



Effects of Reducing Wind-Induced Trajectory Uncertainty on Sector Demand (TBO-Met Project)

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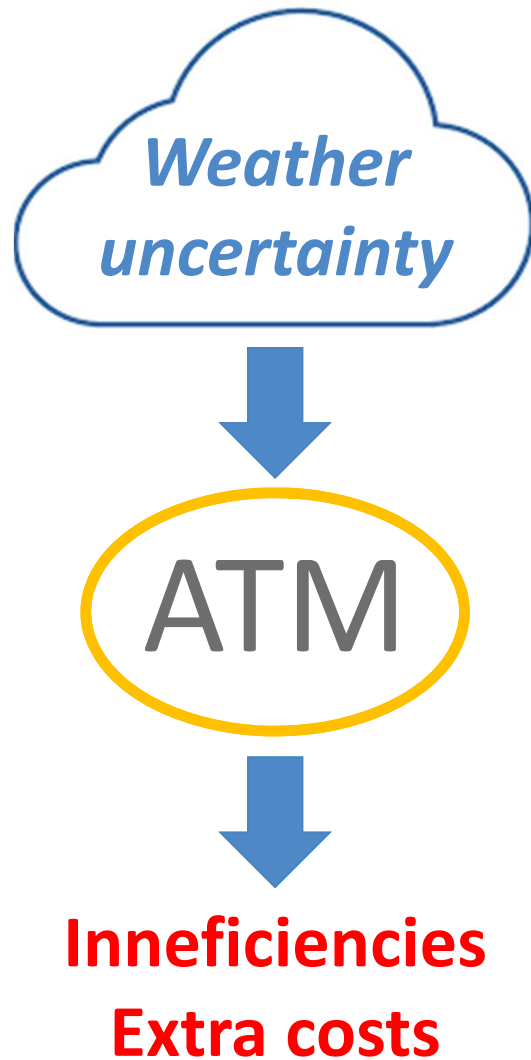
Belgrade 29 of November 2017



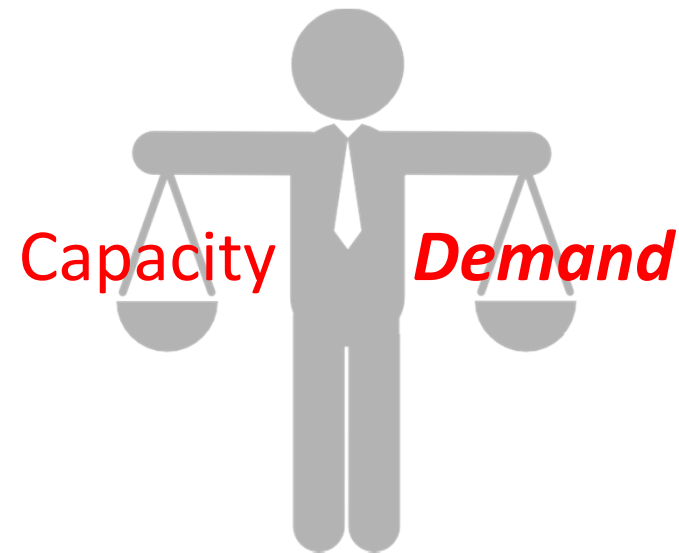
Founding Members



Motivation



Network Manager



An **accurate prediction** of the **expected demand** may lead to a **better identification** of the measures to be applied, thus **minimizing the impact** on the network and **improving the system efficiency**.

TBO-Met Project



Meteorological Uncertainty Management for Trajectory Based Operations (SESAR 2020 Exploratory Research, Ref. 699294)

Overall objective is threefold:

1. To advance in the understanding of the effects of meteorological uncertainty in TBO.
- 2. To develop methodologies to quantify and reduce the effects of meteorological uncertainty in TBO.**
3. To pave the road for a future integration of the management of meteorological uncertainty into the Air Traffic Management system.

Partners:



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METEO SOLUTIONS



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Website:

<https://tbomet-h2020.com/>

Objective of this work



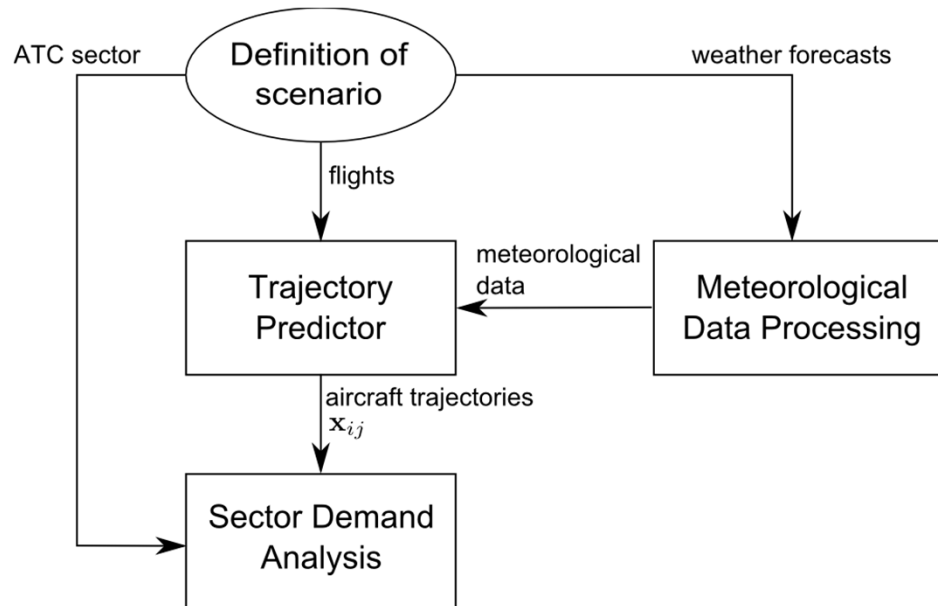
To show that the **effects of wind uncertainty** on the **prediction of the demand** of an Air Traffic Control (ATC) sector **can be reduced** when the **airspace users plan the route of each individual flight** with the objective of **increased predictability**.

Outline



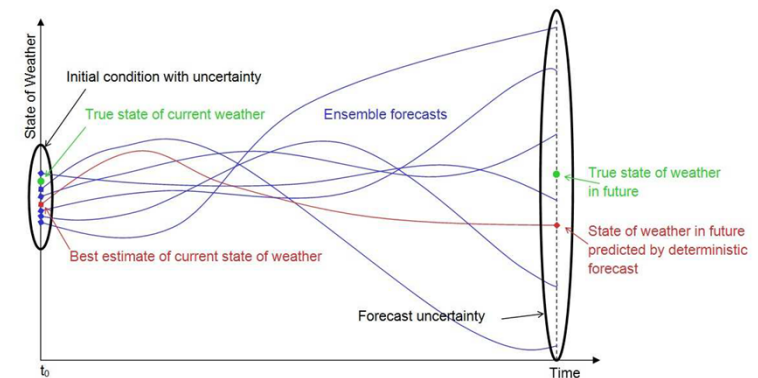
1. Introduction
2. Methodology for Sector Demand Analysis
3. Trajectory Predictor
4. Application Scenario
5. Results
6. Conclusions

Methodology for Sector Demand Analysis



- Definition of Scenario
- Meteorological Data Processing
- Trajectory Predictor
- **Sector Demand Analysis**

The different atmospheric realizations lead to different predicted **entry counts**, which is statistically:



- Meteorological Data Processing
- Trajectory Predictor
- **Sector Demand Analysis**

Definitions and Hypotheses



- **Sector geometry:** fixed and does not change with time. The effects of opening/closing sectors are not analysed.
- **m :** number of flights.
- **n :** number of members of the EPS.
- **$\mathbf{x}_{ij}(t)$:** position of flight i ($i = 1, \dots, m$) for member j ($j = 1, \dots, n$) at time t
$$\mathbf{x}_{ij}(t) = [\lambda_{ij}(t), \phi_{ij}(t), h_{ij}(t)]$$

where λ is the longitude, ϕ is the latitude, and h is the pressure altitude.

For each flight i , one has n trajectories $\mathbf{x}_{ij}$, as many as EPS members.

Entry Time and Entry Distance

- For each trajectory $\mathbf{x}_{ij}$, one has an **entry time** to the sector $t_{ij,E}$ and its associated **entry point**, $\mathbf{x}_{ij}(t_{ij,E})$.
- The n different entry times can be statistically characterized:

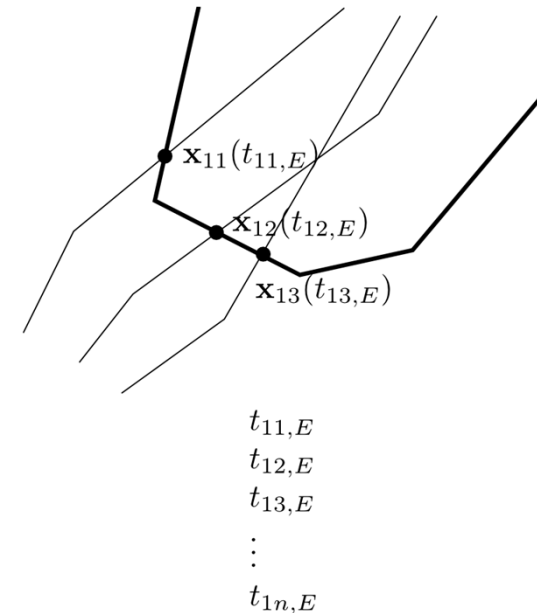
- **Average entry time** for flight i

$$t_{i,E} = \frac{1}{n} \sum_{j=1}^n t_{ij,E}$$

- **Dispersion of the entry time** for flight i

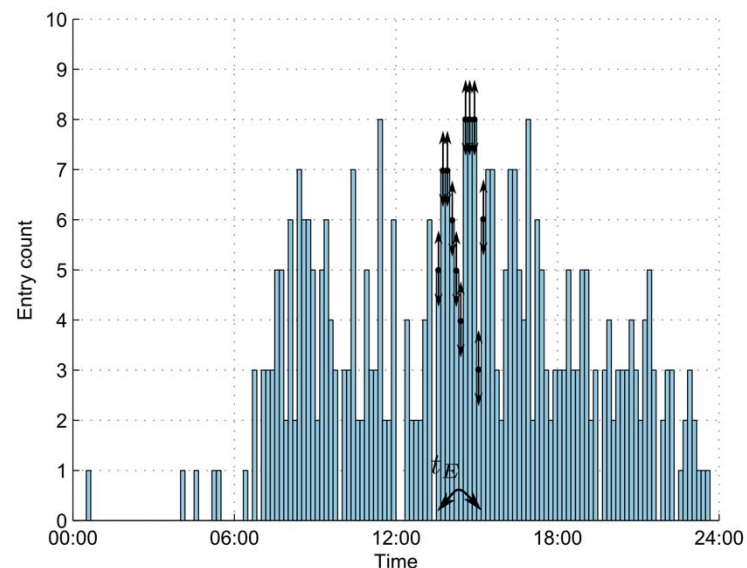
$$\Delta t_{i,E} = \max_j t_{ij,E} - \min_j t_{ij,E}$$

- The **distance** travelled by the aircraft from its origin to the entry point is denoted as $d_{ij,E}$.



Entry Count (I)

- **Entry count:** number of flights entering the sector during a selected **time period**, P_k .
- Because the **entry times are uncertain**, then the **entry count is also uncertain**. The aircraft can enter the sector in different time periods.
- The **duration of the time period** plays a key role in the uncertainty of the entry count. If it is very small, then the aircraft may enter the sector in two or more consecutive time periods.



Entry Count (II)



- Entry count for ensemble member j and time period P_k

$$E_j(P_k) = \sum_{i=1}^m E_{ij}(P_k)$$

where $E_{ij}(P_k)$ is an entry function for flight i , ensemble member j , and time period P_k

$$E_{ij}(P_k) = \begin{cases} 1, & \text{if } t_{ij,E} \in P_k \\ 0, & \text{otherwise} \end{cases}$$

- Statistical characterization

- Mean value

$$\bar{E}(P_k) = \frac{1}{n} \sum_{j=1}^n E_j(P_k)$$

- Max and min values

$$E_{max}(P_k) = \max_j E_j(P_k)$$
$$E_{min}(P_k) = \min_j E_j(P_k)$$

- Dispersion

$$\Delta E(P_k) = E_{max}(P_k) - E_{min}(P_k)$$

- Probability of exceeding capacity

$$P[E(P_k) > a] = \frac{\text{number of } E_j(P_k) > a}{n}$$

Trajectory Predictor



- Solves the problem of **trajectory planning considering uncertain wind** fields provided by EPS. In this work, the **en-route phase** is considered, flown at **constant altitude** and **constant airspeed**.
- **Inputs** for each flight: departure time, departure and arrival airports, altitude, and airspeed.
- **Output** for each flight: **n different trajectories**, each one corresponding to a different ensemble member. **All trajectories follow a common route**, described as a sequence of waypoints.
- The determined route **minimises** a weighted sum of the **average flight time** of the n trajectories and of the **flight-time dispersion**

$$\min \frac{1}{n} \sum_{j=1}^n t_f + p(t_{f,max} - t_{f,min})$$

Parameter p controls the relative weight of time dispersion.

- **Deterministic optimal control problem**, solved with direct methods.

Application

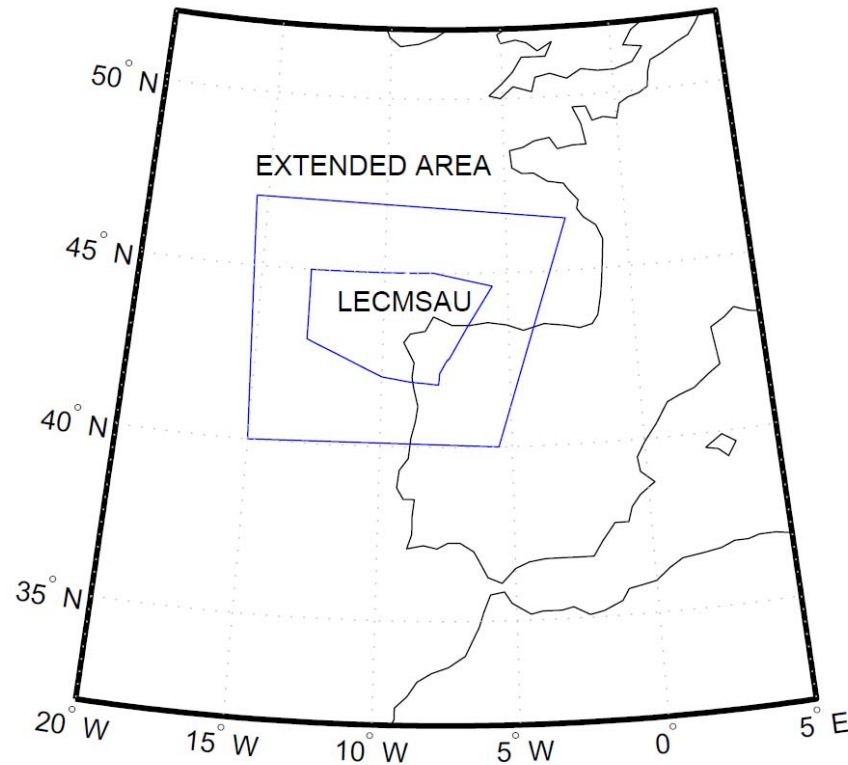


- The **demand** of the ATC sector LECMSAU is **analysed for a whole day**, 01 September 2016 (from 00:00 to 24:00), when **predicted the day before**, 31 August 2016 at 00:00.
- The trajectories are obtained for **two different values of p** :
 - $p = 0$ (time dispersion is not reduced), and
 - $p = 20$ (time dispersión is reduced).

Traffic Scenario: ATC Sector



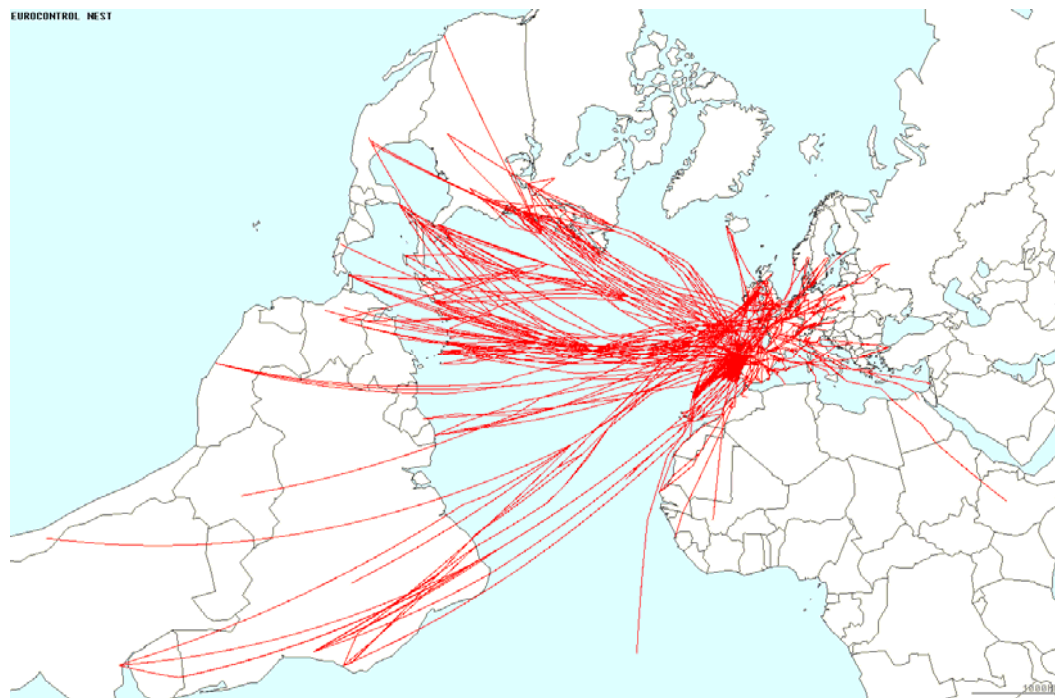
- ATC sector: **LECMSAU**.
- From FL345 to FL460.
- **Declared capacity: 36 flights/hour.**



Traffic Scenario: Flights



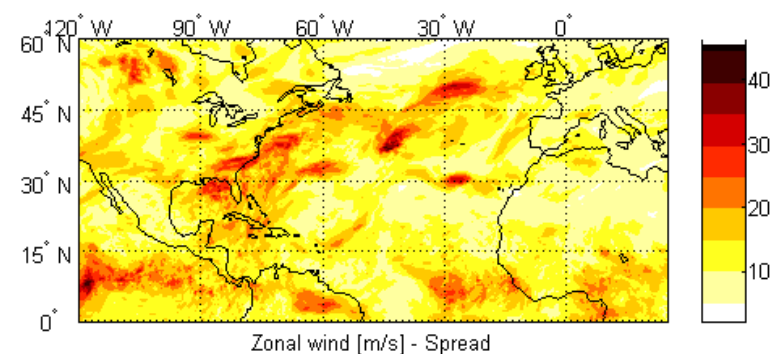
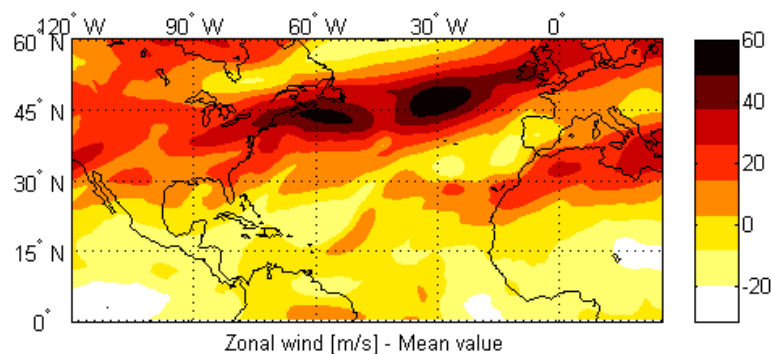
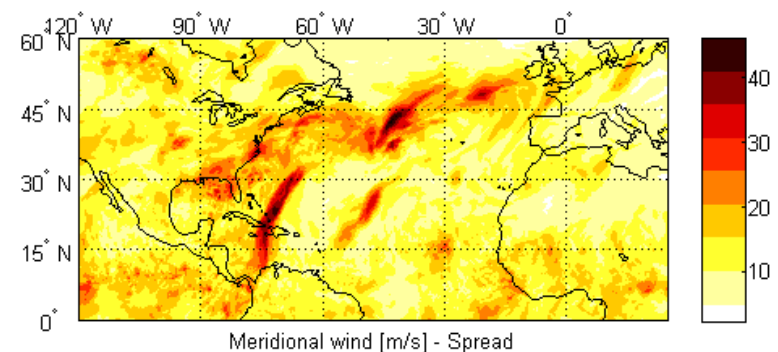
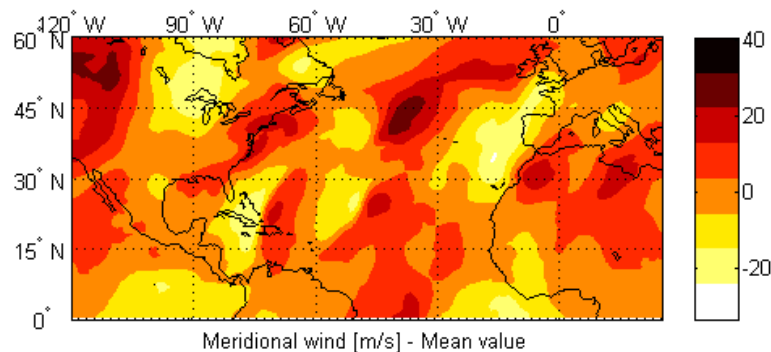
- The flight information (coordinates of origin and destination, departure time) is obtained from **NEST**.
- 1392 flights that planned to cross the extended area between 00:00 and 24:00 on **01-Sep-2017**.
- All flights at **constant pressure altitude** (200 hPa). Cruise speed from BADA 3.13.



Traffic Scenario: Weather Forecasts



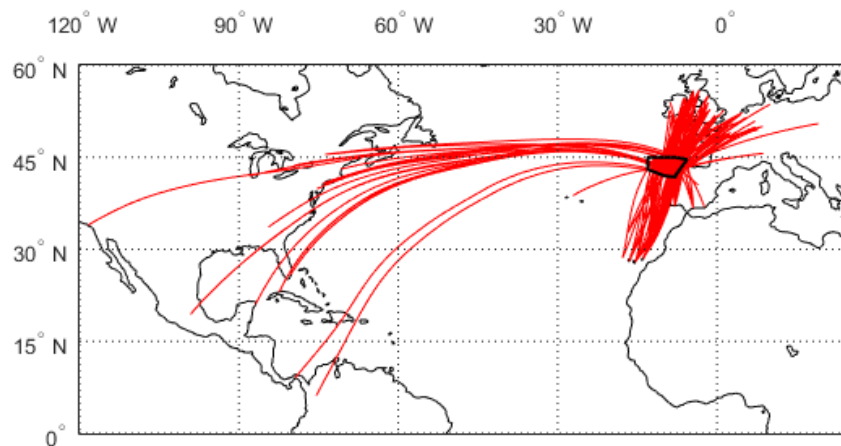
- **ECMWF-EPS**, composed of 50 perturbed members.
- **Release time:** 00:00 on **31-Aug-2017**.
- **Time steps:** 12, 18, 24, 30, 36, 42, 48, 54, and 60 hours.
- **Met data:** meridional and zonal winds.
- Example, mean values and spreads at 36 hours (difference between max and min):



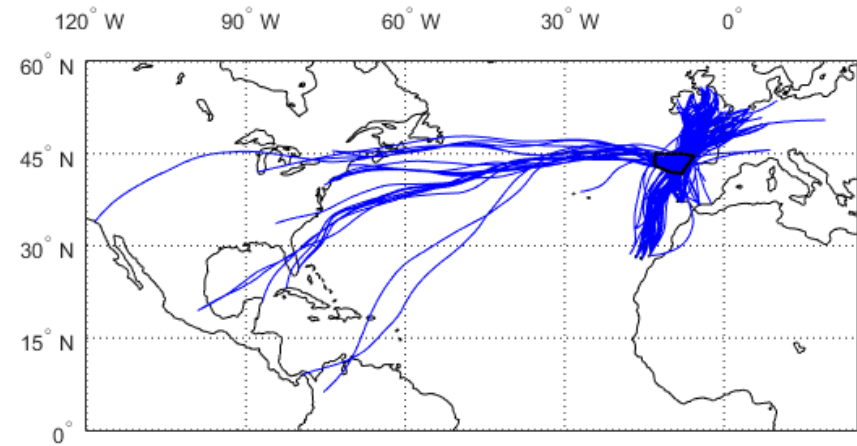
Results: Routes

Number of flights crossing the sector

$p = 0$	$p = 20$	Both p
440	624	328

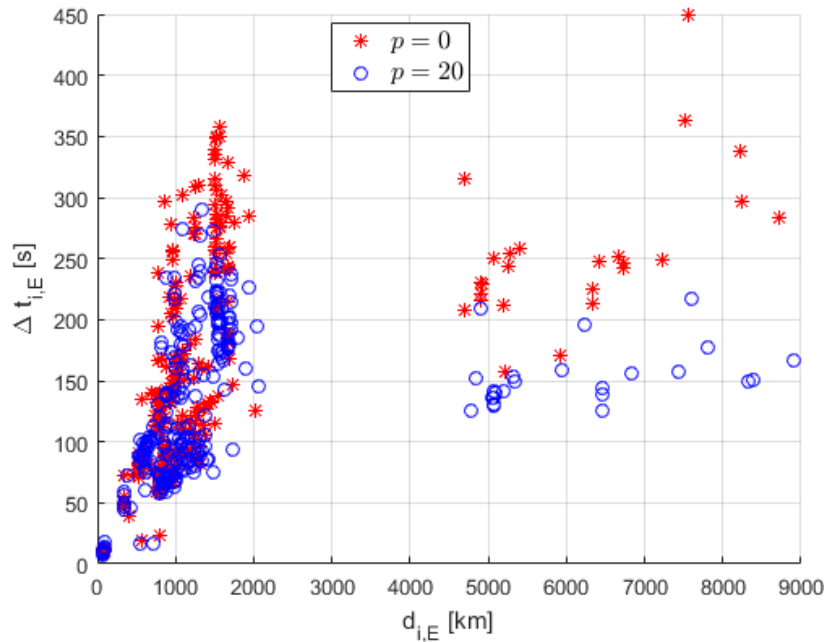


$p = 0$

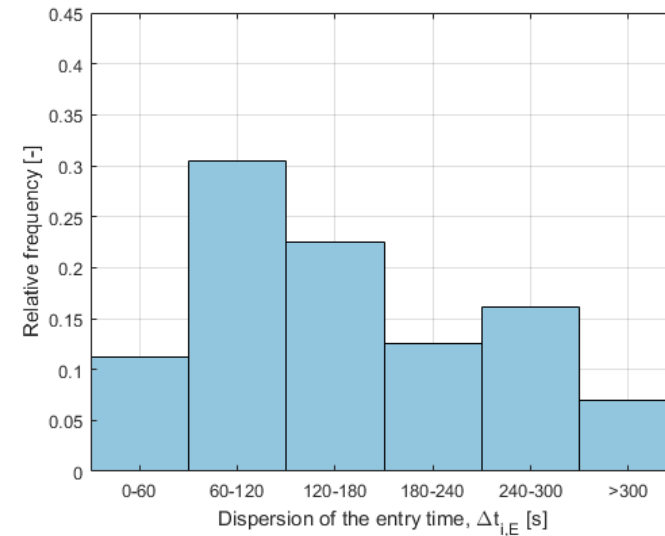


$p = 20$

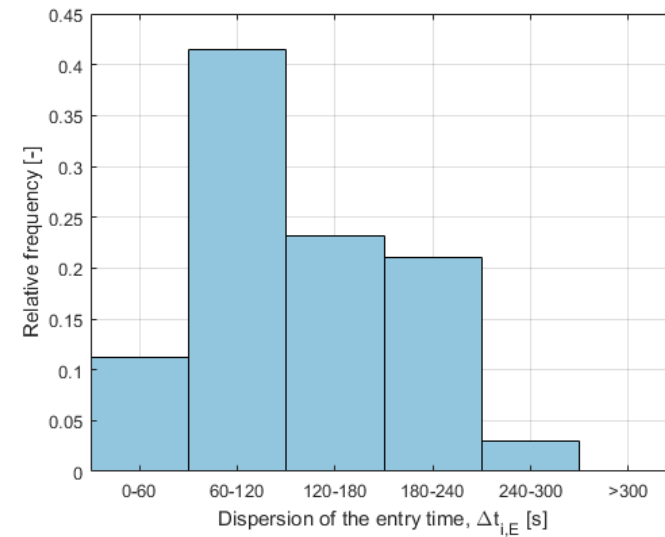
Results: Entry Time



	$p = 0$	$p = 20$	Diff
$\overline{\Delta t_E}$ [s]	156,4	125,8	-30,6
$\bar{t}_f$ [s]	10759	11142	+382,5
$\overline{\Delta t_f}$ [s]	261,5	190,5	-71,0

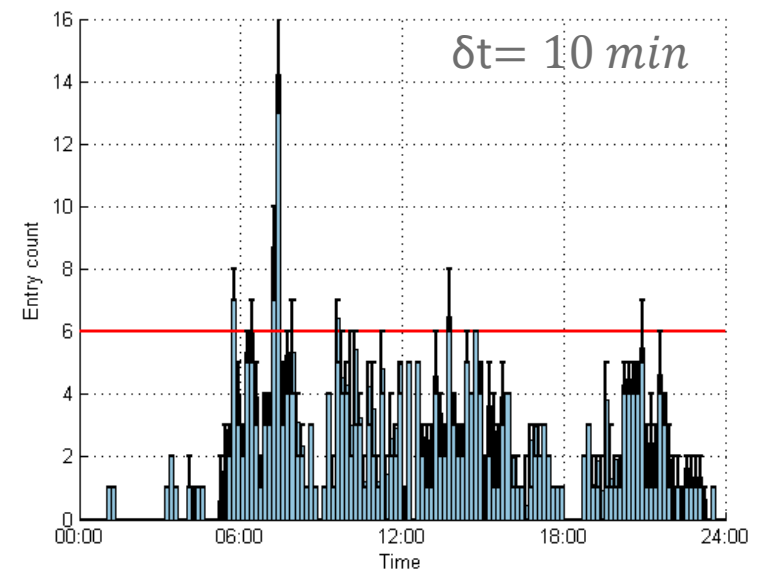
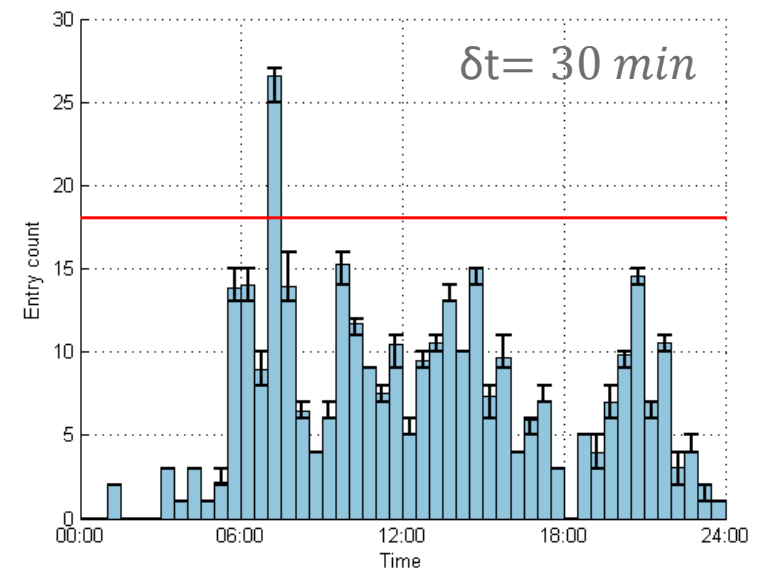
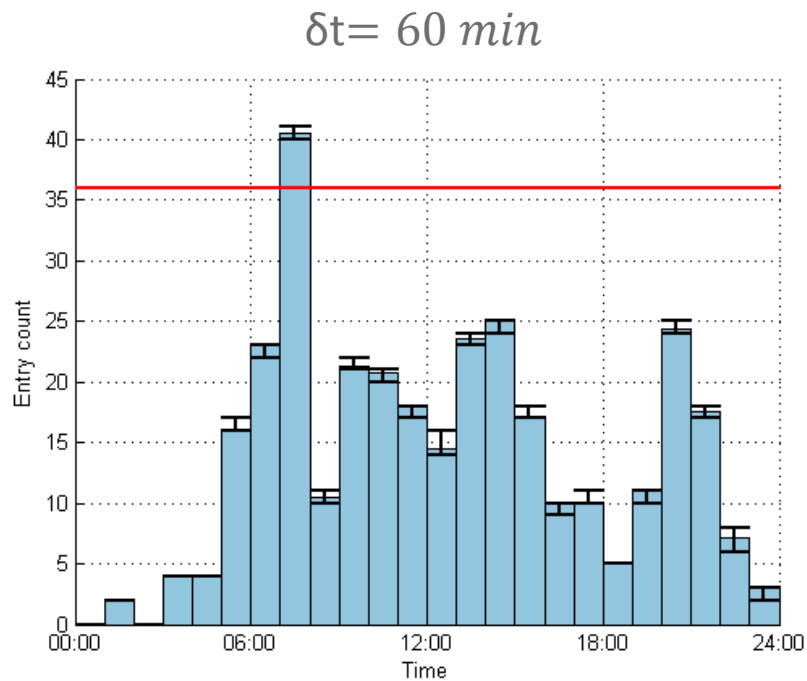


$p = 0$

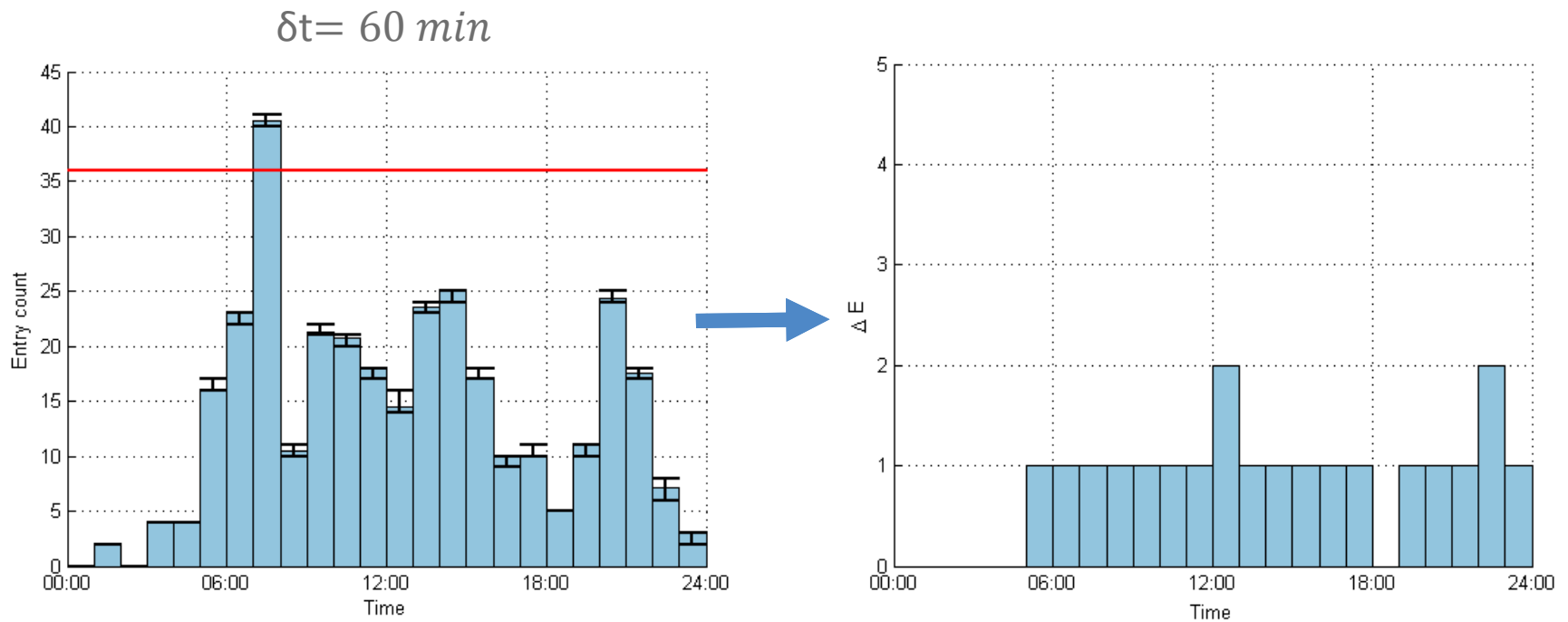


$p = 20$

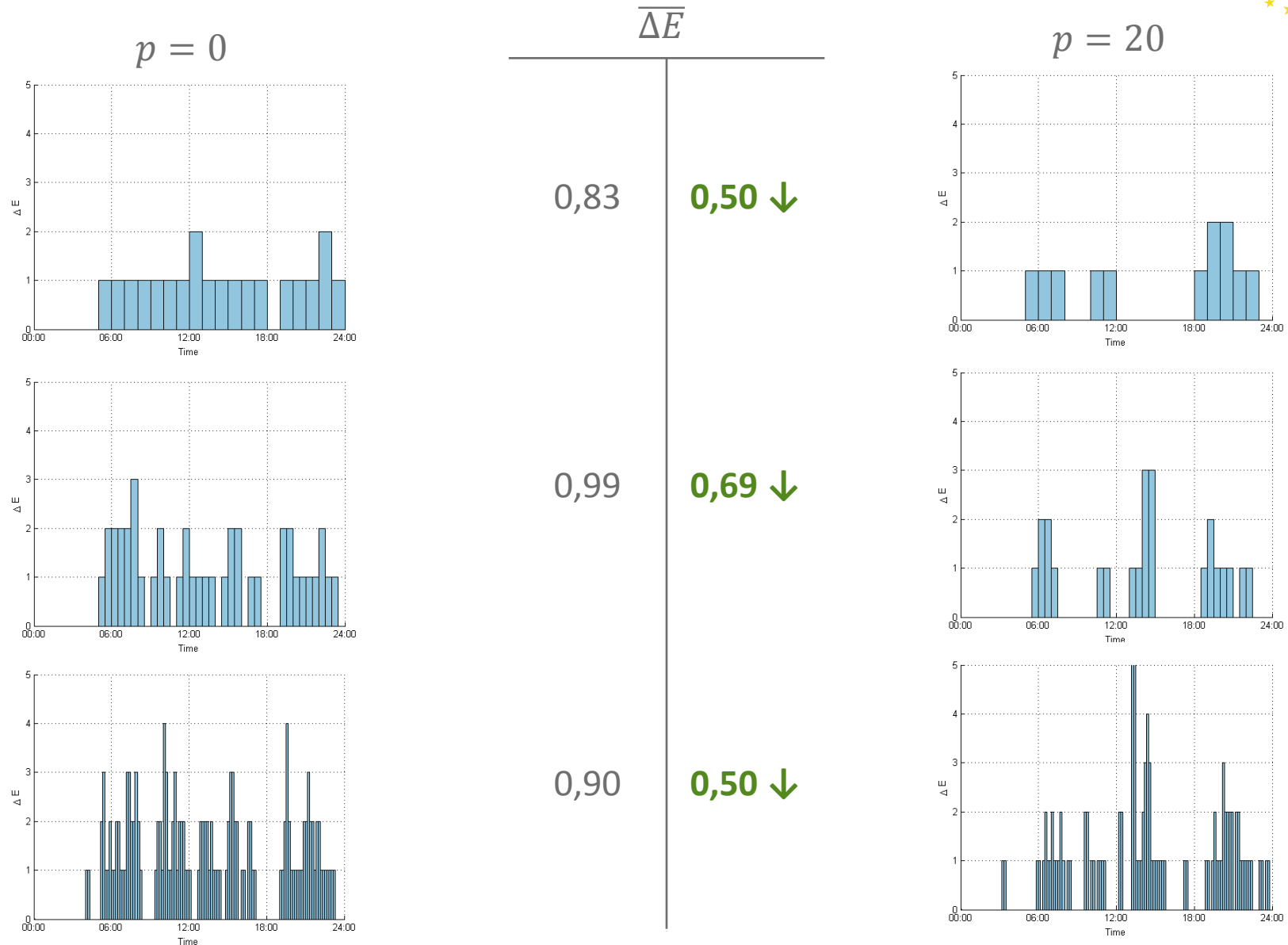
Results: Entry Count (I)



Results: Entry Count (II)



Results: Entry Count (III)



Conclusions



- Methodology to assess the uncertainty of **sector demand when meteorological uncertainty** has been presented.
- The meteorological uncertainty is provided by **probabilistic weather forecasts**, in particular by **Ensemble Prediction Systems (EPS)**.
- The **analysis** is based on **statistical characterization** of **entry time** and **entry count**: mean, max, min, and dispersions. Other variables can be analysed, e.g. **occupancy count**.
- It has been shown that **the dispersion on the entry counts can be reduced** if the **airspace users** choose their **routes** with the objective of **increased predictability**. This comes from an **increase of the flight duration**.
- A more **accurate prediction of the sector demand** is obtained, which is **useful for the Network Manager and the ANSPs**, e.g. when balancing demand and capacity.
- A better prediction of the arrival times may also be **of interest for the airspace users**, e.g. for fleet scheduling. The methodology is **flexible**, each user may give a different importance to predictability.

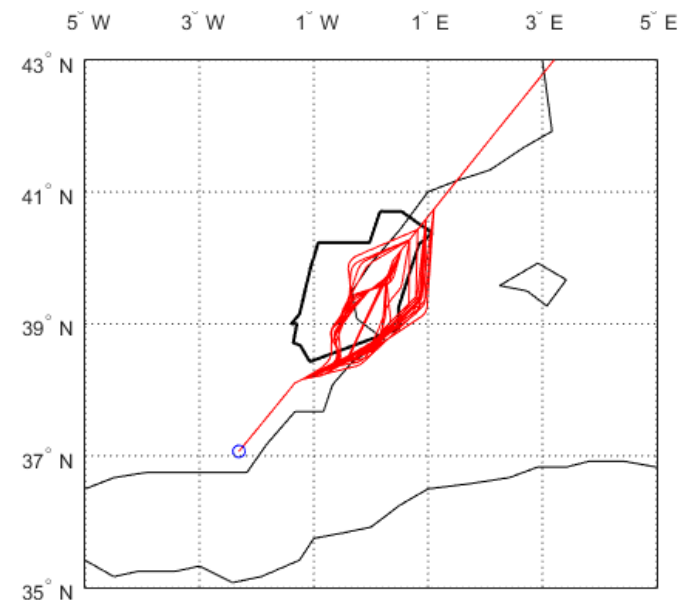
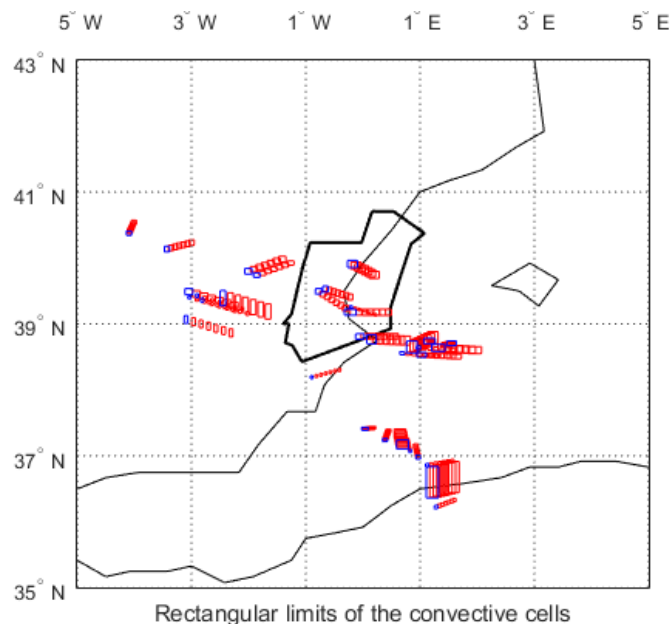
Future Work



1. Multisector analysis:

1. benefit for the whole network,
2. displacement of traffic flows from one sector to another when the predictability of individual flights is increased.

2. Application of the methodology to **tactical scenarios**, with trajectories avoiding **convective cells** provided by **Nowcasts**.





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Thank you very much for your attention!



This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]



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