Using Spatiotemporal Relational Random Forests (SRRF) to Predict Convectively Induced Turbulence
Acknowledgements

- Tim Supinie
- Nathaniel Troutman
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Convectively Induced Turbulence (CIT)

- Generated by air flow asymmetries
- Occurs near and around thunderstorms
  - Effect of large scale convection
- Like clear-air turbulence, invisible (not in cloud)

Image Courtesy: www.yalibnan.com
Turbulence is a major hazard for aviation
- Delays in flight
- Structural damage to aircraft
- Injuries to passengers
- Fatalities
- Airline economics

Current FAA guidelines for CIT:
- Don’t attempt to fly under a thunderstorm
- Avoid severe storms by at least 20 miles
- Clear the top of known severe thunderstorms by at least 1000 feet for each 10 kt of wind speed at the cloud top
- Be warned of thunderstorm tops in excess of 35,000 ft
- Better understanding of turbulence allows for better avoidance of these hazards

Image Courtesy: www.wildlandfire.com

Current Turbulence Prediction Methods and Limitations

- Pilot Reports (PIREP)
- Graphical Turbulence Guidance (GTG)
- NCAR Turbulence Detection Algorithm (NTDA)

Figure 7: NTDA EDR from KPAH 24° s sweeps at 20:37, 20:43, 20:49, and 20:54 UTC on August 6, 2003, ranging from 20 minutes to 3 minutes before the severe turbulence encounter described in the text. The EDR color scale ranges from 0 to 0.7 m/s².

Diagnose Convectively-Induced Turbulence (DCIT)

- Regular random forests trained to create a turbulence prediction on most current data
- Trained random forests create a prediction at each grid point over CONUS where data is available
- Final product is a snapshot of turbulence locations
- Updates every 15 minutes
- Deterministic: gives a turbulence measurement value at each point
Current turbulence prediction enhancements at NCAR (2)

Image Courtesy: Jennifer Abernethy (NCAR/RAL)
Our Approach

Spatiotemporal Relational Random Forests (SRRF)

- Object-oriented
  - Rain, convection, hail, lightning, vertically integrated liquid (VIL), clouds, aircraft, EDR
- Relations
  - SRRF’s work SPATIALLY and TEMPORALLY
- Allows us to follow patterns as they emerge and change
- Aircraft centric
  - Within 40 nautical miles, above 15,000 feet
- Probabilistic prediction that turbulence may occur
You are here

NSSL 2D Radar Reflectivity Mosaic
Co-Located WRF Model Output
Infrared Satellite Data
GTG Forecast Output
NLDN Lightning Strikes Data
In-situ EDR Label Data
Chosen aircraft that flew on March 10, 2010
Randomly choose N questions:

- Is cloud coverage 90% and contained with rain?
- Is hail occurring 15 minutes prior and within convection?
- Is rain above 60 DBZ and nearby lightning?

Chose best split based on chi squared:

- Is cloud coverage 90% and contain rain?
- Turbulence: Yes
- Turbulence: No

Split Instances Accordingly (Recursive)
Example Tree

1. Is aircraft deformation squared less than 3.186 e-05 s^-2?
   - Yes
   - No

2. Is the aircraft near lightning at an angle greater than 112.0 deg?
   - Yes
   - No
   - Prob: No = 0.33, Yes = 0.67

3. Does convection exist for 6 time steps?
   - Yes
   - No

4. Is hail reflectivity greater than 62.27 dBZ?
   - Yes
   - No
   - Prob: No = 0.00, Yes = 1.00

5. Prob: No = 0.98, Yes = 0.02
The Forest

- Send the rest of instances down the tree
- Redo for multiple trees- A FOREST
  - Collect votes
- Repeat creation of forest 30 times
- Verification
  - Skill scores
  - Variable importance
  - Error estimation
Nulls under-sampled by 99% initially

30 runs of every combination of each of the following:

- Samples (# questions at node): 10, 100, 500, 1000
- Number of trees per forest: 1, 10, 50, 100
Experiment Set #1

- 49 Days: March 10 – April 28, 2010
- Effect of under-sampling the training set
  - Helps to further balance null vs. MOG
  - Does not effect testing set
  - 3 under-sampling levels: 40%, 60%, 80%
Performance (Gerrity Skill Score)

Turbulence GSS 40% Undersample: Max Depth=5.0, P-Value=0.01

- Num Trees: 
  - $n = 1.0$ (red)
  - $n = 10.0$ (green)
  - $n = 50.0$ (blue)
  - $n = 100.0$ (magenta)

Num Samples: 10, 100, 500, 1000
Under-sampling Effect

Turbulence GSS 80% Undersample: Max Depth=5.0, P-Value=0.01

Num Samples

GSS

Num Trees
- n = 1.0
- n = 10.0
- n = 50.0
- n = 100.0
Experiment Set #2

- 3 months: March 11 – June 10, 2010
- Effect of training with more data
- 90% null drop on training set
Previous Experiment

Turbulence GSS 80% Undersample: Max Depth=5.0, P-Value=0.01
Same Experiment with 3 months of data and 90% under-sampling
## Performance of Best Tree

<table>
<thead>
<tr>
<th>Forecast</th>
<th>Obs.</th>
<th>Turbulence</th>
<th>Null</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulence</td>
<td>5787</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Null</td>
<td>554</td>
<td>376</td>
<td></td>
</tr>
</tbody>
</table>

TSS: 0.771  =  POD = 0.9126  
FAR = 0.1060  
POFD = 0.1416

Compare to Worst Tree TSS: 0.219
Older experiments used RUC data
Current experiments use WRF-RR version 1 data
Does data source make a difference?

Experiment Setup
  • Schema of WRF-RR data is modified to match the RUC data experiments as closely as possible
    • Certain variables are ignored
RUC-based Performance

Turbulence: Max Depth=5.0, $\alpha=0.01$

Num Trees
- $n = 1.0$
- $n = 10.0$
- $n = 50.0$
- $n = 100.0$
WRF-based Performance

WRF-based Turbulence SRRF GSS: Max Depth=5.0, \( \alpha=0.01 \)

- Num Trees
  - \( n = 1.0 \)
  - \( n = 10.0 \)
  - \( n = 50.0 \)

![Graph showing GSS vs. Num Samples with different Num Trees](image)
## Importance analysis

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Mean Z-Score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft:Frontogenesis Function</td>
<td>1.130</td>
<td>0.341</td>
</tr>
<tr>
<td>Aircraft:NC State Index 1</td>
<td>0.733</td>
<td>0.189</td>
</tr>
<tr>
<td>Aircraft:Temperature</td>
<td>0.722</td>
<td>0.281</td>
</tr>
<tr>
<td>Aircraft:EDR/Richardson Number</td>
<td>0.575</td>
<td>0.354</td>
</tr>
<tr>
<td>Aircraft:MSL Pressure</td>
<td>0.569</td>
<td>0.377</td>
</tr>
<tr>
<td>Aircraft:Total Deformation Squared</td>
<td>0.526</td>
<td>0.258</td>
</tr>
<tr>
<td>Aircraft:Pressure (at flight level)</td>
<td>0.510</td>
<td>0.207</td>
</tr>
<tr>
<td>Aircraft:Geopotential Height</td>
<td>0.495</td>
<td>0.192</td>
</tr>
<tr>
<td>Aircraft:Smoothed Pressure</td>
<td>0.490</td>
<td>0.286</td>
</tr>
<tr>
<td>Aircraft:Altitude (ASL)</td>
<td>0.447</td>
<td>0.168</td>
</tr>
</tbody>
</table>

- Importance determined by permuting each predictor’s value, and seeing how the overall prediction performance of the forest changes due to this randomization
- Specific to 30 runs, 10 trees, 500 samples, 0.8 under-sampling
SRRF gives us the ability to create spatially and temporally varying objects.
In addition, relations allow us to follow how objects interact.
Gives us the unique ability to determine important features in terabytes of data fairly quickly.
Results can offer suggestions as to relevant predictors, though physical understanding must be employed to determine if predictors are reasonable.
Graphical Turbulence Guidance (GTG)

- Combination of turbulence diagnostic quantities derived from 3D forecast grids
- Limitations:
  - Grid is much too coarse in relation to aircraft size

Image Courtesy: www.aviationweather.gov
NCAR Turbulence Detection Algorithm (NTDA)
- Utilizes NEXRAD radar reflectivity data to diagnose turbulent conditions
- Very rapid update cycle
- Limitations:
  - Only available in cloud, CIT missed

Figure 7: NTDA EDR from KPAH 2.4° sweeps at 20:37, 20:43, 20:49, and 20:54 UTC on August 6, 2003, ranging from 20 minutes to 3 minutes before the severe turbulence encounter described in the text. The EDR color scale ranges from 0 to 0.7 m^{2/3}/s.

Image Courtesy: Williams et al. (2004)
Method

- Keep all data we care about
  - Within 40 nautical miles
  - Above 15,000 feet
  - Decide on thresholds to distinguish objects

- Create objects
  - Rain, convection, hail, lightning, vertically integrated liquid (VIL), clouds, aircraft, EDR

- Create relations
  - SRRF’s work SPATIALLY and TEMPORALLY