Science Goals for UAS

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Executive Summary

Unmanned aircraft systems (UAS) are already significantly expanding atmospheric observations. We are currently witnessing a rapidly growing variety of both aircraft and applications with more on the way. For the present discussion, we focus on the use of small UAS (sUAS) for atmospheric research and monitoring. The term sUAS is applied to vehicles weighing less than 55 lbs (25 kg). Moreover, here we will concentrate on those operations pertaining to the atmospheric boundary layer and lower free atmosphere.

We consider a cross-section of various atmospheric research areas being advanced through the implementation of sUAS and provide a look towards some future applications. On account of time and space constraints, it will not be possible to provide comprehensive discussion of this topic, but rather, we will concentrate on several representative applications to initiate discussion on Science Goals for UAS. The focus will be on measurements of thermodynamic and kinematic properties of the atmosphere; turbulence and flux parameters; remote sensing, amounts of trace gasses; and the presence of particulates, including hydrometeors, aerosols, black carbon, and such. The authors are eager to receive inputs from various research groups on their particular science applications involving sUAS .

There are certain regulatory hurdles that must be overcome to ensure compliance with federal and international regulations regarding the operation of sUAS. It is anticipated that these regulations will undergo many changes in the coming years to address safety concerns of manned aviation operations as well as the general public on the ground. The FAA recently established six sites in the United States to test communication and crash avoidance with UAS that are expected to lead to specification of required systems for UAS platforms for operation at various altitudes and weather conditions that might pose threats to manned aviation operations. Meanwhile, current regulations allow for certain low-level operations. In the US, operations can be conducted with an onsite pilot-in-command and other trained spotters at designated sites with Certificate of Authorization granted by the FAA or individuals who have obtained a sUAS pilot license and operate under "Part 107" rules. A more detailed discussion of this topic can be found in the Workshop white paper on the Regulatory Environment.

Finally, when discussing science goals and how they could be achieved through sUAS operations, especially in contrast to traditional research aircraft, we should consider:

- Payload constraints in terms of size, weight, and power (SWaP) and compromises on instrumentation for mission-specific platforms.
- Sampling issues (maximum/minimum altitude, duration, spatial coverage)
- Extended logistics / personnel capabilities (boat launch, operations in remote or dangerous locations, etc.)

Introductory Remarks

Clearly, the availability of quality atmospheric observations is critical to our ability to monitor meteorological conditions and accurately forecast the weather. Meteorological observations fall largely into two categories: in-situ and remote sensing. The former involves the measurement by instruments, which are directly exposed to the atmosphere. In this case, continual observations of the atmosphere are limited to sensors, which can be placed at or near the Earth's surface, e.g., using instrumented towers. To obtain in-situ measurements aloft, balloons, kites, or aircraft must be used. Sensors capable of remotely probing the Earth's atmosphere, such as radar, lidar, sodars, and radiometers, are capable of providing continual observation. However, the number of atmospheric parameters such technologies can provide is limited and the data often must be inferred from other measured quantities, e.g., radar reflectivity. For example, rainfall rates provided by weather radar are estimated based on the strength of the backscattered signal from the precipitation. UAS offers the capacity to make both in-situ and remote sensing observations from a controlled platform capable of operating under conditions and in locations not necessarily possible with piloted aircraft.

As in all areas of experimental research, the evolution of the role of sUAS for atmospheric studies has experienced both the development of sensors and platforms based on specific questions and an aggregation of questions around the availability of sensors and platforms. Some of the sensors in use or envisioned include the measurement of standard atmospheric variables (temperature, pressure, humidity and wind), quantities related to turbulence and flux, common atmospheric chemical constituents (ozone, NO_x, SO_x, particulates and CO_2), imaging sensors (clouds and surface characteristics), rain and cloud particle probes, along with aerosol and particulate probes. Many sensors are currently available off-the-shelf, but most require modification or further development to accommodate size, weight, and power (SWaP) requirements, or to allow the interface with a modular sensor airframe and corresponding telemetry system. Moreover, one must carefully consider such factors as how sensors are placed on the airframe; what is the appropriate response time and sampling frequency; and representativeness of the measurements being collected. These considerations largely overlap with issues related to traditional research aircraft and NCAR has already been filling a community need by helping scientists resolve these issues and when appropriate, providing the needed infrastructure to complete science objectives. In a similar vein, running sUAS operations at research laboratories requires skill sets in aeronautics, sensor development and application, along with state and federal policies and regulations, which not every group will have developed or have the capacity to fulfill within a flight team. NCAR's role regarding sUAS could be similar to the function it plays for manned aircraft in providing the interface between the scientist and technical and logistical issues of operating sUAS .

Sample Applications

The atmospheric boundary layer (ABL) plays a major role in the development of many weather systems. Consequently, there is an ongoing need for improved observations of the ABL and parameterization schemes of the ABL for numerical weather forecasts. For example, height profiles of virtual potential temperature can be used to identify regions of thermal stratification and the degree of atmospheric stability. Moreover, vertical wind shear is capable of producing turbulence and thus turbulent fluxes in the ABL. Overall, processes in the ABL can vary dramatically over a single diurnal cycle.

Currently a significant “measurement rift” exists between tower-based observations of the atmosphere and those provided by manned airborne systems, which is especially acute at critical levels in the boundary layer. Remote sensing systems, such as radar, sodar, and lidar can fill this gap in part, but still do not provide the detailed information, particularly thermodynamic, required for modeling and a complete understanding of the structure and evolution of complex weather systems. Reports from the National Research Council and instrumentation workshops (e.g., NRC, 2009; Hoff, et al. 2012) have recommended that observing systems capable of providing detailed profiles of temperature, moisture, and winds throughout the lowest few thousand meters of the atmosphere are needed to monitor the lower atmosphere, help determine the potential for severe weather development, and rapid changes in the local severe storm environment.

A wide variety of sUAS are currently being used for atmospheric research depending on the particular application or science problem. Platforms in the weight range of 2-5 kg or less have clearly demonstrated that sUAS are capable of producing atmospheric height profiles of temperature, pressure, humidity, and wind, which are important when characterizing the vertical structure of the lower troposphere, and in particular the ABL. They have also been used to monitor certain trace gases in the atmosphere.

The ABL is also crucial to the initiation and further development of severe storms because it provides the moisture, instability, low-level wind shear, and forcing necessary for the formation of severe storms with attendant tornadoes, hail, and dangerous winds. Moreover, within the ABL reside the storm-generated outflows that regulate the strength and longevity of severe storms. Knowledge of these conditions is crucial to improving predictions of severe weather events, yet the highly variable nature of ABL properties on important mesoscale time and space scales is virtually undetected by operational observing systems. Weather radars provide critical information about internal storm structure and processes, but they do not adequately observe the environment surrounding the storms. Satellite data have poor vertical resolution in the ABL. Ground-based remote sensing systems are arguably too expensive if built into a national static observing network. The meteorological community is developing a growing interest in the use of sUAS to help address these issues.

Potential Future Directions

Fixed monitoring sites, such as those in the NWS Automated Surface Observing System (ASOS) and FAA’s Automated Weather Observing System (AWOS) provide valuable, high temporal resolution information about the atmosphere to forecasters and the general public. While these are critical data sources, such networks only provide surface observations while most environmental monitoring and forecasting problems are inherently a spatially threedimensional problem. The deployment of sAUS to collect in-situ vertical measurements of the atmospheric state in conjunction with surface conditions has potential to significantly expand weather observation capabilities. This concept can enhance the safety of individuals and support commerce through improved observations and short-term forecasts of the weather and other environmental variables in the lower atmosphere.

The continuing development of sUAS for meteorological applications requires highly reliable and robust platforms that can routinely perform regular atmospheric measurements in a variety of weather conditions, including day or night operation and during hazardous weather. We must conduct additional research and development on multiple platform types (custom built and commercial off the shelf, rotor craft and fixed-wing platforms), which can be equipped with high-precision and fast-response atmospheric sensors. Moreover, we must adapt miniaturized high-precision and fast-response atmospheric sensors to sUAS platforms. Additionally, we should compare fixed-wing and rotorcraft vehicles as to their suitability for carrying a variety of sensors for the study of ABL properties. Because various properties of the atmosphere are being sensed, the sUAS aircraft, its movements, outgassing, thermal profile, backwash and other properties have the potential to affect sensor data. Future studies will allow us to determine the proper aircraft, sensor position, and sensor suite to use in further research – with the eventual goal of being able to use a heterogeneous system of autonomous vehicles to map critical features of the ABL through both space and time, allowing for a better understanding of this critical set of related atmospheric phenomena.

The development of sUAS as an atmospheric measurement platform is providing better access to regions, which have been traditionally difficult to access, such as, remote and environmentally sensitive locations, volcanoes, forest fires, areas experiencing dangerous atmospheric conditions, and so forth. In this context, we are speaking of the last two components of the "dull, dirty, and dangerous" jobs, for which sUAS are well suited. In some cases, the sUAS could be operated as an expendable resource or serve as a delivery mechanism to deploy other expendable sensors, for example, Lagrangian drifters and dropsonde packages. Along these lines, we can also consider the application of sUAS for aerosol and cloud sampling. For cloud sampling, however, one must consider regulations pertaining to beyond visual line of sight (BVLOS) operations.

We as a community should work towards developing and demonstrating methodologies to overcome some of the most relevant challenges concerning the use of intelligent sUAS to support atmospheric science. To this end we should strive to create solutions which are accessible to researchers with a little specific training in aerospace engineering, robotics, or computer science; self-aware of its own strengths and limitations within the framework of its environment; and able to learn from its own experiences and adapt its behavior. Such systems have the capacity to adaptively monitor the environment and self-aware and self-organizing swarms of vehicles could optimally sample spatially and temporally coherent features such as frontal boundaries, dry lines, clouds, regions of turbulence, outflows, and so forth.

Key challenges and opportunities to be discussed during the Workshop: Here we provide some comments and questions, which could serve to initiate discussion on the role of UAS in the atmospheric sciences

- What are the opportunities for UAS to uniquely address key science questions?
- Does the current suite of UAS platforms adequately serve the needs of the atmospheric science community?
- How do we maximize and manage the utility of UAS in the National / International Airspace System?
- What key science questions are we currently unable to adequately address based on available sensor packages? Is the market large enough to sustain commercial development of these sensors or will they need to be developed in individual laboratories?
- What role could NCAR play in developing and maintaining standard and specialty sensors?
- Do you see a need to have "gold standard" instrumented UAS, which could be used for validation purposes across institutions? Could NCAR play a role in that capacity?
- Is there a coordination function across UAS groups that can improve airspace access, instrument flexibility and access, and measurement quality that is worthy of consideration?
- Are there specific hindrances to the use of UAS and mitigating measures that can be identified?
- How can we define the interface between scientist, instrument developer, and payload engineer?
- How much flexibility exists to test and integrate science payload prior to deployment (ARISTO-type access) – certification / validation procedures?
- Risk assessment (multiple platforms / multiple instruments are needed in case of failure in the field)
- Cross-platform consistency – standardization protocols for sensor measurements when multiple mission-specific platforms have been developed (e.g., T, RH, 3D winds, etc.)
- NASA Aerosonde program (what has been learned from that effort?)