High Flying Interns: NASA’s Student Airborne Research Program (SARP)

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ABSTRACT

NASA’s Student Airborne Research Program (SARP) has completed thirteen years of airborne student research since its inception in 2009. The 8-week summer internship program provides students, typically rising undergraduate seniors, with an opportunity to get hands-on experience in making Earth system measurements using NASA’s airborne science platforms, making complementary surface-based measurements, analyzing the resulting data in the context of related data (e.g., those from coincident satellite measurements or prior year SARP data), and presenting to peers, program leadership, agency management, and the community. The program splits its time between the NASA Armstrong flight facility in Palmdale, California and the University of California at Irvine. It is implemented with participation of faculty advisors (who provide many of the instruments used) and graduate student mentors, under the overall leadership of the NASA Earth Science Division. Disciplinary foci include atmospheric gases and aerosols, ocean biology, and terrestrial ecology using both in situ and remote sensing instruments. Students are also taken on site visits to nearby laboratories and facilities and attend lectures from visiting faculty and NASA agency personnel. The program engages approximately 30 students per year [Figure 1], with overall approximate gender balance. The program has a high rate of STEM-retention, and its alumni are actively engaged in graduate and post-graduate programs in Earth System Science and other disciplines. A summary of scientific and programmatic outcomes and a description of how the program has evolved will be presented.

CAPSULE (BAMS ONLY)

The NASA Student Airborne Research Program (SARP) summer internship has engaged undergraduates in NASA’s Airborne Earth System Science Research for over a decade.
1. Introduction

The Student Airborne Research Program (SARP) is an annual summer internship implemented by the Airborne Science Program of the Earth Science Division of the NASA Science Mission Directorate. The overarching goal of the SARP is to provide an authentic research experience to undergraduate students that exposes them to Earth System Science Research at NASA. Other objectives of the SARP are to:

- Provide research opportunities to students from all types of undergraduate institutions with a strong interest in making opportunities available to students who would not have access to the resources and guidance that SARP enables
- Provide hands-on research experience in the end-to-end aspects of a scientific mission using a NASA research aircraft, instrumentation, remote sensing data and models
- Increase the representation of women, students of color, and underrepresented students in STEM professions through the unique research in NASA’s research enterprise
- Demonstrate that traditional STEM majors (such as biology, chemistry, physics, mathematics and engineering), can apply their STEM background to the study of the Earth system.
- Expose the students to an open, team research environment in which participants learn from each other and from faculty/staff in an effort to “create a cohort” so that the benefits of the team research experience continue beyond the 8-week summer internship

The Majority of SARP undergraduates are not aware of the vast amount of research that NASA carries out in the Earth Sciences (Figure 11), nor that NASA maintains a fleet of aircraft to perform some of this research. Conducting Earth Science research from onboard an
aircraft provides students with an experience that is unique and exciting. This sentiment has been expressed by past SARP students, for example, a 2016 student noted, “My university offers little to no research opportunities. The type of research done at SARP is very unique and I believe that it is a great introduction to Earth Science. I think that this program should continue to take students from small colleges.” The flights also serve to bond each cohort as a team. Students craft individual research projects from the data collected as well as from other NASA airborne, satellite, and ground data with the help of their faculty advisors and graduate research mentors.

Undergraduate research programs have been shown to help retain underrepresented minorities and women in STEM fields (Hurtado et al. 2009). Student-directed research has been shown to be highly effective at promoting retention in STEM fields (Loppato, 2007 & 2009). SARP was also created to inspire, motivate and recruit a diverse pool of talented undergraduate STEM majors to pursue advanced degrees and expose them to careers specifically in the Earth System sciences. Students who participate in undergraduate research programs have been shown to be much more likely to indicate that they plan to attend graduate school (Eagan et al. 2013). Additionally, fostering a sense of belonging within a discipline has been shown to promote retention of women in STEM fields such as physics and mathematics (Lewis et al. 2016, Good et al. 2012). SARP incorporates research, mentoring, networking and enrichment practices of other successful research programs in the Earth, planetary and atmospheric sciences such as SOARS (Windam et al 2004), NSF REUs (Beninson et al. 2011) and the NASA Academy internships.

From 2009-2021, SARP has provided hands-on airborne research experience for 389 college and university students (mostly rising seniors). Students conduct Earth system measurements drawing on NASA’s extensive expertise combining research and engineering. For SARP, this means leveraging NASA’s airborne assets – platforms, sensors, systems, and
people. The eight-week summer program includes two weeks of hands-on research with the students spending time both at NASA Armstrong Flight Research Center’s Palmdale facility where they fly onboard and access NASA aircraft used to collect both remote and in situ measurements; and at research field sites where students collect surface reference measurements. The last six weeks are spent at the University of California Irvine where students learn to analyze the data collected and then develop and implement individual research projects. The program’s location in California was chosen to leverage the NASA aircraft based in Southern California to easily access the rich data locations available across the state and in the coastal ocean. [Figure 1]

During SARP, competitively selected students join a faculty-led group organized around scientific disciplines (atmosphere, ocean, land surface). Students analyze and interpret the airborne and surface data they collected in the context of NASA’s satellite data and report on the results of their efforts. With the period of operation in the same region (Southern and Central California) and same season for over a decade, the SARP data now constitute a valuable time-series dataset that the students, as well as the broader scientific community, exploit as part of their research. In addition, SARP students are able to make targeted measurements of previously under-sampled areas (e.g., atmospheric profiling over the Salton Sea) or opportunistic targets (e.g., the 2016 Sherpa fire near Santa Barbara).

2. Student Recruitment and Selection

Selection for SARP is highly competitive with fewer than 10% of applicants currently admitted. Students are recruited through postings using online job registers and listserves (such as the American Geophysical Union (agu.org), Earth Science Women’s Network (eswnonline.org), Society for the Advancement of Chicanos/Hispanics and Native Americans in Science (sacnas.org), and Pathways to Science (pathwaystoscience.org)). Each year, SARP representatives staff the NASA booth at the annual AGU meeting in order to promote SARP
to students and faculty in attendance. SARP flyers are also distributed at the NASA booth at the AMS annual meeting. In addition, direct emails with a SARP flyer are sent out to over 1000 faculty members at colleges and universities across the United States. The initial email list of faculty was compiled by manually creating a list of department chairs, undergraduate advisors, etc. culled from university STEM department websites across all 50 states. It has been subsequently added annually to target schools in specific regions that have not been represented in SARP. SARP has also benefited from numerous mentions on @NASA social media channels (Twitter, Facebook, Instagram, Snapchat) which are followed by millions of people. SARP alumni often assist in the recruitment of future students at their home institutions by giving presentations or promoting the program at their colleges and universities.

Each summer, approximately 30 students are selected from the applicant pool by an admissions committee made up of SARP program management and NASA Airborne Science Program leadership. Students are selected based on seven criteria: 1) outstanding academic performance (GPA, upper-level STEM courses taken), 2) responses to essay questions describing their interest in applying their background to the study of the Earth, 3) letters of recommendation, 4) institution type (students from smaller schools and Minority Serving Institutions were given additional consideration), 6) Year in school (current juniors strongly preferred) and 7) leadership qualities/experience. Students are ranked on a scale of 0-5 for each of the first six factors and 0-2 on the seventh. Though Earth and atmospheric science majors make up a significant fraction of the students selected, students from across the STEM disciplines are admitted into SARP [Figure 2]. In addition, having a diversity of majors within each class allows for unique learning opportunities when students work together in teams onboard the aircraft and in the laboratory.
In the initial years of the program (2009-2012), sophomores through early graduate students were admitted. However, students in the summer between their junior and senior years are now given strong preference in admissions because they are far enough along in their academic careers to have the scientific background necessary to succeed in research. However, they still have the ability to be influenced by their SARP experience to pursue Earth and atmospheric science studies in their future graduate careers, aligning with the program goals. There are many examples of physics, chemistry, biology, mathematics and engineering majors who subsequently applied to Earth, ocean, or atmospheric science graduate programs and attribute this decision entirely to their participation in SARP.

As word has spread about the program, the applicant pool has significantly increased with time [Figure 3]. Typically, only three students accepted into SARP in a given year will decline SARP for other programs. Their slots are subsequently filled by students on the waitlist. In selecting students off of the waitlist, the committee strives to maintain the academic major diversity of the class. For example, if a meteorology major declines, that slot will be offered to another meteorology major.

SARP has attracted a diverse group of students. For example, women constitute slightly more than half of the alumni (52%) and students of color make up more than 25% of the more recent classes. The colleges and universities from which the program draws (238 schools from 2009-2021) range from major research universities to small undergraduate colleges. [Figure 4. Supplemental Table 1]. Minority Serving Institutions (MSIs) make up 17% of the schools represented by students in SARP (greater than the 14% of US institutions that are considered MSIs) and 70% of the faculty come from MSIs. A slight preference in admissions (plus one point in the institution type ranking criteria (4)) is also given to students who are enrolled at schools that have not yet been represented in SARP and for applicants
who attend smaller schools without access to earth science research opportunities at their undergraduate institutions.

3. Program Structure

The program is structured to build camaraderie among the students from before their arrival, through their participation in the program, and beyond. After their selection in March, the program manager emails students weekly with updates about the program, faculty and staff introductions, background reading, etc. Before the program starts, students are expected to read project, instrument, and aircraft descriptions as well as background information on Earth system science and coding. The background reading, website and video links are hosted on an online binder that is accessible to the students throughout the summer and added to throughout the program. Students begin interacting with each other on a variety of social media channels that SARP management sets up for each class in April, including a private Facebook group as well as other private messaging channels. All students create a poster describing their background and research interests that they present at the opening night icebreaker/poster session. The purpose of this poster session is to allow the students, mentors, faculty as well as any NASA instrument scientists and administrators to get to know each other. It is done in the style of a scientific poster session to also give the students experience presenting and interacting in this common scientific conference format. In addition, this format gives introverts assistance in interacting since the poster itself can help launch conversations.

The first two weeks of the program take place at NASA’s Armstrong Flight Research Center Aircraft Integration Facility in Palmdale, CA. During the first week, students attend lectures from and interact with NASA program managers, scientists, and engineers, university faculty members, and others involved with the NASA Airborne Science Program. These lectures provide background information on NASA Earth and atmospheric science,
NASA aircraft and missions, meteorology, flight planning, airborne instrumentation, remote sensing, and environmental science. In addition, students receive tours of NASA Armstrong facilities and aircraft. During this first week, students are assigned to one of four (2012-2021) research groups (Land, Ocean, Whole Air Sampling, Air Quality/Aerosols) each led by one or two faculty members and an advanced graduate student research mentor [Figure 5, Table 1].

Outside of the formal group structure, students from all groups have the opportunity to work with NASA scientists and program managers, a SARP mission meteorologist, as well as a graduate student who assists them with learning to code in languages such as Python, Matlab, IDL, and R. Exact research group topics vary year to year based on faculty interest. The overall make-up of the four groups since 2012 have been two with a remote sensing (ocean and terrestrial) focus and two with a focus on atmospheric composition/chemistry and/or aerosols. Each group now contains seven students (in the first three years (2009-2011), groups contained up to ten students and there were only three research groups) [Table 1]. The increase in the number of research groups and the decrease in size of those groups was implemented to provide more personalized attention to the students in each group as well as to increase the number of faculty and research projects in SARP.

During the second week, all students fly onboard a NASA research aircraft [Table 1] [Figure 6, Figure 7] as well as take surface measurements at field sites [Figure 8]. Typically the NASA DC-8 was flown, although the NASA P-3B, NASA C-23 Sherpa, and NASA Langley B-200 have also been used. Onboard the aircraft, students assist in the operation of instruments such as the UC Irvine Whole Air Sampler (WAS) as well as a variety of other in-situ atmospheric sampling (e.g. Langley AVOCET CO₂ (airbornescience.nasa.gov/instrument/AVOCET) & Goddard CAFE Formaldehyde (airbornescience.nasa.gov/instrument/CAFE)) and remote sensing instrumentation (JPL
MODIS/ASTER Airborne Simulator (MASTER) (science.jpl.nasa.gov/projects/MASTER)).

In total, 3.98 million measurements of atmospheric gases have been taken during SARP flights [Supplemental Table 2]. The 2009-2019 SARP atmospheric composition data are all publicly available on the NASA Langley data archive at (www-air.larc.nasa.gov/missions/sarp/index.html). The final SARP 2020/2021 atmospheric composition data will be archived within 6 months of the December 2021 aircraft flights. Additional imaging spectroscopy remote sensing data (i.e. Airborne Visible Infrared Imaging Spectrometer (AVIRIS & AVIRIS-Next Generation) have also been acquired for the program on the NASA ER-2 and a Dynamic Aviation B-200 [Table 1]. These data are available by request through the NASA JPL AVIRIS (https://aviris.jpl.nasa.gov) and MASTER archives (https://science.jpl.nasa.gov/projects/MASTER/). [Supplemental Table 2]

Though SARP is typically flown as a stand-alone NASA airborne campaign, a few notable exceptions have occurred. In 2016, SARP flew with the same instrument payload as the Korea-US Air Quality (KORUS-AQ) mission. SARP flights in 2016 took place in California just days after the mission returned from Korea. This benefitted both SARP and KORUS-AQ as the students had access to more instruments and could learn from the scientists involved in the mission [Table 1, Supplemental Table 2] and KORUS-AQ benefitted by having additional flight hours in California. Similarly, in 2019, SARP flew immediately before the Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ) campaign with the same aircraft/payload allowing for additional instrument testing before that campaign deployed.

With the period of operation in the same region (mostly Southern and Central California) and same season for over a decade, the SARP data now constitute a valuable time-series dataset of Los Angeles Basin air quality, Santa Barbara ocean biology and biogeochemistry, and Central/Northern California terrestrial ecology that the students can...
exploit as part of their research [Figure 8]. Altitudes and locations of the flights vary depending on research interests of the faculty in a given year, but will typically include low-level flying in the California Central Valley, some excursions to higher altitudes for sampling over Total Carbon Column Observing Network (TCCON) sites, and planned missed-approaches at LA basin airports to capture vertical profiles of atmospheric gases and particles. In total, 165 flight hours were flown for SARP 2009-2021 using the NASA DC-8, P-3B, C-23 Sherpa and Langley B-200. [Figure 9]

After the research flights and field trips are complete, the program location moves to the University of California Irvine. Each group of seven students, along with their graduate mentor, live together in UC Irvine dormitories throughout the summer. Students in all four of the research groups analyze the data collected onboard the aircraft and on the ground using laptops provided to each student by the program. Additionally, students in the atmospheric Whole Air Sampling group perform gas chromatography to analyze the air samples collected for ~100 different gases, including greenhouse gases such as methane and carbon dioxide, vehicular exhaust gases, and gases related to industrial and agricultural activities. Students are encouraged to use data from previous-year SARP flights, other NASA airborne campaigns, as well as data from NASA satellites and ground stations. Faculty and mentors guide students to topics of mutual interest. The data analysis portion is broken up by regular enrichment lectures from local scientists and engineers as well as visits to nearby scientific research facilities of interest such as the Scripps Institute of Oceanography, Palomar Observatory, and NASA Jet Propulsion Laboratory.

At the conclusion of the program, each student writes an abstract and delivers a 12-minute oral AGU-style conference presentation on the results of their individual research project. These presentations are all recorded and uploaded to the SARP website (https://baeri.org/sarp). Students are encouraged to use the video link to their presentation on
their resume/CV as an example of their public speaking and research skills. The SARP staff, faculty, mentors and NASA scientists in attendance at the final presentations decide on the top research project(s) from each group. In recent years, the students with the top-rated presentation from each of the four research groups have been funded to attend the AGU Fall Meeting to present their results. In some years, funding is available for additional students to attend and present their research. Students with more meteorology-focused projects have also or alternatively presented at the AMS annual meeting.

After the program concludes each summer, alumni are encouraged to network with students from other classes and to keep in touch via an online alumni network/database as well as through SARP social media sites on Linkedin, Facebook and Instagram. Each year, a SARP alumni reunion event is hosted at the annual AGU Fall Meeting that typically draws ~50-60 alumni from all classes as well as SARP faculty, instrument scientists and NASA managers. Alumni get-togethers are also frequently organized at the annual AMS meeting.

[Figure 10]

4. Scientific Results

The program strives to provide a high-quality research experience for the students. They work closely with SARP instrument scientists and faculty (who come from multiple academic institutions and NASA centers) and graduate student mentors, who work with them on a day-to-day basis. Twenty peer-reviewed publications have resulted from SARP research/data. Several papers have SARP undergraduates as first-authors (i.e. Buysse et al. 2018, Demetillo et al. 2019, Finger et al. 2021, Guar et al. 2016, Hilton et al. 2018, Tuchow et al. 2016, Roy et al. 2013). Between 2011 and 2021, 72 students gave first-author presentations on their SARP research projects from the previous summer at the fall AGU meeting. As one measure of the quality of the research, the capability of the students, and the mentoring they received, three
SARP undergraduate students who presented at AGU were awarded “Outstanding Student Paper” awards in 2014. These awards typically go to graduate students.

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5. Program Personnel and Implementation

5.1 Program Faculty

SARP faculty members all have established research programs that involve the use of NASA airborne data [Table 1]. They are recruited based on word-of-mouth, their desire to work with talented students, and their desire to acquire more data for their own research programs. 70% of the faculty have come from Minority Serving Institutions in California (6 schools) and Texas (1 school) [Table 1, Supplemental Table 1]. The four SARP research groups are each led by one (or sometimes two) faculty members. Faculty members work with their students onboard the aircraft and in the field to collect data as well as direct the development of the individual research projects.

SARP 2009-2021 faculty were given a stipend of $1500 and travel reimbursement but were not otherwise compensated for their time. However, there are many benefits to faculty who participate in SARP. One benefit is that the program pays for flight hours on NASA aircraft and the faculty are therefore able to acquire airborne data at locations they specify (within the constraints of the flight trajectories) without incurring flight hour costs themselves. Other benefits to the faculty include working with extremely motivated undergraduates and the opportunity to encourage these students to apply to work with them as graduate students in the future.

5.2 Graduate Research Mentors
Each faculty member selects a graduate student research mentor to work and live with the students in their SARP research group throughout the summer. Often the graduate mentor is a graduate student from that faculty member’s laboratory/research group. However, some graduate mentors have been recruited from other laboratories to participate for the summer. In recent years, about half of the SARP mentors in a given year come from the ranks of SARP alumni. In working with and living with the students throughout the entire 8-week program, the SARP graduate mentors receive a unique teaching and research experience themselves. SARP mentors have gone on to receive NASA Postdoctoral Fellowships, returned to SARP as NASA instrument scientists, and advanced to management positions in the NASA Airborne Science Program.

In addition to the four graduate research mentors for the four research groups, SARP also employs a 5th graduate mentor who works with all of the students to teach them how to code and develop computer programs. The “coding mentor” gives lectures on beginning, intermediate, and advanced coding topics and holds open office where students can troubleshoot coding issues related to their individual research projects. The coding mentor has always been a SARP alumn(a/us).

5.3 SARP Mission Meteorologist

Accurate local and regional weather forecasting is critical to the success of Airborne Science Program missions for mission safety as well as to make sure that useful data is collected. For example, high-quality visible and near infrared remote sensing data collection requires there to be no clouds or fog between the aircraft and the ground. Each summer, SARP has had a mission meteorologist associated with the program. This person is with the students for the first two weeks at NASA Armstrong (including participating on the flights) and prepares daily weather forecasts that are used by the pilots, scientists and students.
addition, the SARP meteorologist gives introductory meteorology lectures to all the students on basic concepts as well as tutorials on tools such as HySPLIT trajectory modeling (Stein et al. 2015). After the research flights, the mission meteorologist remains a resource to all of students throughout the program (although the meteorologist typically returns to his/her home institution after the first two weeks of the program). Students are encouraged to contact and work with the meteorologist on weather-related questions related to their individual research projects if appropriate.

6. STEM Engagement and Retention & Program Evaluation

The combined efforts of the SARP leadership, the airborne science and research programs, and NASA’s university partners all make this a highly successful program (clearly documented in research results and student evaluations) demonstrating its ability to engage, motivate, and retain students. The program helps position students well for graduate school and future careers in science and engineering. As of June 2020, ninety-three percent of SARP alumni are employed or pursuing degrees in STEM fields. Over fifty Ph.D. and over seventy-five M.S. degrees have been awarded to SARP alumni with over 100 additional degrees currently in progress. As examples of the career development and mobility that it enables, nine SARP alumni have now advanced to faculty positions and twenty alumni have gone on to participate as scientists and engineers on seventeen different NASA airborne campaigns including HS3, DISCOVER-AQ, GRIP, ABoVE, DC3, SEAC4RS, KORUS-AQ, AJAX, UAVSAR, PECAN, NAAMES, AirMSPI, LISTOS, FIREX-AQ, OWLETS, and CAMP2Ex and TRACER-AQ (airbornescience.nasa.gov) [Table 2]

At the conclusion of each summer, all students complete an extensive, anonymous evaluation of the program. Students are asked if and how the program benefitted them, if it has influenced their career plans, and about their knowledge of NASA Earth and Airborne
Science Programs before and after the program [Figure 11]. Student, mentor and faculty feedback for how to improve the program over the years led to an increase in the number of research groups (from three to four), a decrease in the number of students (from thirty-two to twenty-eight), an increase in the length of the program (from five to eight weeks), and to the addition of a coding mentor. Based on our survey results, 100% of the students stated that the program benefitted them and that they would advise future students to apply. Students are also asked if the program influenced their career plans and/or plans for future education. 86% responded affirmatively, with comments such as “I am now considering graduate programs with a greater focus on the earth sciences. I know from SARP that I want to do science as a career.” Another student remarked that: “I love this program not just for the unique experience that it offers, but also due to the advancement of me as a student researcher. I had not done in depth research before this program, but now I am excited and confident to conduct my own research during my senior year and beyond.”

7. SARP 2020 and 2021 Pandemic Virtual Program

Though this article has primarily focused on SARP 2009-2019, the program continued in 2020 and 2021 as a virtual programs during the COVID-19 pandemic. In an effort to assure the safety and well-being of the student and their families, the in-person 8-week Summer SARP was conducted virtually and the research flights were postponed to December 2021. The SARP 2020/2021 virtual programs leveraged the eleven year existing dataset of SARP observations along with other airborne and satellite data to allow the students to complete research projects with the guidance of their faculty and graduate research mentors. Students were overwhelmingly positive in their evaluations of the virtual SARP experience. One student remarked, “this research experience gave me the independence to choose what I investigated and how I went about it, yet it was accompanied with outstanding mentorship
(from professors, mentors and fellow peers!). SARP was the most amazing opportunity and
gave me a ‘grad school/research fellowship’ preview. SARP is the most electrifying and
incredible academic experience I have had.”

The virtual summer program also included an at-home hands-on air sampling and aerosol
measurement component. The two cohorts of 28 students in the program (as well as 12 other
mentors, faculty and NASA scientists involved in the program) were each mailed a box of 24
UC Irvine Whole Air evacuated sampling canisters. They used these to sample their local
environments starting in April with the goal of tracking changes in emissions related to the
pandemic. These samples were subsequently analyzed in the laboratory after the program
concluded in August for 100 different gases including greenhouse gases such as methane and
carbon dioxide, vehicular exhaust gases, and gases related to industrial activities (Yang et al
2020, Jarnot et al. 2020). In addition, students each received and operated an Aerosol Mass
and Optical Depth sensor from the Citizen Enabled Aerosol Measurements for Satellites
(CEAMS) program, a NASA-funded program at Colorado State University (csu-ceams.com).

Several lessons learned from the virtual program will be implemented when the
program returns in-person. No longer limited by geography, guest speakers in SARP
2020/2021 were much more diverse than in previous years. In addition, daily informal
“coffee chats” with faculty as well as with NASA scientists and administrators allowed for
more time networking and socializing than was possible when the program was in person.
Finally, alumni involvement in the program also increased due to the ability of alumni to
attend lectures as well as the final student presentations. In the future, SARP will continue to
offer supplemental online lectures, informal meetings, and alumni interactions online.
Acknowledgments.

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Student Research Examples

1. In the summer of 2012, Laura Judd, a meteorology/climatology major from the University of Nebraska and SARP student in the Los Angeles Air Quality group, decided to investigate how the in situ nitrogen dioxide (NO₂) measured in central and southern California on the P-3 aircraft compared to the tropospheric NO₂ column observed by the Dutch/Finnish Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite (launched in 2004). Laura quickly saw that in cleaner (rural)
areas the satellite and aircraft NO2 column comparison was quite similar, yet for the more polluted (urban) locations, the satellite amount was always much lower. Later that year when Laura presented a poster of her SARP results at AGU (Judd et al. 2012), an OMI science team member, Eric Bucsela, told her that she had stumbled on to a well-known issue with the OMI data, but no one had bothered to publish a paper explaining what was going on. After AGU, Laura teamed up with a NOAA modeler, Hyun Cheol Kim, to work on and eventually publish a paper showing how the relatively higher concentrations of NO2 in urban pollution plumes are “diluted” in the spatially averaged column amounts retrieved from large OMI pixels (typically 13 x 24 km at nadir). As part of the project, Hyun Cheol developed a new way to use a chemical transport model to downscale the OMI pixels to enable better comparisons with aircraft data for satellite validation and the calculation of NO2 emissions (Kim et al, 2016). After SARP, Laura went on to get her Ph.D. in atmospheric sciences at the University of Houston, received a NASA Postdoctoral Fellowship, and is currently a research scientist at NASA Langley where she is the Co-PI of the TRACER-Air Quality mission [Table 2].

2. Students in the SARP Oceans Group have developed projects on a wide range of topics ranging from applied optics to climate change, with a correspondingly broad use of in situ, airborne, and satellite remote sensing as well as ancillary data from various research and monitoring programs. An excellent example was the project led by Annette Hilton, a SARP 2016 student and geology major from the College of Wooster who examined concentrations and distributions of polychlorinated biphenyls (PCBs) in San Francisco Bay (SFB; Hilton et al. 2018). This project leveraged AVIRIS data collected by the HyspIRI Preparatory Airborne Campaign (Lee et al. 2015) and built on several previous SARP projects focusing on quantification of
suspended sediments in SFB. In situ PCB monitoring within SFB is extremely limited due in large part to the high monetary costs associated with sampling. Annette developed a cost effective alternative to in situ PCB monitoring by demonstrating the feasibility of remotely sensing PCBs in SFB indirectly via satellite by correlating PCB concentrations, which cannot be directly detected, to suspended sediment concentration (SSC). The end product is an empirical two-step relationship capable of deriving PCBs via SSC from satellite imagery using both the NASA/US Geological Survey Landsat-8 and the European Sentinel-2. Compared to traditional sampling which currently takes place every ~10 years and with limited sampling sites, this method can provide synoptic maps multiple times per year, correlating PCB concentrations to human and environmental drivers such as river flow, storm events, and changing land-use practices. Annette is now pursuing a Ph.D. in hydrology at the University of California Santa Barbara. “SARP really helped propel my career. I gained skills and networking connections that have continued to benefit me since SARP. Having a first-author publication made me a competitive candidate for graduate positions.”
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<tr>
<th>Year</th>
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<th>Number of Graduate Student/Postdoctoral Research Mentors</th>
<th>SARP Mission/Geographic Location</th>
<th>Research Groups (Topic, Faculty Leader, Institution)</th>
<th>Aircraft</th>
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*Indicates students flew on board

**See Supplemental Table 1 for instrument list, measurement descriptions, and data volume/samples

Table 1: SARP year, number of students, number of graduate students/postdoctoral mentors, mission meteorologist (name, institution), research groups (topic, faculty leader, institution), aircraft flown, number of instruments flown. During 2016 and 2019 additional instrumentation was onboard the DC-8 due to the KORUS-AQ and FIREX-AQ field.

Accepted for publication in Bulletin of the American Meteorological Society. DOI 10.1175/BAMS-D-19-0269.1.
campaigns, respectively. The post pandemic SARP research flights conducted in December 2021 are not captured in this table.

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<th>Mission Acronym</th>
<th>Mission Name</th>
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<td>Uninhabited Aerial Vehicle Synthetic Aperture Radar</td>
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Table 2: SARP alumni involvement on Airborne Science Program missions post-SARP.

Alumni have been involved in at least 17 different airborne campaigns that have flown all over the world.

FIGURES
Figure 1: SARP 2019 students, faculty, and mentors pose in front of the NASA DC-8 inside the hangar at NASA’s Armstrong Flight Research Center in Palmdale, CA.
Figure 2: The undergraduate majors of the SARP 2009-2021 participants span the STEM disciplines. Double and triple majors are counted separately in this figure. All students (except for one student in 2010) have a primary STEM major. The non-STEM majors indicated on the chart are secondary or tertiary majors.
Figure 3: The number of applications to SARP with time. Approximately 10% of applicants are currently accepted into the program. The average GPA of SARP participants is over 3.7/4.0. The average GPA of the applicant pool is 3.4/4.0.
Figure 4: Map of the United States showing the educational institution locations (red dots) for SARP 2009-2021 students. The 389 students came from 238 different colleges and universities in 50 states and Puerto Rico. These educational institutions included small liberal arts colleges, large research universities, and minority serving institutions.

SARP Organizational Structure

- **Ocean Remote Sensing**
  - Faculty Member: 1
  - Graduate Student Mentor: 7

- **Terrestrial Remote Sensing**
  - Faculty Member: 1
  - Graduate Student Mentor: 7

- **Atmospheric Whole Air Sampling**
  - Faculty Member: 1
  - Graduate Student Mentor: 7

- **Atmospheric Chemistry/Aerosols**
  - Faculty Member: 1
  - Graduate Student Mentor: 7

- **Resources accessible to all students throughout the program:**
  - Instrument Scientists & Engineers
  - NASA Program Managers
  - SARP Meteorologist
  - Graduate Student "Coding Mentor"

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Figure 5: Schematic diagram of SARP implementation (showing program, faculty, mentors, students, etc.). The four research groups model started in 2012 with eight students per group. In 2018, the program size was decreased from 32 to 28 with seven students per research group.

Figure 6: SARP 2011 participant, Esther Thomas (University of New Orleans) operates the UC Irvine Whole Air Sampler onboard the NASA DC-8 aircraft. Image Credit: Jane Peterson, University of North Dakota
Figure 7: Shadow of the NASA DC-8 flying over Oildale, CA during a SARP 2014 flight. Image Credit, Jane Peterson, University of North Dakota.
Figure 8: SARP students taking complementary measurements at field locations in Southern and Central California. The upper left image shows the DC-8 in-flight over the Santa Barbara Channel during SARP 2015 while a student on a research vessel (bottom left) prepares to deploy the Satlantic HyperPro II profiling spectral radiometer which measures the underwater light field. A SARP 2016 student in the terrestrial ecology group (center) used an Analytical Spectral Devices (ASD) full range spectrometer. SARP 2019 students in the Whole Air Sampling group took air samples at wineries to track their emissions (upper right). Students in the 2019 aerosol group, took air samples at the Salton Sea (lower right).
Figure 9: Map of SARP 2009-2019 Summer flight tracks shaded by altitude. The aircraft generally flew at low altitudes in the LA Basin and CA Central Valley with excursions to higher altitudes over the Total Carbon Column Observing Network (TCCON) site at NASA Armstrong as well while acquiring MASTER remote sensing data over Santa Barbara coast and Central Valley agricultural sites. 141 total flight hours have been flown for the Summer SARP with students on board. 25 additional Winter flight hours were flown for the 2020/2021 SARP cohorts in December 2021 over the same region.
Figure 10: SARP 2015 alumnae, Katelyn Zigner (top left) and Karimar Ledesma (top right), presented their SARP summer research projects at the AMS 2016 meeting. A group of alumni from SARP 2010-2015 met up for a reunion dinner at the meeting. Alumni reunions at the American Geophysical Union Fall meeting now also typically draw ~50 alumni.
Figure 11: Survey results of SARP participant (2012 - 2021) self-assessment of pre/post knowledge of NASA research opportunities in the Earth Sciences.