Metrics for Evaluating the Impact of Weather on Jet Routes

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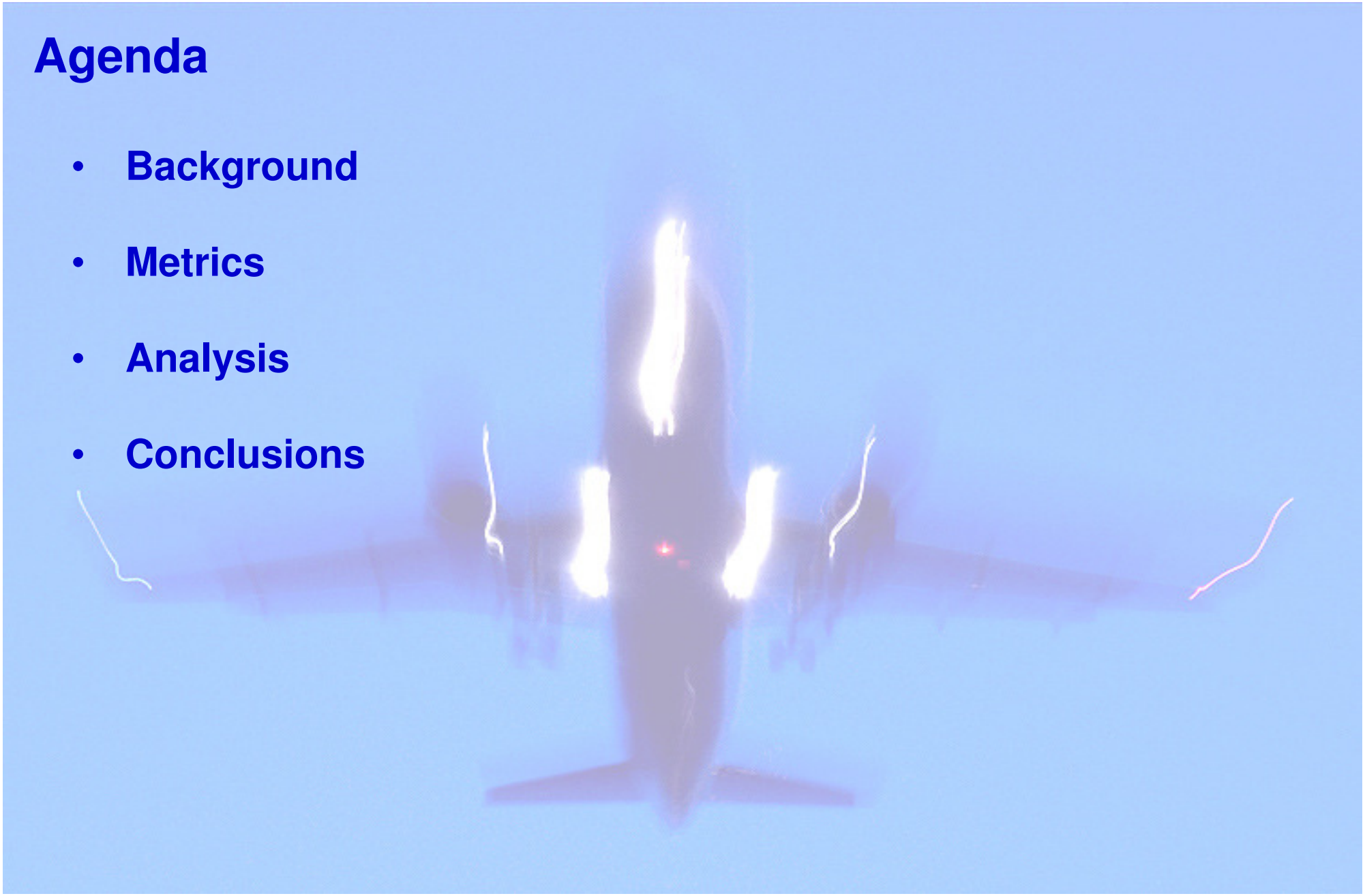
THE SCIENCE OF HARMONIZING AIR TRAFFIC

Agenda

- Background
- Metrics
- Analysis
- Conclusions



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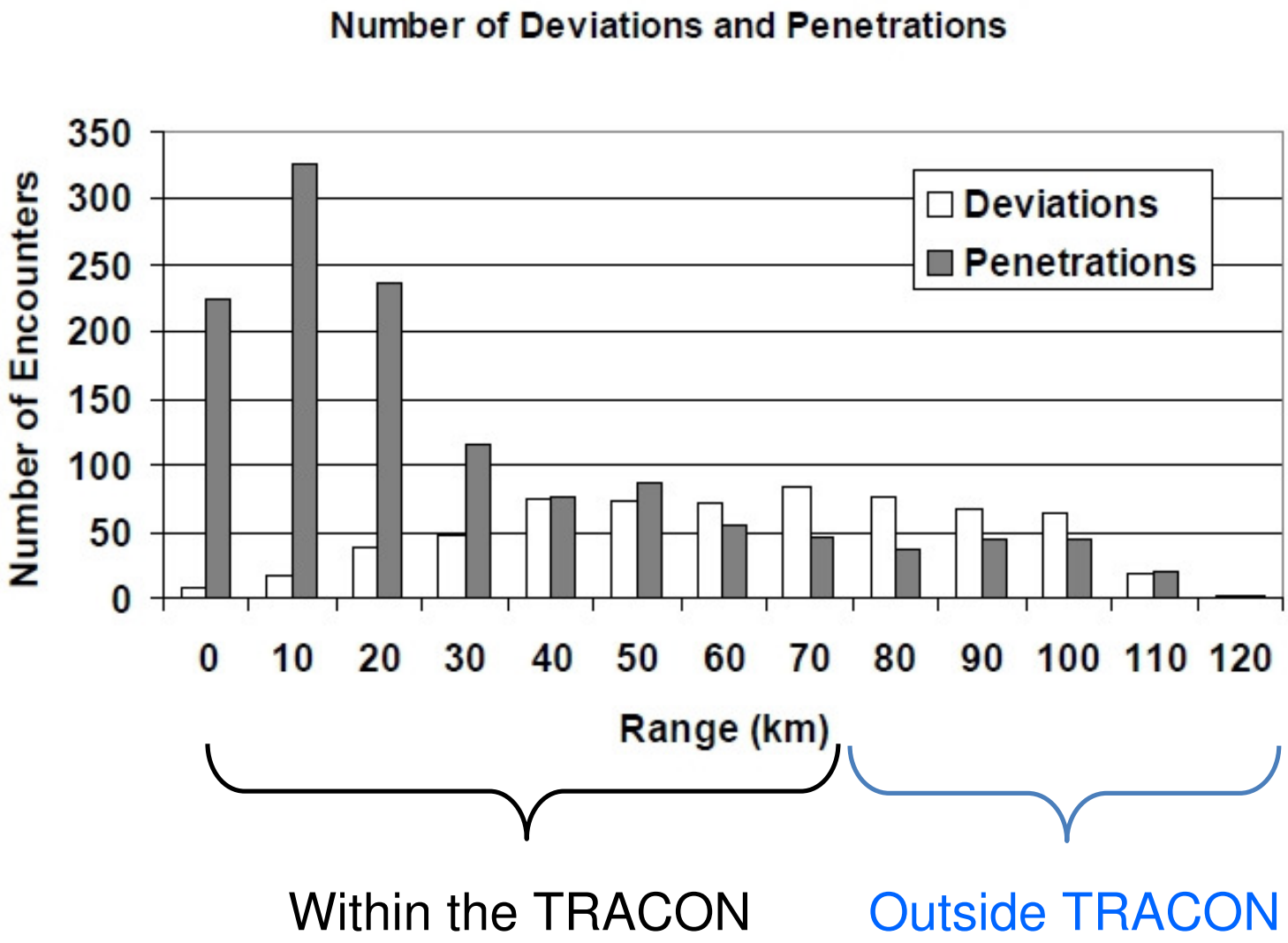
Early Work on Weather Deviations and Penetrations



Results of MIT-Lincoln Laboratory

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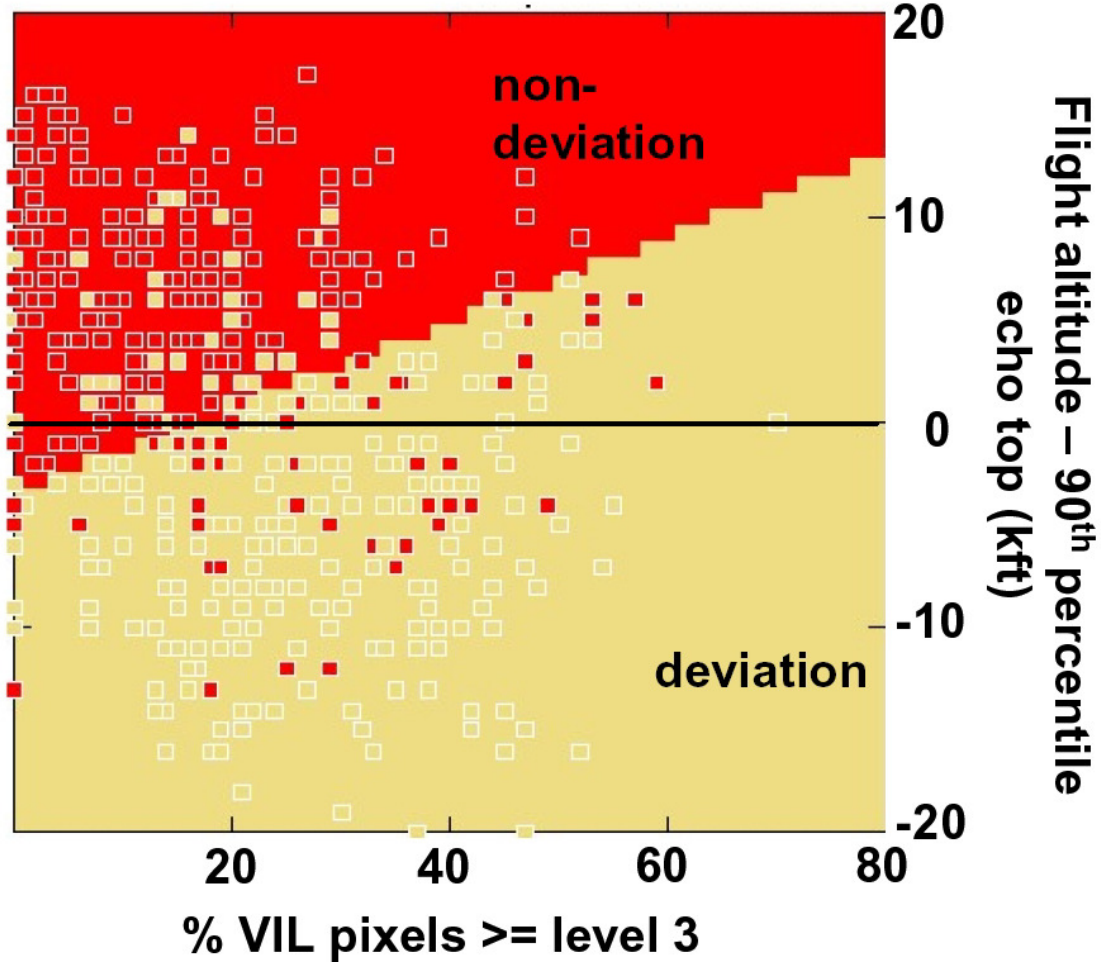
Convective Weather Avoidance Model (CWAM)



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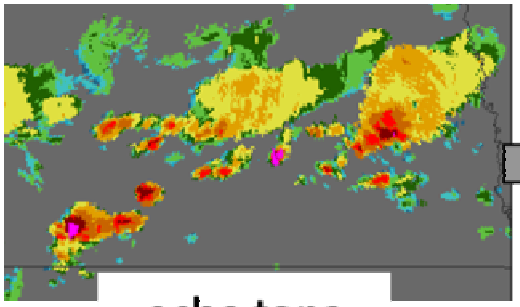
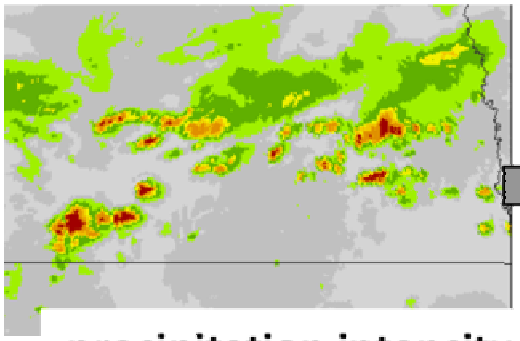
CWAM Weather Avoidance Fields (WAFs)

Weather Forecast Data

Weather Avoidance Field



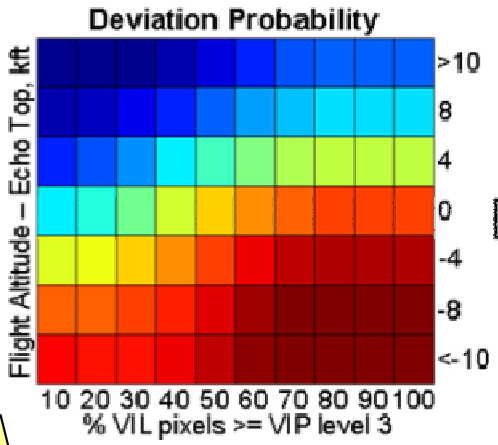
echo tops



precipitation intensity

CWAM

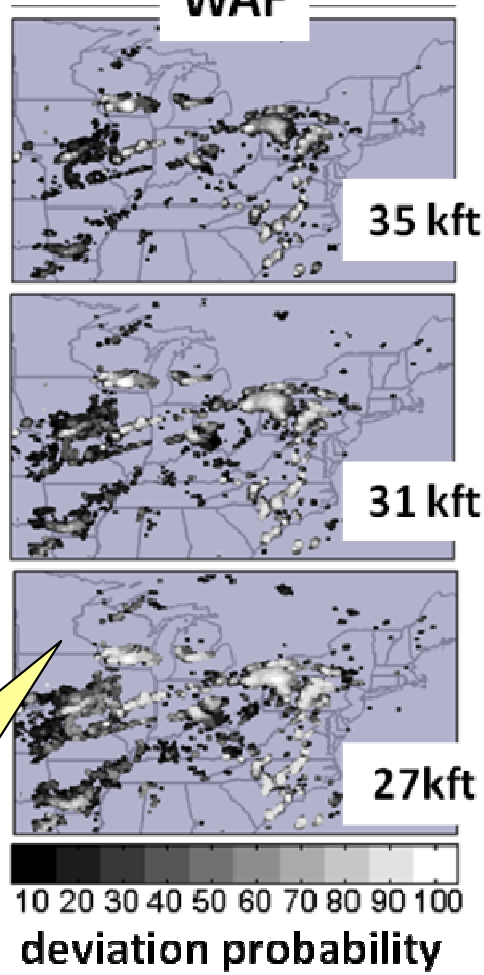
extract predictors



deviation probability lookup

Observe 1000s of flights and classify as deviate or non-deviate

WAF



En Route models differ from Terminal models

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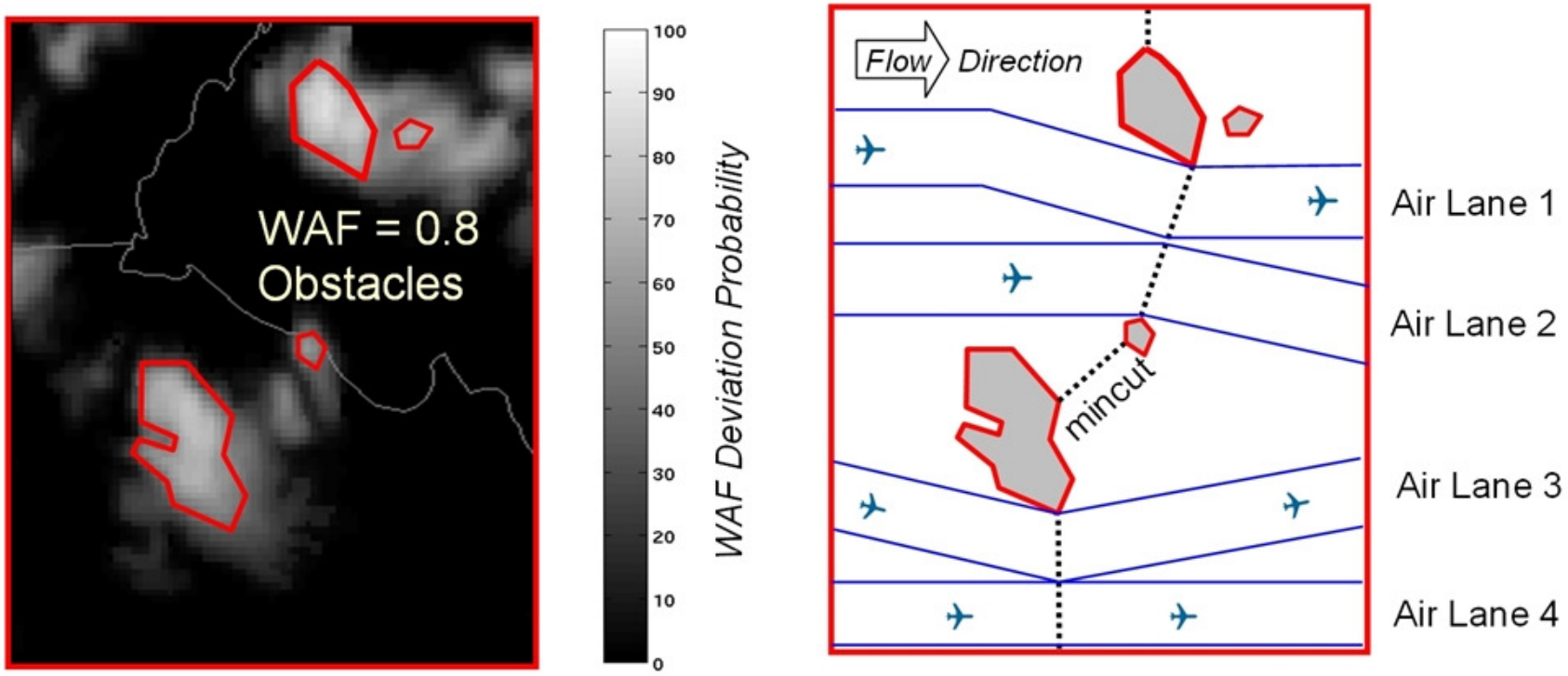
Mincut Metric



(a) Weather hazard defined by WAF threshold

(b) Mincut bottleneck and maximum number of lanes of traffic that may pass through the airspace

- **Minimum Cut (Mincut) and Maximum Flow (MaxFlow) are geometrically related via Duality: MaxFlow-Mincut Theorem**
- **Mincut can quantify the maximum flow through an airspace given a weather hazard map**
- **We are interested in how it characterizes the "wiggle room," "operational flexibility," or "permeability" of the airspace around a jet route or an aircraft trajectory**

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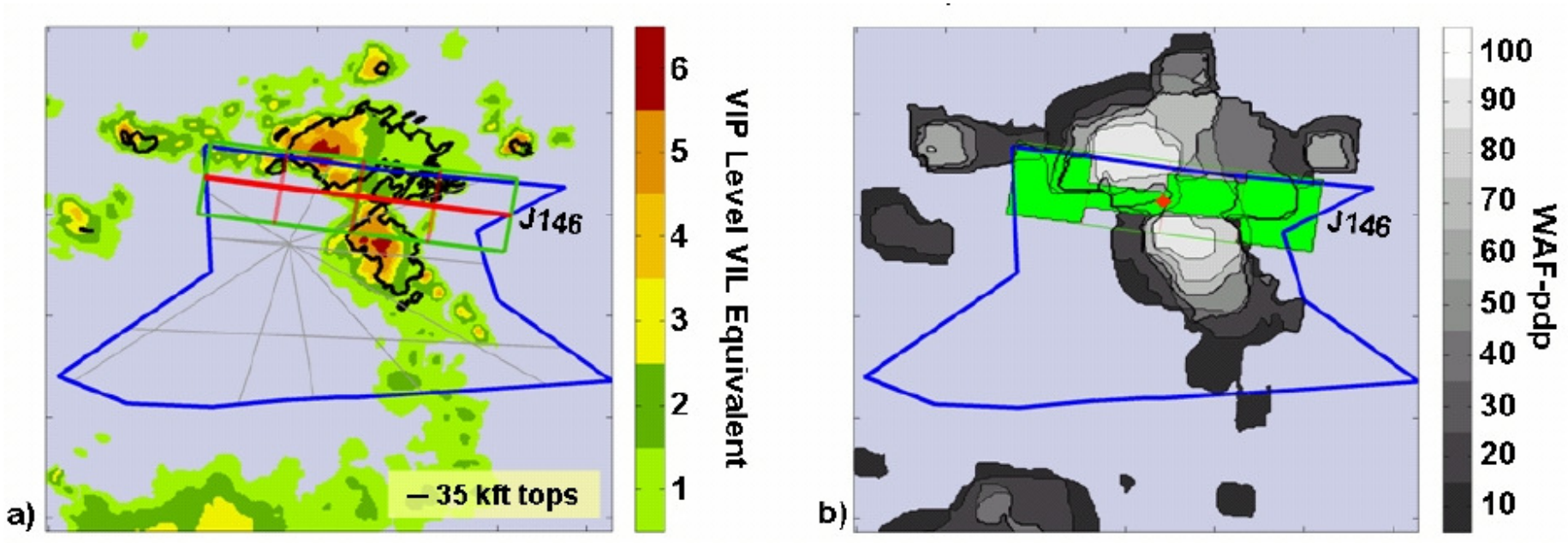
Route Blockage / Route Availability

Weather Forecast Data

Route Availability



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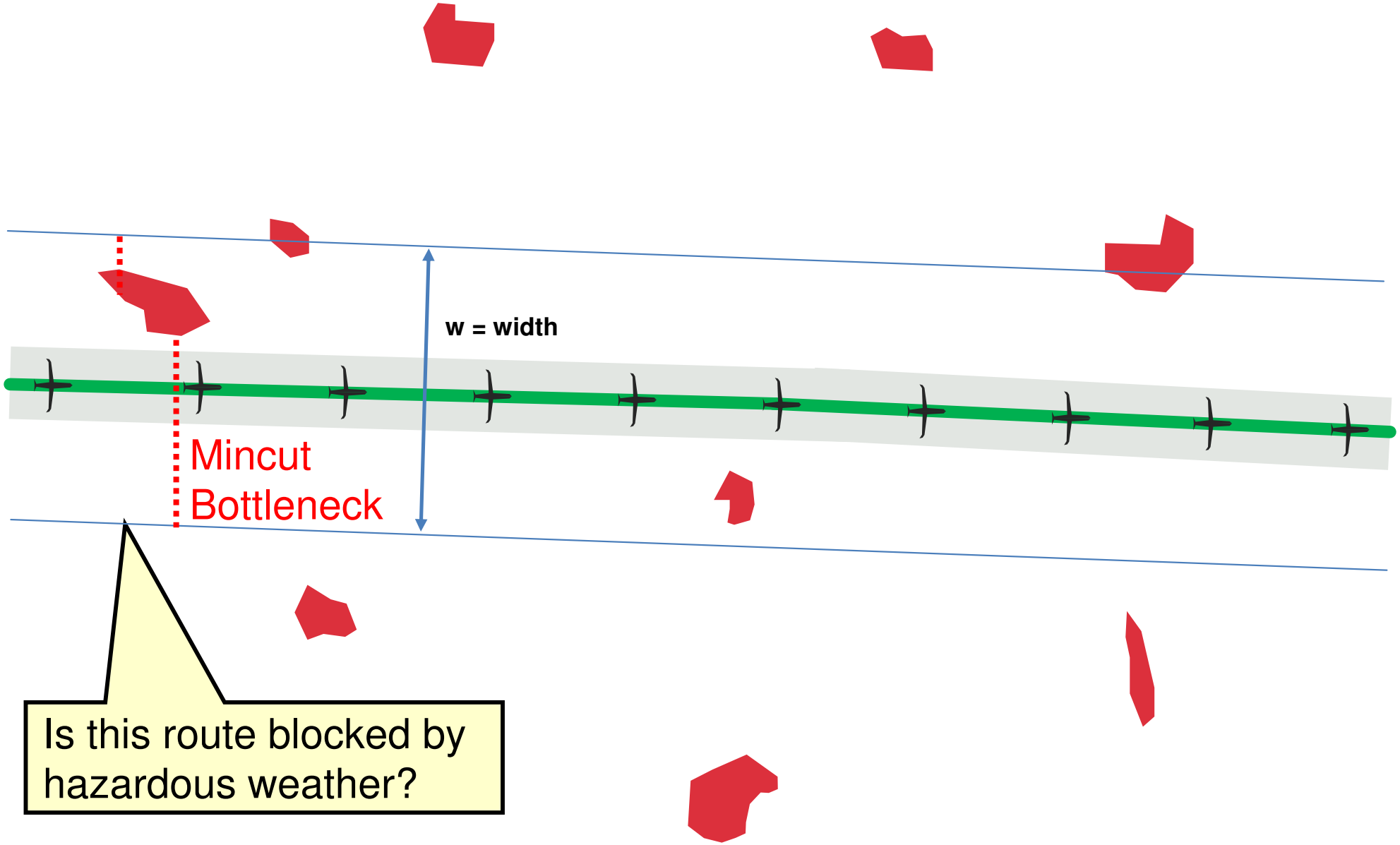
Metric 1: Based on Route Blockage Geometry



Current Work

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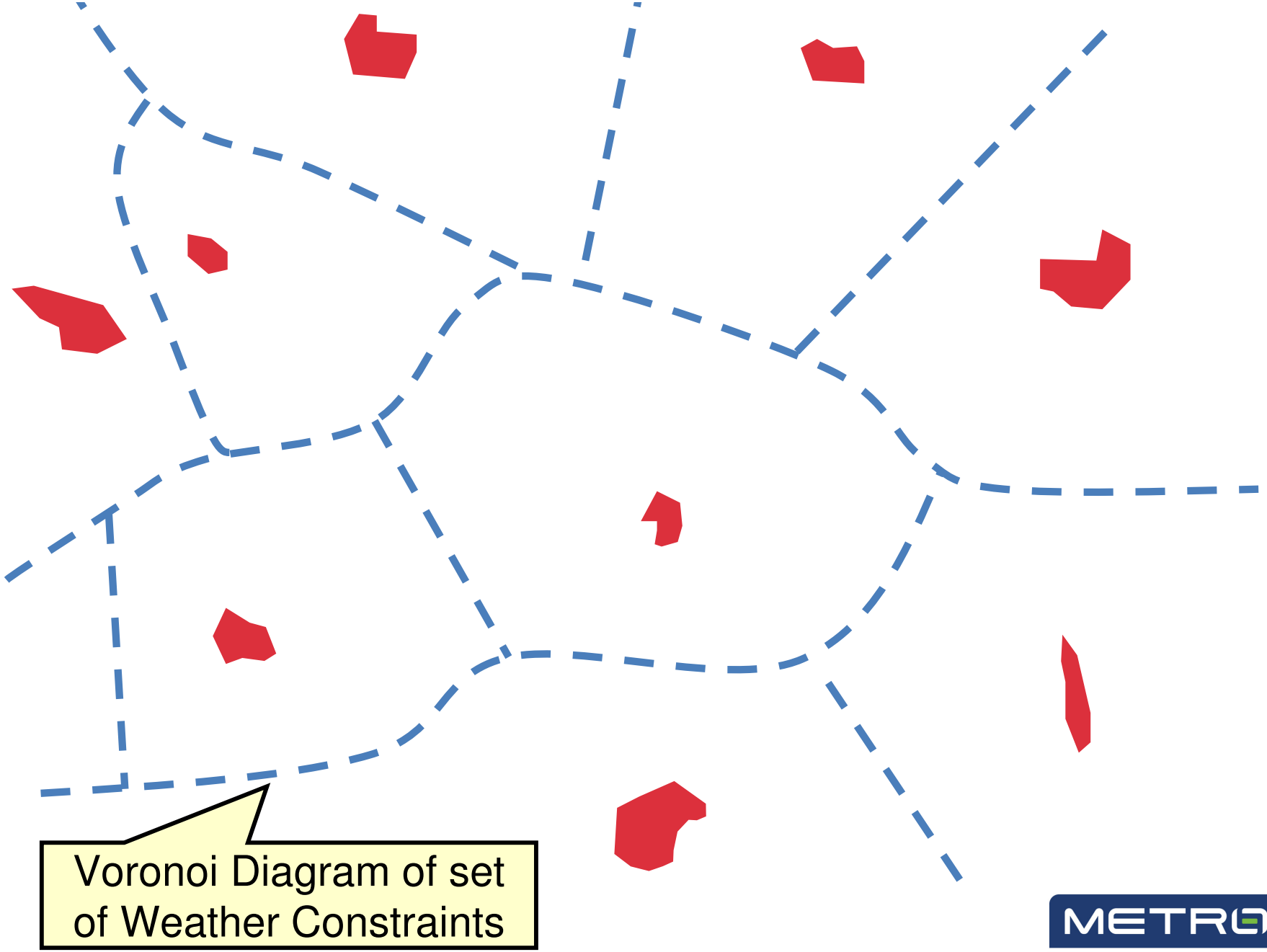
Voronoi Diagram Geometry



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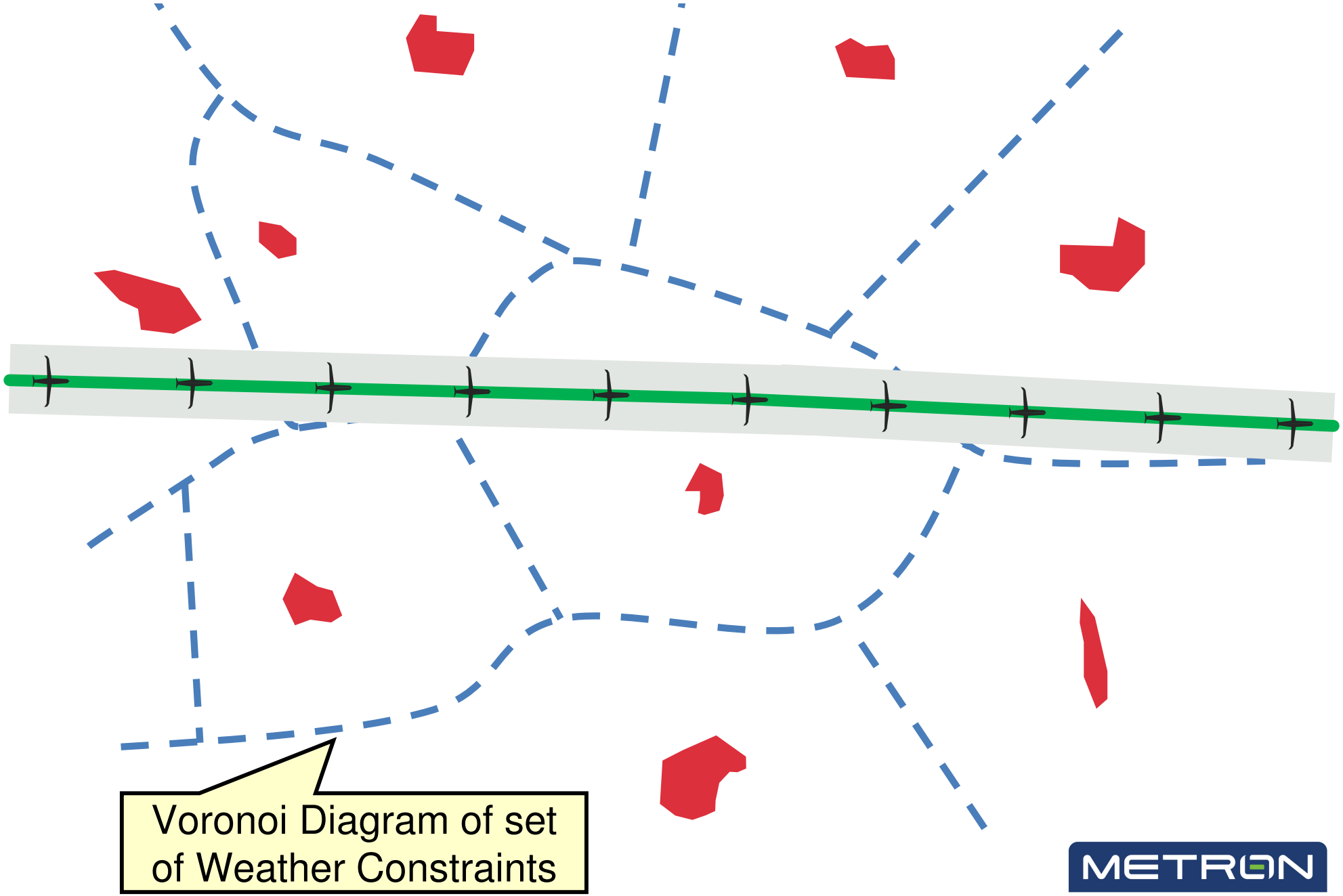
Voronoi Diagram Geometry



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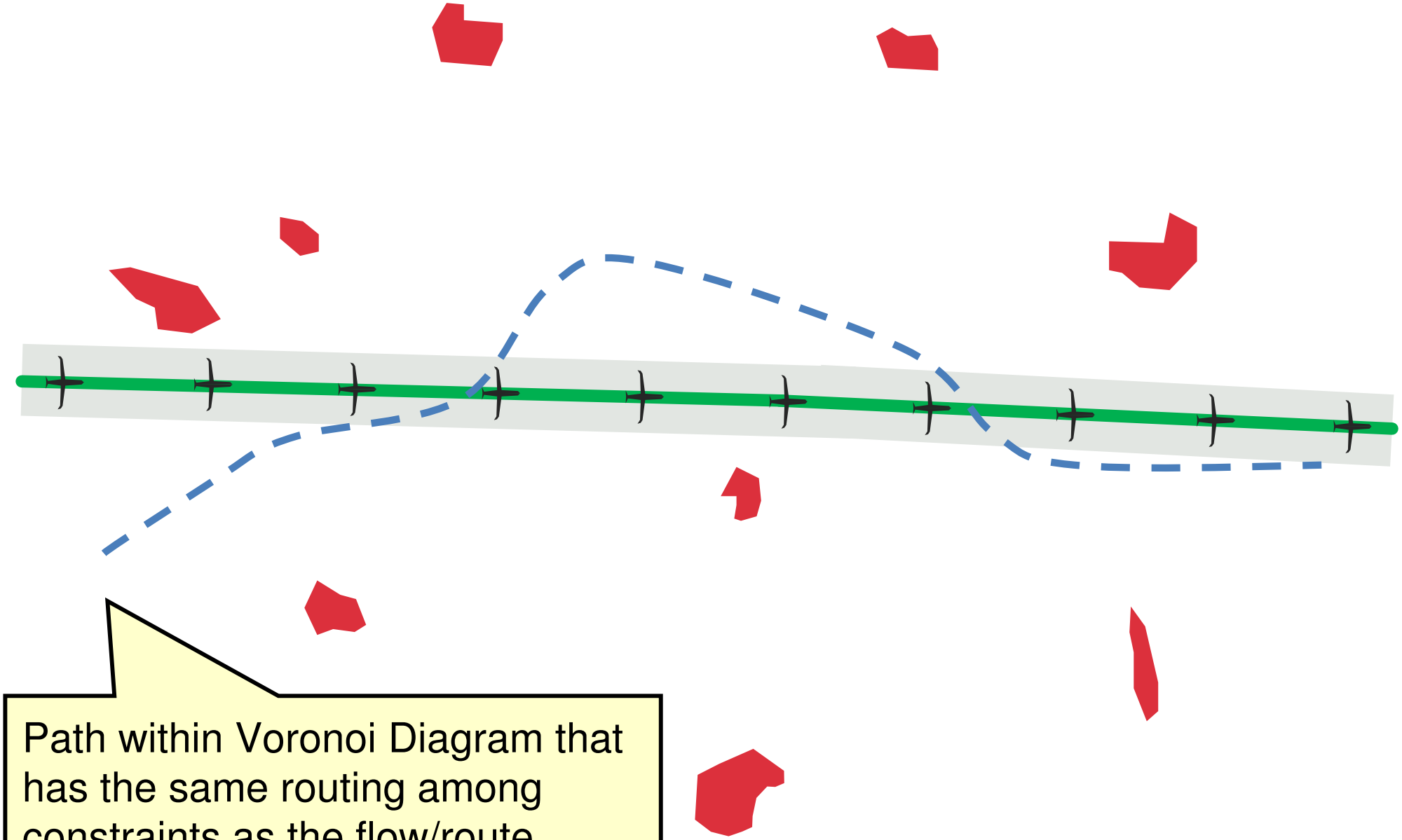
Homotopy Class



Path within Voronoi Diagram that has the same routing among constraints as the flow/route

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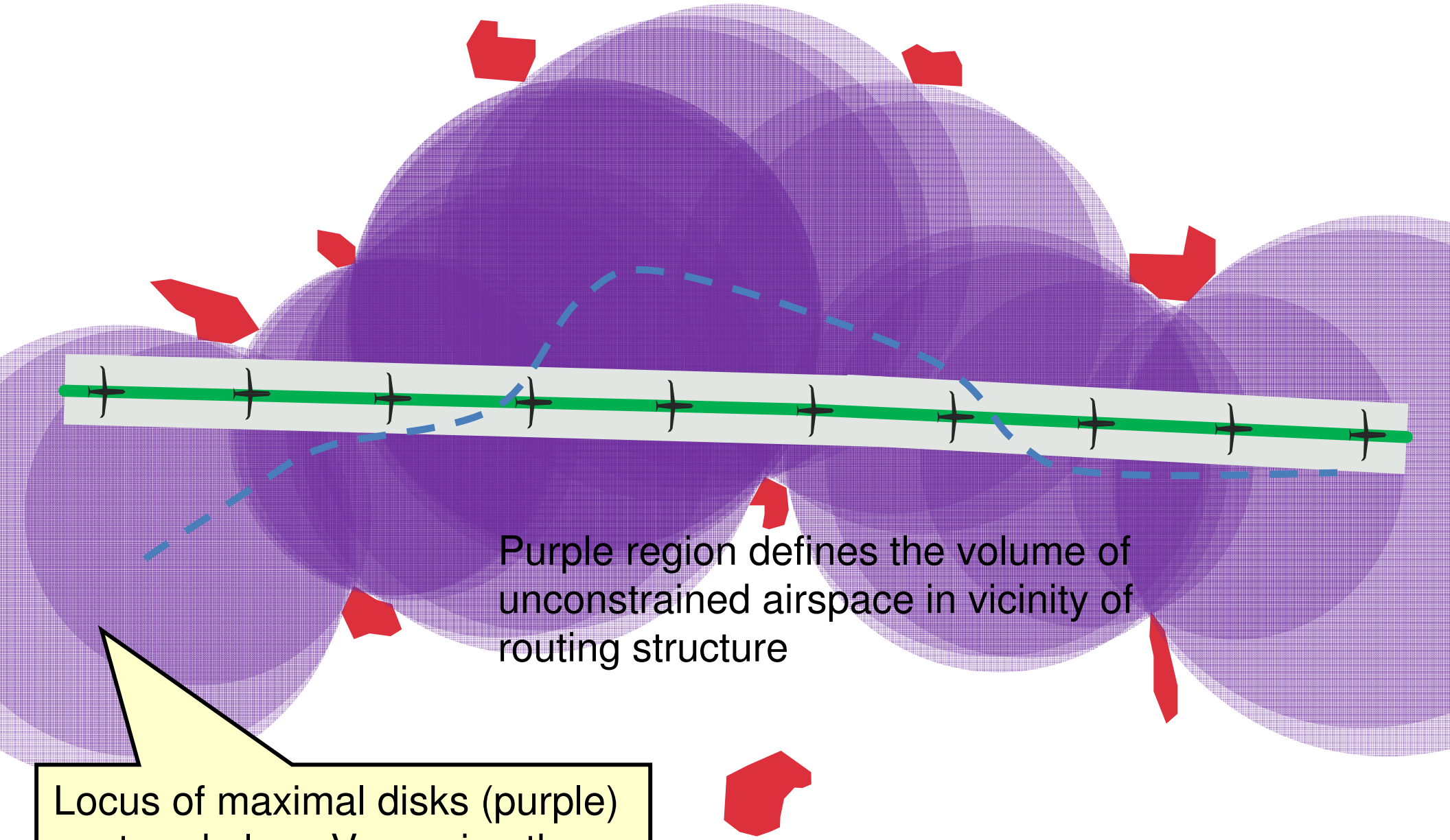
Metric 2: Constrained Airspace Metric



Future Work

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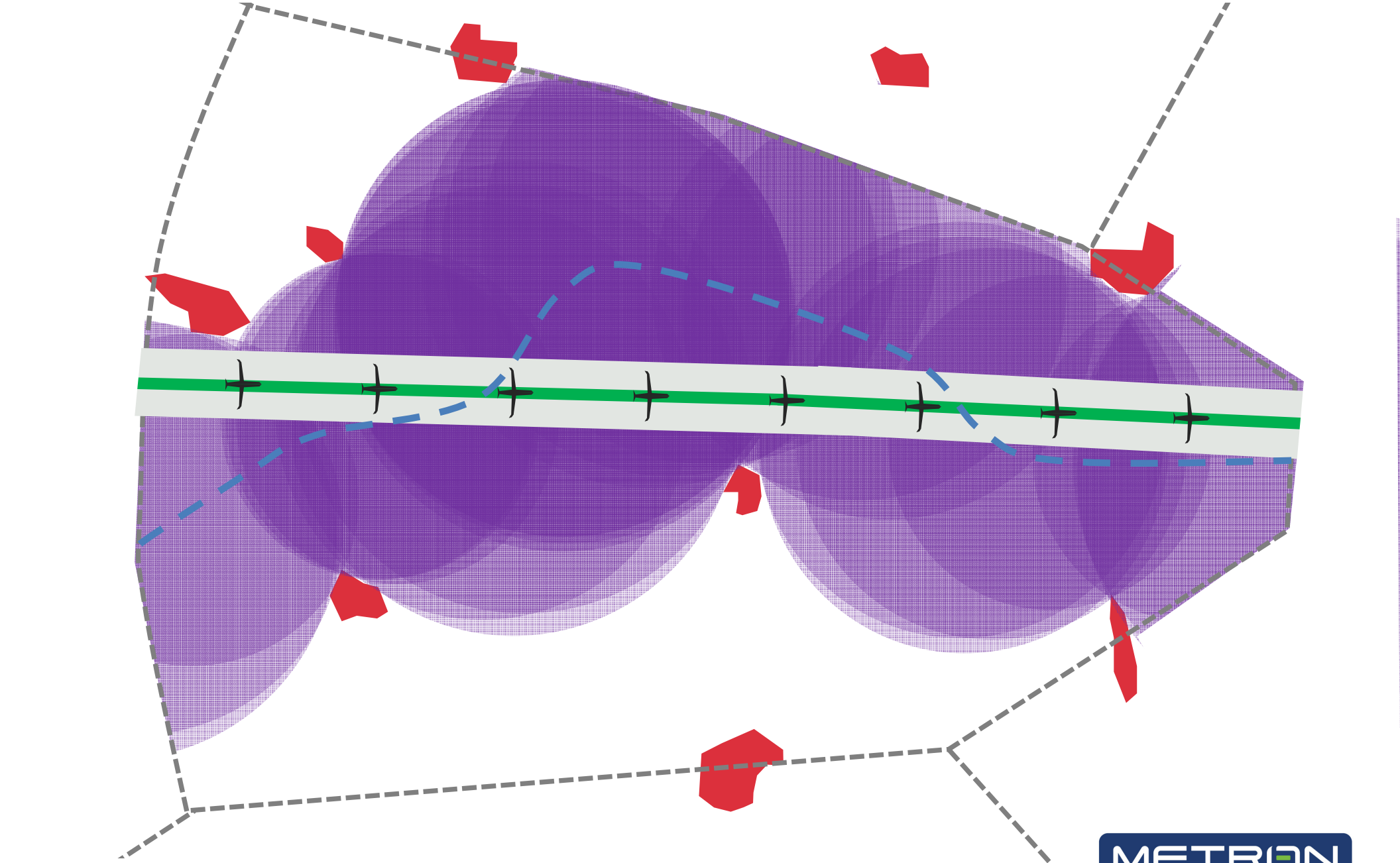
Metric 3: Constrained Airspace Metric within a Sector



Future Work

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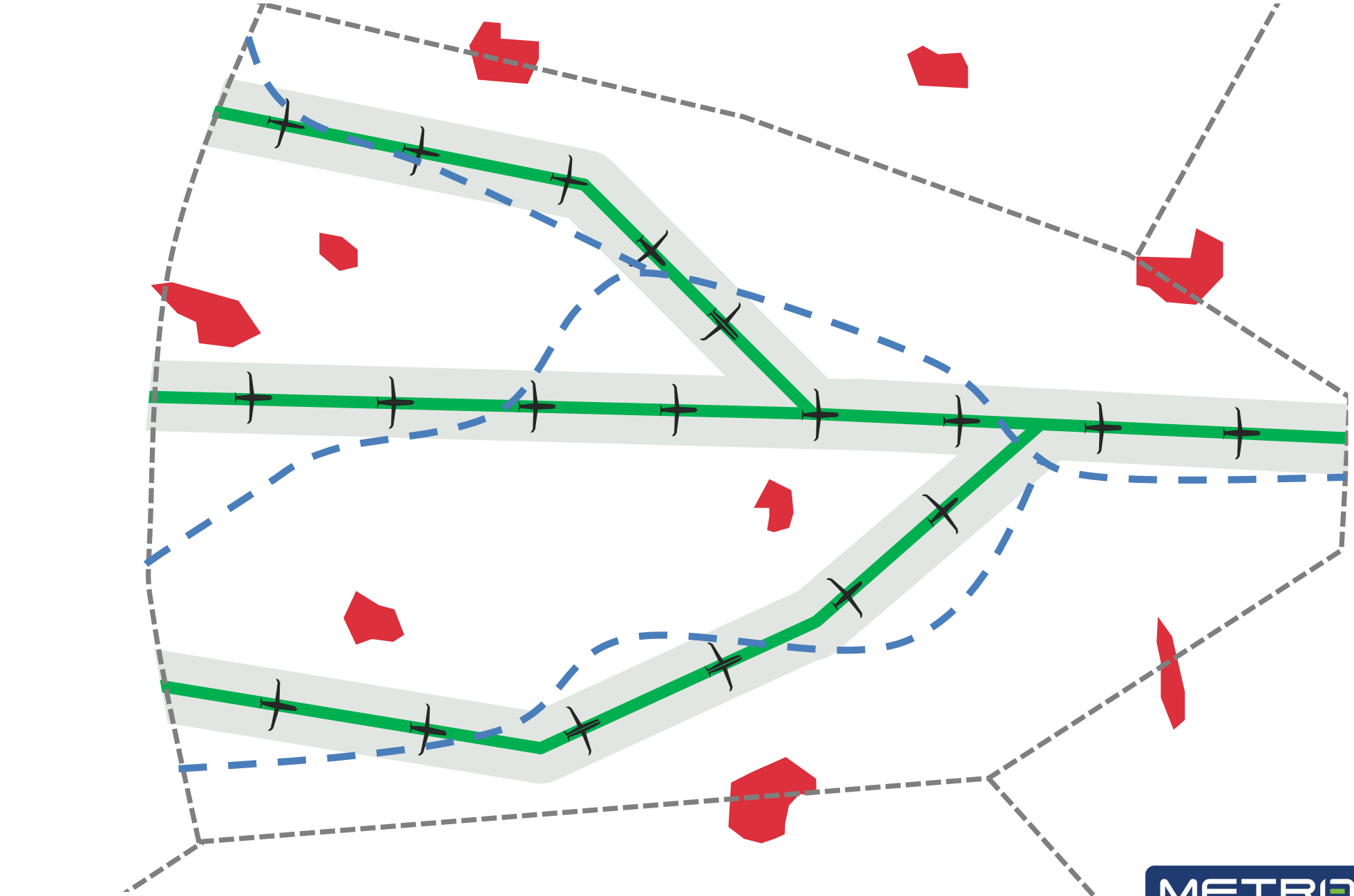
Metric 4: Considering Sector and Merge Tree (e.g., STAR)



Future Work

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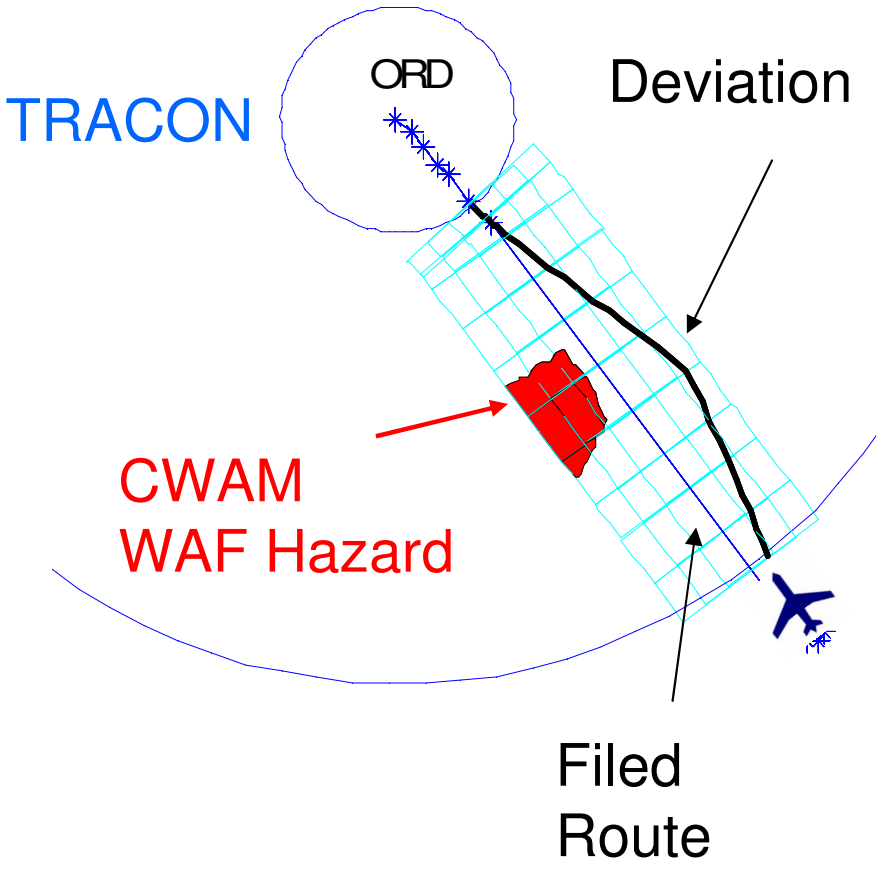
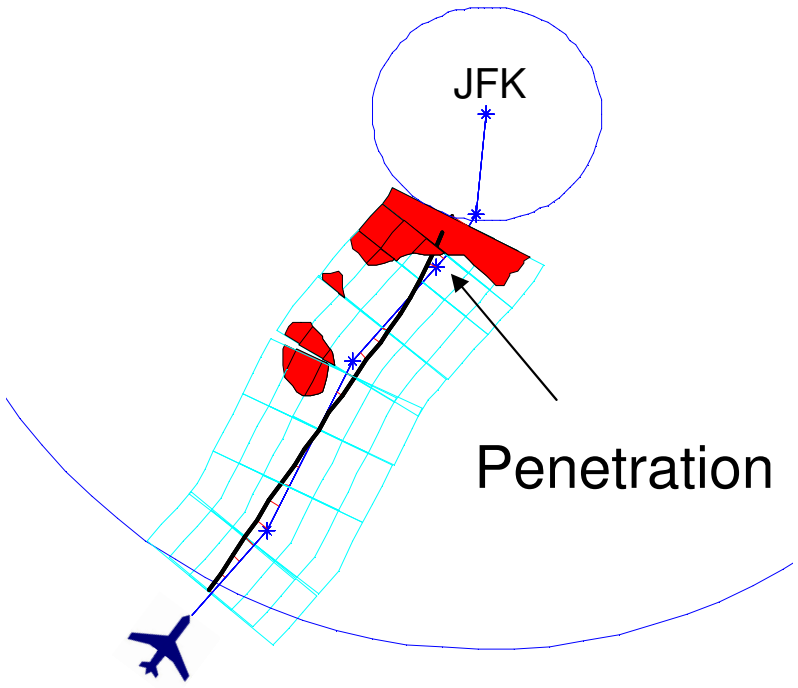
Weather Deviations and Penetrations – Transition Airspace





Deviation

Penetration

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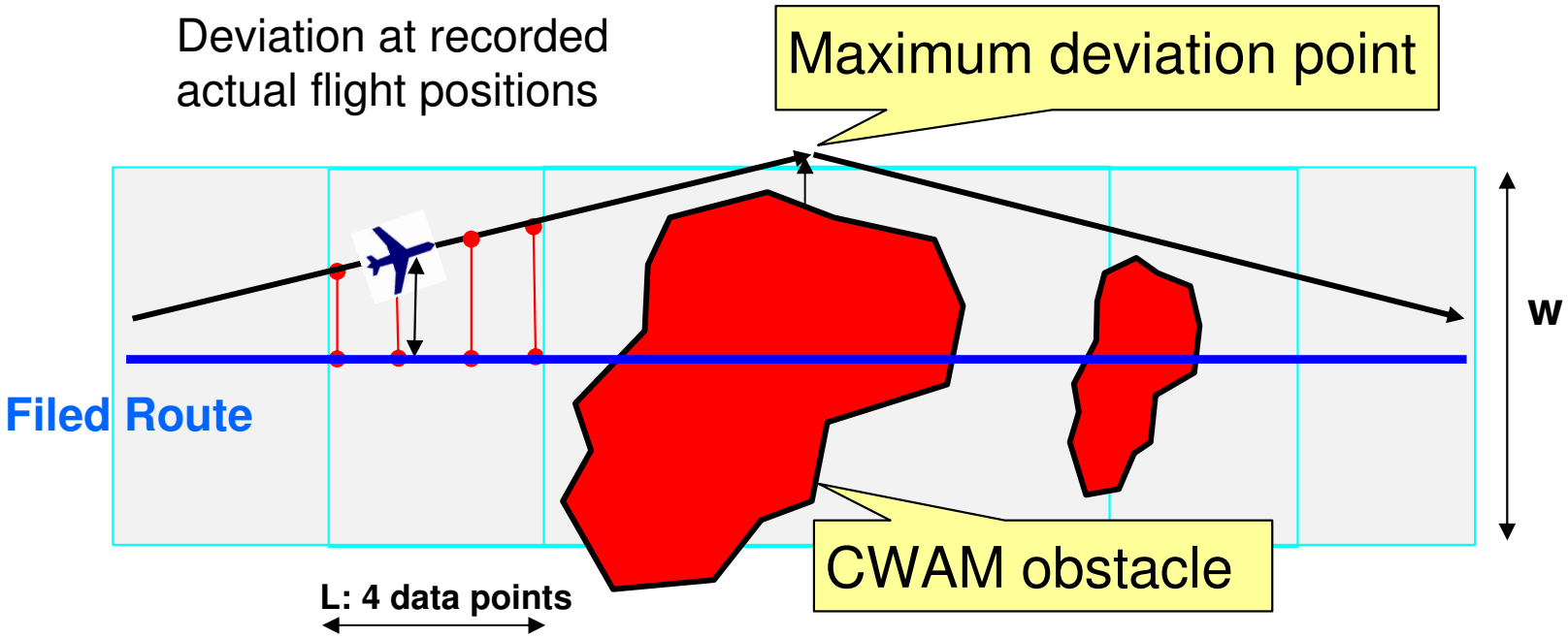
Weather Deviations



- **Moving window along the filed route measures route blockage**
- **Width = $w \in \{10, 20, 30, 40\}$ nmi**
- **Length = L corresponds to 4 data points of flight track data (approx 4 min)**

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Data Analyzed

ETMS data:
- flight filed route geometry,
- flight actual position (time, latitude, longitude and altitude)
- 1 minute update rate

Time Periods:
1- July 13 2010 arrivals between 10:45 AM and 12:00 PM
2- July 13 2010 arrivals between 16:05 PM and 17:20 PM
3- July 22 2010 arrivals between 10:45 AM and 12:00 PM
4- July 13 2010 arrivals between 15:45 PM and 17:00 PM

Number of flights= 3535

Weather Data:
- CWIS→ Deterministic WAF
- Altitudes for WAF polygons = [5000:1000:35000] ft
- Only nowcasts with 10 min update rate

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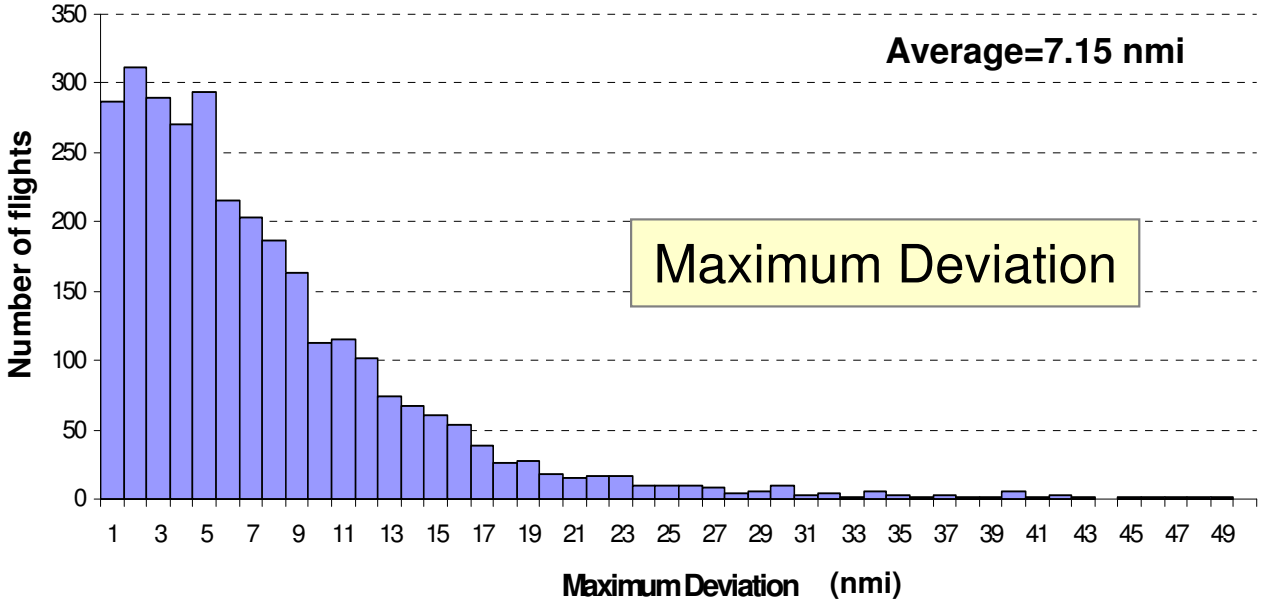
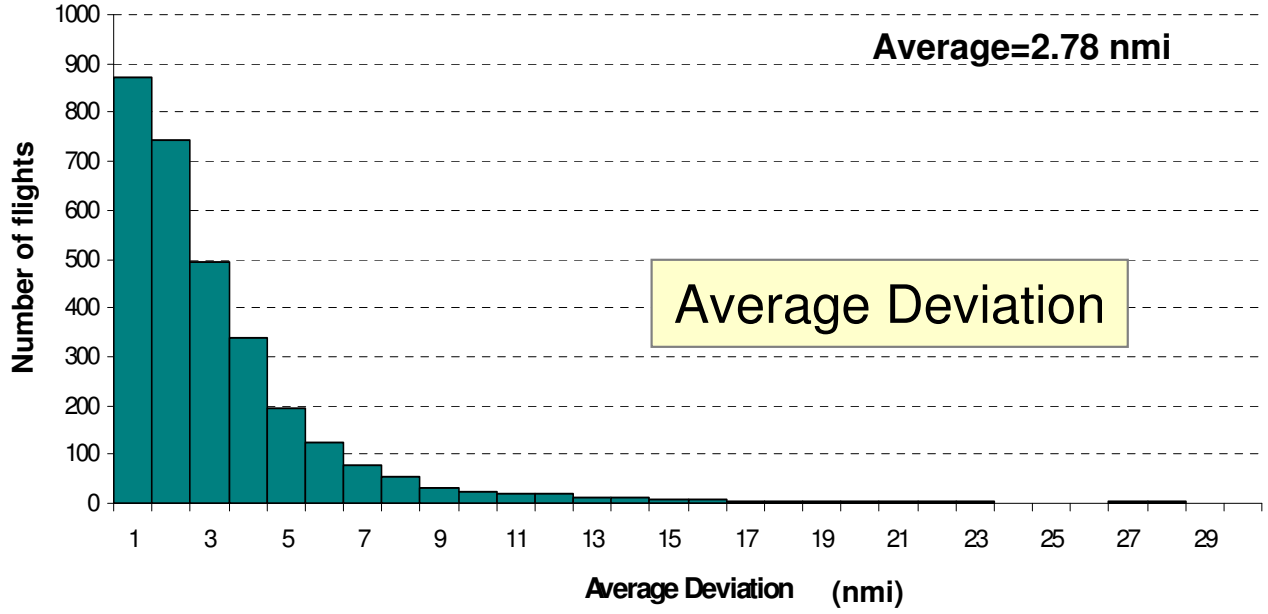
Clear Weather Baseline for Deviations





- Flights with no weather activity in their vicinity

- Up to 10 nm of actual route centerline and up to 10 nm of filed route centerline

- Includes direct to routing, path stretching, conflict avoidance, and other causes

Number of flights=3060

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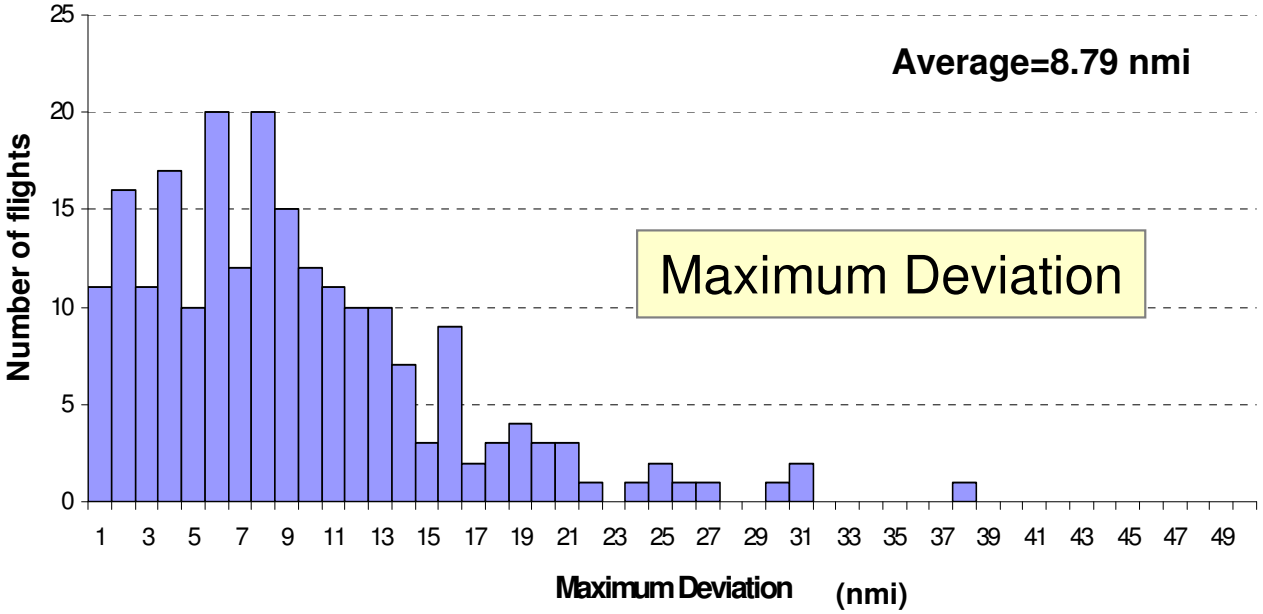
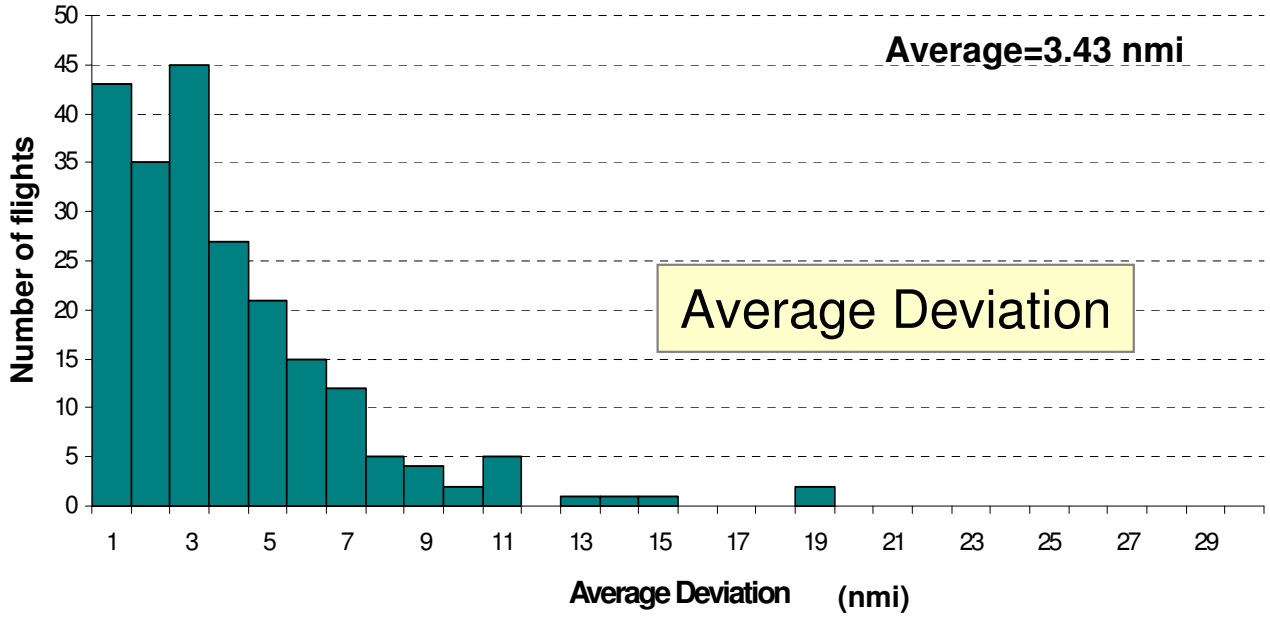
Penetrations



- Flight penetrating the weather with complete route blockage

- Blockage up to 10 nmi of actual route centerline and 10 nmi of filed route centerline



Number of flights=219

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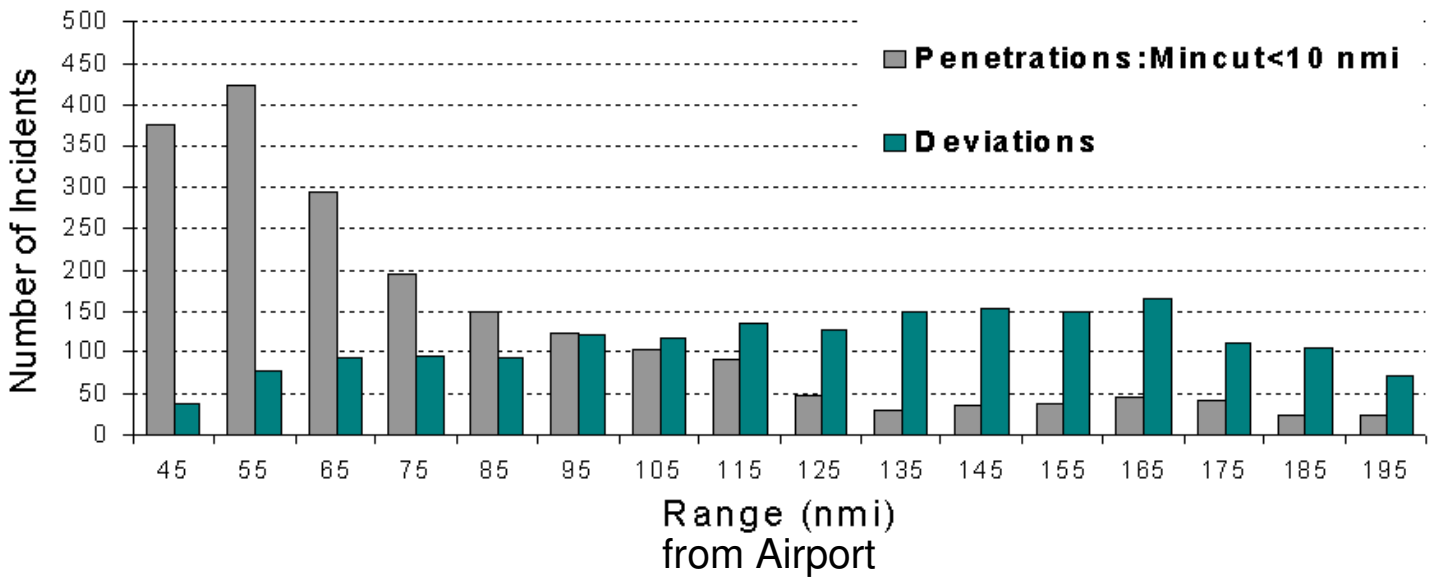
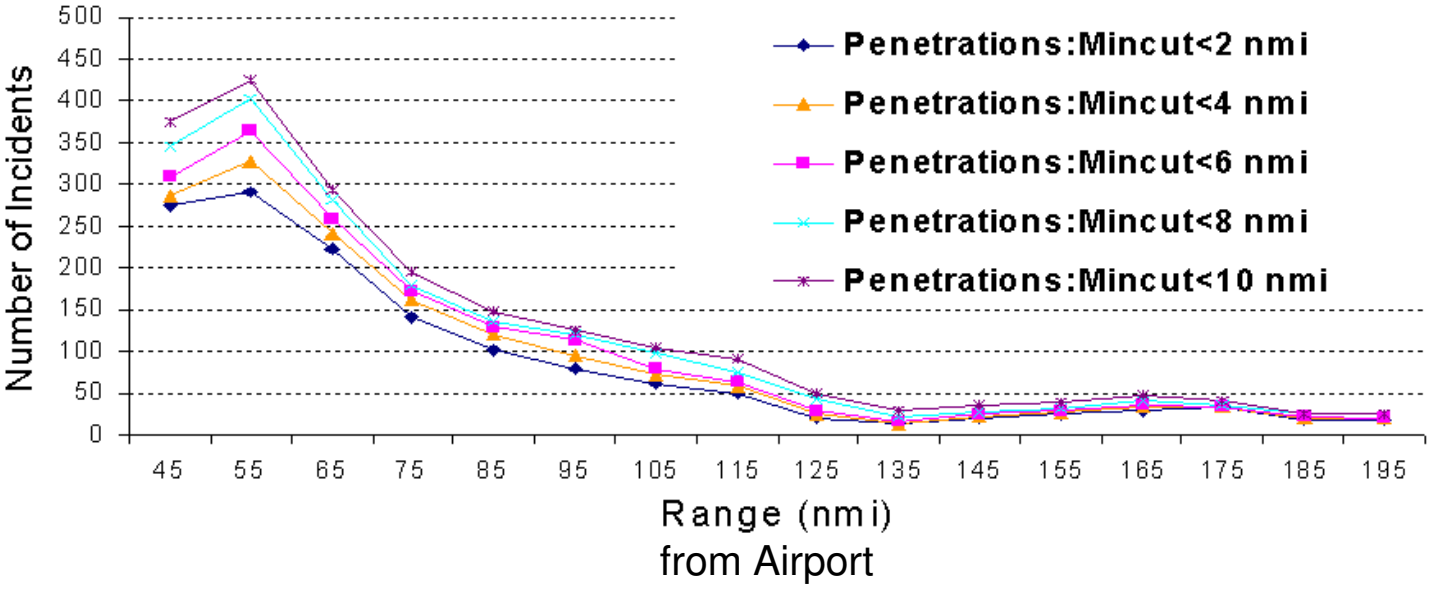
Relationship between Actual Route Permeability and Range





One **Penetration** incident if at any given point of flight data:

1-Deviation < 4 nmi and

2-Mincut value within 10 nmi of the flight actual route centerline is less than 10 nmi (or 8,6,4,2 nmi)

One **Deviation** incident if at any given point of flight track data:

1-Deviation > 4 nmi and

2-Mincut value within 10 nmi of the flight actual route is more than 10 nmi and

3-Minimum Mincut value within 10 nmi of the flight filed route centerline from that point to arrival fix is less than 10 nmi

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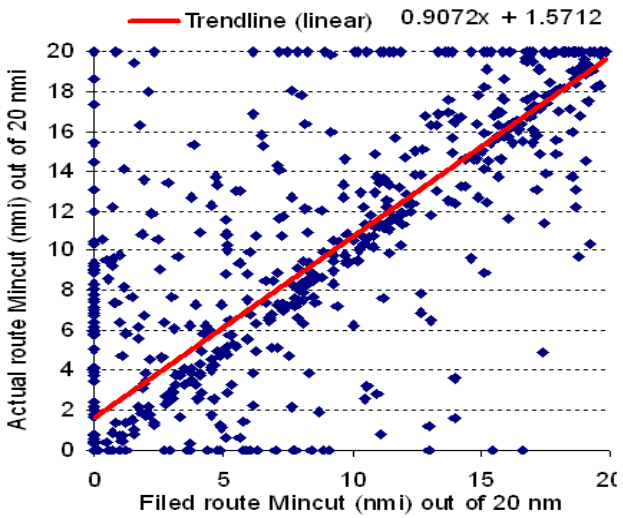
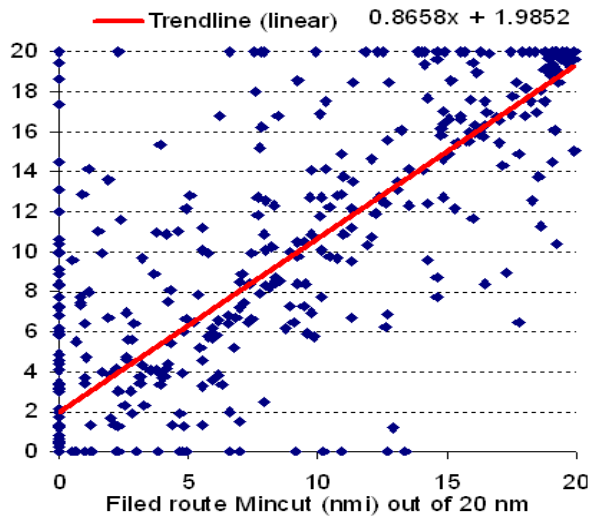
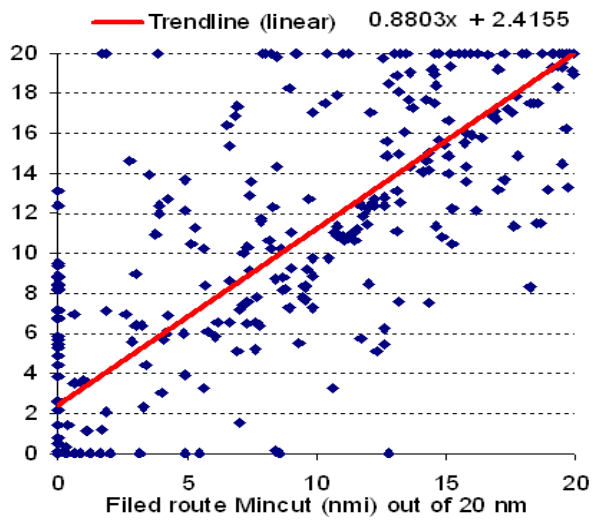
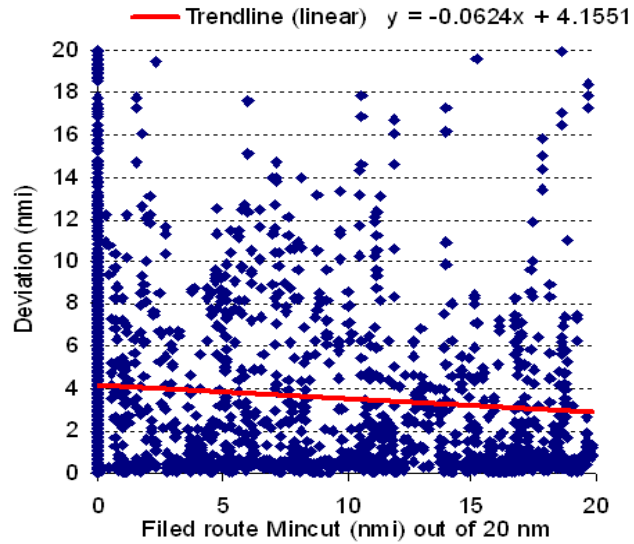
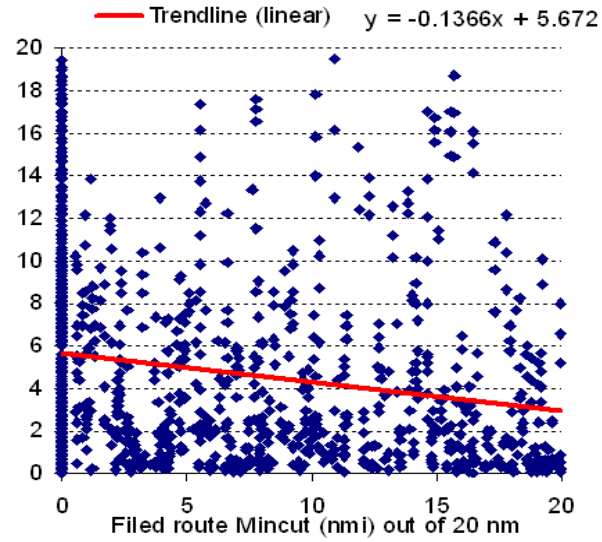
Mincut Permeability: Filed Route vs Flown Trajectory

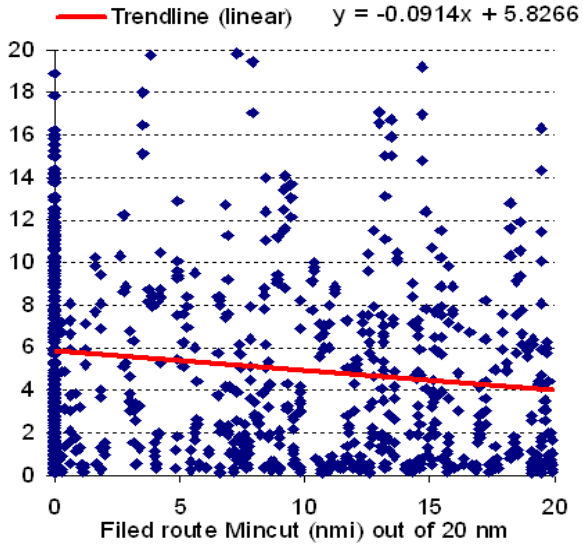












40 < Range < 80 nmi **80 < Range < 120 nmi** **120 < Range < 200 nmi**

Range from Destination Airport

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Conclusions

- Studied the permeability of the airspace on the filed route versus the trajectory flown around weather constraints for transition airspace arrival traffic into major airports
- Four metrics were defined; one (a mincut permeability metric) was used to analyze pilot weather avoidance decision making
- Pilots are more likely to penetrate weather or penetrate through smaller gap sizes between weather cells closer to the metering fixes than further away
- Deviations away from the filed route are larger the further the aircraft is from the metering fix
- Future work - explore alternative metrics, determine the metric size triggering “route blockage,” and if a local adjustment of the route can provide acceptable permeability to pilots

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