At the core of the Engage KTN is the definition of various thematic challenges: new ideas suggested by the research community, not already included within the scope of an existing SESAR project. They are developed along with the ATM concepts roadmap and complementarily with some of the network's PhDs and theses.

Thematic challenge 3

Efficient provision and use of meteorological information in ATM

Edition 3.0, December 2019

This is an evolving document that summarises the key concepts (and, later, findings) for thematic challenge 3.

Abstract

The main objective of this challenge is to improve overall ATM system performance by providing better user-support tools based on improved meteorological ('MET') products. The focus is on the synergy of several methods and techniques in order to better meet the needs of operational users and to support aviation safety (e.g., through creating: early warning systems; an EU-wide weather picture) and regulation-makers (e.g., moving from text-based to graphical information provision). All stakeholders may benefit from this synergy: ANSPs (e.g., sector reconfiguration, separation provision, runway use), airlines (e.g., storm avoidance), airport operators (e.g., airport management under disruptive events), and the Network Manager (e.g., demand-capacity balancing). The challenge is, therefore, to bring the following perspectives closer: (a) for meteorological/atmospheric science, the development of products tailored to ATM stakeholders' needs, which are unambiguous and easy to interpret; (b) for stakeholders, the identification of the most suitable information available and its integration into planning and decision-making processes.

Description of challenge

Weather is an integral part of ATM, especially in the light of increasing traffic levels, where weather conditions present a significant source of uncertainty in the planning process, and one of the major causes of disruption and consequent delay during operations. About 20-30% of total ATFM delay has been caused by weather in recent years, while this grew to 20-45% in the first six months of 2018, thus challenging the achievement of the Performance Scheme goals for the year. In addition, extreme weather phenomena such as hail, severe icing and lightning present significant hazards as they can inflict substantial damage to aircraft. As extreme weather events are becoming more frequent in Europe, and forecast certainty is apparently decreasing, ATM performance is negatively impacted.

This thematic challenge aims at understanding how ATM may benefit more from the advances in meteorology/atmospheric sciences, especially in the light of climate change and the weather uncertainty that it brings. This is a key issue in the current European ATM research arena because on the one hand, extreme weather patterns are changing with climate change and, on the other hand, the impact of weather on different parts of the ATM network and its stakeholders (e.g. airports, ANSPs, airlines, passengers, Network Manager) varies in the type and magnitude of disruption, and consequent costs. For example:

- Airports – different conditions (e.g. rain, fog, snow) can cause capacity reductions and even closures (see also the ACI policy brief[1] on climate adaptation by airports);
- En-route – winds impact aircraft speed, weather cells can cause ANSPs to change flights' trajectories, or impose regulations for more severe weather, etc;
- Airlines – trajectory changes[2], delays and schedule disruption occur, resulting in various types of cost (e.g. passenger reaccommodation);
- Network level – the Network Manager (NM) coordinates and circulates the information to all stakeholders regarding local weather impacts on flow management, without taking decisions on local weather-related actions, apart from facilitating network-level harmonisation; an overarching, reliable and shared view on weather is not yet fully in place in the European network. Initial testing of cross-border forecasts and ATFM procedures with five States (with related ANSPs and MET providers) took place in summer 2019.

Hence, meteorological information needs differ across stakeholders, either in the type of information, or in the useful time horizon and in the certainty/uncertainty that can be tolerated in the decision-making processes. The time horizon may span from a few days to real-time, depending on the stakeholder and the function the stakeholder performs (e.g. ATC, or baggage handling at the airport). Furthermore, different forecast (and observation) resolutions are needed - a grid of 100 km^2 could be quite adequate for an ANSP, but lacks necessary detail for terminal manoeuvring/airport management. Another important component is the level of uncertainty that weather conditions impose. In the planning processes, higher uncertainty is tolerated, while in real time operations more certain information on the extent and trend of meteorological conditions is needed.

At present, the delivery and format of meteorological information provision is regulated by ICAO Annex 3, EASA and national regulations (in Europe). Regulated MET services and products[3] from certified MET ANSPs are quality controlled and are, in principle, free. In the USA, the National Weather Service provides a comprehensive set of forecasts, observations and tools *via* the Aviation Weather Center, and the Federal Aviation Authority deploys various weather-related decision-support tools aimed at more efficient air traffic management. In Europe, there are about 40 MET information service providers, some being certified by National Meteorological and Hydrological Services , some by air traffic service organisations, or a mixture of the two. Each has different responsibilities and cost structures. Commercial value-added services exist, and allow tailoring to user needs. These can be provided by a commercial MET provider or MET ANSP (for a fee).

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[1] https://store.aci.aero/wp-content/uploads/2018/10/Policy_brief_airports_adaption_climate_change_V6_WEB.pdf

[2] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2. Readers should be mindful of the different objectives of the two thematic challenges.

[3] MET products refer to different types of meteorological information, such as forecasts, observations, now-casts.

The Pilot Common Project (EU 716/2014) and Regulation EU 2017/373 are calling for additional MET services, and there is a widespread belief that if action is not taken promptly, new climate conditions will pose ever greater challenges to all ATM stakeholders.

In fact, the number and the intensity of extreme weather events increased in recent decades in some areas of the globe including Europe (Hov *et al*., 2013). Damage is mostly caused by strong winds, hail and precipitation intensity. Studies suggest that higher precipitation intensity for northern Europe, dry-spell periods for southern Europe, high intensity and extreme precipitation are expected to become more frequent within the next 70 years. The increased frequency is estimated to be larger for more extreme events, but will vary considerably from region to region (*ibid*). For instance, Black *et al*. (2010) reported decreasing winter rainfall over southern Europe and the Middle East and increased rainfall further north caused by a poleward shift of the North Atlantic storm track.

Long-term changes in European storminess are not very clear and sometimes show conflicting results. Some studies show a strong multi-decadal variability (Alexandersson *et al*., 2000; Bärring and von Storch, 2004; Wang *et al*., 2009), and analyses of extreme wind speeds highlight significant upward trends in central, northern and western Europe (Donat *et al*., 2011b; Brönnimann *et al*., 2012). Models under scenarios with increasing greenhouse gas concentrations indicate an increase in the number of severe storms in north-western and central Europe, which is also in accordance with other simulation results (Beniston *et al*., 2007). These simulations also suggest a significant increase in cyclone intensity and the number of intense cyclones over northwest, central and western Europe, under future climate conditions (Leckebusch *et al*., 2006, 2008; Pinto *et al*., 2009; Ulbrich *et al*., 2009). A belt stretching from the United Kingdom to Poland will experience an increase in extreme storminess and wind speed, while southern Europe and the Mediterranean will rather see a decrease in strong winds (Leckebusch *et al*., 2006; Donat *et al*., 2011a).

It must be recognised that recent years have witnessed important improvements in observational (e.g., satellites, light detection and ranging (LIDAR), Global Navigation Satellite System (GNSS) receivers) and numerical weather prediction (NWP) models in the atmospheric sciences (e.g., models for air quality in megacities that consider topography and resolution of under 100m). However, little has yet filtered down to the ATM world. Several workshops and MET-related projects came to similar conclusions: it is important to bring ANSPs, airlines, academics, MET service providers and atmospheric scientists together to better understand the effects and requirements of mitigation actions to convective, winter and hazardous weather at trajectory, network and airport levels. In some cases, tools and know-how exist, in others better models and outputs became available but are not exactly what ATM needs.

Thus, the initial step towards delivering the improved MET information needed for more efficient air traffic management consists of learning about improvements in the atmospheric sciences, about ATM needs in the light of the uncertainty that weather imposes on the network (and related uncertainty management), possible educational needs to foster better understanding between the two scientific and operational groups and, possibly, associated regulatory issues. The ultimate goal of this thematic challenge is therefore to define further research and operational needs regarding the use of weather information for more efficient ATM.

Workshop conclusions

This section consolidates conclusions from the first two workshops. See the [Engage website] for the presentations. Readers are also invited to refer to abstracts of on-going research by the [Engage PhDs] and projects funded through the [first catalyst funding wave].

MET-related research should enhance situational awareness of MET conditions for all ATM stakeholders, using state-of-the-art MET products. MET provision in Europe is fragmented, as each state is responsible for the provision for its territory. This is one of the reasons for the lack of a consistent and agreed weather 'picture' for ATM in Europe. To overcome this issue, and to reduce the impact of weather on delays, the NM and EUMETNET trialled a procedure with the goal of introducing a common weather picture and to better cope with adverse weather and the consequent delays. The trial involved the NM, DSNA, NATS, DFS and MUAC, and EUMETNET comprising: the Met Office (UK), KNMI (Netherlands), Skeyes (Belgium), Météo France and Deutsche Wetterdienst (Germany). As the impact of weather is usually worse in the period from May to July, as the high traffic demand coincides with summer convection, the trial took place during the summer season.

The procedure was based on existing technology, with the goal to improve collaboration, planning and dissemination of information with the ultimate intention of reducing the number of weather regulations, increasing lead times of regulation application and increasing stability. The MET providers established a common weather picture over the agreed geographical area, for the pre-tactical period (Day-1), where it was concluded that a 'consistent' view of the weather collaboratively agreed between stakeholders is more important than a 'perfect' view of the weather. An important part of the trial was the need for simple communication between meteorologists and controllers. With that in mind, EUMETNET developed a coloured risk matrix across two dimensions - probability/confidence and distribution/frequency, categorising the events into N (none), L (low), M (medium), H (high) and VH (very high), where only H and VH are of interest for the impact on the network. That forecast was then shared with the participating ANSPs and any H or VH events would trigger the teleconference to agree on the plan of action for the next day (i.e. 'red' coding leads to action).

The procedure was assessed as a good first step, with the following benefits: increased situational awareness - as forecast and insight from other ANSPs gave context on what to expect the next day; the risk matrix allowed for clear decision making as everyone knew when collaboration was expected; the triggers (H or VH) were about right; some issues (prompting further discussion) emerged regarding some medium-risk occasions; teleconferences gave a wider network overview; additional participants were invited when needed, which generated positive feedback. The plan is to continue this collaboration, extending the geographical scope, and then to work on including jet streams, more tactical forecasts and collaborations. This common weather picture should be available in the Network Operations Portal, i.e. in an easily accessible place. The Engage catalyst fund project, "MET enhanced ATFCM", aims to develop a MET product for convection (multi-model/multi-parameter) to support ATFCM decision making, ultimately leading to optimised en-route weather regulations.

Regarding common awareness, the OPAS project aims to develop an alert product for sulphur dioxide, which is often used as a proxy for the presence of volcanic ash in the atmosphere. Currently, the Volcanic Ash Advisory Centers do not need SO_2 information. However, there are discussions to include it in ICAO considerations around volcanic ash alerting for aviation.

Another aspect of MET-related situational awareness relates to the information available to pilots, which EASA has been addressing in recent years. A strategy paper on weather information for pilots was published in March 2018 (EASA, 2018a), and lists nine, non-binding recommendations to be taken forward by the "Best intervention strategy" proposal. EASA also published the results of a survey on the use of electronic flight bags and installed weather applications to facilitate in-flight weather updates to the cockpit by the airlines (EASA, 2018b). All survey respondents had EFBs, with about half having weather applications for pre-flight briefings, while for in-flight briefing, including in-flight updates, only 15% of respondents had them included in EFBs (whilst many planned to include some functionalities in the next five years).

Currently, the trend in MET research is focused on ensemble prediction systems. Thus, in the next 5-10 years we should expect MET products to be realised as ensembles, providing measures of uncertainty in different atmospheric variables. A long-term educational and communication effort should be undertaken so that ATM stakeholders are prepared to understand and interpret these new MET products, in order to incorporate them into their decision-making processes, taking advantage of better information. The Engage catalyst fund project, "PSA-Met", and the Engage PhD, "Stormy", both address ensemble forecasts and the development of decision-support tools for stochastic storm avoidance, using different methods for storm evolution prediction.

The climate impacts of aviation, comprise more than CO2 impacts – such as NOx, ozone and contrails. Aviation emissions impact the climate and more research is needed to establish these quantitative effects and whether there is (further) potential for mitigation actions. The Aviation and Global Atmosphere report by the Intergovernmental Panel on Climate Change lists the different components of aviation emissions. There is consensus on the direction of impact of these components, but there is still no consensus on their magnitude. An interesting point, is that some regions of the atmosphere are more sensitive to certain types of emissions than others, and negative effects can be propagated to larger regions and last longer. The climate impact of non-CO2 emissions depends on the time and position of aircraft, actual weather conditions (processes, transport pathways, temperature and humidity) and background (emissions) concentrations. This points to the importance of having 4D (weather-like) forecasts of environmental impact, which could enable trajectory planning to account for these environmental impacts.

MET products can be classified along two dimensions: spatial and temporal resolution. In terms of spatial resolution, forecasts can be cast as global (resolution of about 1 degree), limited-area models (covering regions such as Europe, resolution in terms of tens of kilometres), and of very high-resolution (smaller areas, such as terminal manoeuvring areas, resolution of hundreds of metres). In terms of temporal resolution, there are long- (about 1 week), medium- (about 1 day), short- (about 3-6 hours), and very short-range (about 1 hour) forecasts. Both the temporal and spatial resolution are important depending on the stakeholder application. For example, the NM is interested in medium-range / limited-area forecasts; dispatchers, in short-range / limited areas; pilots/controllers, in very short-range / very high resolution when facing storms; airports, in very short-range / very high-resolution, etc.

The higher the resolution, the forecast becomes more challenging. NWPs alone are not sufficient for this type of product, and call for data assimilation of the observed values of varied atmospheric characteristics (e.g. lightning, deep convection). *In situ* sensors and sensor networks that collect and deliver information for forecasting are needed. The aggregation of different sources of data for blended ensemble forecasts in the very high-resolution, very short-range scales seems to be the trend for the next 10 years.

The Engage catalyst fund project, "CARGO", is studying the use of low cost GNSS receivers, and lightning detectors, to develop nowcasting forecasts for convection at very short range / very high resolution. Input from different sensors will be fed into a neural network model. The Engage PhD, "IWA", is evaluating the impact of weather conditions on route planning in the TMA. Probabilistic models are to be applied on the weather data, and mathematical tools to be used to develop a prototype for decision-making.

Often-cited barriers to the progress of MET and MET/ATM research are the inadequacy of research funding available to the MET offices (only partial funding), and fragmented provision of MET products for aviation (coupled with regulatory and sovereignty matters). Further important barriers revolve around the trust the ATM users have in available MET products, and not particularly high usage in operational decision-making. This points to the two underlying issues:

1. fitness of purpose of MET products (e.g. medium-range, limited-area forecasts are of little practical use to airport tower supervisors, while the very high-resolution, very short-range forecasts would be more easily included in this decision-making process);
2. ATM stakeholder knowledge of the available MET products, especially on the characteristics and meaning of MET products being developed.

The following have been identified as *example* ideas for potential further exploration:

1. Very high-resolution, very short-range forecasts using numerical weather prediction models and observational data assimilation;
2. Quantifying the sensitivity of operational processes to MET uncertainty, comparing these with other sources of uncertainty;
3. Incorporation of ensemble weather information into decision-support tools, adapted for different ATM stakeholders;
4. Accurate prediction of weather conditions (e.g. visibility, glide-path wind) influencing airport arrival and departure operations;
5. Consolidation of climate risk assessment methodologies for airports;
6. Creating a climate forecast 'baseline' for aviation from the IPCC UN panel report;
7. Developing quality EU-wide weather information in the tactical air traffic control context (an integrated, pre-tactical EU-wide picture is beginning to be developed);
8. Forecasters and end-users (e.g. controllers and pilots) co-developing products that are easy to interpret in terms of the impact weather will have on such users (e.g. airspace, flights);
9. Transferring knowledge to end-users (e.g. controllers and pilots), reflecting that the state of the art in modelling is moving towards probabilistic approaches;
10. Producing an EU-wide, one-stop repository of MET data, addressing data harmonisation and scoping the archiving of such data.

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