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Short history of NASA applied science teams for air quality and health

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Abstract. Starting in 2011, a team-based approach has been developed to connect NASA science with air quality and health communities. These teams, funded by the NASA Applied Sciences Program, promote collaboration within the team, communication with end-user communities, and the rapid advancement of applied research. The team structure provides increased flexibility to address high-priority research areas, better aligning research questions with user needs. The first NASA team built on this structure was the Air Quality and Applied Sciences Team (AQAST, 2011 to 2016), and continued with the Health and Applied Sciences Team (HAQAST, 2016 to 2019). Over the years of AQAST and HAQAST, we have experimented with different approaches to manage an Applied Sciences Team. We have adjusted our approach based on lessons learned and feedback gathered from stakeholders, team members, program mangers, and meeting attendees. We have found that this type of team succeeds by building a culture of collaboration, advancing communication with stakeholder communities, and identifying issues where the team structure can provide a rapid response. AQAST and HAQAST represent a model of funding and research with positive outcomes for air quality and public health engagement with NASA data and tools. This team-based approach is well suited to mission-driven, applied science activities. *© 2018 Society of Photo-Optical Instrumentation Engineers (SPIE)* [DOI: 10.1117/1.JRS.12.042611]

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1 Introduction

Ever since the first analyses of clouds from space in the early 1960s,[1] satellites have advanced our understanding of the atmosphere. Studies through the 1990s expanded upon satellite capability to detect near-surface aerosols in the visible spectrum,[2] and radiative characteristics of both gases and aerosols in the troposphere.[3] Early on, space-based data were used primarily by atmospheric and space scientists, who focused on developing and validating satellite retrievals. As confidence in the data grew, applications were found, including the quantification of global emissions,[4–6] evaluating global chemical transport models,[7] and chemical data assimilation.[8] Through the early 2000s, the list of socially relevant applications of satellite data for air quality grew. By 2011, there had been over 600 peer-reviewed papers linking satellites and air quality, according to a search of publications on Clarviate Analytics Web of Science (search for "satellite" and "air quality"). Still, there was little awareness of these data and tools outside of the scientific research community.

To help connect Earth observations with users, the NASA Applied Sciences Program (ASP) launched an initiative in 2011 to connect satellites and other NASA data with stakeholder information needs. From 2011 to 2016, the Air Quality Applied Sciences Team (AQAST, pronounced "ay-kast") focused on U.S. air quality management. Air quality professionals at the federal, state,

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and local levels had the potential to directly benefit from satellite data capabilities available at that time. The AQAST design was put forward in the 2009 NASA Research Opportunities in Earth and Space Science (ROSES) omnibus solicitation. NASA invited proposals for AQAST as the first in a series of Applied Sciences teams, designed "to focus on key applications-oriented challenges and critical data products needed by the applied community and end users. These teams will contribute to the body of knowledge on methods to enable institutions to apply types of data and information in traditional processes and decision-making activities." (Quoted from the ROSES 2009 Clarifications, corrections and amendments, Amendment 30: Final text for Appendix A.32: Air Quality Applied Sciences Team, accessed from the Internet Archive.[9]) Proposals were due in 2010, and selections were announced in 2011.[10]

Air quality management in the U.S. operates under the regulatory framework of the 1970 Clean Air Act (CAA). Satellite data could support a range of activities associated with CAA compliance, including monitoring ambient air quality, understanding how emission sources contribute to regulated pollutants, evaluation of models used for policy and planning, and communicating air quality and public health data to the public. Although ground-based monitors remain the "gold standard" for air quality management, the work of AQAST changed the conversation about data sources and the value of satellite information for air analysis.

Following on the success of AQAST, in 2016 ASP launched the Health and Air Quality Applied Sciences Team (HAQAST, pronounced "hay-kast"). Recognizing that air quality issues and the value of satellite data extend beyond the CAA, and beyond the U.S., HAQAST has a wider scope of stakeholders and application areas.

To accomplish their missions, AQAST and HAQAST mixed research, engagement, and outreach in novel ways. The teams have built relationships with stakeholder communities as individuals and as groups, through in-person and online activities, with focused collaborations and broad communications. The teams' structure supports collaboration, communication, and acceleration of research. Flexibility has also been fundamental to the success of these initiatives, especially in responding to stakeholder requests. In a traditional research grant, an individual scientist or small group of collaborators propose a research question and work plan. The proposed plan is subject to peer review, and the researchers are expected to hew closely to the plan over the duration of the grant. In a traditional science-funding model, it might take 6 months to write a proposal, 6 months to go through peer-review and selection, and 3 years to complete funded research. Thus, it is not unusual for 4 years to elapse between the time a research question is posed and the final research results. This time frame does not align with the needs of most decision-makers. The Applied Sciences Team structure aimed to promote a faster response time.

Like traditional science programs, AQAST and HAQAST proposals were reviewed based on planned activities. Like other NASA grant processes, principal investigators (PIs) are expected to submit annual reports outlining research activities and accomplishments. In addition to these traditional oversight measures, the team structure promoted accountability through regular team meetings (twice a year), updates coordinated by the team leader, collaborations with other team members, and the formation of subteams (known as "Tiger Teams," TTs) eligible for supplementary funding. However, AQAST/HAQAST team members were also encouraged to be responsive to the needs of stakeholder partners. Work plans could be adjusted to support more effective stakeholder engagement, and the supplementary TT funding was explicitly designed to fund applied research questions raised by end users.

This team-based approach to science funding is well suited to mission-driven, applied research. To bridge the academic and the applied, there is a need to balance scientific creativity with user needs, funding accountability with responsiveness. This approach provides autonomy to the PIs and collaborators while promoting collaborative activities and engagement with data users.

We expand on past discussions of AQAST[11,12] to present here the work and activities of HAQAST, and metrics that speak to the impact of both teams. Beyond the specific number of papers, meeting attendees, and website visitors, these teams have built awareness of NASA's relevance for the air quality and health communities, and changed the conversation on the role of Earth observations for these user groups.

2 AQAST (2011 to 2016)

Nineteen members were selected for the Air Quality Applied Science Team (AQAST), with the PI for each proposal defined as the "member" of the team. As shown in Table 1, the majority of the members were faculty at U.S. universities; the balance, senior scientists from federal research laboratories. Most of the PIs received base funding, and all were eligible for supplemental funding over the course of AQAST. The supplemental funding was designed to support collaborative

Table 1 Names and institutions of the 19 AQAST members and 13 HAQAST members. Members are defined as the PIs on grants awarded by the AQAST and/or HAQAST NASA funding solicitations.

Member/PIs	Institution	AQAST	HAQAST
Tracey Holloway HAQAST team leader; AQAST deputy team leader	University of Wisconsin–Madison	x	x
Daniel Jacob AQAST team leader	Harvard University	x	
Gregory Carmichael	University of Iowa	x	
Daniel Cohan	Rice University	x	
Minghui Diao	San Jose State University		x
Russell Dickerson	University of Maryland	x	
Bryan Duncan	NASA Goddard Space Flight Center (NASA/GSFC)	x	x
David Edwards	National Center for Atmospheric Research	x	
Arlene Fiore	Columbia University Lamont-Doherty Earth Observatory	x	x
Jack Fishman	Saint Louis University	x	
Daven Henze	University of Colorado, Boulder	x	x
Jeremy Hess	University of Washington		x
Edward Hyer	Naval Research Laboratory (NRL)	x	
Pius Lee	National Oceanic and Atmospheric Administration (NOAA)/NRL	x	
Yang Liu	Emory University	x	x
Richard McNider	University of Alabama	x	
Jessica Neu	NASA Jet Propulsion Laboratory		x
Susan O'Neill	US Forest Service		x
Brad Pierce	National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service	x	
Armistead Russell	Georgia Institute of Technology	x	x
David Streets	Argonne National Laboratory	x	
James Szykman	Environmental Protection Agency (EPA)	x	
Anne Thompson	Pennsylvania State University/NASA	x	
Daniel Tong	George Mason University		x
Jason West	University of North Carolina		x
Mark Zondlo	Princeton University		x

TT projects: short-term, high-impact subteams made possible by the collaborative strength of the overall AQAST/HAQAST cohort. Each TT was designed to meet needs identified by air-quality stakeholders.

The leader of AQAST was Daniel J. Jacob from Harvard University, an atmospheric chemist with strong ties to both satellite measurements and air quality research. Jacob organized AQAST research activities around the mandate of delivering Earth Science solutions for air quality management problems, and promoted active collaborations among AQAST members and air quality managers through commonly identified priority projects. In 2012, Jacob invited AQAST Member Tracey Holloway from the University of Wisconsin–Madison to serve as a deputy leader, with particular responsibility for communications and outreach.

AQAST partnered with a total of 36 stakeholders (5 federal, 9 regional, 16 states, and 6 local), and hosted a popular biannual meeting that drew participants from around the US as shown in Fig. 1. Over the course of AQAST, the research cohort produced 123 publications, many of which represented collaborations among team members and/or with air quality managers as shown in Fig. 2. AQAST's communications efforts included a special issue of "EM Magazine" in February 2014 (the monthly magazine of the Air and Waste Management Association, reaching consultants, regulators, industry, and other environmental managers); a newsletter with 559 subscribers (as of 2016), two websites (Ref. 13 and a media center now archived at Ref. 14), and a Twitter account with ∼2300 followers (as of 2016). Through these efforts, AQAST came to be seen as the "front door" for air quality managers to access NASA data and tools.

In a December 2015 survey of the AQAST senior investigators (of which 13 of 19 members responded, as well as two senior non-PI investigators), all respondents reported an increase in their collaborative relationships with air quality managers under AQAST. Prior to AQAST, respondents reported having 0 to 6 air quality management collaborators or partners (average 1.7); at the end of AQAST, respondents reported having 1 to 16 air quality management partners (average 5.7). Qualitative responses on this same survey included: "AQAST enabled crossing paths with regional and state air managers across the country in a way that hadn't happened with earlier work relevant to air quality policy"; "Being part of a high-profile team increased my ability to connect with stakeholders"; and "great to have as an official goal of a grant to work with AQ managers."

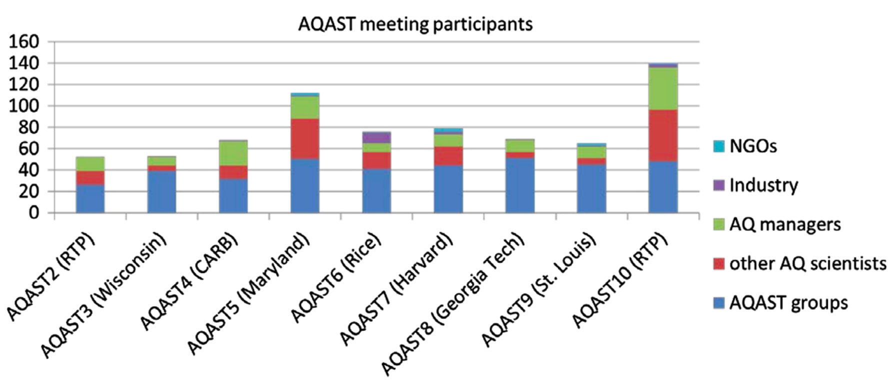

Fig. 1 Number and representation of participants at AQAST Meetings held approximately every 6 months from 2011 to 2016. AQAST2 was the second meeting of the AQAST Team, held November 2011 in Research Triangle Park (RTP), North Carolina. Meetings held at RTP were hosted by the EPA, and had a large participation of EPA air managers. AQAST3 was held June 2012 in Madison, Wisconsin. All meetings starting with AQAST3 had a strong representation of regional/state/local agencies. AQAST4, held December 2012, at the California Air Resources Board (CARB), had a large participation of California air quality managers. AQAST5, held June 2013, at the University of Maryland, had a large participation from NASA/GSFC and NOAA/ARL. AQAST6, held January 2014 in Houston, had a large participation from industry. AQAST7 was held June 2014, in Cambridge, Massachusetts at Harvard University; AQAST8, December 2014, in Atlanta, Georgia, at Georgia Tech; AQAST9, June 2015, at in St. Louis, Missouri, at Saint Louis University; AQAST10 in January 2016, returned to the EPA office in RTP.

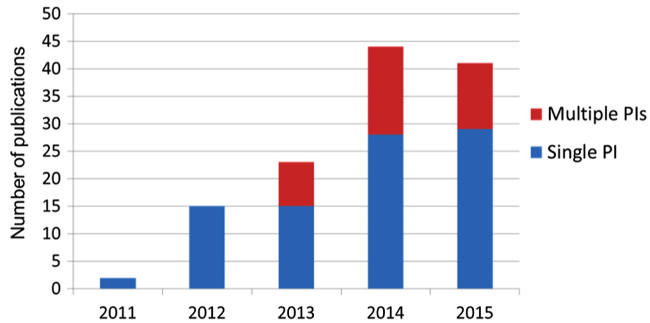

Fig. 2 Publications supported with funding from AQAST, by years. Blue represents publications where coauthors represented one or more investigators within a single member's AQAST grant; red represents publications where coauthors drew from two or more different members' AQAST grants. Many papers also include coauthors who were not funded by AQAST.

When AQAST was first solicited, the ASP had separate divisions for Air Quality and Health. Between 2010 and 2011, ASP was reorganized to merge these two programs into a new Health and Air Quality (HAQ) program. When a follow-up competition for a second phase of AQAST was announced as part of ROSES 2015, it was under a new name and a broader mandate: the Health and Air Quality Applied Sciences Team (HAQAST). The new name and mission were consistent with the structure of ASP, and broadened the impact of this initiative to connect NASA with a wider community of potential Earth observation end users.

3 HAQAST (2016 to 2019)

Where AQAST focused on U.S. air quality, HAQAST has a wider mission of serving both air quality and health organizations, in the U.S. and globally. Despite the large scope, the cohort size is smaller: 13 members/PIs compared with AQAST's 19, and the duration is shorter, i.e., 3 years rather than AQAST's five.

HAQAST has learned from the success of AQAST, and built on many of the collaboration and communication activities already in place. Seven of the 13 HAQAST members had previously served on AQAST (Table 1); the communications effort built on the AQAST mailing list, which was transitioned over to HAQAST; and the AQAST Twitter account changed to @NASA_HAQAST. This transition was supported by HAQAST leader Tracey Holloway, who had previously served as AQAST deputy leader.

HAQAST has a mission of connecting NASA satellites and data with public health and air quality stakeholders. While similar to AQAST, the addition of health introduced new opportunities and challenges. HAQAST's focus on health includes U.S. air quality management, as well as public health organizations at the community to global scale, health-focused nonprofits, and organizations working on nonregulated air issues, such as pollen and forest-fire smoke.

As with AQAST, each member serves as a PI of a grant, working with co-investigators named in the original NASA proposal. Relative to AQAST, a higher level of funding was allocated for HAQAST TT subprojects, selected in 2017 and 2018, respectively.[15] HAQAST continued the process of biannual meetings, which have attracted both scientists and end users. The November 2017 HAQAST3 meeting took place at Columbia University's Lamont–Doherty Earth Observatory in Palisades, New York (120 in-person attendees, ∼100 online) and the July 2018 HAQAST4 took place at the University of Wisconsin–Madison (140 in-person attendees, ∼222 online). The growth in attendance at HAQAST meetings is shown in Fig. 3.

HAQAST has expanded the investment in communications, with a professional science communicator, Daegan Miller,[16] as well as part-time digital media specialists. HAQAST issues a regular newsletter (642 subscribers, built on the original AQAST list) and maintains an active Twitter account @NASA_HAQAST (over 3900 followers as of October 2018, built on the original @NASA_AQAST account). The HAQAST website has pulled nearly 3000 discrete visitors, with nearly 11,000 page views between October 2017 and June 2018. In coordination with

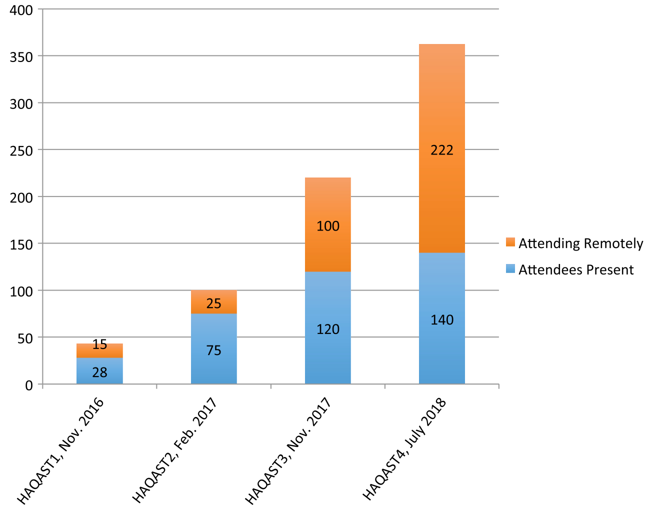

Fig. 3 Number of participants at HAQAST meetings, including in-person and remote/online participation. Remote estimates are uncertain and depend on the streaming technologies available at each meeting. For example, for HAQAST4, the meeting was live-streamed on YouTube, which allowed us to log discrete IP addresses. At the time of largest attendance, 222 discrete IP addresses were reported. HAQAST1 was held November 2016 in Atlanta, Georgia, at Emory University; HAQAST2, February 2017 in Seattle, Washington; HAQAST3, November 2017 in Palisades, New York, at Columbia University; HAQAST4, July 2018 in Madison, Wisconsin, at the University of Wisconsin–Madison. HAQAST5 will be held January 2019 in Phoenix, Arizona.

the NASA Applied Remote Sensing Education and Training (ARSET) program, HAQAST has built a portfolio of resources to guide users through satellite data analysis.

4 Impacts of AQAST and HAQAST

When evaluating the role of a team-based structure, such as AQAST and HAQAST, a meaningful point of comparison is the traditional research grant portfolio. Both teams were structured as a portfolio of research grants with a PI and Co-Is, with selections made by a review panel akin to other federal science-funding processes. Relative to a group of separate grants, the team structure developed a culture of collaboration, encouraged communication with end-user communities, and supported the rapid advancement of applied research on priority issues.

4.1 *Building a Culture of Collaboration*

Collaboration is the key that differentiates a team from a group of individuals. In the case of AQAST and HAQAST, specific steps were taken to build cultures of collaboration across the separate research grants. Three methods were employed to support this culture: TT supplemental funding for collaborative projects, regular meetings, and the focus on stakeholder engagement.

TT supplemental funding represents the primary collaboration infrastructure that NASA ASP built into the formulation of AQAST and HAQAST. Participation in AQAST/HAQAST included base funding, in most cases, as well as eligibility to compete for supplemental funding through TTs. The TTs were intended to leverage expertise from multiple team members and to support short turnaround (∼1 year) projects of direct relevance to stakeholders. Over the course of AQAST, different TT selection processes were tested, with varying results. We found that a traditional competition for resources could work against the collaborative culture of the overall cohort. In particular, if each TT had a fixed budget, then a smaller TT (fewer collaborators) would increase the per-person budget. As a result, tying funding to each TT served as a disincentive for collaboration.

In the later years of AQAST, and continuing through HAQAST, we found that a hybrid approach to promote both collaboration and competition worked best: competition for ideas rather than resources. Each member would have access to an equal amount of potential funding, with additional support going to project leaders and/or TT communications activities. As such, all members had an incentive to step forward as a TT leader, both to promote their own goals and interests, and to access additional funding. Furthermore, every project leader had an incentive to engage a wider scope of AQAST peers to grow the project budget. For example, a project that involved two AQAST members would have a smaller budget than a project with five members involved. This approach to budget allocation emerged as an effective approach to TT management, as it supported the participation of all members of the cohort, incentivized new partnerships, and catalyzed a wider range of discussions on possible research topics.

HAQAST has had remarkable results from this approach to TT design. About 12 proposals were submitted to the initial call for TTs, of which four were selected for \$1.5 million in funding. In the second TT year, nine proposals were submitted, of which four were selected for \$1.6 million in funding. The process of generating proposal ideas, building a subteam around a stakeholder-defined problem, and writing a joint proposal helped HAQAST investigators get to know each other and find areas of common and complementary expertise. The proposal format was very short—two pages—to further incentivize a wider range of ideas and collaborations. The short proposal format and relatively high number of submitted ideas also facilitated the review of projects by 8 to 10 health and air quality stakeholders. The large number of proposals ensured that a meaningful choice was being made based on reviewer scores, but the short format of proposals reduced the work burden on the HAQAST members and volunteer reviewers.

The TT process "forces" collaboration among the AQAST and HAQAST members, but also promotes a collaborative culture that extends to all activities of participating scientists. The twice-yearly team meetings involve members and collaborators presenting talks on recent activities and research. Over time, informal networking has grown to be an important component of the team meetings, with regular poster sessions, dinners, and other opportunities to build relationships within the cohort. These regular meetings ensure that investigators get to know each other's work and hear about new lines of research.

In the 2015 AQAST survey noted already, respondents reported that "stay[ing] up-to-date on issues and science at regular meetings" ranged from very successful to transformative (rated 3.5 on a scale of 1—not at all successful, 2—somewhat successful, 3—very much successful, or 4—transformative). Other top-ranked successes included "Encourag[ing] your engagement in science with impacts and use to stakeholders" (3.5), "Shar[ing] updates at regular meetings" (3.45), and "Build[ing] collaborations with other AQAST members" (3.40).

The Applied Science Team mission of supporting stakeholder needs enhances the culture of collaboration. With a common mission of serving communities and broadening the relevance of NASA data and tools, we celebrate successes and tackle challenges with a shared sense of purpose. Respondents to the 2015 AQAST survey reported that "over time there is a real team that crosses individual interests," and "Regular semi-annual meetings were valuable. . . . We have developed really strong working relationships."

Compelling evidence for the success of this collaborative culture is seen in AQAST's publication record as shown in Fig. 2. Where the first 2 years of AQAST had no publications in which more than one members' grant was represented, the proportion of publications with multiple PIs grew over the course of the 5-year AQAST period (0% in 2011 and 2012; 35% in 2014; 36% in 2015; 29% in 2016). While some of these publications emerged from TTs, others were formed through *ad hoc* discussions and research synergies.

4.2 *Communicating with Stakeholders*

Communication with stakeholders has been part of the AQAST/HAQAST recipe since the very beginning. Early on, meetings were structured to have 1 day for science talks, often by AQAST-funded researchers, and 1 day for talks from air quality managers and other stakeholders. This approach was very effective at helping the scientists understand pressing air quality issues, and for beginning relationships between scientists and stakeholders. In the 2015 AQAST survey, "Emphasis on serving air quality managers" was ranked highest (3.57, between 3—very successful and 4—transformative) in terms of "how. . . AQAST affected your overall work. . . relative to a regular NASA grant at the same funding level and duration." One respondent commented, "feedback from AQAST members and AQ managers allowed my research objectives to focus better and evolve over the last five years."

As these initiatives matured, we recognized the need to increase two-way dialogue. We used meeting time more directly to build dialog and discussion, and launched opportunities for stakeholders to provide feedback to AQAST and HAQAST. Our changing meeting format is an example of the growth of two-way dialog over the AQAST/HAQAST process. HAQAST meetings are now structured around small topical panels, comprised of both scientists and end-users to provide different perspectives.

This interactive format is supported by very short talks—most are 5-min long—to allow for extended discussion. The typical panel includes a 30-min series of four talks (a 15-min talk and three 5-min talks), followed by a 15 to 20 min group discussion of the shared topic. This unusual format allocates ~75% of talks to the 5-min length, with 25% of talks in the 15-min length. This format also reserves a third of all meeting time for interactive discussion and questions for topical panels. At our two most recent meetings, HAQAST3 (Palisades, New York; November 2017) and HAQAST4 (Madison, Wisconsin; July 2018), survey results suggested satisfaction in the mix of scientist and stakeholder talks. HAQAST has seen a continual increase in the numbers of attendees, both in person and online, as shown in Fig. 3.

Although meeting attendees expressed some skepticism about the 5-min talk format before each meeting, survey results suggest that this nontraditional format works well to promote dialog. At HAQAST3, 96% of the 28 respondents felt that the right amount of time (86%) or too little time (10%) was spent on 5-min talks. At the HAQAST4 meeting, 100% of the 20 respondents felt that the right amount of time (74%) or too little time (26%) was spent on 5-min talks. To quote one respondent, "I liked the format of the talks– alternating between longer 15-min talks and 5-min talks. This kept my attention throughout the event;" and another: "I really like that presenters give us just enough information to get a flavor of their research and then we can follow up with them electronically (via email and links they provide) or in-person to discuss more." For comparison, at HAQAST3, 96% felt that the right amount of time was spent on 15-min talks (1 respondent felt too much time was still spent on long talks; none thought too little time was spent); at HAQAST 4, 89% felt that the right amount of time was spent on 15-min talks (1 respondent each choose "too much" and "not enough"). Even with 75% of presentation time allocated to 5-min talks, survey results suggest that attendees would like to see more of these very short talks and no more of the longer talks. The extended discussion and question/answer (Q&A) was also viewed favorably, with 82% and 89% of respondents, for HAQAST3 and HAQAST4, respectively, responding that the right amount of time was spent.

The largest change made to the meeting schedule between HAQAST3 and HAQAST4 was expanding the time for conversation and networking. At HAQAST3, there was 230 min of networking time during the 1.5-day agenda. While 64% of respondents found this to be the right amount of time, 36% felt it was not enough (0% said was too much). At HAQAST4, we scheduled 50% more networking time over the same meeting duration. Surveys from HAQAST4 found a higher level of satisfaction in networking time, with 83% reporting that the "right amount" of time was available for networking and informal talks (two respondents said "not enough" and one said "too much"). To quote one respondent: "Most of the presentations were concise and informative. Networking, however, was the most important thing for me;" and another "I liked that there was ample time to speak to the scientists I wanted to talk to."

As a science team meeting, talks by scientists are a core activity. These were considered valuable by attendees. Most respondents (93%) felt that the right amount of time was given to scientist talks, with an almost even distribution choosing too much time (two respondents) and not enough time (one respondent). Stakeholder talks are also an essential component of these meetings, and a component that attendees would like increased. At HAQAST3, 13 talks were from stakeholders (versus 32 scientists' talks); at HAQAST4, 17 talks were from stakeholders (versus 29 scientist talks). It should be noted that in some cases the stakeholder-or-scientist distinction is not obvious, as some public health analysts are considered scientists if they are funded by HAQAST, but stakeholders if they are not funded by HAQAST. Across the two meetings, 22% of respondents felt that "not enough" time was dedicated to stakeholder talks, and no respondent felt that too much time was given.

In addition to the meetings, AQAST and HAQAST have various mechanisms for scientists to engage with stakeholders. Early in the AQAST TT process, we received feedback from air quality managers who requested ongoing communication over the course of the project. Under AQAST, one TT hosted monthly conference calls with air quality management agencies, which allowed the number of stakeholder to grow over the course of the project. Based on this success, in the first year of HAQAST, all four of the TTs used a similar approach with regular teleconferences to connect the researchers and stakeholder partners. Stakeholders were also engaged in the HAQAST TT review process (with 8 to 10 stakeholders reviewing short-format proposals with an online survey tool), as collaborators on individual applied research projects, and as advisors to inform the message, format, and audiences where our work could have the greatest impact.

An assessment of AQAST's impact on air quality management by Milford and Knight[12] speaks to the lessons learned from this process. In that study, a web-based survey and follow-up interviews found that air quality managers who had been involved in AQAST had an increased awareness of NASA data products, and found that the team was helpful in assisting their organizations with the use of satellite data and other outcomes. In that study, 56% of respondents reported that their agency or someone within their agency had worked with AQAST. Of these, the leading impacts of AQAST engagement were found to be that the experience "created awareness of research that is of interest to my agency" and "helped staff in my agency access new resources or tools." Beyond the survey results, Milford and Knight[12] found that in interviews the air quality managers had a high level of appreciation for relationships built with AQAST scientists, which were established by meeting attendance and/or being invited to join TTs, and grew through regular interaction, often expanding to multiple members of AQAST.

4.3 *Rapid Advancement of High-Value Applied Research*

The regular team meetings, the innovation required of 1-year TTs, and collaborations across the cohort as a whole had the result of quickly moving forward productive lines of research.

A striking example of this rapid research advance during AQAST was in the area of satellite-derived NO_2 for air quality applications, especially from the Ozone Monitoring Instrument (OMI[17]). A timeline of AQAST publications and outcomes on this topic highlights the synergies emerging around a topic, where NASA science has clear application potential. Although we focus here on OMI data and pollutant emissions, similar histories could be constructed for AQAST research on ozone transport, air quality forecasting, fires and smoke, field campaigns, data assimilation, particulate matter (PM), and other lines of applied research.

If we follow the thread of OMI NO_2 for emissions calculations, the earliest published AQAST papers came out in 2012.[18,19] While prior studies had also used OMI NO_2 for emissions analysis, we start with these AQAST papers as an example of how the team-based structure of AQAST built collaborations and advanced successful lines of research. In 2013, five AQAST papers directly extended this line of OMI-based emissions evaluation. Three papers used OMI NO_2,[20–22] one estimated power plant emissions from OMI SO_2,[23] and one provided a review on the potential to estimate emissions from satellite data, with authorship from 10 of the 19 AQAST member groups.[24] In 2014, four AQAST publications extended the linkage between OMI and emissions evaluation.[25–28] In 2015, the last full year of AQAST, this line of research was carried forward in at least seven AQAST papers. Analyses included power plant NO_x emissions,[29] urban NOx emissions,[30] regional model evaluation with OMI NO_2,[31,32] the impact of the 2008 recession on U.S. NO_x,[33] NO_x emissions over Texas,[34] and a comparison of NO_2 from satellites and ground-based monitors to assess NO_x emission trends in the U.S. from 2005 to 2013.[35]

The Lamsal et al. study,[35] in particular, set the stage for two of the most high-profile AQAST outreach successes. By indicating that satellite-derived NO_2 trends were broadly consistent with the same trends from regulatory monitors, this study directly supported the inclusion of OMI NO_2 in the 2016 EPA Air Trends Report, and provided the research evidence to support the April 12, 2016 Discovery Channel video-short narrated by then-U.S. President Barack Obama, illustrating U.S. reductions in NOx emissions using OMI's NO_2 images.

At the time of this writing, HAQAST is 2 years into our 3-year grant period. Over this time, the role of satellite-derived fine particulate matter ($PM_{2.5}$) for health assessment has emerged as a line of research advancement in HAQAST. The appropriate use of satellite-derived $PM_{2.5}$ has been a major topic of discussion at HAQAST meetings, drawing the team's focus to this important issue. In 2016, the first partial year of HAQAST, West et al.[36] used satellite-derived $PM_{2.5}$ for global health assessment. In 2017, eight publications developed methods to improve satellite derived $PM_{2.5}$ and/or applied existing satellite-derived $PM_{2.5}$ to health studies.[37–44] Further HAQAST publications related to better calculating and applying satellite-derived $PM_{2.5}$ have been published in 2018 or are in preparation. From conversations with public health stakeholders, it is evident that the incorporation of satellite-derived $PM_{2.5}$ in the Global Burden of Disease[45,46] has increased interest and awareness of satellite-derived products for air pollution exposure assessment. The potential for satellite-derived $PM_{2.5}$ to inform a number of issues, from the local to global level, for daily wildfire smoke forecasts, annual average risk estimates, and a host of other scenarios, highlights the potential of NASA Earth observations for air quality to serve potential end-users.

5 Conclusion

The traditional approach to research funding typically requires four or more years from question to answer—a timescale that is incompatible with the needs of most real-world data users. The NASA ASP has created a new model for funding science, through the creation of AQAST and HAQAST. With a collaborative team and a shared mission, this research model increases responsiveness to stakeholder needs, includes stakeholder experts in the research process, and reduces the time for research results and application.

Over the years of AQAST and HAQAST, we have experimented with different approaches to manage the unique mission of an Applied Science Team. We have adjusted our approach based on lessons learned and feedback gathered from stakeholders, cohort members, program mangers, and meeting attendees. We have found that the success of this type of team depends on building a culture of collaboration, advancing communication with stakeholder communities, and identifying issues where the team structure can provide a rapid response. With additional implementation and assessment, there is the potential for a model of scientific research funding to extend across organizations and disciplines, connecting advanced research with a range of real-world information needs.

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