

Advances in Digital Meteorological Services (DMET) for ATM

Aviation Meteorology in support of air traffic optimization and automation

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Abstract— A change is required in the meteorological support for the future Air Traffic Management (ATM) System. New concepts of weather services must be tailored to safe efficient aviation requirements: improved accuracy, increased data availability, real time support, digital service and the use of shared information are some of the basis aimed to achieve the trajectory optimization, automation of operations, and fuel & time cost-reductions. DMET (Digital Meteo Service) paves the way for a net-centric service-oriented ATM system architecture where available data, air-ground connectivity and modern computational resources are taken advantage of to attain a 4D predictive model of atmospheric properties specifically designed for real-time support to aircraft operations. The effort, conducted as part of the ATLANTIDA project, consists of the prototyping of a digital service computing atmospheric data from several sources into a 4D predictive scenario that is periodically available to subscribers. By using many data sources -forecasts from global and mesoscale weather models, live observations provided by ground stations and the introduction of local airborne observations-, a well-tailored forecast product is developed. It consists of a 4D grid of pressure, temperature and wind data fields that are valid into an airspace cube of about $150 \times 150 \times 20$ km, within a time interval of 2.5 hours. On top of this model, minimum time, minimum consumption and other interesting cost-effective mechanisms in the weather use are covered, all being processed remotely in a supercomputing centre.

Keywords-component; digital meteorological model; air traffic automation; trajectory prediction; atmospheric wind; 4D grid; supercomputing; data assimilation

I. INTRODUCTION AND MOTIVATION

Air traffic operations are highly exposed to weather influences. A detailed knowledge about the past, current and future state of atmosphere, provided as Aeronautical Meteorological Information (MET) is required to enable the European ATM (Air Traffic Management) Master Plan and the objectives to be met [1].

The ability to have accurate predictions of atmospheric aspects such as pressure, temperature and wind at any place and time is instrumental in supporting automation in ATM.

Current automation tools such as Flight Planning and Traffic Flow Simulation Systems, Flight Management Systems, Flight Data Processing Systems or Electronic Flight Bags, among others, rely to some extent on Trajectory Prediction (TP) techniques, and so will achieve next generation automation in a sturdier way. Meteorological Services are addressed as a component to increase ATM performance. Weather Forecast is established as a transversal perspective throughout the SESAR work programme in WP11: Meteorological Services.

DMET is currently a small prototype to provide a point of interest for the future weather services. However continuous efforts will be carrying out for the optimization of aircraft weather related operations.

A. Aviation Weather Services: State of the Art

Heterogeneous formats, standards and the voice communications (problems of accent, pronunciation, phraseology, VHF voice channels saturation) are some of the traditional system limitations crawling to the present in the air traffic operations. In other way, the weather forecasts do not provide the necessary accuracy and updating to make possible the optimization required by the air traffic growth. Existing Meteorological Services, (centred in general requirements and standards) take little or no advantage of today's availability of data and computational resources. In the near future airspace users will need to operate much more efficiently. The way forward is that services and users will evolve taking full advantage of automation.

Prior work in this domain is driven by meteorological agencies and does not exactly point to the same objective. Other initiatives, focusing more on ATM, are quite incipient: NextGen (Next Generation Air Transportation System) Network Enabled Weather [2] is proposing a Virtual 4D Weather Data Cube, and ALICIA project [3] plays with meteo forecast focused on reducing weather-related delays in Europe.

The Digital Meteorological Service (DMET), in a prototype state, is a step forward in time and maturity with respect to the mentioned proposals. DMET model embeds the

state of the art of meteorological models with the most recently acquired datasets, both air and ground based, in order to provide highly accurate forecasts taking advantage of modern communication techniques and proposed airplane digital network protocols.

B. Resources for improvement

This research is followed by the recent developments in the prediction of aircraft trajectories based on stringent requirements about accuracy and reliability. Chief among those aspects are the spatial and temporal 4D, (four-dimension concept) distributions of atmospheric variables such as pressure, temperature and wind, in reference to one of the main objectives in SESAR WP4; the definition of the en-route trajectory management and separation based upon performance based 4D Navigation.

A major challenge nowadays consists of replacing existing meteo services by more sophisticated ones enabled by modern computational resources. Combining technology with the computing of extensive series of weather data and through the development of a net centric service for the forecast distribution, increased benefits will be performed with regard to current services.

This paper summarizes architecture, data flow, preliminary system/service implementation and tests of the DMET model as well as a brief evaluation of its performance to provide real-time operational support to ATM automation. The technology is in hand and now it is time to demonstrate that new concepts of operations will be available in the near future.

II. DMET CONCEPT OF OPERATION

Change the operational concept is the basis of the future European ATM System. Efforts for the next years are focused to obtain a single global scenario. Cooperation between participants, data sharing and systems interoperability using compatible technologies are some of the main ways to achieve the overall objective. The solution lies in a reform from the concept of operation. A change of Systems, Services, infrastructures and user procedures must be done by a continuing and progressive improvement. Focusing the subject to the Services (weather especially), concept must be based in a fully digital environment to ensure the right information and its availability. DMET has been defined to achieve the next key features of the evolving SESAR Operational Concept [4]: 4D Trajectory Management, Automation support, System Wide Information Management and Network Operations. Accordingly, main objectives of the Service are detailed below:

1) Weather Service Objectives:

- 4D weather scenario forecasts with detailed meteorological conditions
- Provision of web-based net-centric services supplying meteo forecasts in support of flight operations [5].

- Real-time short-term predictions (0 to 2.5 hours) of the 4D weather scenarios in support of tactical operations
- User tools to facilitate the integration and exploitation of the weather forecasts within user's systems
- Companion tools for trajectory optimization based on weather forecasts and other influencing parameters.

In addition, the design of the supporting services should be commonly aligned and based on processes of information management and decision making in a cooperative manner. According to this, particular attention should be paid to WP8 and his contribution to the ATM Master Plan by the definition of information exchange methods and support the standardization of ATM Information.

2) Requirements for future Weather Services:

- Access by all participants to existing meteo data
- Enabling collaborative decision making based on a common situational awareness -same weather scenario for all the participants coexisting in the same time
- Ensuring up-to-date 4D weather forecasts to service subscribers through frequent updates.

DMET is the prototype of a web based net-centric Aeronautical Digital Service and Meteorological Model focused to support future air traffic operations, based on the 4D concept and the future requirements. The overall objective to be satisfied by the service is to support aircraft operations based on predicted trajectories with the best possible degree of accuracy as far as the atmospheric aspects are concerned.

III. SERVICE ARCHITECTURE

The prediction of the atmospheric aspects is the result of a full-physic atmospheric model that evolves in fast-time simulation. At any given time instant, the model must have incorporated to the extent possible the information coming from the live observations that were available up to that point. Additionally, the model must provide the propagation of the atmospheric aspects within a predetermined time span in the future. Thus, the model is computed over a 4D grid of spatial-temporal cells. A major problem consists of selecting the size of the cells in a way that the amount of resulting data and the propagation time span for which the accuracy remains acceptable, reach a certain optimum. An additional problem appears related to the need of synchronizing model updates in order to ensure that, at any time, all users compute their trajectories based on the same weather scenario.

A. Global Architecture and Data Flow

The DMET architecture (Figure 1.) encompasses three main blocks that interact on a continuous basis: data providers, computation processes and service subscribers (clients/users).

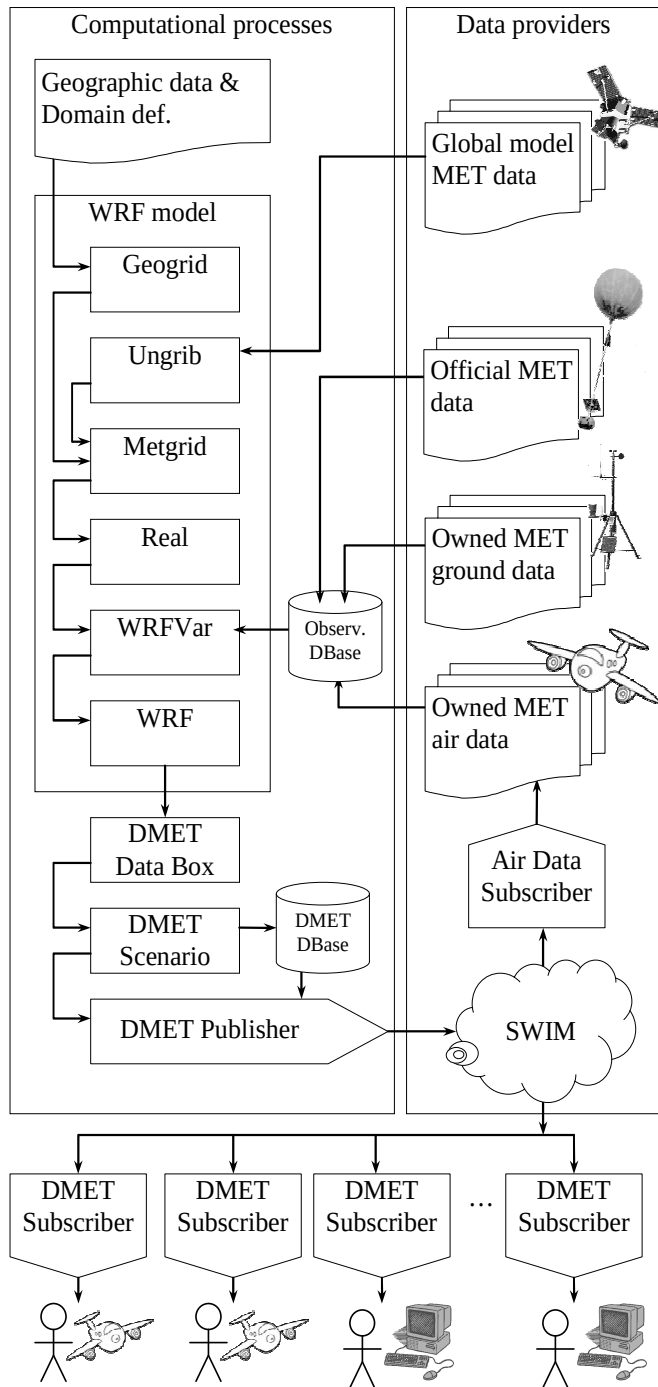


Figure 1. DMET Architecture

Access to external data sources and support to service delivery is performed through a SWIM (System Wide Information Management) middleware. The middleware enables users to subscribe in real-time to the weather forecasts produced by the DMET model. Essentially, DMET operates as a full-physicmeteorological model, very focused on certain geographical domains, that routinely updates the outputs as soon as external data is received from several sources of

information, some external and some others available to the project.

One of the pillars of the model is the Global Forecast System, widely used by the research community, and by now the only global meteorological model that is publicly delivered. Both spatial and temporal resolutions of the products are insufficient for ATM applications, but continuous updates from satellite and ground references are valuable as starting points for many mesoscale propagators. Refresh time is about six hours, extending the forecast to ten or more days.

B. Baseline Weather Data

1) Weather Data Types:

Global weather models, fed by existing weather scenarios and large scale thermo-fluid mechanics engines, are systematically published by international agencies to be used as starting points for mesoscale and regional models.

The Spanish Meteorological Agency (AEMET) provides free online data about real-time observations made by its network of ground stations as well as outputs coming from the HIRLAM [6] model. The data, which is updated every 10 minutes, comes from main stations located in airports and other national facilities. A couple of those stations are located within the area where our experimental airspace is centered and many more are settled in adjacent domains, which are used to settle appropriate boundary conditions for the finer computation of the central model.

Accuracy improvements and customizability in the scenario modeling are achieved through the introduction of local data in the computing process. Apart from satellite captures, real time meteorology -observations based- is also taken into account. Such local data corresponds to real time observations of atmospheric characteristics captured by all airborne and ground sensors available.

- A network of own meteorological stations deployed on the scene allows the fundamental atmospheric parameters to be continuously acquired and reported to a main (computation) cluster. The idea is to make real observations available, which the primary computation output has to fit to. Geo-referenced observations of atmospheric conditions obtained in real time are introduced in a first grid iteration aimed at attaining a better match between model and reality. Thus, observations referenced to the met stations are assumed to represent the exact existing atmospheric conditions at the respective locations while the volumes near about (volumes of influence) are forced to fit a reasonably good approximation. The configuration of sensor network must be tailored according to scenario characteristics such as size, relief and typical climatology.
- Local Airborne observations: A new concept is here provided looking towards future standards of

information sharing and networking. The introduction and use of local airborne observations is a high value tool. Considering multiple data from different time-space locations and altitudes around the world airspace will perform the obtaining of an accurate 4d map about the next and future weather conditions in different earth domains. Challenge is very accessible in terms of technology; Modern aircraft are equipped with navigation capabilities that allow them to accurately sense and all interesting atmosphere parameters along their flight path. Having an air-ground datalink in place, the local airborne observations made by all aircraft operating within the airspace of interest could be taken advantage of to enhance the accuracy of atmospheric predictions, especially at those altitude levels where the aircrafts operate. Tests had been made receiving airborne data from simulated ATM scenarios. Thus, the DMET service traits the aircraft capable of sensing atmospheric parameters as mobile meteo stations and considers the data provided by them within the computation processes in the same way as it does with the ground sensors. Preliminary results show further benefits in the accuracy of parameters. The downlink of aircraft met data may be future based on the introduction of new surveillance systems as well as by the use of ADS-B applications. Integration requirements, standardization needs and the sum of benefits are facing hard in WP 11. Considering the majority of aircrafts operating within European airspace will be required to be equipped with some form of the surveillance technology, this may be the way to satisfy the required information for the weather forecast accuracy improvement.

Finally, other applicable detectors like infrared cameras for land way temperature or modern LIDAR (Light Detection and Ranging) have been considered in simulations, although no specific development has been included in experimental activities so far.

2) Local Data Assimilation:

A non-trivial problem arises associated with the acquisition and treatment of local observations coming from heterogeneous sources within the undergoing processes in the remote model computation cluster. In effect, in addition to the disparity in format, location, timestamps, and communication protocols, each data source has different inherent accuracy and must be given a different level of confidence accordingly. Three steps are necessary, i) first guess from global models, ii) external data harmonisation and iii) data assimilation in the model. Official global weather data from Met Agencies and local observations coming from ground-based and airborne sensors are collected and channelled to a common database where the data remains stored until the appropriate process makes use of it. Timestamp, data source, location and meteo variables are homogenised in units and scales, and appended to the table as soon as there are received from the different

external engines (local or remote). This way, the data storage is asynchronous with respect to the model execution, minimising latency in the use of the information.

For data assimilation, a mature time-static variational scheme has been used [7], where correlation background files are obtained from hourly model outputs processed during 30 contiguous days. The process tries to minimize a quadratic cost function providing the best compromise (minimum variance) between the a-priori estimate (or first guess) from the model and the available observations, the fit of which are weighted by their corresponding errors.

Extending this approach to time-dynamic schemes or more complex ensembles that transform the Kalman filter is foreseen in the future, once these techniques have proved an improved accuracy with the available throughput.

C. The Atmospheric Model Structure

The basic model structure is a 4D Grid of spatial temporal cells. Size of cells is function of the propagation stamp and the acceptable accuracy for ATM. The structure of the 4D grid that represents a particular weather scenario is divided into the following elements (from less to more complex): “LAYER”, “BOX”, “OBJECT” and finally the “SCENARIO”.

For each specific time instant, a “Layer” is a 2D grid of values of a certain atmospheric property at equally spaced points located over a surface of equal pseudoaltitude (an internal dimensionless vertical coordinate based on pressure levels). The complete set of layers that covers the range in altitude is called a “Box”. Each time instant is associated with five boxes, which correspond to pressure, temperature, the two horizontal wind components and the geopotential altitude. The set of these five boxes is called DMET “Object”. The time dimension is achieved by queuing objects into a so-called DMET “Scenario”.

D. Computational Process:

DMET Computational process uses the WRF (Weather Research and Forecasting) architecture. The WRF model is a fluid computational dynamics code for atmospheric simulation and weather prediction that implements a full-physic non-hydrostatic equation model. WRF is referred as a multi-agency effort to build a next-generation mesoscale forecast model and data assimilation system to advance the understanding and prediction of mesoscale weather and accelerate the transfer of research advances into operations [8]. Thus, WRF meets all the requirements for the present application, being rigorous in its formulation [9], but flexible and efficient in parallel computers.

The modular architecture of WRF can be summarised as follows:

- Geogrid: domain definition, boundaries and digital elevation model setup; this module needs only to be run once per simulation site, generating the working mesh. Three domains are nested, to deal with large

mesoscale, regional and local domains (typically 10000, 1000 and 100km in width).

- Ungrib: in charge of global data decoding to generate the first meteorological fields to initialize the model.
- Metgrid: performing the horizontal interpolation of meteorological data to the domain grid.
- Real: same for vertical interpolation to pressure levels.
- WrfVar: this module is in charge of the external data assimilation, inserting observations through variation techniques. In DMET model, the observations are all stored in a common database from which data is transferred to the simulator every time this is executed.
- Wrf: propagation module able to produce forecasts using fluid mechanics equations.

Every time an object is generated, the publisher module is activated; again, time to publish a full box should not exceed the processing time for the next box, although this can happen if the network is saturated and the system has to survive that by implementing FIFO queues). In a single run, the model produces enough predictions to support trajectory propagations during TMA (Terminal Manoeuvring Area) operation.

One hour later, the process repeats. Some of the forecasts are then redundant, since that point in time had already been calculated in the former run. New datasets, however, embed more recent observations and possibly, after three hours, updates of the global model. The timestamps and other control identifiers allow subscribers to compose a coherent 4D scenario with a good understanding of the accuracy expected at every future time.

Current implementation of WRF produces 4D scenarios every hour, each one including a 2.5 hour forecast at intervals of 10 min (15 time samples). Domain size is configurable; the default being 150km x 150km, compatible with the TMAs allocated to the test airports. Vertical dimension comprises from ground/sea level to 20km high (top of atmosphere level) with a resolution of 27 layers.

IV. DMET IN THE FUTURE INFORMATION MANAGEMENT SYSTEM

A. ATM Service Requirements

ANS (Air Navigation Services) in future ATM contexts demand the fulfilment of higher requirements in terms of amount, availability, real-time updating and accessibility of information. WP8 (Information Management) and WP 14 (SWIM Technical Architecture) set the ideas for the developments of the properly communication and dissemination architecture: future services must be implemented in the "Service Oriented Architecture" in order to get the "Aviation Intranet Concept" [10]. The infrastructure supporting such data distribution requirements has been paid much attention in the past years, the research efforts leading to a service-oriented concept called System Wide Information

Management (SWIM) [11], which is envisaged as the medium-long term effective solution for data management and services in multiple-user net-centric environments. SWIM will be the enabler for the information sharing in the required time, quality and security. In Eurocontrol terms relating to the future ATM system, SWIM is focused as being "the tool for the establishment of a network centric information environment". The bases are the provision of air traffic services living in a middleware in which the data distribution must be done in a common digital format and under a standardized management system.

B. Communication and Dissemination

The weather Data modelling and the building of the required infrastructure to make possible the forecast distribution by SWIM have been developed by two ways: firstly, the selection of the communications paradigm and secondly by the outputs modelling. The terms are right defined here:

1) *Technologies*: the DMET approach to the dissemination of atmospheric 4D models is based on a Publish/Subscribe paradigm. In effect, users subscribed to the DMET service will receive periodical information with the latest forecast available. Thus, DMET provides a widespread, periodic and automated service. The technology used for its implementation is based on the OMG Data Distribution Service (DDS) for real-time systems [12]. DDS is the first open international middleware standard addressing publish-subscribe communications for real-time and embedded systems.

2) *Datapacket modeling*: process outputs had to be modelled to fit to the aforementioned dissemination standard. Data packages making up the MET scenario should satisfy both: user and technical requirements for an optimal publication, specifically; i) multiple user support; ii) regular and real-time updating, iii) compliance with DDS technology specifications, iv) acceptable bandwidth usage and v) provision of user- understandable data or decoding support. User multiplicity, data updating and data flow management are addressed by means of the features provided by the of DDS technology. DDS creates a globally-accessible shared data space in which components and interfaces can be decoupled from each other and from the underlying platforms their location in the network. In turn, delivery time is dependent on the particular resources and the control of data flow can be managed to certain extent through customization of QoS (Quality of Service) configuration parameters.

DDS operation lies with the reading and writing of data-objects defined as "topics". Topics are the basic units of information or data packets. Thus, all data to be distributed over the network must be contained in a fixed structure previously agreed among the end-parts that can be expressed in IDL (Interface Definition Language). To accomplish with

DDS, DMET service outputs are required to be locked in fixed data structures.

The size of 4D meteo models instances is so large that, if put in single data packet, their transmission would monopolize all the network communications resources in a typical infrastructure. Thus, in order to avoid conflicts with other information flowing through the network that can be more time-critical, an approach for splitting the 4D meteo model has been developed. The approach defines 2 topics:

- The “MetaData” Topic, that identifies data for the generation of the new met scenario, and
- The “DMET Scenario”, which itself splits into layer instances of the overall atmospheric model.

The MetaData topic includes the data header that provides the necessary information for the assembly of the new updated model structure at the end-user side. The second topic hosts the meteorological information following the compositional structure settled by the former. Metadata topic is a layer instance of the atmospheric model.

V. DMET PERFORMANCE ESTIMATIONS

In order to estimate the feasibility of the proposed service, a miniature test has been performed in a Beowulf cluster composed of four computers (seven slave nodes and one master). The system is homogeneous in hardware and software: Intel Core 2 Quad CPU Q6600@2Ghz, 2GB RAM, OpenSuse 11.2 OS. Besides this, there is a data collecting computer in a hangar by the local airport (León – Spain) runway, where local meteo stations (two of them) delivers their readouts. Finally, a dedicated computer offers a model viewer linked to the SWIM network, where products can be checked for quality, navigated in altitude and time, compared cell-to-cell and prepared for fast access to support real operations. All the products received are stored in a general archive that can be used for off-line validation.

Performance is always a critical issue [13] in meteorological simulations. Each model run takes a lot of time and the requirements often recommend better resolution, shorter refreshing times, longer forecasts and even ensemble products. Thus, it is important to improve every simulation step in order to get outputs as fast as possible. Some DMET modules can be compiled with parallel support so that global process can be divided into smaller tasks, executed in different processor cores in the machine or in the network. Operation timeline is of paramount importance, since real time, processing time and simulated/forecast time are involved in the process. Besides these, communication time can be relevant if datasets are large and refresh time short.

But all this is only possible if the geographic domain is limited. On the other hand, very limited territory leads to few readouts from official stations, and the poorer forecast. A compromise solution could be to use a 150 x 150 x 20 km domain, which can be successfully contained in a 100 x 100 x 27 cell grid. Time domain is atomised in 10 min forecast time

steps, producing 15 files in each simulation (2.5h). A proper performance index is the processing time spent on producing one hour forecasts per square kilometre. For the first case, in the small cluster of 20 cores total, simulation takes 20 min, resulting in 21.33 ms/km²/h. The transmission speed currently reaches 140s/object, fully compatible with the cluster performance. The same simulation in 32 8-core machines of the supercomputing centre takes 2.13 ms/km²/h, one tenth of the former figure. Scaling with number of nodes has a limit, determined by the size of the chopped domain. With the above numbers, coverage of whole Europe would need to multiply by 30 the computer throughput if 1500 m resolution needs to be maintained. That is not impossible nowadays, since there are various supercomputing centres in Europe that clearly overcome the figure of 1024 4-core computers. The explained model has been tested for accuracy using two kinds of references, both from AEMET: meteorological forecast service and atmospheric sounding data. Preliminary results obtained from data corresponding to August 2010 at Santander airport (North coast of Spain), show excellent matching with AEMET-HIRLAM forecasts and less than 10% mean error in wind speed modules within the operational range below tropopause. Obviously, this analysis needs to be extended in space and time to certify an acceptable quality of service for future operational use.

Illustrations provided on Figure 2. show a comparative among DMET and HIRLAM forecasts with AEMET observations. The root mean square errors of the forecasts are represented for different heights in order to get some conclusions about the performance of DMET and HIRLAM models. It should be highlighted that DMET was working without any external data assimilation.

The main conclusions are

- Pressure: considering the atmospheric truth given by AEMET sounding, DMET model is as good as HIRLAM or even better in most of the altitude range, with the only exception of ground level; the availability of ground truth in the airport at the time the simulation was conducted would have clearly removed this small error. In any case, the pressure error is below the margin that could affect flight performance.
- Temperature: DMET model is more accurate than HIRLAM over 2000 m high; below, a typical shift of less than 0.5 K is present; again, ground truth is the key point for this behaviour.
- Wind velocity: both the official HIRLAM and DMET present quite similar errors in wind speed estimations. Typical error figures of 2/3 m/s in the range of interest for aviation are obtained. This performance can be improved with the inclusion of more external wind data in real time, specifically those taken in altitude. The fact that both models behave similarly with respect to the balloon sounding may reflect the difference between spatially/temporally averaged wind data versus instantaneous readouts.

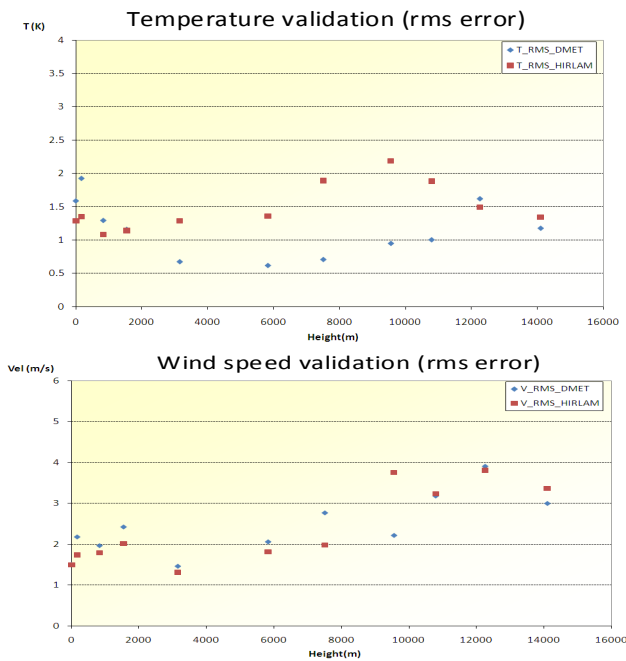


Figure 2. Temperature and Wind Speed errors estimated from wind validation campaigns

VI. TOWARDS THE ATM AUTOMATION SUPPORT: DMET FOR THE OPTIMIZATION OF FLIGHT TRAJECTORIES

Presently, there are efforts worldwide to automate the air traffic management, compressing from seasonal route programming to the development of decision-helping tools for air controllers. In all cases, meteorology is a key issue both for security and effectiveness reasons. When dealing with light aircrafts, atmospheric conditions such as rain or wind fields can become critical. Moreover, should the flight manager (or pilot) be autonomous enough, the real-time decisions on the optimum trajectory to the final destination may sensitively improve the performance.

Apart from safety issues, one of the most relevant applications of a DMET service is the optimization of flight trajectories. In order to check the validity of the developed model for this particular job, some numerical and analytic methods for airplane trajectory optimization have been designed and tested, initially for cruise phase. In this paper, only a brief overview of these studies is presented.

The algorithms implemented are twofold:

- Constrained programming methods (Dijkstra algorithm [14]): developed for structured and unstructured meshes, demonstrate good performance when state vector dimension is very limited (minimum 2D-flight time at constant velocity, minimum consumption at 2D-flight constant throttle and vertical wind, etc.)
- Analytical methods: direct or indirect, these methods solve differential equation systems meeting Pontryagin's minimum principle [15][16], a necessary

condition to reach the optimum path. Pseudospectral algorithms are currently under assessment.

In all the above techniques, atmospheric parameters play a relevant role. Dynamic pressure is proportional to air density, impacting heavily on engine and propeller performance and aerodynamic actions. Wind velocity adds to ground speed to modify aerodynamic speed, with quadratic impact on aerodynamic actions. Besides, most of the optimisation algorithms explicitly include wind speed components and their spatial derivatives in the resulting trajectory equations. The availability of DMET products, with high spatial and temporal resolutions, allows a comparison between conventional trajectory prediction simulations and a more sophisticated scheme where non-uniform atmospheric conditions are used.

In order to provide clarifying examples, tests developed until now have included the utilization of cinematic models for several cases of level flight: cruise at constant air speed, constant propulsion power, air speed constrained within certain range, flight in thermal ascending winds and obstacle negotiation. The most common cost functions include minimum time and minimum consumption. The importance of wind field knowledge, especially when the desired (or available) aircraft speed is comparable with present winds is demonstrated. Should the aircraft be very fast, the influence of winds on best path design is lesser.

Even in that case, a common meteorological reference is of paramount importance to proceed with automatic conflict resolution and hence safe optimization of the airspace usage.

Next steps in the demonstration of these concepts shall include dynamic aircraft models, ascending and descending paths and other more complex optimization functions. Besides, spatial resolution is more and more demanded in today's trajectory prediction systems, specifically in the surrounding of airports. The combination of coarse meteorological models and detailed CDF (Computational Fluid Dynamics) computing provide useful information at the expense of computer throughput requirements and complex interface decisions. Modern supercomputer centers and advances in the state of the art of terrestrial boundary layer studies envisage a promising perspective in the operational use of these techniques, which are currently under implementation in DMET.

CONCLUSIONS

The long term support tools for ATM automation shall necessarily rely on consolidated, reliable, available and fully accepted meteorological models. The nature of the atmosphere and the fluid dynamics laws make this goal a challenge for current developers of technical and legal frameworks of operations, as SESAR or NextGen. In the current work, main technical difficulties are reviewed and some concepts proposed to better estimate the capabilities of current systems and the needs for the future.

A step ahead in the integration of modern meteorological models in the process has been proposed, simulated and tested. The effort consisted of the development of a digital meteo

model (DMET) that combines atmospheric data from several sources into a 4D predictive scenario that is made available to subscribers through periodic updates.

Atmospheric data sources include forecasts from global and mesoscale weather models as well as live observations provided by ground stations and aircraft in the scene. The final product consists of a 4D grid of pressure, temperature and wind data fields valid over an airspace cube of about $150 \times 150 \times 20$ km, within a time interval of 2.5 hours. Preliminary validation is very encouraging, so more effort is currently being dedicated to move the concept closer to operational requirements.

On top of this model, minimum time, minimum consumption and other interesting trajectories are simulated and shown to check impact of wind. The service has also been used for trajectory propagation and conflict resolution by other Spanish research partners, with promising results.

Now, apart from accuracy and processing requirements, efforts should be also allocated to the paradigms of management of meteorological maps, in order to ensure all the actors involved in ATM perform operations using compatible data (dates of generation of predictions, formats and data involved, etc.). This is a huge work that would need a lot of coordination within SESAR.

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