Towards a Comprehensive Characterization of the Arrival Operations in the Terminal Area

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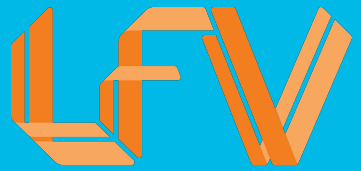


Introduction

- Characterisation of TMA arrival operations
- Existing and new performance metrics
- Three European airports
- Different metering and sequencing techniques

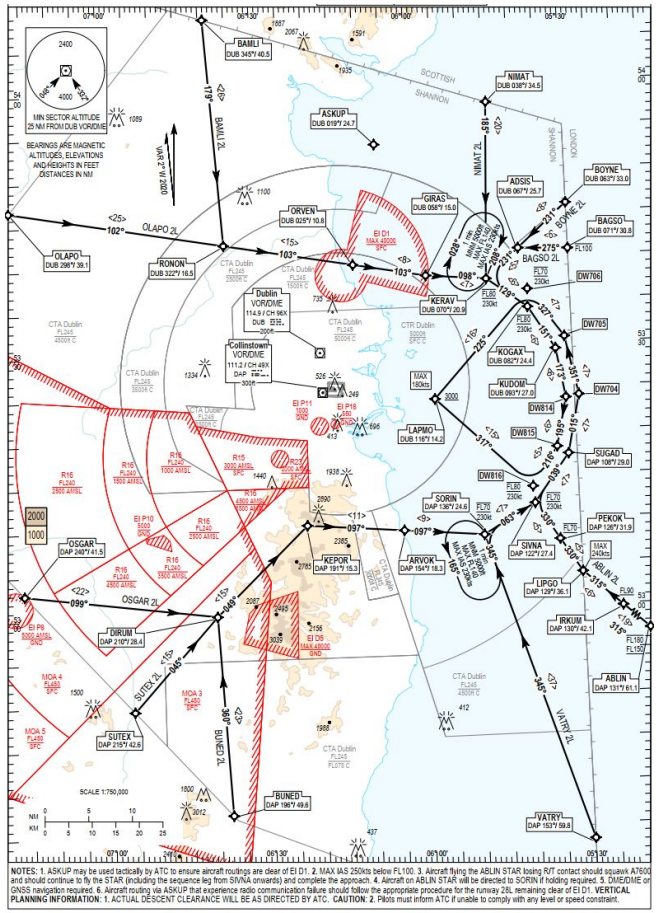
Airports

- Chosen airports:
  - Dublin (EIDW) – point merge – rwy 28L
  - Stockholm-Arlanda (ESSA) – vectoring – rwy 01R
  - Vienna (LOWW) – trombone – rwy 16

- 220,000 to 270,000 aircraft movements annually
- Operations inside TMA boundaries for Arlanda and Vienna. 50 NM circle for Dublin to cover eastbound arrivals.

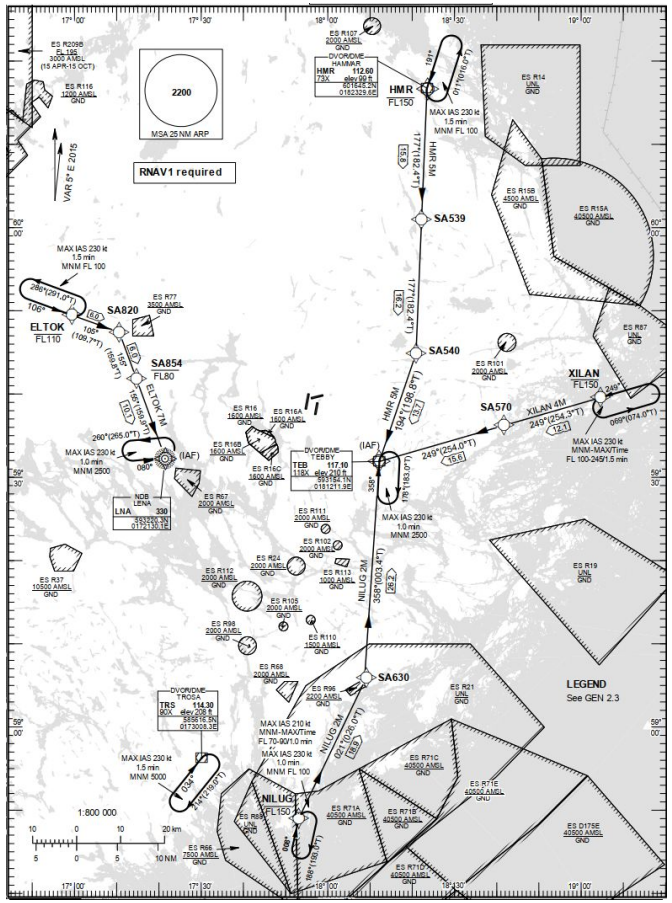
Point Merge - Dublin

- Main runway 10R/28L (used 95 % time)
- Sequencing legs in the shape of arcs for path stretching flown at level flight
- Merge point
- Designed to work in high traffic loads, improve runway capacity and reduce controllers' workload



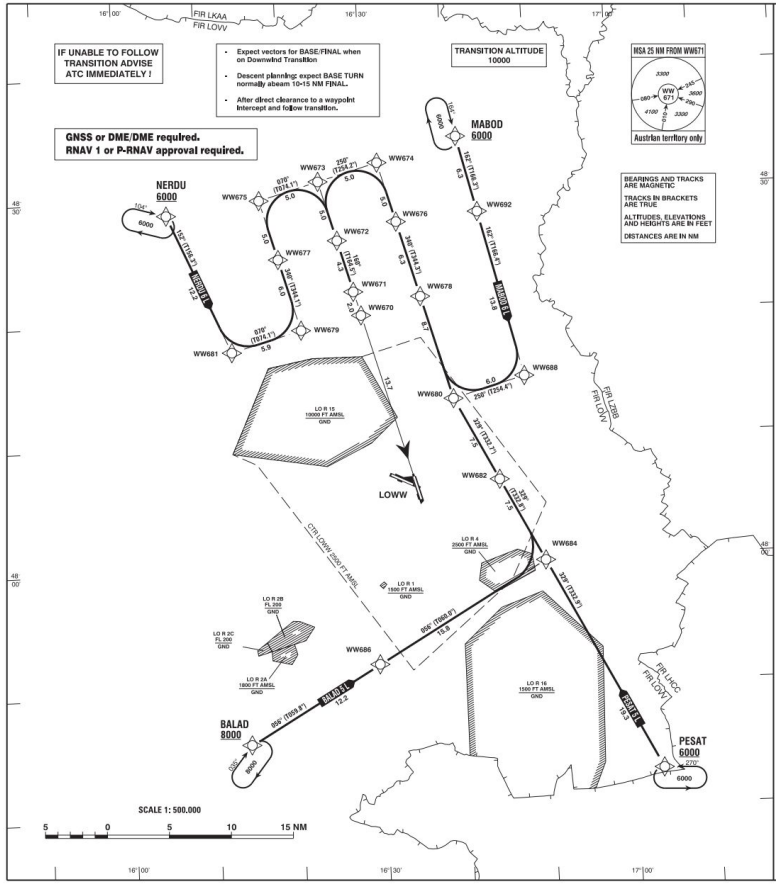
Vectoring – Stockholm-Arlanda

- Three runways
- Pair of parallel runways (used during busy hours)
- Mix of closed STARs and open STARs
- Runway 01R – open loop vectoring only



Trombone - Vienna

- Two intersecting runways
- Simultaneous usage
- Set of STARs and four IAFs
- Waypoints for path stretching and shortcuts



Data

- Historical database of the OpenSky Network
- ’States’ data representing the parts of the arriving flight trajectories inside TMA
- Month with the highest number of arrivals at our 3 airports
- Full four weeks of October 2019

Data Cleaning

- Fixing all incorrect positioning using linear interpolation
- Gaussian filter to smooth the altitudes
- Removing the trajectories:
  - representing landings too far from the runway
  - that are incomplete within TMA
  - starting from an altitude lower than 600 m
  - representing go arounds within TMA
  - for some non-commercial flights

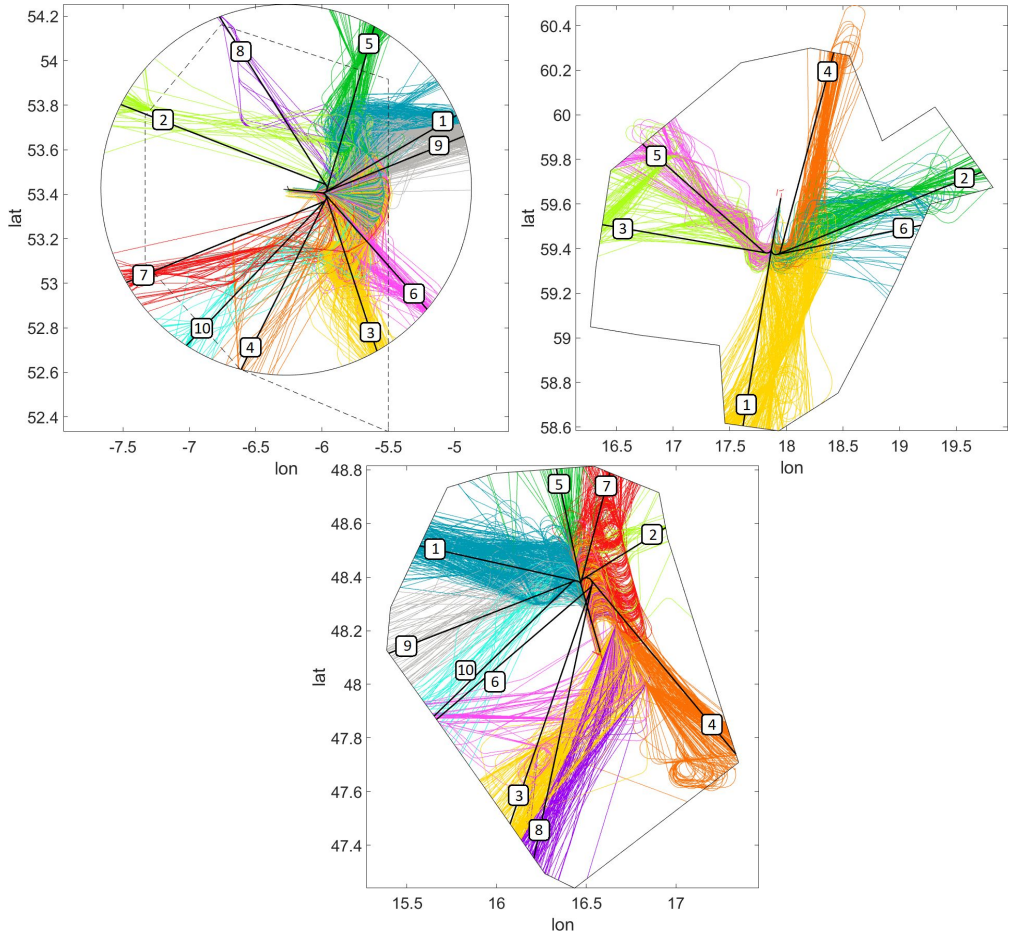
Dataset

- Peak-time periods in October 2019
- Calculate average per hour time in TMA for each airport
- 0.7 percentile removed from the set of values
- 2587 flights for Dublin, 1045 for Arlanda and 1641 for Vienna

Methodology

Additional distance

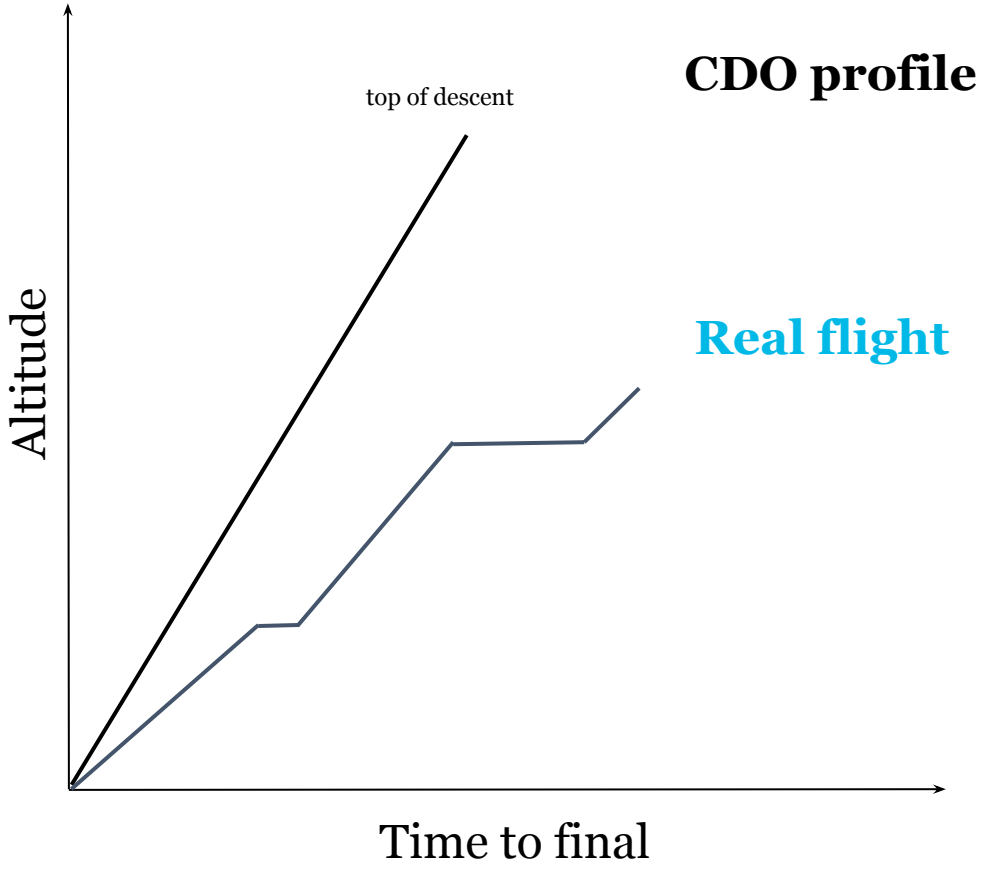
- To evaluate horizontal flight efficiency
- Clustered trajectories in each TMA
- Ideal reference trajectory
- Calculated as the difference between the actual path length and the length of the corresponding reference trajectory inside TMA



Methodology

Time of flight levels

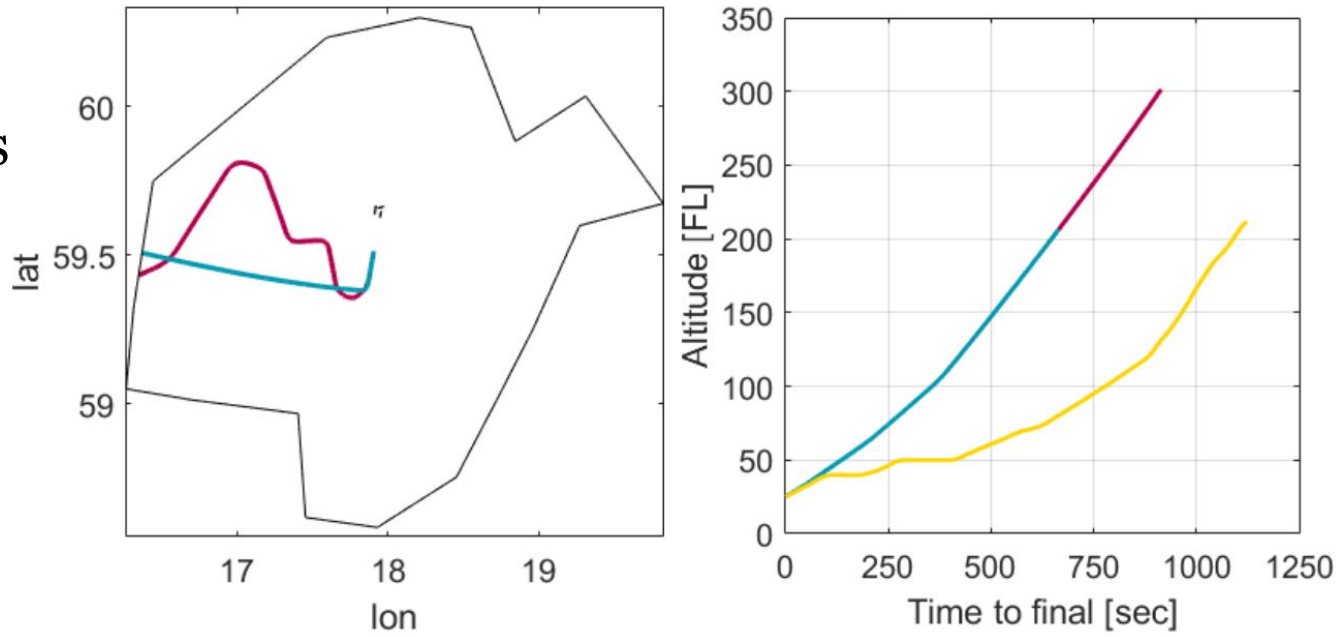
- To evaluate the vertical flight efficiency
- VFE by EUROCONTROL: Level segment = vertical speed below 300 feet per minute for at least 30 seconds



Methodology

Vertical reference trajectories

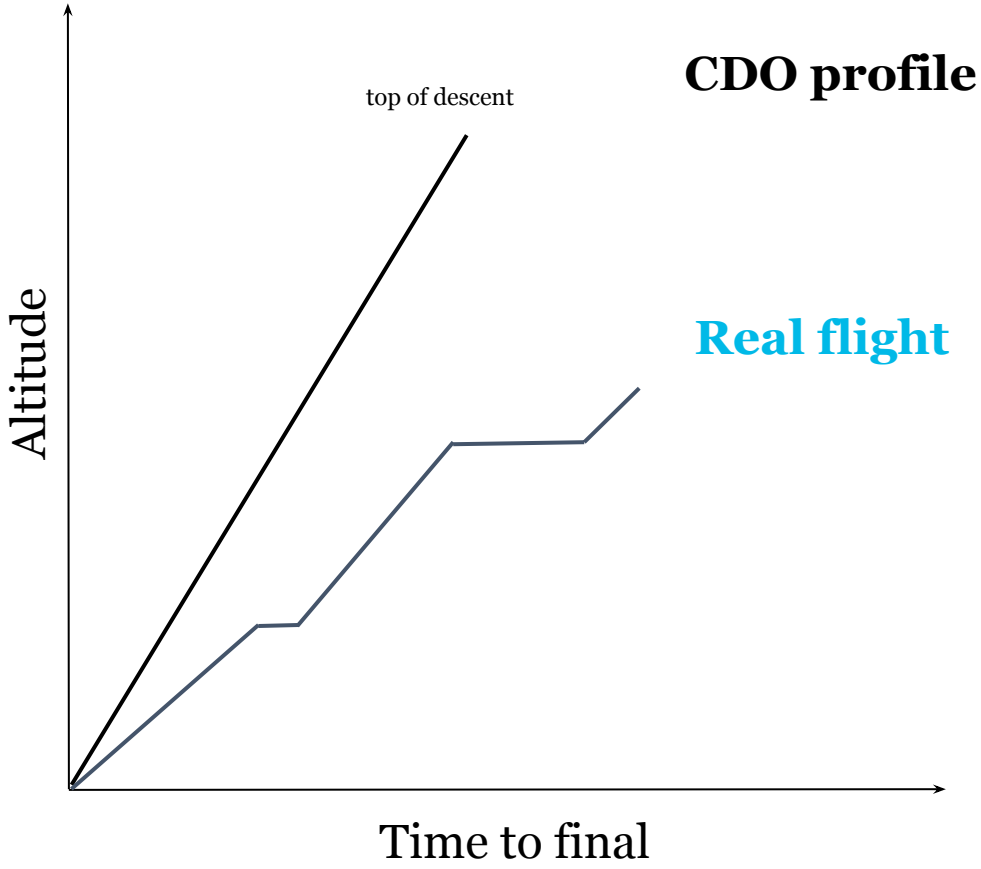
- Two CDO reference trajectories per flight (RT1 & RT2) created with BADA v4.2
- RT1: same horizontal route as the real flight
- RT2: shortest route from TMA entry to final approach



Methodology

Vertical deviation

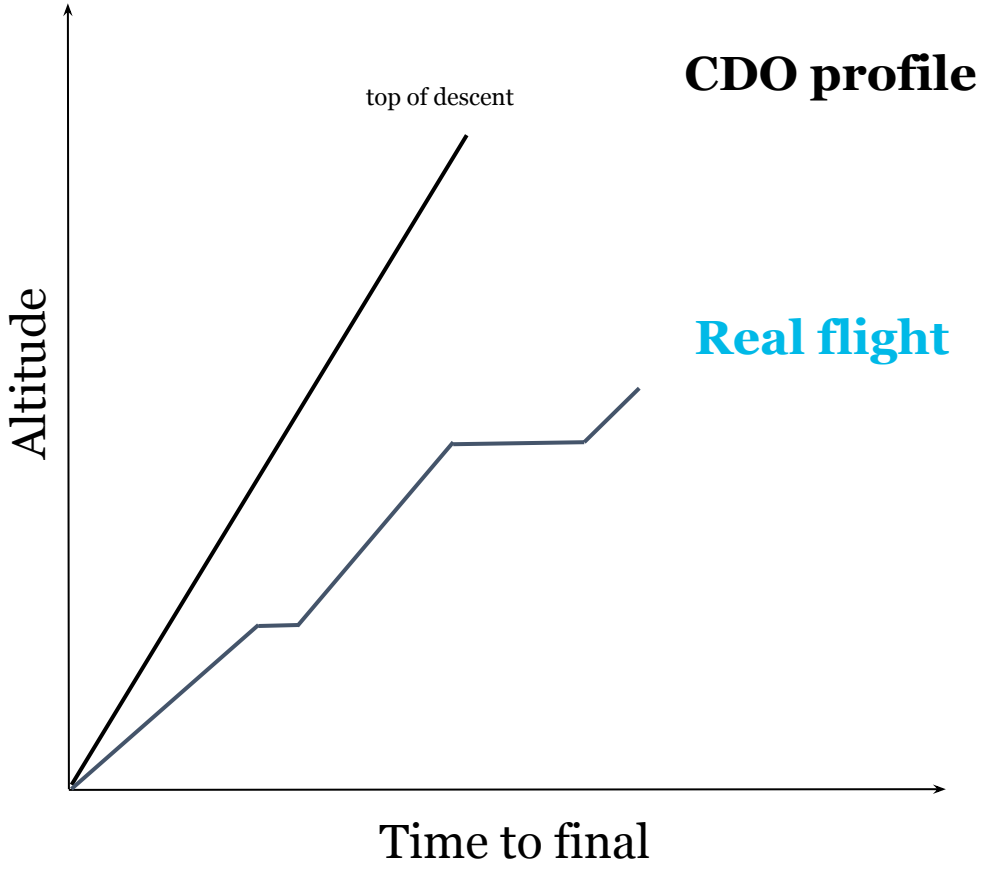
- Assessed as the vertical deviation from a CDO reference profile
- 10 minutes prior to final



Methodology

Additional fuel burn

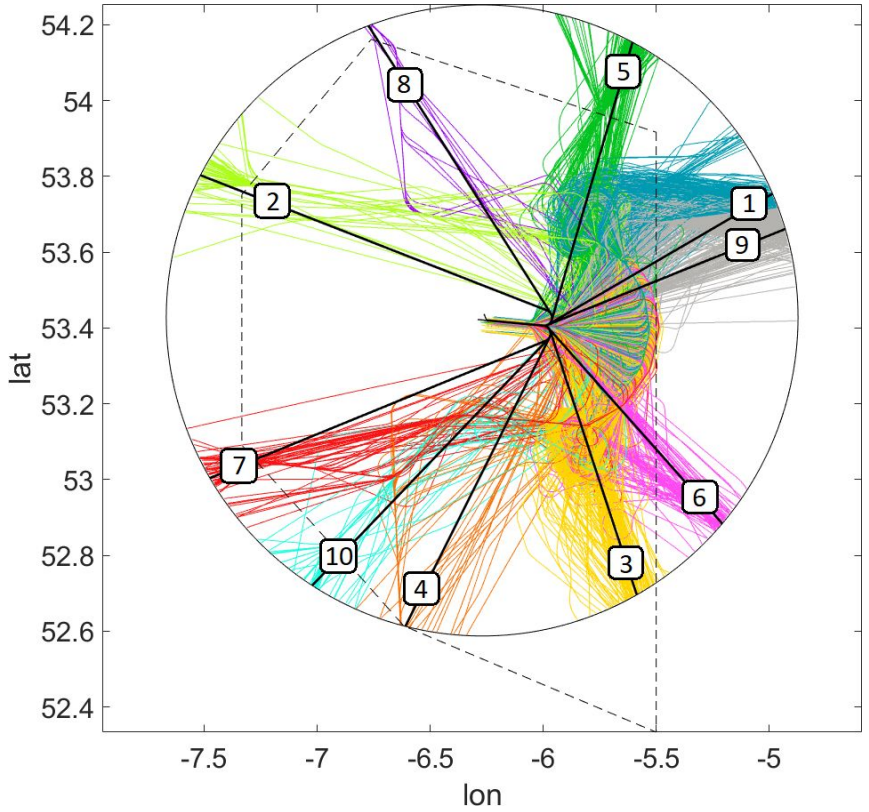
- To evaluate environmental efficiency
- Difference in fuel consumption between the real trajectory and a reference flight performing a CDO at idle thrust, flying RT1 and RT2
- CDO profiles and fuel consumption calculated with Eurocontrol BADA v4.2, considering actual wind and temperature conditions from ERA5



Methodology

Cluster analysis

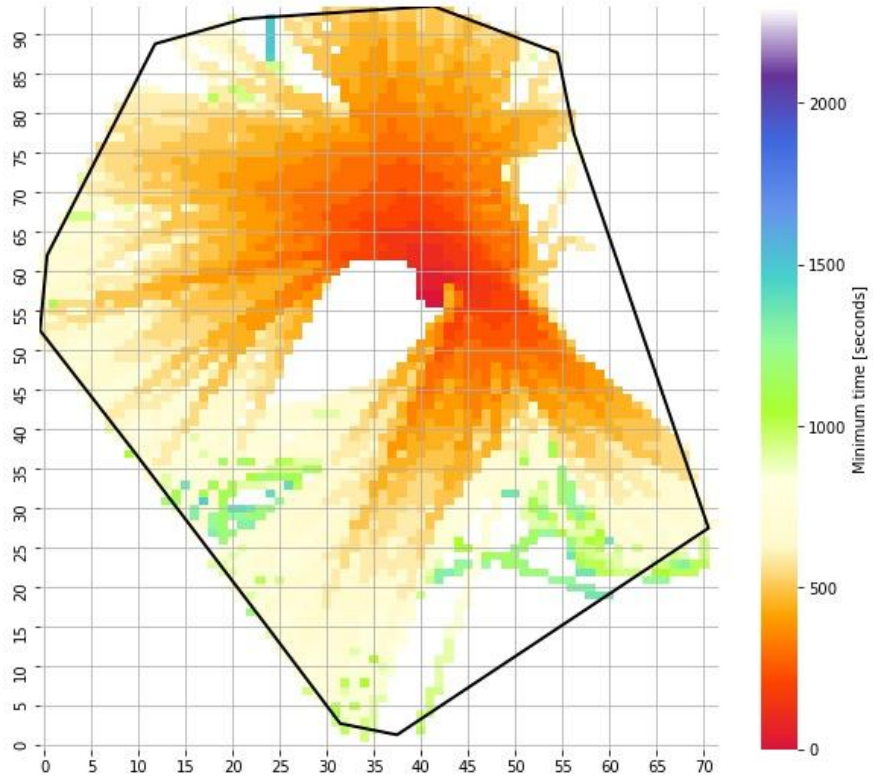
- Evaluation of flight efficiency per flow
- Horizontal, vertical efficiency, and additional fuel burn



Methodology

Minimum time to final

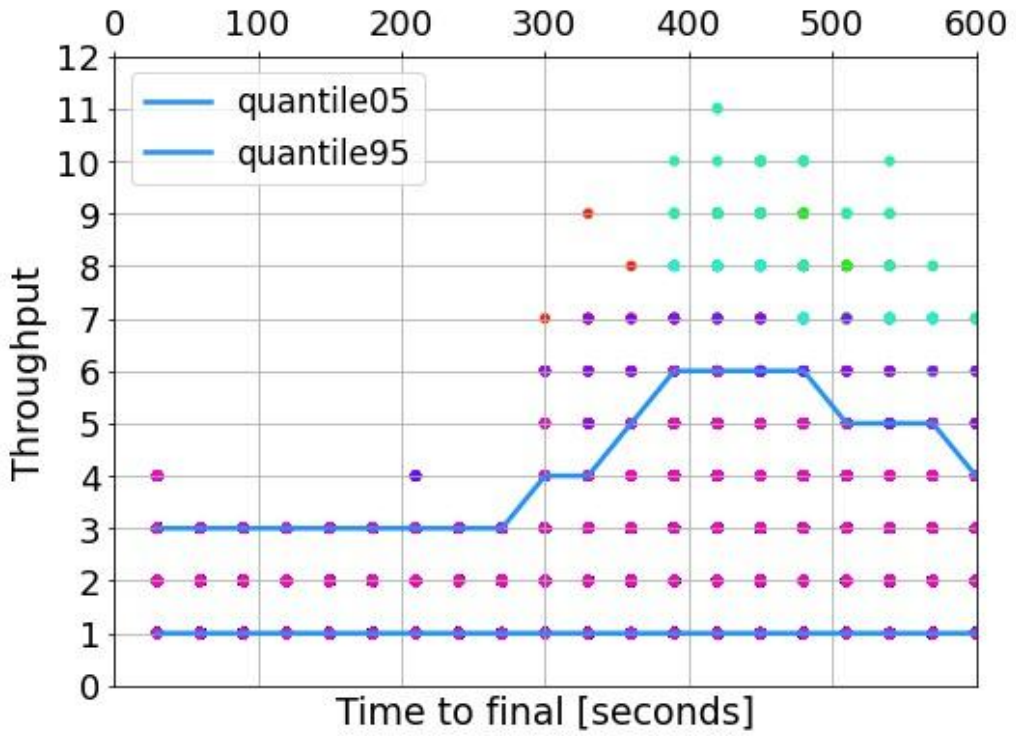
- A rectangular grid with the cell side of ≈1 NM laid over the TMA
- The minimum time needed from any point within the cell of the grid to the final approach
- Infinite for the cells through which no trajectories pass
- Heatmap visualization



Methodology

Throughput

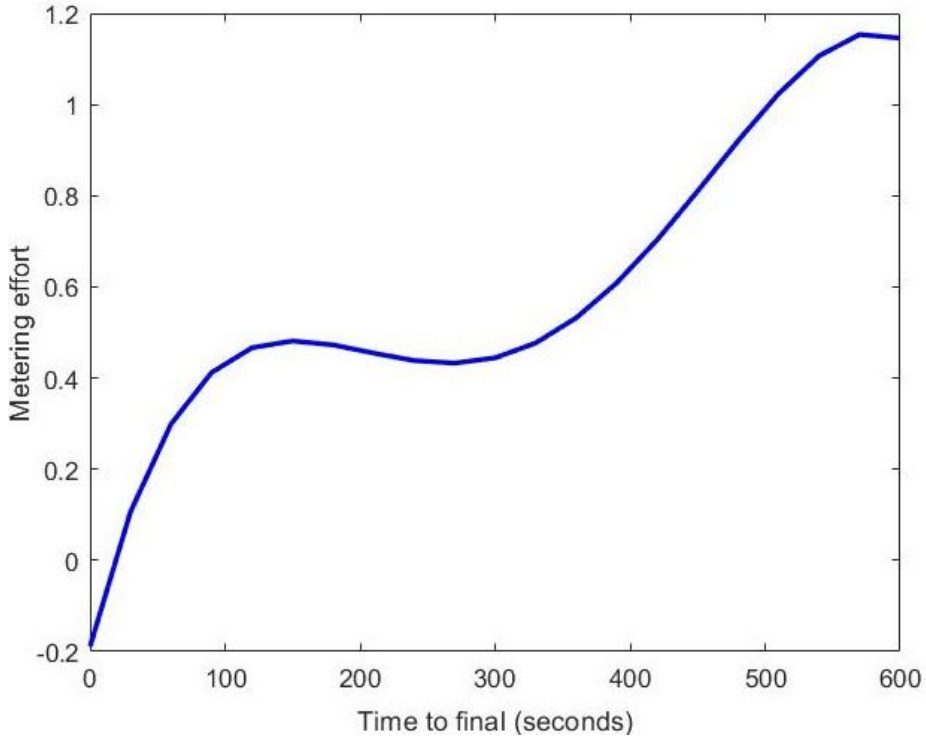
- The number of aircraft with the same minimum time to final within a given time window
- Iso-minimum time lines from 600 to 30s to final
- 30 seconds sampling rate over 5-minute periods



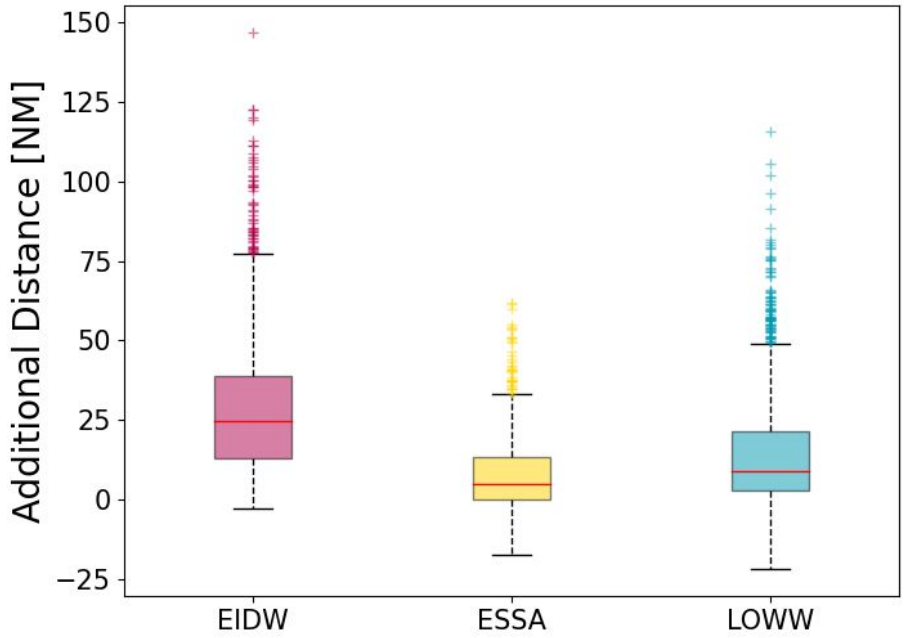
Methodology

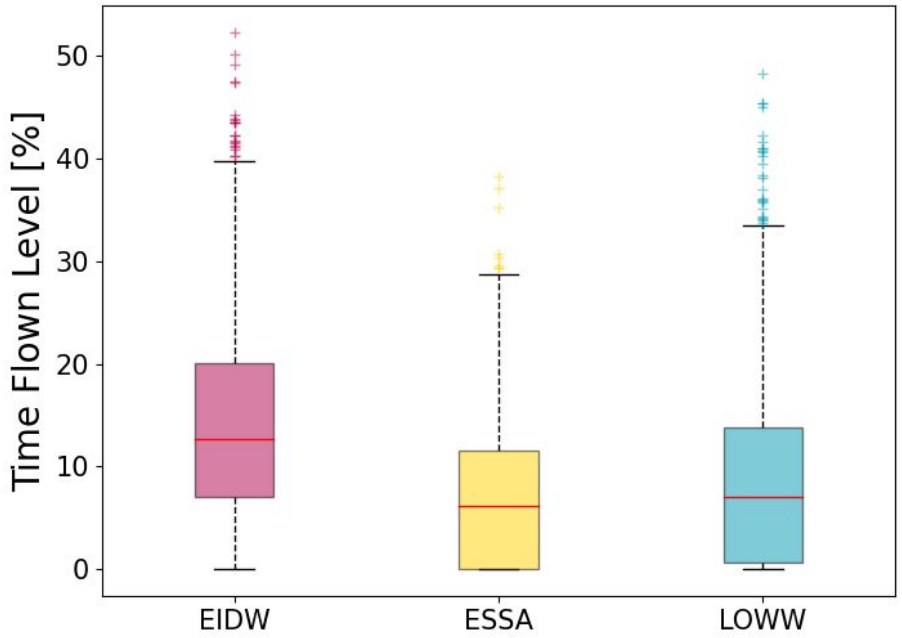
Metering effort

- Difference between the throughput at the given time horizon and the one close to the final
- Quantifies the controller's effort for metering
- Proxy to controller's workload



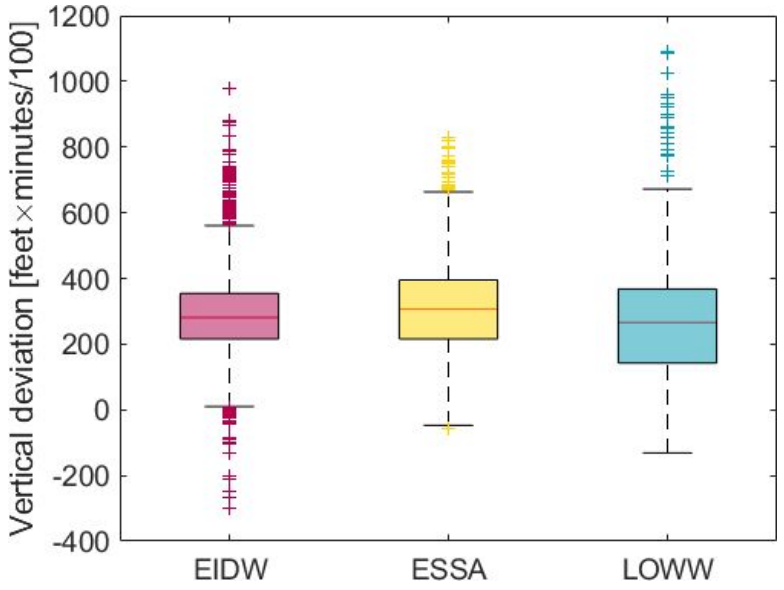
Results

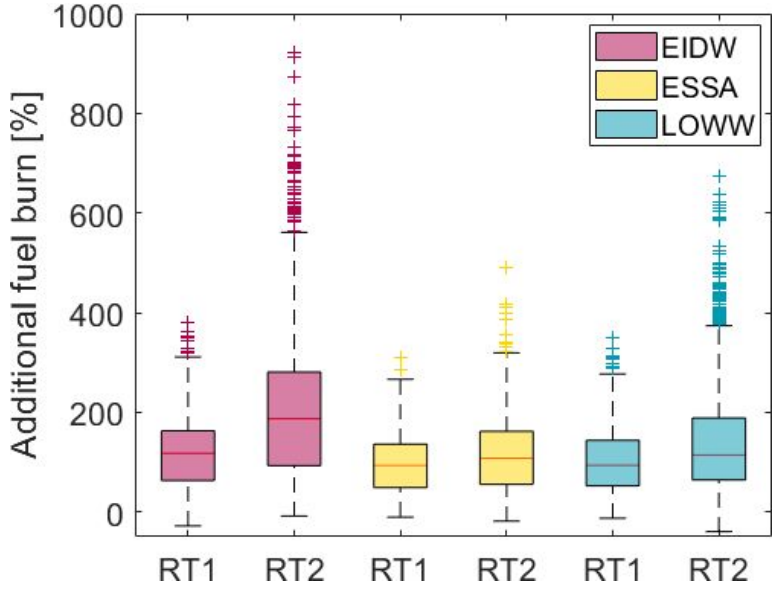




- Dublin shows higher median values for both additional distance and time flown level than Arlanda and Vienna

Results

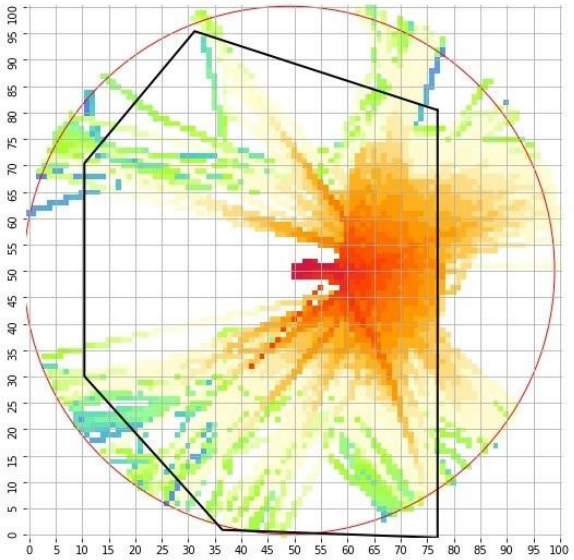




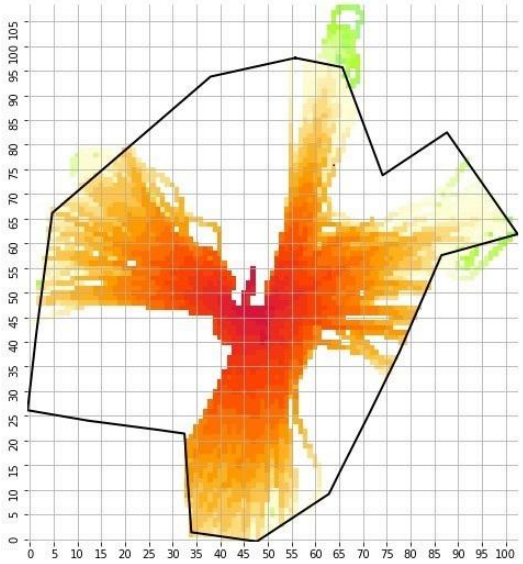
- Dublin and Arlanda show similar median values for vertical deviation, while Vienna has the lowest. The spread is greater for Vienna.
- Dublin shows the highest additional fuel burn, both for RT1 and RT2, followed by Vienna and Arlanda.

Results

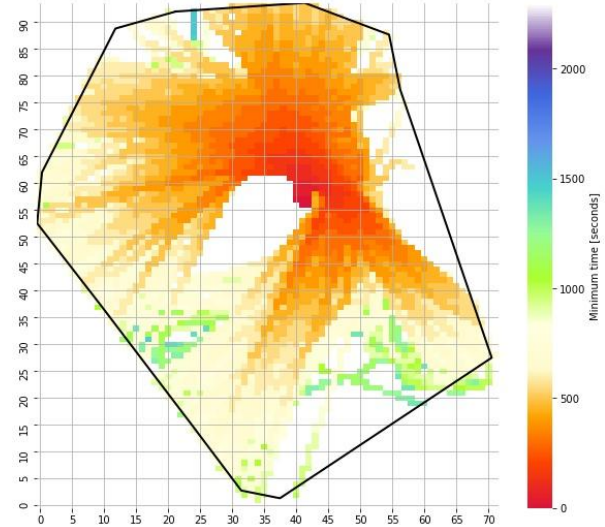
Dublin



Arlanda



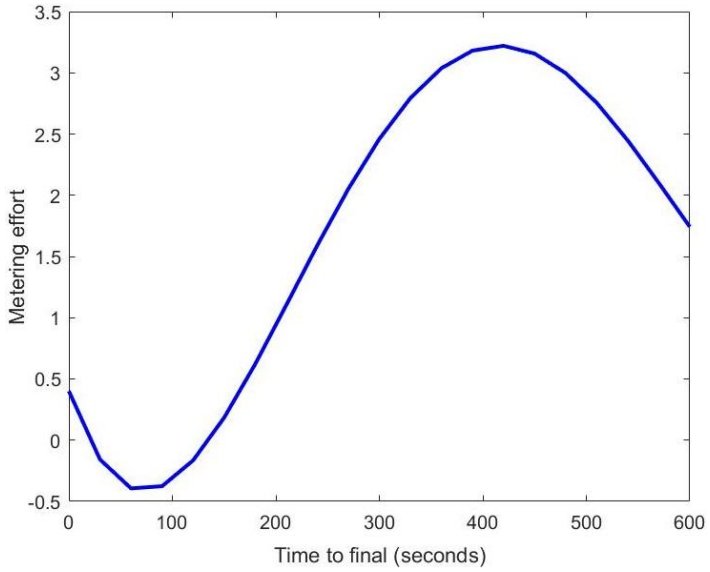
Vienna



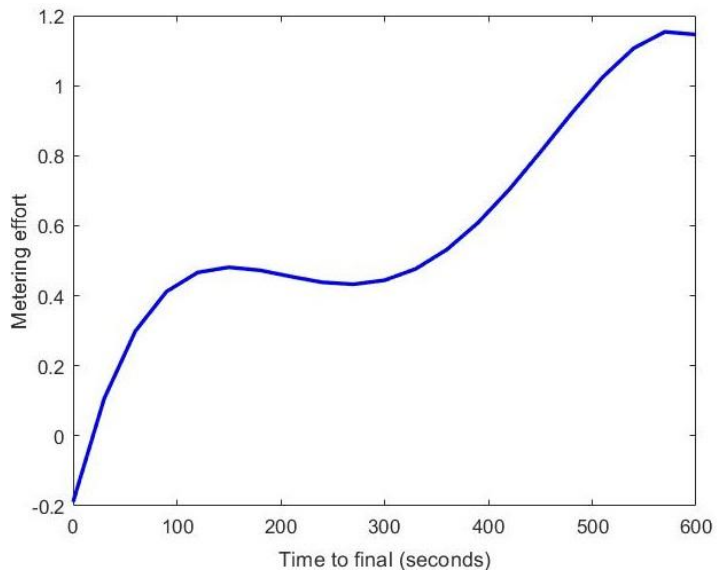
- Horizontal spread is 64% for Dublin, 59% for Arlanda, and 84% for Vienna
- Significantly higher minimum time to final values for Dublin
- Consistent with the results obtained for the Additional Distance

Results

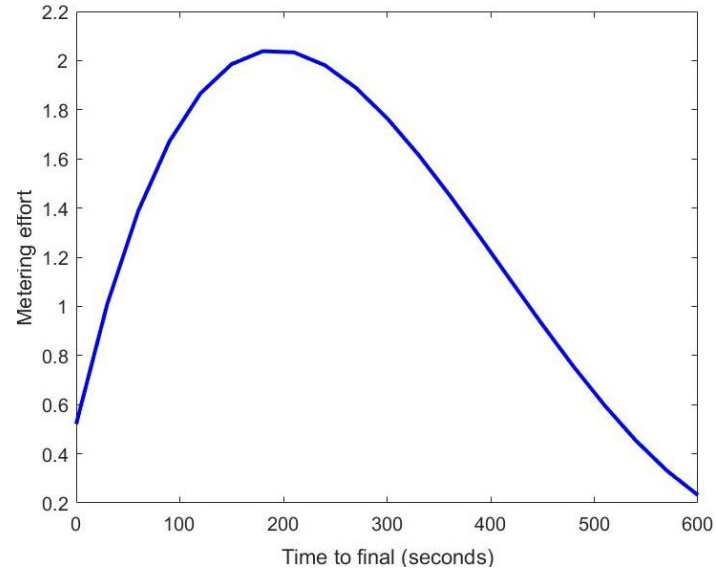
Dublin



Arlanda



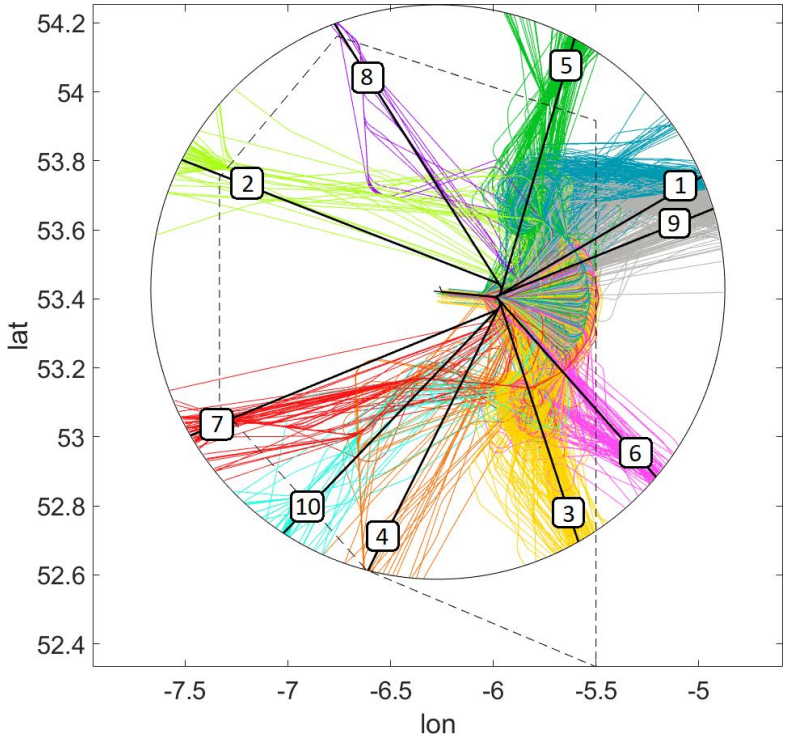
Vienna



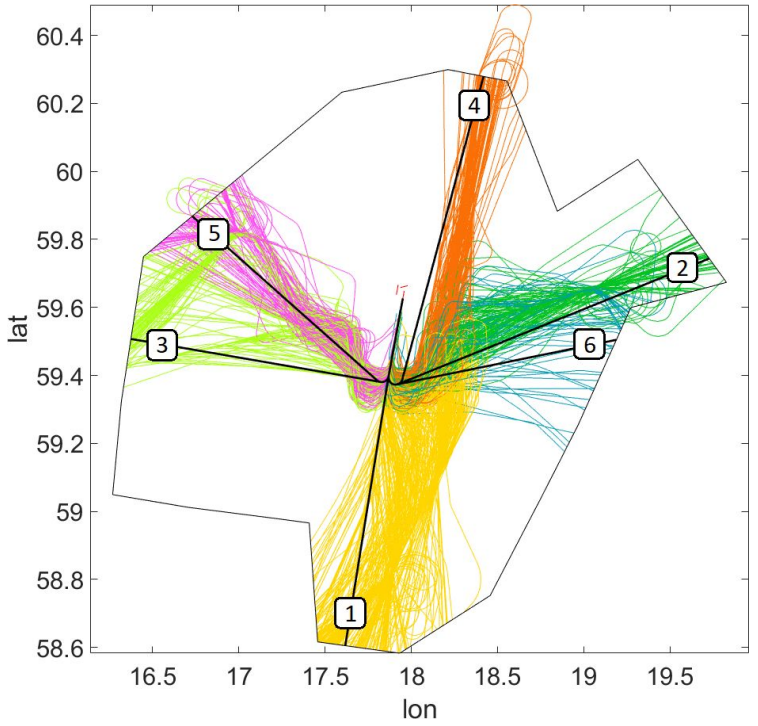
- The figures of metering effort indicate significant differences of entry conditions among the airports, with the traffic samples considered
- Dublin is having by far the highest effort (3), followed by Vienna (2) and then Arlanda (1.2)

Results per cluster

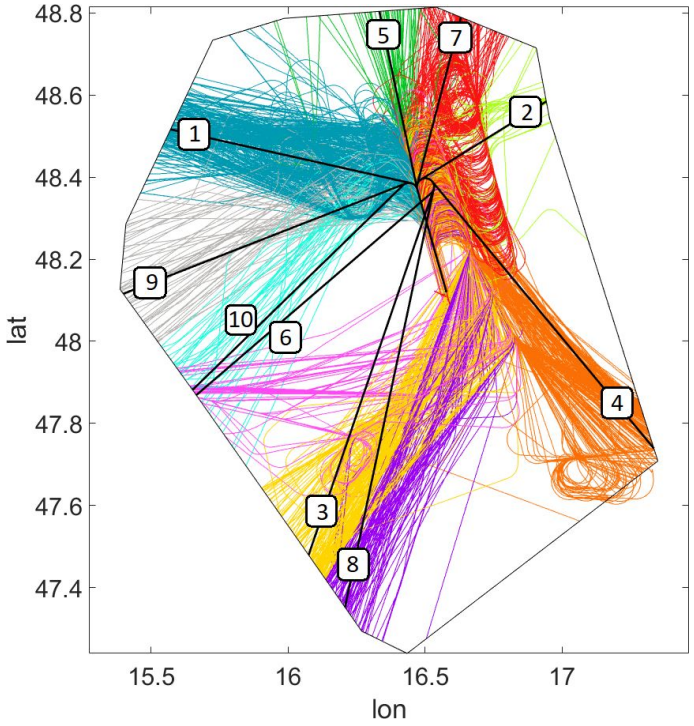
Dublin



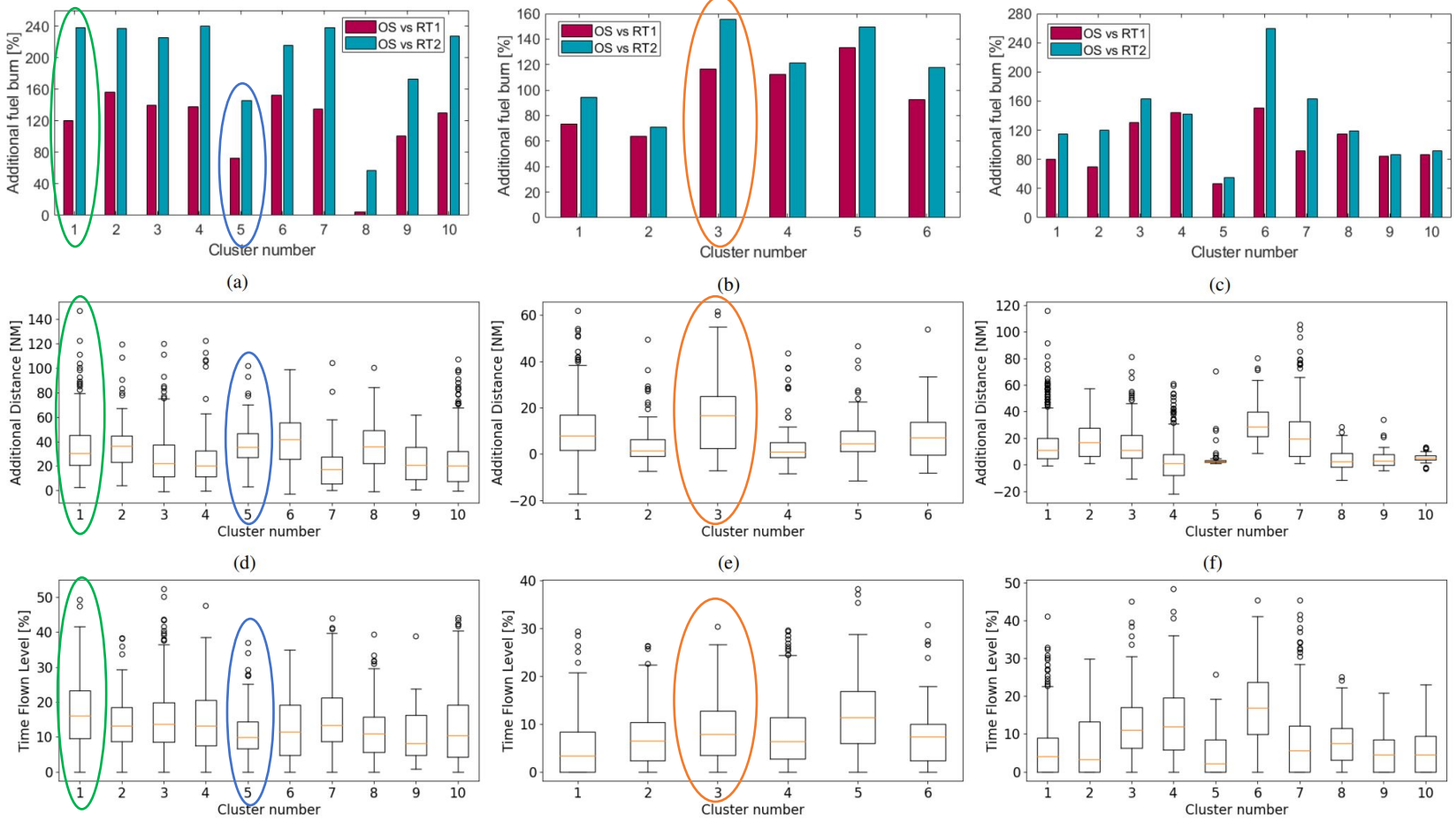
Arlanda



Vienna



Results per cluster



Arlanda

- Noticeable difference between RT1 and RT2 additional fuel burn
- High additional distance
- Moderate time flown level

Dublin

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- High additional distance
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Dublin

- Noticeable difference between RT1 and RT2 additional fuel burn
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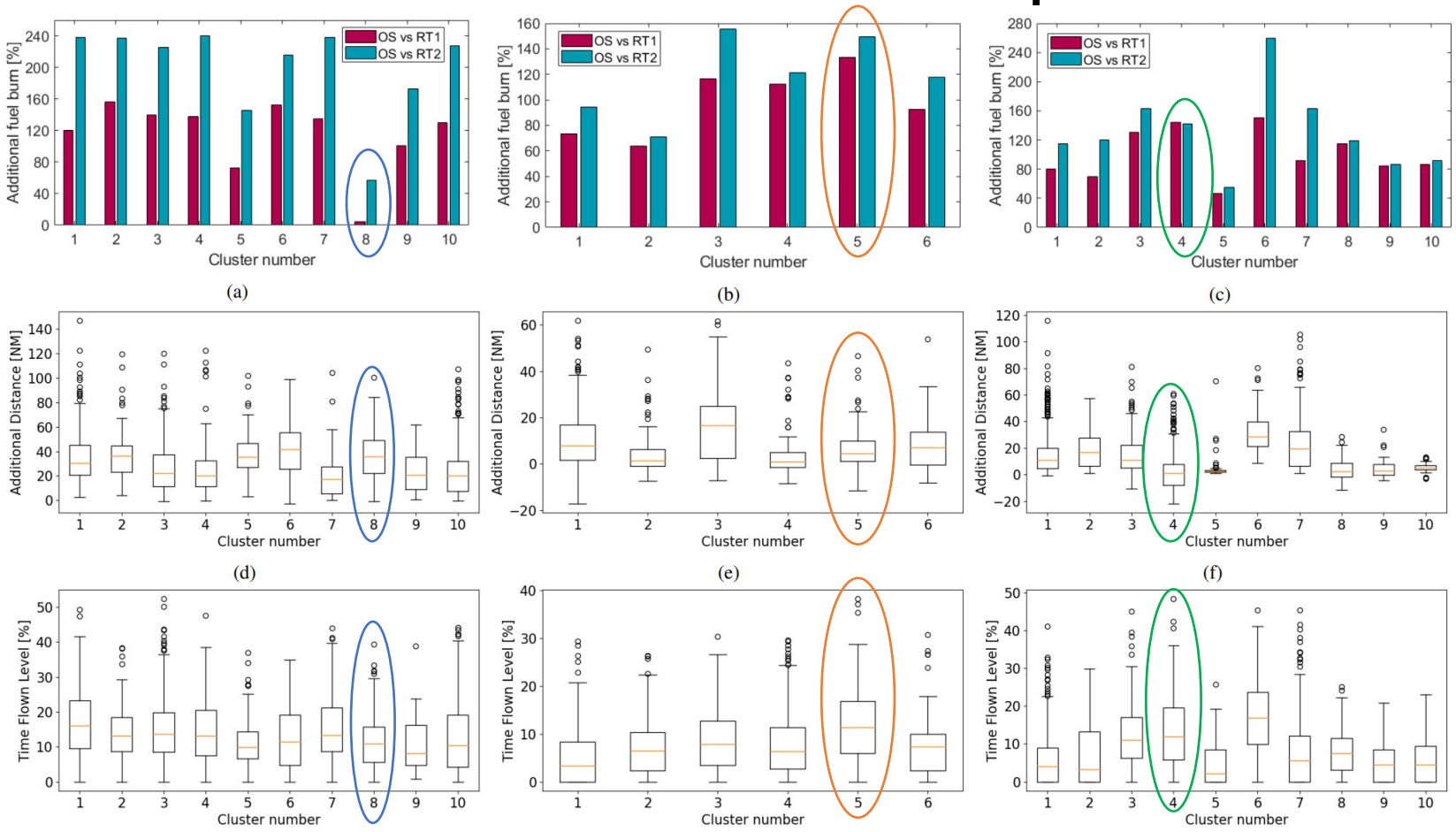
Results per cluster



Arlanda

- Small difference between RT1 and RT2 additional fuel burn
- Additional fuel burn mostly caused by vertical inefficiency

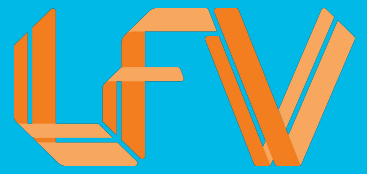
Vienna

- Negative difference between additional fuel burn for RT1 and RT2
- RT1 shorter horizontal trajectories
- Confirmed by low additional distance
- Additional fuel burn mainly caused by vertical inefficiency

Dublin

- RT1 additional fuel burn very low
- Vertical inefficiency still exists
- Turboprop a/c with low cruise altitudes
- Later RT1 ToD → cruise in TMA

Conclusions

- Evaluation of the arrival efficiency at three European airports with different airspace complexity and different sequencing and merging techniques
- Evaluation for all flights combined and per flow
- Reveals varied situations among three airports with similar number of yearly aircraft movements
- No fair comparison is possible without considering the entry conditions to the terminal area, and further studies would be required to analyze flight efficiency under comparable entry conditions
- Further work should also consider a breakdown of the two main sources of inefficiencies (airspace and operations), and take into account the weather conditions as well as other sources of perturbations and uncertainties

Thank you!