Statistical Prediction of Flight Behavior in the Vicinity of Convective Weather

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Some Numbers

- 2 of 3 events correctly predicted
- 1 of 4 alerts are false alarms

All you have to do is...

Gaussian Copula Likelihood Approximation for Arbitrary Feature Vector Data

Putting it all together...

\[
\Pr \{y|x\} \approx \prod_{i=1}^{m} \frac{1}{\sigma_x^{(i)}} \phi \left( \frac{y^{(i)} - \mu_x^{(i)}}{\sigma_x^{(i)}} \right) \frac{\Phi^{-1}F_x^{(i)}}{\sigma_x^{(i)}} \left( \frac{y^{(i)} - \mu_x^{(i)}}{\sigma_x^{(i)}} \right)
\]

- Standardized data
- PDF of
- CDF of

\[
\frac{y^{(0)} - \mu_x^{(0)}}{\sigma_x^{(0)}} = \text{standardized data}
\]

\[
f_x^{(0)} = \text{p.d.f. of } \frac{y^{(0)} - \mu_x^{(0)}}{\sigma_x^{(0)}}
\]

\[
F_x^{(0)} = \text{c.d.f. of } \frac{y^{(0)} - \mu_x^{(0)}}{\sigma_x^{(0)}}
\]

\[
\frac{1}{\sqrt{\det 2\pi C_x}} \exp \left( -\frac{1}{2} \Phi^{-1}F_x \left( \frac{y - \mu_x}{\sigma_x} \right) \right) \left( \Phi^{-1}F_x \left( \frac{y - \mu_x}{\sigma_x} \right) \right)
\]

\[
\mathcal{N}(0, C_x) \text{ density evaluated at } \Phi^{-1}F_x \left( \frac{y - \mu_x}{\sigma_x} \right)
\]
John Frank Stevens
High resolution weather information w/ minimal latency

Conditioned flight dataset

Integrated analysis environment

Clear definitions for weather-related flight deviation

Automated identification of deviations when they occur
High Resolution 3D CONUS-wide Weather Feature Mosaics
New feature extraction routines built on FAA/NWS WDSS-II/MRMS Core

Markov Switching Model for Flight Deviation Detection
Implemented in Java for scalable processing of large data sets. Approximately 1 minute to process 30,000 flights

PDARS – Wx Analysis Environment - Flight View
Built using Java and OpenGL. Specifically designed for rapid visual analysis of very large multi-dimensional data sets

Gaussian Copula-based Classifier
Implemented in Java. Adaptable to arbitrary feature data, including non-Gaussian data
Acceleration away from path is flagged as deviant (distance of first deviant posit is ~1 km)

Large-scale view shows an extensive deviation until acquiring new flight plan

Declared as Deviation
Declared as Non-deviation

Examples of correct behavior during flight plan crossings

<table>
<thead>
<tr>
<th>Statistic</th>
<th>7/26/12 (severe)</th>
<th>6/8/12 (mostly benign)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conservative</td>
<td>Aggressive</td>
</tr>
<tr>
<td>Deviations near weather</td>
<td>3,172</td>
<td>5,728</td>
</tr>
<tr>
<td>Deviations not near weather</td>
<td>1,391</td>
<td>2,979</td>
</tr>
<tr>
<td>All deviating flights</td>
<td>3,849</td>
<td>6,821</td>
</tr>
<tr>
<td>Terminal deviations near weather</td>
<td>1,238</td>
<td>2,568</td>
</tr>
<tr>
<td>Terminal deviations not near weather</td>
<td>1,398</td>
<td>3,133</td>
</tr>
<tr>
<td>Total number of flights</td>
<td>29,424</td>
<td>29,707</td>
</tr>
</tbody>
</table>

For comparison, published CWAM training/test data set captured a total of 1,564 deviations over 5,235 events
## Comparison of Approaches

<table>
<thead>
<tr>
<th></th>
<th>CWAM</th>
<th>PMAB-CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Set</td>
<td>5,000 Interactions</td>
<td>2,400,000 Flights</td>
</tr>
<tr>
<td>ARTCCs</td>
<td>3</td>
<td>All</td>
</tr>
<tr>
<td>Deviation Detection</td>
<td>Lateral Distance &amp; Manual Review</td>
<td>Automated Markov Switching Model</td>
</tr>
<tr>
<td>Potential for Performance Gains</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Output Type</td>
<td>Geographic</td>
<td>Trajectory + Geographic*</td>
</tr>
<tr>
<td>* future add</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airline Specific Classifiers</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Aircraft Type Classifiers</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Classifiers by Region</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Classifiers by Season</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Classifiers by Day/Night</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Metron’s Scalable Approach Provides Flexibility & Increases Feasibility for New Applications*
Benefits to the NAS

**Inputs**
- Traditional NEXRAD Products
- Short-Range Weather Predictions
- New NEXRAD Products; Dual Polariz. & 3D
- Aircraft Data

**Methods & Impacts**
- Markov Switching Model + Gaussian-Copula Architecture
  - Scalable for very large datasets
  - Improved performance & flexibility
  - Greater ability to adapt to new data/ops patterns
  - Adaptable classifiers by season/region/airline/type/etc
- Improved Definition of Usable & Unusable Airspace
- Reduced Latency

**Applications**
- Improved Cockpit Wx Information
- Improved En Route Automation Tools
- Improved TFM/CDM Tools

**Operational Capabilities**
- Improved Flight Crew Decisions
- Improved Controller Advisories, Decisions
- Improved Airline FOC Decisions
- Improved TFM/CDM Plans, Decisions

**Operational Performance**
- Reduced Penetrations of Hazardous Conditions
- Reduced Unexpected Maneuvers
- More Predictable Ops
- Improved Use of Available Capacity; Less Waste
- Smoother, Less Disruptive Flows; Higher Throughput
- Reduced Workload

**Operational Outcomes & Benefits**
- Improved Safety
- Fuel and Time Savings