Turbulence Avoidance Modeling

Developing Predictive Models of Pilot Behavior in Response to Turbulence Encounters

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Motivation

Turbulence impacts flight operations

- Discomfort for passengers
- Temporary loss of aircraft control
- Aircraft damage
- Injuries, or even deaths, of passengers and flight attendants

and Air Traffic Control (ATC)

- Increased controllers' workload as pilots request altitude changes
- Reduced airspace utilization when air traffic controllers "close" the airspace

When compared to convection, is adds another layer of complexity

- It cannot be physically observed by pilots and controllers
- Different types of aircraft can be affected differently by the same atmospheric conditions

"American Airlines officials say five passengers were injured on a flight from Grenada to Miami after the plane encountered some unexpected turbulence.

American's Flight 982 landed at Miami International Airport shortly before noon Thursday without incident. Five passengers were taken to a hospital for minor injuries."

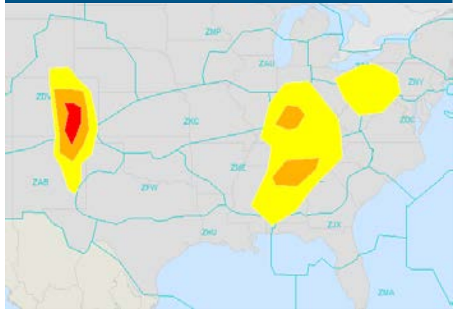
Source: ABC News, Oct 1, 2015

Objectives

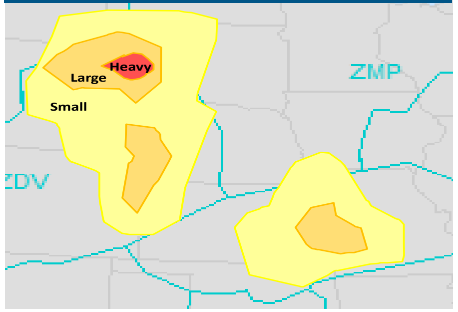
Develop a predictive turbulence translation technique relating pilots' behavior to encountered turbulence and providing

- Automated and consistent interpretation of turbulence information relevant for operational decision making
- Depictions of actionable turbulence constraints
- Shared situation awareness of turbulence impacts to stakeholders

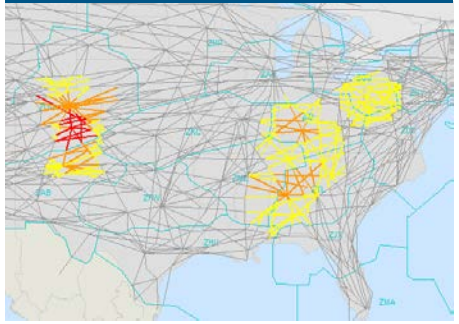
Turbulence avoidance regions



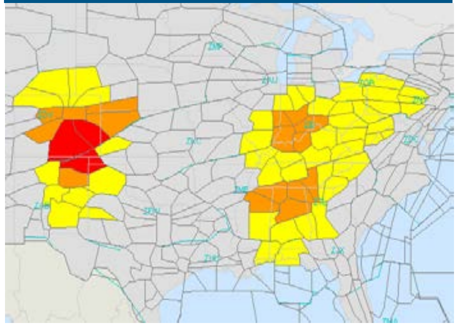
Aircraft type/weight class specific avoidance regions



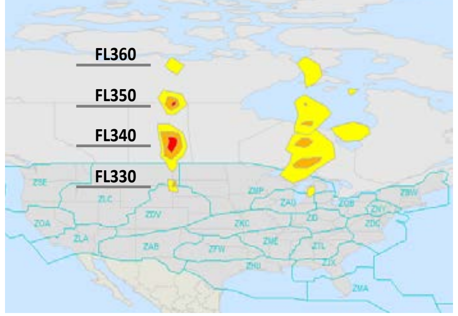
Route Impacts



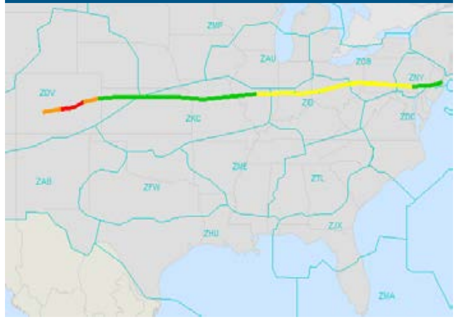
Sector Impacts



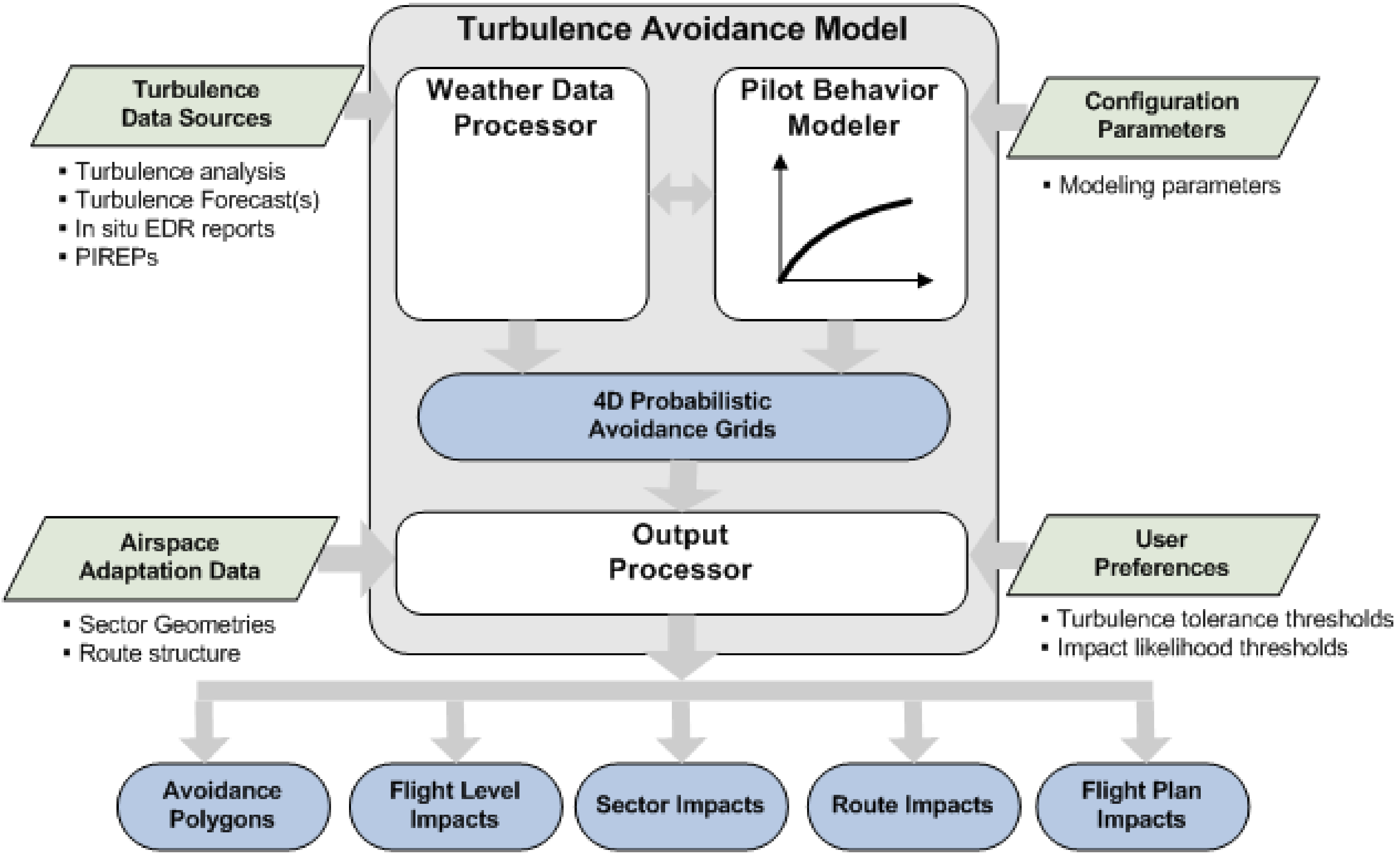
Flight Level Impacts



Flight Trajectory Impacts



Turbulence Avoidance Model (TAM) Overview



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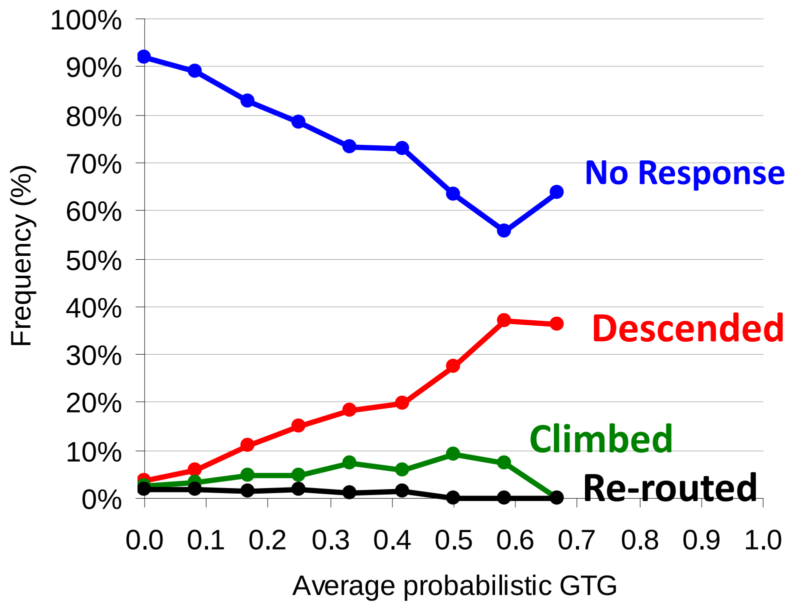
Prior Work



Turbulence Impact Analysis and Modeling

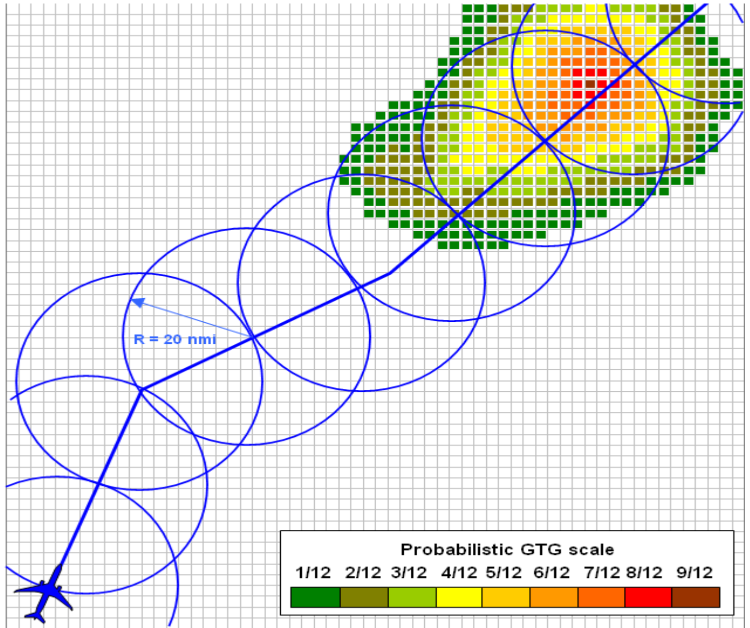
- Part of weather impact and weather translation NRA projects for NASA Ames in collaboration with NCAR (Sharman)
- Initial formulation of turbulence impact models based on limited datasets (Krozel, Klimenko)

TAM Phase 1

- Needs and benefits analysis for the FAA in collaboration with AvMet
- Development of initial turbulence encounters repository
- Stakeholder surveys to determine operational needs and shortfalls
- Initial concept of use development

TAM Phase 2

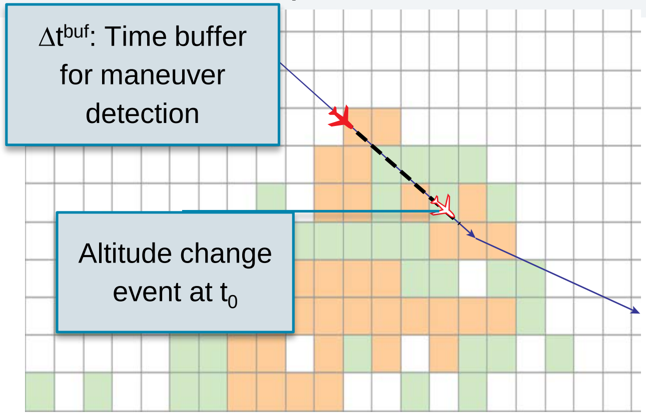
- Analysis of accuracy and consistency of turbulence information
- Development of refined pilot behavior models
- Validation of TAM outputs



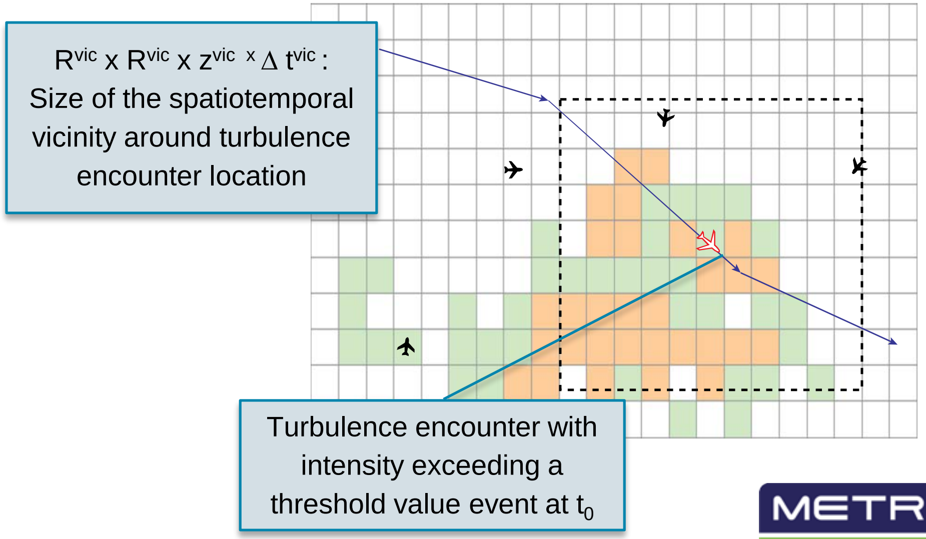
Pilot Behavior Analysis: Approach

- Detect and quantify pilot responses behavior to turbulence encounters
  - Focus on altitude change events, or lack thereof, when encountering turbulence of given intensity
  - Scope limited to cruise phase of a flight
- Develop statistical approach for identifying best predictors for pilot responses
  - Size of local spatiotemporal neighborhood in the vicinity of a turbulence encounter
  - Sample estimator
- Develop parameterized representations of pilot behavior models that can be stratified based on
  - Aircraft weight class
  - Region
  - Airline policy/tolerance to turbulence encounters

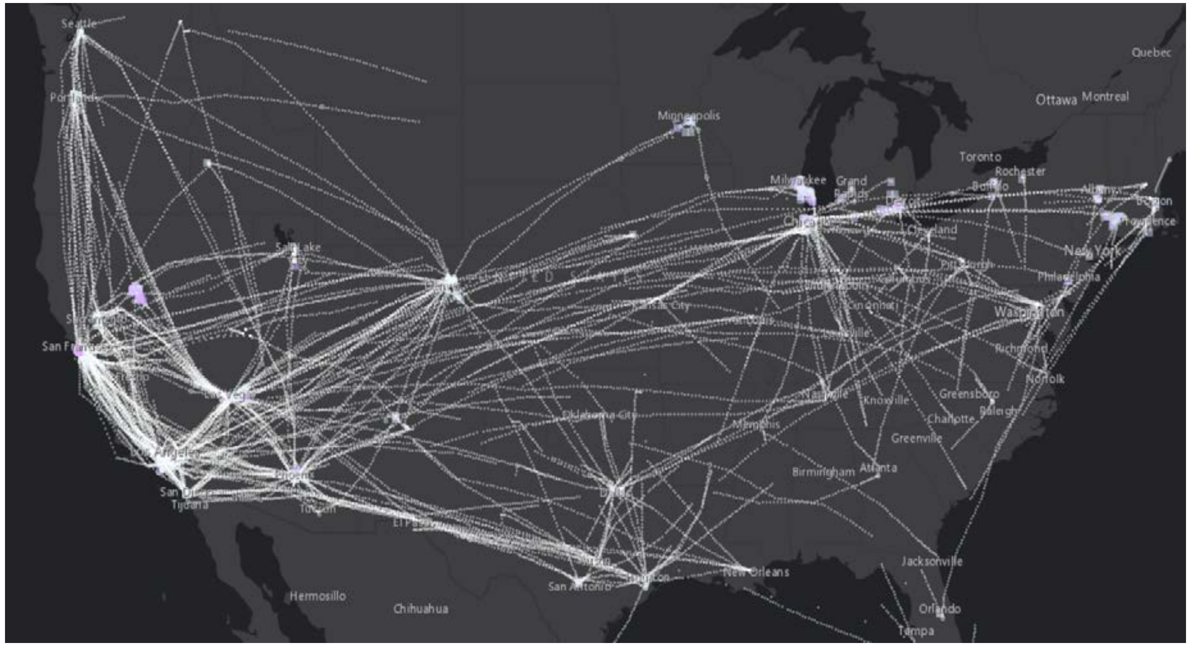
Classifying pilot's response based on in situ EDR reports

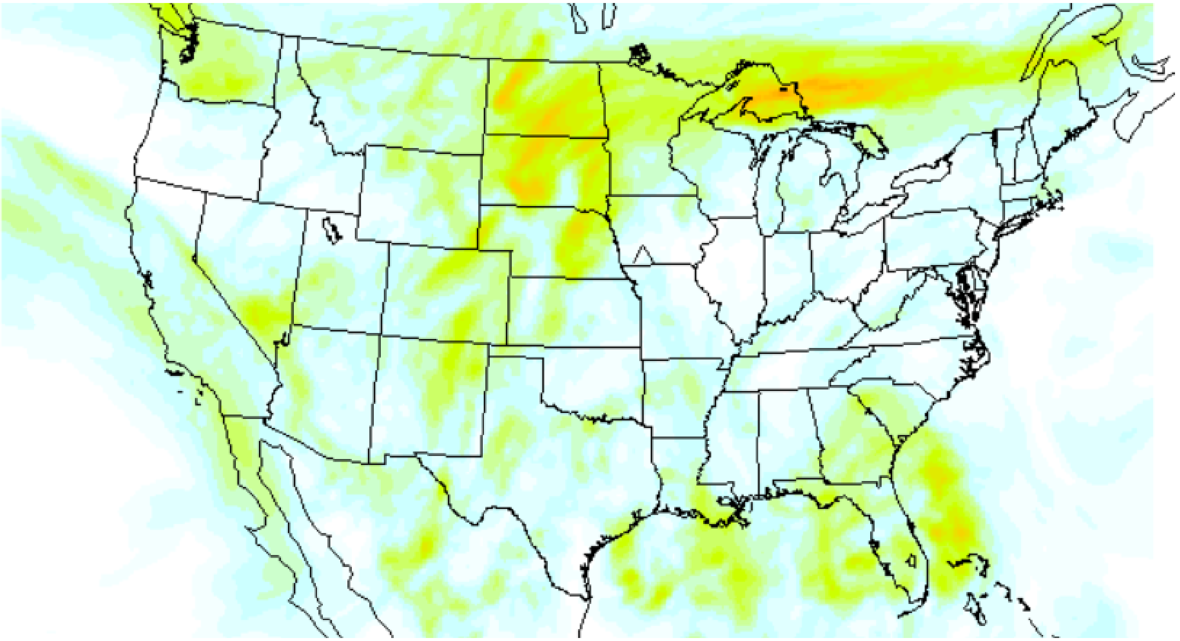


Classifying pilot's response based on gridded GTGN vicinity values



Pilot Behavior Analysis: Data Sources





In situ EDR data from a major US airline

- 1+ year of in situ EDR reports, 200,000+ EDR reports per day
- Each report includes peak and median EDR values, position, time, ACID, origin and destination airports
- About 12% of these reports are non-interpolated (i.e., contain actually observed values

Graphical Turbulence Guidance Nowcast (GTGN) from NCAR

- 2+ years of gridded EDR nowcast data spanning the entire CONUS
- Updated every 15 minutes
- Altitude range from surface to FL500

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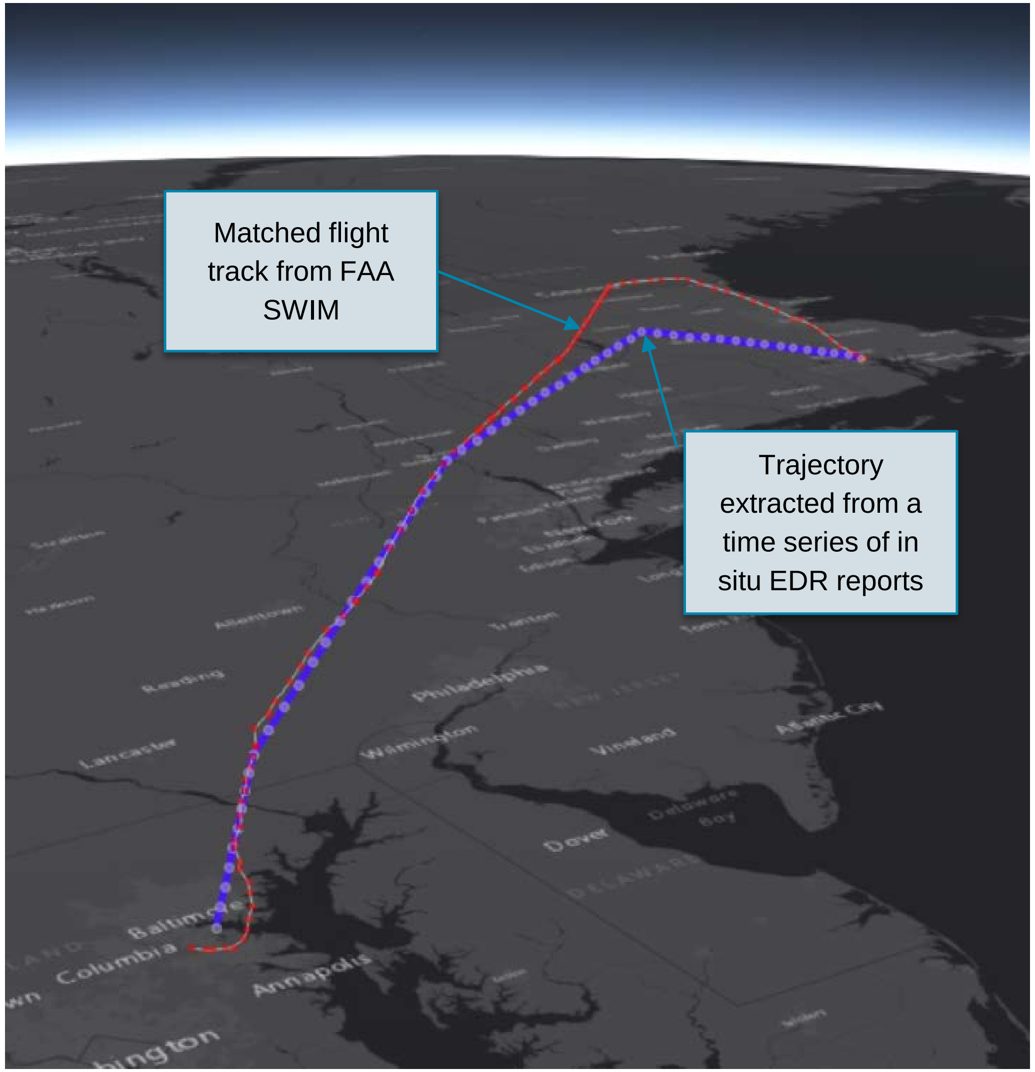
Pilot Behavior Analysis: Data Cleansing and Trajectory Matching

In situ EDR data is processed and matched into trajectories:

- Each trajectory corresponds to an individual flight leg (origin-destination pair)
- Invalid trajectories (minimum number of EDR reports, minimum number of non-interpolated EDR reports) are filtered out
- Matching flight track data from FAA SWIM are identified for each extracted EDR trajectory to address position report issues
- Correct position data are determined for all non-interpolated EDR reports based on SWIM flight track data and used in the analysis



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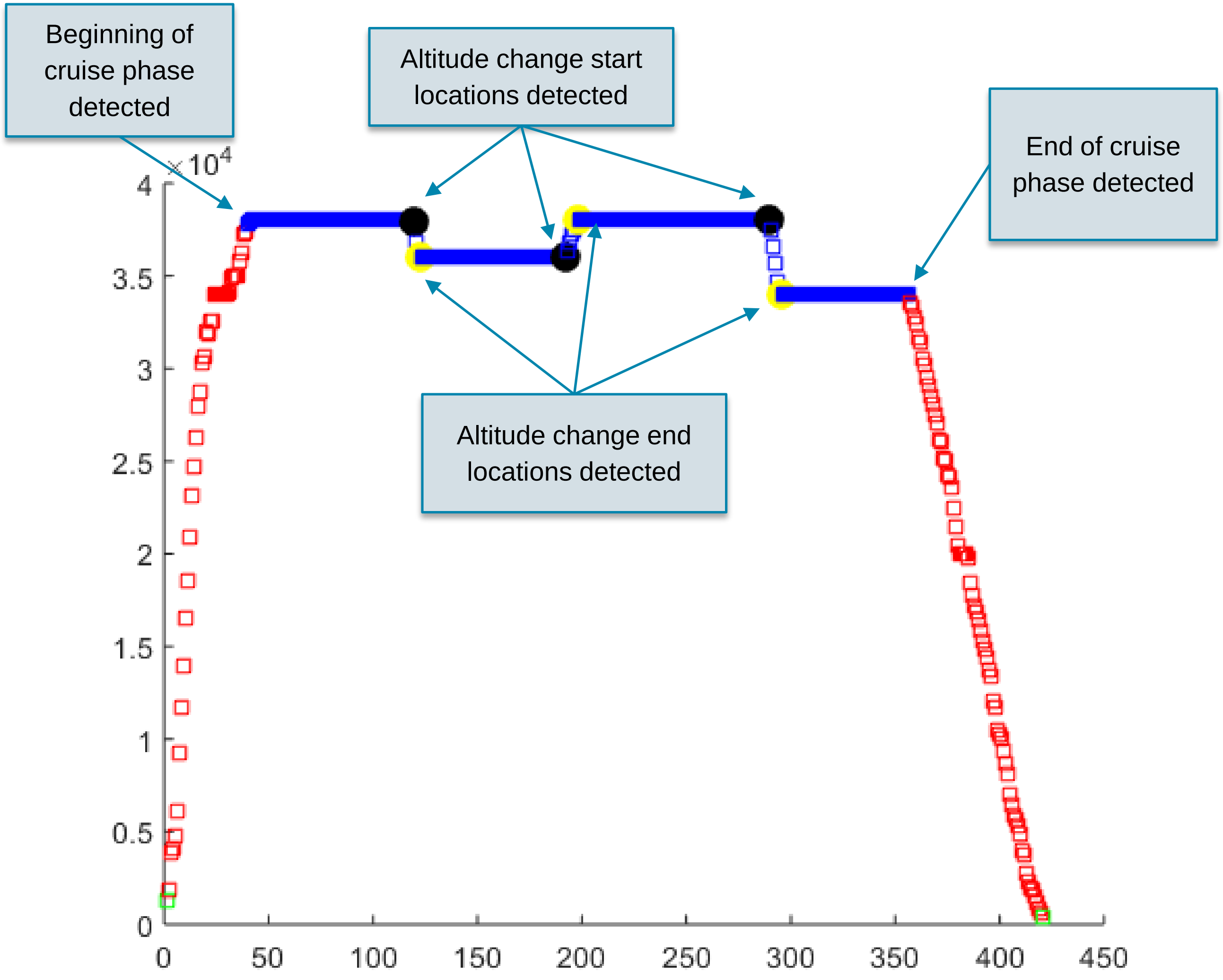
Pilot Behavior Analysis: Cruise Phase and Altitude Change Identification

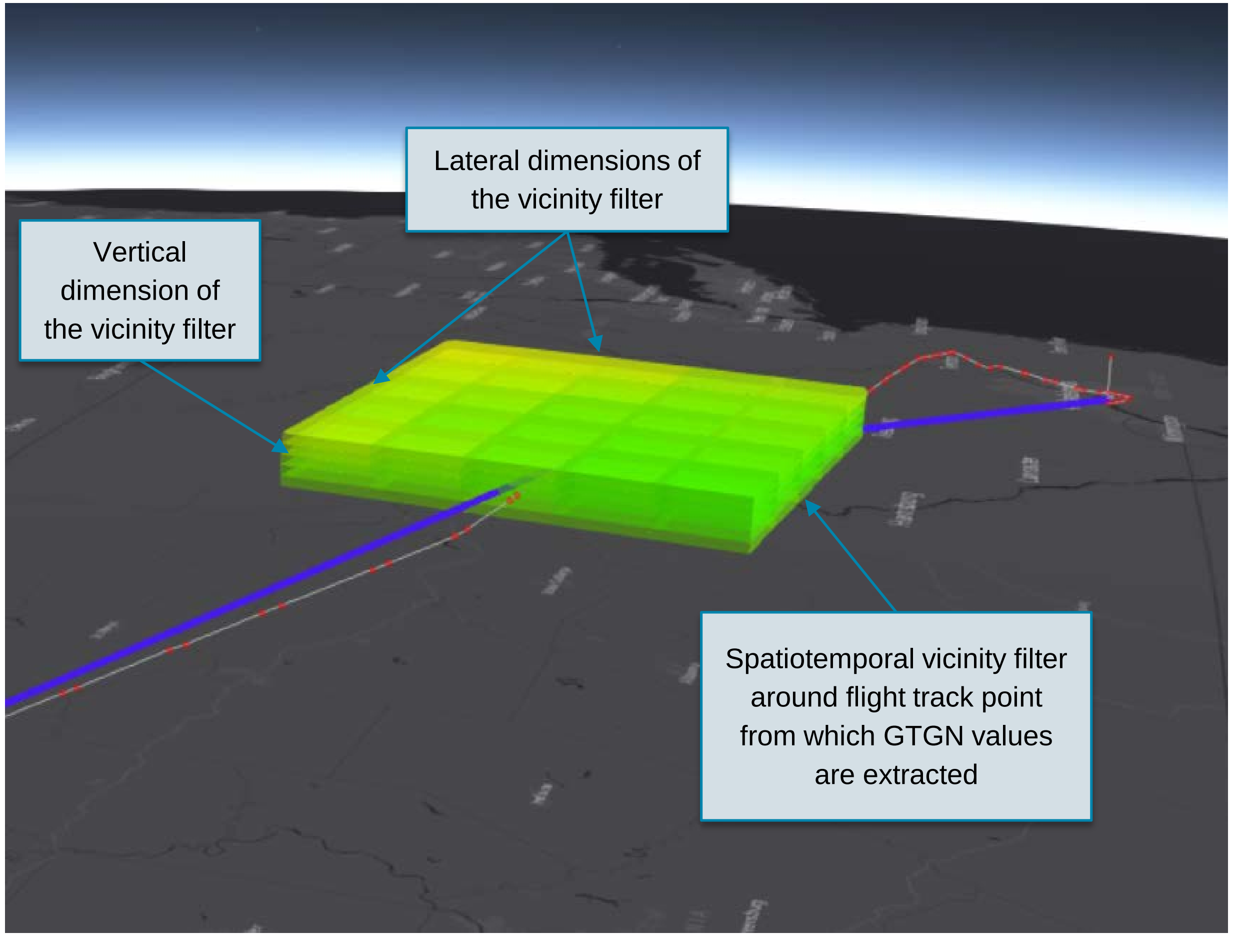
Matched SWIM track data are used to identify:

- Cruise phase for each flight
- Altitudes changes, if any, occurring during the cruise phase
    - Start and end locations identified from track data
    - Magnitude of altitude change also computed
- Identified altitude change events are subsequently added to the repository for analysis



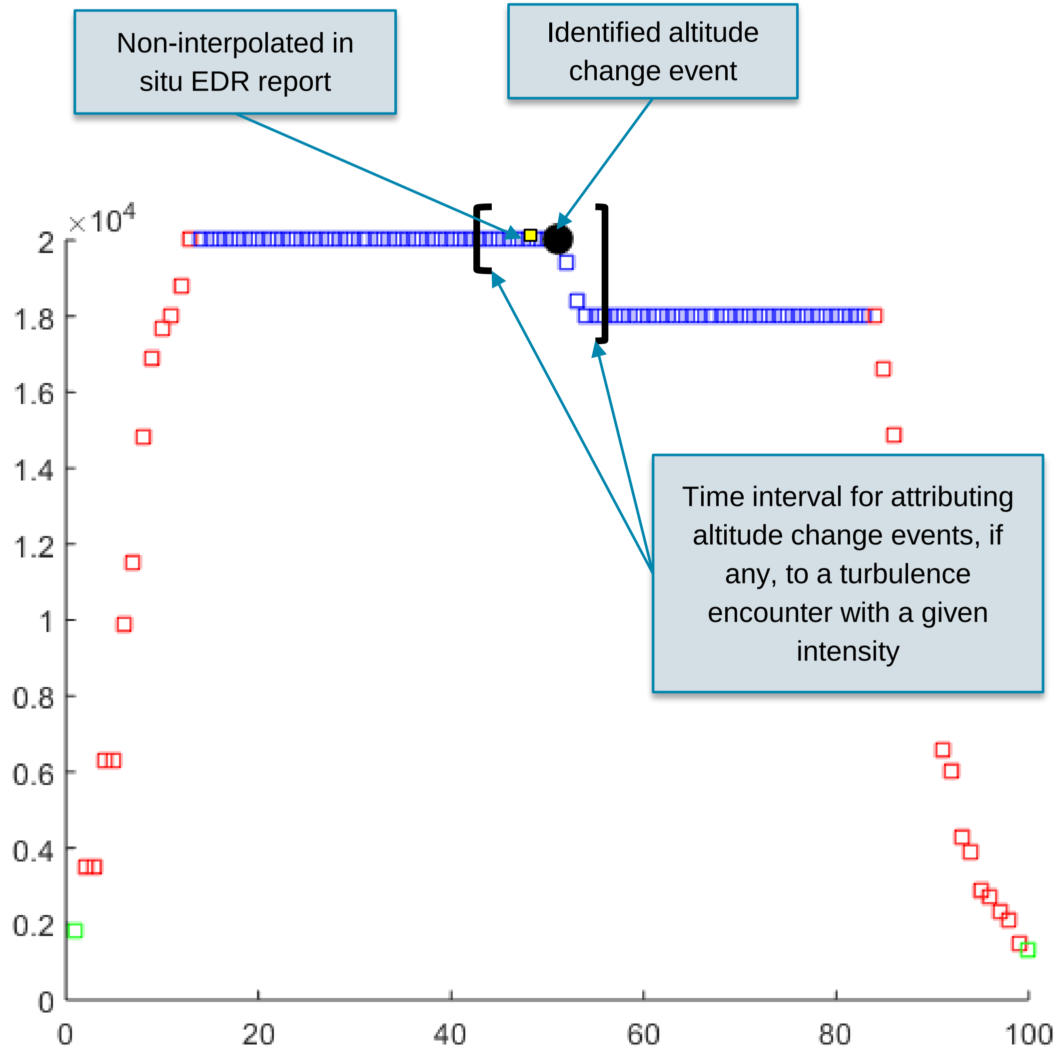
Pilot Behavior Analysis: Turbulence Encounter Identification

- Turbulence encounter identification relies on spatiotemporal vicinity filters defined for each cruise phase track data point:
  - Lateral dimensions (distance in km from the analyzed track data point)
  - Vertical dimensions (number of flight levels above and below the analyzed track data point altitude)
  - Temporal dimensions (time window around the analyzed track data point time)
- Analysis includes varying sizes od the spatiotemporal vicinity filter and sample estimator to determine best predictors for altitude change



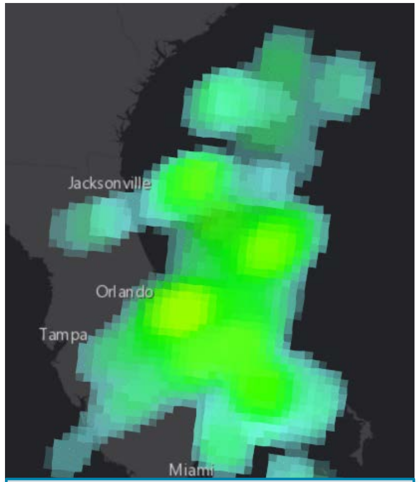
Pilot Behavior Analysis: Response vs Non-Response Identification

- Two methods used depending on the turbulence data source:
  - In situ EDR data:
    - Time interval of size *t* centered at a non-interpolated in situ EDR report.
    - Altitude change events, if any, in that time interval are attributed to this turbulence encounter
    - Peak EDR value determines the magnitude of the encountered turbulence
  - GTGN data:
    - Time interval of size *t* defined for each cruise phase track point
    - Magnitude of the encountered turbulence determined by a sample estimator using the sample extracted from the spatiotemporal filter
- Encounters with similar turbulence magnitude are binned together and the frequency of altitude changes attributed to this encounter is computed

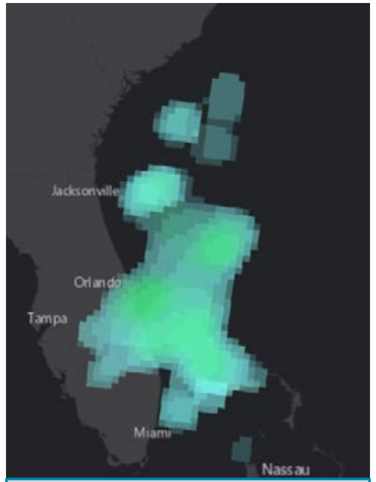


4D Turbulence Avoidance Grids

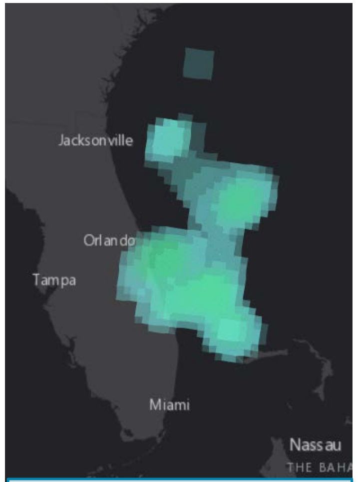
- Best predictors and spatiotemporal filters* used to compute 4D turbulence avoidance grids based on derived pilot behavior models
  - Grids defined for each aircraft weight class
- 4D avoidance grids define common baseline for defining derived turbulence translation outputs
  - Avoidance polygons
  - Route impacts
  - Flight plan impacts
- A set of parameters is provided to adjust derivation of translation outputs
  - Likelihood of altitude change
  - Dwell time



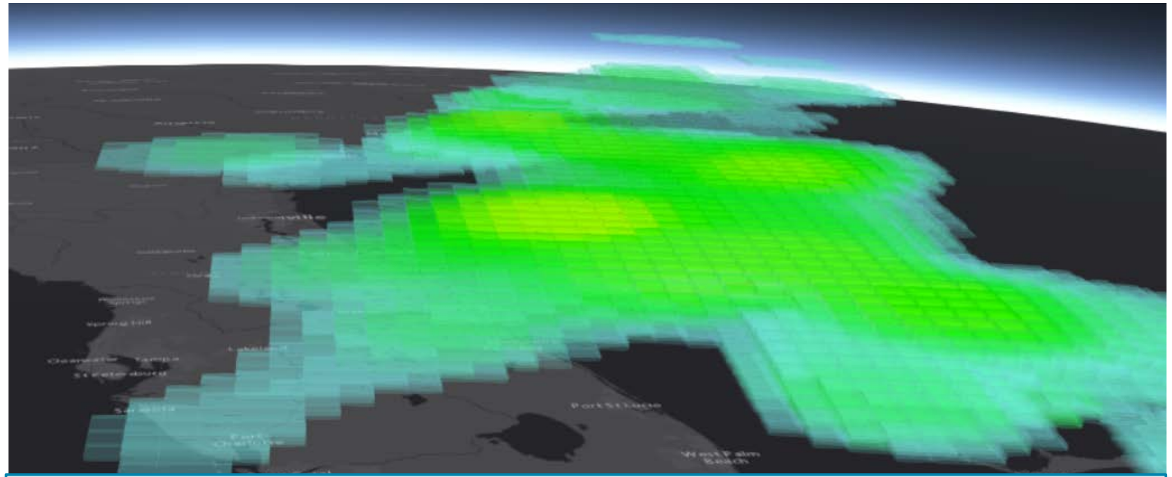
Small aircraft grid



Large aircraft grid



Heavy aircraft grid



3D view of the small aircraft avoidance grid illustrating vertical extent

* Analysis in progress in evaluating and validating TAM predictors for derived pilot behavior models

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Summary

- Developed a concept of TAM, a turbulence translation technique aimed at providing automated and consistent interpretation of turbulence information relevant for operational decision making
- Developed a methodology for analyzing pilot behavior in response to turbulence encounters
    - Core component of TAM
- Conducted analysis of in situ EDR data and GTGN data to develop models of pilot behavior in response to turbulence encounters
    - Tens of thousands of flight trajectories processed
- Developed a proof of concept TAM implementation to support analysis, display, and validation of turbulence translation outputs

Next steps:

- Evaluation and validation of pilot behavior models
- Stakeholder feedback on TAM concept and generated turbulence translation outputs
- Documentation of research results

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