Data-Driven Planning of Conflict-Free Trajectories

Trajectory Planning for Conflict Free Trajectories

A Multi-Agent Reinforcement Learning Approach

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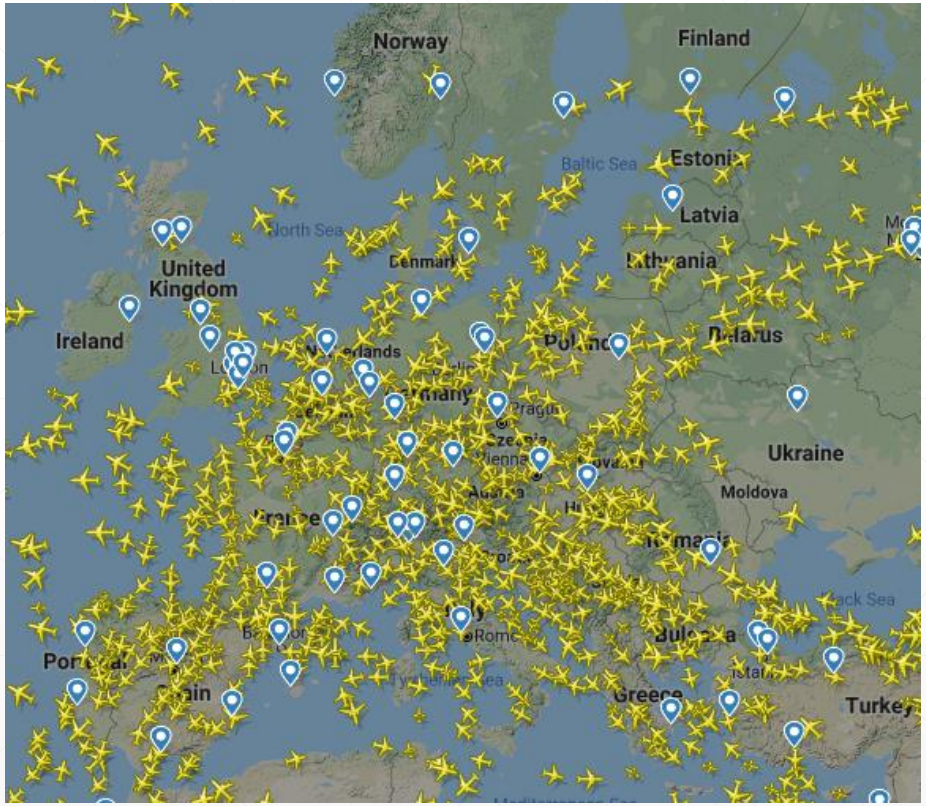
Problem Background



Traffic over Europe (flightradar24.com)

- *Complex airspace (30000 aircraft)*
- *ATM needs to handle:*
  - *Greater Complexity*
  - *Larger Volumes of Traffic*
- *Safety Guarantees*
- *Solution*
  - *Efficient Planning*

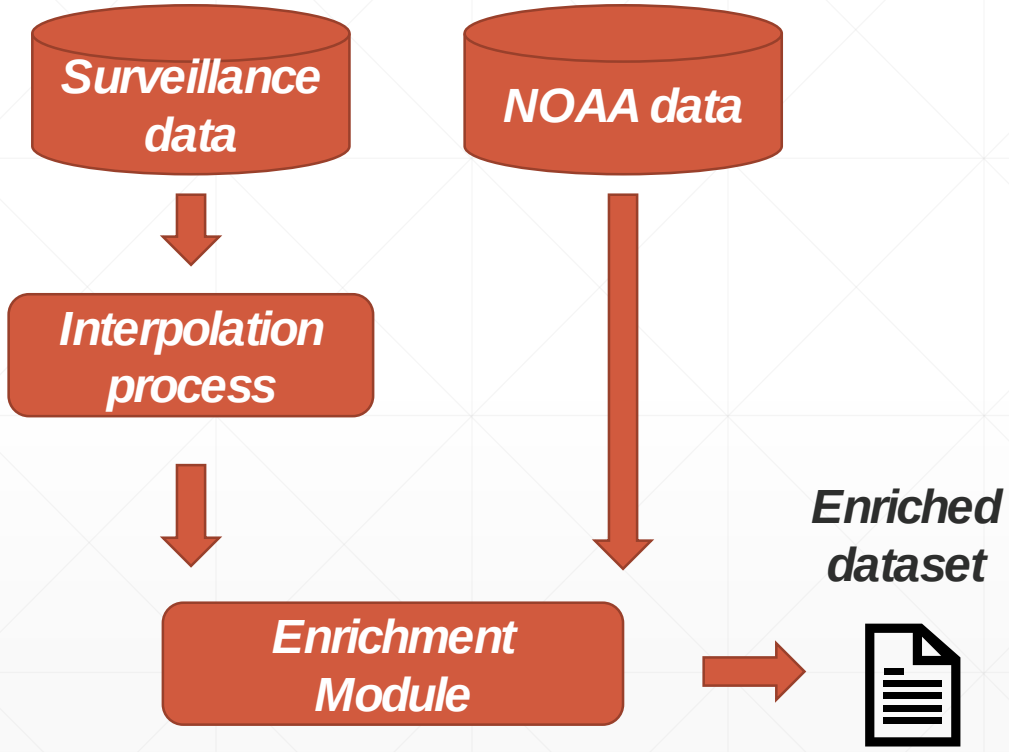
Operational Goals

- ***Eliminate Conflicts at the pre-tactical phase***
  - Reducing ATC's workload
  - ***Enabling them to deal with complex traffic situations***
- ***Incorporate preferences, interests, constraints of different stakeholders (AUs, ATCs, etc.)***
- ***Increase predictability***
- ***Reduce the mismatch between planned and flown trajectories***
- ***Reduce uncertainty***
- ***Reduce flight inefficiencies***
- ***Better planning of operations for Airspace Users***

Data Sources

- *Surveillance data*
  - *operational quality data with actual flights trajectories and ATC best practices at conflict-solving (Spanish ATC Platform SACTA)*
- *Flight plan data*
  - *all flight plan updates for any given flight, since flight plan creation, allowing continuous snapshots (Spanish ATC Platform SACTA)*
- *Sector configuration data*
  - *as schedule of deployed sector configurations, as well as the catalog of possible sector configurations (Spanish ATC Platform SACTA)*
- *Weather data (NOAA)*

Data Sources: Processing



Per 5 seconds points:

- ***Spatiotemporal Information***
  - *Longitude (degrees)*
  - *Latitude (degrees)*
  - *Altitude (feet)*
  - *Timestamp*
- ***Weather Information***
  - *Pressure surface (Pa)*
  - *Relative humidity (%)*
  - *Temperature (K)*
  - *Wind speed gust (m/s)*
  - *U component of wind (m/s)*
  - *V component of wind (m/s)*

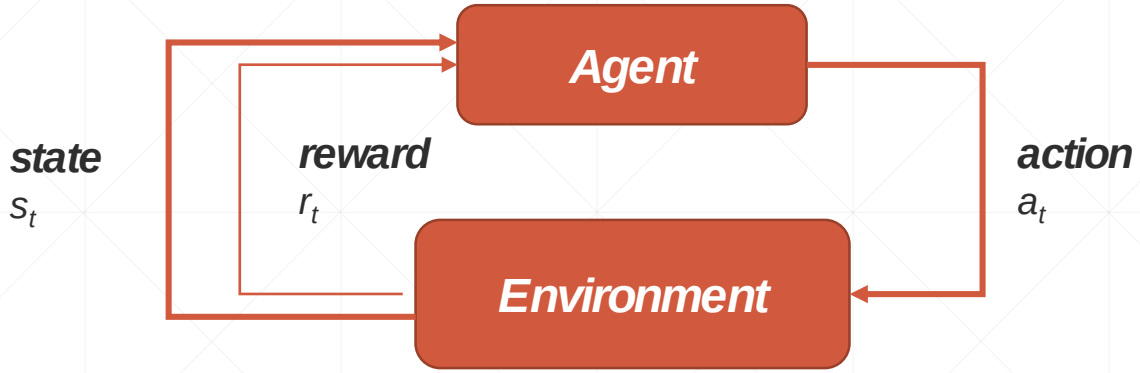
Approach

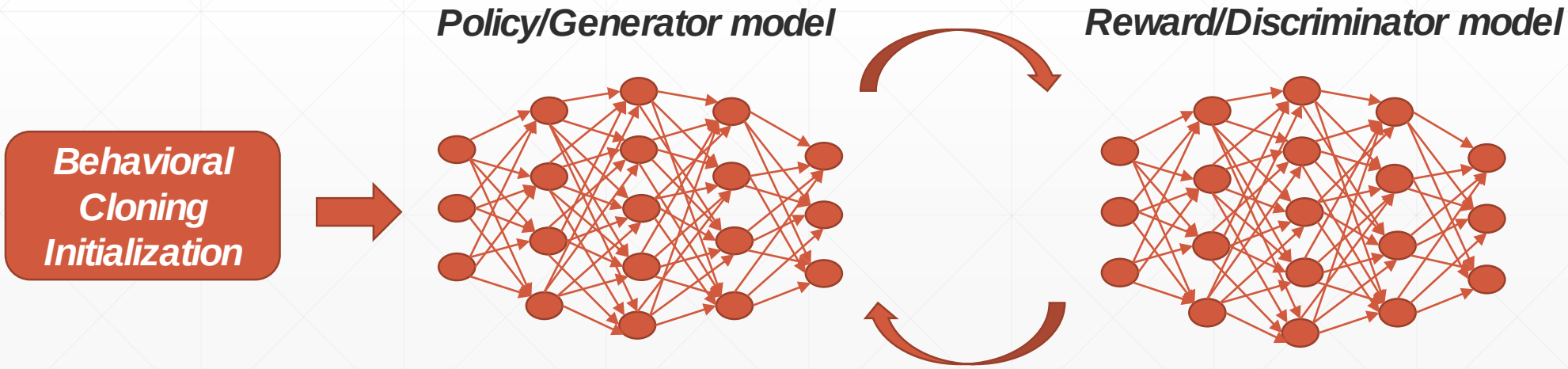
- *4-D Trajectory: sequence of spatiotemporal points*
- *Combination of*
  - *Data-Driven methods that based on historical data learn:*
    - *Preferences / Interests*
    - *Patterns*

    of stakeholder's behavior
  - *Agent-Based methods using RL towards CF Trajectories*
- *Planning Trajectories per pair Origin-Destination (single agent)*
- *Apply Conflict Resolution at planned Trajectories (multi-agent)*

Approach:
Generative Adversarial Imitation Learning

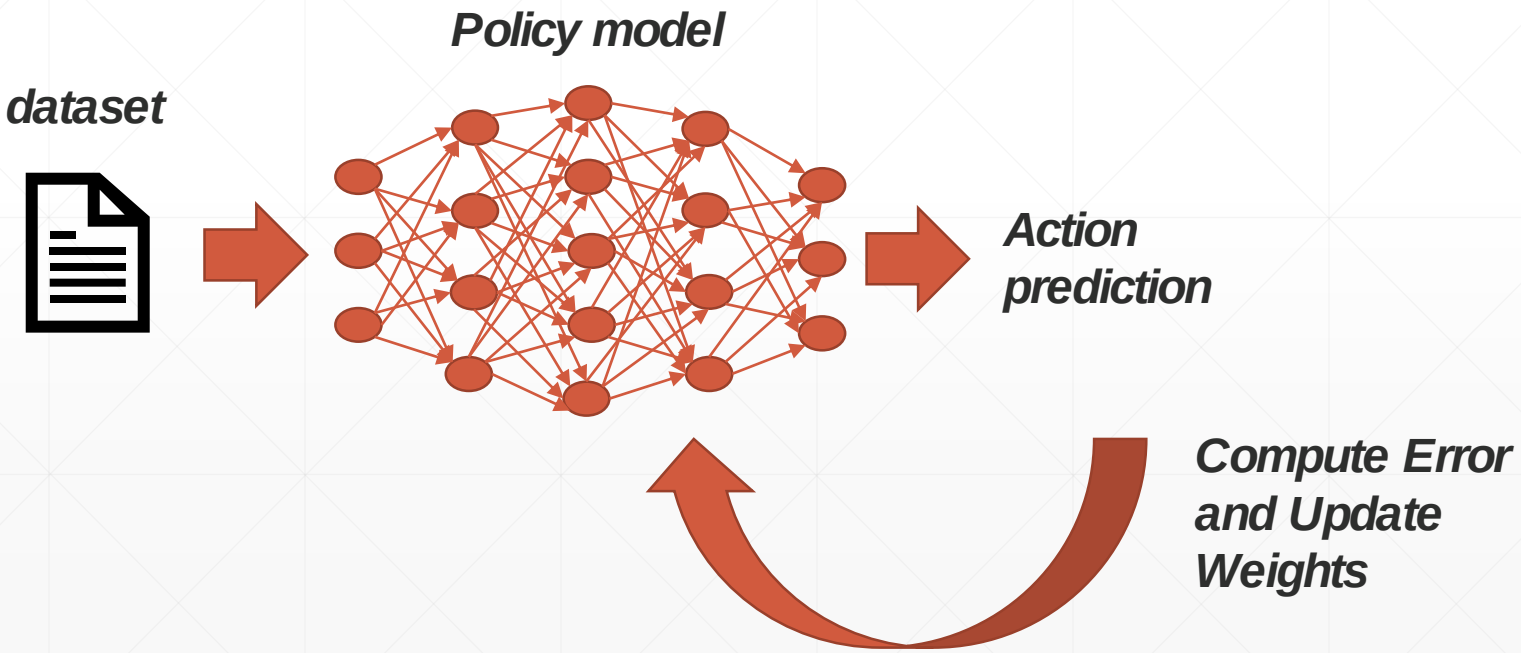
[Ho Jonathan, Stefano Ermon 2016]





Approach: Behavioral Cloning

- *Train the Policy as Supervised Learning*



Planning Trajectories: MDP Problem Formulation

Data-Driven Planning of Conflict-Free Trajectories

Set of States S *Spatiotemporal & Weather information*	***Set of Actions A*** *Agent takes an action every 5s*		***Reward R(s,a)***	Agent's Goal
	ACT Formulation	***DS Formulation***		
Spatiotemporal Information • *Longitude (degrees)* • *Latitude (degrees)* • *Altitude (feet)* • *Timestamp* ***Weather Information*** • *Pressure surface (Pa)* • *Relative humidity (%)* • *Temperature (K)* • *Wind speed gust (m/s)* • *U component of wind (m/s)* • *V component of wind (m/s)*	• *Bearing (degrees)* • *Horizontal Speed (m/s)* • *Vertical Speed (feet/s)*	*ΔLongitude (degrees)* *Δlatitude (degrees)* *Δaltitude (feet)*	*Approximated by the reward model*	*Maximize the expected total reward*

Planning Trajectories: Methods

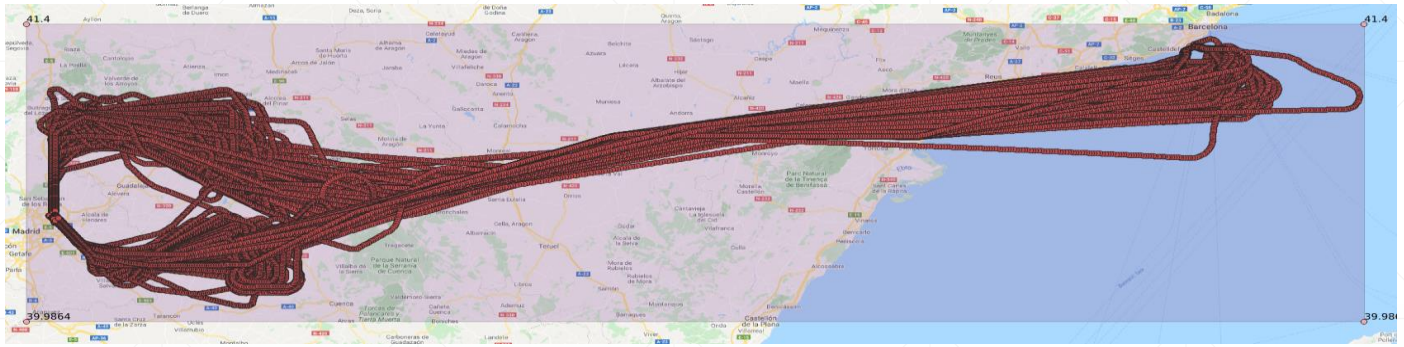
Method	State
GAIL – ACT	• Spatiotemporal
	• Spatiotemporal & Weather
GAIL – DS	• Spatiotemporal
	• Spatiotemporal & Weather

Method	State
Behavioral Cloning	• Spatiotemporal
	• Spatiotemporal + Weather

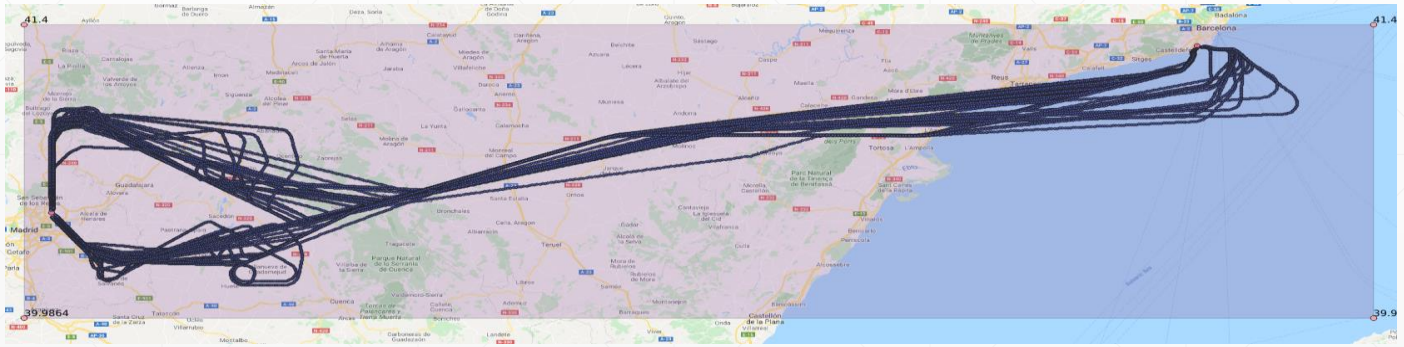
Preliminary Experimental Results: Dataset

- *Surveillance & Weather data*
- *Spatial Coverage:*
  - *Origin Airport: Barcelona*
  - *Destination Airport: Madrid*
- *Temporal Coverage:*
  - *April 1st – April 24th 2016*
- *Flights:*
  - *Total Flights: 530 flights*
  - *Training Set: 480 flights*
  - *Test Set: 50 flights*

Training Set



Test Set



Preliminary Experimental Results: Metrics DTW

Data-Driven Planning of Conflict-Free Trajectories

Method	Formulation	State	DTW Mean	DTW Std
Bcloning	ACT	Spatiotemporal	17.76	10.05
GAIL	ACT	Spatiotemporal	18.36	14.02
Bcloning	ACT	Spatiotemporal & Weather	25.09	11.44
GAIL	ACT	Spatiotemporal & Weather	10.60	8.39
Bcloning	DS	Spatiotemporal	20.26	14.26
GAIL	DS	Spatiotemporal	11.25	9.83
Bcloning	DS	Spatiotemporal & Weather	25.72	16.76
GAIL	DS	Spatiotemporal & Weather	9.88	9.44

Preliminary Experimental Results: Metrics RMSE

Data-Driven Planning of Conflict-Free Trajectories

Method	Formulation	State	RMSE Mean	RMSE Std
Bcloning	ACT	Spatiotemporal	0.28	0.17
GAIL	ACT	Spatiotemporal	0.32	0.25
Bcloning	ACT	Spatiotemporal & Weather	0.37	0.15
GAIL	ACT	Spatiotemporal & Weather	0.18	0.13
Bcloning	DS	Spatiotemporal	0.30	0.21
GAIL	DS	Spatiotemporal	0.18	0.13
Bcloning	DS	Spatiotemporal & Weather	0.33	0.16
GAIL	DS	Spatiotemporal & Weather	0.16	0.14

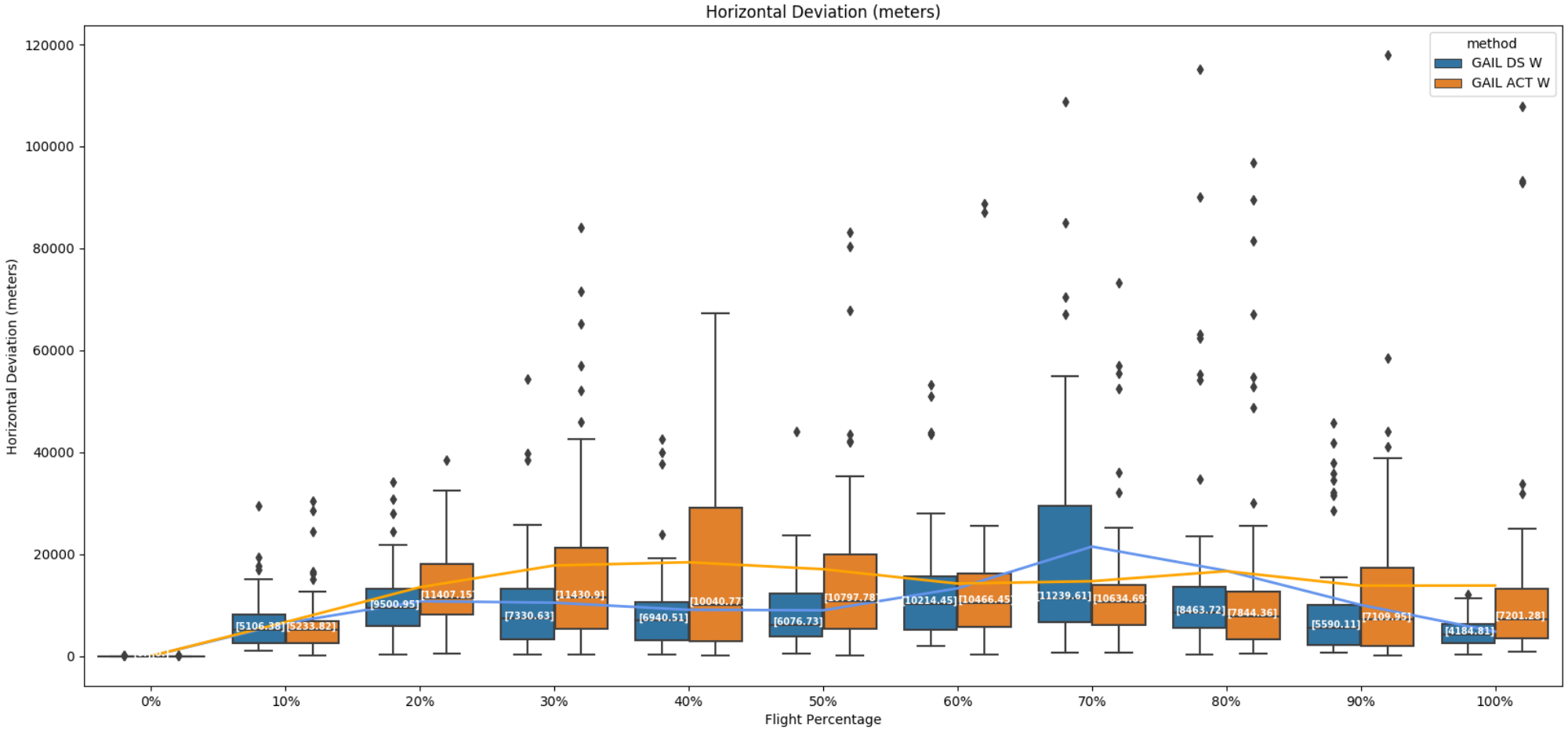
Preliminary Experimental Results: ACT vs DS Visualization

- ***Blue: Test Set***
- ***Yellow: Generated Trajectories***

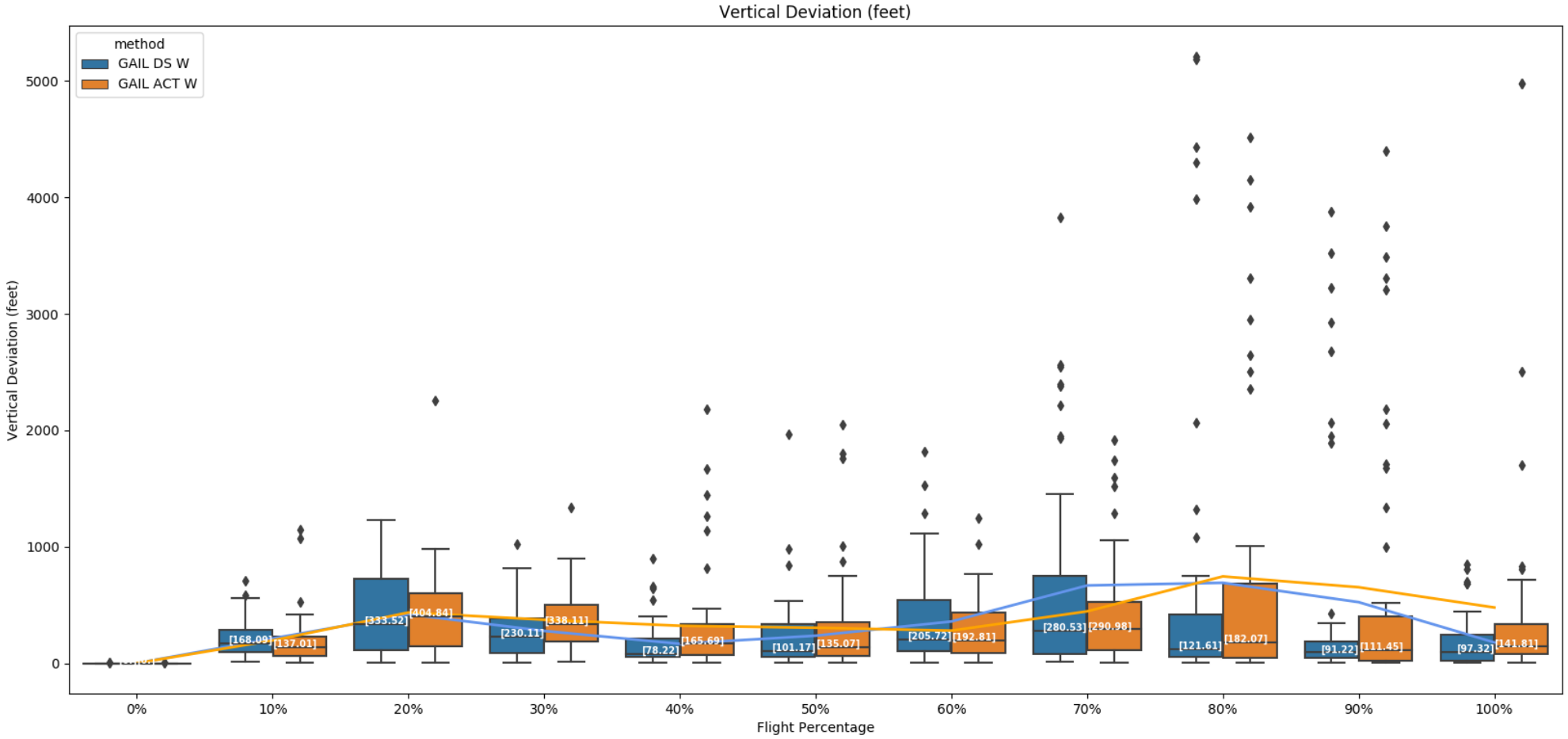
ACT

DS

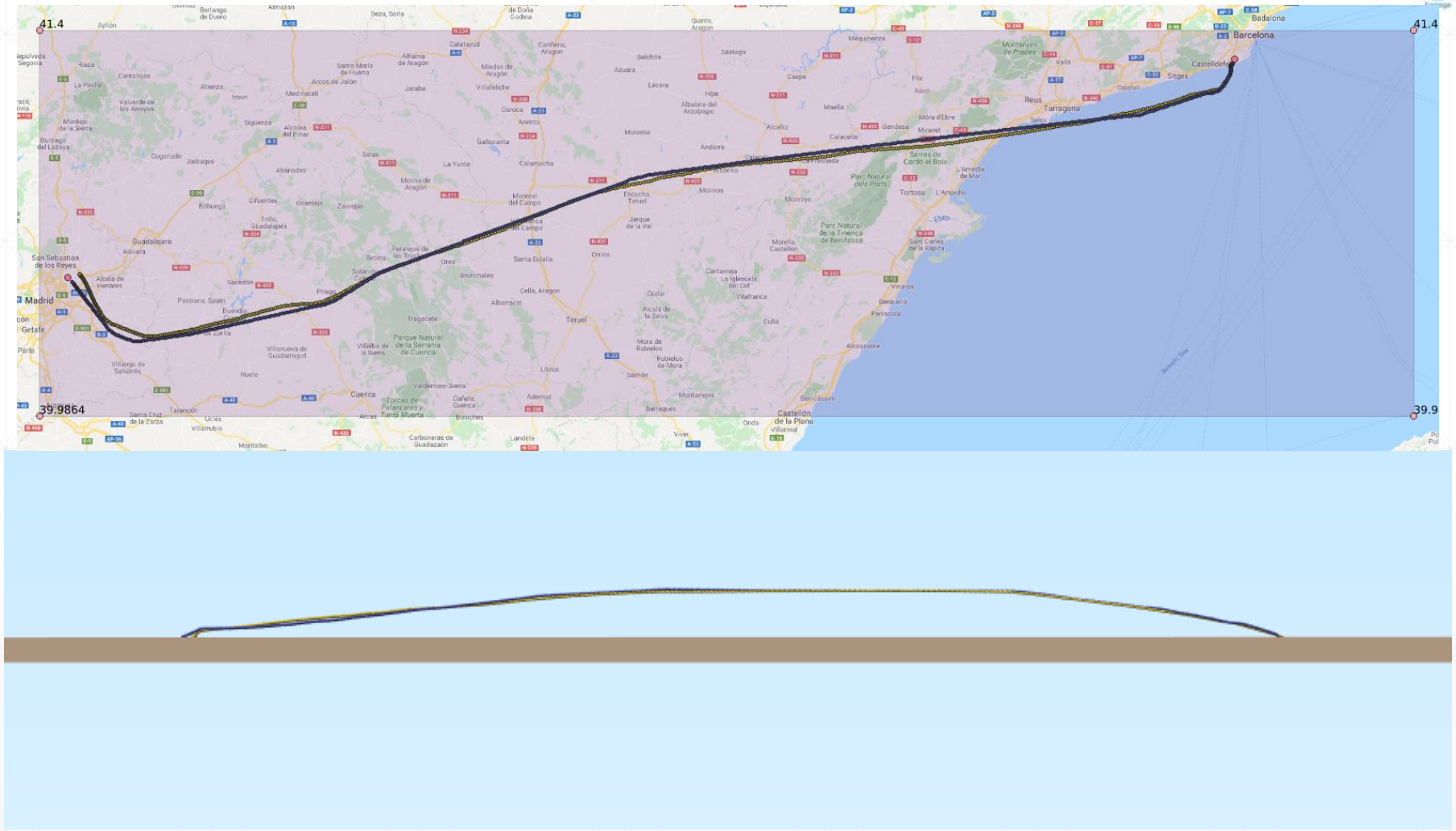
Experimental Results: Horizontal Deviation GAIL St & W



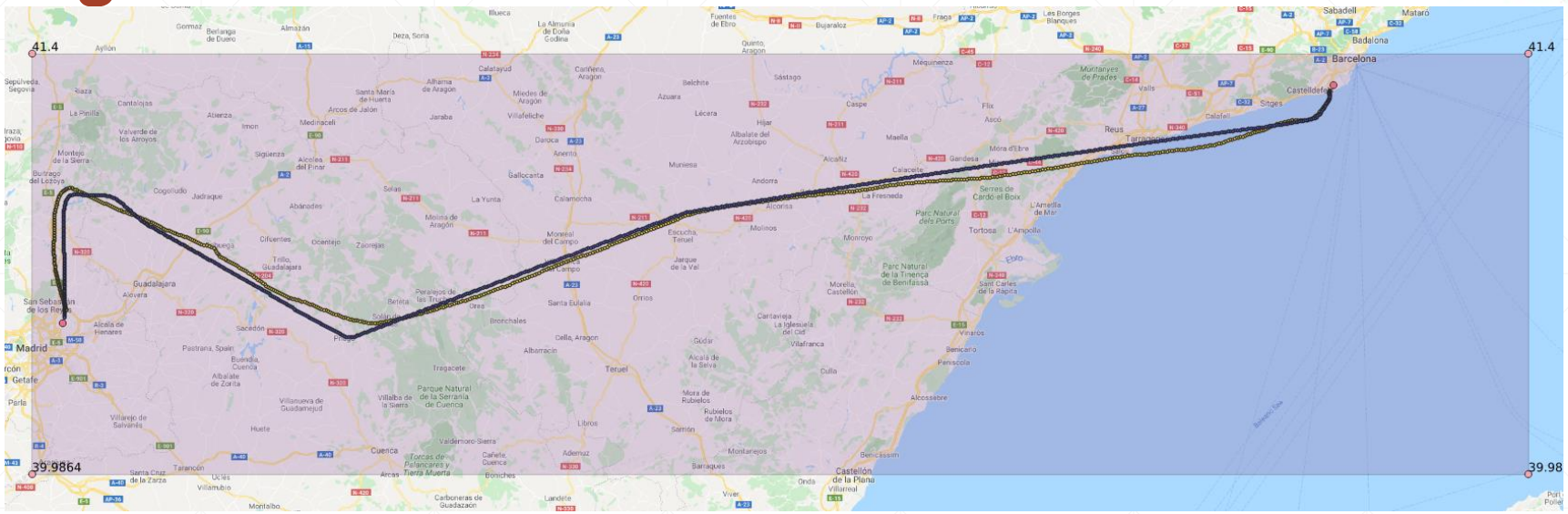
Experimental Results: Vertical Deviation GAIL Formulation DS St & W

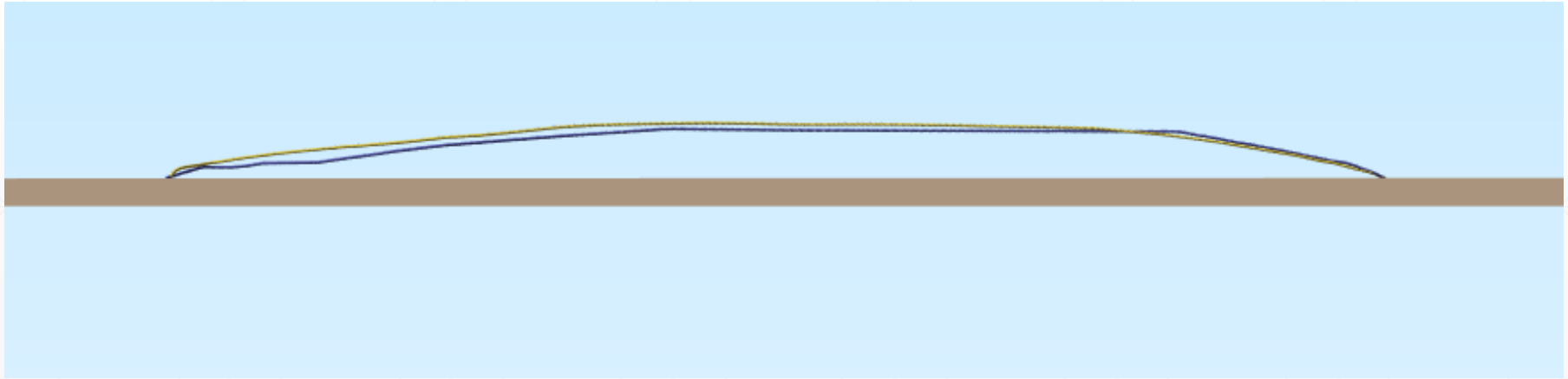


Experimental Results: Trajectory Visualization Best Case

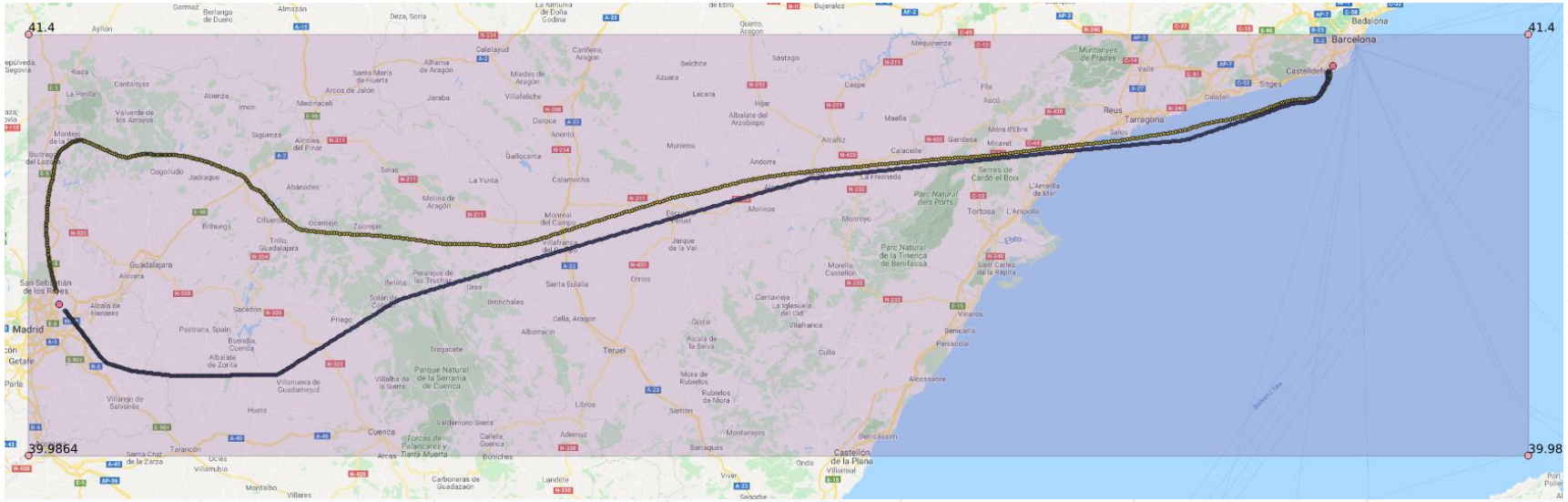


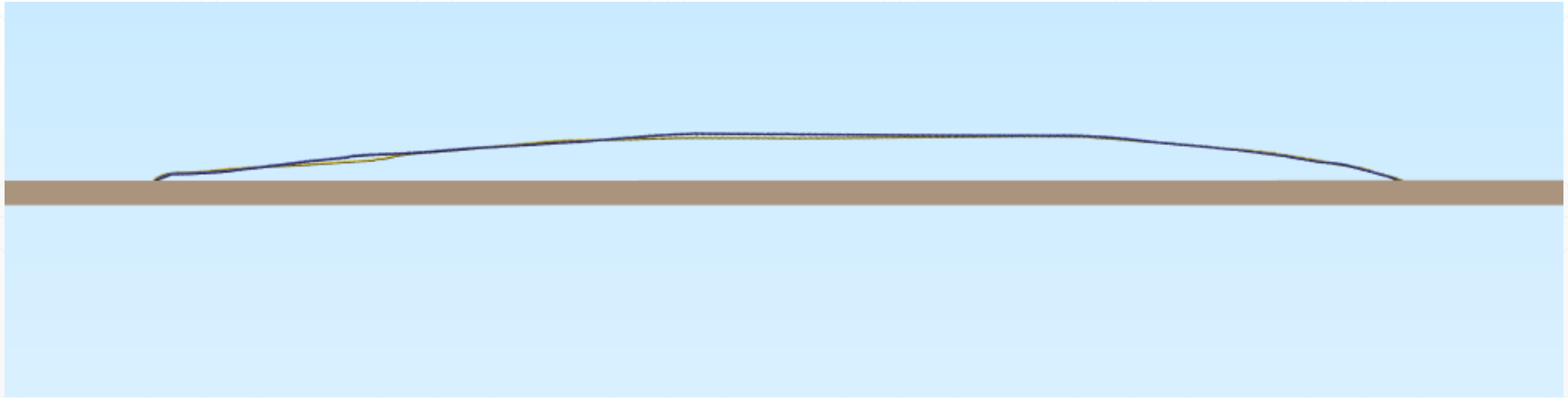
Experimental Results: Trajectory Visualization Average Case





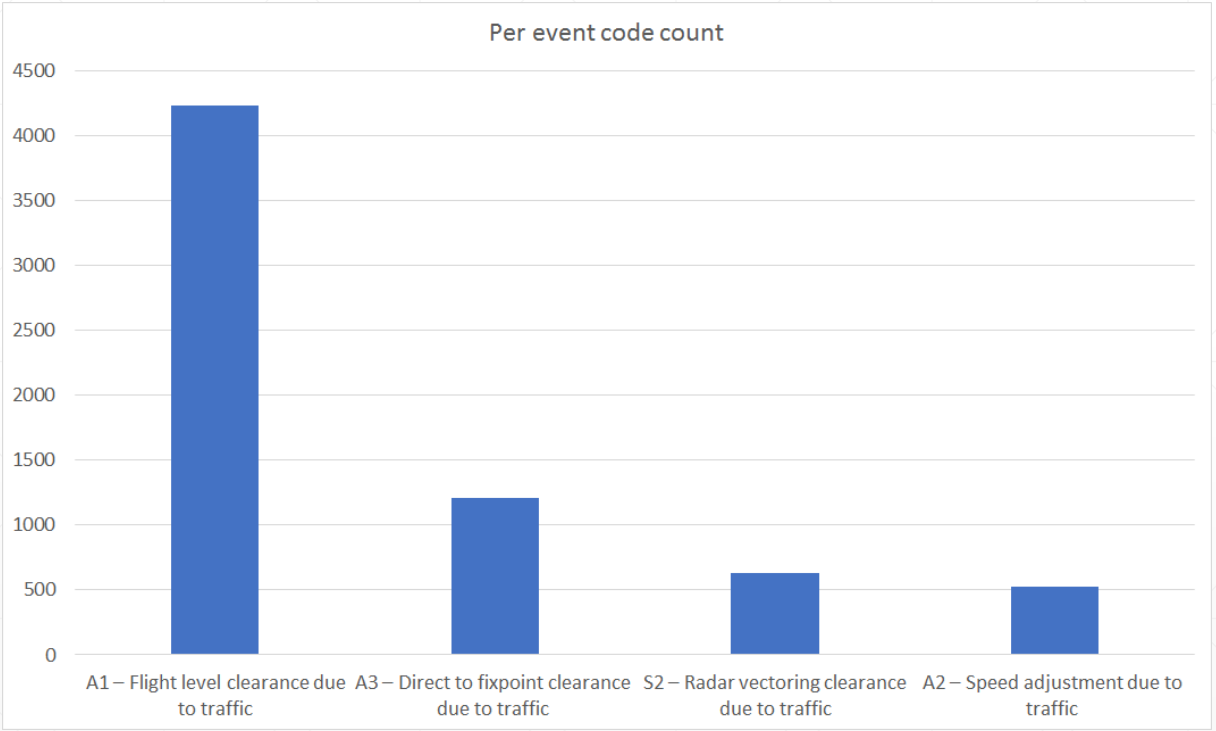
Experimental Results: Trajectory Visualization Worst Case





ATCO Dataset

- *Temporal Coverage: April 2016*
- *Includes flights over Spain:*
  - *International*
  - *Domestic*
- *6608 events of the following types*
  - *A1 – Flight level clearance due to traffic (4232)*
  - *A2 – Speed adjustment due to traffic (524)*
  - *A3 – Direct to fixpoint clearance due to traffic (1211)*
  - *S2 – Radar vectoring clearance due to traffic (631)*
- *6599 events linked to corresponding flights*
  - *Other 10 occurred seconds before first point*



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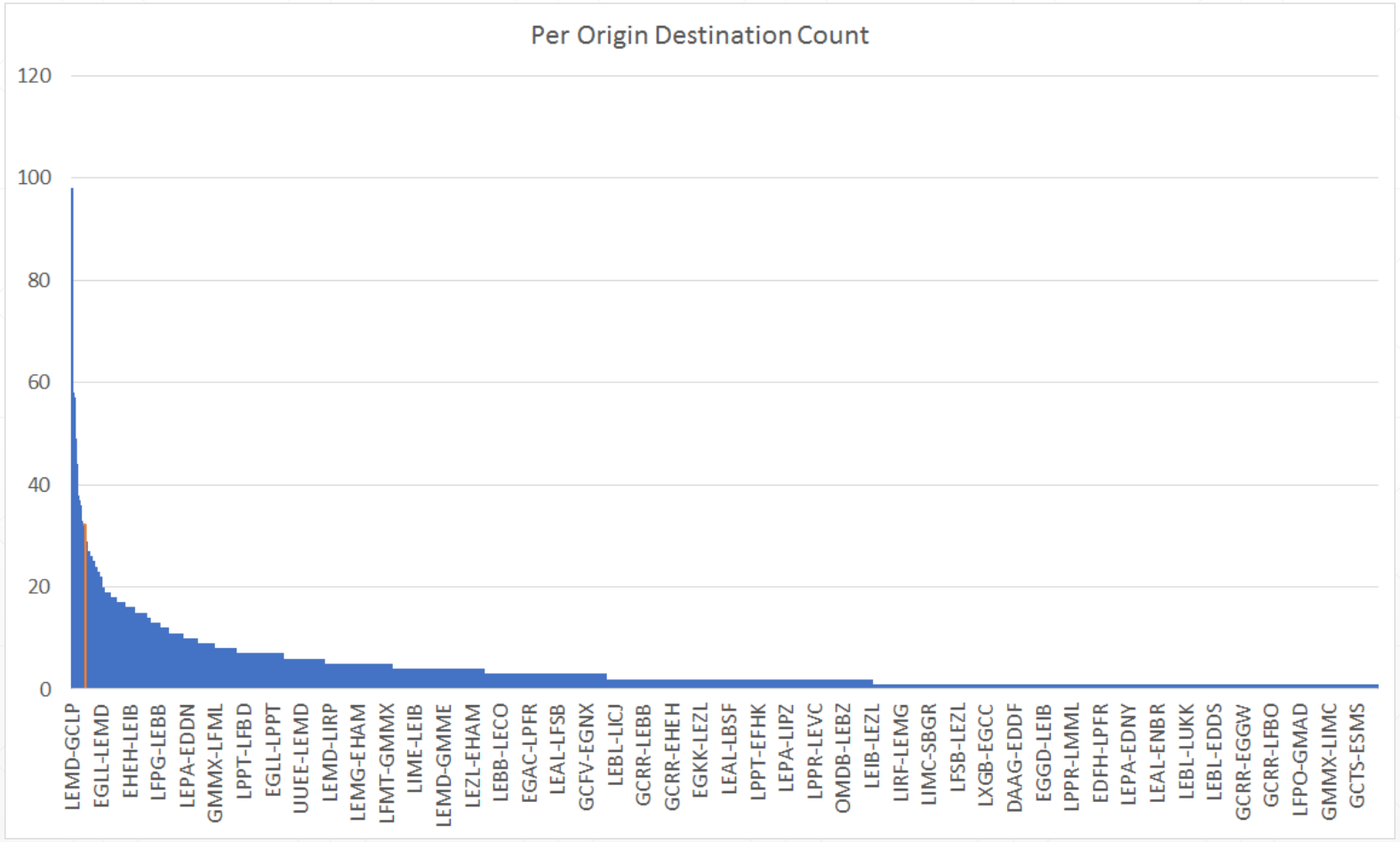

Further Work

- *More experiments also with other Origin Destination Pairs*
  - *will be selected based on the available ATCO events*
- *Collaboration with the Engage Catalyst Project on Data-Driven Trajectory Imitation with Reinforcement Learning to:*
  - *Optimize results*
  - *Consider more variables:*
    - *Airport traffic etc.*
- *Formulation of the Conflict Resolution Problem*
- *Method selection and first formal results in the first quarter of 2020*

Thank you