5CY&feature=youtu.be (see time between 1:54 to 5:09 minutes). MU had the advantage of having the UWKA nearby at KLNS so that we were able to host visits such as the STEM Sisters, a group of middle school girls (Fig. 40) who participate in a program of this name, which is offered by the North Museum of Nature and Science in Lancaster, PA (https://northmuseum.org/stemsisters/), and over 50 freshmen meteorology majors from MU program. In addition, 58 6^{th}-graders and half-dozen teachers and the principal from Ann LeTort Elementary School in Manor Township, Lancaster County had the chance to see the plane as it flew a low over the school and launch and track a radiosonde as part of a visit during SEAR-MAR. Two Millersville students spoke to the 6^{th}-graders about SEAR-MAR and weather in general. PI Clark discussed general topics in science and careers in

Figure 40: Six STEM-Sisters visit the hangar and are given a tour of the aircraft. STEM-Sisters is a program of the North Museum of Nature and Science in Lancaster, PA. Its goal is to entrain more female students into STEM areas.

atmospheric science. The visit to LeTort School was coincidentally aligned with their current lesson about weather and climate, so our timing could not have been better. Students were highly engaged and participatory. Fig. 41 is photo collage of the LeTort visit including a view of the student group from the plane (top-left).

Figure 41: A photo collage of the outreach activities during the MU visit to Ann LeTort School. In all, 58 students took part in these activities.

The period from 4-18 NOV 2017 when the partner institutions were actively involved in the UWKA deployment, spending extended time on outreach was a challenge. Now that the field campaign is behind us, the partners are committed to continued collaboration and outreach. On April 26 Dr. Ken Davis from PSU will give a seminar at MU on methane emissions, which will include the SEAR-MAR data collected over western PA during the coal mine and Sugar Run missions. With this spring and summer offering opportunity for further investigation of the scientific missions, we anticipate that students and project scientists will be invited to give talks at partner institutions, non-partner institutions, and present papers at professional conferences on SEAR-MAR. One event currently on the calendar is that R. Clark will lead a break-out session at the UCAR October Meeting on the value of using the NSF-NCAR/EOL deployment pool for educational enhancements.

VI. Future Research and Research Training

With 40 hours of aircraft time, 15 science missions, and scores of students enthusiastic for independent research projects, honors theses, and graduate student research, there will be a sustained interest in the value of the SEAR-MAR data and opportunity to present and publish. This summer the partners of this multi-institutional collaborative will submit a manuscript to the *Bulletin of the American Meteorological Society* (BAMS) describing for the atmospheric and related sciences community the SEAR-MAR educational deployment. Students are already working with their mentors on some of the scientific missions including, but not limited to frontal fine structure (MU/PSU); cold pool (MU), cold air damming (MU), static pressure defect (MU), mountain waves(MU/PSU), methane emissions (PSU), on-shore flow (RU), and complex planetary boundary layers (UMBC). The collaboration has brought the partner schools closer under the common cause of education and research. Every effort will be made to maintain the collaborative to bring this research to fruition by providing meritorious opportunities for students. Data gathered during SEAR-MAR and the resulting research can be used to seed new funding for further investigation. In fact, surprising atmospheric conditions have been observed that demand further inquiry and could lead to discovery. As we move beyond SEAR-MAR, new students, not involved in the field component, will be exposed to SEAR-MAR through data analyses and subsequent research opportunities.

VII. Student Summaries and Testimonials

1. MILLERSVILLE UNIVERSITY

Millersville University students involved throughout SEAR-MAR worked directly alongside professors and researchers from Penn State University, Rutgers University, and the University of Maryland - Baltimore County. In this regard, students held instrumental leadership positions and accrued responsibility before, during, and after the UWKA educational deployment. Approximately 60 undergraduates from Millersville University participated in various SEAR-MAR initiatives, including planning experimental flight paths, updating daily forecasts and weather briefs, serving as research scientist during fifteen UWKA missions, and employing an observation system (via SODAR, LiDAR, Flux Tower, Radiosondes, and Windsondes). Students represented all class levels (freshman through senior) and provided accounts of their experiences during SEAR-MAR. Detailed below are their testimonies.

Experiment and Flight Path Design:
During the summer leading up to SEAR-MAR, students prepared for the project by studying climatologically likely events and designing experiments around those probable patterns. Senior meteorology major Robert Capella explains, “Preparing for SEAR-MAR was just as hands-on as the project itself. We developed a climatology of likely frontal passages and other probable features. Afterwards, we interrogated the ideal events with the WRF model and visualization software packages. Finally, while collaborating with the pilot, we developed flight paths that would be ready for different synoptic regimes. It was an exhilarating feeling to see the events we predicted and prepared for play out during SEAR-MAR.”

UWKA Missions:
Millersville University’s UWKA missions focused on instrumentation—including statically characterizing the defect in the aircraft’s static pressure sensor—as well as regional weather features such as topographically induced gravity waves, cold front propagation, and cold air damming. Timothy Keebler, a junior MU meteorology major and member of the Static Pressure Defect mission writes, “[SEAR-MAR] was an excellent opportunity to get firsthand experience with research aircraft operations. Each flight carried three students; it was their responsibility to direct flight modifications in-air.”

For some Millersville students, this opportunity represented more than a research flight. Junior meteorology major, Grant Carlton writes, “I am proud of the work that everyone has put in, and have learned so much from the incredible crew of the King Air. For this being my first time on any aircraft, I am so please of the outcomes and look forward to the research ahead.” Freshman meteorology major, Chad Wiley recollects, “Reflecting on my opportunity to fly in the SEAR MAR airplane was an opportunity that will be one of the defining moments in my academic career at Millersville University. The experience cemented my love for meteorology and helped to ignite a passion for getting involved in [MU Meteorology Department-sponsored activities such as] AMS and Campus Weather Service. Coming into the project, my knowledge about meteorology was limited (being a first semester freshman) but this project gave me valuable field experience as well as a greater knowledge for my major. Overall, the SEAR-MAR project was an unforgettable experience that will stay with me for a lifetime.”

Alyssa Cannistraci, a senior meteorology major at MU, notes that although she felt nauseous onboard the UWKA, she was incredibly grateful for this unique opportunity. She elaborates, “SEAR-MAR was certainly a highlight of my undergraduate time at Millersville University. I can now say that I can safely operate an Allen wrench as well as set up a Flux Tower. SEAR-MAR ultimately provided lasting memories and experiences that I do not take for granted.”

Forecasting, Weather Briefs, and Flight Operations:
In support of the fifteen UWKA missions, Millersville students briefed SEAR-MAR flight crew and project investigators with daily weather conditions. This effort, led by Millersville Assistant Professor of Meteorology Dr. Brian Billings, introduced students to an operational forecasting environment similar to a WFO. Students worked around the clock to update weather discussions. This included arriving to the Millersville University Weather Information Center in the extremely early hours of the weekend. Senior meteorology major Erin Jones reflects, "Forecasters sometimes had very early mornings preparing for that day's flights. One morning, I started my forecasting duties at 3am! It was definitely worth it, though, to see the success of that day's mission." Senior meteorology major, Blaik Thompson writes, "I was tasked with preparing forecasts for some of the flights during SEAR-MAR. I learned the basics of aviation forecasting, what to find for certain events that we were studying, and the use of the program BUFKIT in order to give descriptive forecasts for pre-flight briefing. I thought that this was an amazing experience to increase my skills and interest in forecasting by learning different aspects, and also hopefully use what I experienced for future career opportunities." Senior Colin Eberwein, reflects on his flight-watch experience, "During SEAR-MAR, I was involved with flight tracking. I monitored and communicated with the copilot and students aboard the cold air damming flight over central PA. Having no experience with meteorological instruments before SEAR-MAR, it was a very rewarding and beneficial experience."

SEAR-MAR Class Integration:
Students enrolled in Millersville University's ESCI 447 Meteorological Instrumentation had a unique opportunity to gain exposure to instruments such as SODAR, LiDAR, Flux Tower, Radiosonde, and Windsond. Amber Liggett, a senior meteorology major writes, "With SEAR-MAR being my first experience with the Flux Tower, I came away with a greater understanding and appreciation for this instrument." Moreover, Tim Keebler describes, "In Meteorological Instrumentation, our class was primarily responsible for the setup and operation of our ground [observing system]. We assembled a 10-m Flux Tower and Micro Pulse LiDAR at a representative site with only moderate assistance from professors. Most of our instruments at Millersville are operated by student expertise, and this project was no different." Shelby Fuller, Millersville senior meteorology major, concurs with Keebler. Fuller explains, "Having the opportunity to fly onboard a research aircraft was the most rewarding experience of my undergraduate career. It opened my eyes to the different possibilities that are present in atmospheric research. Also, getting the chance to set-up, maintain, and collect data from instruments like the LiDAR, SODAR and Flux Tower gave valuable hand-on experience in field research. SEAR-MAR, as a whole, helped students gain marketable skills and knowledge that can greatly benefit them in future research and professions."

The UWKA aircraft was also used in Millersville University's ESCI 390 Mountain Meteorology course to exemplify, in a dramatically physical manifestation, many of the Appalachian Mountain effects that drive Mid-Atlantic weather. Three UWKA missions were directly incorporated into class content: Mountain Wave (RF07), Cold Air

Damming (RF08 and RF01), and Cold Pool. In reflecting upon the Cold Air Damming mission, junior meteorology major Brian Rinaldi writes, “It was an enjoyable experience to be a part of the King Air Cold Air Damming team. My role was to help launch two Windsonds, one in Antietam, MD and one in Waynesboro, PA. We had to prepare the sondes, sync them to the computer, and tie them to the balloon before we could launch. The fun came when it was time to recover [the Windsonds]. The Waynesboro sonde was an easy recovery as it landed on a nearby farm. The Antietam sonde was trickier, as it blew over the Potomac River into West Virginia. Fortunately, we were able to access the property and recover the Windsond. I am very glad that I got to take part in this research experience because of all the things I learned, and all the new people I met.”

The Mountain Meteorology class worked with Dr. Billings in designing appropriate flight paths and forecasting weather conditions. Moreover, students presented upon data at the end of the semester in the form of a final project. Graduating senior, Amanda Sleinkofer assisted in developing an excellent visual representation from the flights via IDV and AEROS software. Various Millersville students are using SEAR-MAR data for conference presentations and senior theses. Keebler is presenting upon his work—surrounding static pressure defect—at the 43rd annual Northeast Storms Conference in March 2018. Senior meteorology major Erin Jones is writing her senior thesis on the assimilation of flight and sounding data, and its influence on simulating fine-frontal structures. Keebler summed up the general conscience of student opinions concerning SEAR-MAR when he writes, “There is no better way to learn instrumentation than a field experience where one must consider both the theory behind site selection and instrument operations as well as apply this knowledge in an operational setting from data collection through analysis.”

2. PENN STATE UNIVERSITY

Dr. Ken Davis’ Graduate Students

Student A

“… thanks are given to multiple people and organizations for making this research project possible. First of all, this paper would not have been possible to write if it were not for the University of Wyoming for providing the King Air aircraft, as well as the National Science Foundation for funding this research. Furthermore, the unforgettable opportunity to fly on the King Air and be an active part of this research mission would never have arisen if not for Dr. Ken Davis (professor of my Global Carbon Cycle class) and Dr. Paul Markowski (professor of my Mesoscale Meteorology course). Their collaboration and effort to make students an active part of this project is much appreciated.”

Student B

“When we began the project, I was completely inexperienced with flight planning and even atmospheric gas measurements. The experience we gained designing and planning a flight, collaborating with our group members, and learning about how large-scale, cooperative collaborations between other universities function was invaluable.”

Dr. Paul Markowski's students
I appreciated this experience as it offered real time data for real time situations. I also appreciated witnessing firsthand where data collection can go wrong.

I was excited when Dr. Markowski informed us that we would be doing balloon launches in our Mesoscale Meteorology class. When it came down to actually launching the balloons, it was an incredible experience. There was always competition to see whose balloon launch would get the highest. Each time we did a launch we observed something unique to the other launches, whether it were intense gravity waves or intense shear. I remember a specific time that I launched a balloon and it got caught in a jet stream at around 300 hPa - the balloon was traveling horizontally at 115mph! An added bonus was the fact that we could track the 3-D path of the balloon as it rose through the atmosphere. The balloon launches were a great idea and a great supplement to an already amazing class, it was also rewarding to know that the sounding data we collected would be used as supplemental data for actual research.

It wasn't until Dr. Markowski's mesoscale meteorology class that I had the opportunity to launch weather balloons. Needless to say, I was extremely excited about this opportunity. I was able to launch a balloon several times and it was such an amazing experience being able to do something like this. Even though you're essentially just letting a balloon go into the atmosphere, this is something I've always wanted to do. I also thought it was really cool to be able to see the real time data come right into the program that we were using. This is an experience I will never forget, and I am truly honored that we were able to partake in this opportunity.

3. RUTGERS UNIVERSITY

My involvement with the SEAR-MAR aircraft research dealt primarily with gathering information to verify the accuracy of ground-based measurements of the lower atmosphere. Specifically, the wind speed and direction measurements from a 915 MHz Wind Profiler located on Rutgers Horticulture Research Farm 3 in East Brunswick, NJ. The instrument measures wind speed/direction and virtual temperature up to about 5,000 and 1,200 meters above ground level, respectively. The research aircraft made trips to the site on 2 different days and provided our first ever glimpse into just how well the ground-based instrument is performing.

It is important that this instrument, first installed in 1993, is still working accurately, as the data from this profiler will not only be used in my master's thesis which will be analyzing the longer-term trends at the site, but also because it is part of an official PAMS (Photochemical Assessment Monitoring Station) for the state of New Jersey. The profiler's data is used by the New Jersey Department of Environmental Protection's Air Monitoring Group to make crucial decisions about issuing air quality alerts and determining the causes of unexpected poor air quality events, so it must be accurate. As the site is situated over 'final approach' for Newark Liberty International Airport, launching radiosondes at the site is understandably impractical due to FAA regulations, so the aircraft flyovers were an excellent solution.

The other part of the PAMS aircraft flights were related to assessing boundary layer development over the state of New Jersey, both overland and just off the coast. The plane flew in a spiral over some set locations taking measurements to determine the boundary layer depth and dynamics. Boundary layer measurements are an important component of many plume dispersion and behavior models, and therefore also play an important role in understanding and predicting air quality in the state. Not only that, but the comparison of the boundary layer development on land versus offshore is a valuable data set to have for future student projects.

"My flight was one of the most exciting experiences of my academic career so far. I'd known about research aircraft and the vital purpose they served, but I never thought I would get the opportunity to fly in one and have the flight be related to my research so soon in my academic career. It was a tremendous learning experience and one that I would happily participate in again in the future. I look forward to incorporating the data from the flights into my master's thesis research."

It was also a very helpful and interesting learning experience to see and participate in the logistics behind how field campaigns operate. It's something I don't think very many people know about unless they're directly involved with it. Working in the meteorology and atmospheric science field, this may not be the last field campaign I will be a part of. This campaign serving primarily as an educational and teaching deployment was a unique opportunity I feel fortunate to have been a part of. It will hopefully prepare me for future campaigns where a more basic understanding of the logistics might be assumed of the participants.

4. UNIVERSITY OF MARYLAND – BALTIMORE COUNTY

As a participant team from the University of Maryland, Baltimore County (UMBC) in the SEAR-MAR project, we joined in the whole process of the study of the atmosphere from an airborne platform (University of Wyoming King Air), even though there were only two experiments conducted by UMBC among 14 flight experiments. From the very beginning, we had discussions led by Dr. Richard D. Clark on the plan for each possible flight experiment before the project began. Each participant university submitted multiple planned flight paths with science objectives and requirements. During the campaign we had pre-flight meetings to discuss the real-time weather conditions on the experiment day and made any necessary adjustments to the flight path on that day. Through these meetings, all the attendees could give a brief analysis of the weather conditions based on various forecasts and observations. On most days we also had a noon update on flight observations, next-day plans, and any other relevant matters. The flight crew would report conditions and observations from completed flights. This update was a great experience on summarizing the past flight experiments and better conducting the future ones.

The UMBC team conducted two exciting flight experiments based on our own interests. Our team was led by Dr. Belay Demoz and Dr. Zhibo Zhang with students Brian Carroll, Christiana Sasser, and Zhifeng Yang as team members. The first experiment was designed for studying the cold front, with a goal of catching a weak front traveling from urban areas (near Philadelphia, PA) to the ocean. The second experiment was conducted to study the planetary boundary layer (PBL) variability between the land and ocean. The preferred clear and sunny day was good for PBL development, especially during the late morning or early afternoon. During these two experiments, UMBC students went to Lancaster, PA and flew onboard the King Air and collected data.

In conducting this project, we learned how to lead an experiment, how to apply what we learned in class to the real situation, and how to analyze the collected data. Along with these valuable new lessons it also reinforced our knowledge learned in classes. First, we learned how to lead a project. Dr. Richard D. Clark led the discussion almost every day. He is an excellent leader in this project. He analyzed the weather and collaborated with other PIs and students. Second, we refreshed our knowledge learned in classes and applied it to this project. From listening and participating in discussions for other teams' experiments, we knew how others prepared their experiments and how they worked together to get experiment done. Third, during and after our experiments, we learned how to adjust our flight paths and how to analyze the data collected by our lab in the air (King Air). Figure 1 is an example of the data we collected during the PBL variability experiment. There were two lidars onboard, one pointing upwards and one downwards. From the observation of these two lidars' measurements, we could determine the variation of PBL height. Figure 1 shows upward-pointing lidar observations of PBL height in the transitional region between the land and ocean. The PBL is very high on the land (time before 19:40:27), but the PBL became shallow later while the flight was over the Atlantic Ocean. Then when we came back to the land from the ocean (19:43), the PBL became thicker. This is an excellent experiment which captured the PBL transition between land and ocean.

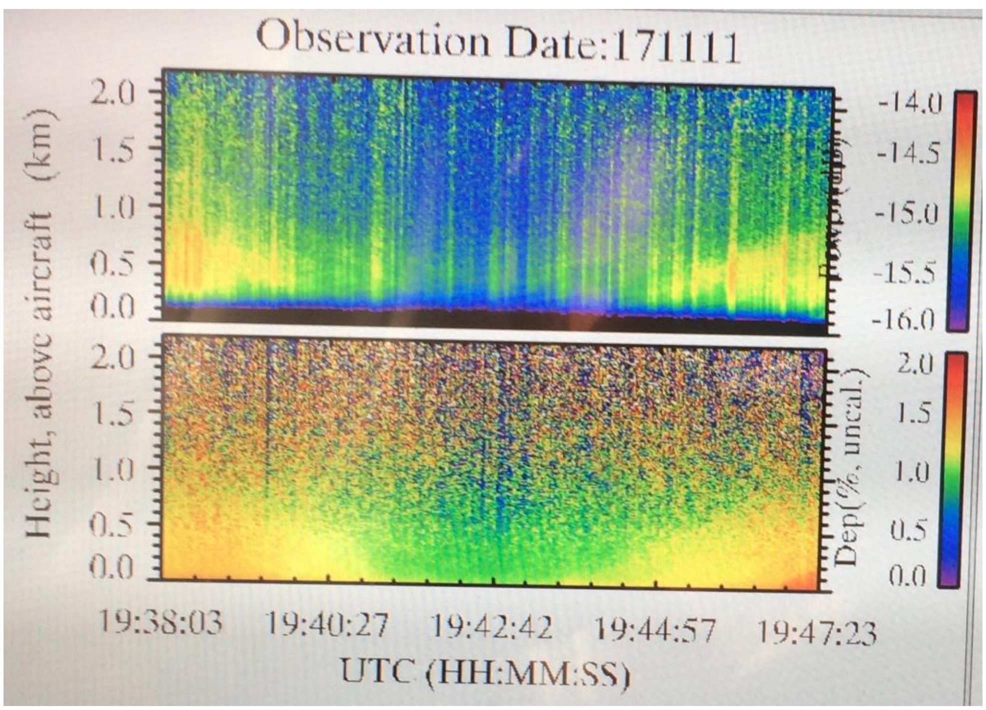


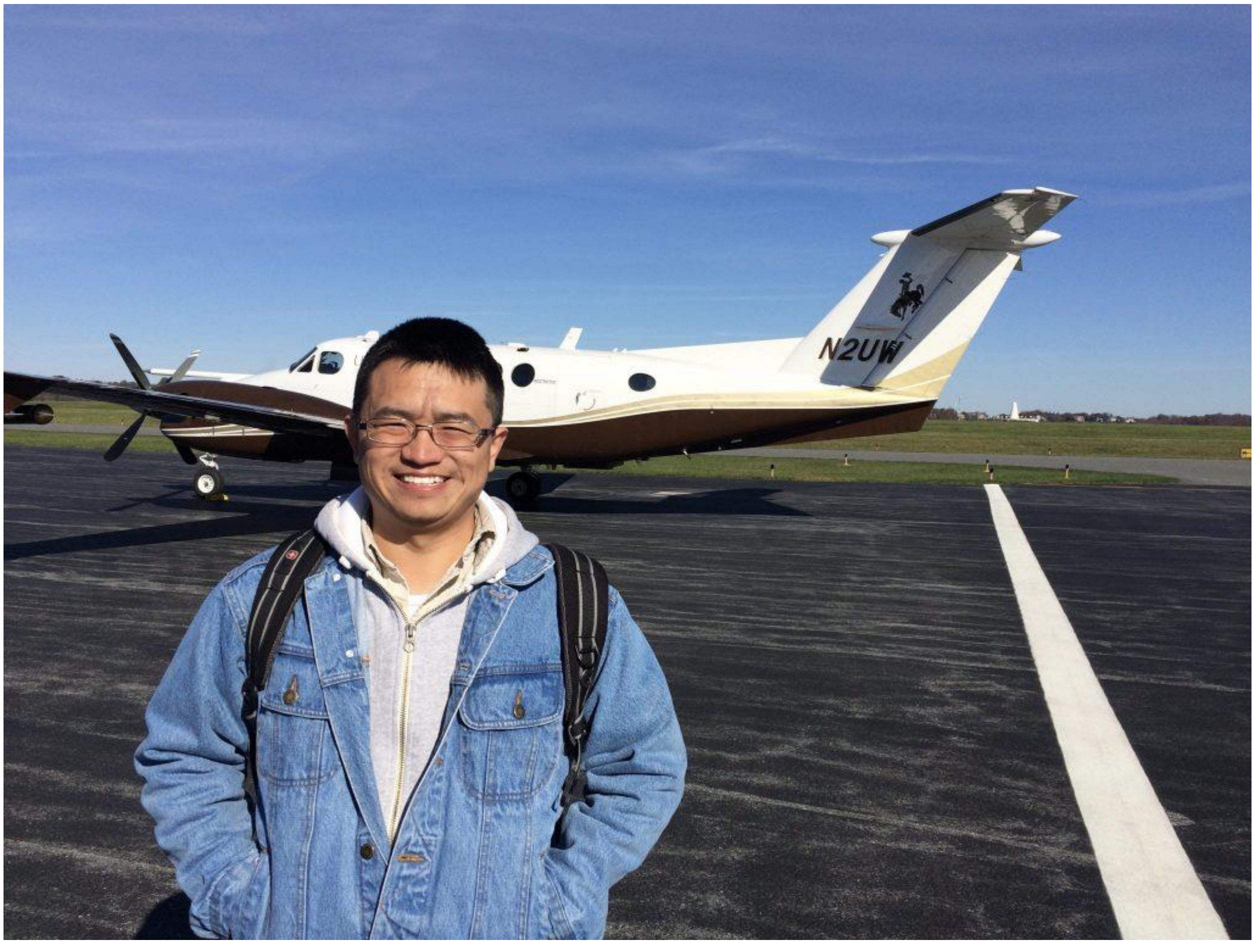
Figure 1. Upward lidar observation on board of King Air.

A public report for UMBC web page visitors on the experiment. An article about the experiment was posted in the UMBC main webpage (see below).

UMBC students take flight to study weather, pollution in multi-institution initiative

On November 16, **Brian Carroll** and **Christiana Sasser** '18, mechanical engineering, rose at 3:45 a.m. to drive to Lancaster, PA. After a briefing, they, a student from Millersville University, a pilot, and a technician took to the skies in a research airplane. Carroll, a student in the atmospheric physics Ph.D. program, had used detailed weather forecasting to meticulously plan the route to track a cold front passing through the area. Onboard instruments would collect data about how it affected the local air mass all along the way.

The plane chased the cold front across Atlantic City, NJ and then out over the ocean. But weather can be fickle, even with the best-laid plans. "We never caught the cold front," recalls Carroll. "We had to decide in the moment how we were going to salvage this and make it a decent research flight." They did—the group instead focused their data collection on exploring differences in the planetary boundary layer (PBL) over water, the coastline, and farther inland. The PBL is the lowest layer of the atmosphere and can be anywhere from several hundred to 2,000 meters from Earth's surface.

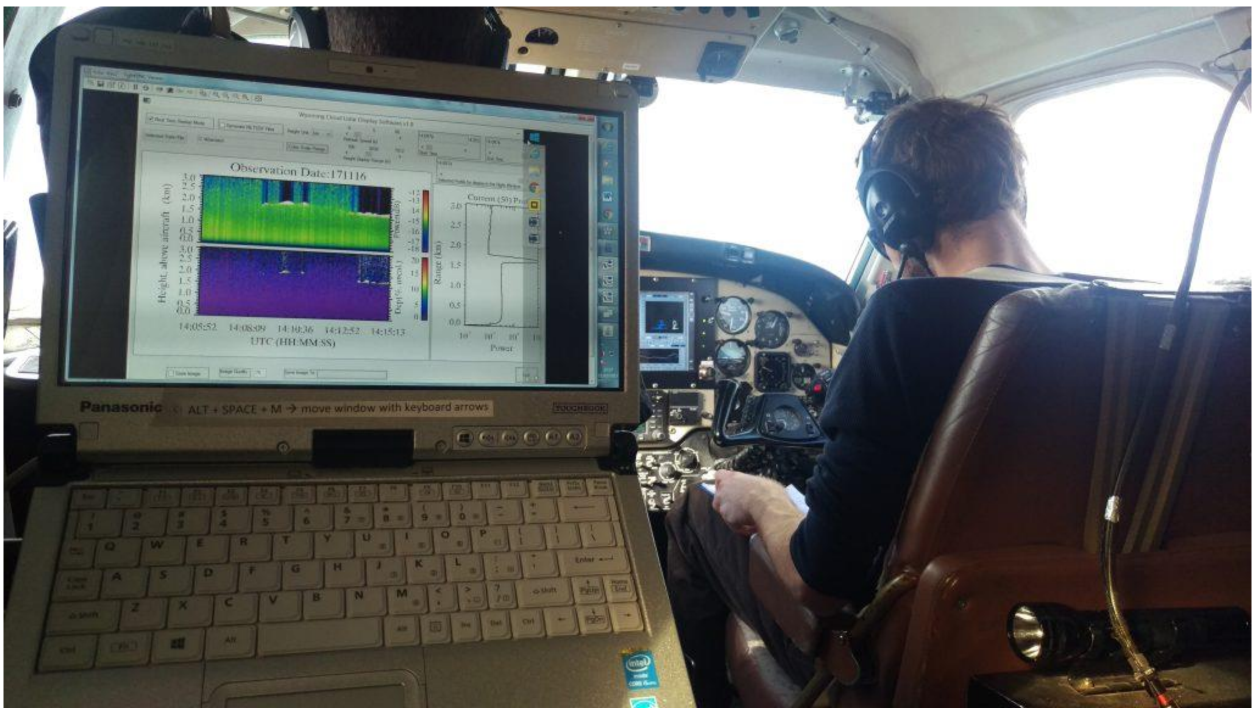


UMBC atmospheric physics Ph.D. student Zhifeng Yang on the runway next to the aircraft he will fly in to collect meteorological data.

Carroll and Sasser's flight was one of 14 student-led flights that occurred as part of a two-week, NSF-funded educational program led by Millersville University with UMBC, Penn State University, and Rutgers University as research partners and the University of Wyoming King Air aircraft and crew as hired support. Far from being a disaster, their flight met the initiative's goal to provide experiential learning opportunities. It showed the group "how the science gets done in real life," Carroll says. "It's not an idealized problem of 'Here's this wonderful data set, you need to get something out of it.' We needed to improvise with what was going on while we were in the air, and we now know about a lot of very real, small issues that we wouldn't know about otherwise." The third UMBC student participant, atmospheric physics graduate student **Zhifeng Yang**, participated in a second UMBC-led flight with Carroll on November 11. **Belay Demoz**, director of UMBC's Joint Center for Earth Systems Technology and professor of physics, and **Zhibo Zhang**, associate professor of physics, supported the students.


The view from the King Air aircraft during one of the two UMBC-led flights.

In all, over 100 students participated in the program, which was intended to serve as a springboard for students’ research projects while giving them hands-on experience with the instruments and process required for in-flight data collection. The resulting data cache was immense: Instruments on the aircraft measured a few dozen variables every second for 40 total flight hours, in addition to data collected by 50 weather balloons and two ground stations. The instruments included two Light Detection and Ranging (LiDAR) systems (one pointing skyward and one toward Earth), sensors to detect gases such as methane and carbon dioxide, and tools to measure temperature, humidity, wind speed, and more. Demoz, who encouraged his students to get involved with the project, would like to see a similar flight series happen in the future, closer to UMBC. “He’s always pushing students to get as much professional experience as they can,” says Carroll.



Atmospheric physics Ph.D. student Brian Carroll and a visualization of data instruments on the plane.

Carroll didn’t need the nudge, because “it’s possibly a once-in-a-lifetime experience. Even though aircraft are used often, it’s not often oriented in this give-everybody-a-turn sort of way.” Yang agrees. “It’s a very rare opportunity for us to observe the data in flight,” he says, “and now we know how to use a lot of the instruments that we didn’t know before.”

Carroll will use a similar type of aircraft to collect data for his doctoral research, “so knowing their capabilities and how to deal with them is definitely going to be valuable,” he says. Yang’s research seeks to improve weather forecasting models, so “we need observational data to evaluate the model, so we can adjust it to get better simulation results,” he says. Both, however, have goals that go deeper than collecting, analyzing, and modeling data. “After I got introduced to this field, and when I realized that this work is very important for human health,” Yang says, “I wanted to do something to make this field better and better.” As for Carroll, “My long-term goals are to save the world and go into space,” he says. “If I enjoy doing math and science, which I do, then it’s good for me to put those skills to use toward helping the greater good and preserving the planet.” *Banner image: The King Air aircraft, ready to fly. Photos by Zhifeng Yang.*