Comparison of operational wind forecasts with recorded flight data

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Emilien ROBERT
Navigation and CNS Research Unit
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Outlines

1. Methodology
2. Data overview
3. Waypoint wise analysis
4. Trajectory wise analysis
5. Conclusion
Outlines

1. Methodology

2. Data overview

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4. Trajectory wise analysis

5. Conclusion
1.1 Wind error - wind difference

Real wind

Forecast error

Wind model and forecast

Aircraft measurement error

Aircraft measurement

Comparison study

Comparison of operational wind forecasts with recorded flight data
1.2 Comparison volumes

- **En Route comparison volume**: 2 parameters, radius and height
  - 4D volume
  - Aircraft trajectory
  - Wind measurement averaged

- **Climb or Descent comparison volume**
  - Aircraft trajectory
  - FL defined in wind message
  - Only 1 parameter, the radius is defined by the aircraft trajectory
1.3 Data processing, filtering and analysis

- **Directional references:**
  - Aircraft heading has been converted to True North to ensure consistency with recorded and forecasted wind directional reference.

- **Wind speed and direction difference:**
  - Wind speed difference = wind speed (FDR) – Wind speed (MET)
  - Wind direction difference = wind direction (FDR) – Wind direction (MET)

  ![Diagram](Not computed if wind speed < 10 kts)

- **Ground speed difference:**
  - GS difference = FDR ground speed – MET ground speed

  ![Computed with:](✓ A/C TAS
  ✓ A/C track
  ✓ FDR wind

  ![Computed with:](✓ A/C TAS
  ✓ A/C track
  ✓ MET wind)
1.4 Comparison volume determination

EnRoute +/-25ft/3NM

STD=9.5kt/Mean=-0.8kt
4691 points

STD=9.2kt/Mean=1.9kt
4691 points

STD=20.4°/Mean=0.9°
4430 points

EnRoute +/-150ft/10NM

STD=9.4kts/Mean=-0.6kts
9966 points

STD=9.1kts/Mean=1.6kts
9965 points

STD=21.8°/Mean=0.6°
9400 points

EnRoute +/-250ft/30NM

STD=9.4kts/Mean=-0.8kts
15822 points

STD=9.3kts/Mean=1.6kts
15822 points

STD=24.2°/Mean=0.4°
14943 points
### 1.4 Comparison volume determination

#### En route comparison point

<table>
<thead>
<tr>
<th>4D vol parameter</th>
<th>Nb points</th>
<th>Wind speed diff (kt)</th>
<th>Wind direction diff (°)</th>
<th>Ground speed diff (kt)</th>
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<td>mean</td>
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<td>250</td>
<td>15822</td>
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#### Descent comparison point

<table>
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<th>height (+/-)</th>
<th>Nb points</th>
<th>Wind speed diff (kt)</th>
<th>Wind direction diff (°)</th>
<th>Ground speed diff (kt)</th>
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<td>13299</td>
<td>9.2</td>
<td>1.4</td>
<td>28.3</td>
</tr>
</tbody>
</table>
1. Methodology conclusion

- The comparison volume has been defined:
  - Radius 10NM
  - Height +/-150ft

- The dimension of the comparison volume has a slight impact on the results

- Using that volume, we have found:
  - 9965 comparison points for En Route
  - 13299 comparison points for Descent
  - 136 comparison points for Climb

⇒ **A total of 23400 comparison points**
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1. Methodology
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2.1 Period of analysis

- 2728 flights from July, 1st, 2011 to June, 30th, 2012. The last 2 hours only of each flight has been analyzed
- A total of 23400 comparison points have been computed
- Flights occurred mainly during summer
2.1 Geographical coverage
2.3 Wind distribution

- Average: 32 kt
- Max: 160 kt
- 95% of the winds are lower than 80 kts. Average wind speed is 32 kts and maximum wind speed is 160 kts
- Winds are mainly coming from West
2.3 Wind distribution

- Average wind speed is higher at high altitude and for winds coming from West.
- Winds faster than 80 kts are only coming from West and at altitude above FL180.
2. Data overview: conclusion

1. 2728 flights from July, 1st, 2011 to June, 30th, 2012. The last 2 hours only of each flight has been analyzed

2. 95% of the winds are lower than 80 kts. Average wind speed is 32 kts and maximum wind speed is 160 kts

3. Data are not equally spread all over the year. More flights have been recorded during summer

4. Wind speed is not equally spread over the wind direction or altitude. Strongest winds are coming from West and are occurring at high altitude
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3.1 Overall results

⇒ 95% of the comparison points have a wind speed and ground speed difference around 18kt (2*sigma)
3.2 Impact of the flight phase

No significant impact of the flight phase
### 3.3 Impact of the wind magnitude

- **Diagram Description:**
  - **X-axis:** Wind speed (kt)
    - Categories: < 20 kt, 20 kt - 40 kt, 40 kt - 80 kt, > 80 kt
  - **Y-axis:** Standard deviation (kt)
    - Values range from 0 to 16
  - **Legend:**
    - Wind Spd Diff STD
    - Ground Spd Diff STD

- **Observation:**
  - The standard deviation increases with wind speed.
  - For instance, the standard deviation is lower in the < 20 kt category compared to the > 80 kt category.

**Conclusion:**

- **Standard deviation increase with wind speed**
3.4 Impact of the altitude

Standard deviation increase with the altitude but the wind speed also increase with altitude.
3.5 Impact of the season

- Standard deviation varies with the season but the wind speed is also varying with the season.
3.6 Impact of the aircraft

- Same results for every aircraft
3.7 Impact of the forecast latency

- Latency: time between when the forecast is available and when the aircraft is crossing the comparison volume

![Graph showing standard deviation increase with forecast latency](image-url)

⇒ Standard deviation increase with the forecast latency
3. Waypoint analysis: conclusion

1. The main drivers seem to be the wind magnitude and the forecast latency. The standard deviation of the wind and ground speed difference increase with the wind magnitude and the forecast latency.

2. The standard deviation dependency on the wind altitude and season seems to be linked with the wind magnitude.

3. In order to perform a reliable trajectory analysis, a subset of flight equally distributed over the season has to be selected.
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4.1 Average along descent

⇒ 95% of the flights have a wind speed and ground speed difference around 12kt (2\*sigma)
4.3 Interpolation of the wind profile

Descent interpolation

Wind speed (kt)

Altitude (x1000 ft)

Wind direction (°)

Altitude (x1000 ft)
4.3 Interpolation of the wind profile

⇒ 95% of the flights have a wind speed and ground speed difference below 12kt (2*sigma)
4.4 Estimated Time of Arrival error

- 95% of the flight descending from FL300 to FL100 will arrive at FL100 with a time error of less than 32s

- 95% of the flight descending from FL420 to ground will arrive with a time error of less than 64s
5. Conclusion

- The waypoint wise comparison showed that the wind and ground speed difference is around 18kt for 95% of the comparison points.

- The trajectory wise analysis showed that during descent, the average ground and wind speed difference is below 12kt for 95% of the flights.

- The ETA error analysis showed that:
  - 95% of the flight descending from FL300 to FL100 will arrive at FL100 with a time error of less than 32s.
  - 95% of the flight descending from FL420 to ground will arrive with a time error of less than 64s.
Questions