Commission for Basic Systems
and
Commission for Instruments and Methods of Observation

Workshop on Use of Unmanned Aerial Vehicles (UAV) for Operational Meteorology

Météo-France Conferences International Centre Toulouse, France

2-4 July 2019

Contents

EXECUTIVE SUMMARY

In cooperation with the French national meteorology service, Météo-France, the World Meteorological Organization (WMO) workshop on Unmanned Aerial Vehicles (UAV) was held from 2 to 4 July 2019 at the Météo-France International Conference Centre in Toulouse, France. This was the first WMO workshop held exclusively on UAVs for operational meteorological application.

Thirty-four participants attended the workshop including: National Meteorological and Hydrological Services (NMHS) observing system and Aircraft Meteorological Data Relay (AMDAR) Observing System experts, researchers and UAV users; representation from the International Air Transport Association (IATA); Industry manufacturers and developers; and other invited experts. The primary purpose of the workshop was to consider and discuss the potential of UAVs to meet requirements sufficiently to be considered operational for meteorology and also to consider the challenges of regulatory requirements.

The WMO Integrated Global Observing System (WIGOS) aims to provide a standardized framework for all observing systems and enables the provision and availability of observations based on the requirements of the 14 Application Areas of WMO. The requirements for observations are established and maintained through the WMO Rolling Review of Requirements (RRR). From the WMO international perspective, an observing system could be considered to be operational when the data derived is available on the WMO Information System and has the capability to meet the requirements for one or more Application Area.

The benefits of using AMDAR data are supported by many scientific studies that illustrate the positive impact of aircraft observations on the accuracy of meteorological forecasts and services. UAVs equipped with meteorological sensors meeting observation requirements have the potential to greatly increase the number of vertical profiles at the planetary boundary layer and fill gaps in data sparse areas. The workshop participants were informed that larger more expensive high-altitude UAVs would be most useful for global Numerical Weather Prediction (NWP) models, while smaller platforms, reporting at high frequency, with a boundary layer focus and lower costs would have the greatest impact on regional and storm scale NWP. The challenge to WMO member nations is to determine how best to implement UAV systems efficiently and effectively while overcoming the challenges of meeting airspace regulatory requirements and limited resources available to NMHSs.

The workshop presentations included research organizations and NMHS experts discussing the challenges and successes experienced using UAVs in field campaigns collecting data in support of environmental and meteorological applications. The challenges included airspace use regulations and technical capabilities of the UAVs. UAV industry representatives spoke to the workshop audience on the types and capabilities of UAVs and about their collaboration in field campaigns with research organizations and NMHS represented at the workshop. IATA and other experts informed the workshop audience of the various national and international airspace regulations.

The plenary sessions focused on the potential and requirements for operational use of UAVs and whether NMHS would operate UAVs or form partnerships with private/public companies and organizations to acquire the UAV data. The WICAP financial framework of cost sharing amongst multiple countries in one or more WMO regions was presented as a model for cost sharing if UAV data was purchased from private companies. The workshop closed after identifying key outcomes, recommendations, and future activities.

WORKSHOP REPORT

1. Workshop Opening

The World Meteorological Organization (WMO) Workshop on Use of Unmanned Aerial Vehicles (UAVs) in Operational Meteorology was held 2 to 4 July 2019 at the Météo-France International Conference Center, Toulouse, France.

The workshop was opened by Mr. Yann Guillou, Deputy-Director of the Observation Department, Météo-France. Mr. Guillou welcomed all participants to the workshop and to Toulouse and discussed the importance Météo-France placed on finding solutions to various technical issues with UAVs to help bring these emerging in-situ observation platforms into use within operational meteorology.

Mr. Dean Lockett of the WMO Secretariat welcomed all participants to the workshop on behalf of the WMO Secretary-General, thanking Météo-France for hosting the event, the presenters, and, in particular, Mr. Bruno Piquet, of Météo-France for his excellent support and coordination of the event in Toulouse.

Mr. Lockett pointed out that the theme of the workshop was mutual understanding of how UAVs are used currently by research organizations and National Meteorological and Hydrological Services (NMHS) and how UAV data can be brought into the operations of the NMHS to support Numerical Weather Prediction (NWP) and other applications. Mr. Lockett introduced Dr. Curtis Marshall, and Mr. Stewart Taylor, the Chair and Vice-Chair of the WMO Inter-Programme Expert Team for Aircraft Based Observations (IPET-ABO) and informed the workshop participants that the WMO Aircraft-Based Observations Programme (ABOP) would be expected in the future to expand its scope to include activities related to UAV development and operational implementation.

2. Workshop Programme

The workshop programme consisted of a series of presentations and panels by WMO-invited speakers from national and regional AMDAR and upper-air programmes, international research organizations, UAV industry representatives and other experts, over seven sessions and interspersed with periods for questions and open discussion. While WMO recognizes that some countries and organizations use the term Unmanned Aerial System (UAS) interchangeably with UAV, throughout this report the term UAV will be used to indicate both UAS and UAV.

Day 1, Session 1

Session 1 included four presentations on the topics of the WMO role with observing systems, the benefits of AMDAR, upper air requirements, and potential for use of UAVs in operational meteorology. The presenters' names are listed below followed by a summary of the content and key points of the session.

Mr. Dean Lockett, WMO Secretariat, Introduction to WMO, WIGOS and ABO Programme
Dr. Curtis Marshall, Chairman of the IPET-ABO, Benefits and use of Aircraft Based Observations in Operational Meteorology
Mr. Lars Isaksen, European Center for Medium-Range Weather Forecasts (ECMWF), Requirements for Upper-Air Data to support Operational Meteorology and Current Gaps
Dr. Debbie O'Sullivan, United Kingdom Met Office, Opportunities and Potential for UAV's in Operational Meteorology

Session 1 Summary

The primary purpose of the workshop was to consider and discuss the potential of UAVs to meet requirements sufficiently to be considered operational for meteorology and to consider the challenges of regulatory requirements. The role of the WMO in international meteorology is to facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations The WMO role includes supporting the establishment and maintenance of national and global centres charged with the provision of meteorological and related services, coordinating the establishment and maintenance of systems for the rapid exchange of meteorological and related information, and developing and promoting standardization of meteorological and related observations to ensure the uniform publication of meteorological, hydrological and climate-related observations and statistics. From the WMO international perspective, an observing system could be considered to be operational when the data derived is available on the WMO Information System and has the capability to meet the requirements for one or more application areas The WMO Integrated Observing System (WIGOS) provides a standardized framework for all observing systems and enables the provision and availability of observations based on the requirements of the 14 Application Areas of WMO. The requirements for observations are established and maintained through the WMO Rolling Review of Requirements (RRR) process.

The benefits of using AMDAR data in Numerical Weather Prediction (NWP) have proven to have a positive impact which, consequently, resulted in more accurate forecasts and improved meteorological services in a diverse number of applications including climatology, meteorology/NWP. When considered operational for meteorological applications UAVs will be another component of the WIGOS ABOP and data should be derived according to WMO standards. During research campaigns using UAV data, it has been demonstrated that the benefits to NWP are similar and consistent with those benefits observed and measured from use of AMDAR, especially in high resolution mesoscale NWP. It was suggested that Larger more expensive high-altitude UAVs could be most useful for provision of data to support global NWP while smaller UAV platforms, reporting at high frequency, with a boundary layer focus and lower costs would likely have a significant positive impact on regional and storm scale NWP. The challenge to WMO member nations is to determine how best to implement UAV systems efficiently and effectively while overcoming the challenges of meeting airspace regulatory requirements and limited resources available to NMHSs.

UAVs have the potential to bridge the gap between land surface networks and satellite data to support high resolution NWP and other meteorological applications. NMHS do not yet use UAV's operationally, however aircraft-based observations are used both operationally and for research to great effect, and research is currently being undertaken to ascertain how to make better use of UAV's. UAV's offer a very promising way of collecting data for many application areas and filling in some of the gaps in existing observing systems. UAV's offer a cost-effective alternative for atmospheric measurements compared to aircraft and satellites.

It can be summarized that observation impact in NWP depends on data volumes and how an observation system complements and fills in gaps in the existing observing system. ECMWF believes UAVs could be a valuable gap filler with accurate in situ measurements from the Planetary Boundary Layer (PBL) and/or the stratosphere. It is also believed that crowd-sourced data and via the "Internet-Of-Things" will be important observations data sources for NWP in the coming years.

Day 1 Session 2.1

Session 2.1 included four presentations on the topic of meteorological and climate research activities and campaigns. The presenters' names are listed below followed by a summary of the content and key points of the session.

Captain Phil Hall, National Oceanic and Atmospheric Administration (NOAA), UAV for Meteorological and Atmospheric Science.
Dr. Jamey Jacobs, Oklahoma State University (OSU), Swarming small UAVs for ABL Observations and Development of the 3D Mesonet
Mr. Konrad Bärfuss, Technische Universität Braunschweig, contribution to the WMO UAV workshop on UA Meteorology
Dr. James Pinto, National Center for Atmospheric Research (NCAR), Impact of assimilating UAV data on fine-scale weather prediction

Session 2.1 Summary

The mission of NOAA's UAV Program is to facilitate UAV applications and utilization in NOAA and accelerate the transition of UAV capabilities from research to operations by providing expertise and resources for UAV research and development. To meet NOAA meteorological and atmospheric science data requirements, the NOAA UAV Program has completed field experiments to demonstrate the capabilities of UAVs for various applications.

Swarming involves the control of multiple unmanned aircraft in formation without direct pilot input, in which each can adapt to observations of the current conditions autonomously to optimize the observation strategy parameters, for example, grid spacing. OSU is currently working on utilizing the capabilities of UAVs to develop a "3D Mesonet" to demonstrate extending the conventional surface mesonet concept to include vertical profiling capabilities by the addition of small, instrumented, profiling UAV platforms to existing mesonet sites as a proof of concept for the entire network. The long-term vision is to autonomously operate UAVs at the sites to provide atmospheric profiles at scheduled intervals to be used by forecasters in operational meteorology, and to send the data to a central facility for dissemination.

At the Institute of Flight Guidance, the whole observing system is considered, which includes the design and implementation of the mission, the aircraft, the sensors, the field work operation and the data processing. Besides other UAV applications, meteorological research with UAV has been carried out including meteorological investigations of the boundary layer, pollution and new particle forming.

It is expected that the assimilation of UAV observations, once widespread enough, will result in improved mesoscale analyses and predictions. UAV data assimilation studies have shown that localized UAV measurements can be used to improve fine scales predictions at relatively short lead times. Various examples were provided that have shown advanced data assimilation methods have significant impact on mesoscale modeling.

Day 1 Session 2.2

Session 2.2 included seven presentations on the topic of current use of UAV for operational meteorological purposes and issues with transitioning from research to operations by National Meteorological and Hydrological Service (NMHS). The presenters' names are listed below followed by a summary of the content and key points of the session.

Ms. Dörthe Ebert, Deutscher Wetterdienst (DWD), UAV at Deutscher Wetterdienst:Use in Meteorological and Climate research activities and Campaigns
Dr. Bruce Baker NOAA Air Resources Lab, The work of the NOAA Air Resource Laboratory towards the operational utilization of UAVs
Mr. Greg Roberts, Météo-France, Deploying UAV for Atmospheric Research
Dr. Debbie O'Sullivan, United Kingdom Met Office, Current use of UAVs at the Met Office, and Issues of Transition to Operations.
Ms. Anne Hirsikko, Finnish Meteorological Institute (FMI), View on the Drone: Activities in FMI
Mr. Marin Mustapic, Croatian Meteorological and Hydrological Service, Measuring Air Pollution in Zagreb using UAV
Mr. Lars Isaksen ECMWF, Use of UAVs in Meteorological Activities and Campaigns at ECMWF discussing the use of UAVs in NWP research and operations at ECMWF.

Session 2.2 Summary

It was a clear outcome of the session that the primary barrier to the operational use of UAVs for meteorology is the overcoming of regulatory issues associated with the use of regulated airspace in a way that would enable the required meteorological data to be collected. Other perceived and current barriers are the costs of either buying a service from a private company or the development and maintenance costs if done in house. Additionally, the current level of automation in UAV operation is not yet advanced enough to allow predominantly human-free operations, which is perceived to be a requirement to make such operations viable and efficient, particularly in remote locations where many gaps in observations exist. The automated refueling and the maintenance of fuel levels in UAVs is also considered an important requirement to be able to meet operational standards for use. While several NMHS are clearly endevouring to develop or obtain UAVs for operational purposes and applications, these issues are yet to be fully resolved satisfactorily.

It is evident that UAVs have the potential to provide a useful supplementary platform for in-situ measurements adding value to and complementing existing operational sounding and remote sensing systems. They especially have the potential to close the data gap in the boundary layer, improving the results of data assimilation, thus leading to improved numerical weather prediction accuracy and skill.

UAVs are well-suited to complement ground-based measurements, to obtain measurements in remote or dangerous locations and to study physical processes in the lower part of the atmosphere. In-situ observations are often ground-based, and UAV offer an important synergy with ground-based measurements to access the vertical dimension of the atmosphere, particularly within existing networks of atmospheric monitoring stations. The use and application of UAVs for research are wide and range from shorter-term atmospheric process studies, to their long-term use in campaigns and the monitoring of various meteorological parameters and phenomena. Such research can range from the use of a single UAV only, up to the use of coordinated fleets operating in a single contained area, or in distributed networks. Equipped with appropriate sensors, the UAVs can offer a new approach for research opportunities into air pollution and emissions monitoring, as well as for studying atmospheric trends. UAVs have great potential as a new observations platform for monitoring atmospheric state, which, for some applications, require detailed, fine scale weather information.

The position of the instrument payload on the UAV is a critical factor for the accuracy of the measurements.

For international data centres to be able to use UAV data efficiently and easily, it is very important to implement and use well-defined data formats (e.g. WMO BUFR). Near-real-time availability (within 3 hours of measurement time) is highly desirable for the optimal use of data in operational NWP systems. Availability and open access to data will increase the likelihood that NWP centres can justify the effort to assimilate and monitor and evaluate data sources such as those from UAVs.

There is a need for a full demonstration of small UAV capabilities using a testbed, with should have the aim to develop a robust set of protocols to assess the costs and operational feasibility of UAVs for routine applications using various combinations of aircraft and sensors. The testbed could also be used to design and develop processes and protocols to support the transition of UAVs from research to operations, including such aspects as data processing and transmission, validation and integration into data user applications and systems.

Day 2 Session 3

Session 3 included eight presentations on the topic of UAV capability, manufacture and availability. The presenters' names are listed below followed by a summary of the content and key points of the session.

Mr. Chris Flynn, Flyht Aerospace, TAMDAR-Edge: UAV Weather Sensor Technology
Dr. Jack Elston, Black Swift Technologies, Types and Capabilities of UAS for Meteorology
Mr. Christian Schluchter, Meteomatics, Meteodrones
Mr. Luis Carillo, Singular Aircraft, Singular Aircraft FLYOX1
Mr. Chris Mazel, DroneXsolutions, The ReNovRisk UAV campaigns and the BOREAL drone,
Mr. Jean-Francois Vinuesa, Airbus, Improving Service Coverage with High Altitude Pseudo Satellite,
Mr. Stewart Taylor, EUMETNET for Zipline, High Volume Operations with Drones
Dr. Thomas Wetter, Deutscher Wetterdienst, Application and Use Generally Provision of Meteorology for the operations of UAS

Session 3 Summary

While not currently used operationally to support traditional meteorological weather forecast applications, UAVs are already being used operationally for several different atmospheric applications including volcanic monitoring, plume detection and dispersion measurement, in situ thermodynamics, soil moisture measurement and snow water equivalent measurement, among others. Critical to the value of the contribution of these systems is the ability to routinely collect the measurements in a safe and reliable manner. This depends largely on the capabilities of the UAV.

Among the characteristics to consider when selecting a UAV platform for use in meteorology, some of the main areas of focus should be ease of use, robustness, and capability to be integrated within the national airspace system. Use of UAVs for operations will require higher-altitude flights, beyond visual line of sight (BVLOS), and possibly within close proximity to buildings and challenging terrains. Such meteorological user requirements, along with those of other UAV applications, will mean that the regulatory requirements of airspace will continue to change and adapt, and UAV systems will need to provide the necessary interfaces, onboard systems and autonomy to safely operate with other traffic and within challenging and varying regions.

FLYHT has developed the *TAMDAR-Edge™* system for unmanned aerial vehicles (UAVs). It is a low-power, miniaturized version of the commercial TAMDAR sensor and provides the same key weather parameters including relative humidity, temperature, winds as well as icing conditions

Meteomatics manufacturers and operates Meteodrones, which are designed for profiling the lower atmosphere up to 3000m altitude, measuring temperature, relative humidity, dew point, pressure, wind speed and direction. These data are sent to Meteomatics servers in real time and are then assimilated into a high-resolution weather model. The MeteoBase is a fully autonomous ground station that can be controlled remotely. This allows a drone operator to remotely control several drones from one control center instead of being at the flight site.

The mission of Singular Aircraft is to manufacture UAVs that are reliable, efficient, safe and of low cost. Singular produces the FLYOX1 UAV which while capable of operating in fully-automated mode, requires a pilot onboard to meet airspace regulations. The High-Altitude Pseudo Satellite or HAPS. HAPS offer benefits of persistence and flexibility to complement satellites and (un-)manned aviation. HAPS has a strong potential for complementary, layered services including meteorology.

Météo-France collaborated with DroneXsolutions, utilizing the BOREAL drone, during a field campaign studying cyclogeneses in the southwest Pacific. In order to achieve its mission, the fixed-wing BOREAL drone was equipped with avionics embedding automatic flying, multiple C2link capabilities for short and long range communication, remote identification with a transponder mode S / ADS-B out, visual anti-collision with strobe, and support for traffic separation with a real-time, front video sensor.

The Zipline UAV flies at 30 m/s below 500ft above ground level with a 50 min average flight duration, 100 km average flight distance and have meteorological sensors which include 2x redundancy on pressure, temperature and humidity sensors and 1hz+ sampling cellular communications uploaded to a cloud site every 15 minutes. This data supplements the very sparse NMHS reporting locations in Rwanda and Ghana.

Some of the challenging tasks for future considerations related to UAV operations is how to prepare weather briefings and consultations for beyond visual line of sight (BVLOS) operations, and the provision of longer-range forecasts to support long-range and long-term UAV operations to conduct in-flight weather detect and avoidance (DAA) of hazardous weather.

Day 2 Session 4

Session 4 included six presentations on the current status relating to regulations for use of UAVs and potential regulatory issues with operational use of UAVs. The presenters' names are listed below followed by a summary of the content and key points of the session.

Mr. Manfred Mohr, IATA, Use of Airspace the Regulatory Aspects and the Airline View
Mr. Chris Mazel, DroneXsolutions, Current Status relating to Regulations for use of UAVs
Dr. Debbie O'Sullivan, United Kingdom Met Office, Potential Regulatory Issues with the Use of Airspace for Operational Meteorology
Captain Phil Hall, NOAA, US Aviation Policy and Challenges for Meteorological Operations for NOAA.
Dr. Thomas Wetter, Deutscher Wetterdienst, Use of Airspace and Regulatory Aspects
Mr. Stewart Taylor, EUMETNET, Issues with Use of Airspace

Session 4 Summary

It is important that there is a comprehensive approach to UAV integration into the wide family of air space users aligned with international and global recommendations. The European Union (EU) drone regulation, EU commission delegated regulation 2019/945, was adopted in June 2019 and it will progressively replace the EU individual national rules over a transition period of 2 to 3 years. The harmonization of the rules is aiming to regulate and support what is expected to be a big European market for drone services. The European drone regulations address UAVs ranging from toy drones to High Altitude Long Endurance (HALE) UAVs and encompassing both current and envisaged future operations.

A large level of flexibility is provided to EU member states to implement the new regulations at the national level and the individual EU national aviation authorities (NAA) will still play a key role in delivering authorization and defining airspace zones with specific limitations/requirements, such as, no-fly zone, altitude restriction, requirement for remote identification, etc. A mutual recognition of the authorizations delivered by the NAA of the member state will be valid throughout the EU (after coordination with the relevant NAA).

The EU regulations will also incorporate related law enforcement, including privacy rights, and will contribute to address security risks by enforcing registration of all UAVs heavier than 250 gram or operating above 120 meters of altitude. The EU regulations have identified three categories of operations with varying degrees of operator risk, so as to cover from visual line of sight (VLOS) operations, through to instrument flight rules (IFR) operations with different regulatory approaches.

In Europe, there is a requirement to keep UAVs within direct unaided visual contact during operation visual line of sight operations. There is however a general exception where UAVs can be piloted using the view from an on board camera, known as first person view (FPV) flying, provided there is a competent observer maintaining unaided visual contact with the UAV. It is an added complication that most useful UAV meteorological flights will require beyond visual line of sight (BVLOS) operations. In order to maximise the potential of UAVs for operational meteorology there needs to be a mechanism in place to allow for routine BVLOS operations

The United States (U.S.) Federal Aviation Administration (FAA) classifies all UAVs as aircraft and small UAV (55 pounds or less) are regulated under FAA Part 107 of codified U.S. law. Challenges to the transition of UAV to meteorological operations include these Part 107 regulatory requirements to keep the UAS within visual line of sight, which prevents flights above 3,500 feet and prohibits flights in clouds. Additionally, it is challenging to train NOAA personnel to be proficient as UAV operators as an addition to conducting their normal duties.

International regulations on UAVs are categorized by UAV type and risk of the mission, these regulations are supported by the Joint Authorities for Rulemaking of Unmanned Systems (JARUS). Major aspects of regulations relating to UAV are safety (Air risk & Ground risk), security (sabotage, terrorism), privacy (cameras and other recording payloads) and airspace capacity (integration of UAV into existing airspaces).

Day 3 Session 5

Session 5 was a plenary session with 4 panel discussions on the potential and requirements for operational use of UAV data. The panel leader names are listed below followed by a summary of the content and key points of the session.

Mr. Dean Lockett, WMO, Panel discussion on the definition of "Operational" in the WIGOS context for UAV systems
Mr. Dean Lockett, WMO, Panel discussion on UAV Data Communication, and Data Management
Dr. Curtis Marshall, IPET-ABO, Panel discussion on Public Sector Partnering.
Dr. Curtis Marshall, IPET-ABO and Dr. Debbie O'Sullivan, United Kingdom Met Office, Panel discussion on Implementation and use for Operations

Session 5 Summary

For WMO WIGOS observing systems to be considered operational, the data must meet the WMO WIGOS requirements for one or more of the application areas, including its provision to end users in a timely manner and in standardized formats. It is clear that UAVs have great potential to meet requirements and fill observations gaps in support of the range of NWP applications. Their suitability for monitoring a wider range of atmospheric variables also suggests that they could have the potential to meet operational requirements for health and safety and environmental-related applications, including weather, pollution and aviation hazard monitoring and prediction.

There is a general lack of information on UAVs and their capabilities available to the wider NMHS community and there is clearly a need to develop guidance and advice on the value of UAVs to the operational community. WMO guides, technical reports and news bulletins can serve as authoritative sources for the provision of such information.

Before UAVs can be widely implemented for operational use, there are several actions that need to be undertaken to facilitate their acceptance in this role. It was suggested that a first action could be to undertake well-planned and coordinated cost/benefit analyses based on the establishment and use of UAV test beds to demonstrate their capabilities over a suitable period of time and perhaps even coordinated at the international level. Such demonstrations along with analysis of performance and efficiencies, could provide a business case to help NMHS determine where UAVs add the most value, assist manufacturers in tailoring their products and also allow data users to prepare for the availability of such data in the future. Potentially, WMO could coordinate and support international efforts in this regard through its Infrastructure commission, possibly including the organization of a dedicated inter-comparison of UAV systems.

It was suggested and agreed that when there is a convenient and standardized way to share data, operators and data providers will do it, and data users will make use of such data. For it to be optimally useful operationally, UAV data needs to be gathered centrally, processed, quality controlled and then disseminated, whether at the national, regional or global level. There needs to be standards agreed and established for data collection and redistribution, including for relay from instrument to collection centre and also for exchange of data at the regional and international level. Another important aspect of data management is data policy and licensing for use. WMO Aircraft Meteorological AMDAR (AMDAR) data, provided in partnership with commercial airlines, conforms to WMO Resolution 40 and is therefore available for use by all NMHS members via the WMO Information System (WIS). In the case that UAV data becomes available to NMHS via 3rd party partnerships and arrangements, efforts should be made to ensure that such data is also compliant with WMO Resolution 40 and able to be shared on the WIS.

It is evident that there will exist opportunities for NMHS to form partnerships with public sector organizations and entities and individuals to derive meteorological data from UAV systems. This might include systems deployed for dual or multi-purpose application or deployed solely for meteorological application under voluntary or paid service. While perhaps not strictly "operational" by definition, this means for obtaining data in partnership is an important consideration, particularly for modern meteorological applications which have a requirement for a high density of observational data and for which data quality is either less important or is facilitated and managed by the application. For example, there are opportunities in the developing and expanding industry of delivery drones that could potentially provide large volumes of data under a suitable cost sharing model. The management of such data obtained or provided under such partnerships require the consideration of a range of issues, including data quality management and control, data security, privacy issues and metadata management. It was agreed that WMO might consider how to facilitate and coordinate the advancement of such partnerships through initiatives such as demonstration projects, the development of public voluntary data provision programs and the development of standards and mechanisms for data collection and sharing.

Over the next few years in the EU, every drone over 250 grams must have an e-signature and have the capability to transmit required metadata (height/course/speed). Every drone over 900 grams will have to carry an ADS-B transponder and could potentially transmit weather data automatically. This could potentially be an additional source of meteorological data if coordinated and advocated with the corresponding regulatory bodies.

In general and in summary, the significant existing barriers and challenges to operational implementation with UAVs by NMHSs include: access to airspace and complying with airspace regulations, attainment of required levels of system automation (including fuel/energy management), and data quality for some variables (e.g. wind speed and direction).

However, it is likely that there are a range of options available to NMHS to be able to make use of UAVs for the production or provision of useful meteorological data and it may be possible to employ more than one of these options to meet the range of requirements. While it may be necessary in some cases to purchase, operate and maintain systems internally for some applications, it should also be possible to establish partnerships with private entities to provide voluntarily or sell data more efficiently and effectively. In some cases, UAV operations NMHSs may be best facilitated through a private partnership resulting in a UAV "data buy" for meteorological applications.

Day 3 Session 6

Session 6 was a plenary session with three panel discussions on the topic of key outcomes, recommendations and actions. The panel leader names are listed below followed by a summary of the content and key points of the session.

Dr. Thomas Wetter, DWD. Panel discussion on Recommendations for UAV Manufacturers.
Mr. Stewart Taylor, EUMETNET, Panel discussion on UAV Operational Demonstration Project
Mr. Dean Lockett, WMO, Panel discussion on WMO Upper Air Intercomparison

Session 6 Summary

There were several important recommendations and ideas that were suggested throughout the course of the workshop.

It was agreed that there is a need for a white paper on UAVs that describes the current status of their capabilities and their potential to fill gaps in the global observing system. The development of such a paper should be coordinated by WMO, possibly though its expert team on aircraft-based observations, which would benefit from the addition of several experts from the UAV community. It should address both the benefits and current issues with UAV systems associated with their transition to operation and outline possible solutions and requirements for their advancement and improvement, for example, through the establishment and operation of test beds and the holding of UAV intra-comparisons. It should address key future requirements in the areas of data quality, data formats, regulatory issues and operating costs. The paper should outline a roadmap for UAVs to become a well-defined and integrated component of global observing system.

The future integration of UAVs into the national and international airspaces presents new challenges for NMHSs in their role as service providers for public and private aviation operations. In particular, NMHSs will need to work towards the capability to be able to meet requirements for services associated with operational safety including support for detect and avoid measures for weather events

It was recognized that regulatory requirements for UAVs may also offer the opportunity to implement regulations for the automatic and mandatory collection of weather data to support their operation. For example, where UAVs are required to transmit ADS-B or ADS-B-like information, it might be conceivable to regulate or strongly recommend to provide weather information if and when possible.

It was suggested that, given the potential and likely benefits and impacts of UAVs to NMHS, weather and forecast-related application, and the flow-on benefits to clients of NMHS through resulting improvements to products and services, a possible mechanism for advancing their transition to operation might be achieved through a large-scale demonstration of UAV capabilities. The purpose of the demonstration would be to assess the viability of the utilization of UAVs to collect and share meteorological data on an “end-to-end” basis and would therefore potentially require the involvement of manufacturers, operators/data providers and data users from a range of application areas. A plan for this activity should first be developed with the aim of beginning the demonstration later in 2020 or early in 2021.

An inter-comparison of UAV systems, potential also involving comparison with relevant upper-air systems and standards, would be another means for demonstrating the capabilities and potential of these systems to meet requirements for their operational implementation and integration.

In 2021, WMO will coordinate and hold an Upper-Air (UA) inter-comparisons to test and characterize the performance of operational radiosonde systems and other upper-air remote and in situ observing systems in use. The inter-comparison serves to assess and validate the performance of the various systems and assist WMO members in selecting radiosonde systems according to their requirements. It is possible that AMDAR and UAVs might be included in this inter-comparison, in which case, the participants agreed efforts should be made to encourage manufacturers and operators to do so.

3. Key Outcomes, Recommendations and Future Activities

- 3-4 workshop participants to become IPET-ABO associate members to provide expertise on UAV systems to WMO and the team to:
    - Work with IPET-ABO leadership to develop WMO UAV guidance materials.
    - Provide input to the WMO Integrated Global Observing System (WIGOS) vision for observing systems evolution to 2040 and the subsequent implementation plan for the evolution of WIGOS.
    - Develop a white paper on UAV systems which should include:
        - Assessment of current status of UAVs.
        - Benefits and impacts.
        - Roadmap for UAV integration in operational meteorology.
        - Recommendations to manufacturers and regulators.
- IPET-ABO to assess requirements for development of a data model for international exchange of UAV meteorological data.
- IPET-ABO to advise and coordinate any involvement of UAVs in the next WMO upper-air inter-comparison.
- WMO to investigate the possibility to collaborate with ICAO and national civil aviation authorities regarding the possibility to request approvals and appropriate regulations for use of dedicated airspace for operational vertical atmospheric profiling for meteorological applications.
- IPET-ABO to assess the possibility for it to coordinate the establishment of dedicated test bed sites for UAV capability and testing for operational meteorology, including an organised demonstration program.
- WMO and the IPET-ABO to consider how to promote wider implementation and use of UAVs in meteorological observations, including the publication of articles in relevant forums.
- The IPET-ABO to develop Specific Operations Risk Assessment (SORA) standard scenarios for use of UAVs for meteorological purposes to facilitate their approval in accordance with national and international regulations.
- Workshop participants to develop a summary table of the status of known UAV applications in meteorology to be included in this report.

4. Close of the Workshop

Following the completion of the workshop programme of presentations and discussions, Mr. Dean Lockett and Dr. Curtis Marshall thanked all presenters and participants for their input to the workshop, and also thanked Météo-France for their support in hosting the event and for their generous hospitality to all participants.

ANNEX-I Summary Table[1] of Applications from UAV Data

Country	Organization & Contact	Type of UAV	Application from use of UAV	Payload on UAV	Status of development/operation ; Current UAV operating restrictions/limitations
Croatia	NMHS	N/A The UAV is property of Faculty of Transportation sciences	Air pollution monitoring	5 kg	initial phase of the project with the Faculty of Transportation Sciences for measuring of traffic-generated air pollution in Zagreb city
USA	Black Swift Technologies - Jack Elston (elstonj@bst.aero)	Black Swift Technologies S2 UAS (Fixed Wing)	Soil moisture measurement, plume monitoring, volcanic monitoring, wildland fire observation, atmospheric profiling	wind probe, temperature, pressure, humidity, trace gas, nephelometer, radiometer, thermal camera, multi-spectral camera, RGB camera (swappable payload)	Operational, limited to FAA part 107 operations, but has been allowed high altitude flights, flights at night and beyond line of sight flights through waivers and a TFR
France	DroneXsolution cmazel@dronexsolution.com	Fixed Wing / UAS BOREAL	Maritime surveillance, earth observation, technical inspection	Multipurpose and Modular payload bay for the drone BOREAL. Various configuration options from optronics gimbal, photogrammetry, LiDAR or customized set of sensors (such as Met.)	COTS product BOREAL, regulatory restriction of use because of the MTOM (up to 25kg) and the Long Range/Large Endurance capabilities
Nether-lands	KNMI Marijn de Ha	DJI-Matrice 600 Pro	Boundary layer profiles	Vaisala RS41 radiosonde	Status: single experiment. Performed in summer 2017, reported here: BAMS

[1] Additional information may be added to this table

Country	Organization & Contact	Type of UAV	Application from use of UAV	Payload on UAV	Status of development/operation ; Current UAV operating restrictions/limitations
					article. Restrictions: Desired range up to 700m was not feasible in the short term. Requires a comprehensive flight plan due to nearby air traffic (~3500ft) and road traffic. Maximum altitude reached 235 m by company with RPAS Operator Certificate (national regulations by Dutch Human Environment and Transport Inspectorate)
UK	Met Office Meteorological Research Unit (MRU), Cardington, Jeremy Price, Debbie O'Sullivan	DGI S900 Multi Copter	Boundary layer fog research / other boundary layer studies	FP07 fast tip thermistor, Vaisala HMP 110 humidity/ temperature probe, HYT-271 humidity/ temperature sensor, BMP 280 pressure sensor, BMP055 9-axis sensor to calculate pitch, roll and direction	Currently being used for boundary layer fog research. Operated within restricted airspace at Cardington, up to 6000 ft (1 mile radius around the MRU site) This UAV is used in profiles up to 500 m
UK	Met Office Meteorological Research Unit (MRU), Cardington, Jeremy Price, Debbie O'Sullivan	Yuneec H520 multi-copter	Boundary layer fog research/ other boundary layer studies	FP07 fast tip thermistor, Vaisala HMP 110 humidity/ temperature probe, HYT-271 humidity/ temperature sensor, BMP 280 pressure sensor, BMP055 9-axis sensor to calculate pitch, roll and direction , and probably room for a few more things too	About to be used for research. Will enable profiles up to the top of the Cardington restricted airspace in theory – 6000 ft. yet to be tested to that altitude
UK	Met Office Meteorological Research Unit (MRU), Cardington, Jeremy Price, Debbie O'Sullivan	Bormatec Maja	Fixed wing capability with Pixhawk autopilot, could be used for		

Country	Organization & Contact	Type of UAV	Application from use of UAV	Payload on UAV	Status of development/operation; Current UAV operating restrictions/limitations
			cloud studies/ and fluxes using horizontal runs and profiles		
Germany	Working Group "Airborne Meteorology and Measurement Techniques", Institute of Flight Guidance, TU Braunschweig iff-mmt@iff.ing.tu-braunschweig.de Group Leader: Dr. Astrid Lampert, astrid.lampert@tu-braunschweig.de	Fixed Wing UAS, 25 kg MTOW, 3.6 m Wingspan, electrically powered	Research on atmospheric particle formation and small-scale ABL processes	T/RH/Wind/Solar irradiance/Surface Temperature Sensors, black carbon sensor, 2x condensation particle counter, 1x optical particle counter	Operational for research campaigns, applied to campaigns in Europe, Svalbard, West Africa up to 1500 m, VLOS, needs grass/ice/sand/concrete runway (50x200m)
Germany	Working Group "Airborne Meteorology and Measurement Techniques", Institute of Flight Guidance, TU Braunschweig iff-mmt@iff.ing.tu-braunschweig.de Group Leader: Dr. Astrid Lampert, astrid.lampert@tu-braunschweig.de	Rotorcraft UAS, 25 kg MTOW, electrically powered	Research on trace gases (methane etc.) and small-scale ABL processes	Air sampling, T/RH/Solar Irradiance Sensors, surface temperature	Operational for research campaigns, applied in Europe and the Arctic from research vessel Polarstern up to 1000 m, VLOS
Germany	Working Group "Airborne Meteorology and Measurement Techniques", Institute of Flight Guidance, TU Braunschweig iff-mmt@iff.ing.tu-braunschweig.de Group Leader: Dr. Astrid Lampert, astrid.lampert@tu-braunschweig.de	Fixed Wing UAS, ~3 kg, ~1.2 m Wingspan, electrically powered	Operational Meteorology, NWP	at least T/RH/Wind Sensors	Design studies, ceiling ~12 km AMSL
Switzer-land	Meteomatics AG, Christian Schluchter, cschluchter@meteomatics.com, info@meteomatics.com	Meteodrone Classic, Quadrocopter	Boundary layer soundings up to 3km above ground; regular soundings several times an hour; mobile soundings e.g. for storm chasing; vertical soundings & alternative flight paths; VLOS/BVLOS/E-VLOS	Sensors for humidity, temperature, dew point, pressure, wind speed and direction; emergency rescue system; redundant energy and communication links; Additional optional payload: ~150g	In operational use at Meteomatics for data assimilation into numerical weather forecasts and on sale Max. ascent speed: 10m/s Max. wind speed: 60km/h Max. flight altitude: 3000m Max. flight endurance: ~20min Max. payload: ~150g

Country	Organization & Contact	Type of UAV	Application from use of UAV	Payload on UAV	Status of development/operation ; Current UAV operating restrictions/limitations
Switzer-land	Meteomatics AG, Christian Schluchter, cschluchter@meteomatics.com , info@meteomatics.com	Meteodrone SSE, Hexacopter	Boundary layer soundings up to 1.5km above ground; regular soundings several times an hour; mobile soundings e.g. for storm chasing; vertical soundings & alternative flight paths; VLOS	Sensors for humidity, temperature, dew point, pressure, wind speed and direction	In operational use at NOAA and other organizations Max. ascent speed: 19m/s Max. wind speed: 75km/h Max. flight altitude: 1500m Max. flight endurance: ~12min
Switzer-land	Meteomatics AG, Christian Schluchter, cschluchter@meteomatics.com , info@meteomatics.com	Meteodrone XL, Quadrocopter	Boundary layer soundings up to 3km above ground; regular soundings several times an hour; mobile soundings e.g. for storm chasing; vertical soundings & alternative flight paths; Applications using payload, e.g. atmospheric pollution measurements, custom sensor package etc.; VLOS/BVLOS/E-VLOS	Sensors for humidity, temperature, dew point, pressure, wind speed and direction; emergency rescue system; redundant energy and communication links; Additional optional payload: ~ 1kg	In operational use at Meteomatics for atmospheric pollution measurements and on sale Max. ascent speed: 6m/s Max. wind speed: 40km/h Max. flight altitude: 3000m Max. flight endurance: ~40min Max. payload: ~1kg
Switzerland	Meteomatics AG, Christian Schluchter, cschluchter@meteomatics.com , info@meteomatics.com	Meteodrone v2.0, Hexacopter	Boundary layer soundings up to 6km above ground; regular soundings several times an hour; mobile soundings e.g. for storm chasing; vertical soundings & alternative flight paths;	Sensors for humidity, temperature, dew point, pressure, wind speed and direction; emergency rescue system; redundant energy and communication links; Additional optional payload: ~2kg	On sale in Q1 2020 Max. ascent speed: 20m/s Max. wind speed: 100km/h Max. flight altitude: 6000m Max. flight endurance: ~40min Max. payload: ~2kg Anti-Icing system

Country	Organization & Contact	Type of UAV	Application from use of UAV	Payload on UAV	Status of development/operation ; Current UAV operating restrictions/limitations
			VLOS/BVLOS/E-VLOS		
Germany	Deutscher Wetterdienst (DWD), Department Climate and Environment Consultancy , contact: Lutz.Plueckhahn@dwd.de	Multi-rotor-copter drone	Meteorological and air quality measurements in various environments (including cities) from ground level to max 3 km above ground. Measurement results will be analysed to study and document atmospheric processes and will be used for the evaluation of local climate and urban climate computer simulation models.	max 5 kg	Currently we do not own or operate an UAV, but we intend to purchase a suitable UAV system off-the-shelf or custom-built. The UAV shall have a transponder to enable air traffic control. Restrictions/limitations for UAV operation have not been clarified so far.

ANNEX-ll Workshop Programme

Day 1 (2 July)			
Session	**Time**	**Topic or Item**	**Presenter / Chair / Panel**
Session 1 Introduction, Aims, ABO Benefits and Application	0930 10 min	Welcome and Aims of workshop	Mr. Yann Guillou, Météo-France Mr. Dean Lockett, WMO
	0940 5 min	Workshop Schedule & Practical Arrangements	Mr. Bruno Piquet, Météo-France Mr. Steve Pritchett, WMO
	0945 25 min	Introduction to WMO, WIGOS and ABO Programme	Mr. Dean Lockett, WMO
	1010 25 min	Benefits and use of ABO in operational meteorology	Mr. Curtis Marshall, NOAA & IPET-ABO Chair
	1035 15 min	Coffee/Tea Break	
	1050 40 min	Requirements for upper-air data to support operational meteorology and current gaps	Mr. Lars Isaksen, ECMWF
	1130 30 min	Opportunities and potential for UAVs in operational meteorology	Ms. Debbie O'Sullivan, UK Met
	1200 15 min	Session 1 Discussion	Mr. Curtis Marshall
End Session 1	1215	Lunch break	
Session 2.1 Summary of Current Use of UAV for General and Meteorological Purposes By Research Organizations	1320 20 min	Use in Meteorological and Climate Research Activities and Campaigns: • Use in operational meteorology • Current issues with transitioning from research to operations	Mr. Phil Hall, NOAA
	1340 20 min		Mr. James Pinto, UCAR
	1400 20 min		Mr. Jamey Jacobs, Ok. State University
	1420 20 min		Mr. Konrad Bärfuss, TU Braunschweig
	1440 20 min	Session 2.1 Group Discussion with Q&A	Mr. Stewart Taylor
	1500	Coffee/Tea break	
Session 2.2 Summary of Current Use of UAV for General and Meteorological Purposes By NMHS	1515 15 min	Use in Meteorological and Climate Research Activities and Campaigns (continued): • Use in Operational Meteorology • Current Issues with transitioning from research to operations	Ms. Doerthe Ebert, DWD
	1530 15 min		Mr. Bruce Baker, NOAA
	1545 15 min		Mr. Greg Roberts, MeteoFrance
	1600 15 min		. Debbie O'Sullivan, UK Met Office
	1615 15 min		Ms. Anne Hirsikko, Finland Met Ins.
	1630 15 min		Mr. Marin Mustapić, Croatia Met

	1645 15 min		Mr. Lars Isaksen, ECMWF
	1700 30 min	Session 2.2 Discussion	Mr. Dean Lockett
End Session 2	1730	**End Day 1**	

Day 2 (3 July)			
Session	**Time**	**Topic or Item**	**Presenter**
Session 3 UAV Capability, Manufacture and Availability	0930 15 min	Summary Day 1, Questions, Introduction to today's programme and topics.	Mr Dean Lockett, WMO
	0945 25 min	Types and capabilities of UAVs: • Application and Use Generally • Application for operational meteorological observations • Costs and Issues	Mr. Chris Flynn, Flyht
	1010 25 min		Mr. Jack Elston, Black Swift Technologies
	1035 25 min		Mr. Christian Schluchter, Meteomatics
	1100	Coffee/Tea/Break	
	1115 25 min	Types and capabilities of UAVs (continued): • Application and Use Generally • Application for operational meteorological observations • Costs and Issues	Mr. Louis Carillo, Singular Aircraft FLYOX
	1140 20 min		Mr. Chris Mazel, DroneXsolutions
	1200 25 min		Mr. Jeff Vineusam, Airbus
	1225 15 min		Mr. Thomas Wettle, DWD Mr. Steward Taylor, for Zipline
	1240 20 min	Session 3 Group Q&A	Mr. Curtis Marshall
End Session 3	1300	Lunch Break	
Session 4 Use of Airspace and Regulatory Aspects	1430 30 min	Issues with use of airspace: • Current status relating to regulations for use of UAVs • Potential regulatory issues with met. operational use	Mr. Manfred Mohr, IATA
	1500 30 min		Mr. Chris Mazel, DroneXsolution
	1530 20 min		Ms. Debbie O'Sullivan UK Met Office
	1550	Coffee/Tea/Break	
	1605 20 min	Issues with use of airspace (continued)	Mr. Stewart Taylor, EUMETNET
	1625 20 min		Mr. Phil Hall, NOAA
	1645 20 min		Mr. Thomas Wetter, DWD
	1705 25 min	Session 4 Group Discussion and Q&A	Mr. Stewart Taylor

End Session 4	1730	**End Day 2**

Day 3 (4 July)			
Session	**Time**	**Topic or Item**	**Presenter**
Session 5 Potential and Requirements for Operational use of UAVs for Met.	0930 15 min	Summary Day 2 Questions, introduction to today's program	Mr. Dean Lockett, WMO
	0945 45 min	Panelists and group discussion on: What does operational mean with respect to UAV systems and for WIGOS?	Panelists: Ms. Anne Hirsikko, Finland Met Inst Mr. James Pinto, UCAR Dean Lockett, WMO
	1030 30 min	Panelists and group discussion on: Data communications and data management issues	Panelists: Mr. Jack Elston, Black Swift Mr. Chris Flynn, FLYHT Mr. Dean Lockett, WMO
	1100	Coffee/Tea Break	
	1120 45 min	Panelists and group discussion on NMHS Implementation and Use for Operations	Panelists: Debbie O'Sullivan, UK Met Office Curtis Marshall, NOAA
	1205 15 min	Partnerships with Industry	Mr. Stewart Taylor, EUMETNET
	1220 15 min	Partnerships with Public	Mr. Curtis Marshall, NOAA
End Session 5	1235	Lunch break	
Session 6 Key Outcomes, Recommendations and Future Activities	1345 90 min	Panelist and group discussion on: Potential for UAV systems to be used for operational meteorology and summary of current issues	Panelists: Curtis Marshall, Stewart Taylor, and Dean Lockett
	1515 15 min	Recommendations for manufacturers concerning: • Operational safety for the remotely piloted aircraft • Recommendations for manufacturers for AMDAR-like usage of UAS	Mr. Thomas Wetter, DWD
	1530	Coffee/Tea Break	
	1545 20 min	Pilot Project / Demonstration	Mr. Stewart Taylor, EUMETNET
	1605 10 min	Inclusion of UAVs in WMO, CIMO, Upper-air Inter-comparison, 2021	Mr. Dean Lockett, WMO
	1615 30 min	• Recommendations for WMO advice to Members • Recommendations for WMO advice to manufacturers and suppliers • Recommendations on WMO future activities	Mr. Stewart Taylor, IPET-ABO Mr. Dean Lockett, WMO Mr. Curtis Marshall, IPET-ABO
	1645 15 min	Workshop close	Mr. Dean Lockett, WMO
	1700	**End of Workshop**	

ANNEX-lll List of Participants

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Name	Organization	Country	email
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ANNEX-IV Summaries of Presentations

This annex contains summaries of the presentations from sessions 1-4 of the workshop. Sessions 5 and 6 were plenary sessions.

Day 1, Session 1

Mr. Dean Lockett, WMO, Introduction to WMO, WIGOS and ABO Programme
Mr. Lockett provided a brief overview of the role of the WMO in international meteorology including its role to facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations. The WMO role includes supporting the establishment and maintenance of national and global centres charged with the provision of meteorological and related services, coordinating the establishment and maintenance of systems for the rapid exchange of meteorological and related information, and developing and promoting standardization of meteorological and related observations to ensure the uniform publication of meteorological, hydrological and climate-related observations and statistics.

Mr. Lockett briefly described the WMO Integrated Observing System (WIGOS), which aims to provide a standardized framework for all observing systems and enables the provision and availability of observations based on the requirements of the 14 Application Areas of WMO. The requirements for observations are established and maintained through the WMO Rolling Review of Requirements process. Mr. Lockett suggested that, from the WMO international perspective, an observing system could be considered to be operational when the data derived is available on the WMO Information System and has the capability to meet the requirements for one or more Application Areas. He went on to describe the AMDAR system and programme, as a component of the ABOP in the WIGOS, briefly summarizing its current status, its key technical and operational aspects and the roles and requirements of NMHS and airline partners in its operation.

Mr. Lockett said that the primary purpose of the workshop was to consider and discuss the potential of UAVs to meet requirements sufficiently to be considered operational for meteorology and also the challenges of regulatory requirements. Additional aims of the workshop were to discuss and reach mutual understandings of:

- Gaps in WIGOS and the potential for UAVs to fill them.
- Technical capabilities & current use of UAVs
- Requirements to enable use of UAVs in operational meteorology.
- Existing issues relating to use of airspace and regulations and their impact on use for meteorological operations.
- Future possible WMO activities to advance UAV capabilities.
- Requirements of WMO to support UAV operations, including, regulations, operational guidance, data management, etc.

Dr. Curtis Marshall, Chairman of the Expert Team on Aircraft-Based Observing Systems, Benefits and use of Aircraft Based Observations in Operational Meteorology

Dr. Marshall reiterated that the WMO AMDAR Observing System was comprised of aircraft-based observing systems which derive meteorological data from an aircraft platform according to WMO standards and specifications using predominantly innate sensors and systems. The benefit of this observing system can be expressed with the general statement that AMDAR supports weather services to aviation and all WMO Application areas. Dr. Marshall highlighted the positive impact of the use of AMDAR data on NWP which, consequently, resulted in more accurate forecasts and improved meteorological services. To the airline operations this would result in a more efficient fuel loading and consumption, and in improved flight safety.

The critical component of AMDAR is that observations are made during ascent and descent. These observations can be represented as profiles, similar to data available from radiosondes, with comparative data quality. AMDAR profiles are produced at a fraction of the cost for radiosonde profiles and because of their higher temporal frequency, provide a complementary source of observations to other operational upper-air observing systems.

In a variety of examples, the benefits of AMDAR data were presented to a diverse number of applications, including climatology, meteorology/NWP and the airline operations. Also, the positive impact on the results of several (global and regional) NWP models was presented. Dr Marshall presented outcomes of impact studies, among them the example that aircraft-based observations are placed 3rd to satellite and radiosonde data for positive impact and error reduction in NWP. A UK Met Office study has demonstrated that AMDAR is the most efficient observing system when assessed as impact per unit cost. Dr Marshall described how several meteorological applications benefited from their use of AMDAR data.

Dr Marshall concluded with thoughts on UAV for the audience to consider during the workshop. He said larger more expensive high-altitude UAVs would be most useful for global NWP while smaller platforms, reporting at high frequency, with a boundary layer focus and lower costs would likely have the greatest impact on regional and storm scale NWP. The challenge to WMO member nations was to determine how best to implement UAV systems efficiently and effectively while overcoming the challenges of meeting airspace regulatory requirements and limited resources available to NMHSs.

Mr. Lars Isaksen, European Center for Medium-Range Weather Forecasts (ECMWF), Requirements for Upper-Air Data to support Operational Meteorology and Current Gaps

Speaking firstly about the data assimilation process in modern NWP (Numerical Weather Prediction) systems, which support the use of data from a large number of sources over increasingly larger time ranges. At ECMWF a 12-hour 4-dimentional variational method is used, he told the workshop audience

Observations are essential for data assimilation into NWP systems. A very significant effort goes into using more observations and extracting more information from observations, for example by developing more accurate methods for comparing model fields with observations. For global NWP, satellite instruments provide most of the observations (95% versus 5% for in situ). Over the last two decades ECMWF has gone from using 12 satellite instruments to using more than 90 operationally. Because in situ observations are more accurate and complements satellite data, they have larger information content, leading to 70% overall impact from satellite observations versus 30% from in situ observations. The ranking of satellite data, in order of overall importance are: microwave water vapour, microwave temperature, infrared temperature, infrared water vapour, Atmospheric Motion Vector, GPS-Radio Occultations and scatterometer data. For in situ data the overall ranking, in order of importance are: aircraft, land surface stations, radiosondes, drifters and wind profilers. On a “per observation basis”, drifters and dropsondes are the most important. There is a need for more surface pressure data over the oceans and remote land areas because satellites cannot provide accurate surface pressure information.

There is a special need for increased wind (profile) observations, either from in situ or satellite or both. The recently launched Aeolus ESA Earth Explorer provides wind profiles from space and has shown promising impact in NWP. There is also a need for more accurate (likely in situ based) humidity observations in the troposphere. Aircraft data impact has increased significantly over the last two decades due to the exponential growth in aircraft data volumes. It can be summarized that observation impact in NWP depends on data volumes and how an observation system complements and fills in gaps in the existing observing system.

ECMWF believes UAVs could be a valuable gap filler with accurate in situ measurements from the Planetary Boundary Layer (PBL) and/or the stratosphere. It is also believed that crowd-sourced data and via the "Internet-Of-Things" will be important observations data sources for NWP in the coming years.

In the arctic regions in situ observations are even more valuable because the complexity of sea ice, snow, ocean and low-level clouds makes use of satellite data very challenging. More snow observations, especially snow water equivalents would be beneficial. Increased GTS distribution of snow observations is encouraged.
Mr. Isaksen suggested the following in relation to gaps and requirements in observations for NWP:

- NWP relies on observations – the more the better.
- There is no current sign of saturation or redundancy in the Global Observing System.
- There is a need for more direct wind observations, wind profiles especially are very valuable.
- There is a need for more accurate (in situ based?) humidity observations in the troposphere.
- More snow observations, especially snow water equivalents would be beneficial (note a lot of snow observations measured are not distributed on the GTS!)
- A need for more surface pressure data over the oceans and remote land areas (satellites cannot provide any accurate surface pressure information).
- Using satellite data in the polar regions (especially the Arctic) is very challenging – a need for more in situ measurements or UAV based measurements.
- Data assimilation methods progress, enabling better use of observations – difficult to predict the long-term future of data assimilation methods!

Dr.. Debbie O'Sullivan, United Kingdom Met Office*, Opportunities and Potential for UAV's in Operational Meteorology*

Dr. O'Sullivan explained that the UK Met Office does not yet use UAV's operationally, however aircraft-based observations are used by the Met Office both operationally and for research to great effect, and research was currently being undertaken to ascertain how to make better use of UAV's. There are a number of areas the Met Office actively is engaging with government and industry on how to use UAV's for operational meteorology and into what kind of meteorological service they might want in return. They are also using UAV's for boundary layer research and fog studies at the Met Research Unit in Cardington and working with Exeter University using UAV's for air quality and aerosol research.

Advances in NWP mean that there is now a need for more measurements in the boundary layer, particularly for temperature, humidity and wind profiles with a good vertical resolution at all levels. Ideally with better temporal and spatial coverage. There is also a need for better measurements of soil moisture. UAV's offer a very promising way of collecting this data and filling in some of the gaps in our existing observing systems. Dr O'Sullivan further stated the Met Office is interested in the potential using UAV's for measuring soil moisture, boundary layer fluxes and vertical profiles, as well as for volcanic ash and air quality measurements. UAV's offer a more cost-effective alternative for atmospheric measurements (compared to aircraft). They have the potential to bridge the gap between land surface networks and satellite data to support higher performance NWP. Opportunistic (crowd-sourced) observations would be of great interest, and the Met Office is actively engaged in discussions with the private sector about this.

Day 1 Session 2.1

Presentation: Captain Phil Hall, NOAA, UAV for Meteorological and Atmospheric Science.

The mission of the NOAA UAS Program is to facilitate UAS applications and utilization in NOAA and accelerate the transition of UAS capabilities from research to operations by providing expertise and resources for UAS research and development.

To meet NOAA meteorological and atmospheric science data requirements, the NOAA UAS Program has completed field experiments to demonstrate UAS applications. These experiments included:

- High impact weather monitoring on NASA Global Hawk
- Expendable, aircraft launched UAS for Tropical Storms
- Aerosol and Flux Measurements from UAS in the Arctic
- Fire Observations from UAS
- Flood Observations from UAS
- Vertical Profile Meteorology from UAS

Collecting meteorological and atmospheric science data with UAS is a priority to the NOAA UAS Program and the future, funded programs include:

- High Altitude Glider Return System
- The next generation of Expendable, aircraft launched UAS for Tropical Storms
- UAS for Alaska NWS Operations
- NWS Drone Team Pilot Project
- Vertical Profile Meteorology from UAS
- Aerosol and Flux Measurements from UAS in the Atlantic Ocean
- Flood Observations from UAS

Dr. Jamey Jacobs, Oklahoma State University, Swarming small UAV for ABL Observations and Development of the 3D Mesonet.

He suggested that unmanned aircraft systems (UAV) offer new perspectives on research and monitoring of the atmosphere, and their use in atmospheric science is expanding at a fast pace. In particular, three dimensional measurements of the atmospheric boundary layer (ABL) provide a unique view of its transient and spatial nature. Previous studies have demonstrated using fixed wing UAV to measure various areas of interest, such as the diurnal boundary layer or the wake of turbines. However, a novel approach is to measure multiple points simultaneously using highly coordinated and autonomous UAVs, in a technique known as swarming. Swarming involves the control of multiple unmanned aircraft in formation without direct pilot input, in which each can adapt to observations of the current conditions autonomously to optimize the observation strategy parameters, for example, grid spacing. The ability to perform such measurements is made possible due to the integration of fast response aerodynamic probe technology with compact hardware that enables the UAV to be used in this operation. This insight provides real-time full-scale measurements of the effects on the boundary layer conditions.

In addition to developing capabilities for observations from single sites using swarms and fixed-wing/rotary-wing UAV, the university has also compared results between observations and predictions, particularly from the HRRR model.

OSU is currently working on utilizing the capabilities of UAV to develop a "3D Mesonet." Fixed monitoring sites, such as those in the NWS Automated Surface Observing System (ASOS) and the Oklahoma Mesonet, provide valuable, high temporal resolution information about the atmosphere to forecasters and the general public, but these networks are only capable of providing surface observations. The Oklahoma Mesonet (Brock et al. 1996) is comprised of a network of roughly 120 surface sites providing a wide array of measurements with an update time of five minutes (www.mesonet.org). The intention is to demonstrate the value of extending the conventional surface mesonet concept to include vertical profiling capabilities by the addition of small, instrumented, profiling UAV platforms to several Oklahoma Mesonet sites as a Proof Of Concept for the entire network. The resulting "3D Mesonet" will leverage resources available through the existing Oklahoma Mesonet as well as considerable engineering and meteorological assets at OSU and OU. The long-term vision would be to autonomously operate UAVs at the sites to provide atmospheric profiles at scheduled intervals to be used by NWS forecasters (e.g., at the Storm Prediction Center in Norman), and to send the data to a central facility for dissemination.

Additionally, results were presented from two UAV campaigns, including from CLOUD-MAP and the LAPSE-RATE campaigns. CLOUD-MAP – the *Collaboration Leading Operational UAV Development for Meteorology and Atmospheric Physics* – is a 4 year, 4 university partnership examining numerous systems including both fixed wing and rotary wing solutions predominantly focused on atmospheric boundary layer measurements. Between 2016 and 2018, over 100 participating team members and other collaborating agencies including NOAA, NWS, and the DOE. Selected sites included the Oklahoma State University Unmanned Aircraft Flight Station, the Marena Mesonet, the Kessler Ecological Field Station, and the US DOE Atmospheric Radiation Monitoring Climate Research Facility Southern Great Plains site. Over multiple periods, the team has conducted thousands of individual flights and logged hundreds of total flight hours focused on gathering comprehensive, accurate, and relevant atmospheric data. Sensors included standard meteorological sensors for pressure, temperature, and relative humidity, various wind sensors such as five-hole probes, hot wire sensors, and IMUs, gas concentration sensors including CO_2 and CH_4, and small inexpensive meteorological packages designed for aerial deployment. This effort culminated in Lower Atmospheric Process Studies at Elevation—a Remotely-piloted Aircraft Team Experiment—LAPSE-RATE – a field campaign conducted in July 2018 in Colorado. The comprehensive LAPSE-RATE campaign took place across the northern half of the San Luis Valley, evaluating the environmental conditions that support or inhibit Convective Initialisation (CI) along with optimized system configuration for targeted surveillance of the atmosphere for improved CI prediction, and cold-pool drainage. In addition to a coordinated "community day" which offered a chance for groups to share their aircraft and science with the community, LAPSE-RATE participants conducted nearly 1300 research flights totaling over 250 flight hours.

Mr. Konrad Bärfuss, Technische Universität Braunschweig, Contribution to the WMO UA workshop on UA Meteorology

UAV expertise at the TU Braunschweig reaches back to the year 2000. At the Institute of Flight Guidance, the whole observing system is considered, which includes the design and implementation of the mission, the aircraft, the sensors, the field work operation and the data processing. Besides other UAV applications, meteorological research with UAV has been carried out including meteorological investigations of the boundary layer, pollution and new particle forming. In a current project (in collaboration with the AWI [German Polar Institute], DWD, and an industrial partner), the aim is to use UAV operationally for atmospheric soundings up to at least 10 km. Based on technical and safety issues, two probable solutions were derived: A balloon-borne glider harmless to aviation (passive safety) capable to be released in altitudes up to 35 km, as well as an electrically driven fixed wing system able to reach heights around 15 km directly above the launch site even in strong winds (with active safety). Mr. Bärfuss closed by identifying their key challenges which included: air density induced loss in thrust, propeller/ wing icing, and airspace integration.

Dr. James Pinto, National Centers for Atmospheric Research, Impact of assimilating UAV data on fine-scale weather prediction

He began by pointing out to the audience that small UAV offer the promise of flexible, high resolution, accurate measurements of key atmospheric state parameter that fill a region of the atmosphere characterized by a relative data void. The number of commercial vendors operating small UAV in the lower atmosphere) is forecast to grow by 300% over the next 5 years (FAA, 2019). Private companies are already offering UAV weather-sensing drones (e.g., Meteomatics) or are collecting weather data to support their Beyond Visual Line of Site (BVLOS) operations (e.g., Zipline). As commercial UAV operations continue to expand in scope and range of operations (e.g., package delivery, precision agriculture) it is likely that these aircraft systems will include atmospheric sensors to improve the safety, reliability and efficiency of their operations.

Dr. Pinto informed the workshop that the assimilation of atmospheric measurements collected by airlines (e.g., AMDAR, TAMDAR) into regional and global weather prediction models has been shown to greatly improve forecast accuracy (e.g., Benjamin et al. 2010, Moninger et al. 2010). While data from small commercial UAV will likely be restricted to lower altitudes (due to engineering and regulatory limitations), their spatial distribution over land and near shore areas may ultimately be broader than that of commercial airlines which are anchored to major airport locations. In addition, as automation technologies become cheaper and more robust and FAA regulations are met, one can imagine that networks of small UAV could be added to existing state mesonets to develop 3D mesonets capable of providing unprecedented sampling of mesoscale variability of winds and stability of the lower atmosphere (Fengler 2017, Chilson et al. 2019). Analogous to the impact of atmospheric measurements from commercial aircraft, it is expected that the assimilation of these observations (from commercial UAV and or 3D mesonets), once widespread enough, will result in improved mesoscale analyses and predictions. Through the upscaling of energy (e.g., impact of convective scale on synoptic scale features) this could ultimately lead to improved global scale predictions as well.

There have been several initial studies looking at the impact of assimilating small UAV data into NWP models but, there is still a great deal of work to be done to fully evaluate their potential. Preliminary studies have shown that the representation of mesoscale environment can be improved by assimilating UAV data into relatively high-resolution models (Jonassen et al. 2012, Jensen et al. 2018, Flagg et al. 2018, UnmannedNews.net 2019). So far UAV data assimilation studies have shown that localized UAV measurements can be used to improve fine scales predictions at relatively short lead times. For example, Jensen et al. (2019), showed that Four Dimensional Data Assimilation (FDDA) or Newtonian relaxation improved the simulation of low-level stability and winds associated with mesoscale cold air drainage flows. Jonassen et al. (2012) indicated that FDDA improved the simulation of mesoscale features of a land breeze circulation. Flagg et al. (2018) found that assimilation of UAV data using 3DVAR DA approach improved short term mesoscale predictions of flows in a coastal zone but degraded some aspects of longer range predictions likely due to inadequately specifying the decorrelation length scales of the observations. Finally, Meteomatics demonstrated that value of assimilating UAV data flown at multiple profiling sites in the prediction of low ceilings and fog (UnmannedNews.Net 2019).

Another area of active research area is the assimilation of UAV data using Ensemble Kalman Filter (EnKF) DA approaches. EnKF offers the advantage of being a highly flexible framework for assimilating data in 4 dimensions while at the same time taking into account model and observations errors. The EnKF approach also offers a means of quantifying analysis and forecast uncertainty which will become more and more crucial as predictions are needed at increasingly finer scales. Experiments are being performed using UAV data collected from separate platforms flown by multiple universities during International Society of Atmospheric Research using Remotely-piloted Aircraft (ISARRA) Flight Week which took place in the San Luis Valley of Colorado in July 2018 (de Boer et al. 2019). The dataset collected during ISARRA offers an excellent testbed for developing and testing approaches for assimilating UAV data. Questions related to required data densities, sampling strategies and sensitivity to observational error estimates can be explored. With EnKF an ensemble of initial condition background fields is generated using the WRF model and a set of perturbations. The background field is then compared with the observations to produce a set of innovations (i.e., difference fields). The amount that the background model fields are adjusted depends on a number of factors including localization and assumptions of the observational error.

Dr Pinto concluded stating further studies are needed to assess other DA approaches including hybrid techniques (4dVAR and EnKF) and to scale up these localized performance improvements to larger scales by assimilating UAV data across wider scales and performing Observing System Experiments (OSEs).

Day 1 Session 2.2

Ms. Dörthe Ebert, Deutscher Wetterdienst (DWD), UAV at Deutscher Wetterdienst: Use in Meteorological and Climate research activities and Campaigns

DWD considers UAVs to have the potential to provide a useful supplementary platform for in-situ measurements adding value to existing operational sounding and remote sensing systems and especially having the potential to close the data gap in the boundary layer, improving data assimilation and thus numerical weather prediction accuracy and skill.

Currently DWD employs UAVs for atmospheric research only and primarily in the boundary layer. Experiments are conducted at the National Observatory Lindenberg in cooperation with universities and other research institutes. Additionally, drones are employed for aerial inspection work to support maintenance, e.g. at towers and antenna arrays. For the future, Ms. Ebert said, the DWD envisages the operational use of return gliders to improve and supplement balloon-borne soundings; especially to implement multiple-use sounding sensors of higher quality and significantly improve return rate of the equipment.

An advantage of UAVs is that environmental measurements can be conducted with drones where other airborne platforms or remote sensing are not feasible, esp. in urban areas, as well as for measurements in hazardous environments; e.g. volcanic ash, radioactive and chemical clouds, especially when missions with manned aircraft are too risky.

Dr. Bruce Baker, NOAA Air Resources Lab, The work of the NOAA Air Resource Laboratory towards the operational utilization of UAVs

Provide data to meet requirements to improve forecasting skill and support other applications, which could conceivably include:

- Provision of more accurate storm damage surveys;
- Improved river flood forecasting by recognizing inundation from multiple crests, and providing more data input for river forecast models;
- Greater data input into more frequently run, high-resolution models;
- Improved tornado warning lead time and reduced false alarms owing to better observations; and
- research that could support improved operations, such as improved understanding of why some boundaries generate thunderstorms and others do not, despite being in similar environments.

Dr. Baker also discussed the advances and improvements in UAV systems necessary to be able to meet such requirements, including:

- Ability to evaluate the accuracy of questionable observation data (particularly from non-NWS sources);
- Determination of maximum altitude and vertical resolution needed to obtain critically important information about the severe storm environment (*"Key Performance Parameters"*);
- Optimal frequency of soundings from the fixed sites;
- Required separation distance for making vertical take off and landing (VTOL) soundings;
- The benefits and impacts of the implementation of fixed-wing UAV in the U.S. National Weather Service warning and forecast process (achievable lead-time and accuracy improvements)

Other key aspects or important considerations for the developing NOAA UAV program include:

- further investigation, and UAV design refinement will be needed to demonstrate the capability of recording observations at altitudes of 1,000 ft AGL and higher within conditions such as heavy precipitation, icing, and stronger turbulent flow that may reach or exceed 40kts.
- the idea that UAVs should be flown autonomously within designated sectors of airspace;
- obtaining data from a range of different sources including 'targets of opportunity' (e.g. partnering with operators of delivery drones);
- the use of networked UAVs;
- operation of UAVs in 'swarm' formations; and
- how to manage large quantities of data and ensuring it is adequately quality controlled; and
- many practical aspects of operations, including for example the charging of batteries.

Dr. Baker suggested that there was a need for a full demonstration of small UAV capabilities using a testbed, with the aim to develop a robust set of protocols to assess the costs and operational feasibility of UAVs for routine applications using various combinations of aircraft and sensors. The testbed could also be used to design and develop processes and protocols to support the transition of UAVs from research to operations, including such aspects as data processing and transmission, validation and integration into data user applications and systems.

It is believed that the potential benefits and impacts of small UAVs to the National Forecast Centers and to the customers the agency serves are numerous and substantial enough to support a large-scale (perhaps international) demonstration of their capabilities. The demonstration could evaluate:

- Air worthiness of the UAV in carrying a given payload to a given height;
- Ability to collect the required data and return it to the launch site;
- Ability to efficiently relocate the UAV to alternate locations;
- Demonstration of cost-effectiveness for weather services.

Mr. Greg Roberts, Météo-France, Deploying UAV for Atmospheric Research

The workshop was informed UAV are well-suited to complement ground-based measurements or conduct measurements in remote or dangerous locations to study processes in the lower part of the atmosphere. In-situ observations are often ground-based, and UAV offer an important synergy with ground-based measurements to access the vertical dimension of the atmosphere, particularly within existing networks of atmospheric monitoring stations . Research interests of using UAV include process studies and long-term sampling using a single UAV, coordinated fleets or in distributed networks.

UAV require less logistical requirements than human-piloted research aircraft and allow for observations in otherwise inaccessible locations. UAV also provide unique capabilities such as coordinated formation flying in a scalable to study processes that span many orders of magnitude in temporal and spatial scales. Take-off to landing automation has been achieved with multi-copters; however, fully autonomous operation remains a challenge for fixed-wing UAV, particularly the launch and recovery phases. However, fixed-wing UAVs operate with longer endurance and higher altitudes compared to multi-copters which make fixed-wing UAV important tools for atmospheric research. In addition, logistical requirements and costs scale with UAV size, therefore selecting or designing the smallest size UAV to accomplish the mission reduces operational costs.

Developing and deploying UAV platforms and science payloads require convergence between engineering, research and operational goals. The engineering efforts in developing a UAV and payload is only the starting point for science research; yet, technology readiness level is often not sufficient for operational use. The conversion to an operational level requires additional engineering investment to convert 'research-grade' UAV and instrumentation to a fully autonomous operation. During the development phase of a UAV platform or payload, the team must pay special attention to 'requirement creep', whereby more and more requirements are added to the UAV or payload system until meeting all of them becomes technically unworkable. The calibration and quality control of airborne sensors are platform specific and require a standardization protocol for data products before their integration in a measurement network. In addition, the regulatory environment and accumulated experience of the UAV operator requires continuity in personnel to conduct routine measurements with UAV.

Mr. Roberts described that his research has focused on the use of UAV for atmospheric research in topics related to atmospheric winds, aerosols, clouds and solar fluxes. Highlights of this research are described below:

- Aerosols, clouds, and radiative budgets were studied using a coordinated UAV fleet in the Maldives in 2006. Three vertically-stacked UAVs directly measured aerosol absorption and aerosol-cloud interactions leading to publications in Nature and Proceedings for the National Academy of Sciences. More than 23 hours of synchronized stacked flights were conducted to directly measure the heating of aerosol layers that extended over the Indian Ocean, and sampled 350 individual clouds to link aerosol-cloud interactions on individual cloud scales.

- Since 2013, ultralight UAV have been used at CNRM to study atmospheric conditions associated with the formation of fog by conducting frequent profiles (every 20 min) to follow the evolution of the boundary layer. Temperature, humidity, horizontal wind profiles from UAVs have been compared to AROME 2.5km operational model from Meteo France, and UAV measurements show fine detail (such as temperature inversions) that are not captured in the model.

- Aerosol / cloud interactions have been studied in Ireland and Cyprus in 2015 by coupling UAV observations with models and satellite. Comparisons between UAV-observed and modelled cloud properties demonstrated the impact of entrainment on cloud radiative forcing. UAV and model-derived cloud microphysical properties accounting for entrainment compare well to satellite retrievals.

- UAV have been used to study air-sea exchanges and the impact of marine aerosol emissions on the formation and evolution of cyclones. UAV measurements were conducted in March 2019 over the Indian Ocean and measured primary marine aerosols feeding Cyclone Joaninha.

He concluded his briefing by telling the workshop that a UAV fleet is currently under development to follow a cloud life cycle using adaptive sampling and optimized trajectories for dense mapping of cloud layers. Cloud maps from in-situ observations of the UAV fleet will then be compared to large eddy simulations to assess model parameterizations of entrainment.

Dr. Debbie O'Sullivan, United Kingdom Met Office, Current use of UAVs at the Met Office, and issues of transition to operations.

She began the presentation with a discussion on The Met Research Unit in Cardington that has two multi-copters which are used for boundary layer and fog research and a number of fixed wing UAV's which are used for higher altitude work for example cloud studies. The UK Met Office is also beginning to work with Exeter University to test a miniaturized optical particle counter (POPS) and a mini-SMPS for measuring aerosol optical depth on a UAV for air quality. There is also some very interesting work being carried out by the CASCADE (Complex Autonomous Aircraft Systems Configuration Analysis and Design Exploration) program, for which the Met Office is acting as an advisor.

Currently the Met Research Unit at Cardington has a DJI S900 multi-copter used for boundary layer research and fog studies as well as instrument testing. A newly acquired Yuneec H520 multi-copter, which can reach 6000 ft (1.8 km) but with a smaller payload and a fixed wing (Borates Maja) more suited to high altitude straight and level work, such as stratocumulus measurements. The DJI multi-copter is being used to test a range of temperature and humidity sensors, including tests to determine the best location on the UAV for different sensors. The UAV is flown next to instrumented met masts, and comparisons have also been done with data from a tethered balloon and radiosonde launches.

The UK Met Office is also beginning to work with Exeter University to test a miniaturised optical particle counter (POPS) and a mini-SMPS for measuring aerosol optical depth on a UAV for air quality. UAV's are a good option for measuring air quality as they are cheap (compared with aircraft-based observations). They are also easy to deploy in the boundary layer, enable measurements to be made where people are, and it is possible to use multiple UAVs to sample different areas for flux measurements or to carry a wider range of instruments, and coordinate the flights.

The main issues with transitioning to operational use, are regulatory issues, getting permission to fly UAV's in a way that would enable the necessary meteorological data to be collected. Other barriers are the costs of either buying a service from a private company or the development and maintenance costs if done in house. The level of automation is not yet high enough, and there needs to be a period of testing and proven benefit before a new system can be adopted operationally

Ms. Anne Hirsikko, Finnish Meteorological Institute, View on the drone: activities in FM .

She stated that the Finnish Meteorological Institute (FMI) believes UAVs have great potential as a new observations platform for monitoring atmospheric state, which, for some applications, require detailed, fine scale weather information. It is expected that there will be a future requirement for the development of a dynamic feedback loop between data provider and weather nowcast data users to support advances in UAV traffic management.

FMI has tested an autonomous drones with a tailor-made ground station with the capability for autonomous battery change and recharge. The first tests of the system, deployed with a drop-sonde, were carried out during September 2018. The system was robust enough for only two weeks of observations at the time of the test. The Drop-sonde, installed underneath the drone, showed good performance when compared against collocated radiosonde observations. A new test period with a drop-sonde installed onboard the autonomous drone, together with its updated collocated ground station is currently ongoing. The data is presented on weather forecasters' workstations in near-real time to obtain their feedback on data usability.

In summary, FMI believes that the current issues with transitioning UAVs from research to operational are:

- Level of autonomy versus required man power;
- Regulatory and related safety aspects (higher altitudes are required)
- Durability – e.g., weather resiliency
- Data quality (sensor and setup testing, development of QC)

Mr. Marin Mustapic, Croatian Meteorological and Hydrological Service, Road traffic air pollution measurement in Zagreb City using UAV

Mr. Mustapic informed the workshop that motor vehicles are a significant source of urban air pollution in Zagreb and pointed out that transportation emits more than half the nitrogen oxides and particulate matter in the air. Such emissions are a major source of global warming emissions in Europe. Atmospheric pollution of particulate matter with aerodynamic diameter less than 10 µm (PM_{10}), derived from traffic, is the most widespread problem in Croatia.

Assessment of air quality has been traditionally conducted by ground-based monitoring. In Zagreb there are three ground-based stations for air quality operated by the Croatia mteorological service, of which two are placed near roads with moderate traffic. UAVs can be used to derive a better understanding of vertical and horizontal distribution of pollutants. Equipped with appropriate sensors, the UAVs can offer a new approach for research opportunities into air pollution and emissions monitoring, as well as for studying atmospheric trends.

The aim of the study being undertaken in Croatia is to design and develop a modular system for UAV-based observation of air pollutants. The research included two different tests:

1. Evaluate the effects of downwash and upwash to determine the best location sensors should be mounted on UAVs; and
2. Determine the optimal flight path for data collecting.

It has been found that the sensor mounting location can have a significant impact on how the pollutant samples emitted by a point source are represented, and that an optimized flight path is necessary to provide an accurate measure of the distribution of air pollutants.

A systematic and objective evaluation of the methods for monitoring air pollution and its 3 dimensional distribution with UAVs will be an important step towards improvement of air quality forecasting and understanding of air pollution.

Mr. Lars Isaksen, ECMWF, Use of UAVs in Meteorological Activities and Campaigns at ECMWF discussing the use of UAVs in NWP research and operations at ECMWF.

For international data centres to be able to use such data efficiently and easily, it is very important to implement and use well-defined data formats (e.g. WMO BUFR). Near-real-time availability (within 3 hours of measurement time) is highly desirable for its optimal use in operational NWP systems. Availability and open access to data will increase the likelihood that NWP centres can justify the effort to assimilate and monitor and evaluate data sources such as those from UAVs.

ECMWF has over the last decade been involved in monitoring, evaluating and assimilating UAV data, derived almost exclusively from the troposphere and lower stratosphere. Some examples are Laboratoire de Météorologie Dynamique (LMD), /École Polytechnique, 6Centre National d'Etudes Spatiales (CNES) stratospheric balloon data. ECMWF is also a keen user of tropical cyclone targeted data, for example NASA Global Hawk drop-sonde data and US Airforce/NOAA hurricane and Atmospheric River dropsonde data. ECMWF has implemented the ability to operationally use high resolution BUFR dropsonde data and BUFR radiosonde descent data (now available from Germany, UK, and Finland). ECMWF is also evaluating airborne campaign data (e.g., Aeolus Cal/Val data from DLR and NOAA) and is in contact with Google on the possible use of their Google Loon stratospheric balloon data. These data will hopefully soon be made available to the NWP community. ECMWF is also involved in the HAPS4ESA activities where ESA has shown interest in evaluating the potential benefit of HAPS (High Altitude Pseudo Satellites) in synergy with Earth Observation Satellites and for evaluating new space instruments. HAPS consists of solar powered aerodromes, balloons, and gondolas all operating at 20-25 km altitude. Finally, for Arctic campaigns, where the main NWP interest is in the lowest five kilometres, ECMWF believes Copter Drones have the potential to replace radiosondes, particularly given that helium delivery for radiosondes is a big issue in remote regions.

Day 2 Session 3

Mr. Chris Flynn, Flyht Aerospace Solutions Ltd., TAMDAR-Edge: UAV Weather Sensor Technology

The presentation provided the workshop audience with information about the services of FLYHT Aerospace Solutions Ltd. which is a leading provider of SATCOM voice and data services for the aviation industry. With the October 2018 acquisition of the assets of Panasonic Weather Solutions, FLYHT is now the provider of atmospheric data using its commercial aircraft-based weather sensor *TAMDAR 6000C™,* complimenting the existing AMDAR-over-AFIRS capability. The Tropospheric Airborne Meteorological Data Reporting (TAMDAR) sensor is currently installed and operational on over 225 aircraft around the globe and has been a valuable source of in-situ atmospheric data since 2003.

In addition to *TAMDAR 6000C™* for passenger aircraft, FLYHT has developed the *TAMDAR-Edge™* system for unmanned aerial vehicles (UAVs). It is a low-power, miniaturized version of the commercial TAMDAR sensor and provides the same key weather parameters including relative humidity, temperature, winds as well as turbulence and icing conditions. It has been used on multiple UAVs flying science missions for NASA, the U.S. Air Force Weather Agency (AFWA), New Mexico State University's Physical Science Lab, and Texas A&M University.

The *TAMDAR-Edge™* system is comprised of three components:

1. TAMDAR-Edge™ - Weather Sensor
2. FlightLink-Edge™ - SATCOM, GPS, and Data Processing Unit
3. Antenna - Iridium, GPS

With a total system weight of 14.9 oz. (422 g) and nominal power of 4.1 W, the *TAMDAR-Edge™* system is ideally suited for fixed-wing UAVs used for atmospheric science missions. The airborne system takes advantage of the same world-class ground system infrastructure which has supported FLYHT's commercial TAMDAR sensor for over 15 years. The combined airborne and ground system provides accurate atmospheric measurements along with reliable storage, quality assurance, and distribution of atmospheric data.

Dr. Jack Elston, Black Swift Technologies, Types and Capabilities of UAV for Meteorology"

He told the workshop that unmanned aircraft systems are already being used operationally for a number of different atmospheric applications including volcanic monitoring, plume detection and dispersion measurement, in situ thermodynamics, soil moisture measurement and snow water equivalent measurement, among others. Critical to the value of the contribution of these systems is the ability to routinely collect the measurements in a safe and reliable manner. This depends largely on the capabilities of the unmanned aircraft system.

Among the characteristics to consider when selecting a platform for use in meteorology, some of the main areas of focus should be ease of use, robustness, and capability to be integrated with the national airspace system. Ease of use is critical when considering the desire to routinely operate aircraft, and especially when considering operations in which the control of several to many vehicles is envisaged, which has been identified as a requirement for meeting the spatial measurement density needs of NWP. It is also expected that, not only will the operational cost of employing UAV for meteorology limit the number of individuals that can work on each system, but also that operators should not have to possess the highly specialized skill set of a manned pilot. Additionally, in an operational capacity, it is expected that each aircraft will need to operate as many days as possible and through many different kinds of weather, meaning that the vehicles will need to be efficient and durable and require specific designs to mitigate the effects of wind, precipitation and icing among others. Use of UAVs for operations will require higher-altitude flights, beyond line of sight, and possibly within close proximity to buildings and challenging terrains. Such meteorological user requirements, along with those of other UAV applications will mean that the regulatory requirements of airspace will continue to change and adapt, and UAV systems will need to provide the necessary interfaces, onboard systems and autonomy to safely operate with other traffic and within challenging and varying regions.

Mr. Christian Schluchter, Meteomatics, Meteodrones

He explained that Meteomatics manufacturers and operates Meteodrones, which are designed for profiling the lower atmosphere up to 3000m altitude, measuring temperature, relative humidity, dew point, pressure, wind speed and direction. These data are sent to Meteomatics servers in real time and are then assimilated into a high resolution WRF numerical weather model. MeteoSwiss has also assimilated into their COSMO weather model Meteodrone data gathered in a campaign in and around Zurich airport, in which six Meteodrones were sounding simultaneously. The results showed that assimilating drone data into weather models significantly improves forecasts.

Meteodrones can also be used for mobile operations. The Meteodrones are delivered within a suitcase including the ground station and all that is needed for soundings. This enables a user to very flexibly react to the current conditions and the Meteodrones can be used for spontaneous soundings e.g. to study pre-convective conditions. The data is delivered in different formats including CSV, RAOB and BUFR.

The Meteodrones are equipped with an emergency rescue system allowing them to be operated fully autonomously under beyond visual line of sight (BVLOS) conditions. In the coming months, Meteomatics will focus on further automation of the Meteodrone system including the MeteoBase. The MeteoBase is a fully autonomous ground station that can be controlled remotely. This allows a drone operator to remotely control several drones from one control center instead of being at the flight site and only being able to control one drone. Scaling up the Meteodrone technology to a grid of automatic sounding stations feeding data to numerical weather models thus becomes technically and financially feasible.

Mr. Luis Carillo, Singular Aircraft, FLYOX

He explained to the participants of the workshop the mission of Singular to manufacture UAVs that are reliable, efficient, safe and of low cost. He briefed the workshop on the FLYOX1, the UAV his company produces which, while fully automated, requires a pilot onboard to meet airspace regulations. The FLYOX is capable of many different types of missions including weather surveillance. In the weather surveillance mode, it can carry several types of radar, drop-sondes and other sensors. He provided the workshop with the FLYOX performance and operating cost breakdown in his presentation.

Mr. Chris Mazel, DroneXsolutions

He informed the workshop audience that in order to illustrate the types and capabilities of UAV in the context of flight campaign, he introduced the mission ReNovRisk-drone as a reference for the various aspects of this topic. The purpose of ReNovRisk-drone flight campaigns was cyclogenesis surveys in the Indian Ocean (area of the island of La Réunion (perimeter of operation up to 250 km from the coast).

The challenges were technical and regulatory addressing the topics of specific flight permissions, logistics for multiple sites of operation, deliver and use of mission data in real-time. The deployment has been achieved beginning of 2019 as part of the research program conducted by the LACy (Laboratoire de Atmosphère et des Cyclones, La Réunion) and CNRM (Centre de recherche Météorologique, Toulouse).

The UAV BOREAL used is a high-performance Fixed Wing drone of 4.2 m wingspan presenting the following characteristics:

- Large payload area, easy fastening
- Up to 5 Kg payload, 100W electric power available
- Stable and precise flight
- Long endurance - long range (10h / 1000km)
- All terrain operation with bungee catapult and short low speed belly landing
- Customizable payload bay
- Cartographic monitoring, waypoint mission programing

In order to achieve its mission, the drone was equipped with avionics embedding the following features:

- Automatic flying
- Multiple C2link capabilities for short and long range communication
- Remote identification with a Transponder mode S / ADS-B out
- Visual anti-collision with strobe
- Support for traffic separation with a real time front video sensor 1080p

The Met payload was a combination of multiple sensors to study the flow of energy and aerosols:

- 5 holes probe for turbulent flow measurements and wind vectors on the 3 axes
- Fast humidity sensors and temperature linked to the turbulence probe
- Infrared sensor to measure the temperature of sea surface
- Aerosol counter sensors to measure particles concentration and size

- Video sensor for a qualitative estimation of the State of sea of
- Sensors for analysis of radiation and extinction

The drone was deployed in a large variability of weather conditions included cyclonic conditions and from different areas of operations from La Réunion Island. The logistic of the flight campaign was mainly addressed during the preparation phase. The identification and the reservation of the infrastructure (airfields facilities) and the protocol of operations with local + international authorities were anticipated with the support of the LACy and the French CAA in the Indian Ocean.

A specific operating mode was defined with the local and international authorities to coordinate and synchronize the access to the airspace. In particular, the operator has to consider the separation with the air traffic and the maritime traffic because of the very low level flight objective. The airspace access was managed by creating 6 Dangerous and Restricted offshore areas with a gradual elevation max constraint based on the distance to the coast.

The UAV BOREAL ground segment embedded a catapult directly deployed at the level of the runaway, a mast for datalink tracked antennas (RF), a power supply by sector plus individual generator and a Control Station located above the ground for a good visibility off the coast and the nearby environment. Additional services such as Wifi access or 4G to be connected to internet, ADS-B (internet) direct monitoring by dedicated local station (located on the coast and inland), AIS monitoring by local receive.

ReNovRisk-drone mission objectives were achieved and the flight statistics were provided during the briefing.

Mr. Jean-Francois Vinuesa, Airbus, Improving Service Coverage with High Altitude Pseudo Satellite,
He providied some information on the Airbus Defence & Space and operational meteorology: current and future programs: including a number of satellites and high altitude platforms equipped with meteorological platforms deployed since the early 2000s. He then told the audience about the High Altitude Pseudo Satellite or HAPS. HAPS offer benefits of persistence and flexibility to complement satellites and (un-)manned aviation. Haps has a strong potential for complementary, layered services, e.g.

- Maritime surveillance (Search and rescue, Smuggling)
- Border security (Irregular migration, Smuggling)
- Telecommunications
- Emergency response;

Integration with existing satellite ground stations best implemented by modification to accept data feeds, e.g. video; Facilitates data validation and cross correlation between satellites and HAPS; and In-situ data collection in remote areas, e.g. polar regions. Airbus is developing and testing will be demonstrating HAPS in 3 configurations beginning in 2020, including Heavier-than-air (aircraft like), Lighter-than-air free flight balloons, and lighter-than-air airships. Mr. VIneusa pointed out that all types of optical & RF instruments can be envisaged on HAPS, with platform selection mainly based on mass & power criteria. He discussed that HAPS has strong potential for climate and environmental monitoring.

Dr. Thomas Wetter, Deutscher Wetterdienst, Application and Use Generally Provision of MET for the operations of UAV

Dr. Wetter told the workshop audience about the introduction of the new aircraft type UAV (unmanned aircraft system) where the piloting crew is not onboard the aircraft, MET ANSP services (observations, forecasts, warnings, briefing material, consultation) needed to be adapted to cope with the new requirements arising from the high variety of technological and operational demands of these new aircrafts.

DWD introduced for basic VLOS operations in the leisure and recreational sector of UAVs a set of NWP winds and maps of WX radar and lightning data freely available to the public, whereas commercial drone operators got access to aeronautical briefing on equal terms as any other pilot of General Aviation.

To establish MET information for flight information services in conjunction with an UTM (UAV Traffic Management System) current under development by the German ATC Deutsche Flugsicherung, DWD provides high resolution NWP model data tailored to Very Low Level Airspace (VLL) up to 250m AGL. A further usage of these weather forecasts for UAV ATM purposes in the future is sought. The most challenging task for future considerations on UAV operations and weather is, how to prepare weather briefings and consultations for BVLOS operations and first and foremost how to conduct in-flight weather detect and avoidance (DAA) of hazardous weather.

Mr. Stewart Taylor, EUMETNET, High Volume Operations with Drones

Mr. Stewart gave a bit of history of Zipline by stating that Since 2014 they have flown 15,000+ flights, over 1 million kilometers, 80 km service radius with up to 9 aircraft at the same time from each distribution center. The Zip line UAV fly at 30 m/s below 500ft above ground level with a 50 min average flight duration, 100 km average flight distance and all have met sensors which include 2x redundancy on pressure, temperature and humidity sensors and 1hz+ sampling cellular comms uploaded to a cloud site every 15 minutes. This data supplements the very sparse NMHS reporting locations in Rwanda and Ghana.

Day 2 Session 4

Mr. Manfred Mohr, IATA, Use of Airspace the Regulatory Aspects and the Airline View

Mr. Mohr commended the workshop presenters on how attentive and knowledgeable they are on current air space regulations. He then stated it is important that we have a comprehensive approach to UAV integration into the wide family of air space users aligned with global recommendations.

Regulation 2018/1139 includes all civil UAV under EU authority and specifies the three regulatory categories of UAV operations:

- Open Category – no preapproval; Limitations: 25 kg, VLOS, height <120m, system of zones 3 Sub-categories: fly over, close, far from people
- SPECIFIC -Increased risk; Authorisation by NAA based on specific operation risk assessment (SORA);Declaration in case of standard scenario; LUC
- CERTIFIED -Risk as manned aviation; Certification of UAV, approval of the operator and licensed pilot (unless autonomous flight)

There are 16 EU aviation industry agencies working together to ensure safe integration of UAV into EU airspace. The main question about how to efficiently implement protection against drones impacting safety and operations, are still mostly unanswered. This can be explained in large part by the lack of regulations at both national and European levels. The industry will implement measures to deny access of malicious drones in certain areas, such as airport vicinities (at Approach and Departure, but not only), independently of the cooperation of the drone user. Technological solutions to prevent or neutralize drones entering restricted airspace must be developed.

Mr. Chris Mazel, DroneXsolutions, Issues with use of Airspace

In order to illustrate the Issues with use of airspace in the context of Met flight campaign, we introduced the UAS Regulation status at the national level of France and at the EU level. A focus on the SPECIFIC category is proposed and the mission ReNovRisk-drone is used as a reference for the various aspects of this topic. An overview of the current limitations and potential evolutions of UAS Regulation is done for Meteorology operations.

The national regulation for Aerial work in France is composed by 4 scenarios:

- S1 = Non-populated area / Mass < 25 kg / Height < 150 m / Dist < 200m
- S2 = Populated area / Mass < 8 kg / Dist<100m / Height<50m / Safety perimeter
- S3 = Non-populated area / D < 1 km / Mass < 25 kg and Height < 50 m or Mass< 2kg and height <150m
- S4 = Non-populated area / Mass < 2 kg / Height<150m

The flight authorization process is based on:

- Technical requirements for UAV depending on the scenario of operation
- Prior notification required in populated areas
- Prior authorization required in controlled airspace or restricted areas
- Away from aerodromes

The Specific operations and experimentation are subject to a case by case risk based analysis.

The European drone regulation was adopted in June 2019 and it will progressively replace the national rules over a transition period of 2/3 years. The harmonization of the rules is aiming to create a big European market for drone services. The European drone regulation addressed all unmanned aircrafts from toys to HALE, incl. model aircrafts and all types of current and future operations.

A large level of flexibility is provided to MS (Member State) to implement the new regulation at the national level and the National Aviation Authorities keep a key role in delivering authorization and in defining Airspace zones with specific limitations/requirements, no-fly zone, altitude restriction, requirement for remote identification, etc.

A Mutual recognition of the Authorizations delivered by the NAA of the Member State will be valid in the whole EU (after coordination with the relevant NAA).

The EU regulation will facilitate the law enforcement including privacy rights and will contribute to address security risks by registering all the Operators of UA > 250 gr or 120 m range.

The EU regulation will contribute to the environmental protection by limited the Noise nuisance.

The Rules are proportionate to the risk of operations by identifying 3 categories of operations to cover VLOS to IFR flights with different regulatory approaches.

- Low risk = OPEN / No prior authorization but CE marking
- Increased risk = SPECIFIC / Authorizations by NAAs based on a risk assessment
- High risk = CERTIFIED / Classical aeronautic rules (certification)

The Expected Timeline for the OPEN Category:

- Entry into force = Q2 2019 / National regulation fully applicable
- Applicability date = Q2 2020 / All UAS operators shall register themselves and register their UAS
- End of transitional period = Q2 2022 / Open category according to EU Regulation

The Expected Timeline for the SPECIFIC category:

- From Applicability date Q2 2020 to Q4 2022
    - Operations in the specific category according to EU Regulation
    - Pre-defined risk assessments published by EASA
    - Standard Scenarios adopted by European Commission
- From Q2 2019 to Q2 2021
    - Member State shall convert national authorizations, certificates and declarations according to the EU Regulation
    - MS may define geographical zones

The CERTIFIED category Concept is addressing:

- All types of UAS operations: IFR in controlled airspace (class A-C) or urban environment (managed by U-space), to extension to D-E linked to availability of DAA
- All elements (e.g. the Remote Pilot Station) placed in Europe (in parallel we will evaluate the impact on elements placed in a third country)
- No fully autonomous flights
- Take off and land at aerodromes under EASA competence
- Operational requirements for the take off and land at other aerodromes and landing ports.
- Urban air mobility for UAS and manned aircraft (including electrical/hybrid aircraft related topics)

For the cooperation at the global level, the EUSCG (European Forum coordinated by EC) is in charge of defining a rolling development plan (RDP) and identified gaps or overlaps looking at needs vs available standards. Several standardization bodies are involved (EUROCAE, ISO, SAE, ASTM)

A Focus on the SPECIFIC category is proposed: The Methodology SORA (Specific Operation Risk Assessment) is introduced from the Source JARUS (Joint Authorities for Rulemaking of Unmanned Systems.
The SORA aims to provide a comprehensive tool to authorize the operation without standard scenario and corresponding to a set of AMC (Acceptable Means of Compliance) to Identify the level of risk and proposed a Derive qualitative security objectives making it acceptable risk.

With the SORA, the operator has to provide the demonstration means proportionate to the risk. This approach is based on the concepts of:

- Safety Assurance & Integrity Level (SAIL) of the operation = Level of confidence in the fact that the operation of the drone will stay under control
- Operational Safety Objectives (OSO) derives from the SAIL to mitigate technical issues or human errors

In summary, a SORA approval can be granted if and only if an operator has provided:

1. Mitigations used to modify the intrinsic GRC (Ground Risk)
2. Strategic mitigations for the Initial ARC (Air Risk)
3. Tactical mitigations for the Final ARC (Air Risk)
4. Containment objectives (Air Risk)
5. Operational Safety Objectives (Ground and Air Risk)

in order to get the approval from the Civil Aviation Authority (CAA)

We could expect to have a homogenization under the regulations applicable to the drones in Europe and worldwide.

The regulatory perspectives for Meteorology drone operations:
Current limitations

- Limited options to flight inland
- Low level (<150m and 120m) risky for high speed and fixed wing system
- Flight authorization to anticipate with an extended advance notice
- Multiple applications needed and multiple contacts with the authorities to manage
- Deep risk analysis mandatory
- No priority for the drone operation and risk to manage on the operator side

Evolutions to expect

- Standard scenario bringing more declarative operations
- Manufacturer standard compliance (airworthiness approved by design and on series)
- Generic SORA process / more REX will be considered

Dr. Debbie O'Sullivan, United Kingdom Met Office, Potential Regulatory Issues with the use of Airspace for Operational Meteorology

She explained to the workshop audience that within the UK it is straightforward to operate UAVs within segregated airspace, and also in class G airspace below 400 feet. However, above 400 feet in class G it is a slow and painful process to gain permission to fly. There is also a requirement to keep UAV's in direct unaided visual contact during operation (VLOS). There is however a general exception where UAV's can be piloted using the view from an on-board camera, known as first person view (FPV) flying, provided there is a competent observer maintaining unaided visual contact with the UAV. It is an added complication that most useful UAV met flights will require BVLOS operations. There are additional restrictions in the UK for UAVs with cameras on-board even if they are flown in class G airspace below 400ft. These restrictions are that they must not be flown within 150 m of any congested area or open-air assembly with more than 1000 people present. They must not be flown within 50 m of any vessel, vehicle or structure which is not owned or under control of the person operating the UAV, and they must not be flown within 50 m of any person, and this reduces to 30 m during take-off and landing. It is only possible to deviate from these requirements if permission is obtained from the CAA. Similar restrictions apply if you want to use the UAV for commercial purposes.

In order to maximise the potential of UAVs for operational meteorology there needs to be a mechanism in place to allow for routine BVLOS operations. In order to achieve that we need more studies like the CASCADE example which demonstrate how it can work. There also needs to be some consideration given to BVLOS operations in class G airspace, below 400ft. It is actually even more critical to get that right, as this a very crowded and unregulated area, where UAV's would need to be able to automatically avoid birds, gliders, other UAV's, potentially connected autonomous vehicles and a whole host of other obstacles. In order for UAV use to become accepted there needs to be a clear demonstration of the benefits and safety to the public.

Captain Phil Hall, NOAA UAV Program, US Aviation Policy and Challenges for Meteorological Operations for NOAA.

Challenges to the transition of UAS for meteorological operations include regulatory requirements to keep the UAS within visual line of sight, which prevents flights above 3,500ft and prohibits flights in clouds. Additionally, it is challenging to train NOAA personnel to be proficient as UAS pilots as well as conducting their normal duties. He concluded the briefing with the status of rule making efforts and the challenges of standards development for UAV.

Dr. Thomas Wetter, Deutscher Wetterdienst, Use of Airspace and Regulatory Aspects

International regulations on UAV converge on risk-based UAV mission and aircraft categories, mainly supported by the Joint Authorities for Rulemaking of Unmanned Systems (JARUS). Major aspects of regulations relating to UAV are safety (Air risk & Ground risk), security (sabotage, terrorism), privacy (cameras and other recording payloads) and airspace capacity (integration of UAV into existing airspaces)

In the "open" category predefined with low weight and low risk UAV and mostly COTS manufactured drones there are basically only restrictions to near to ground airspaces (VLL, U-Space), VLOS operations, and the need to respect restricted areas (e.g. airports, traffic, infrastructure, flying over people). Aside from these regulations the use of UAV in this category needs no further approval from aviation authorities.

In the "specific" category most other UAV concepts of operations will have to be addressed. With a Specific Operations Risk Assessment (SORA) following schematics from JARUS the concept of operations, contingency and emergency procedures UAV applications may be evaluated efficiently. A recommendation for WMO endorsed UAV applications for atmospheric measurements could be to develop own SORA standard scenarios to ease the approval of the most frequent operational and research MET applications. The "certified" category of UAV comprises fully certified aircrafts, which can be integrated into operations using ATC controlled airspace. This kind of UAV should be considered if long duration, long distance, BVLOS or IFR operations are deemed necessary. Dr. Wetter closed with stating currently the main conflicts of UAV regulations arise from the incompatibility of desired U-Space operations and VFR operations claiming access to the same airspace.

Mr. Stewart Taylor, EUMETNET, Issues with Use of Airspace…

Mr. Taylor focused his talk to the workshop attendees on the regulatory bodies and the information they provide to the UAV communities.

- FAA:
  - Extensive Webpage for UAV/RPAS – operators and recreational users,
  - Collaboration with industry, government and academia on UAVs operating in same airspace as manned aircraft.
- Single European Sky ATM Research (SESAR):
  - Less than 20 years ago, UAVs were not part of Definition Phase, SESAR JU for research projects
  - Several new research projects to look at UAVs in shared airspace (H2020)
- ICAO:
  - 39th Assembly (2016), world governments requested a practical regulatory framework for national UAV activities,
  - Working on framework for UAV Traffic Management (UTM).

There are numerous regulatory criteria in use on national levels – news items appear almost daily with reviews and updates and he provided some examples from 2018 to date in his presentation.

Mr. Taylor highlighted a demonstration project launched in 2018, the Gulf of Finland (GOF) U-space demonstration project funded by SESAR Joint Undertaking, the demonstration taking in Estonia and Finland will showcase how U-space can serve both unmanned and manned aviation. The demonstration brings together a broad consortium with 19 members, including three world-leading UTM (Unmanned Traffic Management) technology vendors, two air navigation services providers as well as deep ATM experience is developing interoperability and data-sharing solutions, which are aligned with SESAR’s overall U-space architecture. A pre-operational authority SWIM-based Flight Information Management System (FIMS) integrates existing commercial off the shelf (COTS) UTM components. The consortium is also proposing and demonstrating new interoperability solutions to bridge gaps when needed.

Seven advanced drone operational scenarios including both manned and unmanned aircraft in shared airspace demonstrate many of the most attractive use cases, relying on U-space services to be safe as well as cost effective with the aim to accelerate the realisation of a shared U-space in Europe, starting with low-level airspace.

End of Session 4.