Recommendations on trajectory selection in flight planning based on weather uncertainty

Philippe Arbogast, Alan Hally, Jacob Cheung, Jaap Heijstek, Adri Marsman, Jean-Louis Brenguier

Toulouse 6-10 Nov 2017
Introduction

- Trajectory Predictors (TP) currently use deterministic meteorological (MET) forecast
- Deterministic MET forecasts contain uncertainties due to errors from: (i) intrinsic predictability (atmospheric chaos), (ii) Lack of observations & (iii) modelling errors
- These uncertainties lead to unknown uncertainty in the trajectory
- Unknown uncertainty in flight time and thus fuel consumption
- Approach? Use ensemble prediction & TP
Introduction
Overview

- Introduction
- How does an Ensemble Prediction System (EPS) capture uncertainty?
- Objective comparison of EPSs
- Methodology (EPS + Trajectory Prediction)
- Example Case
- Conclusions and Future Work
How does an EPS capture uncertainty?

- Cover whole envelope of future likely weather scenarios
- Quantify uncertainty in winds in the upper-atmosphere
- Quantify uncertainty in flight planning due to weather
- Lead to a more accurate description of extra fuel needed for flight

![Diagram showing ensemble forecasts and forecast uncertainty](image)
EPS used in this study

Met Office Global and Regional Ensemble Prediction System (MOGREPS) Global, Hor. Res. ~33 km, 70 Vert. Levels, **12 members**, 00,06,12 & 18UTC

MÉTÉO-FRANCE ensemble (PEARP) Global, Hor. Res. 15.5 km (over France), 65 Vert. Levels, **35 members**, 06 & 18UTC

European Centre for Medium-Range Weather Forecast (ECMWF) Global, Hor. Res. ~32 km, Vert. 91 levels, **51 members**, 00 & 12UTC

Multi-model ensemble (mix of all ensembles) **98 members**, 18UTC initialisation time
Objective comparison of ensemble

- ROC measures the ability of the forecast to discriminate between two alternative outcomes (yes/no) at different probability thresholds.
- ROC is conditioned on the observations (i.e., given that an event occurred, what was the corresponding forecast?)
- The Area Under the ROC curve (AUC) is the value which is often used.
- Want AUC close to 1 as possible (translates to high Probability of Detection (POD) and low Probability of False Detection (POFD)).
- The ROC can be considered as a measure of potential usefulness.

<table>
<thead>
<tr>
<th>Event Forecast</th>
<th>Event Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>a</td>
</tr>
<tr>
<td>No</td>
<td>b</td>
</tr>
<tr>
<td>Yes</td>
<td>c</td>
</tr>
<tr>
<td>No</td>
<td>d</td>
</tr>
</tbody>
</table>

\[
\text{HIT} = \frac{a}{(a + c)} \quad \text{POFD} = \frac{b}{(b + d)}
\]
Objective comparison of ensemble

- Relevant spread/error relationship / useful ensemble

- Poor spread/error correlation / useless ensemble
Objective comparison of ensemble

- 4 different model configurations compared using AUC score
- One month (Jan 2015) of observed AMDAR wind data at FL340 compared to wind forecast by model at 250hPa
- Large dataset and thus statistically robust verification of model ability

Domain: 75N-10N, 105W-15E
Objective comparison of ensemble

- AUC score between 0.85 and 0.96 demonstrates excellent model resolution
- Spread/skill relationship (1 is perfect). SUPER (multi-model ensemble) has greatest and appropriate spread at +36hr lead time
Probabilistic Trajectory Prediction (PTP)

Ensemble of trajectories represents uncertainty related to uncertainty in MET forecasts & gives a degree of uncertainty on important flight parameters.
Probabilistic Trajectory Prediction (PTP) : an example

A 12 member MOGREPS ensemble was used as input to a simple TP system for a case study flight from London (EGLL) to New York (KJFK) on the 25th of January 2015

Shortest trajectories for member 1 with the (PDF) of the flight times for each trajectory (shown in the bottom right)

The grey bars represent the standard deviation of the flight times
Probabilistic Trajectory Prediction (PTP) : an example

A 12 member MOGREPS ensemble was used as input to a simple TP system for a case study flight from London (EGLL) to New York (KJFK) on the 25th of January 2015
Probabilistic Trajectory Prediction (PTP): an example

A 12 member MOGREPS ensemble was used as input to a simple TP system for a case study flight from London (EGLL) to New York (KJFK) on the 25th of January 2015.

low projected cost (flight time/fuel)
And low uncertainty

higher projected cost (flight time/fuel)
And higher uncertainty
Conclusion

- A methodology has been proposed which incorporates ensemble prediction systems (EPSs) into existing deterministic TP systems.
- Using specific metrics, we have shown that the EPSs are capable of capturing specific nominal weather 36 hours before take-off time.
- A combination of the EPSs further improves performance.
- A trajectory ensemble was generated using each member of an EPS.
- A representation of the uncertainty involved in each member of the trajectory ensemble was demonstrated to help in decision making by providing a range of trajectory cost (flight time, fuel) values. This would allow TP users to select a suitable trajectory according to their optimum cost distributions.
- Future work: improvement of the probabilistic TP thanks to resampling.
To what extent a real time update of an EPS improves the wind forecast?

- When an EPS is used more recent observations are available
- Theoretical framework: bayesian resampling (the weight of each member is updated using the distance to available observations)
- Reduce the uncertainty
To what extent a real time update of an EPS improves the wind forecast?

![Graph showing improvement using Bayesian resampling](image)

Improvement using the Bayesian resampling