SESAR Engage KTN – catalyst fund project final technical report

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Consortium partners:	METSAFE
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1 Abstract and executive summary

1.1 Abstract

The MET Enhanced ATFCM R&D initiative has been launched by MetSafe and France Aviation Civile Services. This one-year project addressed the provision of accurate convection information for ATFCM activities, with the 6 hours' time-horizon as a target. The research approach focused on both technical and operational aspects, as needs identification and concept of operations, assessment of convection models, design and deployment of a model-based R&D convection product. Up-to-date and accurate European thunderstorm forecasts at +6 hours horizon built from on a multi weather model algorithm have been delivered as a SWIM webservice for Reims Upper Area Control Centre during technical and operational validation trials. Initial project objectives have been fulfilled: Reims air traffic controllers and FMP operators greatly improved their weather situational awareness and would have been likely to take ATCFM measures based on received information.

1.2 Executive summary

Adverse weather conditions are the first cause of traffic delay: the European Network Manager reported 4,8 million minutes of En-route weather delay in 2018, corresponding to 25% of total delayed En-route air traffic.

Forecasting weather hazards with 1-hour horizon and its extension to 3-hours horizon are currently covered by aeronautical existing forecast products, while strong unreliability on usual meteorological (MET) products can be observed beyond this period. The air traffic control declares the ability to absorb the expected traffic with 6 hours of anticipation, therefore it is necessary to consider accurate and high-precision meteorological data for a better decision-making. Expected benefits are an increase of the safety level and an improvement of the overall ATM system performance thanks to a more precise departure slot allocation (Calculated Take-Off Times or CTOTs).

France Aviation Civile Services (FRACS) and MetSafe addressed the "Thematic challenge 3: Efficient provision and use of meteorological information in ATM" with the design and validation of a R&D convection product dedicated to enhanced ATFCM, with the 6 hours' time-horizon as a target.

Two complementary domains of expertise were combined through this MET Enhanced ATFCM (Air Traffic Flow and Capacity Management) project. FRACS, the coordinator, brought its experience on air traffic control operations, concept design and operational validation through a collaboration with Reims Upper Area Centre (UAC). As a MET expert, MetSafe mastered the model-based convection product design and technical validation activities.

The research plan and associated activities were based on a pragmatic and agile approach:

- Step 1: Operational context description and analysis
- Step 2: Model-based convection product definition
- Step 3: Algorithm and SWIM webservice design
- Step 4: Technical and operational validation

The designed MET Enhanced ATFCM algorithm considers several convection parameters from different weather models and provided convection information, which has been integrated into a "general information" screen for Flow Management Positions and displayed through an HMI developed by Reims UAC.

In a traffic shutdown context due to the COVID-19 crisis, several technical and operational validation sessions have been led between May and June 2020, in collaboration with 18 air traffic controllers at

Reims UAC. From an operational point of view, the very first objective of increasing weather situational awareness has been fulfilled with the MET Enhanced ATFCM tool. Indeed, accurate, updated and precise convection information was delivered continuously to Flow Management operators in phase with their ATFCM time-horizon. The results of operational validation sessions highlighted also the pertinence of the tool for the definition of ATFCM measures from 6 hours to 3 hours of anticipation based on convective information. Other results concerned the false alarm and no-detection events, which have to be further addressed from a technical but also operational point of view.

Considering the outputs and positive results of this R&D project, the integration of the tool in an industrial and operational product can be easily envisaged. The convection product will be integrated into the Vigiaero algorithm developed by MetSafe to address the weather impact assessment, without ATM flows. Vigiaero will be made available to Reims UAC during the summer to pursue validation activities.

Additional improvements of the MET Enhanced ATFCM tool can be developed in the future, as the integration of traffic flows and the provision of weather impact on ATM operations. Findings of the current project and future Weather Impact Prediction on ATM (WIPA) activities (the latter launched by MetSafe and FRACS as a second wave Engage catalyst fund project) will then contribute to SESAR actions related to MET and SWIM development.

2 Overview of catalyst project

2.1 Operational/technical context

Adverse weather conditions are the first cause of traffic delay: the European Network Manager reported 4,8 million minutes of En-route weather delay in 2018, corresponding to 25% of total delayed En-route air traffic.

For an air traffic controller, severe weather events as thunderstorms cause an increase of traffic complexity due to flights trajectory changes and flights conflicts to manage with the pilots and adjacent sectors. It is then necessary for them to prepare weather situations by considering accurate and high-precision meteorological data to manage the expected traffic with 6 hours of anticipation, at least. Benefits are the improvement of the decision-making process for ATCFM regulations and the increase of the safety level, especially in congested airspaces. And by extension, the 6-hour time-horizon convection information would help to the improvement of the overall ATM system performance while contributing to a more precise departure slot allocation (Calculated Take-Off Times or CTOTs).

In addition to that, the Flow Management Position relies only on regulated meteorological tools provided by aeronautical forecasters as SIGMETs. The SIGMET or Significant Meteorological Information does not provide sufficient geographical accuracy to take relevant decisions at the scale of an area control centre and can be issued late; it is notoriously imprecise and can lead to improper decisions. Therefore, the air traffic control unit does not have the means to assess precisely the impact of hazardous weather (convection) on the operations, with anticipation.

As an answer to these challenges, the MET Enhanced ATFCM product has been designed to provide up-to-date and accurate European thunderstorms forecast at +6 hours horizon based on a multi weather model. The algorithm considered first a numerical model and a parameter. Then, an extension to various models and several parameters has been taken into account. The embedded numerical weather models with their associated parameters are AROME (MétéoFrance), COSMO

(Deutscher Wetterdienst) and Global Forecast System - GFS (National Centers for Environmental Prediction from the NOAA).

The information has been delivered as a SWIM webservice for Reims Upper Area Control Centre (UAC) air traffic controllers and integrated into an HMI developed by Reims centre. Convective weather impact information has been displayed into a "general information" screen for Flow Management Positions. During May and June 2020, several technical and operational validation sessions with 18 Flow Management operators have been led to tailor and validate the tool benefits for ATFCM needs.

2.2 Project scope and objectives

With the aim to increase weather situational awareness for a better ATFCM decision-making process, the project scope was to design and validate with air traffic controllers a R&D convection tool delivering accurate weather information, with the 6-hour time-horizon as a target.

To do so, the main steps of the research plan consisted in:

- **Step 1: Operational context description and analysis**, to identify the operational needs and define a high-level concept of operations;
- **Step 2: Model-based convection product definition**, with the following goals:
    - Identify the necessary weather models and parameters available to evaluate convection phenomena
    - Explore the possibility of combining several models;
- **Step 3: Algorithm and SWIM webservice design**, with the creation of a model-based R&D convection algorithm considering the 6-hour time horizon and the tool deployment as a SWIM (System Wide Information Management) webservice;
- **Step 4: Technical and operational validation**

Technical and operational validation sessions have been performed with air traffic controllers, with the following validation objectives:

- to provide accurate and up-to-date convection information for ATFCM purposes; and,
- to assess the upholding or improvement of capacity and performance levels when accurate and up-to-date convection information is provided.

2.3 Research carried out

2.3.1 Operational needs collection and high-level concept of operations design

The project involved air traffic controllers (ATCO) from Reims Upper Area Centre (UAC) since the beginning of the activities to better address operational needs and design an R&D tool that would suit their needs. Reims UAC was an ideal candidate, as the en-route centre is located at the heart of the "core area", which is the busiest European traffic zone including Benelux, North-East France, Switzerland, the Netherlands and West Germany.

Several meetings and the collection of users needs through a questionnaire highlighted the added-value the MET-Enhanced ATFCM tool would bring to the Air Traffic Flow and Capacity Management (ATFCM) decision-making process and the operations. Currently, a lack of accurate and updated information within the ATFCM tactical planning timeframe from regulated or usual weather products used by the air traffic control is observed. Flow Management operators collect weather information from various sources and from other centres in an attempt to build a comprehensive weather situational awareness at least with 6 hours of anticipation, especially regarding convection impact on the air traffic. Depending on the impact severity, a traffic capacity reduction or a regulation could be applied. It is then expected that the provision of accurate and updated convection information at a 6-hour time horizon would improve the ATFCM process and measures, as it would ease the weather information collection process for ATCOs and impact assessment.

2.3.2 Model-based convection product definition

Convection parameters selection

The creation of a convection forecast product dedicated to ATFCM begins with the characterization of the physical parameters causing violent weather phenomena and having a direct or indirect impact on aviation, as thunderstorms, hail, high winds, shears, turbulence.

Convection has the most significant impact on air traffic operations. This transfer of energy within the atmosphere occurs constantly. To detect convection through a numerical model under so-called adiabatic conditions, the state of air instability has to be described, usually by a vertical thermal gradient.

All global weather models can provide wind temperature and humidity information on several pressure levels. These baseline data may be useful in determining convective potentials, but some models also provide interesting clues to exploit.

The first step then was to identify the parameters that are useful for convection prediction:

- The CAPE (Convective Available Potential Energy) parameter measures the potential energy available for a storm system. The higher this value, the greater the intensity of the phenomenon. From this parameter are deduced other indicators such as MUCAPE (Most Unstable CAPE), SBCAPE (CAPE brought back to ground level), MLCAPE (CAPE in the mixing layer of the atmosphere);
- The LI (Lifted Index) provides an indication of air stability from temperature and humidity data;
- The CIN (Convective Inhibition) represents convective inhibition energy. If this value is high, it means that it takes a lot of energy for an air particle to exceed its free convection level and initiate a stormy process. On the other hand, if this convection begins, then CIN becomes an indicator of the potential power of the storm. As for CAPE, parameters can derivate from the CIN: MUCIN, SBCIN and MLCIN;
- The SRH (Storm Relative Helicity) or relative helicity may indicate potential for tornadoes and strong wind shears;
- SDI (Supercell Detection Index) uses radar reflectivity to detect convective supercells.

Other parameters may give indirect indications:

- The amount of precipitable water indicates the possibility of hail formation;
- Cloud cover, and in particular the presence of convective clouds, can be used as a first filter to identify areas at risk.

Weather models selection

Following parameters identification, the choice of models delivering those parameters is the next step. There are two large model families: global models that cover the surface of the globe, and regional models with a more limited area but with better accuracy. For the project, an additional requirement was to select free available models (opendata).

Technically, all current weather models can be considered in the process of the convection product development with more or less weight. Indeed, it is very common to find at least information on atmospheric instability (CAPE). For the MET-enhanced ATFCM product, the goal was to use the specific features of the different types of global and regional models as a weather forecaster could do.

The selection criteria were the following:

- [Criterion 1] – Presence of one or more parameters of instability;
- [Criterion 2] – One or more parameters arising directly from the presence of convection;
- [Criterion 3] – Coverage on Europe (our test area), more specifically REIMS UAC;
- [Criterion 4] – Opendata availability.

When considering all these criteria, the selected models were:

- Global Forecast System – GFS, a widely used American global model. It offers the parameters of CAPE, LI as well as a convective rain forecast variable, and covers Criterion 1 and 4;
- ICON-EU, a German model limited to Europe. It has a significant time variable and provides supercell probability parameters. This model covers criteria 1, 2, 3 and 4;
- COSMO, another German model, suited to high resolution and regional forecast. Whereas its coverage is limited, it offers a good accuracy and can detect local phenomena;
- AROME, the French high-resolution model which contains instability settings. It has been used mainly to crosscheck the forecast with a predictive variable of the satellite infrared image.

The ECMWF CEP model from the European Centre for Medium-Range Weather Forecasts has not been selected: it presents many variables around thunderstorms but remains difficult to access.

Identification of observation sources for validation purposes

The impact of convection (storms, strong wind, lightning) is most often observed rather than convection itself. Therefore, the best way to determine a convection zone is to watch where thunderstorms occur. To observe convective clouds causing thunderstorms, radars and weather satellites information can be used. The advantage of the satellite is that the field of vision is wider than the radar one, for which a large fleet would be necessary to obtain a full coverage. On the other hand, the radar is more accurate. The ideal situation then was to cross-reference the two sources of information. RDT (Rapidly Developing Thunderstorm) is a specific product from satellite treatment to detect thunderstorms. Having access to French satellite and radar products via MétéoFrance, both have been used.

To validate the presence of severe thunderstorms, the presence of lightning is also taken into account. The lightning observation data has the advantage of not presenting a possibility of false alarm.

In short, three different sources of observation of phenomena directly related to the impact of the convection have been identified: satellite convection, radar convection and lightning detection.

Confidence index definition

The MET Enhanced ATFCM convection forecast integrates data from multiple models simultaneously, while the various weather services offer the convection parameters associated to their algorithms. In addition, some regional models are better able to predict meso-scale phenomena such as thunderstorms thanks to their finer mesh. As a consequence, it was necessary to introduce a confidence index to cross-reference the different sources.

The final MET Enhanced ATFCM product can be seen as a combination of "layers", each layer being defined by a set of features [model, parameter, threshold] (represented by the little black squares in Figure 1). The reference is from the ICON EU (European model), to which the coefficient 1 is applied. Then, with a trial-and-error approach, the other layers are defined: if the resolution is improved, the layer gets a better coefficient, and vice versa. We considered that this coefficient is increased in the case of a regional model. Weather observations have also been used to better define the layers coefficients, and 5 reference days were considered to tune the coefficients over France.

The final convection product is built from the various layers (see the combination of circles in Figure 1), and the confidence index set for the final weather phenomenon (polygon) is from the superposition and intersection of all the layers. Then, in the case where several models observe the same phenomenon, a higher probability coefficient / confidence index is applied. The confidence index therefore reflects a consensus of models and give more weight to the higher resolution models.

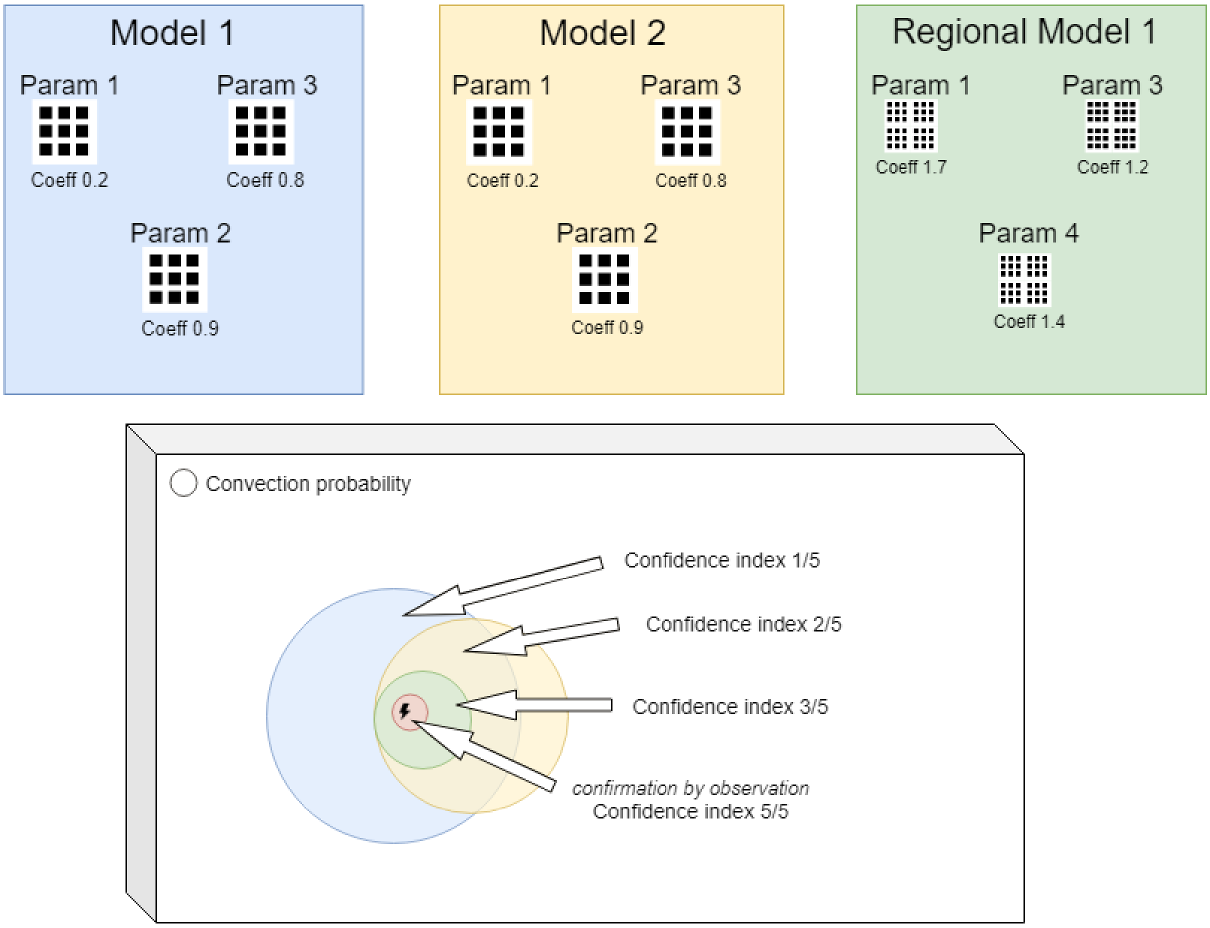


Figure 1: Use of different models to define a confidence index

2.3.3 Architecture, algorithm and SWIM webservice

To support the data and algorithm management process, a cloud-based IT infrastructure has been deployed at the beginning of the project.

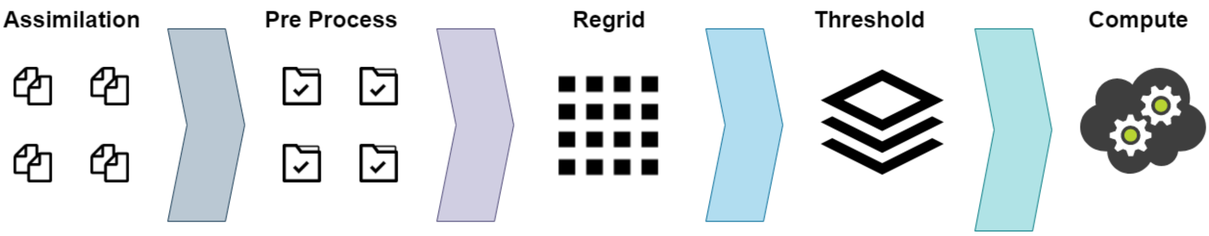


Figure 2: Functional decomposition of the multi model convection forecast algorithm

From gridded data to polygons: dynamic threshold

Gridded data from the weather models are raw 4-dimensional data representing the values in the form of dots. In order to determine the relevance of the convection parameters, a series of transformations are performed to create objects in the form of polygons that are compared to various observation data sources, as satellite, radar and lightning.

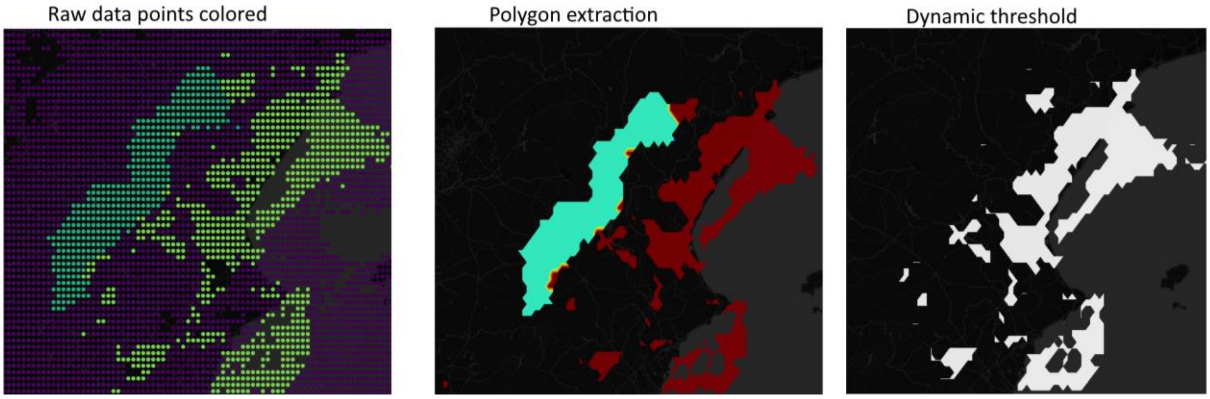


Figure 3: Threshold steps based on a raw significant weather data from the ICON-EU model

The dynamic threshold allows the fine-tuning of the parameters settings tolerances necessary for the development of the product. All of these transformations have been made from the Matplotlib and Xarray tools.

Computing

The infrastructure supports the process of ingestion of the different models and the algorithm to deliver the convection forecast with the confidence index and the access point through a SWIM webservice. The SWIM Webservice has been defined based on latest international standards for yellow profile.

One of the main technical challenges was the orchestration of asynchronous and heterogeneous weather model. The data payload to be ingested (in the Assimilation phase) represents an amount of 20 Go per day. Even at a low TRL, the IT infrastructure needs to be resilient to be able to cope with various downgraded cases regarding availability of weather data.

For the definition of the algorithm, the following iterative approach has been adopted:

- Iterative analysis of relevant parameters and models previously identified and association of a threshold and a weighting in the algorithm;

The convection models and parameters selected in the algorithm were:

- ICON / Significant weather at the time of observation (ww);
- COSMO / Significant weather at the time of observation (ww);
- GFS / Convective precipitation (cprat);
- AROME (1.3km) / Infrared simulation (btmp);
- AROME (1.3km) / Maximum radar intensity (refzr).

For each parameter, a setting is defined: a threshold and a weighting have been applied to different levels.

In particular, the algorithm considered the following:

Model	Parameter	Coefficient/Weighting
icon-eu	Ww - Significant weather at the time of observation	8
cosmo-d2	Ww - Significant weather at the time of observation	9
arome13	Refzr - Maximum radar intensity	8
gfs	Cprat - Convective precipitation	7
arome13	Btmp - Infrared simulation	8

Table 1: Parameters considered in the algorithm

- Design of first laboratory product;
- Review of parameters and models settings;
- Elaboration of convection product with confidence index.

SWIM API

The SWIM API has been deployed in early May 2020. The provision of convection data has been made from an interface http(s) and the protocol WFS (Web Feature Service) which allows a simplified (possibility of geoJSON streams) and standardized access. The selected data model was built from the AIM Information Reference Model (available at http://airm.aero/, see Annex 5.2).

Hence, the MET Enhanced ATFCM convection product is delivered through a SWIM webservice (information available through an http access) and used by the HMI to be displayed. To do so, the Reims UAC ATCOs from the DSNA innovation team developed a web HMI to display the convection forecast on an ATM background suited to their working methods.

2.3.4 Technical and operational validation activities

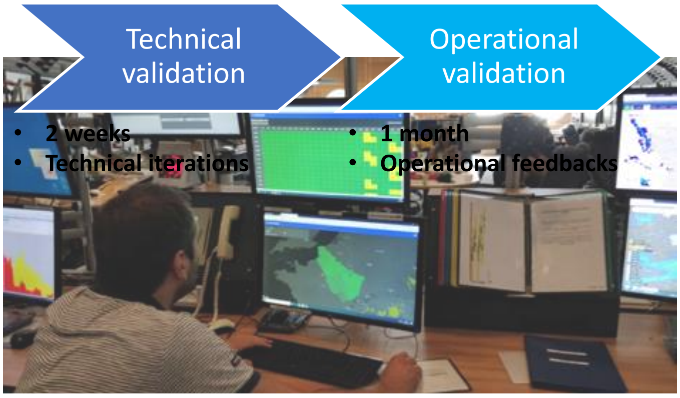


Figure 4: Technical and operational validation methodology

Technical and operational validation sessions were carried over 2 months (May and June 2020), in order to tailor the tool and validate the MET Enhanced ATFCM concept.

A briefing has been performed with Reims UAC before the validation campaign to present the methodology and prepare the validation sessions.

Technical validation

To assess the quality of provided information during the technical validation, the approach was to quantify false alarms and no-detection events. A “sandbox” (repository of historical data) has been used to identify periods and days characterized by lightning. The aim was to superpose and compare what is providing by the MET Enhanced ATFCM tool (lightning observation) and information provided by the SIGMETs, and other observation sources: radar - ASPOC (MétéoFrance), satellite - RDT (MétéoFrance) and lightning detection – Météorage.

In order to develop and adjust the settings, several iterations have been carried out during the technical validation phase:

- Observed data from identified source were visualized and compared with the MET-enhanced ATFCM forecast;
- In case of non-detection or false alarms, the data of the different parameters constituting the weather models are analyzed in order to adjust the settings if necessary;
- The product manufacturing process is restarted and the obtained forecast result is compared again with the observation data.

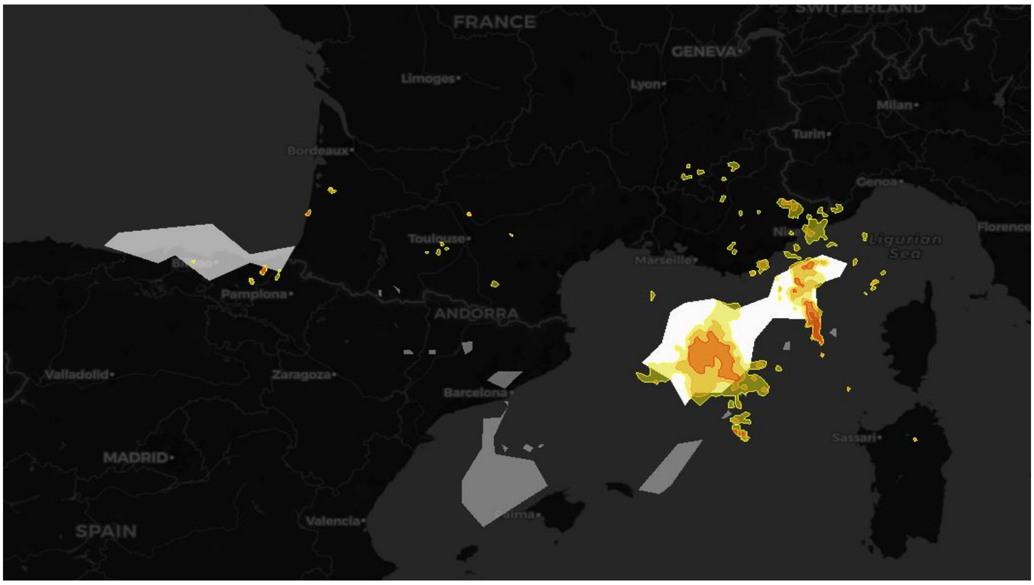


Figure 5: Post analysis – Convection forecast (in grey) versus radar observation of convection – Mediterranean episode

The tools used were product developments within the JupyterLab utility [ref iPython] as well as a proprietary web interface at MetSafe to view SWIM products.

During the month of May 2020, the technical validation focused on the analysis of three significant days:

- May 10th: Very dynamic spring situation

Widespread and particularly active disturbance over France linked to several phenomena are observed. Overall, it is due to the clash of air masses between a cold front that touches the country and warm low-layer air.

There is a non-detection of storm cells, one of which generated a SIGMET and whose impact on aviation was significant.

- May 23rd: Passage of a cold front through France

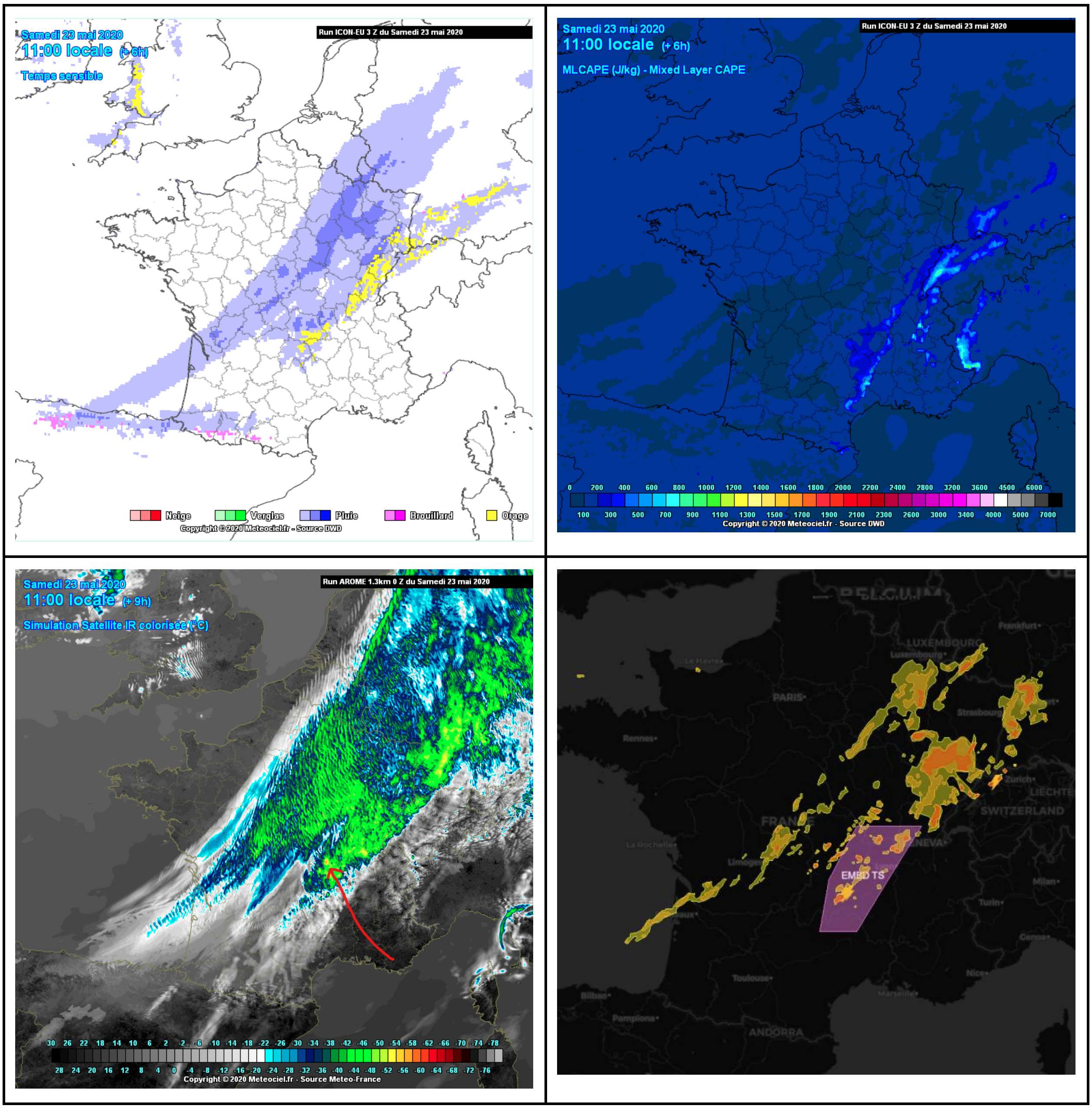


Figure 6: Technical validation and post-analysis example

The post-analysis showed that CAPE is a good indicator but is lagging behind the real situation. CAPE indicates a potential, which is consumed at the time thunderstorms are present.

Infrared image forecasting allowed the observation of colder-than-normal cloud peaks, which corresponds to the presence of cumulonimbus clouds.

- May 27th: Development of convective zones over the Pyrenees and Spain

This very localized situation was difficult to anticipate precisely. The first iteration of the convection forecast product showed this kind of case weaknesses. Observed storm zones (lightning detection, circled in red) were not anticipated by the first iteration of the MET Enhanced ATFCM product (white polygons at the top right):

Figure 7: May 27th, 2020 - Observed storm zones (lightning detection, circled in red) not anticipated by the first iteration of the MET-enhanced ATFCM product

After regular observation of different situations as described previously, it was possible to highlight the gaps in the 1st iteration of the product. Cases of non-detection were frequent and the risk of false alarms was high. This has been managed by an adjustment of the parameters threshold, which caused some false alarm events (see section 2.4 Results). In addition, the confidence index could only be produced from several models, as it gives an indication about models' consensus.

Operational validation methodology

The operational validation was based on an online qualitative questionnaire to fill out and collection of raw Flow Management operators' feedback in order to assess the operational interest and benefits of the tool. The questionnaire addressed the following:

- Weather situational awareness
- Quality and accuracy of provided information
- FMP activities and ability to define ATFCM measures
- Comparison with information provided in the context of the Network Manager Cross Border Trials

The post-analysis has been done in collaboration with Reims UAC. 8 reference days from the various validation sessions have been selected, based on Reims UAC operations and observed weather situations:

Journée	Qualification	SIGMET	Commentaire	Commentaire
03-juin-20	Medium/severe	Yes	Reference for non-detection	Major Lightning bar Non detected
04-juin-20	Medium/severe	No	Reference for false alarm	
08-juin-20	Light	No	Phenomena non detected by convection forecast and NM CBT	
10-juin-20	Light	No	Reims on the edge of a majhor phenomena in central Europe	Diagnostic instability
11-juin-20	Light	No	Reference for isolated cell (non-detection)	
16-juin-20	Medium/severe	No!		No SIGMET on Reims
17-juin-20	severe	Yes	Reference for isolated cell (non-detection)	
19-juin-20	Light		Instability of diagnosis	

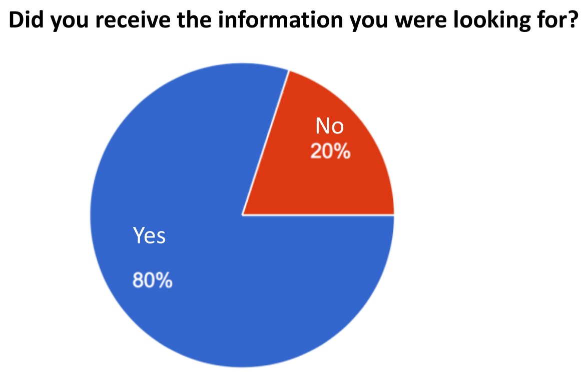
Figure 8: Reference days selected for post-validation analysis

2.4 Results

Operational validation

Questionnaire results and raw feedbacks have been collected from the operational validation sessions (14 sessions in total). Initially, questionnaires were supposed to be filled out after each validation session, and evolved towards detailed ATCOs reports, especially in the case of false alarm and non-detection events. The following conclusions have been validated with Reims UAC ATCOs on June 30th.

ATCOs were expecting convection information with location, size, height of storms cells, and impact on sectors. According to the provided information, results show that the first objective of providing accurate and up-to-date convection information for ATFCM purposes have been fulfilled:



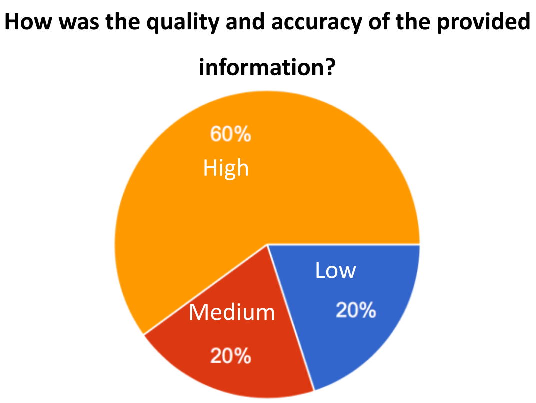
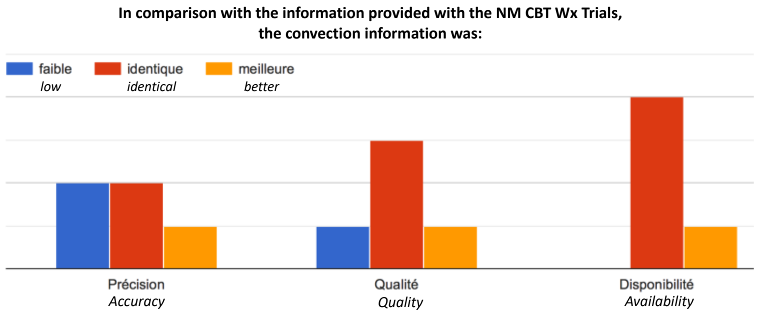


Figure 9: Validation results - reception and accuracy of information

One of the added value of the tool and its HMI (developed by Reims UAC) compared to usual MET products are the assessment of convection impact on ATC sectors, the information accuracy and its readability. The results showed the importance of the HMI for the display and use of the information by the ATCOs. For example, the weather awareness would have been improved with the consideration of the ATC room configuration (elementary and collapsed sectors), the display of information on adjacent sectors, the consideration of the convection impact on traffic flows to better assess the impact severity and the extension of the forecast up to 24 hours (and even 36 hours).

In terms of performance and ATFCM improvement, accurate and precise information was available and in phase with ATCFM horizons (H-6 hours and H-3 hours). It should be noted that the validation sessions have been executed in a post-COVID recovery situation with very low traffic (around 100 flights per day instead of 3000 flights per day), any ATFCM measures have been defined, and due to the validation context, and real tactical measure considering the tool information would have been taken. These considerations limited the performance and capacity benefits assessment with the use of the tool. Nevertheless, the Flow Management operators stated that they would be able to take appropriate tactical measures considering the provided information.

At the time of the validation sessions, Reims UAC began to perform Network Manager Weather Cross Border Trials with other European centres. In this context, and during the summer, the NM coordinates the provision of meteorological information from EUMETNET to several air navigation service providers (ANSPs) and aircraft operators (AOs). It was then an opportunity to compare this reference with the outputs of the MET Enhanced ATFCM tool.



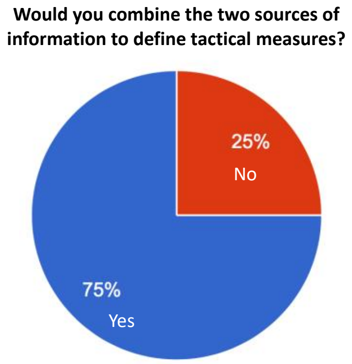


Figure 10: Validation results – Comparison with NM CBT Wx Trials

In terms of future ATFCM processes, the Flow Management operators could consider both sources of information, as they are complementary. Further synergies will be investigated with NM CBT actors.

Forecast instability

An unforeseen result reported by ATCOs was the instability of the forecast when based on one model only. Instability means a significant change of the forecast between two consecutive weather forecast, that might impact the decision making process for ATFCM.

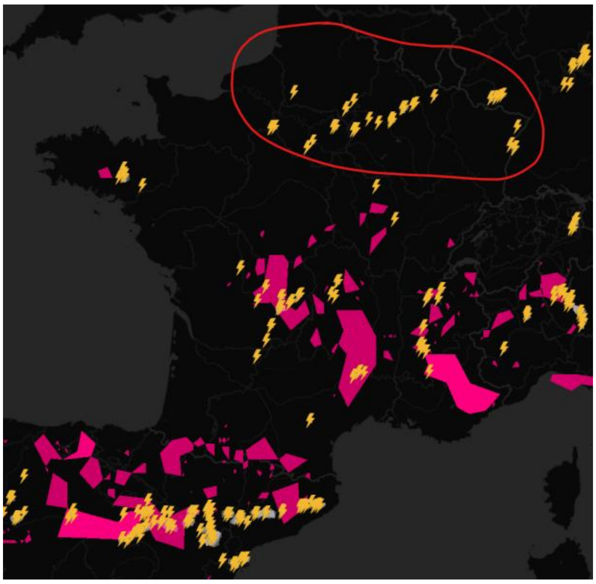
Theoretically, multimodel/multiparameters convection forecast should have a better stability, as the error will be averaged. This is valid at the Flight Information Region (FIR) scale.

At the end of the project, this issue has not been resolved. Further work is needed to address this issue and quantify the instability.

False alarm / Non-detection events

The operational validation activities in June concentrated also on the false alarm/non detection events subject analysis.

- June 3rd of June: reference day for non-detection event, widespread thunderstorms over Western Europe



The convection forecast showed several non-detection events in the north of France and especially in Reims UAC area. The air traffic controllers identified this non-detection and indicated some changes in aircraft trajectories despite the very limited traffic.

Figure 11: Convection information provided by the MET-enhanced ATFCM product (in pink) vs non-detected thunderstorms in the northern part of France

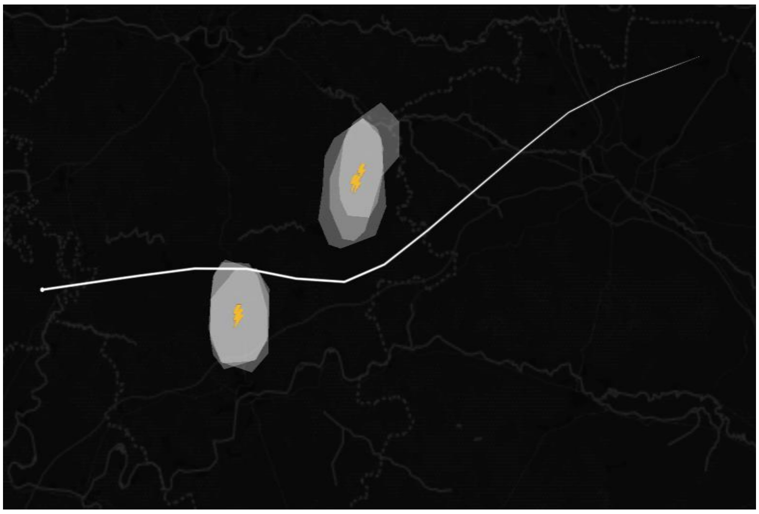


Figure 12: Aircraft avoiding storm cells in the non-detected thunderstorms area

- June 4th: reference day for false alarm event

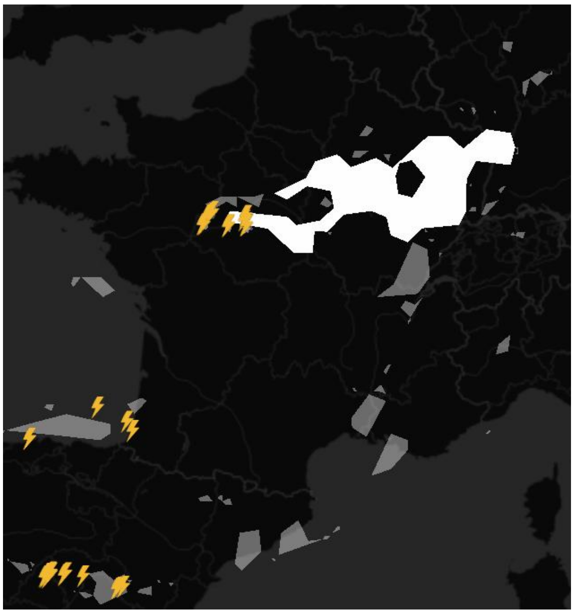


Figure 13: Convection forecast (in grey) vs real-time observation - False alarm in the North of France

For both days, the MET-enhanced ATFCM product settings have been adjusted for a better forecast.

As anticipated, reducing the non-detection phenomenon observed on the 3rd of June by adjusting the settings introduced some false alarm. On the other hand, reducing the false alarm on the 4th of June introduced some non-detection events the following days.

This raised the issue of False alarm / Non-Detection balance that was debated between the ATCOs during the validation debriefing. The challenge is to define what would be more acceptable from an ATFCM point of view between false alarm and non-detection.

On one side, the current weather system for ATFCM is more of a non-detection nature, because of the lack of accurate information and tools. The current ATC system therefore handles already non-detection events. On the other side, if the SIGMET is considered as a reference product, it favors false alarm events as the geographical area of SIGMET is usually more extended than the weather phenomena.

So this challenge is both technical and operational, as ATCOs will build their future concept of operations based on the quality of the convection forecast. More reference days and experience are needed to move forward on this issue.

3 Conclusions, next steps and lessons learned

3.1 Conclusions

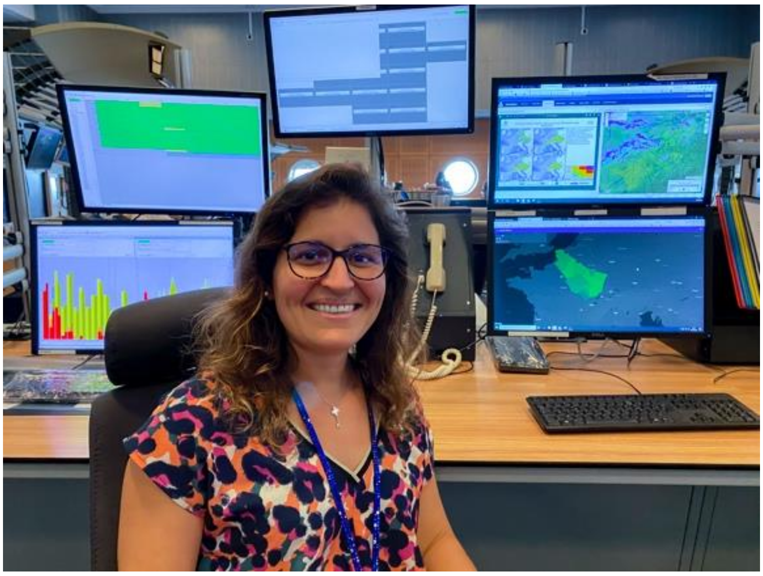


Figure 14: MET enhanced ATFCM tool at Reims UAC

Project and validation objectives have been fully fulfilled: in terms of performance and ATFCM improvement, accurate and precise information was available and in phase with ATCFM horizons (H-6 hours and H-3 hours), and the Flow Management operators stated that they would be able to take appropriate tactical measures considering the provided information.

Even if Flow Management operators are used to deal with uncertainty due to their specific role in the ATFCM process, such a MET Enhanced ATFCM tool would highly benefit in their activities, as it contributes to the improvement of weather situational awareness for a better decision-making process.

Therefore, technical and operational validation activities highlighted the mismatch between the probabilistic essence of meteorology and weather forecasts with air traffic control activities.

The technical validation showed that the CAPE parameter (or any single parameter) is not sufficient to assess the presence of convection for ATFCM. In addition, very localized meteorological phenomena cannot be detected because of the limited geographical resolution when using a unique model (maximum resolution is 1.3 km). Validations led in June confirmed that a multimodel approach combined with an appropriate parameters settings fine-tuning allows to deliver a convection forecast which is not perfect, but is good enough for ATFCM purposes, despite the limited bad weather occurrences. However, more weather situations and validation sessions situations are needed to validate the settings of the convection forecast for a fully operational product.

The confidence index itself is a relevant indication as it informs of a models' consensus, but it should be hidden to the controller as he cannot process it at the level of each convection cell. The perfect forecast does not exist today, and the dilemma related to the false alarm or non-detection events has still to be addressed from technical and operational sides.

In terms of information management and display for an efficient use by ATCOs, the convection forecast needs to be translated into an ATM impact.

Here below is an example of MET information provided to ATCOs:

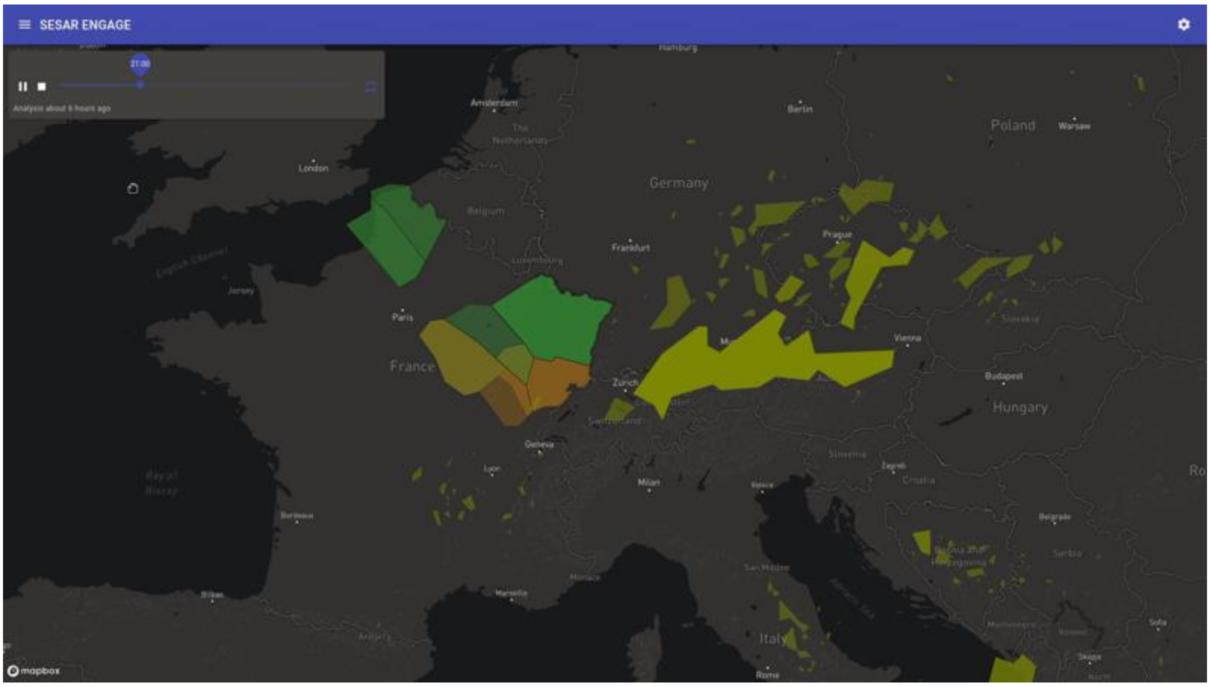


Figure 15: Weather information provided to ATCOs from the MET Enhanced ATFCM webservice

The visualisation of meteorological layer was acceptable for an operational validation context, but not for a day-to-day operational system.

3.2 Next steps

The following areas for improvement and next steps have been identified to reinforce and upgrade the MET Enhanced ATFCM product:

- Integration of the convection tool in an industrial product

Considering the outputs and positive results of this R&D project, the integration of the tool in an industrial and operational product can be easily envisaged. The convection product will be integrated into the Vigiaero algorithm developed by MetSafe to address the weather impact assessment, without ATM flows. The weather information is gradually transformed into actionable data, allowing efficient decision-making.

Vigiaero will be made available to Reims UAC during the summer to pursue validation activities beyond the current project. A roadmap for industrialisation will be defined in parallel.

- Introduction of ATM flows for impact assessment

The Consortium will launch the WIPA – Weather Impact Prediction tool for ATFCM, a SESAR Engage KTN project. The tool will provide weather hazards impact information on air traffic control sectors by intervals of 1 hour over the ATFCM horizon (from D-day to D-day + 3 hours). To provide an impact analysis, WIPA will consider the convection information as an input provided by the MET Enhanced ATFCM product, additional MET information (as turbulences, icing and SIGMET), and ATM flows.

- Other areas for improvement:
    - Necessary automation of post-operations analysis;

- Monitoring of the convection forecast stability, which is an issue that may impact decision-making;
- Lead time extension to +24 hours: the ATCOs expressed their interest for an extension of the forecast lead-time in relation with ATFCM process;
- Integration of observational data over the 1-hour to 3-hour horizon into the product, to refine the algorithm and increase the confidence index.

3.3 Lessons learned

The experience gained through the project leads to the following:

- The SESAR Engage context is well fitted for fast innovation and the design of new ATM solutions.

Indeed, the one-year duration format combined with the agility of SMEs and collaboration with operational experts foster new ideas and quick iterative developments.

- A special attention should be observed for the planning of validation sessions.

In our case, the most interesting weather situations (convective phenomenon) occur during the summer in Europe, mostly in July and August. The one-year project began in May, this implied limited occurrences of bad weather as the validation sessions are usually performed at the end of the project.

- Collaboration with ATC is crucial for the development of innovative operational tools.

The innovation should start in the ATC room, with reduced multi-disciplinary teams. Our links with Reims UAC, the integration of ATCOs in the project and their early feedbacks fasten considerably the development and implementation process.

- A cloud and SWIM-based solution is suitable for ATM operations

The advantages of designing a cloud-based solution were highlighted during to the COVID-19 lockdown. The SWIM webservices allow a resilience capability as a total remote design and fast remote deployment in the ATC room within weeks have been applied for the MET Enhanced ATFCM tool. Only the post-validation results conclusions and final debriefing with ATCOs has been done in person, at Reims UAC.

4 References

4.1 Project outputs

Needs and perimeter definition outputs

- MET Enhanced ATFCM Users needs summary
- Inventory of state-of-the art methods / Literature review

Research and Development outputs

Tool development

- MET-enhanced ATFCM algorithm
- Associated web service

Validation sessions

- Approach and methodology defined with Reims UAC air traffic controllers
- Questionnaire description (online) and results
- Raw Flow Management operators feedbacks (Powerpoint format)

Project Management and Communication outputs

- Internal progress meetings reports
- Project presentation during Engage KTN Workshop (November 2019)
- SESAR Innovation Days poster (December 2019): “MET enhanced ATFCM, a R&D convection tool by DSNA Services and METSAFE”
- Publication of posts on FRACS and METSAFE social networks account
- Publication of articles on FRACS and METSAFE websites:
    - Retrospective of 2019 FRACS projects, published in January 2020 (https://fracs.aero/2020/01/09/cheers-to-2019-projects-and-events/)
    - MET Enhanced ATFCM, a R&D convection tool bay FRACS and METSAFE, published in March 2020 (https://fracs.aero/2020/03/25/met-enhanced-atfcm-a-rd-convection-tool-by-fracs-and-metsafe/)
    - An article will be published in July on FRACS website to inform of the project results.

4.2 Other

Non applicable.

5 Annex

5.1 List of acronyms

ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
CAPE	Convective Available Potential Energy
CIN	Convective Inhibition
GFS	Global Forecast System
LI	Lifted Index
MET	Meteorological, related to meteorology
RDT	Rapidly Developing Thunderstorm
SDI	Supercell Detection Index
SRH	Storm Relative Helicity
SWIM	System Wide Information Management
UAC	Upper Area Centre

5.2 AIM Information Reference Model

The selected data model for the SWIM API was built from the AIM Information Reference Model (available at http://airm.aero/):

Field	Type	Description	Example
identifier	string	Special unique identifier permanently assigned to an entity	876a6992-80cd-520b-ac89-3a5592b57f8c
analysisTime	string	The time at which the forecast process starts	2015-04-22T06:00:00Z
startValidity	string	Date and time at which the data contained in the entity state starts to be effective	2015-04-22T06:00:00Z
endValidity	string	Date and time at which the data contained in the entity state ceases to be effective	2015-04-22T06:00:00Z
contour	geometry	The geometry MultiPolygon	
confidence	float	Confidence index from 0 to 10	1.2