PROJECT FINAL REPORT

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Project title: Weather INformation Fusion and Correlation for weather and traffic situational awareness

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1 Executive summary

The WINFC (Weather INformation Fusion and Correlation for weather and traffic situational awareness) project aimed at the development of an adaptive data processing module that, once on board, collects and processes information incoming from different weather and traffic data providers. The module produces an awareness map by integrating weather and traffic changes data collected during the flight, and an updated weather map. The awareness map is a risk map available to the pilot for a prompt detection of hazard conditions, no matters whether they depend on weather or traffic changes.

The objectives of the WINFC project have been the following:

- The analysis of the information sources about un-forecasted events like weather change and traffic congestion in present and future ATM environment,
- The study of innovative on board measurements methods to provide real-time weather information,
- The development of a SW tool for simulating the information data flow coming from different sources in case of unexpected weather and traffic scenarios,
- The development of a data fusion tool for the adaptive integration and correlation of the information coming from heterogeneous information sources,
- The definition of an efficient and effective unbiased threat/importance factor(s) useful to the pilot and as input parameters to Q-AI trajectory and mission optimization algorithms,
- The validation of the data fusion tool by a test activity based on the data flow SW tool applied to selected realistic scenarios.

2 Summary description of project context and objectives

2.1 Technical background

A Q-AI trajectory optimization software has two types of inputs: meteorological data and a risk map, the first used to evaluate aircraft performances and emissions, the second to integrate weather related hazards and traffic constraints. Information on weather conditions can be obtained from multiple data sources and can be pre-loaded off-board, or collected during the flight from a ground base station, from other aircrafts or by the on-board instrumentations that include the weather radar processed by proper advanced weather radar algorithms. The data sources can include:

- Weather products provided by public or private institutions (NOAA, ECMWF, NHMS, etc..) for aviation: forecast charts (WINTEM, SIGWX), model outputs delivered every one to six hours, observation data including airport weather stations (METAR), ground weather radar, satellite observation, lightning strokes, specific risks assessments (icing, turbulence, convection, volcanic ash), PIREPS, etc.;
- On-board weather radar reflectivity data;
- Classification algorithm from on-board advanced weather radar, options for dual polarization upgrades the current single-polarization systems are considered in WINFC;
- On-board sensors (P, T, Wind, Humidity, Ice detection, etc..);
- Traffic information (Primary surveillance data, ADS-C, ADS-B, multilateration);
- Aeronautical Information Services (e.g. NOTAMs)
- Other sources: GPS, satellite receivers, etc.

The weather data used by the Q-AI (see http://klean.cnit.it/project) belong to two categories:

- Wind field: the direction and the intensity of the wind have a direct effect on the flight of the aircraft; moreover, it can also affect the evolution of a weather front in the near future and the influence of noise on a given environment;
- Air density, temperature, pressure, relative humidity: these quantity can affect the aircraft performances (i.e. thrust, fuel flow, etc.) and/or the pollution emissions model (i.e. CO2, NOx, etc., emission indexes).

A further source of information that can be exploited in the case a dual-polarization option is adopted for the on-board weather radar is the detection, along the route, of hydrometeors related to risky conditions such hail.

Q-AI uses the risk map for updating the range of aircraft states that are feasible in trajectory planning. The risk map integrates problematic weather condition to be avoided during the aircraft trajectory with traffic data related to other nearby flights or regions to be avoided due to security and/or military reasons. The availability of an integrated risk map based data fusion of both weather and traffic information allows warning the pilot with the constraints in the proximity of the aircraft and can be used by the Q-AI to optimize the trajectory reducing the emissions.

2.2 Objectives

The objectives of the WINFC project are the following:

1. Analysis of the information sources about un-forecasted events like weather changes, traffic congestion in present and future ATM environment
2. Study of new measurements methods on board able to provide new weather real-time information.
3. Development of a SW tool for simulating the information data flow coming from different sources in case of unexpected weather and traffic scenarios
4. Development of a data fusion tool for the adaptive integration and correlation of the information coming from different information sources
5. Definition of an efficient and effective unbiased threat/importance factor(s) useful for the pilot and as input parameters to Q-AI trajectory and mission optimization algorithms.
6. Validation of the data fusion tool by a test activity based on the data flow SW tool applied to selected realistic scenarios

2.3 Innovative contributions of the project

Q-AI trajectory optimization software has basically two types of inputs: meteorological data and risk map. The former are used to evaluate aircraft performances and emissions, the latter to integrate weather related hazards and traffic constraints. Weather conditions can be acquired from different data sources. These conditions can be pre-loaded off-board, or acquired during the flight from a ground entity base station, from other aircrafts or by on-board instrumentations, i.e. weather radar and advanced weather radar algorithms. The data sources can include:

- Weather data products for aviation provided by public or private institutions (NOAA, ECMWF, NHMS, etc..): forecast charts (WINTEM, SIGWX), model outputs every one to six hours, observation data including airport weather stations (METAR), ground weather radar, satellite observation, lightning strokes, specific risks assessments (icing, turbulence, convection, volcanic ash), PIREPS, etc.
- On-board weather radar, On-board advanced weather radar algorithm,
- On-board sensors (P, T, Wind, Humidity, Ice detection, etc..)
- Traffic information (Primary surveillance data, ADS-C, ADS-B, multilateration)
- Aeronautical Information Services (e.g. NOTAMs)
- Information coming from other sources: GPS, satellite receivers, etc.

The weather data used by Q-AI and affecting the flight of the aircraft can be divided in two main contributions:

- Wind field: the direction and the intensity of the wind have a direct effect on the flight of the aircraft; moreover, it can also affect the evolution of a weather front in the near future and the influence of noise on a given environment;

- Air density, temperature, pressure, relative humidity: these quantity can affect the aircraft performances (i.e. thrust, fuel flow, etc) and/or the pollution emissions model (i.e. CO_2, NO_x, etc emission indexes) of the aircraft

Q-AI uses the risk map for updating the range of aircraft states that are feasible in trajectory planning. The risk map integrates problematic weather condition to be avoided during the aircraft trajectory with traffic data related to other flights around the plane or regions to be avoided due to security and/or military reasons. The availability of an integrated risk map based on both weather and traffic data fusion allows to warn the pilot with the constraints in the proximity of the aircraft and can be used by the Q-AI to optimize the trajectory reducing the emissions.

2.4 Progress beyond the state of the art

The Data fusion approach

The data fusion approach proposed in WINFC aims at the delivery of two main results that can be used to be directly visualized to the pilot and to be input by the Q-AI software. The first is to build an updated weather representation that considers all the data available according to their spatial and temporal accuracy. The second is to provide an integrated risk map that integrates weather related threats with traffic related constraints, for example it can consider both convective clouds to be avoided and spatial regions temporarily closed to the air traffic. Both are typical inputs of the Q-AI trajectory planner that determine where the aircraft can go and at what environmental costs. These representations can be visualized to the pilot to show weather related constraints near the aircraft or an integrated representation of no flight zones. Notice that if provided data can be wide enough and some computational constraints can arise regarding real time update of situation awareness of flight conditions around the aircraft.

On-board Data Stream simulation tool

The innovation brought by the On-board Data Stream simulation tool have been:

1 to deliver a rich, coherent, and realistic dataset in simulated real-time or batch mode. The dataset covers a large spectrum of awareness information that can be available on-board today, and also in the future (with new on-board sensors, new information from nearby-aircraft or other ground or satellite systems).

2 to make available all the on-board information on a single "data bus". Thus, the complete evaluation bench is used for fusion algorithms (as in the project scope), but is also open to other type of uses in the future (coherent distribution of information to FMS, EFB, ND, etc..). The information distribution architecture can also be considered as first prototype of a future operational airborne implementation.

Satellite nowcasting services to detect and track aeronautical risk areas

Thanks to new satellite observation capabilities and ubiquitous communication facilities, it is possible to deliver on-board a worldwide short term forecast service (up to 1 hour), fast update (5 to 15 minutes), to prevent aircraft to encounter high risk areas. A typical benefit of such technique is to track deep convection over equatorial waters. Integration of such service in the simulation stream enriches the scenarios, and enables assessment of integration of such products in the information fusion process.

Polarimetric weather radar simulator

The main polarimetric observables commonly adopted in radar meteorology have been simulated, namely the reflectivity factor, the differential reflectivity, the linear depolarization ratio, the co-polar correlation coefficient, and the specific differential propagation phase that can be used for the automatic identification of hydrometeor types. A Doppler radar is also capable of estimating the Doppler spectrum of weather targets: in particular, the first and the second spectral central moments, named radial velocity and spectrum width, are measurable. In addition, other two parameters that are indispensable for the risk assessment due to turbulence and wind shear have been simulated.

Real time Weather info by Satellite signals

In case the radar is blinded both due to strong attenuation and maximum distance, the missing info beyond the radar blind distance, in terms of 3D extension of the precipitation structure, could be estimated using the satellite signals that are sensitive to the liquid water and the water vapor content between airplane and the transmitting satellite. Some selected scenario in terms of precipitating structure and navigation and communication satellite constellations have been used to provide the feasibility of the proposed measurement system based on such satellite signals.

2.5 Project work plan

WINFC project has been implemented through the following six Work Packages, those numbered from 2 to 5 concerning research and development activities:

WP1 - Project management: This WP primarily aimed at providing a structured system for the full administrative and technical management of the project, addressing all methods of risk management, quality assurance and confidentiality including Intellectual Property Rights (IPR) handling.

WP2– Information sources, actual and future: This WP provided a clear view about all information sources (present and future), and their possible fusion for on-board trajectory optimization Decision Support System.

WP3 – Simulation environment: this WP developed a software based simulation environment that simulate the information delivery from the different on-board sources accounting for the output of the Weather and Traffic emulation and the output of a Polarimetric weather X-band radar in terms of time sequences of polarimetric parameters, hydrometeor classification and radar risk map.

WP4–Data fusion: this WP developed a data fusion tool of weather and traffic information to produce updated weather data and an awareness map of hazards that can be used as a risk map in the Q-AI optimization.

WP5 –Test and validation: this WP defined a set of test case assuming realistic weather and traffic scenario for analysing the performance of the data fusion applied to the simulation tool outputs

WP6 – Exploitation and dissemination: This WP outlined how to develop an exploitation and dissemination of the WINFC results in the SGO CLEANSKY program, in other European projects (FP7, H2020. etc), manufacturing industries and in the technical and scientific community, following Clean Sky JU directives.

3 Description of the main S&T results/foregrounds

Main S&T results are described in the following subsection according to the technical workpackages breakdown and with reference to projects deliverable (numbered as Dn.m, with “m” denoting the corresponding workpackage).

3.1 Information sources, actual, and future (WP2)

The WP2 analyzed the state of the art of the project, and aims to study possible information sources for data fusion. The work package has been divided in two analysis, related to both legacy (D2.1) and innovative (D2.2) products relevant for data fusion for aircraft situational awareness.

Study of on-board information sources

The first deliverable focuses on describing both weather and aeronautical systems able to detect and provide information about possible risks for the aircraft. The weather sources can be divided between internal and external sources. Aircraft sensors provide essential data, required first for tactical flight management. Pressure (static and dynamic) and temperature sensors provide essential information to avionics, necessary to compute position, altitude and wind speed and direction. Other type of probes have been developed to prevent critical hazards for aeronautics. Humidity (Figure 1), icing (Figure 2), turbulence, lightning (Figure 3) and wind shear sensors are already available but remain optional.

Figure 1: humidity sensor WVSS II

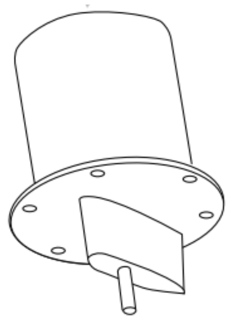

Figure 2: Rosemount Ice Detector

Figure 3: stormscope WX-500

New type of sensors are under development to prevent more complex hazards and offer more protection to air traffic. Contrails, volcanic ash and icing condition sensors are under test.

However, if flight sensors remain the most precise and reliable systems for tactical flight management, they can only provide nearby information. Pilot’s situational awareness and strategic decision making require other means, more global. External sources of information provide more contextual weather data and offer to the pilot a more complete overview of his environment. ICAO Convention on International Civil Aviation has defined in the Annex 3 the mandatory weather information that any country has to provide. This information integrates light text messages (METAR, TAF, PIREP) but also more complex charts (such as SIGWX, Figure 4 and WINTEM, Figure 5) or satellite imagery.

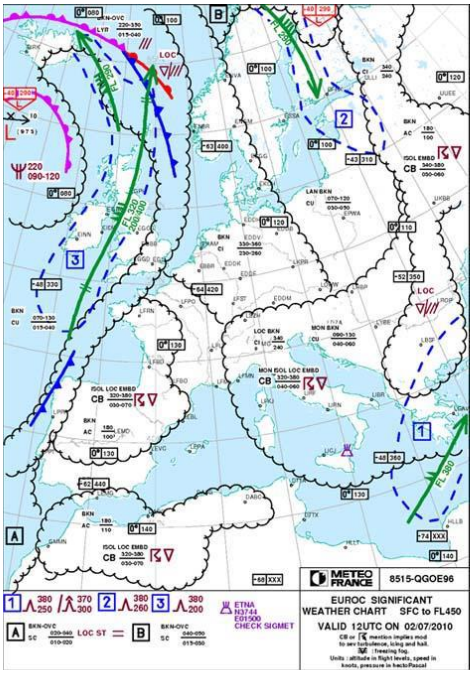

Figure 4: SIGWX chart

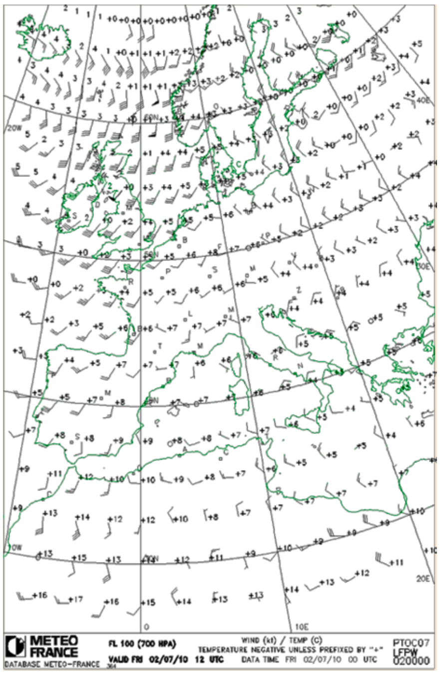

Figure 5: WinTem chart

Finally, the document also details aeronautical information and related risks. The surrounding air traffic remains the main risk for an aircraft. Automatic Dependent Surveillance – Broadcast (ADS-B) is the next main technology used for aircraft surveillance for both air traffic controller and the aircrafts. Based on position broadcasting, it enables every aircraft to be aware of the other airplanes position and intent (Figure 6).

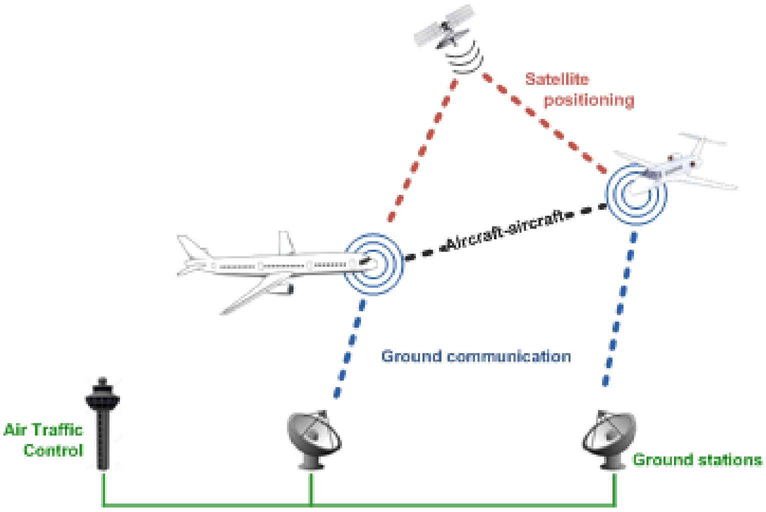

Figure 6: ADS-B principle

The second risk is related to the air traffic management. NOTice to Air Men (NOTAM) information is a notice to alert every pilot of a potential hazard in their flight route or at a specific location. The text message provides the hazard detail, location and date. Currently Eurocontrol in collaboration with the FAA, is developing the digital Notam (X-Notam). The X-NOTAM provides the same information than the classic NOTAM but uses the XML standard (instead of a text message) and integrates geographical information. The X-NOTAM is geolocalised and can be integrated into software applications (Figure 7).

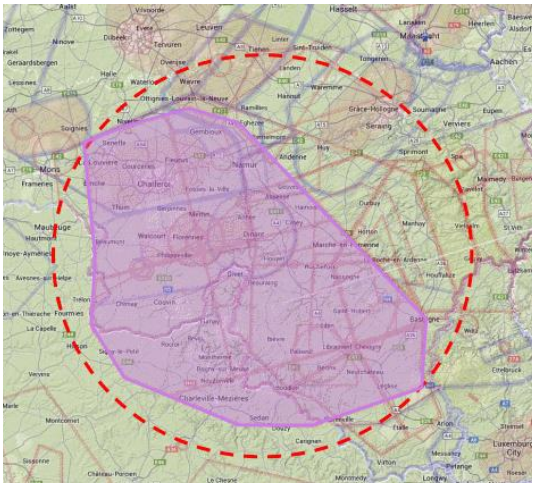

Figure 7: example of X-NOTAM (violet) and classic NOTAM (red)

Innovative methods for real time weather sensing

The last deliverable of WP2 focuses on innovative products and systems for weather sensing for aviation application. It reviews both internal and external evolutions in term of technology for better detection of weather hazards and details an innovative solution to determine water content by exploiting satellite signal of opportunity measurements.

The last evolution in weather radar paves the way to the adoption of dual-polarization radar for civil aircraft. Based on the observation of absolute horizontal reflectivity, differential reflectivity, linear depolarization, co-polar correlation and specific differential propagation phase, the dual-polarimetric radar is able to identify hydrometeor types and then provide a more precise information about the type of potential hazard in front of the aircraft. To measure air turbulence and characterize clear air wind fields, laser technologies and Lidars sensors are under development.

Weather services are investing in developing new algorithms from raw data (satellite images, radar images, etc.), to detect weather hazards and characterize them to provide a computed result, easy to integrate and interpret. Satellite-based convection detection products provide detection and characterization cumulonimbus cells (Figure 8). The detection algorithm, is able to evaluate the temperature, expansion rate, lightning activity or overshooting tops of each detected cells.

Other studies are conducted to improve weather prediction. High Ice Water content detection is important to prevent engine-power-loss events for commercial aircrafts. High Ice Water Content (HIWC) Algorithms for the Prediction of HIWC Areas (ALPHA, see Figure 9) are detection algorithms developed to mitigate such issues.

Finally, the D2.2 details an innovative method, based on the use of opportunistic signals from satellite systems for weather hazard detection. Using Ka or L band satellite signals from GEO, MEO and LEO constellations, the method uses occulting GNSS satellites signals to deduce the content of water vapor with the required precision (see Figure 10). Water vapor is an important parameter for weather evolution prediction. Since the installation of humidity sensors requires significant efforts, using a method based on already available source of information (GNSS signals) provides a significant advantage in term of integration and costs.

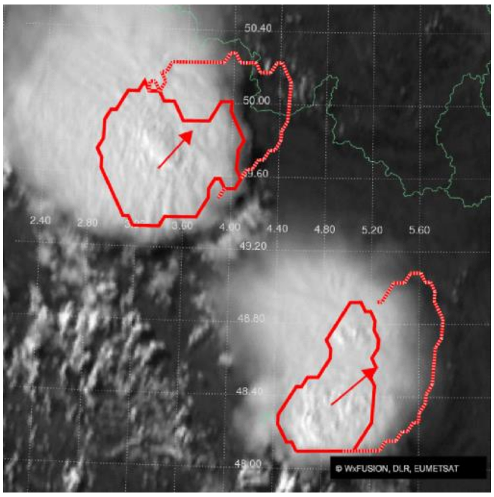

Figure 8: convection detection using satellite imagery (Cb TRAM detection algorithm, source: WxFUSION, http://www.wxfusion.com/products/cb-tram/)

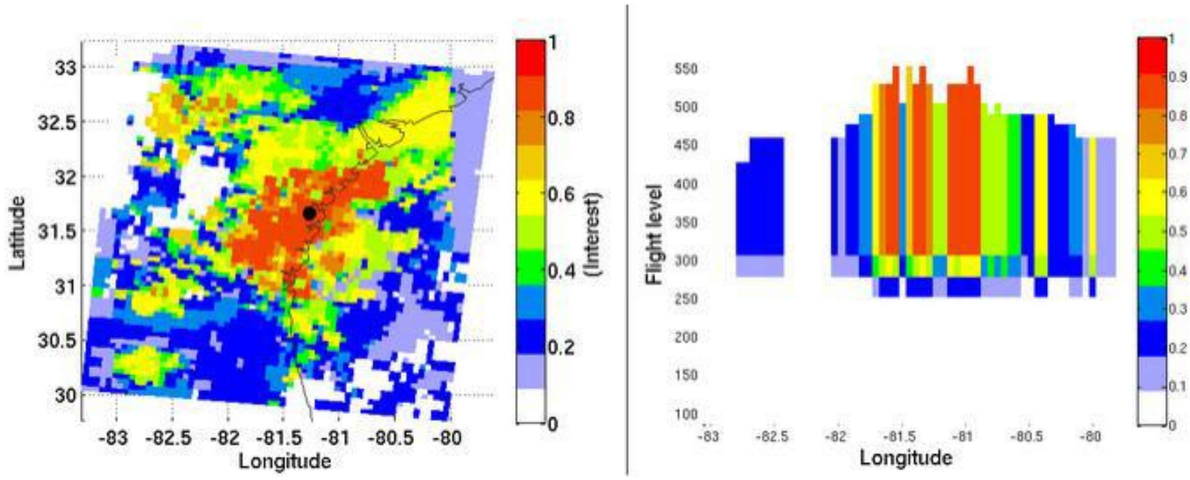

Figure 9: Preliminary ALPHA output displayed in plan-view (left) and vertical cross-section (right) format (Source: NCAR/RAL 2012 annual report, http://www.nar.ucar.edu/2012/lar/ral/icing-inflight-groundand-engine.html)

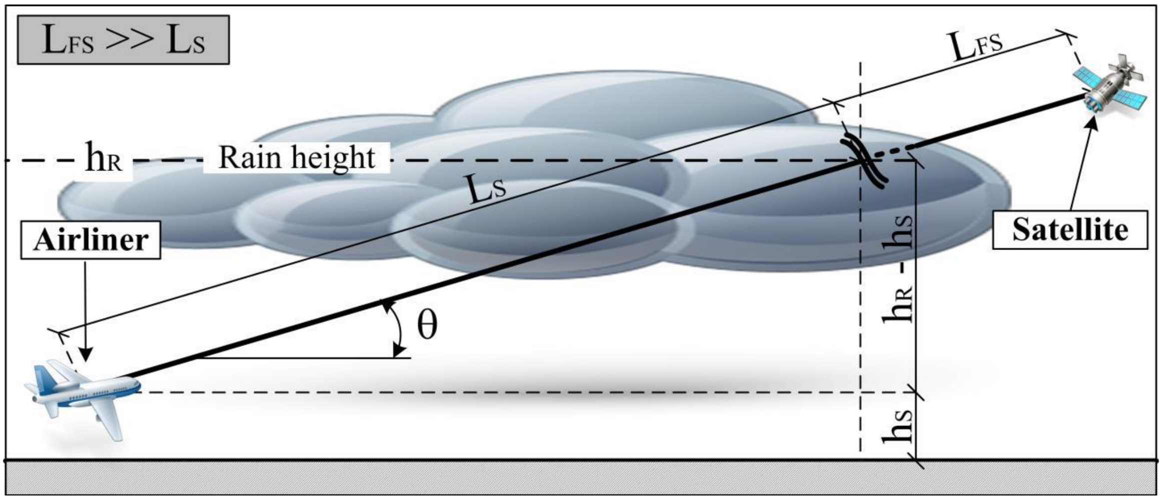

Figure 10: Simplified scheme for the exploitation of opportunistic satellite signals

The general scenario considered in the project involved both opportunity satellite signals and new dual-polarimetric weather radar. Weather radar remains the primary information source for weather hazard, and satellite based method is used as a complement when the radar cannot estimate the size of the hazard (case C and D, Figure 11). Using opportunity satellite signals for weather event estimate could, in such case, provide a precious information for a better determination of strong weather hazards (Figure 12). The external source will then provide a valuable complement of information and help the crew to determine how deep phenomena are.

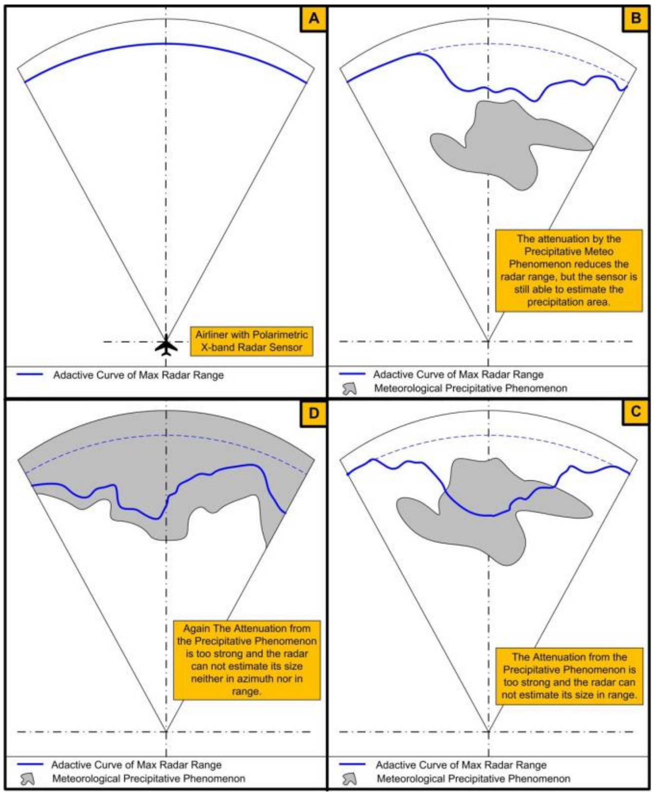

Figure 11: Meteorological event and adaptive curve of radar range: four scenarios where the radar is able (A and B) or not able (C and D) to estimate dimensions and intensity of the precipitations

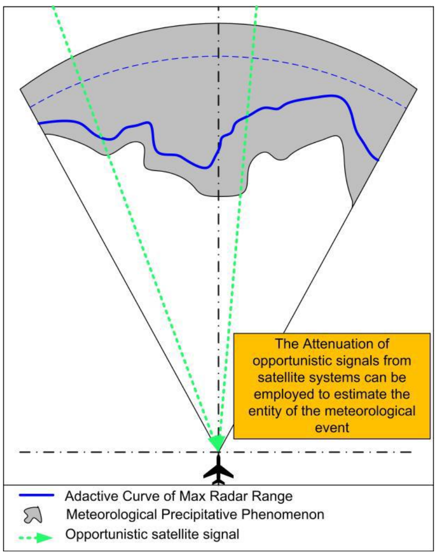

Figure 12: Sketch of the employment of opportunistic satellite signals to infer entity of precipitations

3.2 Simulation environment (WP3)

WP3 aims to simulate weather and aeronautical environment for downstream data fusion algorithms evaluation. The simulation environment, including data and software, has been named Replay. It has been designed as a Web Service which provides various products in simulated real-time. Replay development has been conducted following a classic engineering process from the user requirements retrieval, gathered on the D3.2, to the system design and development (D3.1). Finally, a user manual has been written to detail and explain the services provided by the software.

User requirements

Based on the analysis of weather and aeronautical source of information lead in WP2 D3.2 defines the main functionalities that the software has to fulfill. The general need expressed in WINFC project for data fusion can be divided into 3 main services. A Flight Service shall provide aircraft's positions through a flight route. This part will be used in the data fusion process to simulate the aircraft. Thus, two main functionalities have been designed to fulfill two possible simulation modes required for the project. Replay should be able to calculate and send the complete trajectory but also provide the positions in real time. Furthermore, the service should be able to manage different aircraft types. The second service created in the scope of WINFC is the Flight Traffic service, designed to simulate a surrounding air traffic, representative of a real situation. The functionality shall provide, in real time, the other airplane positions and intents, as if the aircraft receives ADS-B data. Finally, Replay shall provide weather data from different sources and type. Derived from WP2 analysis, legacy (METAR, TAF, sat images, etc.) and innovative (RDT, MPE, etc.) products should be provided to simulate external weather sources. Weather parameters such as wind, temperature and pressure, shall also be evaluated and send to simulated aircraft's probes.

Simulation software design and development

The system design and development has been detailed in D3.1 document. Replay has been designed as a secured web service. As defined in the user requirements, Replay manages three main services (Flight, Traffic and Weather services), to offer a complete simulation environment for the project. Figure 13 is a software overview of Replay.

The Flight Service integrates 57 simplified aircraft profiles and about 500 000 flight plans from Europe and the USA. The service is able to generate complete trajectories using the route provided by the user on a flight plan stored in its database. Thus, the user can either define its own route or request a flight between two airports. The system will then randomly select a flight plan and use it to generate the positions. Replay integrates also a navigation database. This database is required to understand the Flight route in ICAO format. Finally, the service is able to provide the result in 3 main different formats (json, kml or real time trough UDP). Figure 14 shows an example of flight route generated by Replay between Paris (LFPG) and Rome (LIRF).

The Traffic Service aims to generate and simulate other aircrafts position for data fusion. This simulated risk represent the air traffic environment, received by the simulated aircraft and transmited via the ADS-B or legacy mode-S tranceivers. The air traffic generation is limited in term of area and time, and only 2 full days of traffic have been integrated to Replay, only for Europe. User can use Replay to generate and retrieve air traffic position around a given position (circle) or in a polygon (Figure 14).

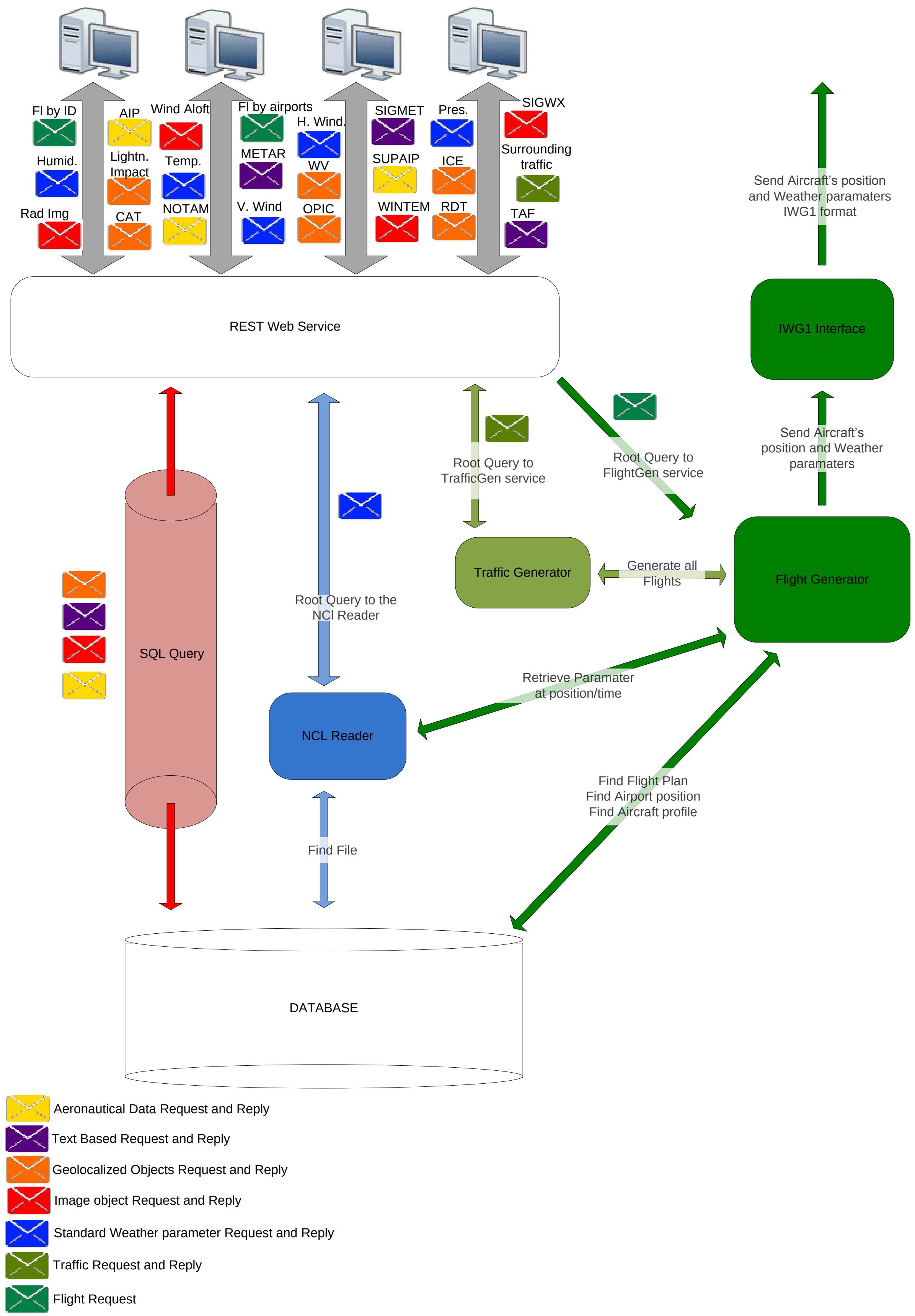

Figure 13: Replay system overview

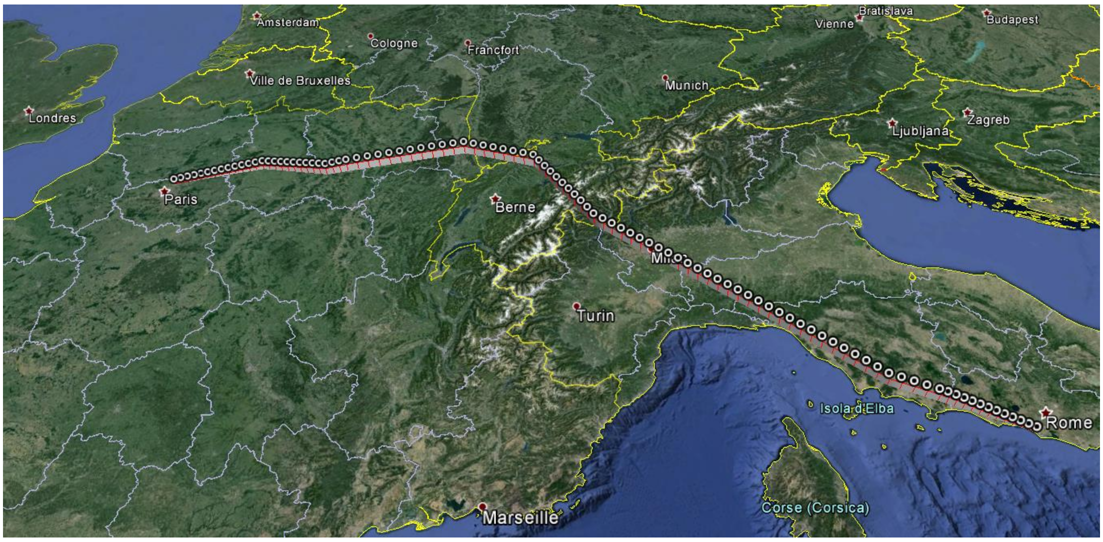

Figure 14: trajectory generated with Replay between LFPG (Paris) and LIRF (Rome)

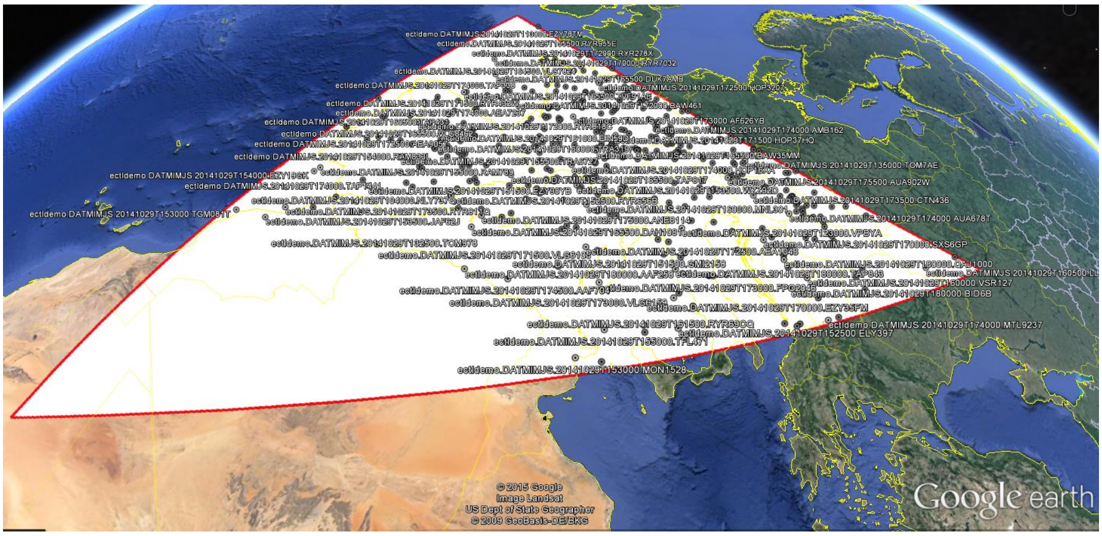

Figure 15: Example of traffic generated via Replay

The *Weather Service* is the last Replay functionality developed in the scope of WINFC. It manages weather data from both external simulated sources and internal probes. The probes simulation function is based on the ERA Interim weather model data that provides wind, temperature, pressure fields worldwide. For each aircraft position, Replay finds the closest area on the 4-dimension model grid (Figure 16) and evaluates the weather parameter values at the position. This information is integrated to the Flight Service and both weather parameters and 4-D position are sent to the user.

Finally, Weather Service also integrates legacy and innovative weather products. User can request METAR and TAF information from aerodromes and query thunderstorms objects in an area. More complex legacy products have been integrated to Replay. SIGWX and WinTem charts are available as binary files. Innovative weather products provide new valuable source of information for data fusion. Thus, Replay integrates convection detection products, determined using satellite imagery. The algorithm used is able to evaluate the treat level of the detected phenomena and determine the speed and direction of the cell. Convection detection using satellite imagery provides thunderstorm risk areas in different part of the world, including Europe, Africa, Caribbean isles or La Reunion. Replay is then able to provide the convective cells detected in the requested area at the requested date. Figure 16 is an example of thunderstorm area, provided by Replay. A second source of information has also been integrated to correlate the convection detection by satellite. Convective areas detected by ground weather radar provide the thunderstorm cells detected in France only. The product, based on weather radar detection, also provides forecasts.

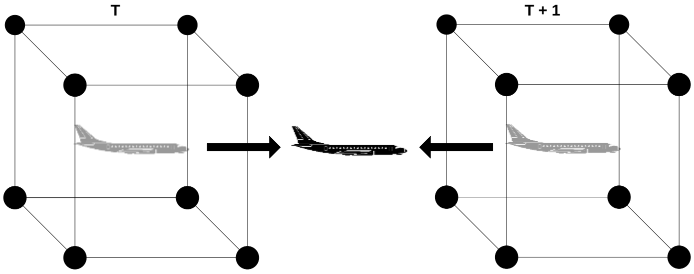

Figure 16: 4D interpolation principle for weather parameter

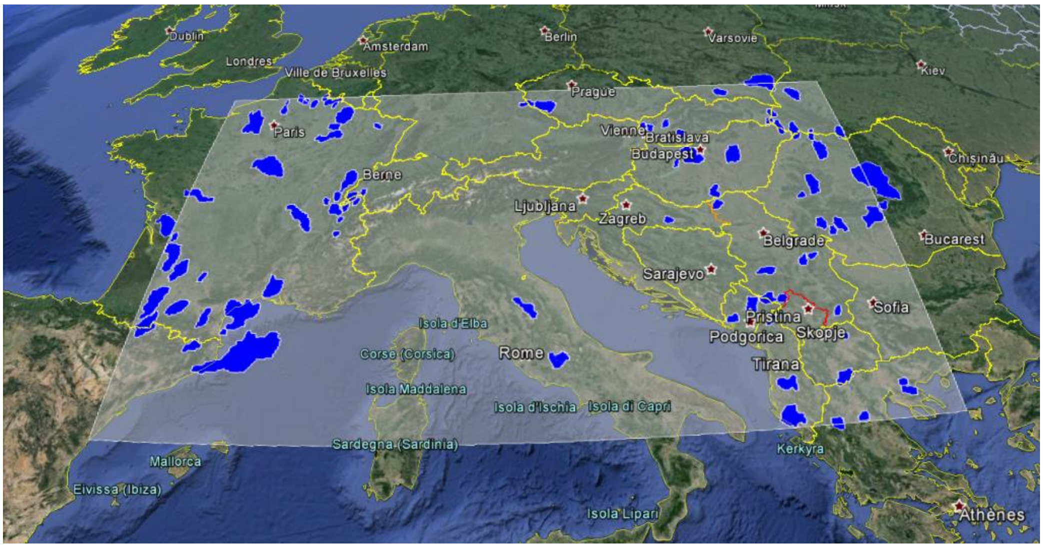

Figure 17: Example of convection detection in Europe

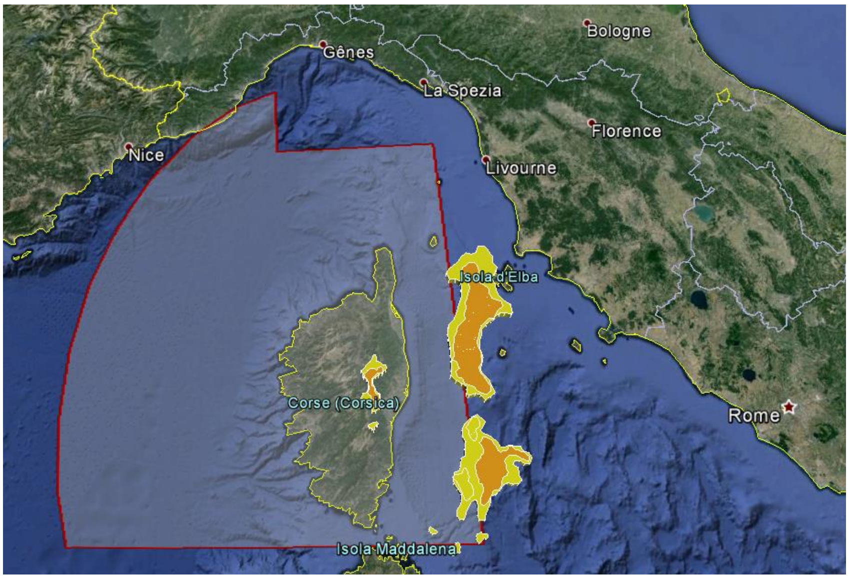

Figure 18: Example of convection detection using ground radar in Corsica

3.3 Data Fusion (WP4)

WP4 aimed at developing a data fusion tool of weather and traffic information to produce updated weather data display and an awareness map of hazards that can be used for the Q-AI optimization. The WP4 activity was divided in tasks, concerning Definition and problem analysis, Design and Development and Validation.

Tisting is performed in a simulated scenario environment that simulates the weather data incoming to the aircraft, together with information about aircraft traffic. After receiving input data, the WINFC data fusion algorithms are executed and produce an output in form of risk map that can be made visible to the pilot and input, if needed, to the on-board route re-planner. If there is the need or opportunity to change planned route, in order to avoid risk regions, a new possible risk-free route will be presented to the pilot by the Q-AI route planner with the ultimate objective of helping and simplifykng the pilot operations and to enhance flight risk awareness.

Scenario analysis

In order to build a scenario suitable for data fusion technique investigation and to provide input to WP3 activities, an extensive search was performed in order to select sources of information to build the desired scenarios. The two most well known sites are www.flightaware.com and www.flightradar24.com, Both sites rely on data from ADS-B network and show a database of past flights. They also can show partial information about weather conditions during flight, notably: reflectivity. Therefore it could be possible to examine data from past flights, particularly those which occurred during bad weather conditions, in order to examine the flight route. Data could then be merged with weather data retrieved from the public access archives of NOAA (http://www.ncdc.noaa.gov/). It is usually possible to see same flights a performed in different days, thus inferring difference in route as a consequence of weather. Unfortunately, the full information regarding planned route is only present, typically, for US flights and is absent for European flights(Figure 19). This is in contrast with the WINFC objective to find a critical European scenario. Moreover, even if planned route was available, it is still the route planned before take-off and based on weather forecast. In fact, it could be seen that several times the route had deviations apparently not correlated to the real weather conditions encountered. This was probably due to incorrect or imprecise weather forecast but the plane followed the planned route anyway. Therefore, although the above-mentioned web sites contain a load of interesting information for traffic analysis, they are not useful for our scenarios, as we cannot find a recording of flights that deviated from planned route and information regarding original planned route.

Other public databases are provided by the Federal Aviation Administration that maintains databases for the US; those are used to produce the operational metrics that are tracked and reported in order to manage and improve FAA efficiency. In particular, the OPSNET database provides the official source for traffic operations and reportable delay. Reportable delay includes the causal information such as the constrained facility, the reason for delay (weather, equipment, runways etc.) and the traffic management initiative employed in delaying the aircraft. (https://aspm.faa.gov/opsnet/sys/main.asp). This database gives the total delay registered during the flight. However, this is not a useful information for project objectives.

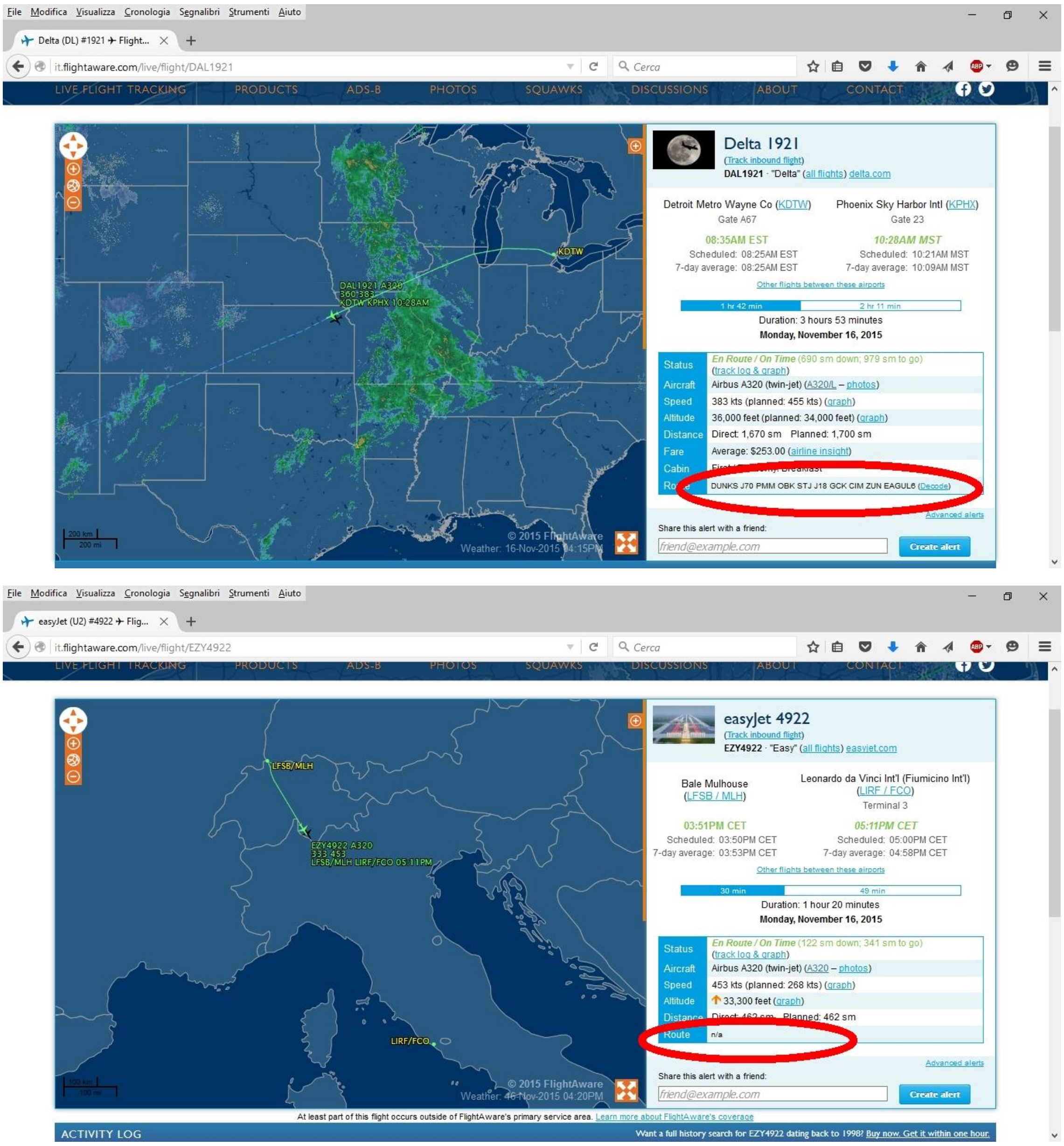

Figure 19: Screenshots from www.flightaware.com showing a flight on U.S.A (top) and a flight in Europe (bottom). The circle in red shows planned route for the flights in the US map, buti s not present in the EU map. Weather along flight is visible on US map (but only as a visual effect).

Other less known databases, constructed within EU funded projects were investigated such as “Programme for Harmonised ATM Research in EUROCONTROL” (PHARE) [http://www.eurocontrol.int/phare/public/subsite_homepage/homepage.html], “Flight Path Monitoring within the PHARE experiments was carried out by the Flight Path Monitor (FPM) one of the PHARE Advanced Tools toolset.” [https://www.eurocontrol.int/phare/gallery/content/public/documents/98-70-18-v6_fpm.pdf].

Part of PHARE project was the development of PHARE Advanced Tools (PAT). One of such tools was the Flight Path Monitor (FPM). The FPM tool provided the following four functions, among which the detection of deviations of aircraft from their planned trajectories. Our hope was that the first point had led to some public database of events. Unfortunately, it was not possible for us to have access to a database of recorded large deviations from planned route. Moreover, as the PHARE project took place in 1999, the flights we could eventually find would not be useful because we could not confront them with the actual or foreseen weather at the time of flight.

A more recent document from 2013: “Severe weather risk management survey - final report” [D3] was issued by EUROCONTROL, the European Organisation for the Safety of Air Navigation. The document analyzes effective management of severe weather impact on the ATM system and flight operations. The survey scope covered the entire chain of severe weather impact and risk management starting with weather forecasting by meteorological offices, addressing pre-tactical management by FMPs and the Network Manager and concluding with the deployment of tactical measures by ATC and pilots. The survey included:

- Analysis of all weather related hazards (except natural hazards) in terms of impact on commercial transport operations and ATS provision;
- Review of available and used meteorological products;
- Review of en-route, terminal and airport ATM procedures related to weather impact management;
- Review of existing severe weather impact assessment and decision support tools;
- Identification and analysis of aviation accidents and incidents in which severe weather and related atmospheric conditions were reported as either a significant causal and/or contributory factor.

One of the most interesting things from for use in WinFC project was that this document, in its Annex 7, contains a summary of accidents and incidents. Unfortunately, again, it was impossible for us to collect all the needed recordings of real route, traffic and weather information in order to replicate those scenarios. All we had was a synoptic list with brief description of various accidents of different gravity. In conclusion, our research did not led to finding a suitable and complete real scenario, including all necessary data regarding planned route, real route, air traffic and weather situation.

WINFC choice was then to develop ad hoc synthetic scenarios for Data Fusion testing, which would be based on knowledge from above described literature and could be realistic as a possible situation.

Data Fusion SW Architecture

The WINFC Data Fusion simulator is a system capable of reading data from different and heterogeneous data sources namely the weather sensors available on-board to produce the fused output of the incoming data, taking into account several factors, namely the sensors accuracy, the spatial accuracy and the update rate of the incoming data. The output, expressing risk maps, is produced in two different formats:

- Colored region output;
- Risk polygon output.

The general architecture of the simulation environment to be used to evaluate the data fusion system is depicted in Figure 20 highlighting the sources of information used to implement the demonstration scenarios and possible application of data fusion output, such as a simple display to be available to pilot, or information that can be handled by a Q-AI trajectory optimization.

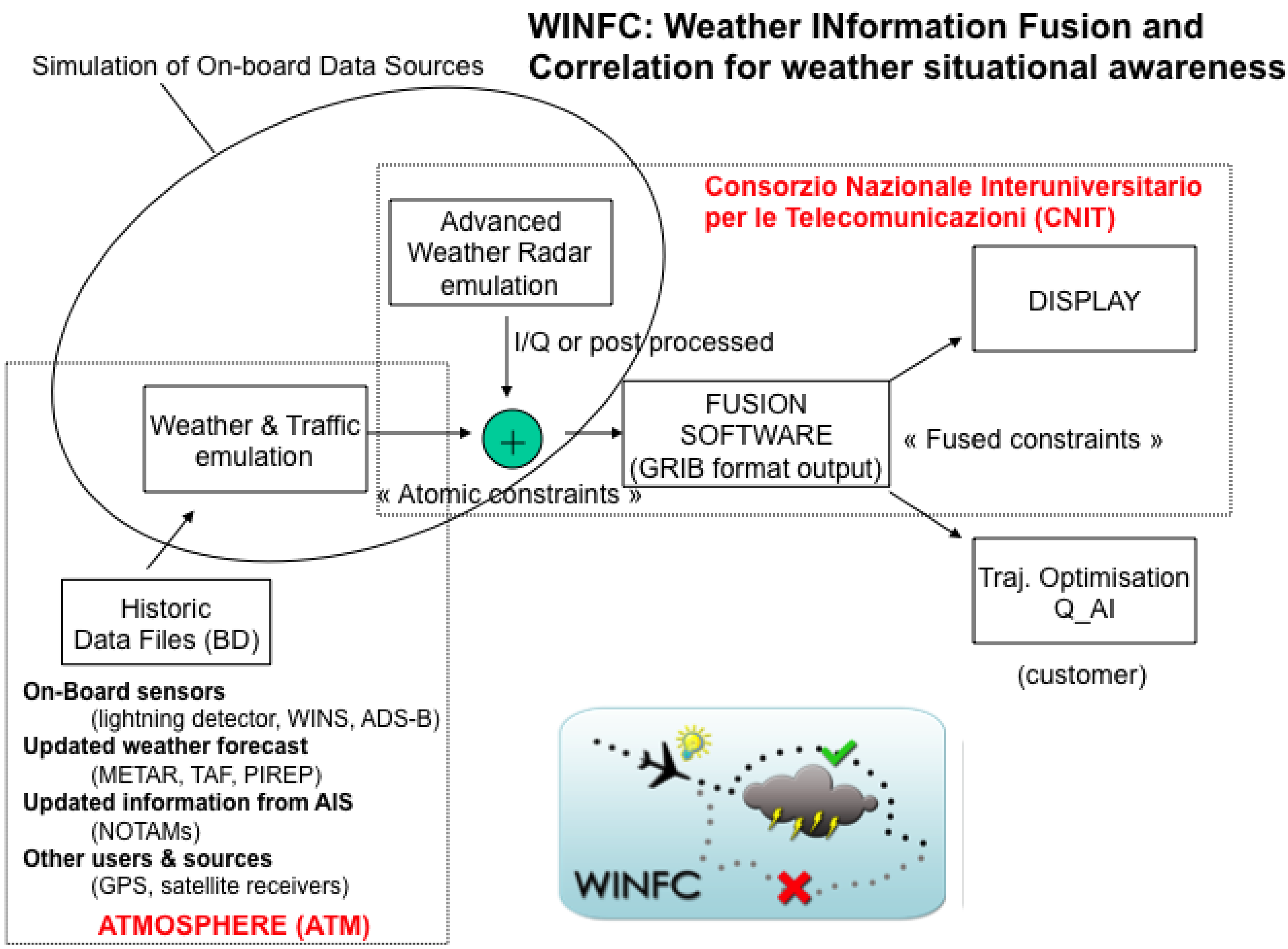

Figure 20. General architecture of WINFC.

The main assumption on the proposed architecture is that all the data sources shall be comparable. Therefore, for each weather data source, related hazards are defined (Table 1).

Table 1 Weather event and relate source of hazard for flights

Weather Event	***Hazard***
Hail	Presence of Hail
Thunderstorm	Presence of Turbulence associayed to convection and Heavy Rain
Turbulence	Turbulence
Heavy/Extreme Rain	Presence of Heavy/Extreme Rain
Light/Moderate Rain/Drizzle	Presence of Light/Moderate Rain/Drizzle
Snow	Presence of Snow
Supercooled droplets	Aircraft Icing (Moderate or Severe)
Downburst	Windshear in NO CAT (Clear Air Turbulence)

The risk factor is provided as results of the processing of different information provided by different sources in order to help the pilot to take the best decisions to reach his own aim: passengers' safety. The properties that are handled by the data fusion system are the following:

1) *Hazard Name*: See (Table 1) for the weather related hazard
2) *Timestamp*: A time identifying when hazard is predicted
3) *Sensor Rank*: A ranking of the sensor expressing heuristically the accuracy of the sensor in generating output for the specific hazard
4) *Phenomenon Severity*: Severity index associated to the Hazard
5) *Spatial Accuracy*: Expected accuracy of the hazard region expected to be affected by an hazard
6) *Temporal Validity*: Time interval for which the hazard is issued.
7) *3D Position* (LAT, LON, ALT): Point, segment describing regions the are affected by the hazard.

The definition of such properties is not trivial for data sources that are very different each other, and for some of them, especially weather data sources, it is not straightforward to define accuracy. However, in a data fusion environment, this approach has the advantage of allowing the use of heterogeneous data, and, in particular, the used of the same common approach for both wheatear data and traffic data. Moreover, additional data sources can be added using this unified approach. The architecture of data fusion is illustrated in Figure 21.

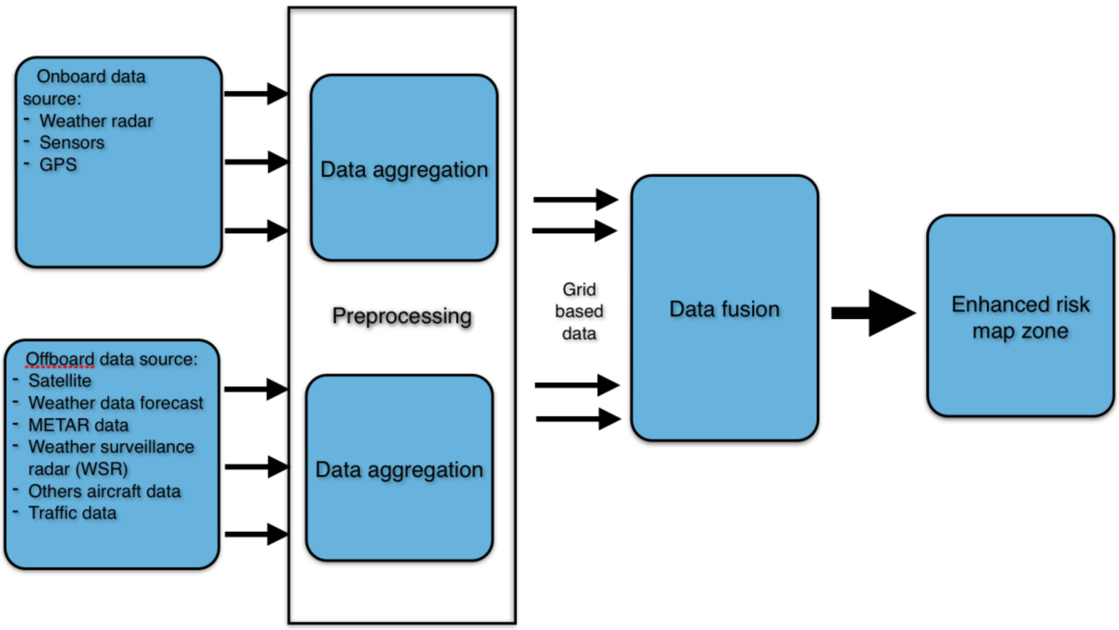

Figure 21. Data Fusion Unified Approach.

Data Fusion algorithms

Data Fusion algorithms are used in a wide variety of fields and different applications. Several different models exist and there are many different classifications used for data fusion processes. In order to begin a new data fusion application it is opportune to have a clear reference process model, choosing among the existing ones. Proposed for WINFFC real-time operation are:

- Occupancy grid based approach,
- Dempster-Shafer data fusion approach,
- Fuzzy rules based fusion approach.

The first applications of data fusion had military purposes. Different military application used a different terminology, so in 1986 Joint Directors of Laboratories (JDL) defined a process model for data fusion and a Lexicon with the aim of standardizing the terminology. In the current revision, adopted for WIN-FC purposes, it is as follows

- **Level 0 Sub-Object Data Assessment**: estimation and prediction of signal or object observable states, on the basis of pixel/signal level data association and characterization
- **Level 1 Object Assessment:** estimation and prediction of entity states, on the basis of inferences from observations.
- **Level 2 Situation Assessment:** estimation and prediction of entity states, on the basis of inferred relations among entities
- **Level 3 Impact Assessment:** estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants (e.g., assessing susceptibilities and vulnerabilities to estimated/predicted threat actions, given one's own planned actions).
- **Level 4 Process Refinement (an element of Resource Management):** adaptive data acquisition and processing to support mission objectives.

Our goal is to obtain a single risk map zone from the data fusion process. The risk map zone can support the pilot during the decision process. The architecture proposed has a centralized sensor fusion unit (represented in Figure 21).

The input data can be split in two categories: on-board data source and out-board data source. The on-board data sources are: polarimetric weather radar, GPS and possibly other kind of sensors. The out-board data sources consist of: Satellite imagery, weather forecast products, air traffic data sources, information for other aircraft, etc. Prior to perform Data Fusion, it is necessary to perform a pre-processing step for a) Aggregating data to describe one type of hazard; b) Make etherogeneous data comparable. For the second goal, we use grid based data, and therefore, different data types are aggregated and transformed in a specific data structure.

At this point, each grid based data is the input for the data fusion process and they are fused to make a risk map with every kind of hazard considered.

In WINFC the data fusion shall operate in real-time and the data fusion approach selected is of local type. The three proposed data fusion algorithms have the following general characteristics:

- Occupancy grid is adopted to cope with data that were present in previous temporal instants;
- DS based data fusion allows to obtain a smarter classification when the hazard phenomenon has been selected among a set of phenomena all present in that spatial position;
- Fuzzy based data fusion is used to manage uncertainties in the incoming data.

The general idea of all the algorithms is to merge two different kinds of data: data related to weather hazards and data related to air traffic, in order to create risk maps that contain more information.

3.4 Test and Evaluation (WP5)

The objective of WP 5 has been to show the test performed on the defined scenarios in order to achieve the requirements of Data Fusion (DF) algorithm and, in general, to achieve WINFC purposes. The test plan has been devoted to indicate a series of case studies in order to highlight the performance of DF algorithms in detecting and merging the principal sources of hazard along the flight identified as weather-related and air traffic-related. The weather-related hazard has been considered to be obtained using different types of data: the Avionic Weather Radar (AWR) at X-band (possibly dual-polarized) installed on board the aircraft, the satellite product Rapidly Developing Thunderstorm (RDT), the ground weather information (such as ground based radar, METAR, TAF). The air traffic has been determined from the information of the position of the other aircraft that could intersect the planned route at a given instant.

During the project development, several case studies, both real or form realistic simulations, have been proposed and discussed. Real case studies selected have been observed in South France or Italy. Important is an event occurred in October 2012 over Tyrrhenian coast in Italy sea. For air traffic, the case studies available occurred during 2014. Since weather data sources are more complex than air traffic to be handled in data fusion system, more case studies for weather than for air traffic have been defined in the test plan. Particular attention has been put on the availability of weather radar data at ground: at the moment any polarimetric radar on board are available and thus simulation or estimation of data need to be used and the availability of weather radar at ground provide an input to simulate X-band observation.

The test plan has been initially proposed separately for weather hazards and for air traffic hazards to allow simple data fusion focused on a single hazard. Three case studies for weather hazard and one case study for the air traffic hazard have been presented. The first case study (CS1) has been a simulated weather scenario occurred along the route Turin Rome. The second case (CS2) is referred to a real weather scenario obtained converting C-band actual radar observation into X-band observation for the area over the Fiumicino (Rome, Italy) airport. The third case (CS3) has been also concerning a real case occurred over South Mediterranean and simulated by the CNIT weather radar simulator. While, the last case (CS4) concerns two different air traffic events occurred during 2014 in Europe. The data availability both for weather related and air traffic related for the four case studies are summarized in Table 2. CS 2 and CS 3 have three weather sources that are referred to real case. The CS1 has just the AWR information not based on a real scenario and CS4 only the air traffic sources. To model a complete awareness pilot test, both weather hazard and air traffic constraints have been considered simultaneously. For this reason, a synthetic test has been built by merging real and realistic sources. In summary, the complete test case has included a set of synthetic case studies obtained merging weather sources of CS1, CS2 and CS3 with air traffic source of CS4. The three synthetic case studies obtained have been re-labelled SCS1 (CS1+CS4), SCS2 (CS2+CS4) and SCS3 (CS3+CS4).

The second part of WP have been devoted to show the results of projects in terms of performances of the data fusion approach and impact of WINFC on aviation. Results of WINFC have been obtained applying the data fusion algorithm to the synthetic test cases available for the test plan. Since DF algorithm manages different sources of data in which each data type has been classified by using a series of properties, such as the risk of hazard that is associated to the severity of phenomena, a specific data preparation of the different data sources have been performed. Furthermore, different approaches of DF have been evaluated. The first two are classical approaches based on arithmetic mean, while the third is the actual fusion result. The third approach has calculated the sum of risk, meteorological and traffic, considering that the risk of collision with another aircraft is greater than the risk of being in a meteorologically unstable region. Each risk cell can assume a value between 0 and 2 (Figure 21).

Table 2. The Weather and air traffic sources availability for the four Case Studies (CS)

	CS1	CS2	CS3	CS4
AWR	X	X	X	
RDT		X	X	
GWI		X	X	
Air traffic				X

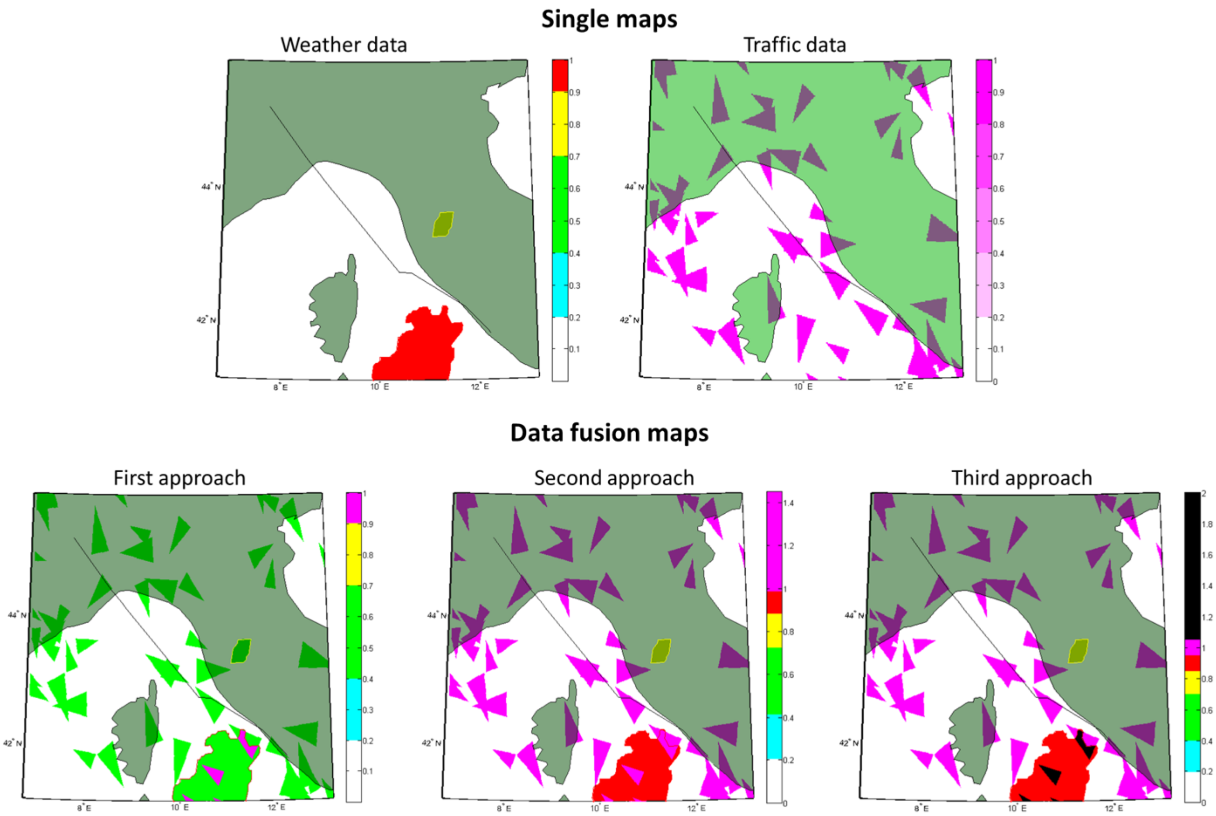

Figure 22. The data fusion test applied to SCS1 (CS1+CS4)

The DF outputs two different type of products: i) the *display* of DF fusion for the pilot decision and ii) *the Risk Area* used for the trajectory optimization (QA-I). The *display* outputs have been discussed testing different fusion approaches. Finally, DF performances have been tested showing the second type of output, i.e. *risk area* to optimize the route. In this test, the advantages of an extended range of pilot awareness as can be given by the data fusion of information coming from different sources was performed using a synthetic situation to implement the Q-AI installed on NEXIS EFB. The data fusion algorithm merges the risk zones elaborated from the different sources and Q-AI computes and suggests a new route that already considers also the risk zone farther away. The suggested route is overall shorter than the one in the calculated without WINFC sources (Figure 23 (a)), where two successive alarm events led to two separate deviations from planned route (Figure 23 (b))

(a) (b)

Figure 23. The EFB display shows the route Turin-Rome (green line), the Q-AI trajectory information in violet line implemented for the risk map (red polygons) calculated without WINFC information (a) and with WINFC information (b).

The impact of WINFC has been calculated using the International Standard Atmosphere (ISA), the BADA (Base of Aircraft Data) model for the Airbus A320 aircraft and the emission model as described by ICAO. We have obtained the following emission for the two different route computed by Q-AI, in the first case with only weather radar input and in the second case using the enhanced risk map obtaining by using data fusion between AWR input and GWI input. Model outputs are shown in Table 3.

This test has shown the impact of the WINFC project in terms of reduction of fuel consumption and emission that is the main CleanSky objective. A shorter route implies lower emissions in term of CO_2 and NO_x and saving costs in term of fuel consumed. Form a quantitative point of view, the impact using WINFC algorithms, applied to a short part of route (260 km) results in a reduction of 3% of emission.

Table 3. Outputs for a part (260 km) of Turin-Rome route calculated by Q-AI for risk map obtained by AWR (first row) and using WINFC (second row).

	Fuel (kg)	CO_2 (kg)	NO_x (kg)	Distance (m)
Q-AI	321,49	1015,91	3,51	268133
Q-AI + WINFC risk map	312,34	987,01	3,42	260400

4 Potential impact and the main dissemination activities and exploitation of results

4.1 Expected impact

The aim of the CleanSky system for Green Operations ITD, and specifically the Management of Trajectory and Mission (MTM) work package, is to demonstrate that the mitigation of external noise generated by the aircraft and the reduction of emissions (main environmental goals of ACARE, the European Technology Platform for Aeronautics and Air Transport) can be supported by the prediction of the new Green trajectory development.

The proposed WINFC module operates on board and collects information coming from weather data provider and traffic data provider. WINFC module can collect data and produces two main outputs: an awareness map that integrates weather changes and traffic changes during the aircraft flight, and an update weather map. The awareness map is a risk map that can be used by the pilot to immediately detect hazard conditions no matters whether they depends on weather or traffic changes. WINFC approach in unique, in its ability to merge data from on-board sensors with external sources, being conventional approaches based separate presentation of internal and external sources. WINFC architecture is sufficiently flexible to accommodate further products for flight safety that will be adopted by the relevant authorities.

4.2 Dissemination of the project

The dissemination of the project results has been carried out in two different ways: internal and external dissemination actions.

- *Internal dissemination*: the dissemination among the consortium partners has been done through the organization of internal meeting operated by audio or video conferences or held directly in the main sites of participants. Internal reports facilitated the divulgation of technical results among the project consortium staff.
- *External dissemination*: External dissemination has been carried out in four different ways.
    - (a) project web site (www.winfc.cnit.it)
    - (b) one open workshops addressed for the Cleansky community
    - (c) Participation to international scientific conferences
    - (d) Participation to Exhibition and DEMO sessions of international conference/events

4.3 Exploitation of the project

The results of the WINFC project provided useful benefits to existing correlated EU projects such as FP6 FLYSAFE (on flight safety), FP7 ALICIA (on operative conditions) SESAR (on overall air traffic optimization), SANDRA (on next generation of air-to-ground telecommunication systems) and CLEANSKY (on air traffic optimization to reduce emissions and noise pollution).

Specifically, WINFC will represent a useful procedure to verify how much the pilot decision support will have an impact in the flight green trajectory

4.4 Management of intellectual property rights

The project partners, CNIT and Atmosphere, agree on rules defining the access rights to the Intellectual Property Rights (IPR) on the Knowledge and on the pre-existing know-how, for the purpose of the achievement of the project on one side, and for further exploitation of those results on the other side.

4.5 Contribution to European Competitiveness

As explained in the impact section, WINFC can be considered as a reference model for aggregating and representing warnings to the pilot for what concerns all the main hazards affecting the aircraft flight. If the output of the WINFC is provided to a suited trajectory optimization module, a possible set of maneuvers to face such hazards are proposed.

European dissemination throughout the Europe also allows stakeholders to have a clear idea of the project results and show it to the air transport community, with a right level of new know how.

All these aspects are in the direction of providing significant gain in Europe, both individually and collectively, to have a significant impact for return of investment on Europe.

5 Address of project public website and relevant contact details.

5.1 Address of project public website

http://winfc.cnit.it

5.2 Relevant contact details

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