Meteorological Uncertainty Management for Trajectory Based Operations — TBO-MET

ENGAGE KTN workshop

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SJU, Brussels, 13 November 2018

SESAR JOINT UNDERTAKING

Founding Members
EUROPEAN UNION EUROCONTROL

TBO-Met Consortium

Universidad
Carlos III de Madrid

Outline

1. PROJECT OVERVIEW
    - Context
    - Objectives
    - Scope
    - Concept
2. PROJECT RESULTS
    - Summary of results
    - Outcome
    - Conclusions
3. PROJECT IMPACT
    - Achievements
    - Contribution to the ATM Master Plan
    - Roadmap for next steps
    - Recommendations for future R&D activities

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Context

SESAR 2020 Exploratory Research

Specific challenge: "to research enhanced meteorological capabilities and their integration into the ATM planning"

Expected impact: "to enhance ATM efficiency by integrating meteorological information"

TBO-Met framework

Development of methodologies to manage weather uncertainty information suitable to be integrated into the ATM system

➡ **A probabilistic approach is required**

Objectives

The **overall objective** of the project is threefold (**Grant Agreement**):

- To advance in the **understanding** of the effects of meteorological uncertainty in TBO.
- To develop **methodologie**s to analyse, quantify and manage the effects of meteorological uncertainty in TBO.
- To pave the road for a **future integration** of the management of meteorological uncertainty into the ATM system.

Scope (1)

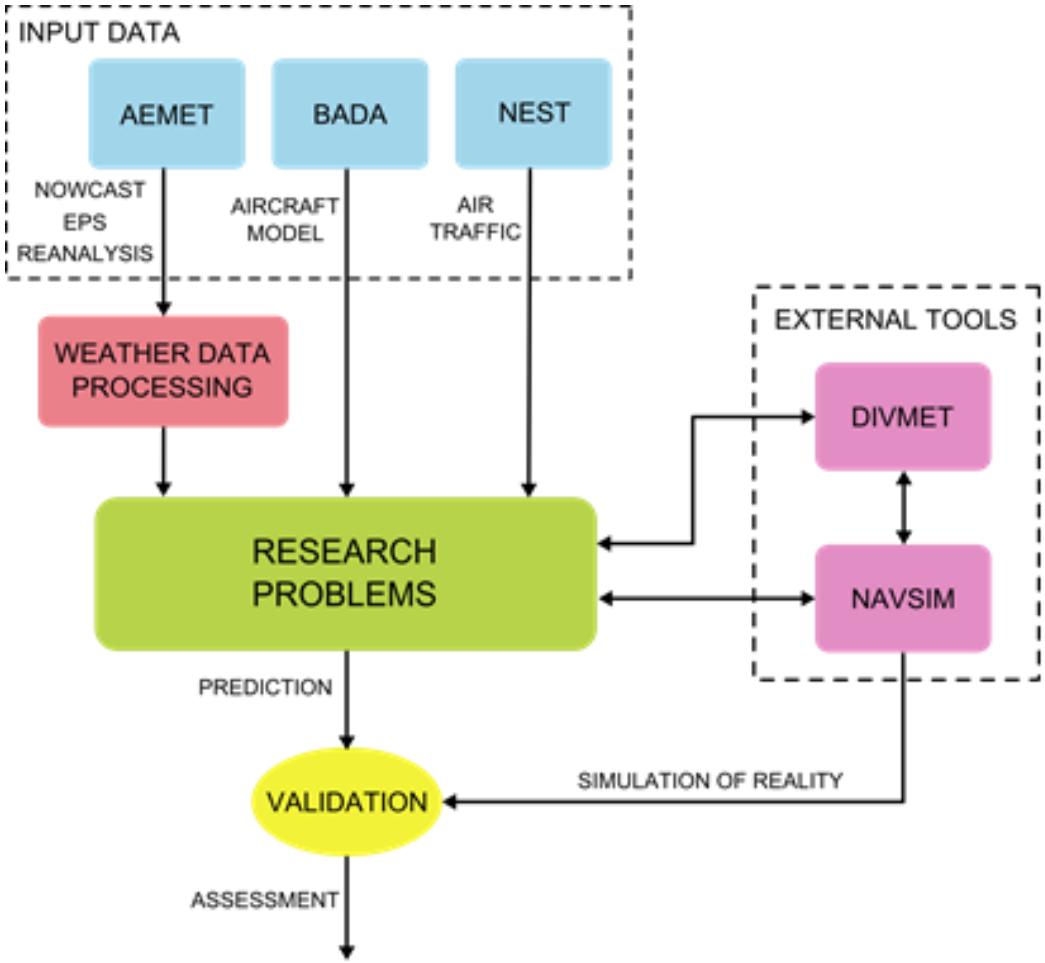
TBO-Met has focused on **three particular problems**:

1. mid-term trajectory planning considering weather forecast uncertainties (**TP**)

2. short-term trajectory prediction under thunderstorm activity (storm avoidance (**SA**)

3. sector demand analysis considering weather forecast uncertainties (**SD**)

Scope (2)


INPUT DATA
AEMET
BADA
NEST
NOWCAST
EPS
REANALYSIS
AIRCRAFT
MODEL
AIR
TRAFFIC
WEATHER DATA
PROCESSING
EXTERNAL TOOLS
DIVMET
RESEARCH
PROBLEMS
NAVSIM
PREDICTION
VALIDATION
SIMULATION OF REALITY
ASSESSMENT

Concept (1)

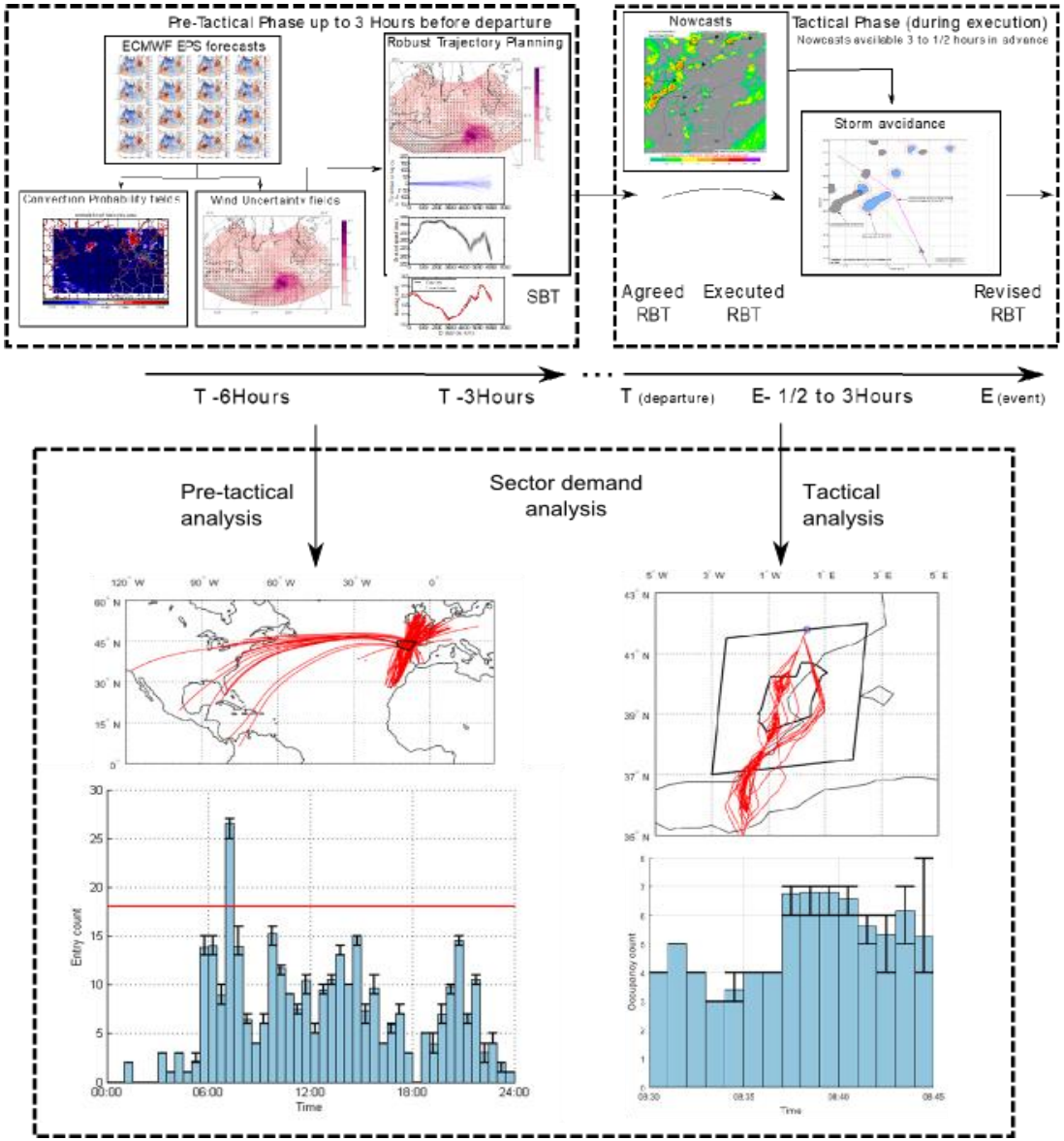
The **overall concept** of the project is the **development of methodologies** to analyse, quantify and manage the effects of weather uncertainty in TBO. For the previous three problems, the **particular concepts** are as follows:

TP: a **stochastic optimisation methodology** capable of trading-off cost-efficiency and predictability and/or exposure to convective risk

SA: a **probabilistic trajectory predictor** with storm avoidance, taking into account the uncertainty in the location of the convective cells (modelled as stochastic no-fly zones)

SD: an **ensemble-based stochastic methodology** to predict the sector demand based on the uncertainty of the individual trajectories

Concept (2)


Pre-Tactical Phase up to 3 Hours before departure
ECMWF EPS forecasts
Robust Trajectory Planning
Convection Probability fields
Wind Uncertainty fields
SBT
Nowcasts
Tactical Phase (during execution)
Nowcasts available 3 to 1/2 hours in advance
Storm avoidance
Agreed RBT
Executed RBT
Revised RBT
T -6Hours
T -3Hours
T (departure)
E- 1/2 to 3Hours
E (event)
Pre-tactical analysis
Sector demand analysis
Tactical analysis
Entry count
Time
Occupancy count

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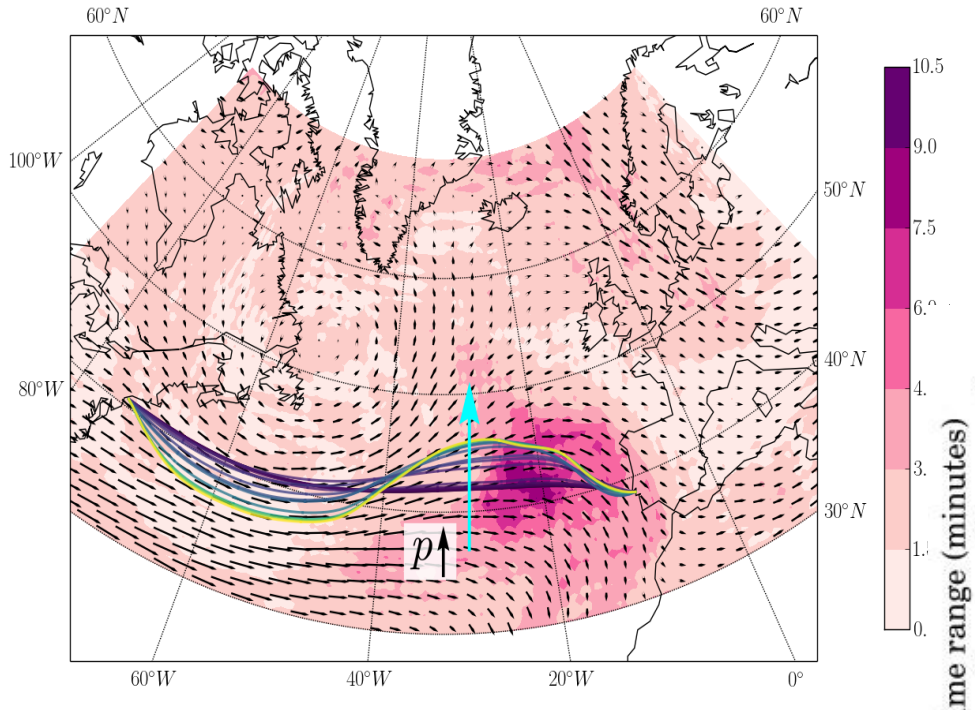
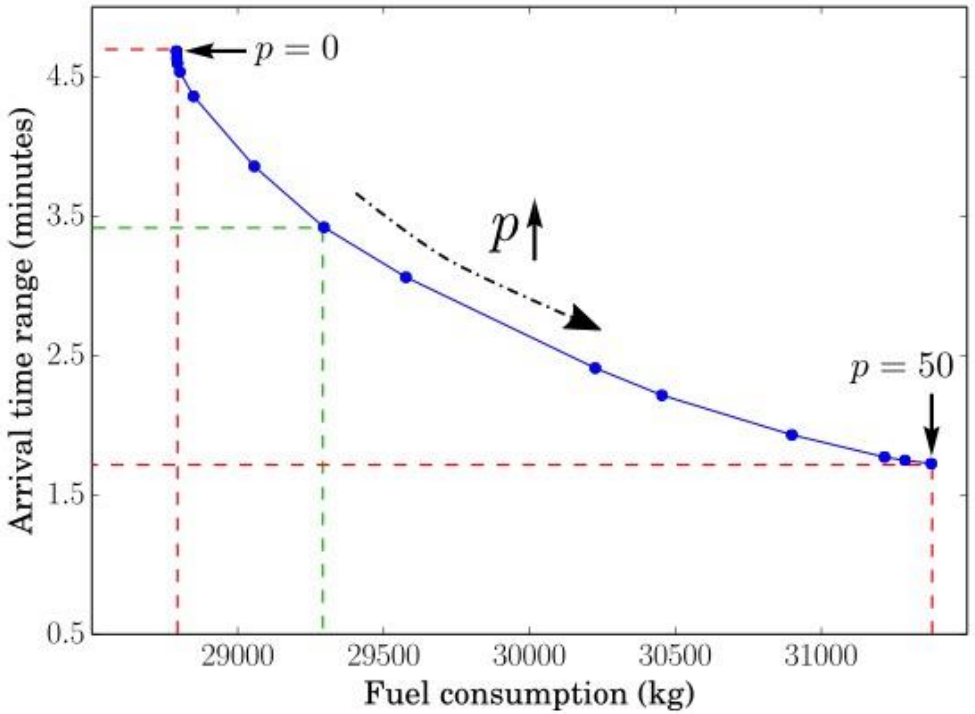
Mid-term Trajectory Planning (1)



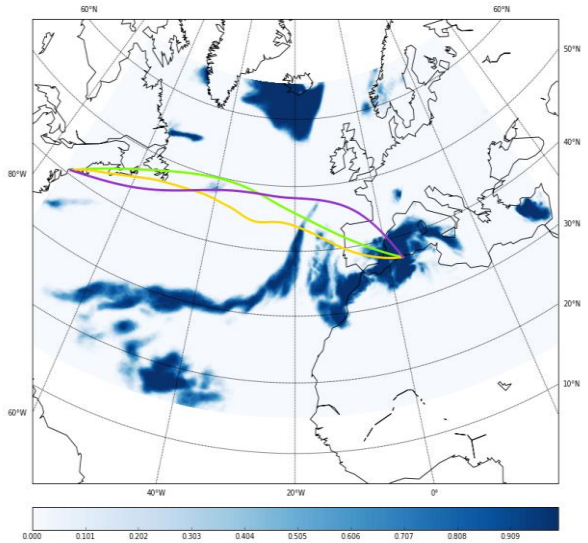
Description:

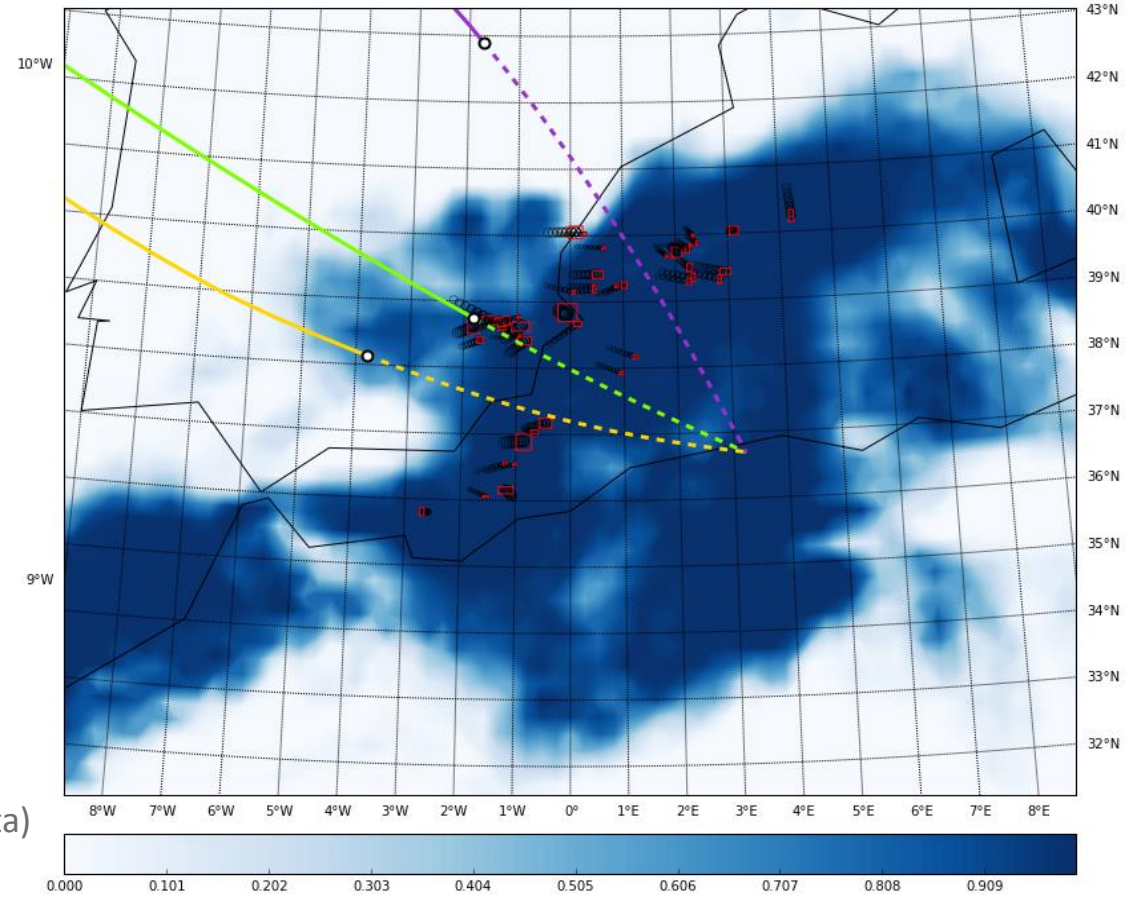
- A330 from NY to Lisbon
- Flying at constant M=.82 and FL380
- 20th of January, 2016
- 200 hPa level EPS



3 minutes reduction in time uncertainty flying the most predictable trajectory (p = 50), with 2500 kg of extra fuel burnt.

Mid-term Trajectory Planning (2)





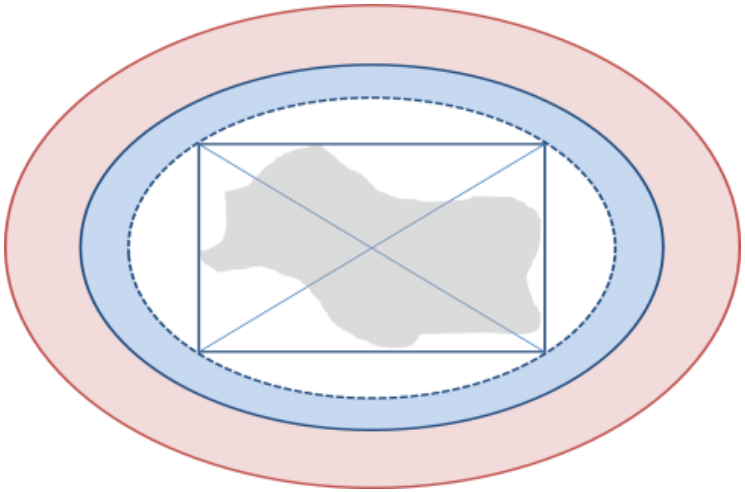
Three planned trajectories:

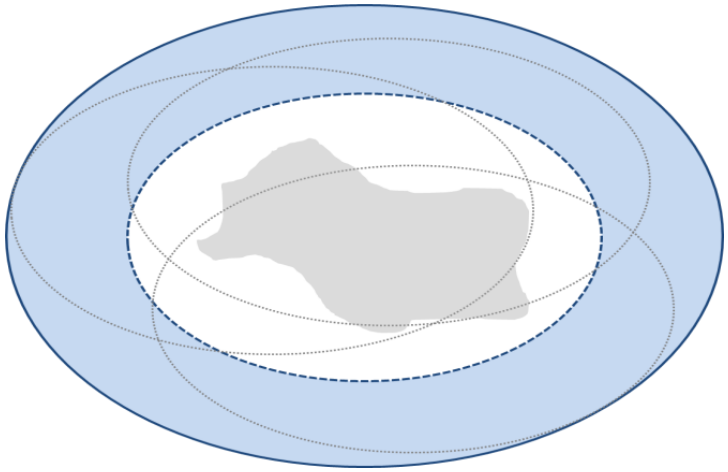
- Min exposure to convection (magenta)
- Min fuel (green)
- Max Predictability (yellow)

Polygons represent storms at different time instants (red-actual time; black 10-20-30-40-50-60 min look-ahead times).
The white dot in the trajectories represents the actual time .

Storm avoidance (1)

Modeling of Storm Uncertainty



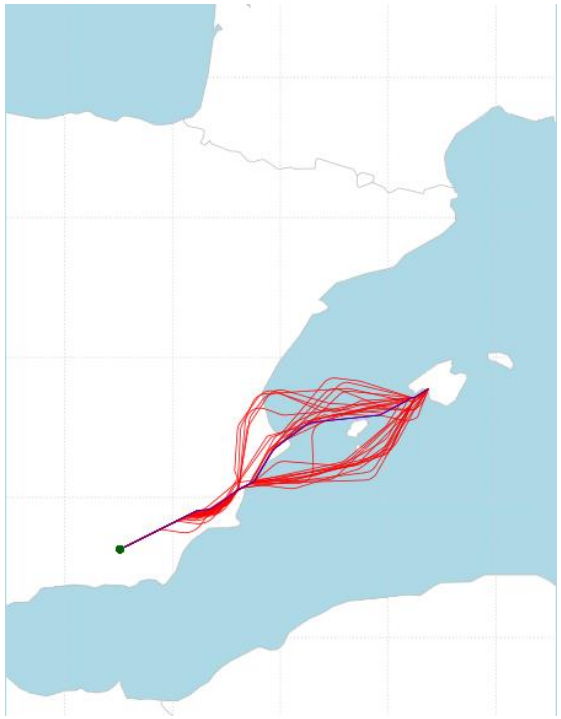


- Outline of Convective Cell as Ellipse with Uncertainty Margin (light blue) and Safety Margin (light red)
- Lead-Time-dependent Uncertainty Margins
- Random elliptic Storm Cells within Uncertainty Margin

Storm avoidance (2)

Deviation routes

DIVMET calculated deviation routes considering 31 storm cell variations per flight



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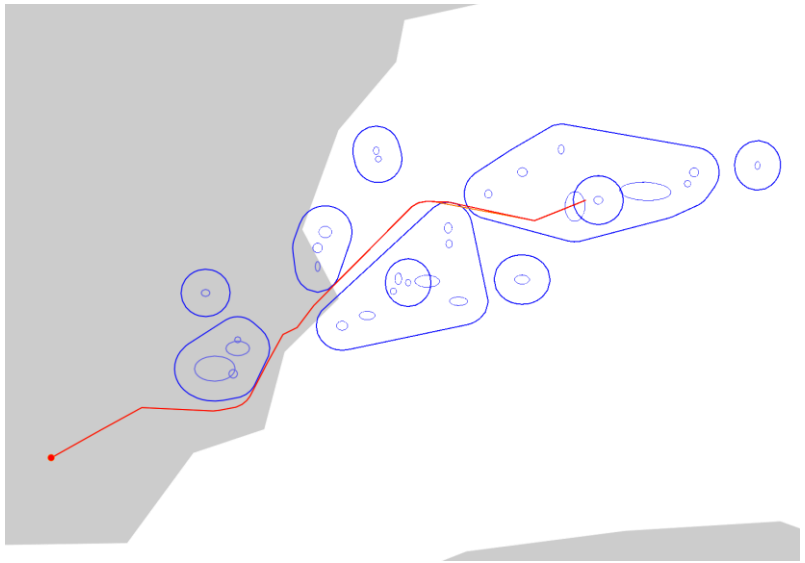
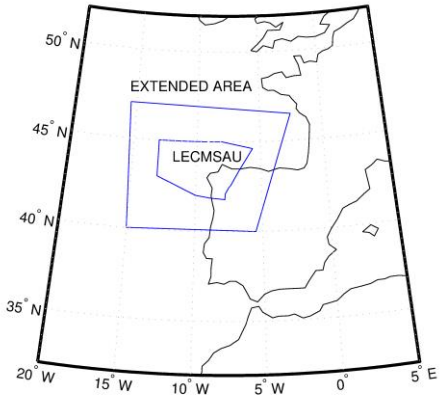


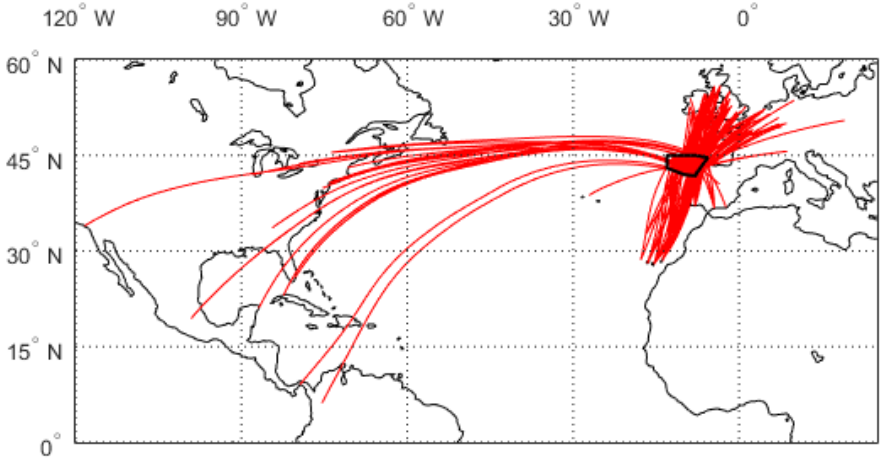
Example of trajectory prediction
Safety Margin: 10NM

Sector demand – Pre-tactical analysis (1)

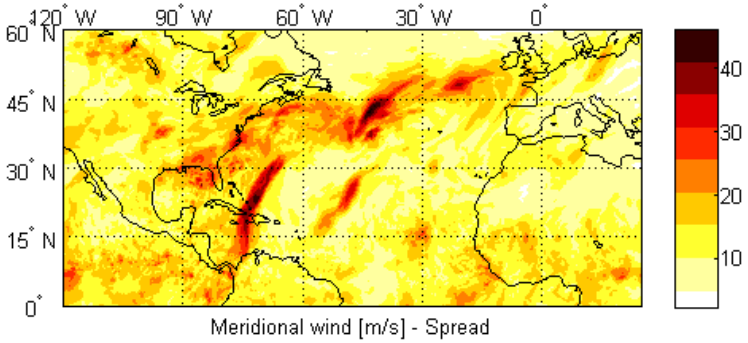
Sector demand predicted for a whole day, when predicted the day before.

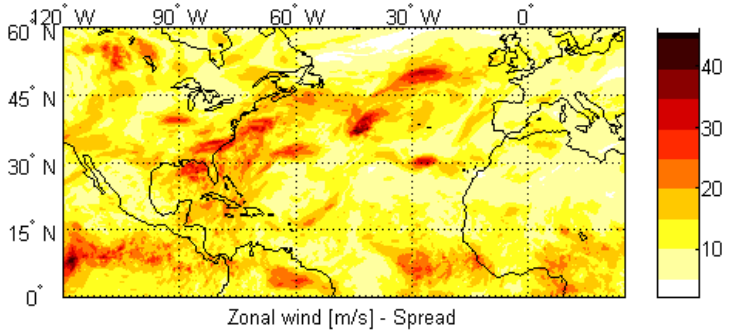


ATC sector, 328 flights



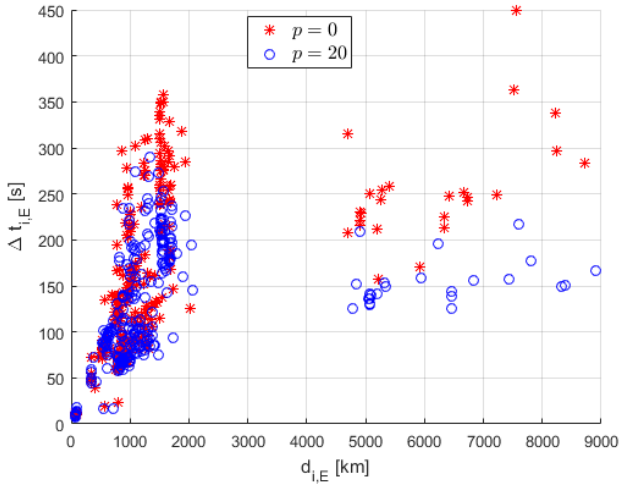
Trajectories crossing the sector



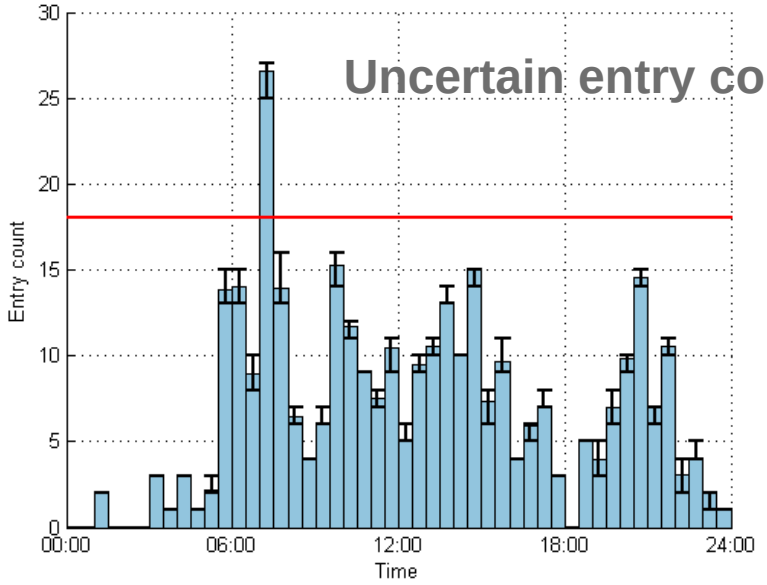


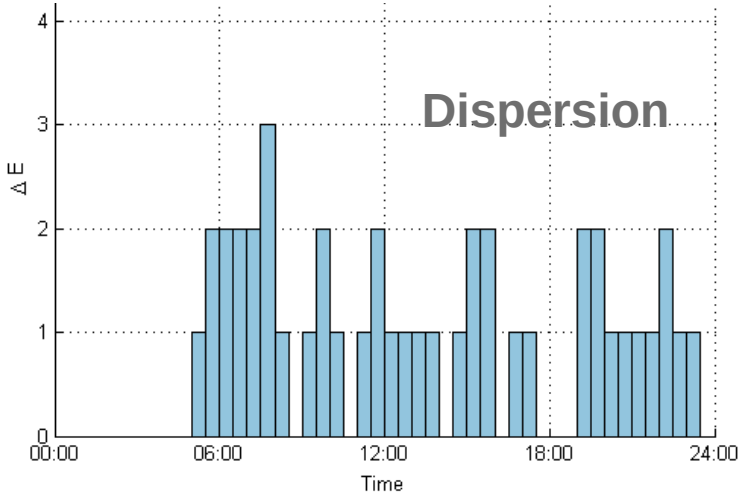
Weather forecast (EPS)

Sector demand – Pre-tactical analysis (2)

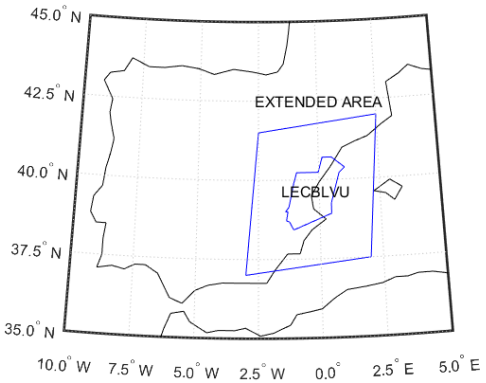


Uncertain entry time

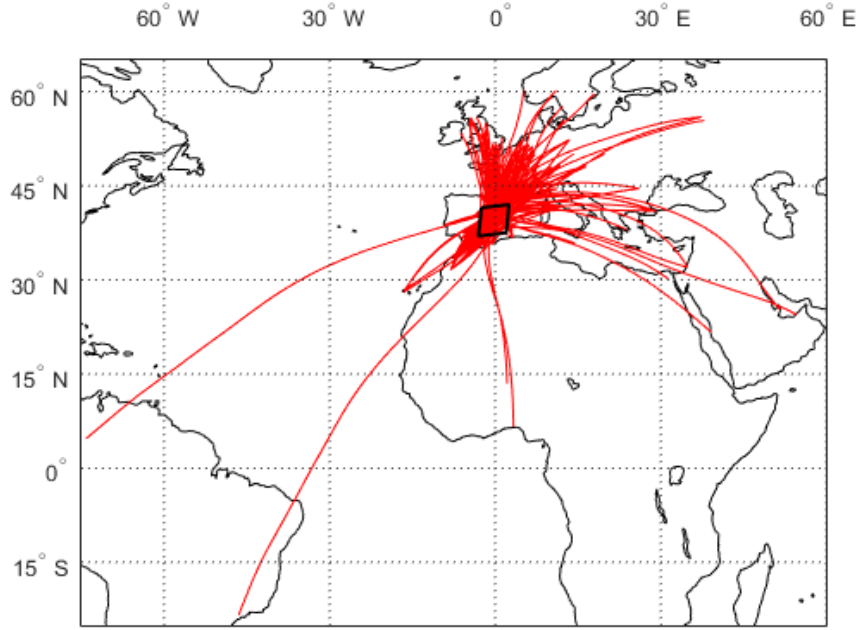




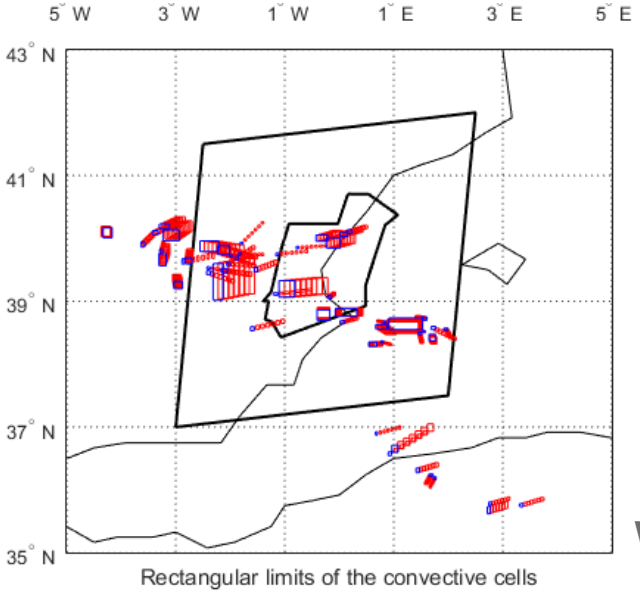
Sector demand - Tactical analysis (1)



ATC sector, 257 flights



Reference trajectories crossing the sector

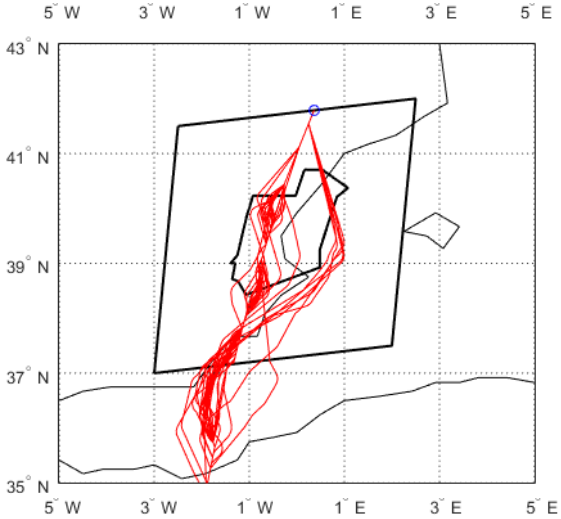


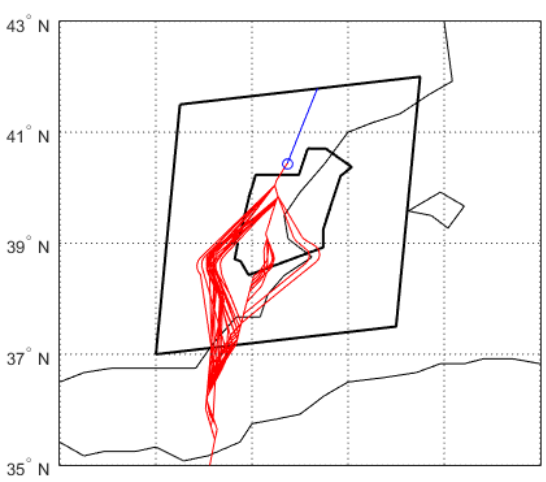
Rectangular limits of the convective cells

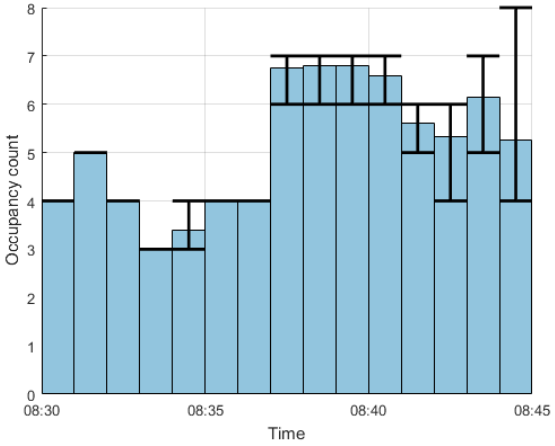
Weather forecast (Nowcasts)

Sector demand - Tactical analysis (2)

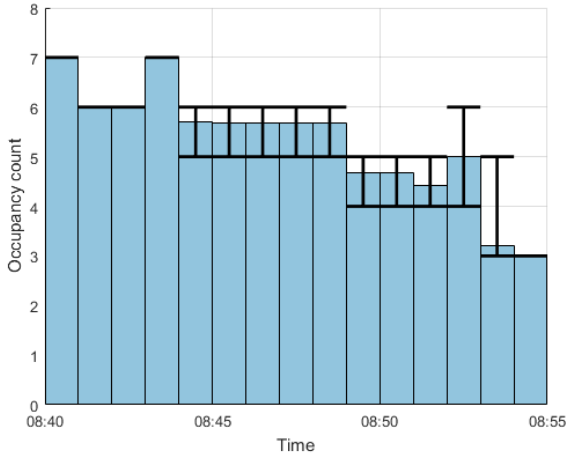
Trajectories and sector demand updated every 10 minutes







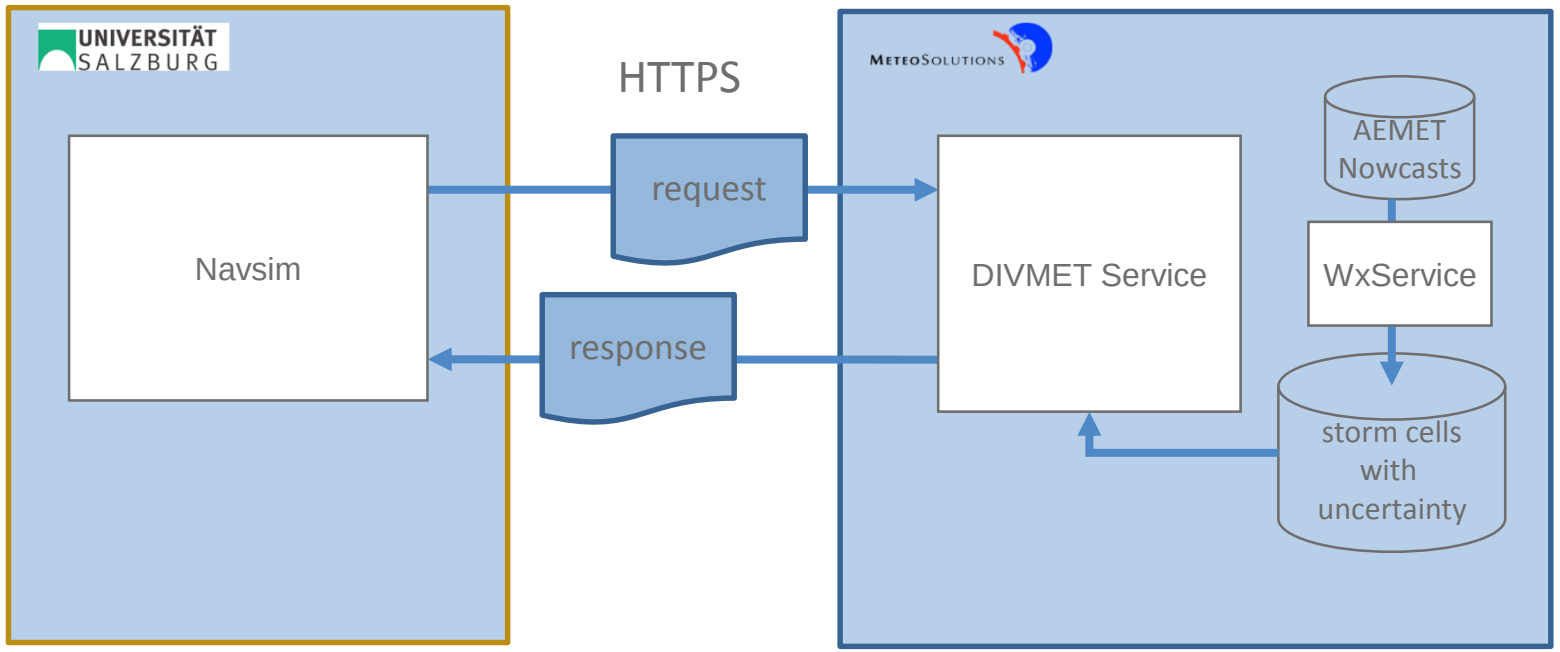
Uncertain occupancy count



Deviation trajectories

Simulation of real world

- Installation of DIVMET as a Service
- Linking DIVMET to Navsim



Outcome

The overall **outcome** has been the **development of methodologies to quantify and better understand the impact** of wind uncertainty and convective weather in trajectory planning and sector demand, both at mid-term and short-term levels.

Methodologies

TP: **stochastic optimization methodology** capable of finding a trade-off cost-efficiency and predictability and/or exposure to convective risk

SA: **probabilistic trajectory predictor** with storm avoidance, taking into account the uncertainty in the location of the convective cells

SD: **ensemble-based stochastic methodology** to predict the sector demand based on the uncertainty of the individual trajectories

Conclusions

The results have shown that

- **the predictability of aircraft trajectories can be increased**
- **the storm avoidance strategy can be better anticipated**
- **the accuracy of sector demand forecast can be improved**

hence, based on these results, the **overall conclusion** is that

the ATM efficiency can be enhanced by integrating into the ATM planning process the available information about the uncertainty of weather forecasts.

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Achievements (1)

Specific achievements

- **TP:**
  - Achievement: the **capability of generating more predictable trajectories** considering the uncertainty of weather predictions;
  - Output: a set of alternative routes, according to the different trade-offs;
- **SA:**
  - Achievement: the **capability of being better informed about the evolution of the hazardous convective weather regions**;
  - Output: an ensemble of possible deviation trajectories that avoid the potential storm realisations, leading to a more proactive way of facing thunderstorms.
- **SD:**
  - Achievement: the **capability of improving the prediction of the sector demand**;
  - Output: a quantitative measure of the uncertainty of sector demand, which can be updated according to the release of new forecasts and the movement of the aircraft.

Achievements (2)

Expected benefits

- **Increased predictability of aircraft trajectories**
  - ➡ Reduction of the buffer times used by airlines
- **Better-informed decision making**
  - ➡ Better anticipation of storm avoidance strategy
- **Improved prediction of sector demand**
  - ➡ Increase of declared sector capacities
  - Better identification of demand-capacity balancing measures

Contributions to ATM Master Plan

In relation to the **three particular problems** addressed in TBO-Met (**TP, SA and SD**)

Three **Operational Improvement (OI) Steps** are proposed (one for each topic):

- AUO-xx01: **Use of probabilistic forecasts to generate more predictable trajectories at mid-term planning level.**
- AUO-xx02: **Use of probabilistic weather information to enhance trajectory prediction under thunderstorm activity.**
- DCB-xx01: **Use of probabilistic weather forecasts to enhance sector demand prediction.**

Next steps – Roadmap

Three possible **Technical Solutions** have been identified (one for each topic):

- **Enhanced Flight-Planning Predictability**
- **Probabilistic Storm Avoidance Human Decision Support Tool**
- **Probabilistic Sector Demand Prediction integrating Meteorological Uncertainty**

Goal: to reach TRL-2

Proposed Follow-Up R&D Activities (1)

Research idea

Development of enhanced flight planning procedures to mitigate the negative effects of adverse weather in today's ATM

- at pre-tactical phase, generation of cost-efficient, minimum-risk trajectories (minimum exposure to weather risks)
- at tactical phase, generation of reliable avoidance trajectories (high probability of avoiding the weather hazards)

Scope

Seamless analysis (mid and short-term planning) in **structured airspace** (predefined waypoints, free routing) considering **uncertain**, **time-evolving meteorology,** and **multiple hazards** (convection, turbulence, …)

Goal

To pave the road for the development of tools that integrate forecast information for **robust flight planning**

Proposed Follow-Up R&D Activities (2)

Research idea

Development of metrics to quantify the sector demand uncertainty including weather prediction uncertainty and weather hazards

- How is the ACC affected by uncertainty?
- How to aggregate the uncertainty information from different sectors?
- Which sectors configuration is less affected by uncertainty?
- How to translate the exposure of the individual flights to weather hazards to sector demand uncertainty?

Scope

Analysis at **network level** (considering several sectors), in close collaboration with relevant **stakeholders** (NM, ANSPs – future partners)

Goal

To pave the road for the development of tools that integrate meteorological uncertainty for **enhanced DCB**

Meteorological Uncertainty Management for Trajectory Based Operations — TBO-MET

ENGAGE KTN workshop

Thank you very much for your attention!

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