The NCAR Earth Observing Laboratory Survey on Unmanned Aircraft Systems

Authors: Holger Vömel, Cory Wolff

Executive Summary

In summer of 2016, NCAR Earth Observing Laboratory (EOL) distributed a survey regarding the needs for Unmanned Aircraft System (UAS)-based atmospheric and interface research to the larger NSF research community. The survey question collected input from the general UAS community and considered any class of UAS platforms. We received 53 responses from experienced users of UAS, novices, who are still building experience, and researchers not yet using UAS.

The survey indicates that open needs exist within the broader UAS community. Given the complexity of UAS-based observations, providing access to fully equipped platform(s) was seen as most beneficial to meeting the needs of the survey responders. However, there was no clear indication as to which platform or platforms would be most appropriate. The survey furthermore indicated that sensor development, calibration, and validation are also seen as highly beneficial for the larger community.

The current UAS user community seems to be divided between those who can manage the regulatory framework well and those who find the regulatory framework challenging. The latter part of the community may strongly benefit from regulatory support.

This survey provided a one-way communication with the research community. A follow-up workshop, which allows an active dialog between all parties involved, should help in further refining how the Earth Observing Laboratory may best serve the national atmospheric research community in the use of UAS.

Introduction

Unmanned aircraft systems (UAS) have been used in atmospheric research for decades in small research projects and niche applications. In recent years, the availability of UAS has increased dramatically and many research projects are now being conducted at universities, research institutions, and government agencies, both nationally and internationally. Historically, almost all airborne atmospheric observations have been taken by manned aircraft, free flying balloons, and tethered balloons or kites. The widespread availability of remote controlled fixed-wing and multirotor UAS provide an additional platform to lift sensors for atmospheric and terrestrial observations off the ground, and thereby provide researchers a new path to upper air observations.

The Earth Observing Laboratory (EOL) of the National Center for Atmospheric Research (NCAR) has been one of the leading research institutions for airborne atmospheric observations using balloons and manned aircraft, but has not developed any expertise with UAS. One of the important roles of EOL is to provide a resource for the larger NSF research community and to support atmospheric science through expertise in atmospheric observations.

EOL initiated a series of workshops to examine the Lower Atmospheric Observing Facilities (LAOF) assets and to identify weaknesses in the capabilities of existing and emerging tools, and in the modes of deployment supported by these systems. The LAOF workshop titled Meeting the Challenges of the Climate System Science (Smith, 2013), which was organized and hosted by EOL in June 2012, discussed outstanding research topics within different areas of atmospheric research. Among other results, this workshop identified UAS as an emerging tool, which had not yet received much attention within the LAOF community. The terrestrial-atmosphere interface, the ocean-atmosphere interface, and the cryosphere-atmosphere interface were highlighted as areas where UAS could provide a new approach to survey regions over a few tens or hundreds of kilometers with miniaturized instruments, possibly deployed from land, shore, ice floe, or ship. Observations in the free troposphere and above were not seen as a high priority for observations using UAS beyond the current capabilities.

Other government agencies (NASA, NOAA, DOE) have operated or leased UAS for specific missions. Most UAS platforms require a significant ground based infrastructure and financial support not only for acquisition but also for maintenance and operation. NCAR, as a national center, is uniquely positioned to provide additional capability and services to the university community involving UASs for atmospheric research. It was suggested that as part of this process, NCAR conduct a survey of university UAS expectations to support atmospheric research and hold a workshop including university, industry, and government entities.

Survey

To gain a better understanding of the community needs and capabilities with respect to UAS, we developed a community survey, which was distributed in July 2016. This survey sought to reach scientists and engineers who are using UAS or are interested in using UAS for atmospheric research. The purpose of the survey was to gauge how UAS are currently being used, what accomplishments researchers have achieved using UAS, and what the strengths and weaknesses are in the use of UAS for atmospheric science.

We asked all respondents about their research area and their experience with UAS. Those, who indicated that they are not currently using UAS, we asked about the research topics for which they could envision using UAS and the greatest benefit that UAS may provide. We also asked, which support category, such as flight operations, community UAS platforms, or instrument development, they might benefit from most, if they were to become active UAS users.

Those, who are already using UAS in their research, we asked a more extensive set of questions, probing in greater detail their research area, their level of experience and skill working with UAS based observations, as well as were they saw unmet needs and research potential.

All respondents were asked, whether several research support categories, which EOL could possibly provide, would be seen as complementary, competing, or neither, and what EOL could provide to support or augment the respondent's research.

The survey was distributed to three groups:

1. UCAR Member University Representatives, with a request to distribute the survey within their departments. This went out twice, once at the beginning of the survey period and again a week before the survey closed.
2. NSF grant recipients, who specifically mentioned research using UAS in their grant application.
3. UCAR employees who were also encouraged to send to interested colleagues.

The survey stayed open until the end of August 2016 and all feedback received by that date was included in the analysis.

Results

Respondents

A total of 53 recipients completed the survey. Of these, 40 were from universities in the U.S., 5 from NOAA, and the remaining from foreign universities, the Desert Research Institute (DRI), NASA, the Pacific Northwest National Laboratory (PNNL), Boulder Environmental Science and Technology (BEST), and NCAR.

Forty-one respondents identified with atmospheric science, five with earth science, five with engineering, one with a private company, and one with system health management. Ocean science was explicitly listed as option to identify the area of research, but was not selected by any of the respondents. Within the respondents who classified themselves as atmospheric science, 23 (56%) identified themselves as current UAS users.

Thirty-three respondents (62%) identified themselves as current users of UAS, while 19 (36%) were not using UAS, but indicated plans to use UAS or expressed an interest in using UAS in the future. One respondent indicated that he was not using UAS and was not planning to do so. This respondent provided no additional input and was excluded from further analysis.

Research Areas

The information available to us prior to this survey indicated a strong focus on UAS for lower atmospheric research. To get a better understanding of the general research areas, we asked respondents, who indicated that they are using UAS, about the research topics they are investigating using UAS. We offered the following choices: boundary layer, turbulence, cloud processes, aerosol measurements, air quality, constituents / atmospheric chemistry, tropical, and other. In the category “other” respondents could provide a free text response to further categorize their research topic and provide options that we had not considered. These responses are included in the charts as appropriate.

For the current research topic, the majority of UAS users categorized their research topic as boundary layer, which is consistent with the preliminary information. Although our survey sample size is relatively small, there is no obvious sampling bias and we consider this result representative of the larger UAS research community. The complete distribution of current research topics of UAS users is shown in Figure 1. It should be noted that Boundary Layer was mentioned in almost all of the responses from those in the atmospheric science community.

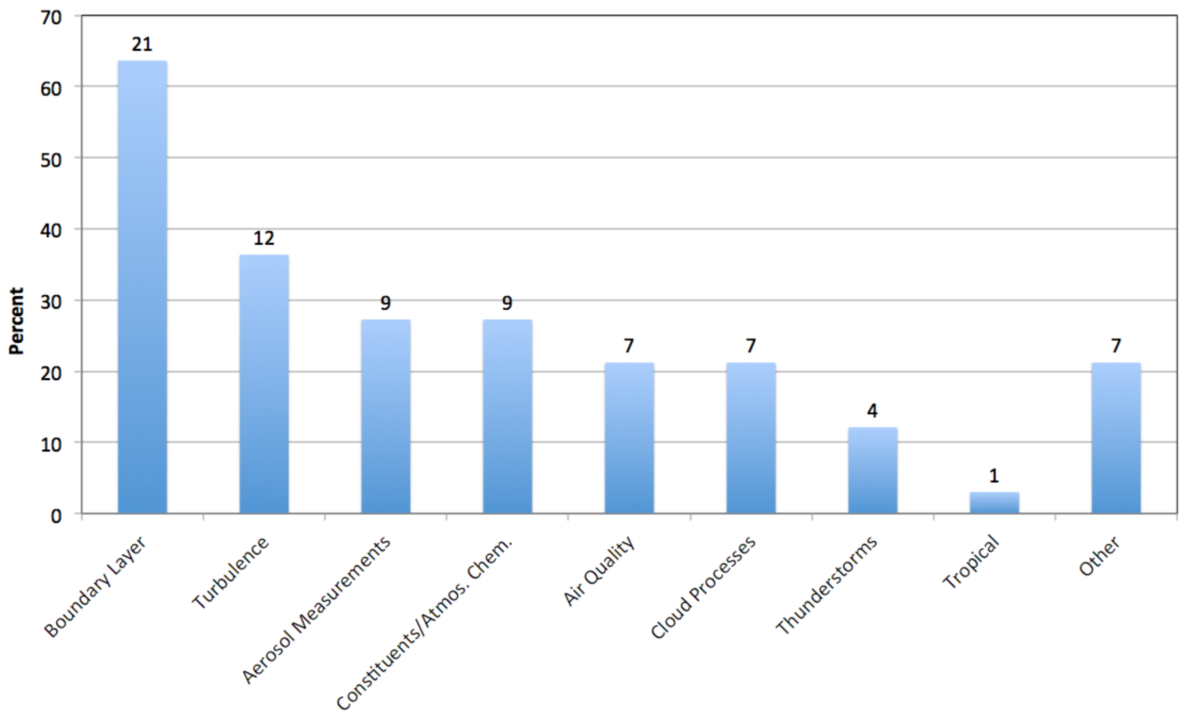

Figure 1: Research topics for which UAS are currently being used. The bars represent the percent of total respondents that selected or entered each topic; while the numbers on top of each bar represent the absolute number of times, each topic was chosen or entered.

We also asked current users of UAS to identify research topics they would like to research with UAS, but are not doing so. The choice of areas of research was the same as those they are currently studying.

Figure 2 shows the distribution of desired research topics. The boundary layer scores high in this group as well, reaffirming that UAS research interests lie mostly within this part of the atmosphere. However, constituents / atmospheric chemistry, air quality, and aerosol measurements rank significantly higher in the topics researchers would like to study compared to the topics, which they are currently studying.

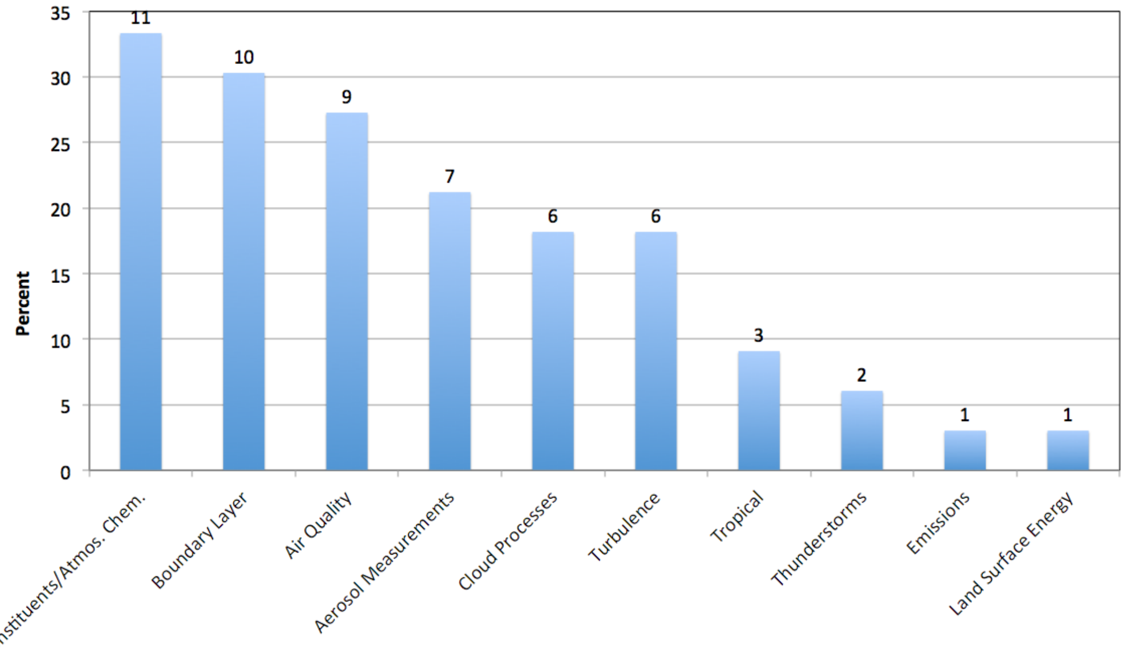

Figure 2: As in Figure 1, but for research topics for which respondents, who are currently using UAS, would like to use UAS but are not doing so now.

We also asked non-users of UAS to identify research topics they would like to research using UAS. Their responses are shown in Figure 3. The research topic "boundary layer" again received the highest number of responses, followed by aerosol measurements and cloud processes.

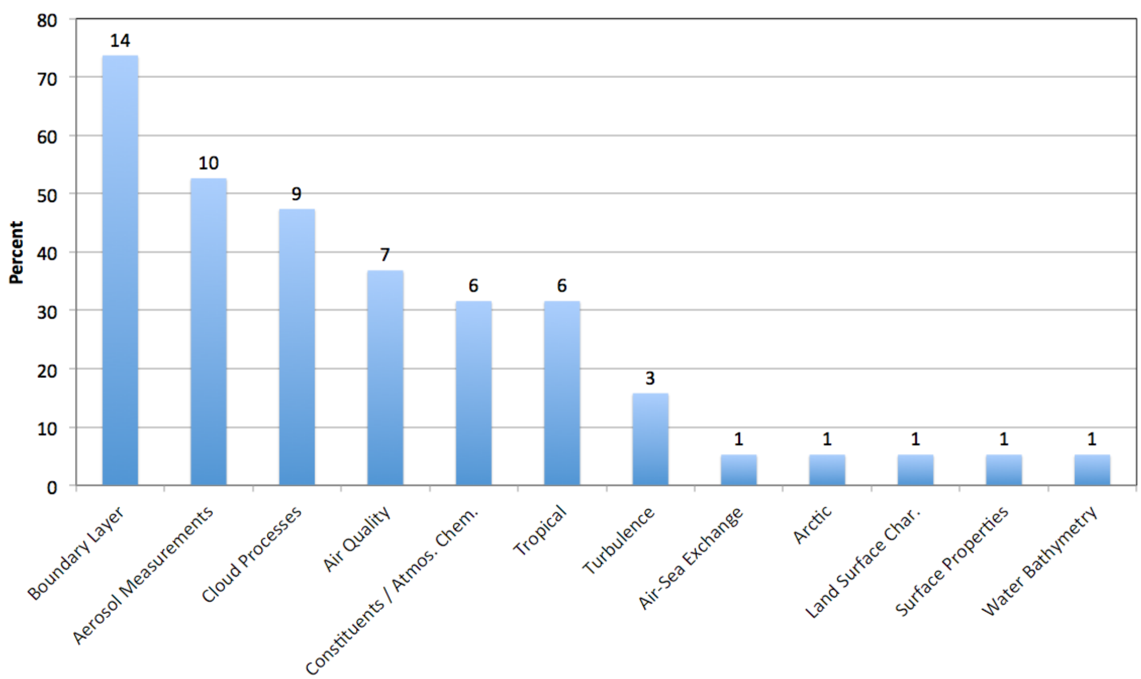

Figure 3: UAS research topics as in Figure 1, but for respondents, who are currently not using UAS.

We also asked whether there are any other UAS applications that the respondents think are promising, but outside of their research area. The most common reply to that question was that there are numerous applications outside each respondent's specific area. Although non-specific, this reply indicates that there is still significant potential in the use of UAS, which has not yet been developed. The collaborative multi-UAS measurements was the second most common response, referring to applications, where more than one UAS are flown simultaneously to obtain better spatial and temporal sampling.

Atmospheric parameters

We asked respondents who indicated that they are using UAS which specific atmospheric parameters they are currently measuring. Possible answers were temperature, pressure horizontal wind, vertical wind, turbulence, humidity, cloud properties, aerosols, air quality, constituents / trace gases, fluxes, radiation, and other. The distribution of all responses is shown in Figure 3. Parameters named in the category "other" were aerial photos, electric fields, polar and maritime surveys, topography, multispectral imagery, thermal infrared (IR), and surface temperature. The question obviously implied the existence of appropriate sensors, but did not probe the quality of the measurements.

Observations of the basic thermodynamic parameters temperature, humidity, pressure, and wind are most common and taken in most studies. Other less frequently measured parameters depend on the interests of the individual researcher and the specific research project.

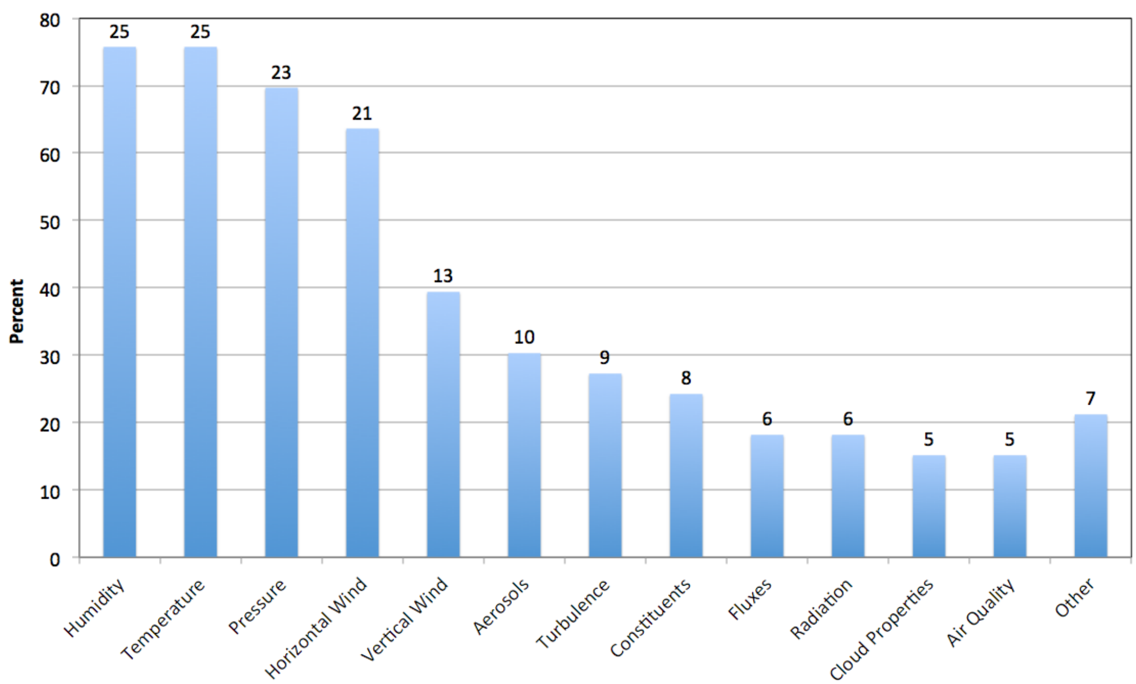

Figure 4: Atmospheric parameters currently being measured by UAS as a percent of total respondents. The numbers on top of the bars represent the absolute number of responses for each parameter.

We referred to the same list of parameters when we asked which atmospheric parameters the respondents would like to measure/retrieve using a UAS, but lack the sensors to do so. Here the parameters turbulence, constituents / trace gases, cloud properties, and vertical wind were listed most frequently (Figure 5). However, a substantial need for sensors exists for all parameters, including those for which sensors are already available.

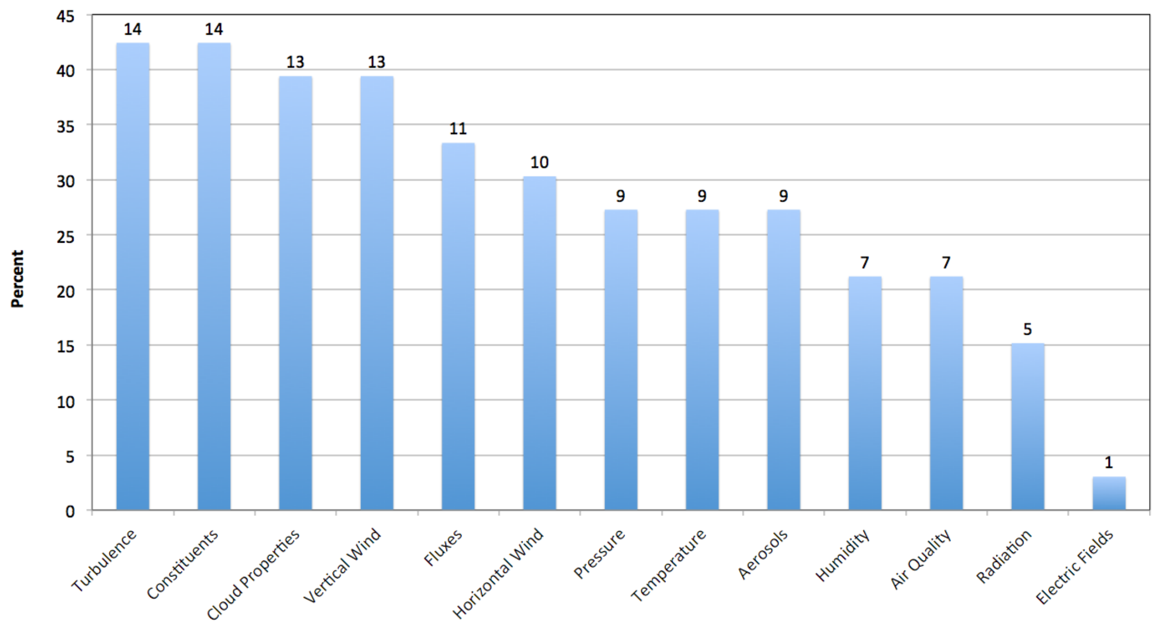

Figure 5: As in Figure 4 but for atmospheric parameters not currently measured by UAS researchers, which they would like to be able to measure.

Platforms

We asked for a description of current UAS research platforms and the considerations that went into utilizing the particular UAS. The number of responses was not sufficient to provide a statistically significant distribution of which platforms were chosen, but the responses still provided very valuable information about the scope of platforms as well as the decision process towards a particular UAS.

Platforms being used are divided about equally between fixed wing and multirotor aircraft. Respondents almost exclusively worked with small UAS, i.e. those with a takeoff weight of less than 55 pounds. Within this class of UAS systems, all sizes are represented. Most respondents have utilized more than one aircraft and typically have access to both fixed wing and multirotor platforms.

Researchers using UAS for terrestrial imaging are more likely to use Commercial-Off-The-Shelf (COTS) solutions, which are widely available. For all other applications researchers are more likely to acquire the sensors independently of the aircraft and then adapt those for their planned use, although a few COTS UAS dedicated to meteorological observations exist. Some respondents indicated that they acquired the avionic electronics independently from the airframe.

Finally, some respondents indicated that they do not own or operate the UAS themselves, but collaborate with academic or private organizations with that capability.

Figure 6 shows a primary consideration for choosing a particular platform. Payload was the most frequently named consideration, closely followed by cost and size. The responses under category “other” were FAA requirements, endurance, ability to measure in storm environment, fulfill observation requirements, potential to work properly within a thunderstorm, in the mixed-phase region, fairly “simple” operational complexity, and flight duration.

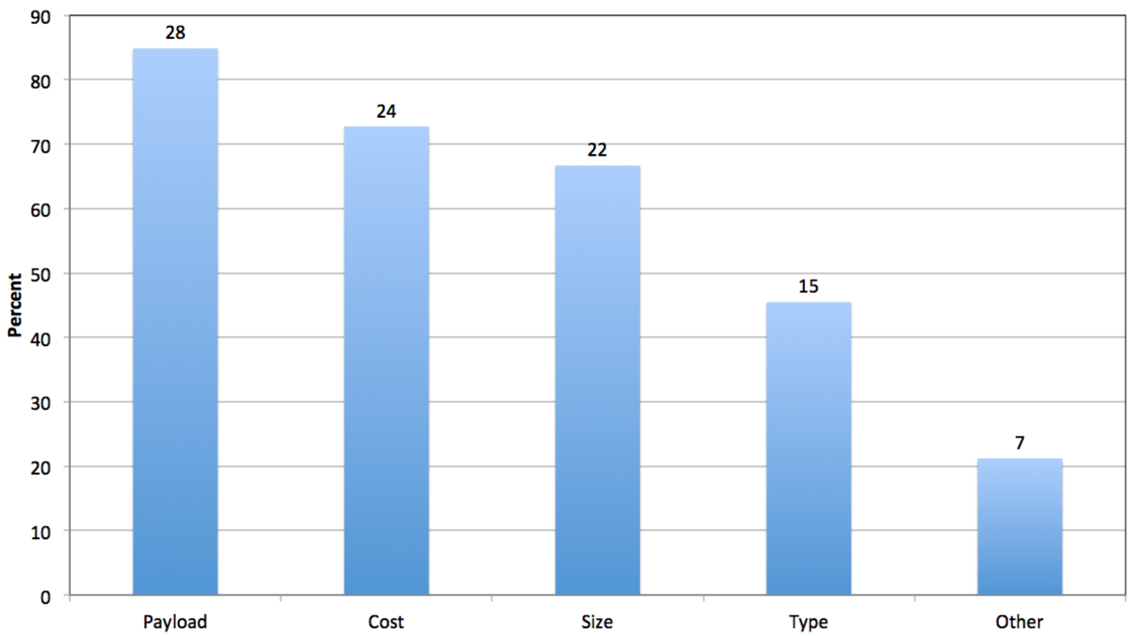

Figure 6: Percent of respondents who indicated a category as consideration for choosing the UAS with which they are performing research.

We gave respondents the opportunity to provide other considerations that went into the decision process so that we could gain a better understanding of the motivation to work with a particular UAS. This question did not offer pre-selected options and answers covered a large range of topics. Many responses stated multiple considerations highlighting the complexity of platform selection.

Operational requirements, such as the need for Vertical Take-Off and Landing (VTOL), the need for a runway, UAS recovery options, the ability to operate in a particular environment (e.g. polar regions) or the need for extended flight duration were most frequently listed. Initial cost and ease of use was listed as an important consideration as well. Some researchers, who expressed the need for low cost and ease of operation, expressed that their research plan might evolve to more expensive and complex systems, once sufficient experience with lower cost systems had been acquired. Other respondents highlighted the science question and the choice of sensors as the driver for the choice of platform. Finally, reliability and robustness of the platform as well as a proven track record were given as important considerations. The last category worth noting are legal considerations. One respondent pointed out the need to obtain a Certificate Of Authorization (COA) for the platform of choice and another respondent pointed out the need for open source hardware and software in order to avoid legal export control issues when working with foreign students.

To evaluate which platforms might be replaced by UAS we asked respondents about what other platforms, if any, were considered for the planned observations. Possible categories were tethered balloons, untethered balloons, kites, manned aircraft, towers, remote sensing, none, and other. Figure 7 shows the distribution of alternative platforms that were considered.

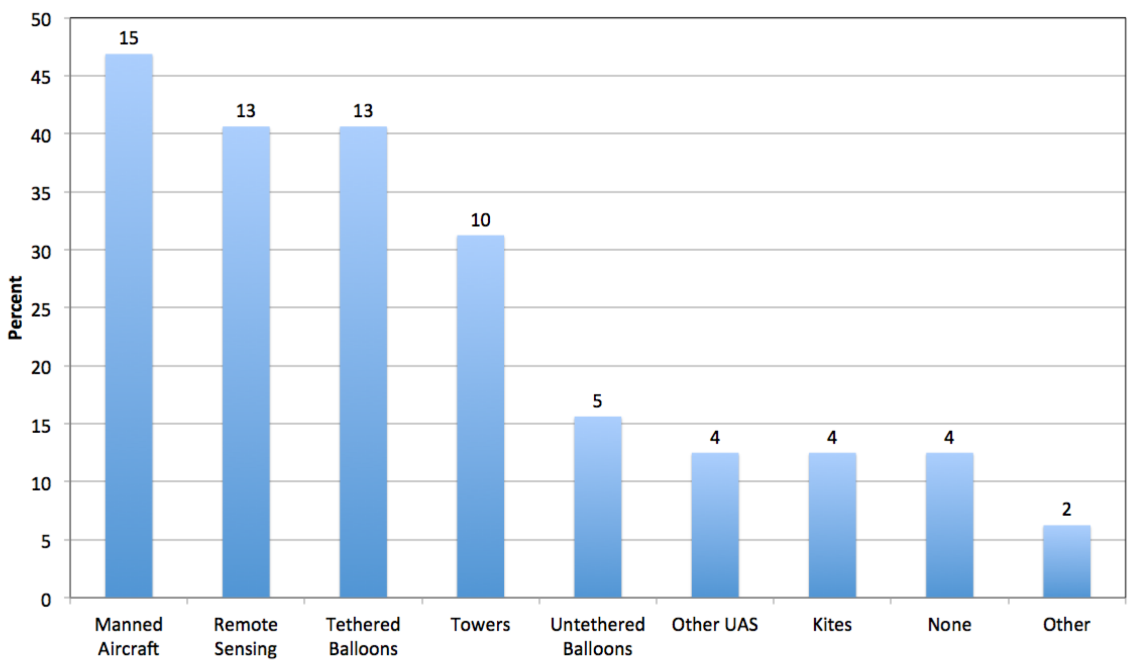

Figure 7: Alternative platforms that were considered for observations.

The category "manned aircraft" was listed most frequently followed by remote sensing and tethered balloons. In the category "other" respondents named micro-meteorological ground stations, water vessels, and other UAS. Four respondents replied "none", which is the same number of responses as for the categories kites and one less than for the category untethered balloons.

Lastly, we asked what other methods are respondents currently use in their research that UAS might be able to replace or complement. The responses clearly indicated that UAS is seen as a new and complementary platform, which augments a number of existing observational techniques. The responses also indicated that UAS could possibly replace two other platforms for some research projects: manned aircraft observations, which were also the most frequent alternative platform considered for the observations, and balloon soundings, which on the other hand were not frequently listed as an alternative platform.

Measurements

Measurements onboard UAS often require sensors, which are optimized for low weight and power consumption. Measurements, in particular for air movement, may also be impacted by the specific aerodynamic behavior of the UAS platform. Therefore, it is not obvious that UAS borne measurements have a data quality equivalent to that from manned aircraft or balloon borne measurements. We, therefore, asked how easy or difficult is it to interpret and use UAS data.

Most UAS researchers find that using and interpreting data from UAS is easy to very easy (Figure 8), with only four respondents calling that task difficult or very difficult. Respondents could also provide clear text comments about the difficulty to interpret and use UAS data. Basic measurements such as temperature, pressure, and moisture are seen to be fairly straightforward. However, kinematic measurements such as winds, turbulence and fluxes are seen as more difficult. Some UAS researchers are familiar with observations from other airborne platforms, in particular manned aircraft, and have experience working with this type of data. For these researchers working with data collected by UAS was not seen as fundamentally different. In some cases researchers found that effects from the UAS itself (e.g. downwash from rotors) negatively influence their measurements and makes data more difficult to interpret. The relative ease of deployment of UAS means that significantly more data can be collected, which means significantly more data may need to be analyzed and archived. This aspect is seen to increase the difficulty of working with UAS observations (i.e. “big data” problem).

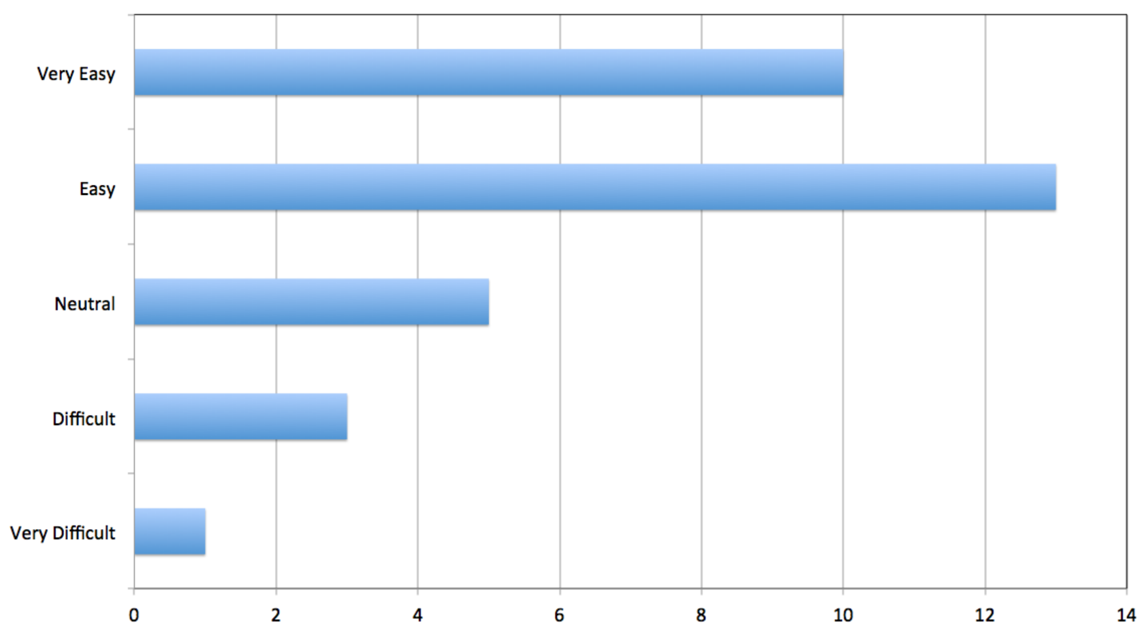

Figure 8: Difficulty or simplicity of using observations from UAS.

As with any measurement, it is important to characterize the uncertainty of UAS observations. To better understand the expected data quality, we asked whether respondents, who are using UAS, characterized the uncertainties of their UAS measurements and how this was done. 62% of respondents replied that they did characterize the uncertainty of their measurements. The comments about the methodology indicate that the extent of the characterization efforts depends strongly on the instrument and availability of other systems to measure the same parameter. It is important to note that these replies referred to different measurements without specifically listing those. Laboratory studies of sensor performance were listed most frequently followed by comparisons to ground based instruments and comparisons to tower measurements. Some respondents listed comparisons with remote sensing instruments separately from comparisons with ground based instruments. Comparisons with other aircraft (manned and unmanned) have been used as well as in-flight calibrations and statistical analysis under stable meteorological conditions. Others are just getting started on calibration efforts and the procedures have not yet been defined. We did not ask those not performing *calibrations* about the reasons for foregoing this exercise.

In addition to uncertainty characterization, validation of measurements is an important aspect for any emerging technology. In this context we asked whether respondents had validated their UAS data against established techniques or measurements. Seventy two percent of the respondents indicated that they did so. Most of these validations have been done against ground-based observations, which most likely includes remote sensing instruments, towers, radiosondes, but also other aircraft. Some respondents did not distinguish between calibration and validation and listed the same comments for both questions or entered “See above”. We did not ask those not performing *validation* studies about their reasons for not doing so.

Respondents who are currently not using UAS

The level of interest in using UAS from respondents, who are currently not using UAS, is shown in Figure 9. The high interest expressed by these respondents is consistent with their willingness to answer a UAS related survey. It is not necessarily an indication of the level of interest in the larger atmospheric science community as the survey recipients with no interest in UAS-based research were less likely to respond.

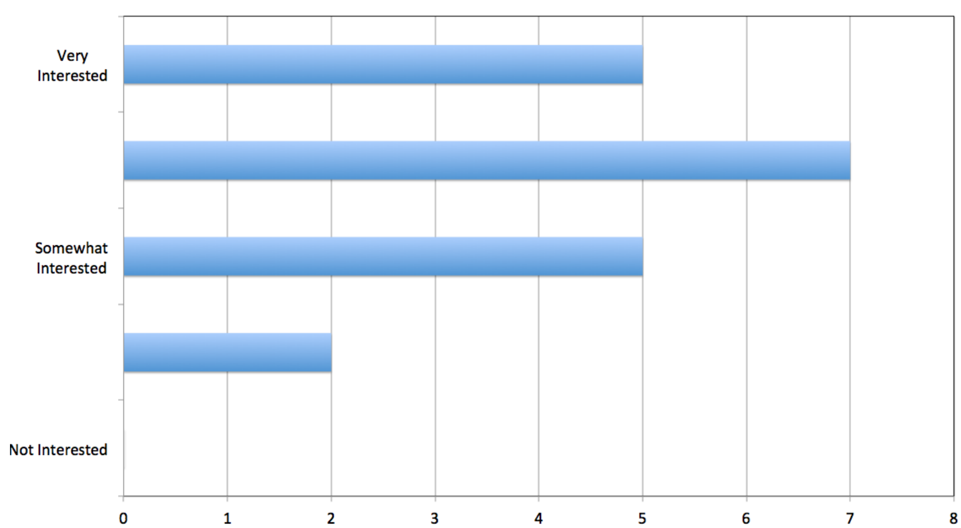

Figure 9: Level of interest in using UAS from all respondents who are currently not using UAS.

We asked respondents to indicate the greatest benefits they feel UAS could have for their research and the support categories they could most benefit from. The responses indicate an expectation to be able to reach areas that are difficult to sample either due to their remoteness or due to the difficult access by manned aircraft (proximity to severe storms or low altitudes). Many also indicate that better vertical and/or horizontal coverage than other techniques is expected. Only one respondent indicated an expectation for low cost and easy use of UAS.

We also asked respondents, who are not currently using UAS, what support categories they would most benefit from. The responses are categorized in Figure 10.

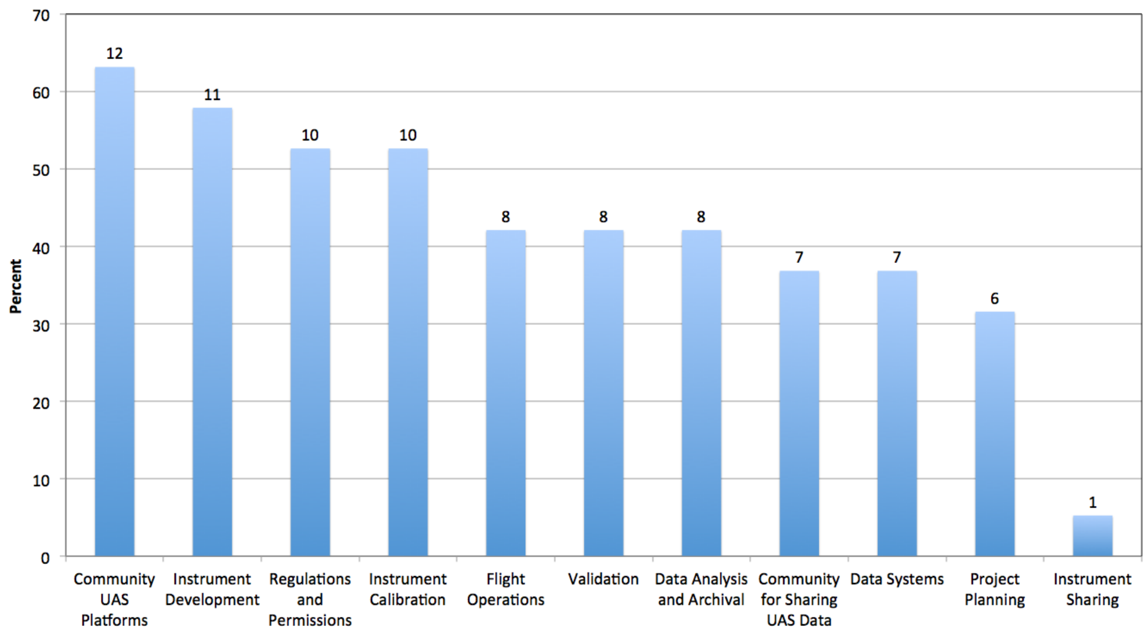

Figure 10: Support categories for which respondents, who are not using UAS, feel they would benefit from if they were to begin using UAS.

Most respondents thought that having access to community UAS platforms would be beneficial, followed closely by instrument development, help with regulations, and instrument calibration. Nine categories were selected by more than a third of respondents, showing that a wide range of support would be appreciated by new users.

Potential benefit of EOL activities

EOL's main mission is to serve the larger science community, in particular the NSF funded university research community, by providing access to facilities, which may be outside the capabilities of individual researchers. To gauge how any newly developed EOL program regarding UAS may be accepted, we asked what EOL's relationship would be to the respondent's research if EOL developed any of the following programs: Operate UAS platforms, develop instruments for UAS, provide calibration facilities for UAS instruments, provide site for validation of UAS observations, or provide data services. Respondents could select between the options complementary, competing, and neither. EOL's role in these potential programs was seen as complementary by between 58% and 75% of the respondents. Between 17% and 31% of the responses were indifferent and less than 12% of the responses viewed EOLs role as competing (Figure 11).

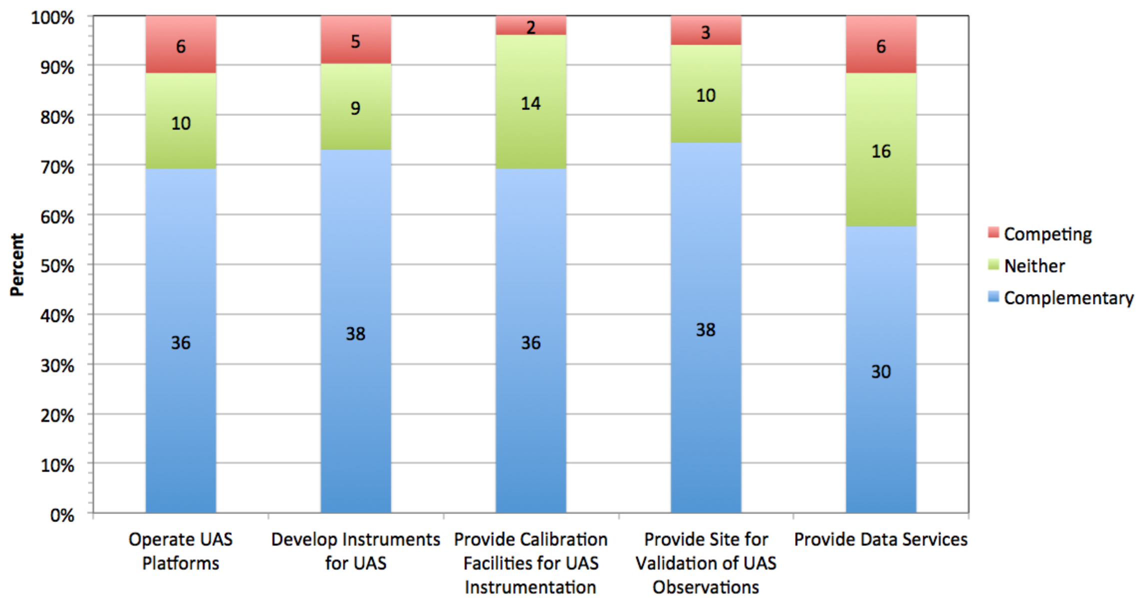

Figure 11: Percent of respondents who view various services that EOL could provide as complementary, competing, or neither complementary nor competing to their research. The numbers in the bars represent the absolute number of responses for each category.

The last question we posed to respondents in this section was to list what EOL could provide that would best augment or support the respondent's UAS research. This question did not offer pre-defined answers and allowed respondents to provide free text comments. This question was presented to both current users and non-users of UAS, which here are not further distinguished. The responses were grouped into seven different categories (see Figure 12). The most frequent comment on potential EOL support programs for UAS expressed a need for EOL to provide a community UAS platform, which could be requested similar to other EOL deployment pool instrumentation. However, no clear picture emerged about which UAS platform would be best suited for this function. Suggestions included, but were not limited to, large UAS (> 55 lb.), a fleet of vertical takeoff and landing (VTOL), UAS capable of carrying a 10 kg payload, or simply a community platform with standardized instrumentation.

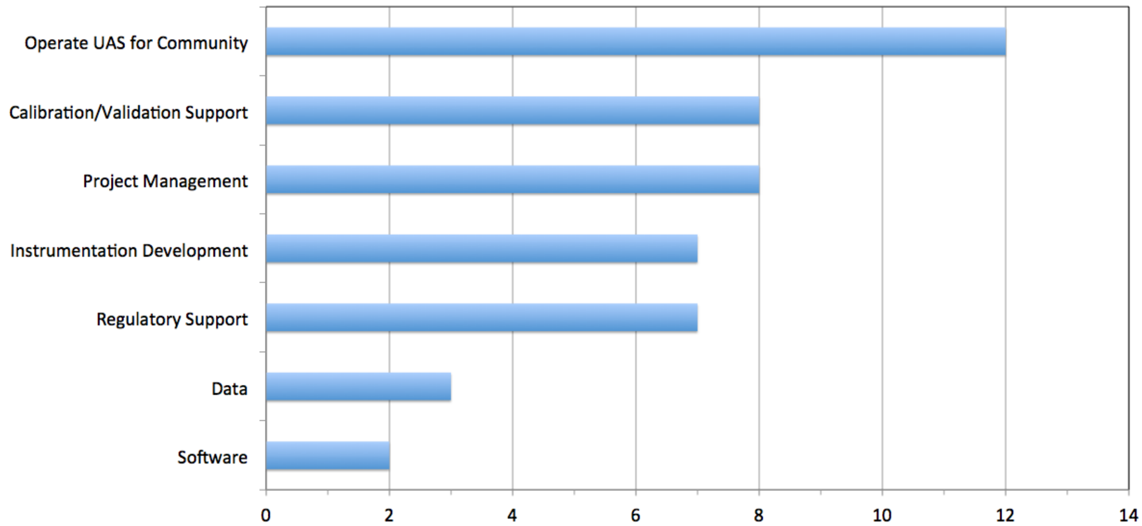

Figure 12: Results from what EOL could provide that would best augment or support the respondents UAS research.

Other potential UAS related programs, which were seen as of high value, are a facility for calibration and/or validation of measurements; project management support, in particular for larger programs involving multiple UAS; support in the development of instruments; and regulatory support. Data services and software support were also mentioned.

Discussion

We asked respondents to think of specific UAS aspects in the context of both their current UAS activities and what they know about the efforts of the larger UAS research community, and asked them to rate how well developed they feel the respective aspect is. The aspects were UAS flight operations, instrument development, instrument validation, instrument calibration, UAS data systems, UAS data analysis, and UAS rules and regulations (Figure 13). Most of these aspects showed a nearly symmetric distribution around somewhat developed. “Instrument validation” and “UAS Rules and Regulations” had a most common response of “less developed”. That instrument validation was rated as less developed is consistent with the previous result that uncertainty characterization and sensor performance may still be improved on average.

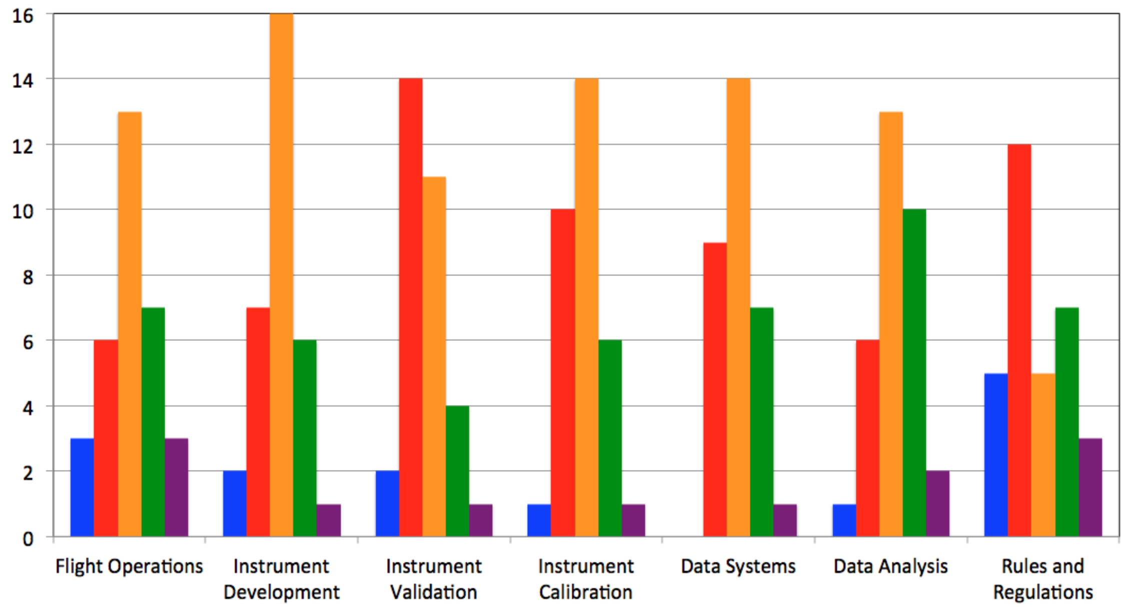

Figure 13: Subjective level of maturity for different UAS aspects. Color-coding of the bars from left: Blue: not at all developed; Red: less developed; Orange: somewhat developed; Green: more developed; Purple: extremely well developed.

The responses for the aspect "UAS rules and regulations" showed a split distribution with most responses indicating less developed and a second peak indicating more developed. This indicates that the user community may be split between users who have established relations with the Federal Aviation Administration (FAA) and for whom understanding and complying with regulations may not be a significant burden, and users for whom understanding and complying with regulations may still create a significant burden in the research effort. A follow up question allowed respondents explicitly describing the reasons for choosing why an aspect was not at all developed. Four out of six responses explicitly described the difficulties working with the FAA under current rules, and one of these four respondent commented on the fact that there are some groups that have well established connections with the FAA, while the respondent did not.

To gauge to what extent this new platform may meet expectations, we asked respondents what has been the biggest success in using UAS for research. Although the responses spread over many areas, the largest number of researchers list new observational results, which may not have been possible with other techniques, as their biggest success. Some observations were taken in very remote regions (polar) or in hazardous regions (near thunderstorms). A sizeable number of publications indicates some level of maturity for these observational programs. New sensor development as well as expanding the regulatory capabilities was another area considered a success, which will expand the capabilities of UAS in atmospheric research.

The survey also asked what has been the biggest challenge in using UAS. Here, air traffic regulations and working with the FAA emerged as the most significant challenge in UAS based observations. Related to this, the availability of trained and certified UAS pilots is seen as challenge, in particular for intensive field campaigns, requiring a lot of staff.

Measurements of winds and turbulence were also indicated as significant challenge for current UAS. This is consistent with the answers to our question which atmospheric parameters the respondents would like to measure/retrieve using a UAS, but lack the sensors. Wind measurements from UAS are considered very important measurements and frequently measured, but at the same time, these measurements are seen as somewhat uncertain with current sensor technology.

Basic atmospheric state measurements of pressure, temperature and humidity were listed as the most frequently measured parameters, but also listed as parameters respondents would like to measure/retrieve using a UAS, but lack the sensors. This indicates that even for these basic parameters there is a need for better sensors in some applications, which is currently not being met, despite a wide availability of sensors.

The need for uncertainty characterization and validation is well recognized, but the large variety of approaches and a tendency not to distinguish between the two indicates that there is still a significant need to characterize the quality of observations.

Measurements of cloud properties also appear to be important to respondents. However, these measurements are difficult to obtain because UAS are largely required to stay within line of sight, which implies outside of clouds. Furthermore, there is a significant risk of icing for flights into supercooled and mixed-phase clouds. There is interest in the development of technology for UAS to fly in these conditions, and working with regulatory agencies to collect these types of measurements would be welcome by the community.

Even though not with high priority, data and software services were seen as potential support to respondent's UAS research. Since UAS may provide a multitude of different measurements, the amount and structure of data may be quite complex. Some level of standardization of software, processing, and data flow may be beneficial to the UAS community. Some researchers mentioned a potential “big data” problem in this context without specifying further.

The replies to the question about UAS applications outside the respondent's specific area is consistent with UAS being a relatively new tool in atmospheric science, which has not yet been fully utilized. In particular, UAS operations using more than one platform in a coordinated flight plan appear to be a promising approach, which has been rarely implemented so far.

The fact that roughly half to three quarters of respondents viewed potential EOL programs in UAS research as complementary and only a small fraction of the respondents saw potential EOL programs as competing indicates that there is a significant need for support of the larger UAS community by NCAR EOL and that this support would be welcome.

Access to community UAS platforms, instrument development and calibration, project coordination and aid with regulations are categories where respondents felt they could use the most help if they were to use UAS for their research. However, there is no clear picture, which

UAS platform(s) or which set of instruments would be most beneficial for the larger community, because most UAS users typically operate multiple platforms and continuously expand their capabilities. A community workshop on UAS would help with this, as it would allow users to provide more feedback on platforms and instruments and contribute to the shaping of EOL's role in the UAS atmospheric research community.

The previous workshops as well as the responses to our survey focus exclusively on the lower atmosphere. This focus may be representative of the larger university research community; however, it may also be a result of an implicit sampling bias due to the choice of recipients of the survey. Considerations of UAS work in the middle and upper troposphere were explicitly neglected as a result of the previous workshops. Aside from this, we do not suspect any sampling bias in our responses. We expect that whichever path is taken as a result of the outcomes of this survey the NSF research community may be well served by some dedicated UAS support program at NCAR EOL.

References

Smith, R. B., 2013: The Lower Atmospheric Observing Facilities Workshop, UCAR/NCAR - Earth Observing Laboratory, http://dx.doi.org/10.5065/D66971M1.

Acronyms

BEST: Boulder Environmental Science and Technology
COA: Certificate of Authorization
COTS: Commercial-Off-The-Shelf
DHS: Department of Homeland Security
DRI: Desert Research Institute
FAA: Federal Aviation Administration
LAOF: Lower Atmosphere Observing Facilities
NCAR: National Center for Atmospheric Research
NOAA: National Oceanic and Atmospheric Administration
PNNL: Pacific Northwest National Laboratory
UAS: Unmanned Aircraft Systems
VTOL: Vertical Take-Off and Landing