

Quantifying Accuracy and Uncertainty in Data-Driven Flight Trajectory Predictions with Gaussian Process Regression

SESAR Innovation Days '21

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1. Introduction



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Background

- Paradigm shift in Air Traffic Management: tactical —→ strategic
 - Implementation of new concepts: Trajectory Based Operations (TBO)
 - Relies on improved predictive capability of 4D-trajectories
- Majority of studies use deterministic models that are evaluated on the predictive accuracy
 - Progression of a trajectory is subjected to a variety of uncertainties



- A probabilistic approach is required to model and quantify the uncertainty of the predictions: Gaussian Process Regression (GPR)

Research objective

To quantify and model the uncertainties that are associated with the predictions of aircraft 4D-trajectories by making use of Gaussian Process Regression

2.

Methodology

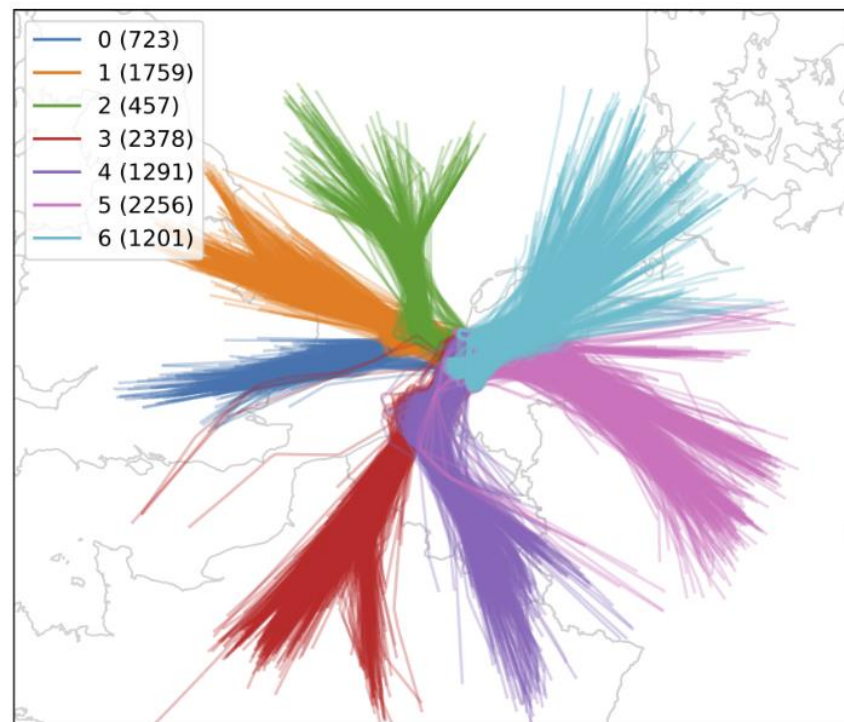


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Trajectory Clustering

- Models are trained on clusters of trajectories with similar spatial features
- Scope: arriving flights to Amsterdam Airport Schiphol
- DBSCAN using x- and y-features of the trajectories



Gaussian Process regression

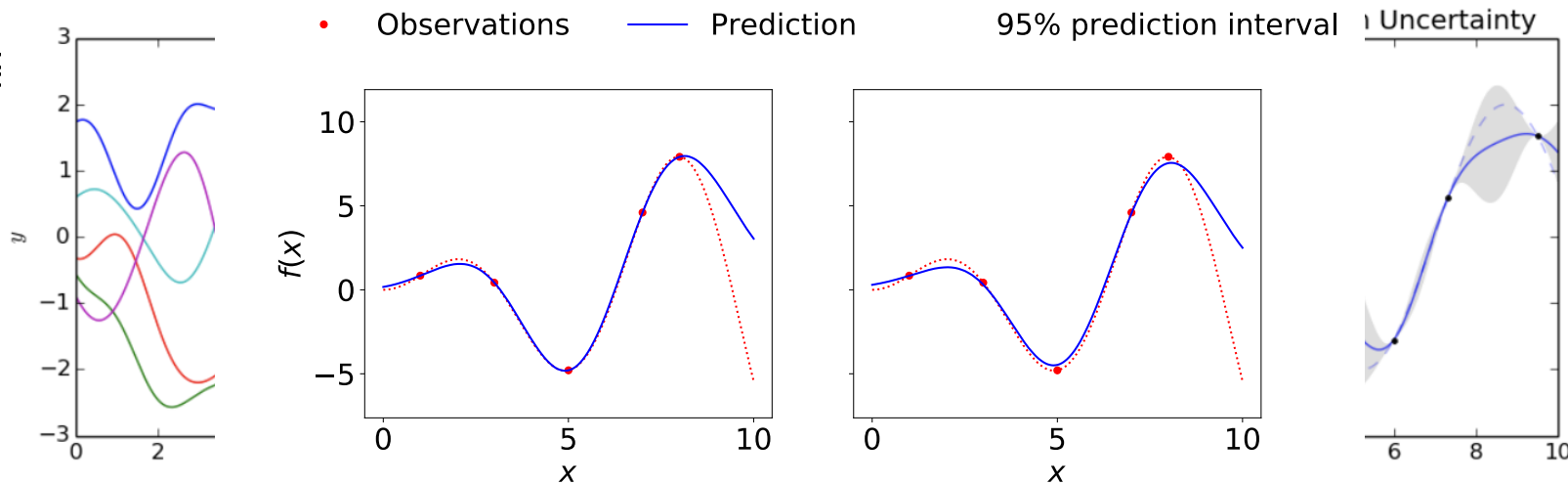
Data-driven Bayesian approach to regression

- Non-parametric regression to predict function $f(x)$
- Possible functions are sampled from a prior Gaussian Process (GP)

$$f(x) \sim GP(\overset{\text{Mean function}}{m(x)}, \underset{\text{Covariance function}}{k(x, x')})$$

- Bayesian approach: prior distribution is updated using training data to obtain posterior distribution

- Noisy training



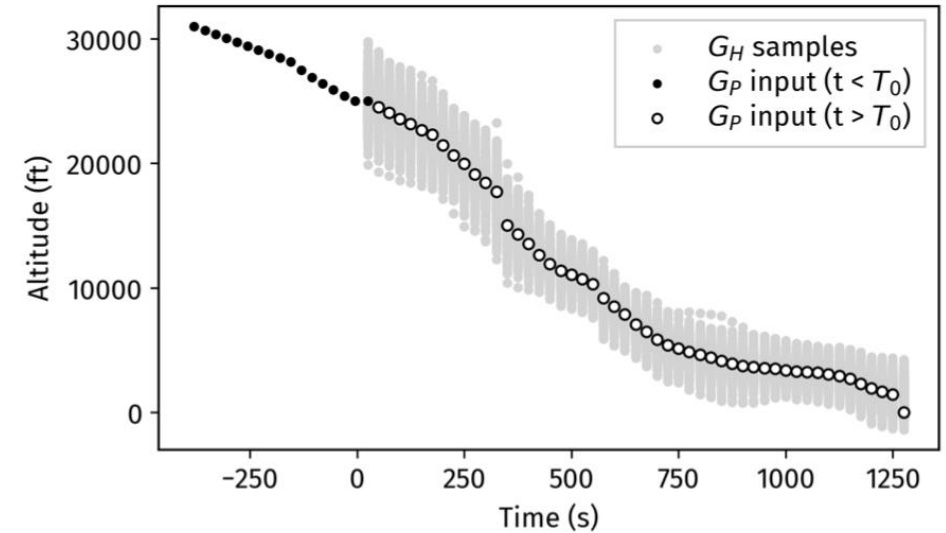
2-Stage GPR

1. Develop *History* Model (G_H)

- Using historical flight data of a cluster of trajectories

2. Develop *Predictive* Model (G_P)

- Trained on dataset specifically constructed to individual flight
 - Extract historic flight data up to T_0
 - Sample from G_H (specific to a cluster) with flight parameters beyond T_0
 - Means of the samples are used complete the training data for G_P



GPR-Model	Predictor variables
GPR-A	ADS-B data only (gs, roc, trk)
GPR-B	ADS-B and Flight Plan data
GPR-C	ADS-B, Flight Plan, and meteo-data

Performance Metrics

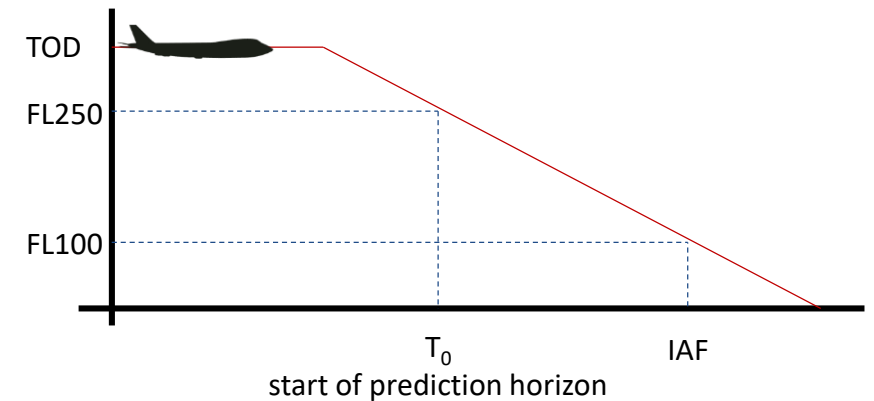
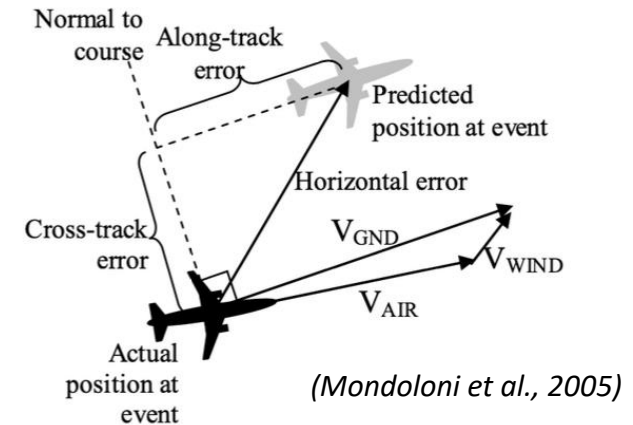
Accuracy

- Spatial errors
 - Horizontal: Along Track Error (ATE) / Cross Track Error (CTE)
 - Vertical: Altitude Error
- Temporal errors
 - Measured at FL100 (IAF)

Uncertainty

- Standard deviation of predictive distribution 3D-position

Evaluated over different look-ahead times (1 – 15 minutes)



3.

Results & Discussion



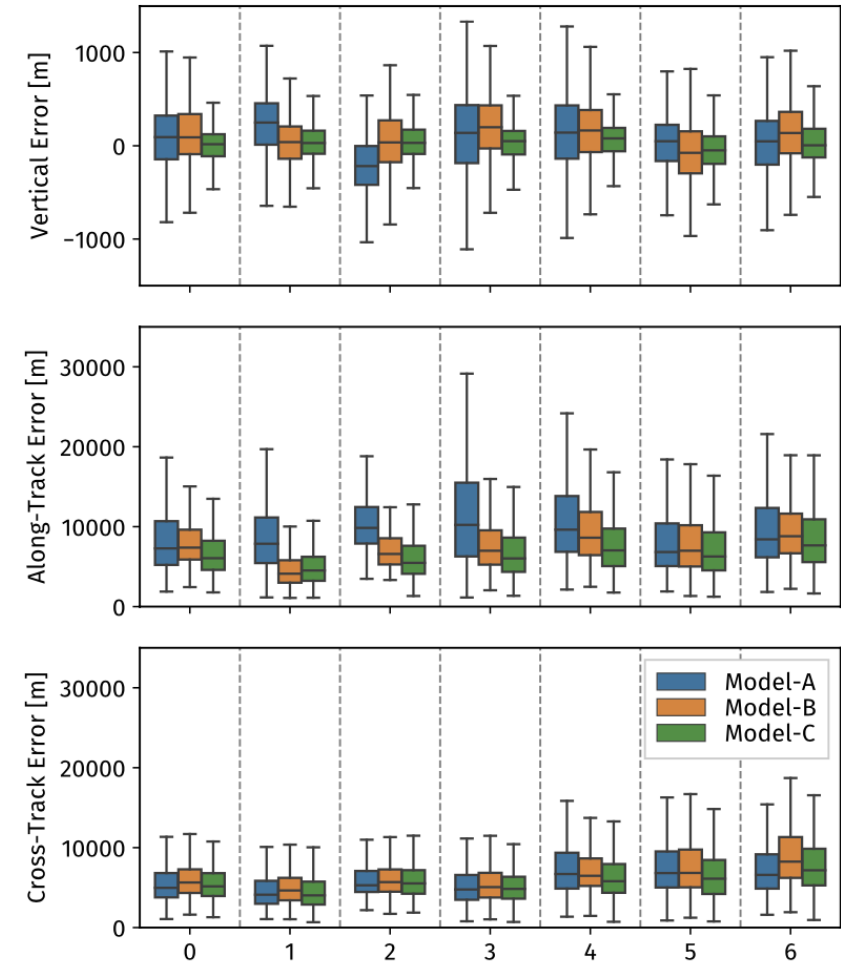
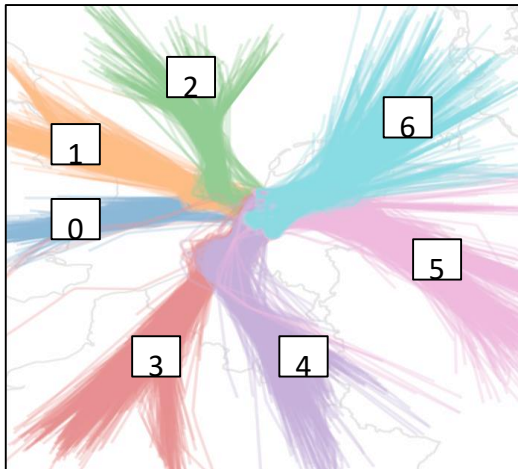
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Cluster Analysis

Predictive accuracy

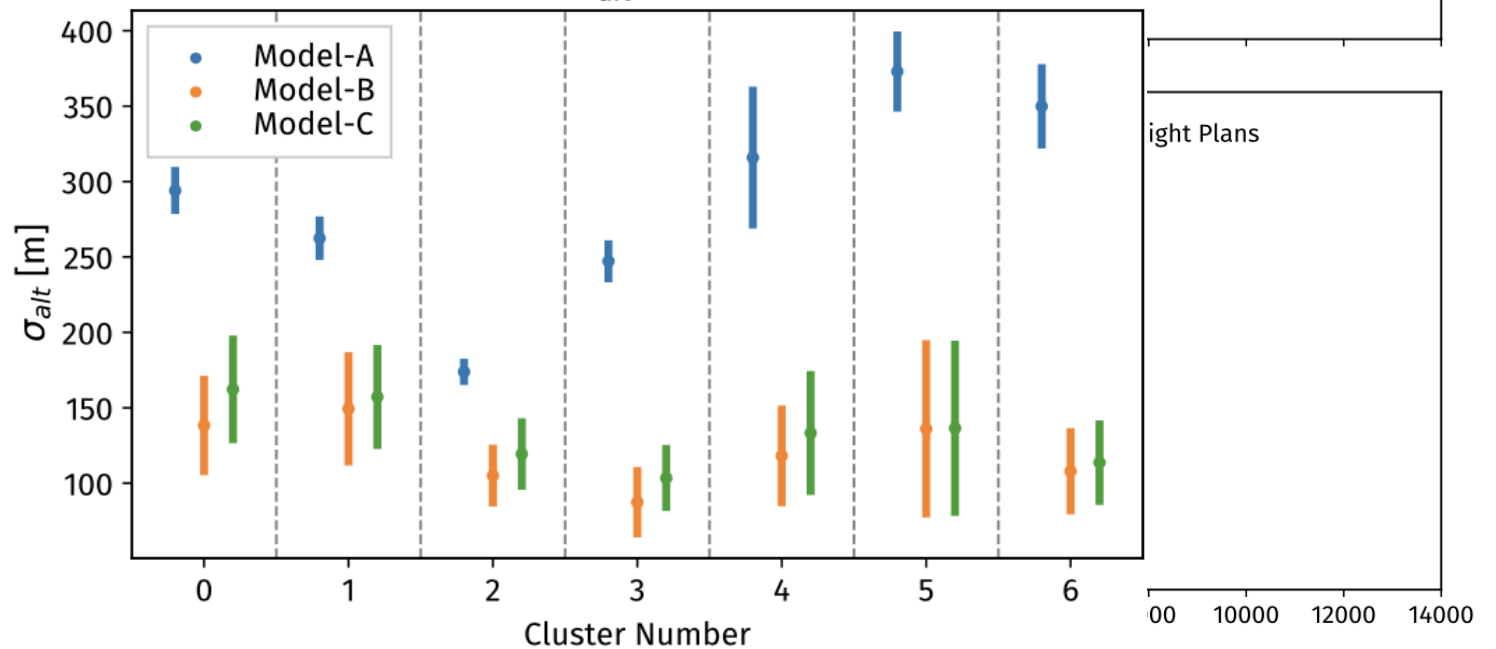
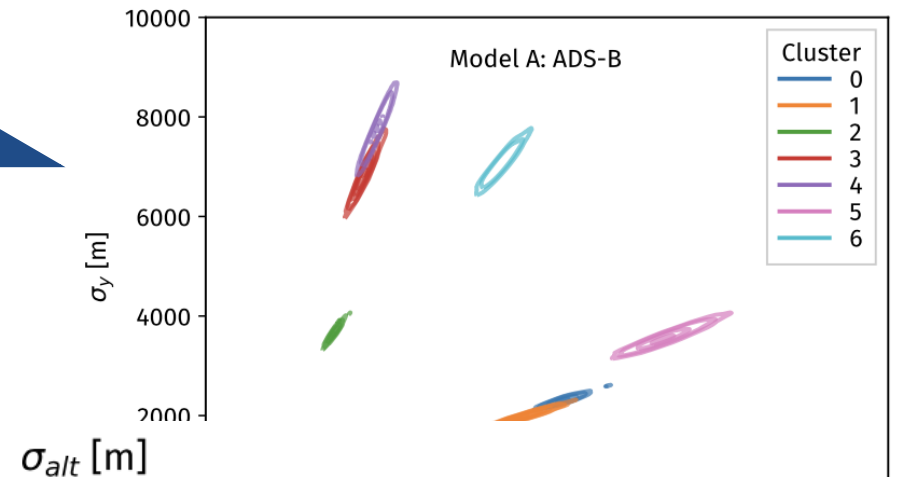
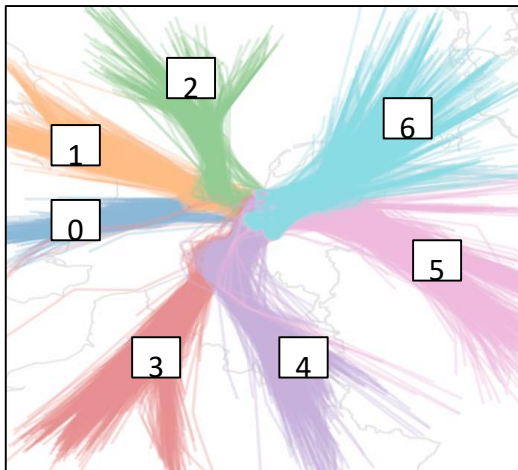
- Predictive accuracy measured for each cluster
 - Vertical error generally center around 0 m
 - Smaller ATE GPR-B/C in clusters 0-4



Cluster Analysis

Predictive uncertainty

- Uncertainty in horizontal position
 - Contours: average standard deviation position prediction
- Uncertainty in vertical position
 - 95% confidence intervals



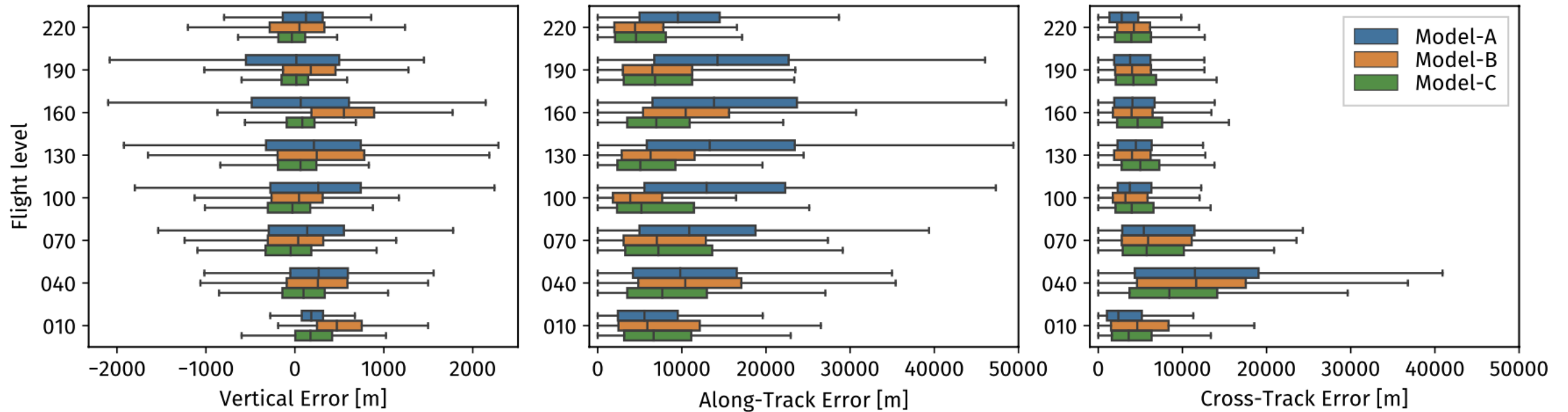
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GPR: Cluster 3

Progression of predictive capability over descent profile

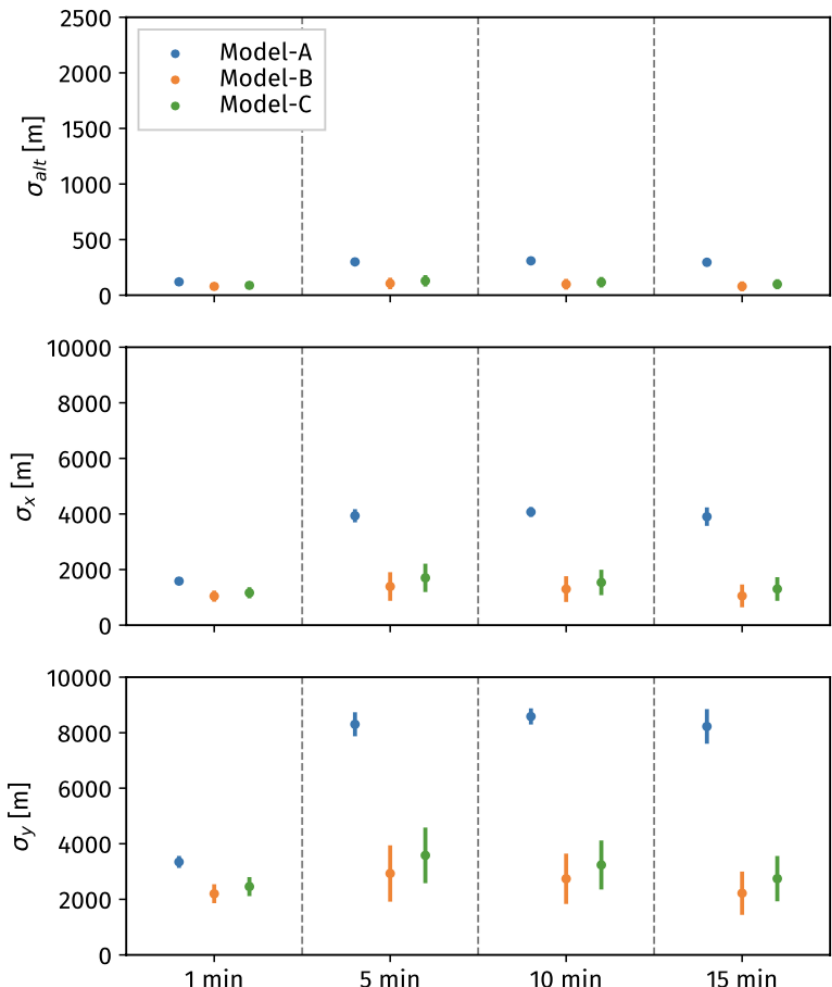
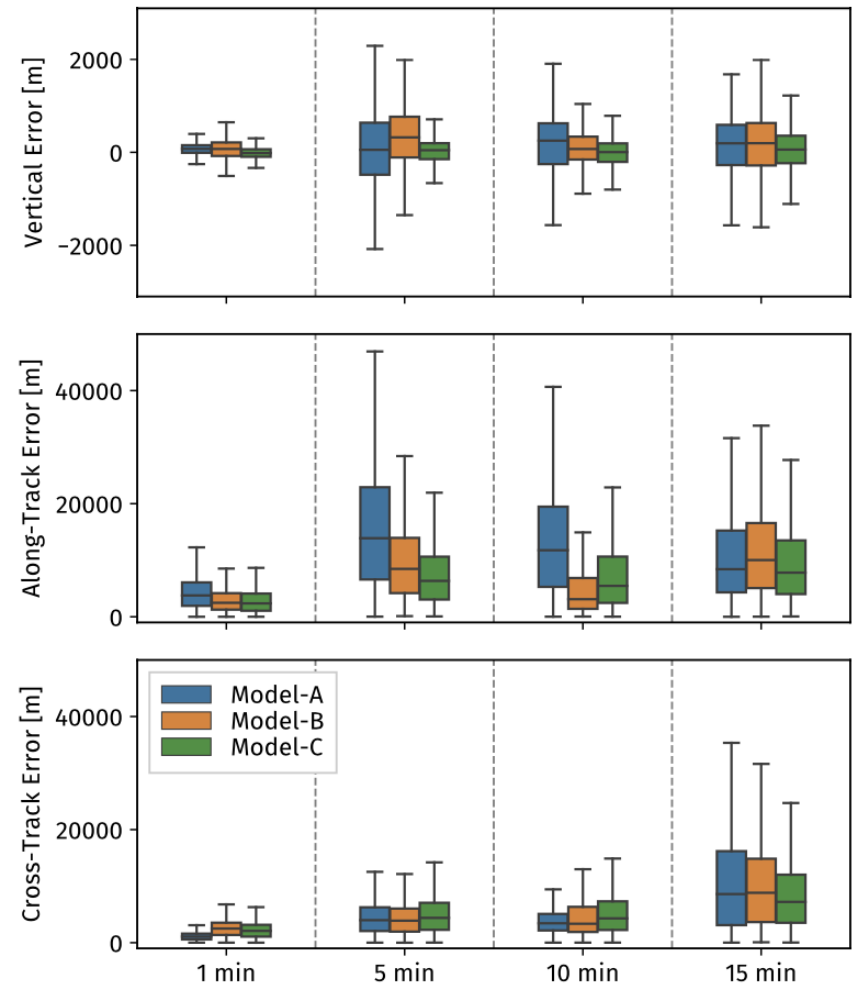
Predictive accuracy

- Smaller ATE for GPR-B/C in initial stage
- Improvement in ATE diminishes in final stages
- CTE increases in final stage



GPR: Cluster 3

Progression of predictive capability over descent profile



4.

Conclusion



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Conclusion

Gaussian Process Regression

- Does not require explicit knowledge of source uncertainty
- Incorporating flight plan data reduces predictive uncertainty
- Adding meteorological forecasts improved predictive accuracy
- Difficulty of predicting final stage of descent
- Importance of trajectory clustering

Future Work

- Apply model to different flight phases
- Multi-aircraft trajectory predictions

Thank you for your attention

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