SESAR Engage KTN – catalyst fund project final technical report

Project title:	WIPA – Weather Impact Prediction Tool for ATFCM
Coordinator:	FRANCE AVIATION CIVILE SERVICES
Consortium partners:	METSAFE
Thematic challenge:	TC3 Efficient provision and use of meteorological information in ATM
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1 Abstract and executive summary

1.1 Abstract

The WIPA – Weather Impact Prediction Tool for ATFCM initiative – has been launched by MetSafe and France Aviation Civile Services, in collaboration with Reims and Marseille Upper Area Control Centres. This one-year project addressed how the provision of weather hazards impact information on air traffic control sectors in intervals of one hour over the ATFCM horizon. To do so, WIPA considered the convection information as an input provided by the MET Enhanced ATFCM product (developed during the first catalyst wave), additional MET information (as real-time convection observation and SIGMET), and ATM information. The research approach focused on both technical and operational aspects, as needs identification, design of the tool and deployment via a SWIM webservice. Technical and operational validation trials showed that initial project objectives have been fulfilled: Reims and Marseille ATCOs and FMP operators highly improved their weather situational awareness and would likely have taken ATCFM measures based on received information.

1.2 Executive summary

The impact of severe weather conditions such as heavy rainfall, strong winds, hail, lightning on air traffic management (ATM) is increasing over the years as they are becoming more intense and difficult to predict sufficiently in advance. According to EUROCONTROL, weather is responsible for 30% of all ATM delays in Europe and 25,5% of Air Traffic Flow and Capacity Management (ATFCM) delays, causing capacity reduction, increase of delays and disruptions to planned schedules. Given the increased workload for the air traffic controllers during the tactical phase, it is necessary to provide them with support decision tools for better weather ATFCM tactical regulations.

Given the rising significance of weather as a factor in reducing ATM capacity in Europe, new ways have to be found to maintain and measure ATM performance. Air traffic management organisations in Europe will have to develop new mitigation methods and build more capacity into their systems to cope with this developing challenge.

FRANCE AVIATION CIVILE SERVICES, or FRACS, and METSAFE addressed the "Thematic challenge 3: Efficient provision and use of meteorological information in ATM" with the design and validation of a Weather Impact Prediction tool for ATFCM (WIPA). The objective of the tool was to provide weather hazards impact information on air traffic control sectors over the ATFCM horizon with a forecast time of 6 hours by interval of 1 hour. For the impact analysis, WIPA considered the convection information as an input provided by the MET Enhanced ATFCM product (developed in the context of the first Catalyst call), additional MET information (as turbulences, icing and SIGMET), and ATM flows.

Two complementary domains of expertise were combined through this *Weather impact prediction for ATFCM* project. Reims and Marseille Upper Area Control Centres (UACs), along with FRACS, the coordinator, brought their experience on air traffic control operations and operational validation activities. As a MET expert, MetSafe mastered the tool design and technical validation activities.

The research plan was based on a pragmatic and agile approach:

- Step 1: Use cases definition
- Step 2: Delivery of WIPA tool
- Step 3: Technical and operational validation
- Transversal Step: Project Management and dissemination

Findings of this project will contribute to SESAR initiatives related to MET (meteorology), and other existing initiatives, such as the annual Weather Trials led by the European Network Manager which involves various Air Navigation Services Providers (ANSPs) and MET services providers.

Beyond the *Weather impact prediction for ATFCM* R&D project, there is an opportunity to evolve towards an operational product. The tool is now integrated into a global product, VIGIAERO, designed by METSAFE and dedicated to the provision of accurate MET information to air traffic control. Beyond the Engage framework, the WIPA service/VIGIAERO will be made available to Reims and Marseille UACs up to November 2021.

2 Overview of catalyst project

2.1 Operational/technical context

The air traffic is increasingly impacted by bad weather conditions over the years, which generate a third of all en-route traffic delay; and all the stakeholders are looking for accurate information and practical solutions to reduce the delays, but also increase the traffic predictability. The goals for the ATM community are to enhance tactical procedures and measures, at the NM level for better planning with the provision of weather-related regulations two to three hours ahead rather than the last minute, but also at the UAC level.

The MET Enhanced ATFCM project (developed by MetSafe and FRACS in the context of the first Catalyst call) highlighted the need to “translate” meteorology to Air Traffic Controllers (ATCOs) working methods and adapt the MET forecasts to the Air Traffic Management features.

In this context, a decision-making tool to enhance weather situational awareness and to support the implementation of ATFCM regulations would be helpful. As an answer to this challenge, METSAFE and FRACS choose to explore the topic of meteorology for ATFCM through a fully automated approach, exploiting the result of our previous MET Enhanced ATFCM project and existing meteorological products that are underexploited. The team proposed to design and validate an R&D weather impact prediction tool for ATM (WIPA), which supports the Flow Management Position (FMP) ATCOs decision-making during the tactical phase.

2.2 Project scope and objectives

The objective is to provide accurate weather impact information to ATCOs in charge of FMP activities via a webservice:

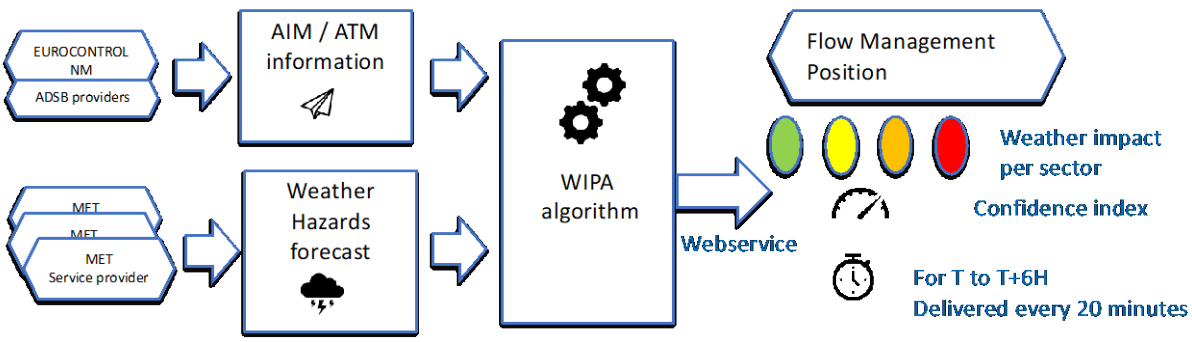


Figure 1: WIPA services approach

To do so, the agile and pragmatic research plan addressed both technical and operational aspects of such tool to be integrated into a future decision-making support system for ATCOs:

- **Step 1: Use cases definition**, to fine-tune the WIPA tool and illustrate the operational benefits.
- **Step 2: Delivery of WIPA tool**, with the identification of the appropriate data sources, the design of the weather impact algorithm and the webservice delivery.
- **Step 3: Technical and operational validation**, involving Reims and Marseille Upper Area Control centres.

2.3 Research carried out

2.3.1 Use cases definition

The objective of this step was to define relevant use cases to illustrate the WIPA concept and tool. It was planned to use these use cases as operational context for the technical and operational validation activities to be led in Step 3.

- **Users' needs collection and problem statement**

As for the previous SESAR Engage "MET Enhanced ATFCM" project, we worked first in close collaboration with air traffic controllers (ATCOs) from Reims en-route control centre. The interest in weather impact information on ATM flows has been strongly highlighted during previous exchanges and after our first collaboration. Operational needs for a decision-making support system using accurate information, as identified last year, are still valid, with a strong focus on the information display to fit ATFCM working methods.

Marseille UAC (CRNA Sud-Est) has been included at the mid-term of the project, their needs and feedback have been also considered for the algorithm improvement and HMI update, as the area is subject to important weather events and traffic deviations. If the operational organisation is different (2 Flight Information Regions, 2 FMP working positions), it has been considered as for Reims regarding the challenges to address: a unique centre, with its own sectors configuration, features and geographical perimeter.

- **Definition of relevant use cases**

The idea was to consider any degraded situation caused by weather events during the validation period: impacting Marseille UAC only, impacting Reims UAC only, or impacting both centres.

With the participation of Marseille UAC, there was an opportunity to study a « flip-flop » use case, i.e., anticipated re-routing or flows re-organisation from East to West proposed to the airlines at the flight plan submission at Day of Operation minus 1 day (D-1), to illustrate collaboration related to weather events between the centres. The French DSNA was also interested in this subject to improve local processes. The idea was to consider Reims and Marseille UAC processes for management of bad weather-related degraded situations and associated measures, as traffic re-routing or flows re-organization.

The WIPA algorithm and the VigiAero tool would have been integrated into the « flip-flop » procedure:

- Pre-tactical coordination between centres at D-1, based on NM Cross-Border Procedure information
- Proposal for mitigation actions and flows re-organisation by the centres and coordination MUAC by the NM
- Use of WIPA / VigiAero during the tactical phase

In parallel, to better assess the added value WIPA impact information would bring to the process, one of the objectives was to analyse the NM Cross-Border Procedure weather information in terms of quality, accuracy and relevance for the process (see § « Technical and operational validation »).

2.3.2 Delivery of WIPA tool

The goal of the WIPA tool was to combine meteorological hazards (convection, icing and turbulence) and ATM flows to produce an impact analysis. The area of interest was the European air traffic "core area" and South of Europe to deliver information suited to Reims and Marseille UAC needs.

- **Identification of MET and ATM data sources**

Air Traffic Management information needed for WIPA algorithm

At the beginning of the project, a large part of the activities was dedicated to the identification of relevant ATM information to feed the algorithm. Several sources have been investigated, as open-source ADS-B data and the Network Manager database (see the "References" section).

The access to the NM PRE-OPS helped in assessing the AIXM 5.1 data format and information, and it has been found that this data source was not suited for WIPA purposes.

With the ADS-B data, the approach was to try to cluster the data to create flows. The following picture represents an extract from the OpenSky API of one hour of ADS-B traffic data over Paris airports on January 20th, 2021. The Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm has been used to define trajectories clustering, the colours representing the barycentre of some of the extracted trajectories for a defined flight level:

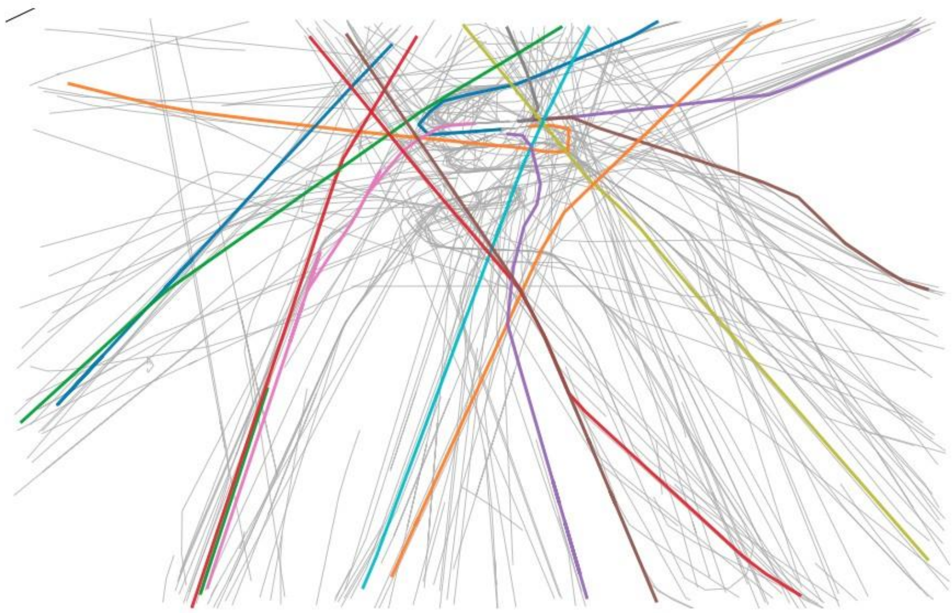


Figure 2: Clustering of ADS-B data to define ATM flows – Source: OpenSky and DBSCAN

However, this approach is not fully reliable as the flows from ADS-B data would take into account over time the flight deviations from planned routes. Also, the assessment of ADS-B flows revealed some "hotspots" around regular flows intersection points:

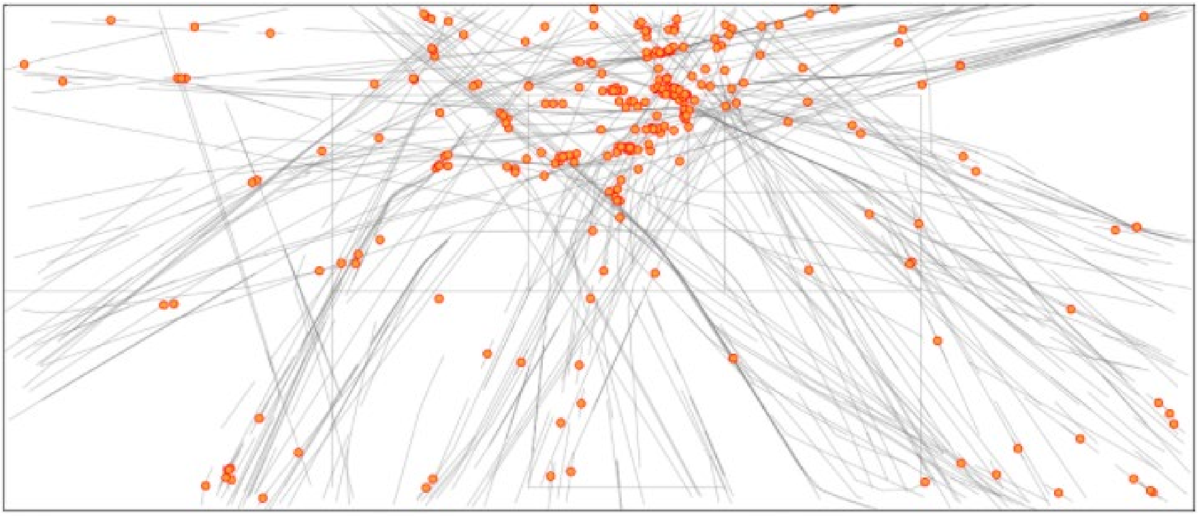


Figure 3: Highlight of "hotspots" over ADS-B flows intersection points – Source: OpenSky and DBSCAN

However, the “hotspots approach” requires an important ADS-B flows filtering process to avoid glitches.
The feedback from the air traffic controllers showed that weather impact information over hotspots or critical ATM areas would be more valuable. Indeed, weather events near critical zones can have strong impact in terms of flows management and anticipation is necessary for better sector management.

Integration of critical ATM points

It has been finally decided few weeks before the end of the project to provide weather impact information over critical ATM points, defined by the air traffic controllers. According to them, this approach is easier and much more relevant as they are used to monitoring key waypoints or areas.

The figure gives an overview of the provision of lightning impact alert within a radius of 50 km over some areas of interest.

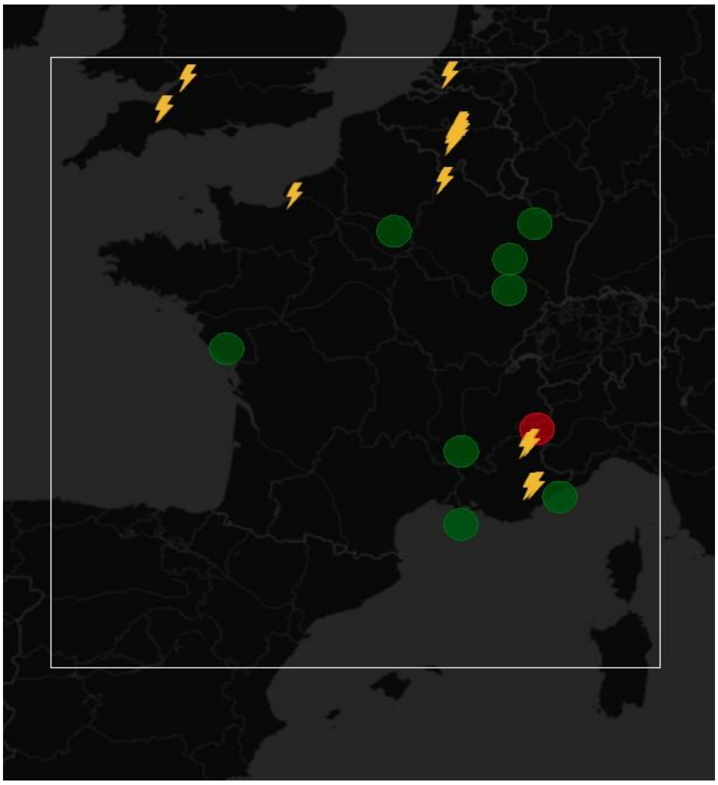


Figure 4: Integration of ATM hotspots – Lightning impact alert

To each navaid or points in space designated by the centres was assigned a sector:

List of critical points / ATC sectors for Reims UAC	
EPL	sector 4E
GTQ	sector 4E
CLM	sector 5R
IXILU	sector 4H
BEGAR	Used for handover
GILIR	Used for handover
LUL	Used for handover
List of critical points / ATC sectors for Marseille UAC	
PIGOS	sector EE
MTL	sector WW
DIVKO	sector MM
BLONA	Boundary with Swiss sectors BB YY

Table 1: List of critical points and associated sectors

Meteorological information needed for WIPA algorithm

Activities related to the algorithm improvement and the management of false alarm/no detection events have been pursued after the end of the first Engage project. We considered the same sources and monitored the evolutions of the open data weather models (potential changes for DWD):

- Convection forecast based on various models extended to +24 hours associated with a confidence index – based on the MET Enhanced ATFCM product extended to +24 hours;
- Icing and Clear Air Turbulence forecasts, produced by MétéoFrance and based on the AROME model (range of 10km and delivered 4 times a day);

For the post operations analysis and the technical validation activities (see Section 2.3.3), the following data have been used in the analytics tool:

- SIGMET (from Météofrance, NOAA);
- Convection observed by radar and satellite (from MétéoFrance);
- Lightning detection (from Météorage).

WIPA algorithm: metrics and indicator

The initial objective was to extract the weather situation on an aircraft trajectory. As explained in the previous sub-section “Identification of MET and ATM data sources”, it has been decided to make a focus on hotspots rather than trajectories. The idea then for the algorithm was to consider a volume around the designated areas and assess the weather events within this volume. In the case this volume is impacted by meteorological phenomenon by more than 60%, an alert is triggered for the ATC sector assigned to the hotspot.

The first idea was to integrate the impact on the hotspot directly to the associated sector (e.g. sector where the hotspot is located). Following discussions with the Flow Management experts, this mechanism would trigger too many false alarms depending on real-time decisions by the controllers. Therefore, the hotspots have been integrated as independent objects in the API so that the controller has a separate information from the overall sector weather impact.

All of the inputs (MET data or ATM data) are processed from a cloud-based solution:

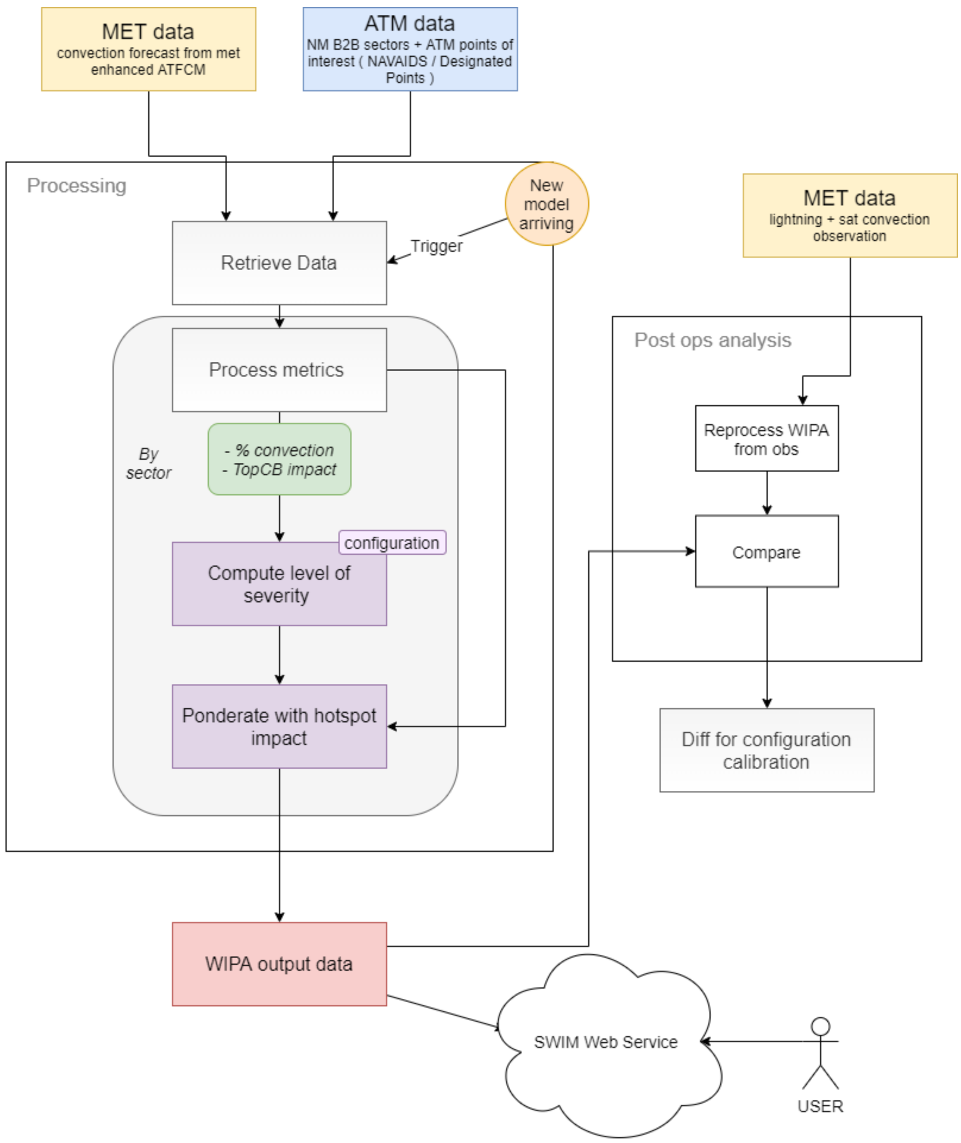


Figure 5: WIPA algorithm principles

The metrics considered for the assessment of the level of severity are the following:

RC (Ratio of Convection in a sector)	Level of severity
90% and above	4
50% to 90%	3
10% to 50%	2
0% to 10%	1

Table 2: Metrics for the assessment of severity levels

The choice of levels of severity per sector have been mapped to the NM cross border procedure impact matrix. This matrix is the reference for weather impact for DSNA.
The algorithm for the hotspot has different thresholds than the algorithm for sectors.
For the Flow Management operator, this level of severity is translated into a colour associated with a sector on DSNA IHM.

Also, the "TOP CB" information has been included in the algorithm. It has been is particularly requested for Reims FIR because most sectors in Reims start above FL200. Bad weather situation below FL200 does not impact Reims FIR and is out of interest for the centre. From a technical development perspective, the TOP CB information is in itself an R&D activity. The information is to be considered in two time horizons: nowcast (derived from observation) and forecast (beyond +1 hour).

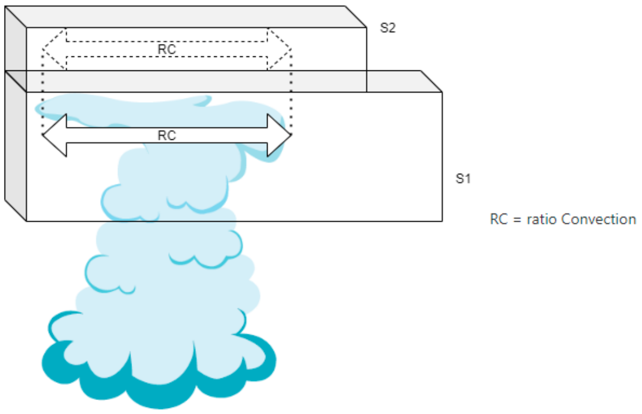


Figure 6: "TOP CB" information principles

The "TOP CB" information and alert is computed as the following:

- The impact on flight level only calculated for sector S1 (because this sector is impacted by the cumulonimbus)
- If the convection ration (or RC) is higher than 10% in 2D dimension, an alert is triggered also on sector S2.

- **Delivery as a webservice**

The API has been defined between November and December 2020, and the WIPA service has been activated as a webservice to Reims and Marseille UACs. Additional activities related to the identification of the geographical ATM weight complexity and airspace sectors had to be developed for Marseille UAC, as it was the first collaboration with this ATC centre.

The API has been declared in EUROCONTROL SWIM registry:
https://eur-registry.swim.aero/services/metsafe-vigiaero-weather-impact-atm-v20
The webservice is a simple request/reply mechanism that delivers JSON/GeoJSON information with traceability to the SWIM standards. The webservice is available through the public internet with security measures (token protection, https…).
For the validation activities with Reims and Marseille UACs, the data provided by WIPA have been considered as inputs for the web-HMI defined and designed by the DSNA.

2.3.3 Technical and operational validation

Technical and operational validation sessions were carried over 2,5 months (between May and mid-July 2021), in order to tailor the tool and validate the WIPA concept. During this period, according to EUROCONTROL assessments about "COVID-19 Impact on EUROCONTROL Member States", the French ATC centres handled around only 60% of 2019 traffic.

Technical and operational validation

This step will help to tune the tool and adjusting the impact indicator, and also improve the concept.

Technical validation	Operational validation
Post operational analysis of the WIPA algorithm output, in order to: - Tune the algorithm; - Quantify the anticipation time brought by the tool; - Quantify false alarms and non-detection events; - Quantify the quality of MET forecast (resolution, temporality). - automated analytics function	• FMP operators in Reims and Aix UACs. • Validation objectives and associated indicators to be defined • Illustrative Use Cases • We will aim to assess and compare the ATM performance without and with WIPA

Figure 7: Technical and operational validation goals

Several briefings have been performed with Reims and Marseille UAC before the validation campaign to design the methodology and prepare the validation sessions. Around 15 FMP operators were involved in the validations at Reims and 24 at Marseille.

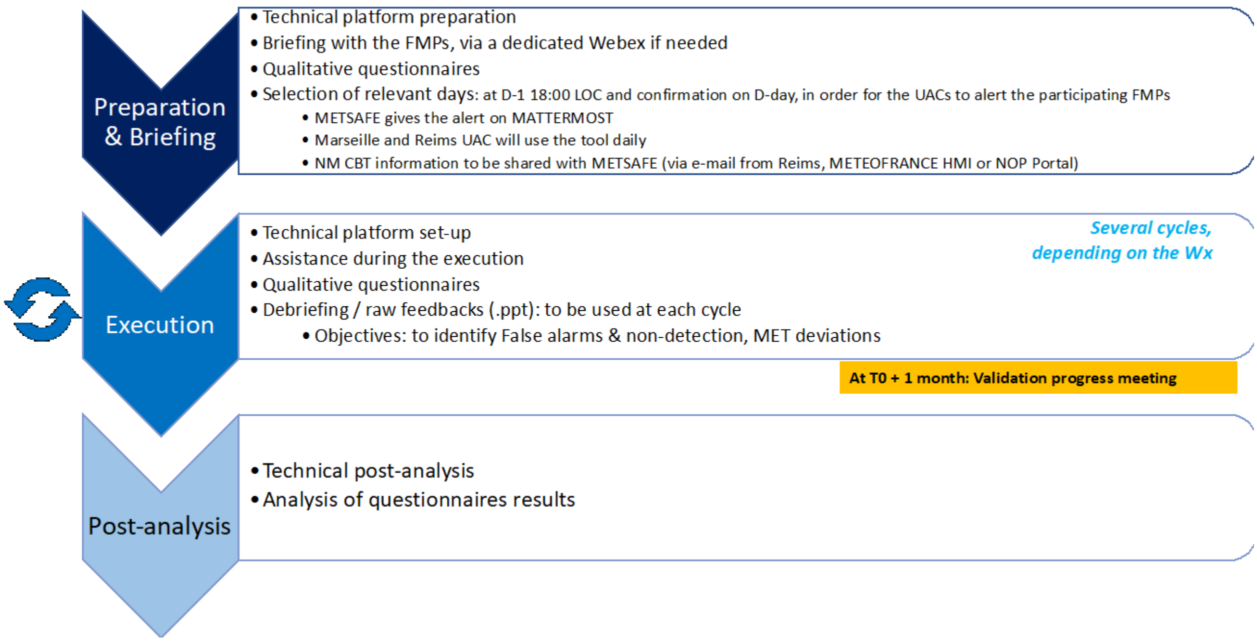


Figure 8: Technical and operational validation approach

Two validation objectives have been defined:

OBJ1 To provide accurate and up-to-date MET information

OBJ2 To assess the capacity or its improvement, and performance levels when accurate and up-to-date MET information is provided

The fulfilment of these validation objectives has been assessed through qualitative indicators, mainly FMPs agreement on the benefits and expressed satisfaction via raw feedback and questionnaires.

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

Day	Raw operational feedback from Reims UAC	Raw operational feedback from Aix UAC	Qualitative questionnaire
11/05/2021	x	x	
14/05/2021	x	x	
18/05/2021			1
19/05/2021	x		1
23/05/2021	x		
04/06/2021	x		
07/06/2021		x	
08/06/2021			1
09/06/2021	x		
11/06/2021		x	
16/06/2021	x		1
17/06/2021	x		
19/06/2021	x		
21/06/2021	x		1
27/06/2021	x		
30/07/2021	x		
08/07/2021	x	x	

Table 3: Reference days and collected feedback

Technical validation

This step consisted in the assessment of a replay of the days of interest indicated by the air traffic controllers (see before) by comparing WIPA results with satellite information and lightning observation of that day.

As an example, on May 19th, 2021, there was convective activity over France with a lot of cumulonimbus cells.

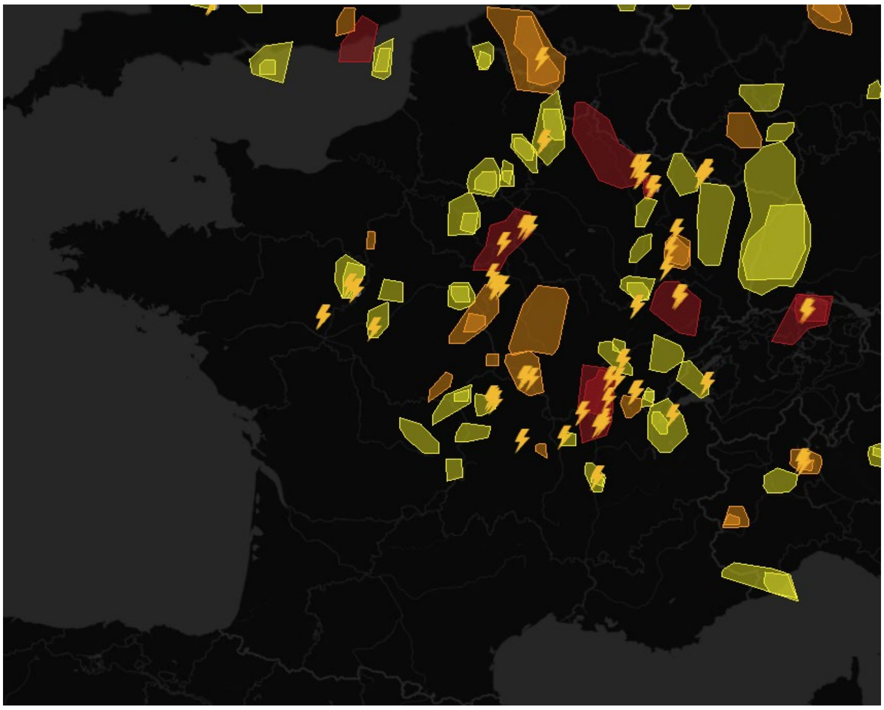


Figure 9: Technical validation - Example of May 19th, 2021 (convective activity)

There was a good forecast of the convection product (colourful areas) when compared to the reality (lightning symbols). Nevertheless, the consideration of confidence levels would have improved the forecast, as shown in the next figure, which corresponds to the convection forecast (at midnight) with different colours depending on the level of confidence. We also have important polygons that can affect a whole air traffic sector:

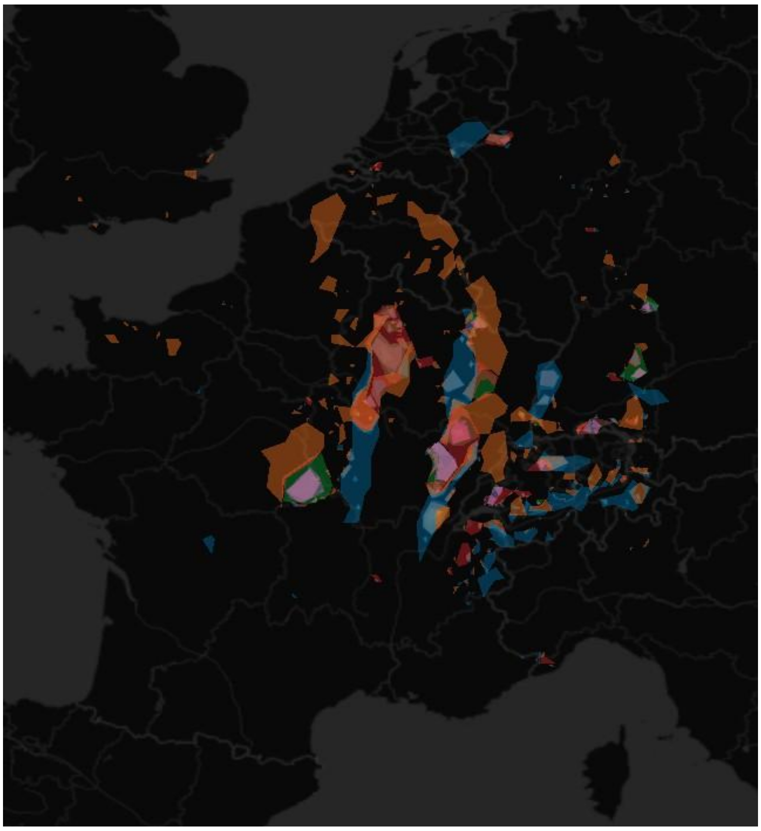


Figure 10: Technical validation - Example of May 19th, 2021 (convective activity with consideration of confidence levels)

When focusing on areas where the confidence levels are higher, a better precision can be observed when compared to lightning observation of that day:

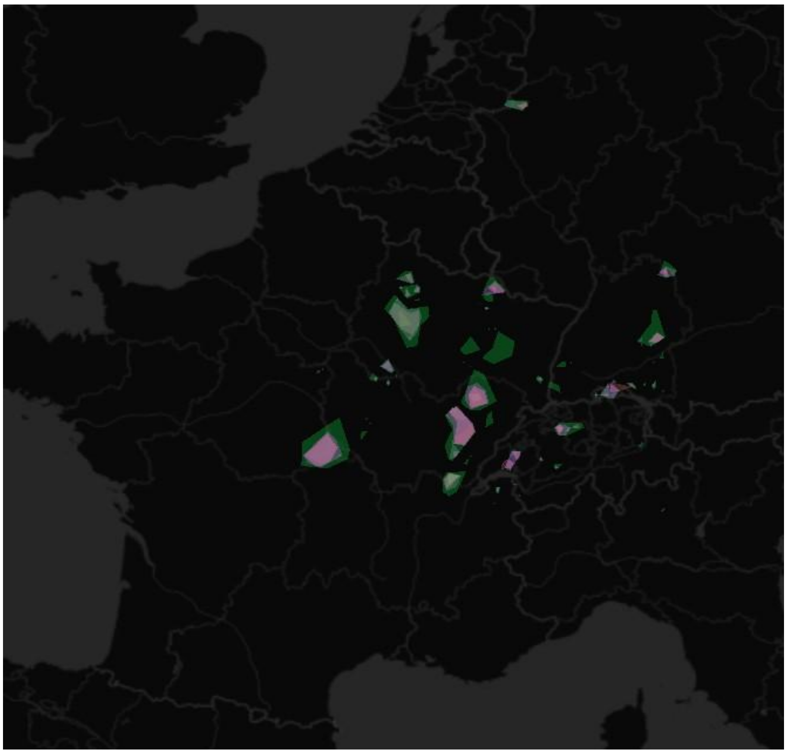


Figure 11: Technical validation - Example of May 19th, 2021 (convective activity with consideration of high confidence levels)

The technical validation showed an improvement of false alarms diagnostics. The monitoring of points of interest helped to avoid false alarms or the application of levels of impact severity that are too intense. In the figure below is shown a sector assessed in purple (higher level of impact) due to its small volume. Here the weather disturbance is approaching but the key points that can serve as entry or exit points to the sectors are not yet affected. An orange or red level would have been sufficient for this sector, thus the introduction of the waypoints in the algorithm improved this this phenomenon.

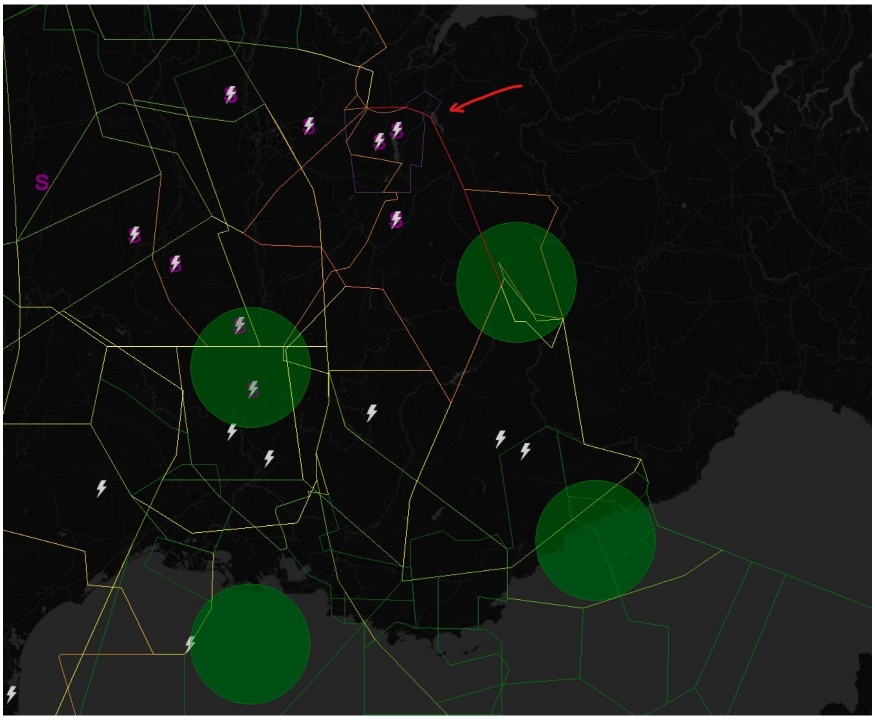
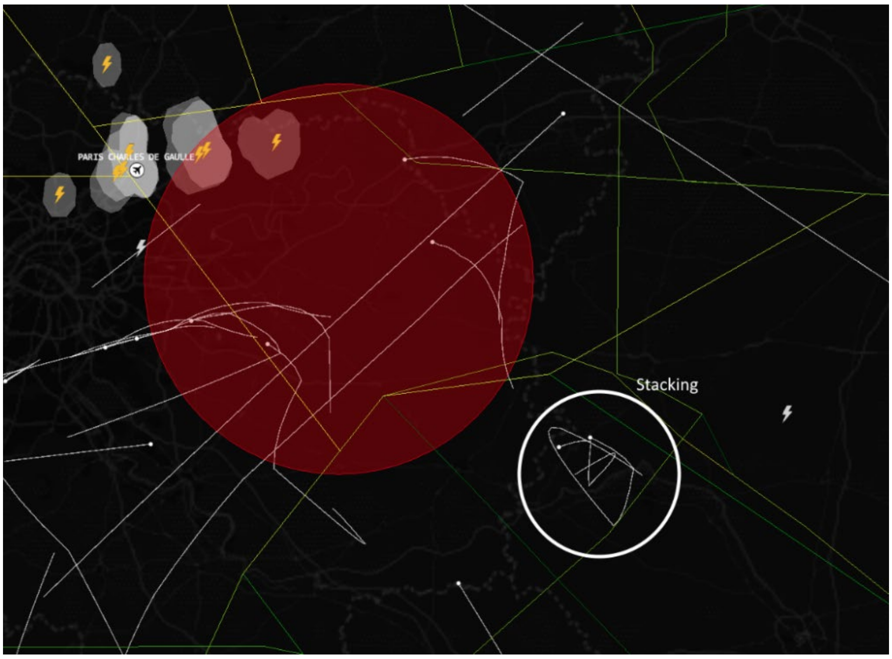


Figure 12: Sectors of LFMM FIR on July 12th, 2021 between 18:00 and 20:00 TU

Another benefit of the hotspots approach is a better anticipation of ATC workload:



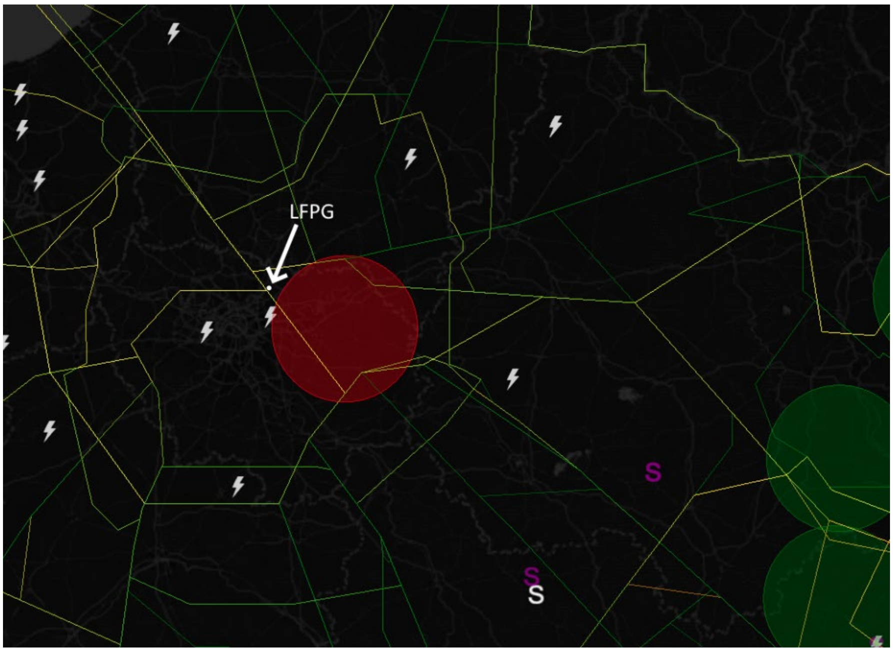


Figure 13: Approach at CDG airport (LFPG) impacted by thunderstorms

In this figure, the WIPA algorithm detects that the approach at Charles-de-Gaulle airport (LFPG) is affected by thunderstorms that lead to impacts on the traffic (in this case, stacking).

When we consider only the weather forecast on sectors, the level of severity is low (green or yellow at a maximum). When considering the hotspot approach, an intermediate level of severity would have been applied (orange). Hence, the sectors related to this approach and area of observation would benefit from this alert issued in advance to better manage the traffic.

There were two obstacles to get statistical figures about false alarm and non-detection events:

- The technical validation period (March-April) was not long enough to get enough severe weather situations.
- Statistical analysis needed automated tools that are on MetSafe roadmap in 2022.

However, based on the situations observed, in agreement with the operational centres, the WIPA algorithm was deemed performant enough to go to operational validation.

Operational validation

For the operational validation, the WIPA information was available 24H to the Flow Management position via a web-HMI developed by DSNA. The Flow Management operator could access the WIPA information on a regular basis.

For the operational validation, the idea was to combine the results of online qualitative questionnaire to fill out and raw Flow Management operators' feedback in order to assess the operational interest and benefits of the tool.

The operational validation considered the HMI designed by Reims UAC (CRNA Est) and tailored to Reims and Marseille context and needs.

Raw feedback from FMP operators provided details (textual description and screenshots) on the following:

- Description of the weather event
- Impact on the operations
- Information provided by the WIPA tool

- Information provided by the Network Manager Cross Border Procedure (NM CBP)
- Update of the situation within time – operational and technical point of view

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 Procedure

WIPA - Validation questionnaire

Section 1 ...

Situational awareness

1. Which information are/were you looking for?

Entrez votre réponse

2. Did you receive the information you were looking for?

- Yes
- No

3. How was the quality of the provided information?

- High
- Medium
- Low

4. How was the accuracy of the provided information?

- High
- Medium
- Low

5. According to your experience, what was the added value compared to the nominal MET tools?

Entrez votre réponse

6. What are the areas for improvement?

Entrez votre réponse

Section 2 ...

ATFCM Processes

7. Did you received WIPA/Vigiaero info:

- at H-24 / D-1?
- at H-6?
- at H-3?

8. With the information you received, were you/would you be able to take appropriate tactical measures?

- at H-24 / D-1?
- at H-6?
- at H-3?

Section 3 ...

Comparison with MET info from NM Cross Border Procedure

9. QUALITY - In comparison with the information provided for the NM CBP, the WIPA/Vigiaero info was:

- Better
- Identical
- Poorer

10. ACCURACY - In comparison with the information provided for the NM CBP, the WIPA/Vigiaero info was:

- Better
- Identical
- Poorer

11. AVAILABILITY - In comparison with the information provided for the NM CBP, the WIPA/Vigiaero info was:

- Better
- Identical
- Poorer

12. Would you combine the two sources of information to define tactical measures?

- Yes
- No

13. How to combine the two approaches for a better situational awareness?

Entrez votre réponse

+ Ajouter...

Figure 14: Validation questionnaire

Very few responses were collected from the questionnaire, because it was easier for the FMP operators to describe the operational situation and the benefits of the tool. Most of the results (questionnaire or raw operational feedback) were provided by the Flow Management Operator less than 24H after the severe weather events. Implication of the users to improve the WIPA algorithm was significant. Nevertheless, the results and their tendencies have been validated by Reims and Marseille centres (see Section 2.4).

2.4 Results

Technical validation

Regarding the integration of ATM flows in the algorithm, the ideal approach would have been to use the flight plans. The research activities showed it was technically difficult to exploit them, the alternative have been to consider ADS-B data with potential deviations from the planned routes. In addition, from an operational point of view, the consideration of hotspots or areas of interest seemed to be more valuable. It has then been decided to adopt the hotspots approach and to improve the concept with Reims and Marseille UACs beyond the WIPA project. An improvement of the weather diagnostic granularity has been noted by team.

Also, the validations showed that to upgrade the concept and to assess the impact of weather on the Network, MET regulations from the NM could be used. This approach hasn't been considered at the beginning of the project, and for further experiments, it will be assumed that these measures are in phase with the operational reality.

There is also a need to provide more objective post-assessments and quantify the results. This approach would be complementary to operational feedback.

Operational validation

In parallel of the Summer Weather Cross Border service provided by the Network Manager (between 3rd May and 30th September 2021), the WIPA tool has been used by FMP operators over two months for weather situational awareness.

Due to the COVID-19 context and slow air traffic recovery, the number of handled flights is lower than usual. Currently, Marseille UAC manages 90% of 2019 traffic, while Reims UAC manages 2000 flights per day instead of 3000. So, the management of weather events were not too difficult and the impact on the flights was limited. Unfortunately, there was not any flip-flop scenario put in place during the WIPA trials (see Section 2.3.1 for validation objectives).

The tool helped them to get information on convective information, cumulonimbus impacting the sectors of interest and complete the forecast provided by the Network Manager. Some of the assets of the tool have been really appreciated: the temporal progression of weather events, the hourly update of the forecast, the lightning impact information on the sectors.

Also, the comparison of each operational feedback with an analysis of the situation from replay of the weather events highlighted the difference of working methods between the two ATC centres and between the air traffic controllers. It also served to validate the operational benefits of WIPA information, as a better anticipation of ATC workload (see CDG approach example in Section 2.3.3, Technical validation).

3 Conclusions, next steps and lessons learned

3.1 Conclusions

Figure 15: WIPA service in the ATC room centre

According to the activities performed and results obtained, project and validation objectives have been partially fulfilled. Indeed, in terms of performance and ATFCM improvement, WIPA provided valuable and precise weather information to the FMP operators within the ATFCM horizons with a forecast time of 6 hours. Nevertheless, the integration of ATM flows turned out to be more complex as expected. An alternative to consider for future improvements is to provide weather impact information over defined areas (hotspots) or waypoints.

Also, WIPA results highlighted the same conclusion as the previous MET Enhanced ATFCM project: such a tool would highly benefit in their activities, as it contributes to the improvement of weather situational awareness for a better decision-making process.

3.2 Next steps

Pursuance of technical and operational validation

METSAFE, Reims and Marseille UACs will pursue the validation activities with the VigiAero tool, built upon the WIPA algorithm. The experimentation will last until November 2021.

Summer 2022 will support further validation, including use case of interests per DSNA En route centres such as the Flip-Flop.

Presentation of WIPA and Vigiaero results

There is an opportunity to present WIPA and Vigiaero results to the ATM community at the next World ATM Congress in October 2021 and at the next SESAR Innovation Days. A first action is planned for end of September 2021 at Marseille UAC.

Industrial perspectives

This WIPA project is considered as a first step towards an industrial and operational decision support system dedicated to weather ATFCM tactical regulation, that could be integrated by an industrial.

Indeed, the WIPA tool has been developed within the MetSafe cloud-based industrial integration platform. A maximum re-use of existing functions and concepts (authentication, security, monitoring, redundancy, sandbox, webservice, etc.) has been observed. The industrialisation of the algorithm including ATM-grade availability towards the Vigiaero tool is estimated at 3 months, with a delivery as a webservice to allow a fast and easy integration for the industry.
With the use of the Vigiaero tool and the delivered impact information of weather-related events on the en-route traffic, the FMP operators would be able to improve their weather situational awareness and tactical regulations.
Beyond the Vigiaero service delivery to a human interface, Vigiaero could be delivered in machine-to-machine mode to support other ATM tools.

Relationship with other SESAR projects and potential upgrade

During the technological state-of-the-art activities, three projects in direct relation with WIPA perimeter have been identified. Their results could be used to upgrade WIPA algorithm beyond the SESAR Engage framework:

- Flight Centric ATC with Airstreams (FC2A) by NEOMETSYS - https://neometsys.fr/fc2a/

This project addresses the ATM flows identification part. The results could be integrated into the flows identification process of WIPA.

- Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning or ISOBAR - https://isobar-project.eu/

Similar topics are addressed in ISOBAR with a more ambitious approach than WIPA. Their strong technical point is the use of machine learning techniques for hotspots and weather forecasting. The activities progress will be monitored (validation report planned for June 2022) to consider the results for the upgrade and improvement of WIPA.

- Meteorological uncertainty management for Flow Management Positions or FMP-MET - https://fmp-met.com/

This project addresses the same perimeter than WIPA, with the horizon of 8 hours. Results of their activities will also be monitored.

In the framework of the SESAR Deployment Manager, a potential source of improvement could come from the European MET service provider EUMETNET which is currently working on new weather hazard service (turbulence and icing) that will be delivered in end of 2022.

The multiplicity of initiatives addressing the same perimeter is a proof of a strong operational need.

Our bottom-up and one-year-stepped approach to innovation with a focus on end-users (ATCOs) is complementary to the top-down and three-year-stepped approach that are observed in other European R&D projects.

3.3 Lessons learned

The experience gained through the project and the SESAR Engage Catalyst framework led to the following:

- The SESAR Engage Catalyst context is well suited for fast innovation and the design of new and innovative ATM solutions.
- Collaboration with ATC is crucial for the development of innovative operational tools.
- The introduction of ATM information through hotspots greatly improved the pertinence of WIPA from a controller point of view. This approach has been developed thanks to the close collaboration with the ATC centres in the development phase.
- A cloud and SWIM-based solution is suitable for ATM operations.

Similar sized budgets should be available as part of a potential future KTN or SESAR 3 R&D activities framework to foster innovation. Agile organisation between the project teams with regular presentation of concrete results during events as thematic workshops, SESAR Innovation Days or working groups are key.

4 Dissemination

Several communication and dissemination actions have been performed within the project duration:

Event	Date	Material
SESAR ER & IR MET and ENV workshop	October 1st, 2020	-
ISOBAR workshop	October 1st, 2020	-
Virtual edition of the SESAR Innovation Days	December 7th to 10th, 2020	WIPA poster, teaser and video
Engage KTN TC3 MET Workshop	January 27th, 2021	Presentation of MET Enhanced ATFCM and WIPA projects approach and expected results
Meteorological Technology Expo Aviation Virtual Conference	March 24th, 2021	Presentation of MET Enhanced ATFCM and WIPA projects approach and expected results (video) Participation to the SESAR panel about MET information integration into flow and capacity management
SMART Weather Task Force workshops	May 5th and June 29th, 2021	Presentation of WIPA project approach and expected results Presentation of VIGIAERO tool by METSAFE
SESAR JU Awards	June 2021	VIGIAERO commercialised by METSAFE – built on MET Enhanced ATFCM and WIPA results
Communication on social media	-	LinkedIn and Twitter posts on FRACS and METSAFE accounts
Article: "The Weather Impact Tool for ATFCM is becoming an Operational Reality"	October 7th, 2020	Published on FRACS website
Article: "Weather impact for ATM: a challenge rewarded!"	June 25th, 2021	Published on FRACS website
Presentation of VIGIAERO tool by METSAFE	June 2021	Published on VIGIAERO website
Meetings with SESAR JU and industrial partners	-	Presentation of WIPA project approach and expected results Presentation of VIGIAERO tool by METSAFE

5 References

5.1 Project outputs

Needs and perimeter definition outputs (internal deliverables)

- Description of geographical scope to consider
- Summary of Marseille UAC user needs and features

Research and Development outputs

WIPA tool development (internal deliverable)

- WIPA algorithm
- Associated web service

Validation sessions

- Approach and methodology defined with Reims and Marseille UAC air traffic controllers
- Questionnaire description (online) and results
- Raw Flow Management operators' feedback (PowerPoint format, internal deliverables)

Project Management and Communication outputs

- Coordination meetings reports (internal deliverables)
- Project presentation made during public events (see Section 4)
- Project presentation made during meetings with the SESAR JU and industrial partners (see Section 4)
- SESAR Innovation Days poster, teaser and video (December 2020)
- Meetings with SESAR JU and EUROCONTROL (December 14th). The integration of WIPA results is now integrated into an NM prototype.
- Publication of posts on FRACS and METSAFE social networks account
- Publication of articles on FRACS and METSAFE websites:
    - Article on FRACS website: "The Weather Impact Tool for ATFCM is becoming an Operational Reality" (October 7th, 2020) - https://fracs.aero/2020/10/07/the-weather-impact-tool-for-atfcm-is-becoming-an-operational-reality/
    - Article on FRACS website: "Weather impact for ATM: a challenge rewarded!" (June 25th, 2021) - https://fracs.aero/2021/06/25/weather-impact-for-atm-a-challenge-rewarded/
- Presentation of VIGIAERO by METSAFE - http://www.vigiaero.com

5.2 Other

References used to update the WIPA algorithm

X. Olive and L. Basora. Air Traffic Data Processing using Python: Trajectory Clustering. https://doi.org/10.29007/sf1f

Modelling Convective Weather Avoidance in Enroute Airspace, R. DeLaura et al. (MIT Lincoln Laboratory), 2008

Air Traffic Management Decision Support During Convective Weather, Mark E. Weber, James E. Evans, William R. Moser, and Oliver J. Newell

6 Annex I: Acronyms

ADS-B	Automatic Dependent Surveillance–Broadcast
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
DBSCAN	Density-Based Spatial Clustering of Applications with Noise
FMP	Flow Management Position
HMI	Human Machine Interface
MET	Meteorological, related to meteorology
NM	Network Manager
NOAA	National Oceanic and Atmospheric Administration
RDT	Rapidly Developing Thunderstorm
SWIM	System Wide Information Management
UAC	Upper Area Centre