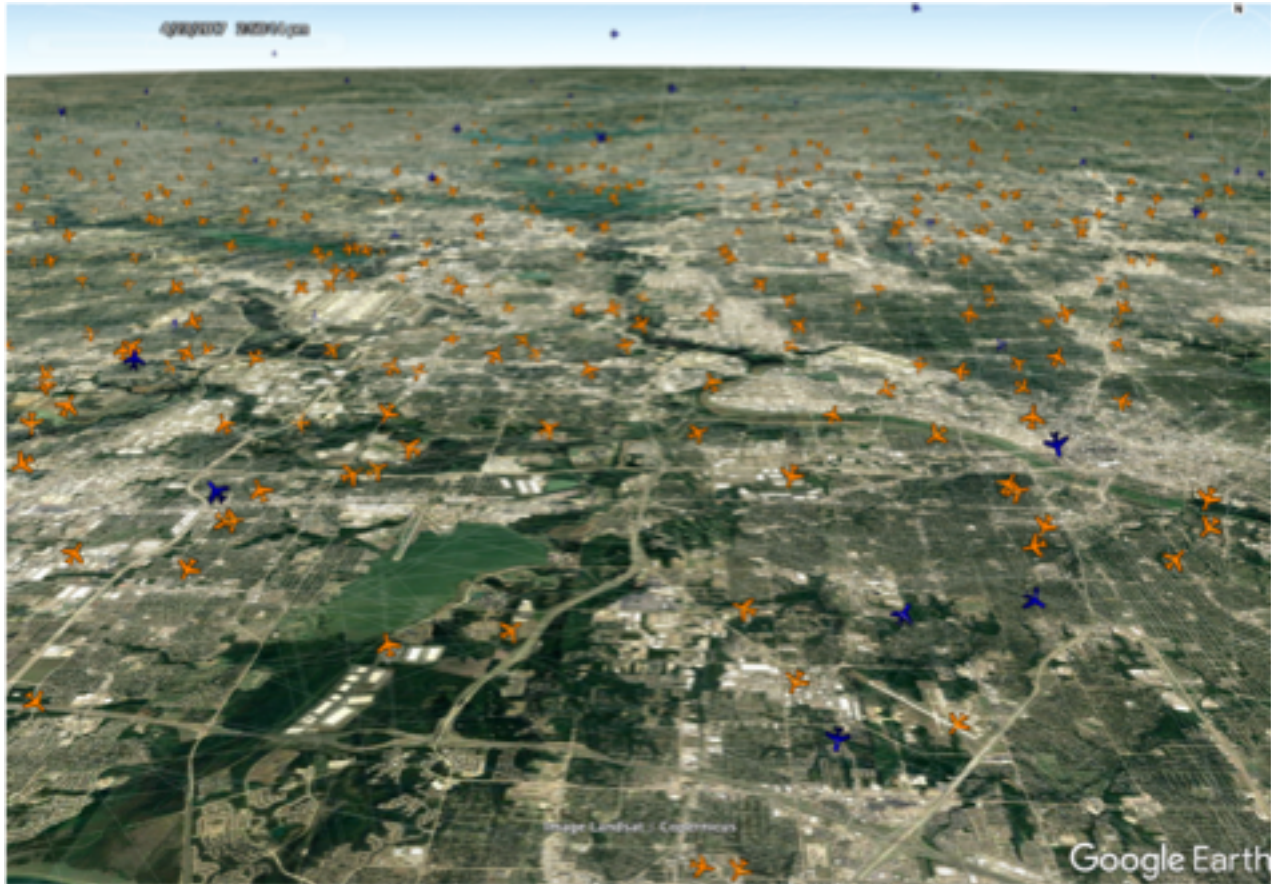


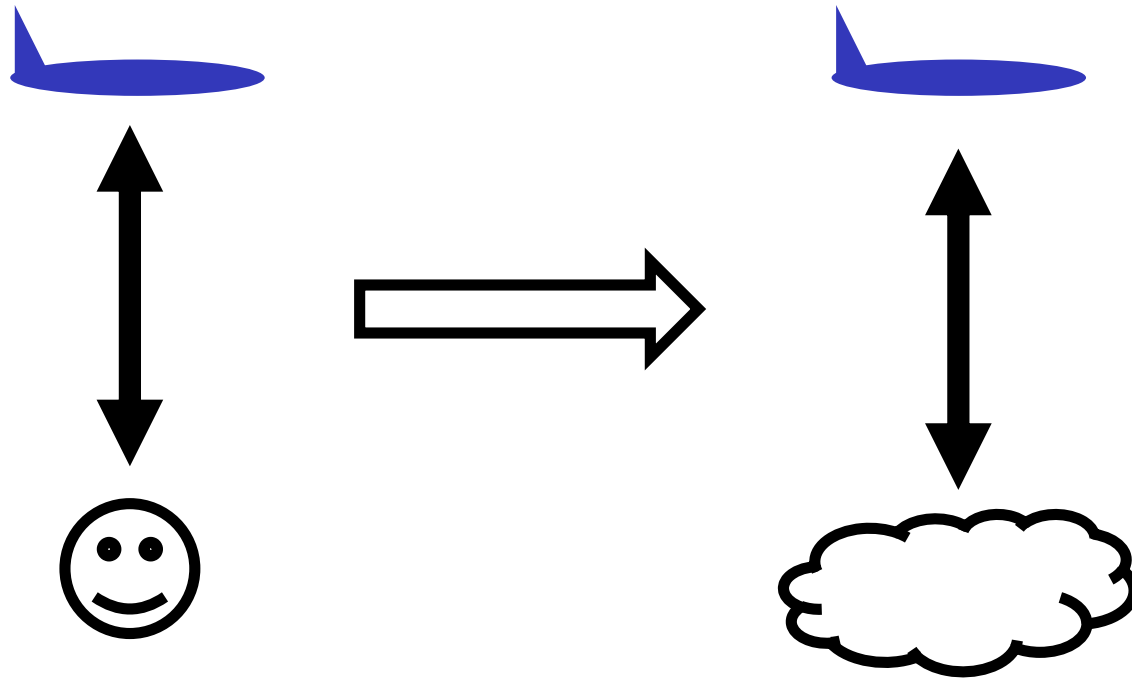
Autonomous Coordinated Airspace Services for Terminal and Enroute Operations with Wind Errors

Todd Lauderdale, Christabelle Bosson,
Yung-Cheng Chu, and Heinz Erzberger
NASA Ames Research Center

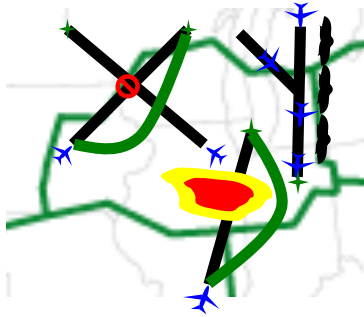
Increasingly Complex Airspace



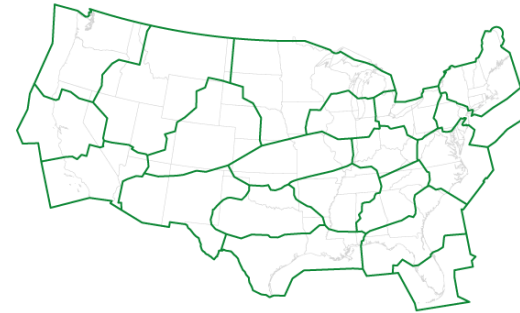
Foundational Autonomy Research



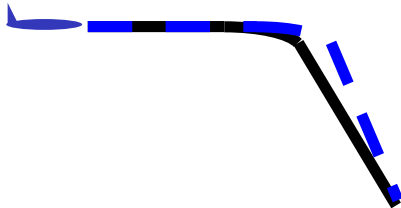
Development of an Autonomous Airspace Service



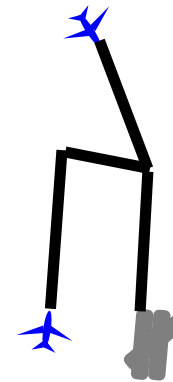
4D separation, arrival
management and
weather avoidance



Coordinated operations
across 20 enroute centers

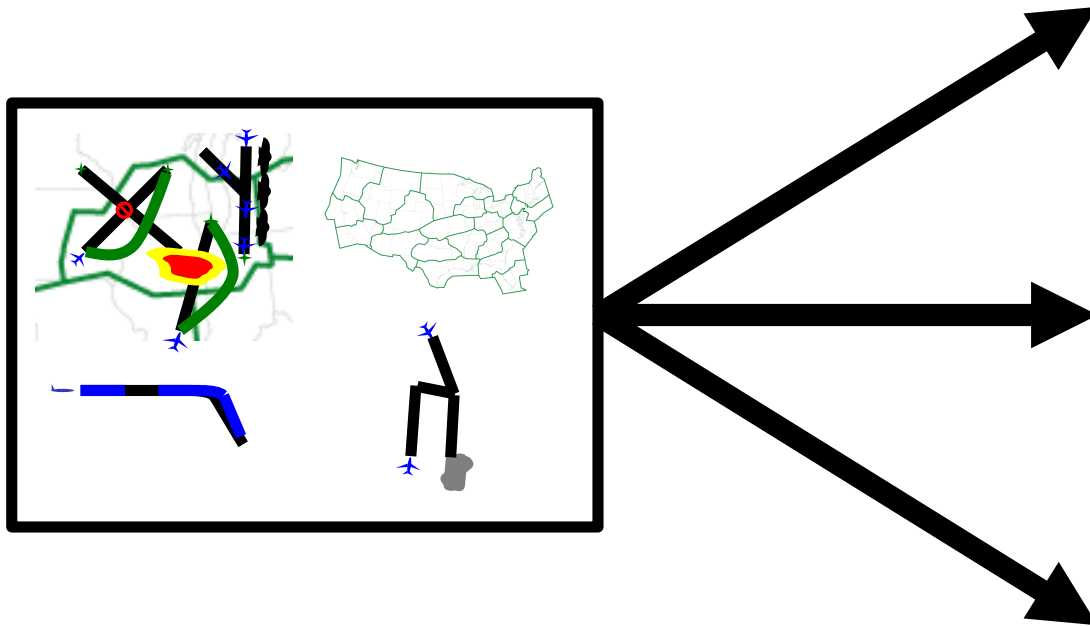


Operations in the presence
of uncertainty and errors

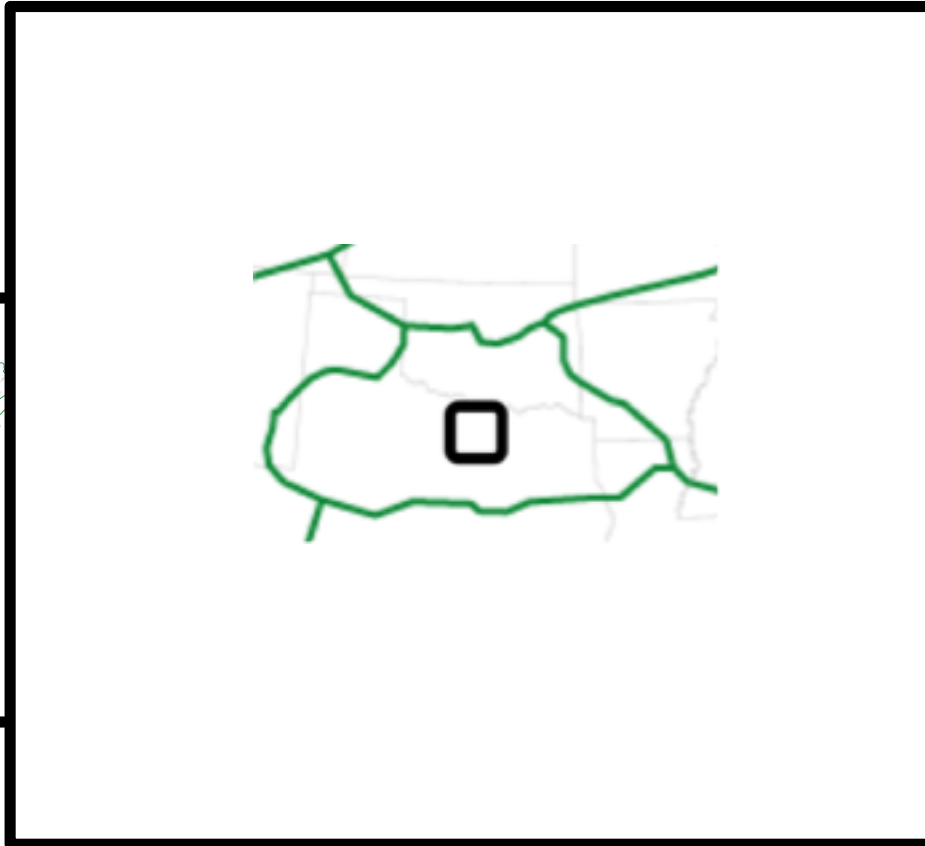
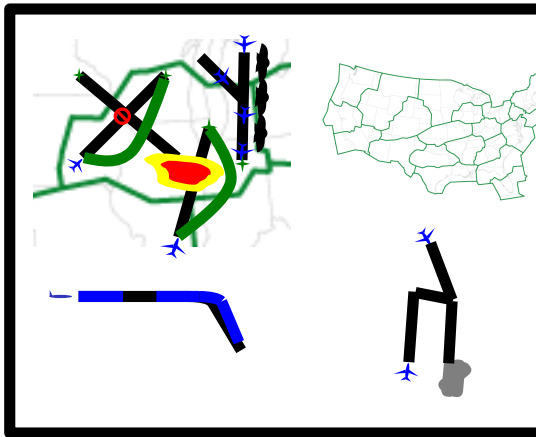


Terminal Area Operations

Current Development

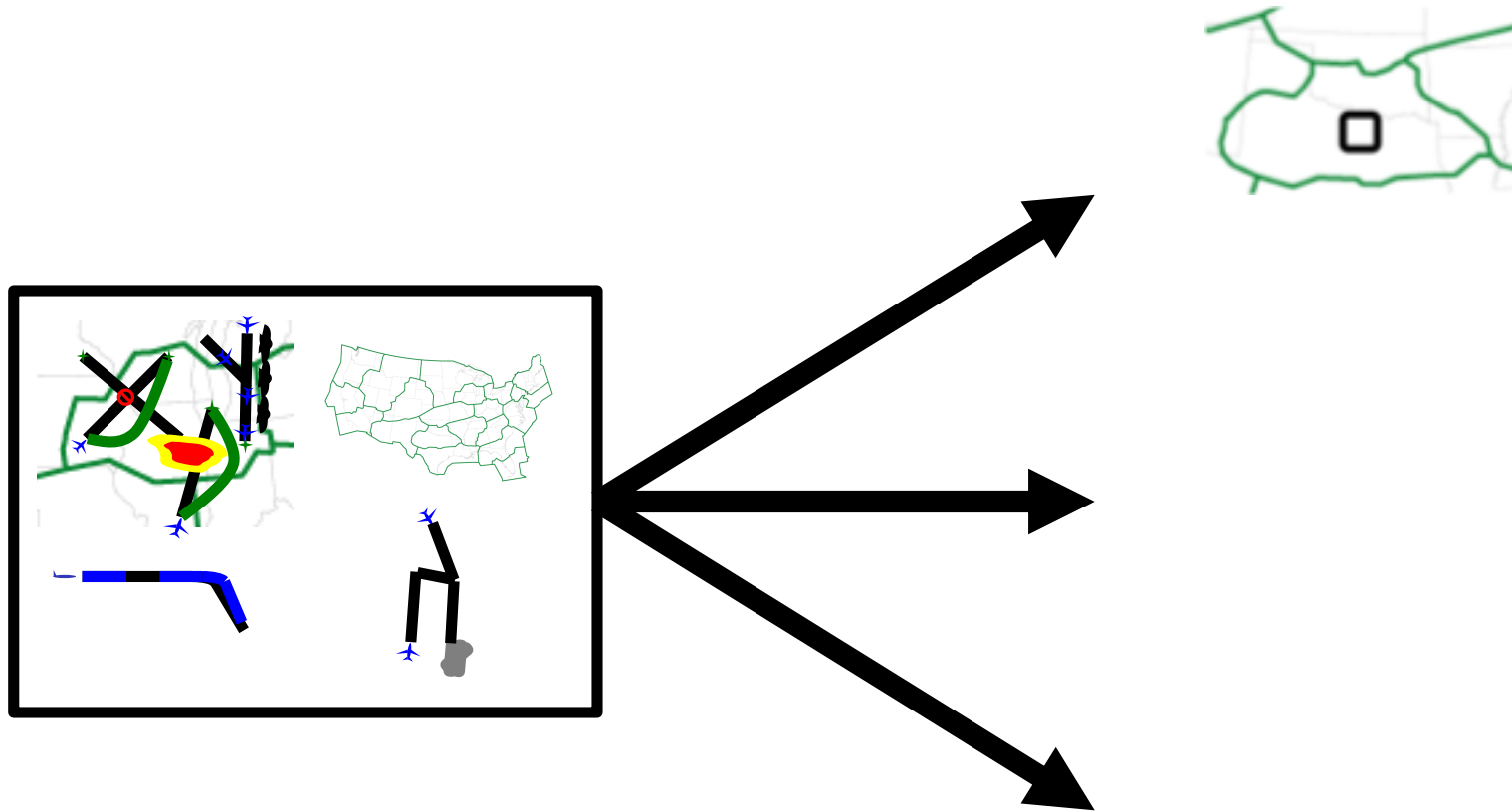


Current Development

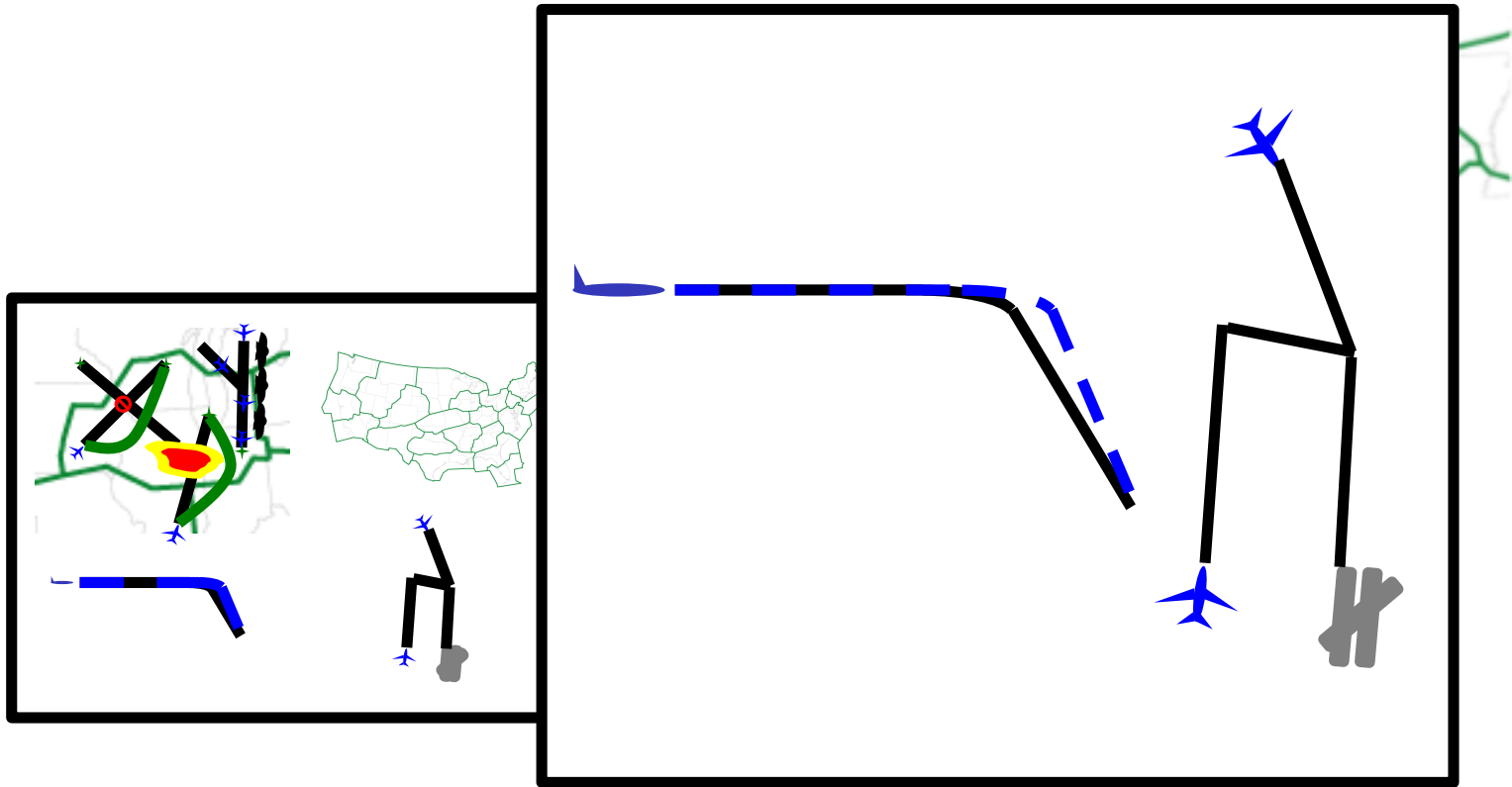


Coordinated Terminal Area and
Enroute Operations

Current Development

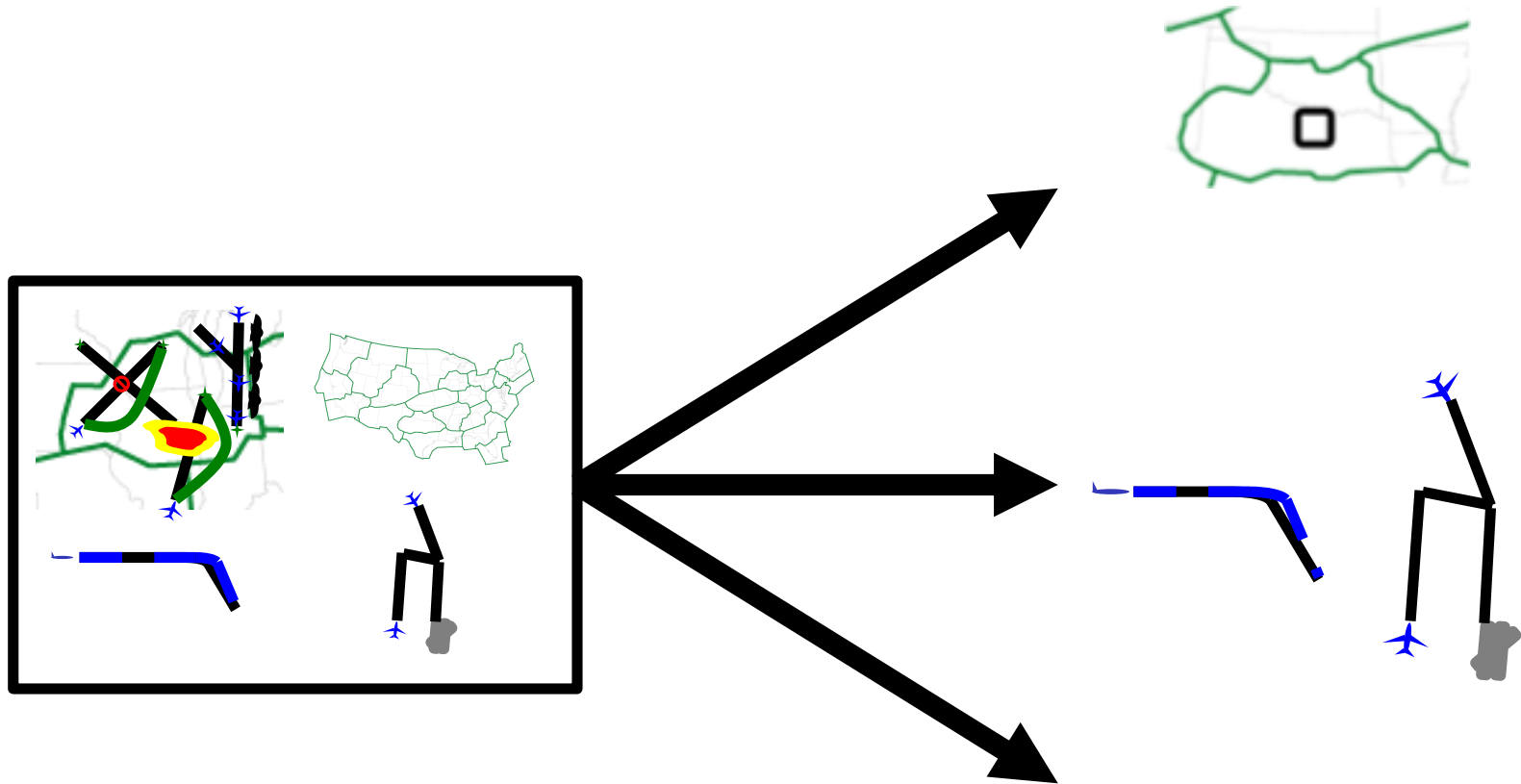


Current Development

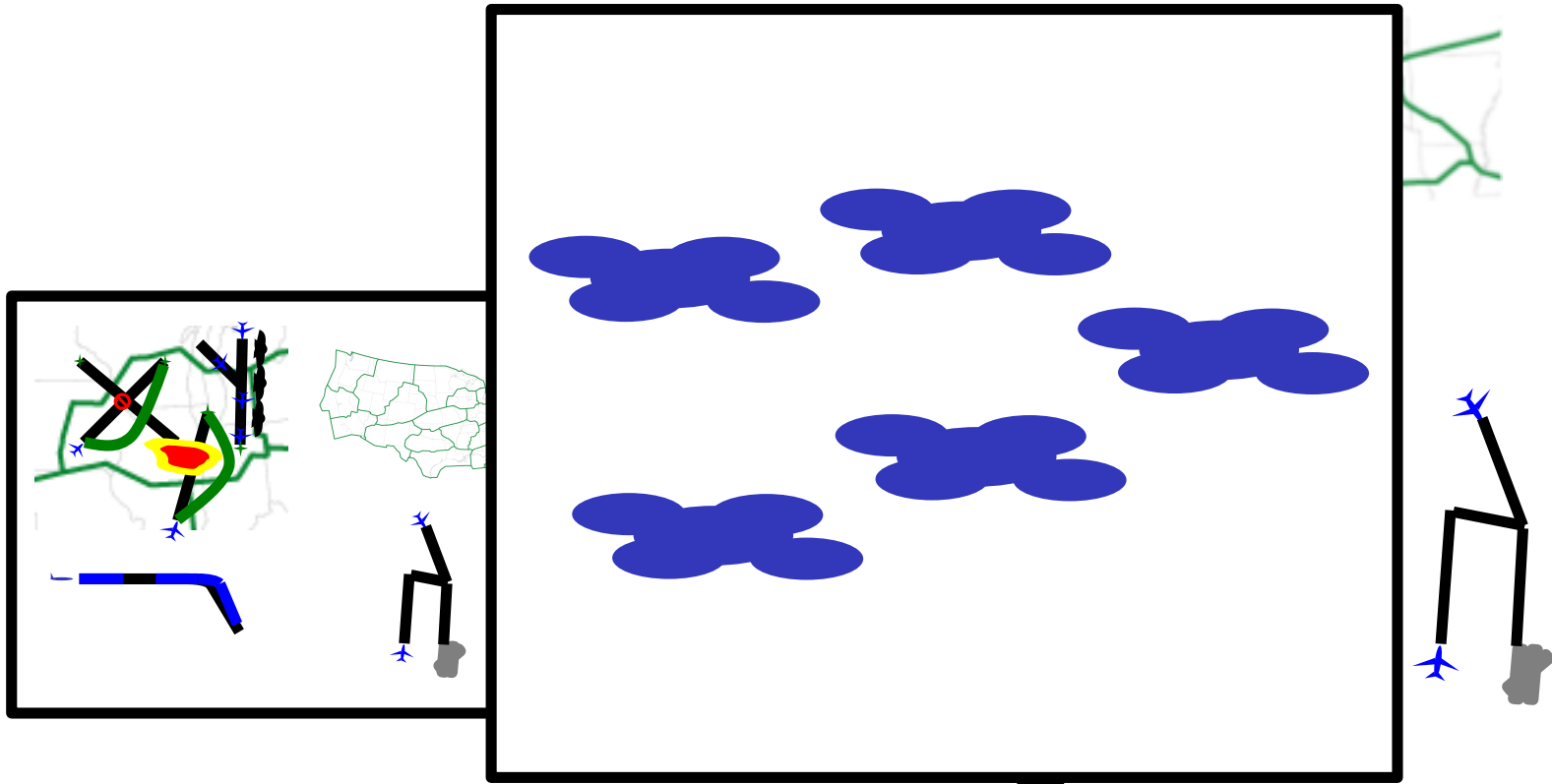


Trajectory Prediction Errors in the
Terminal Area

Current Development

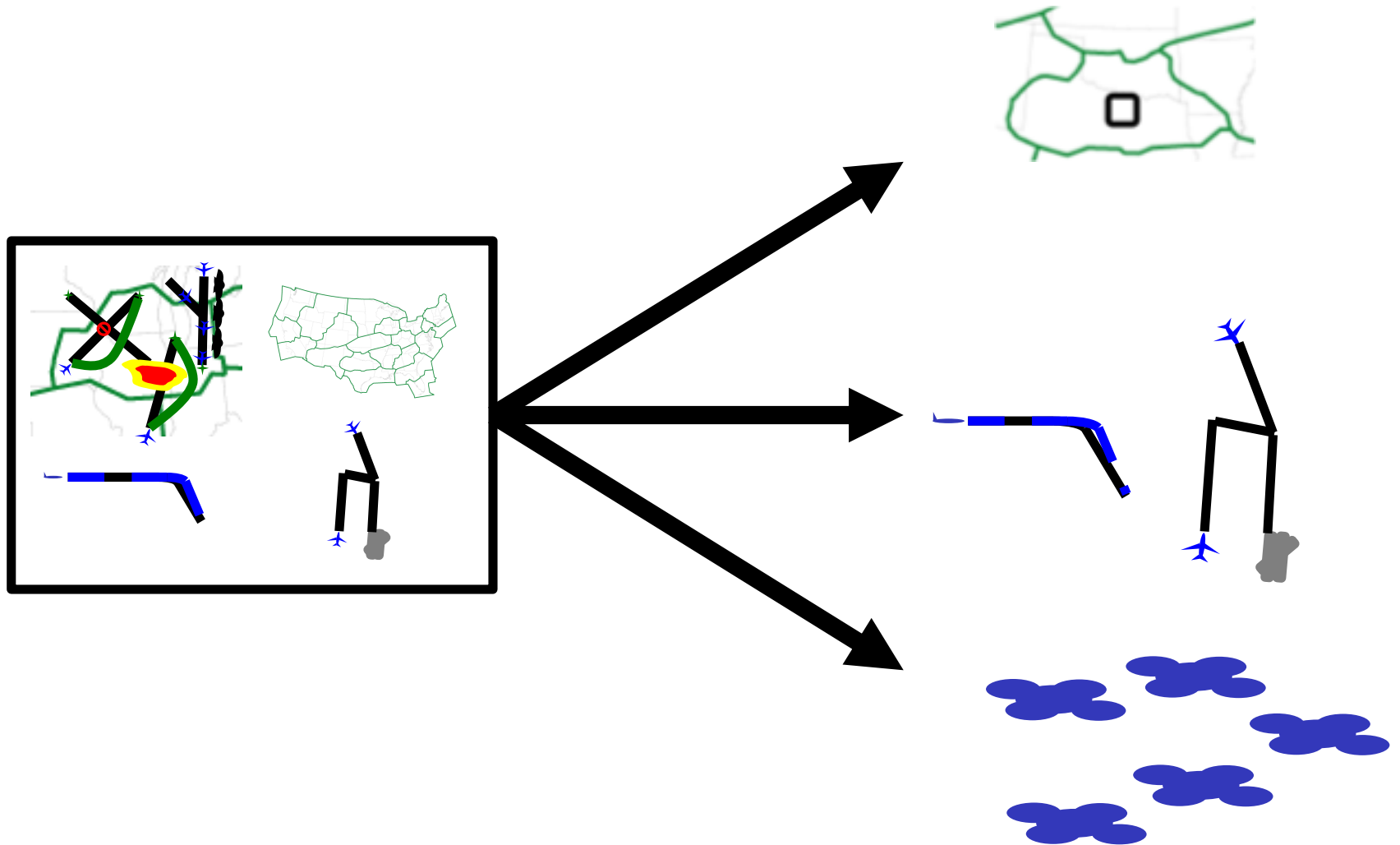


Current Development

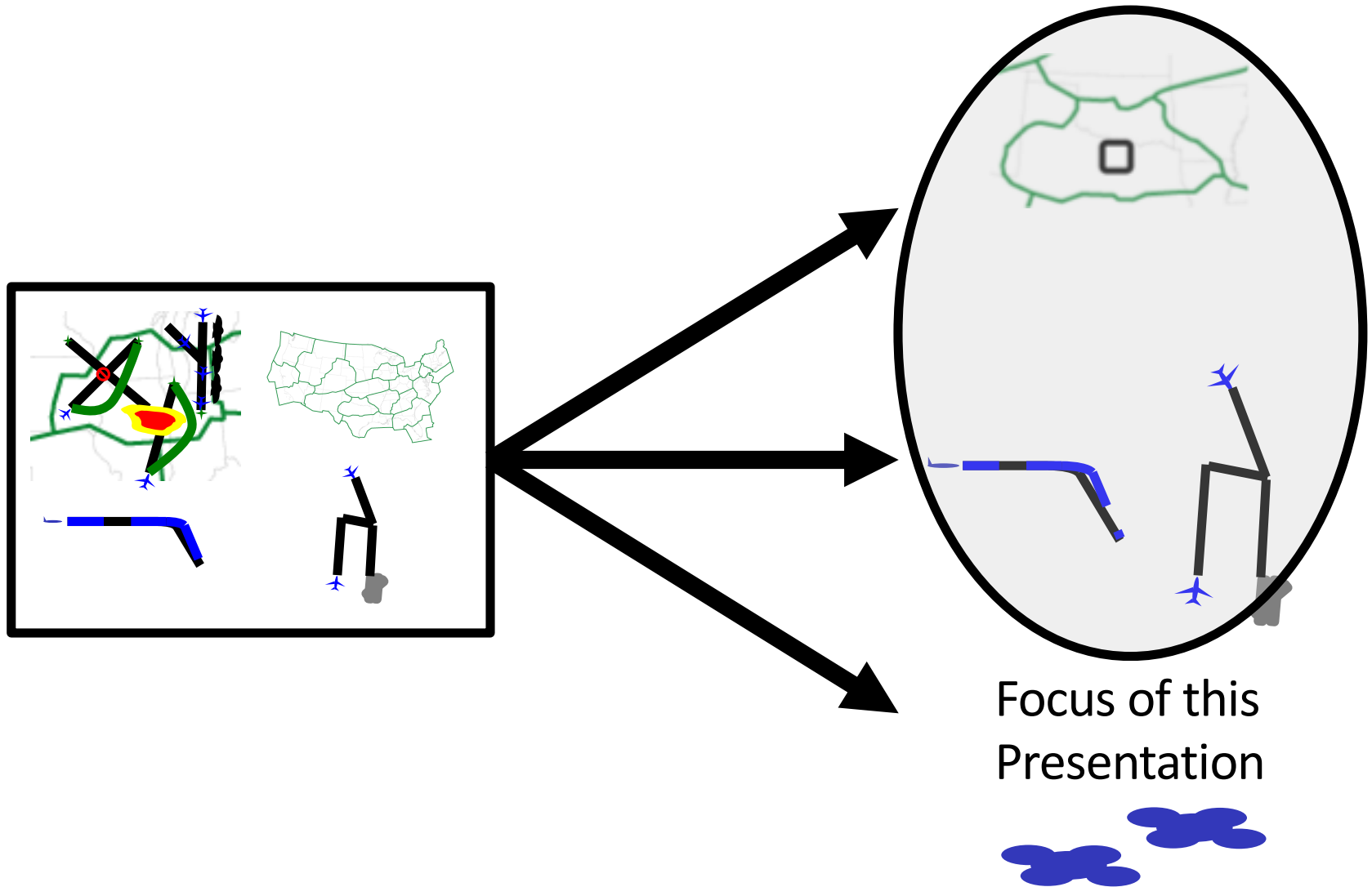


Handling Novel Operations
(Aviation 2018 Talk by Bosson)

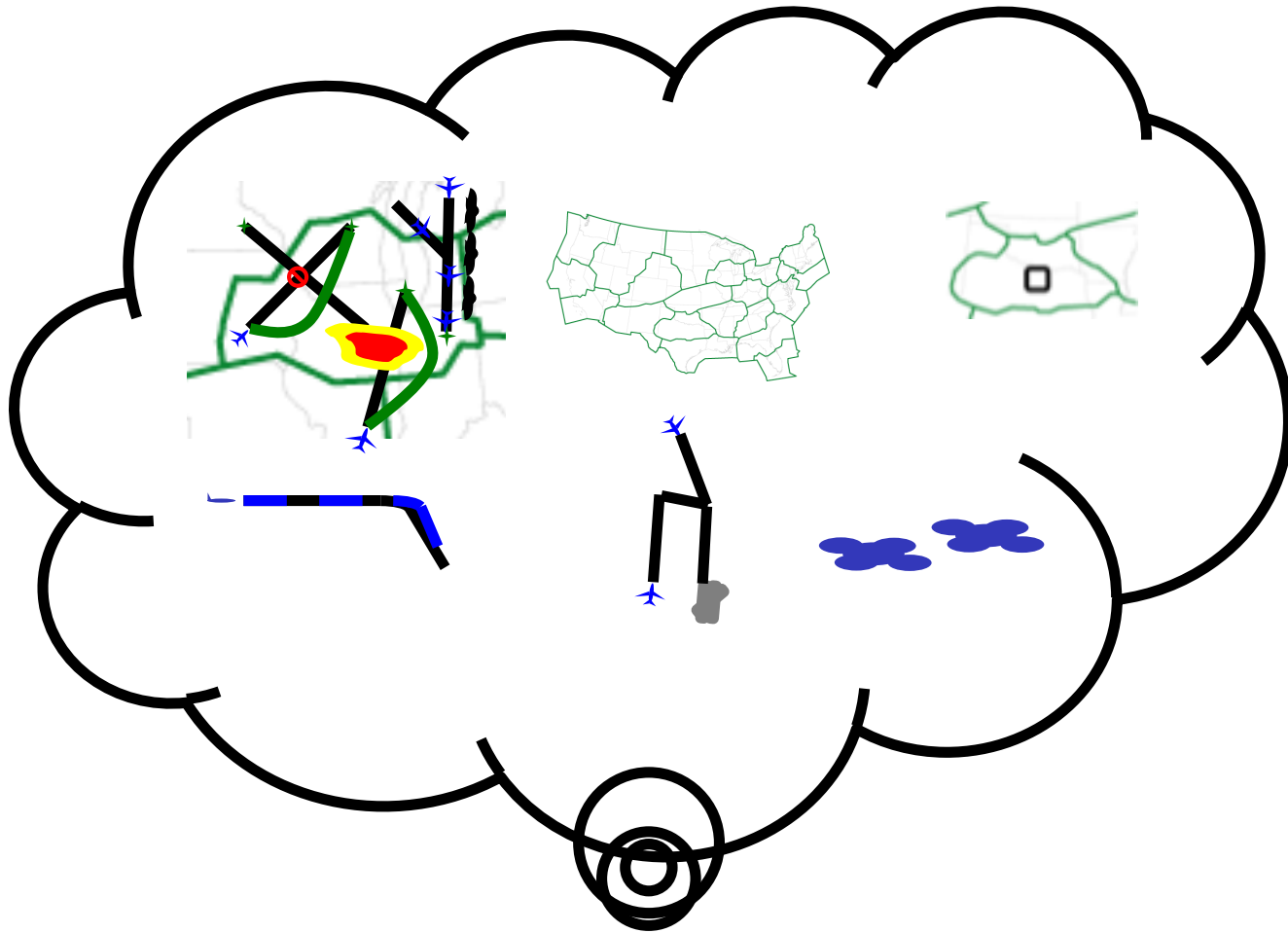
Current Development



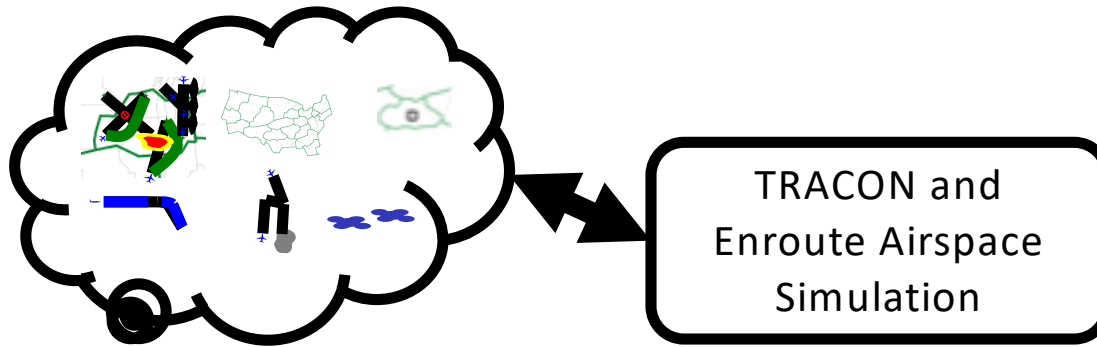
Current Development



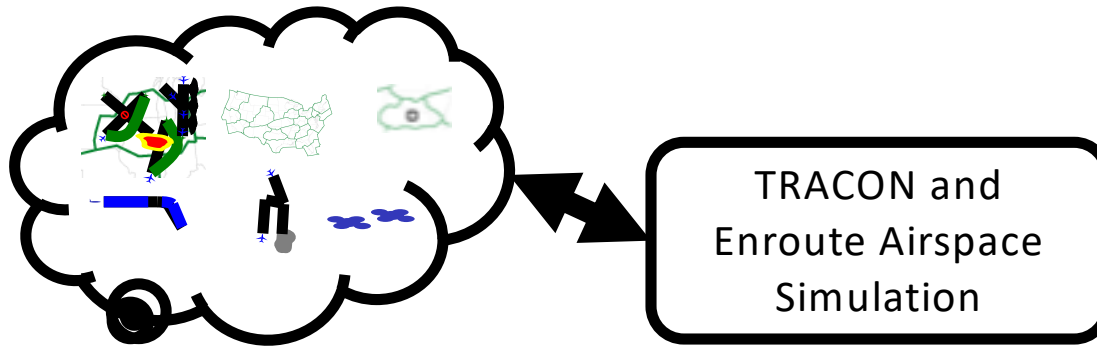
Cloud-Based Service



Exercising New Capabilities

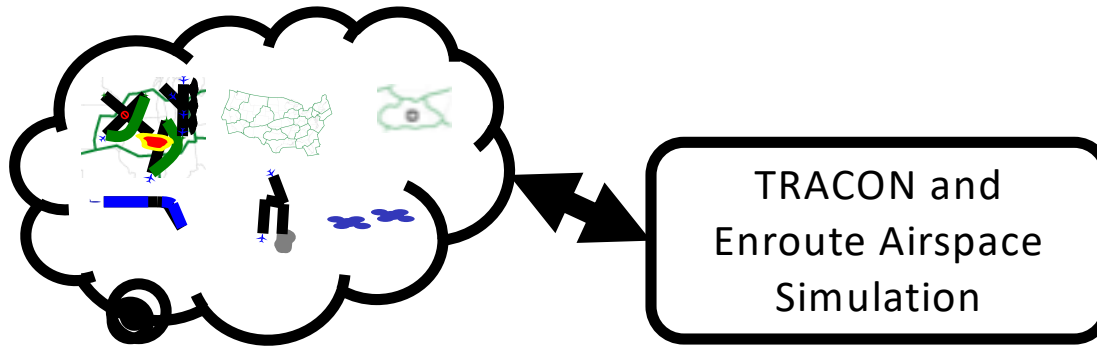


Exercising New Capabilities

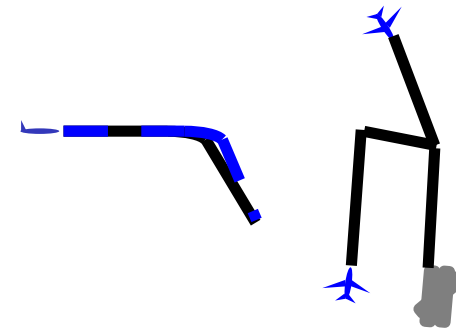


Coordination Rules

Exercising New Capabilities

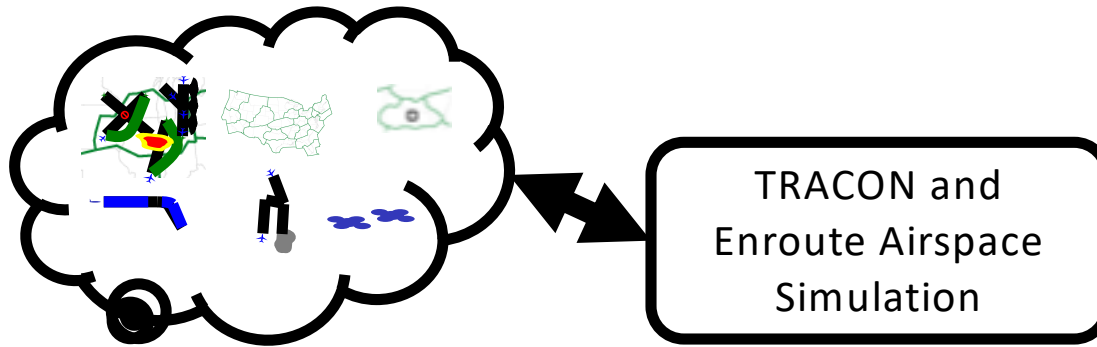


Coordination Rules

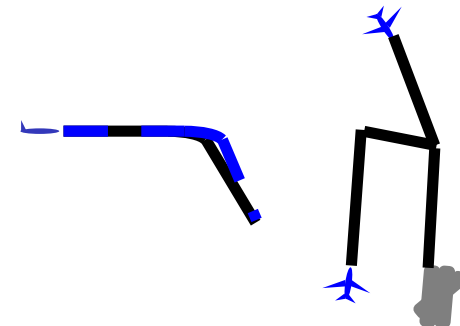


Errors in the TRACON

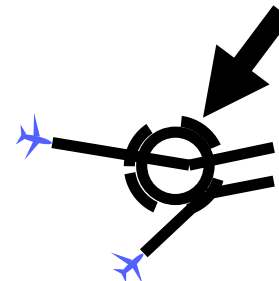
Exercising New Capabilities



Coordination Rules

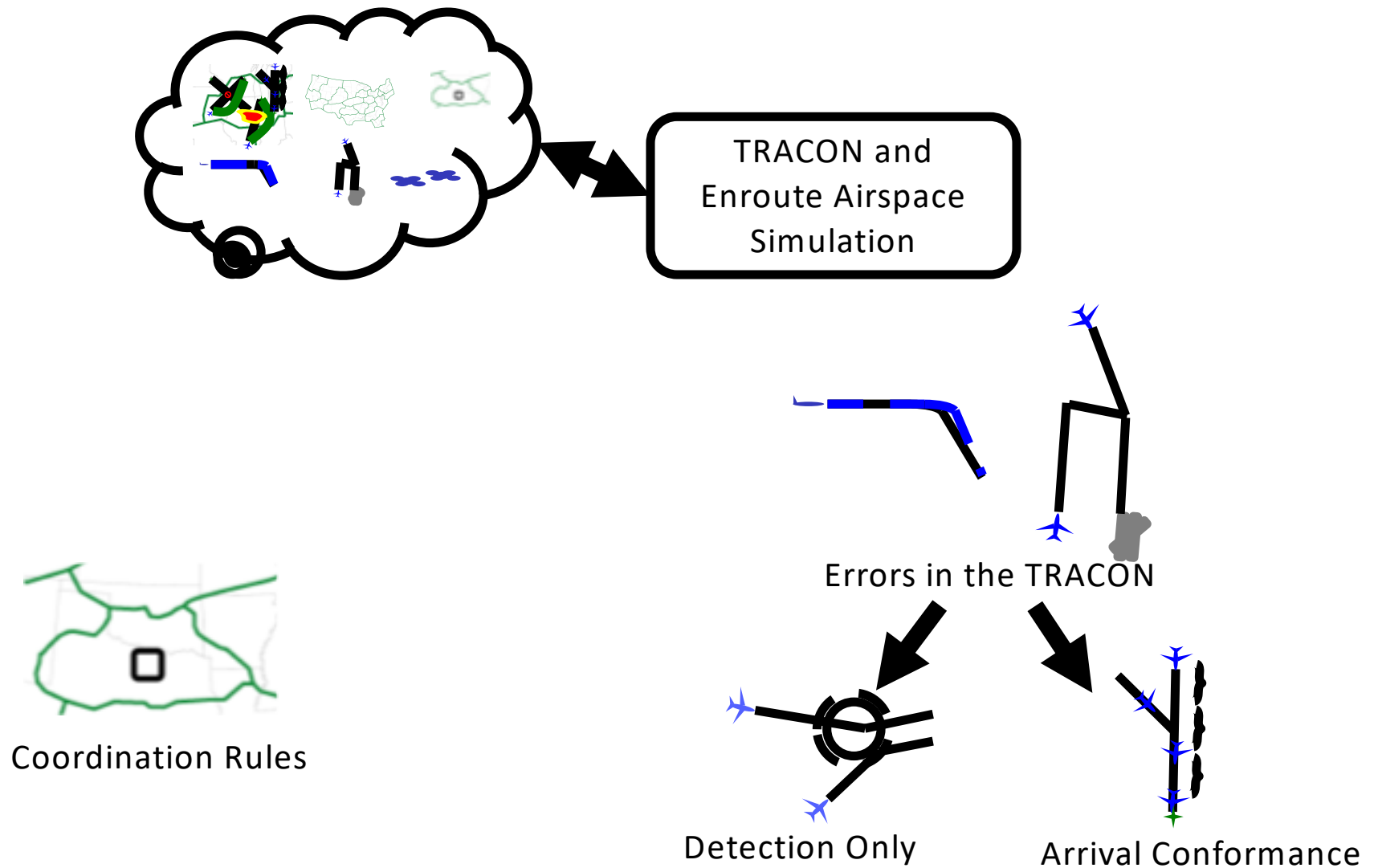


Errors in the TRACON

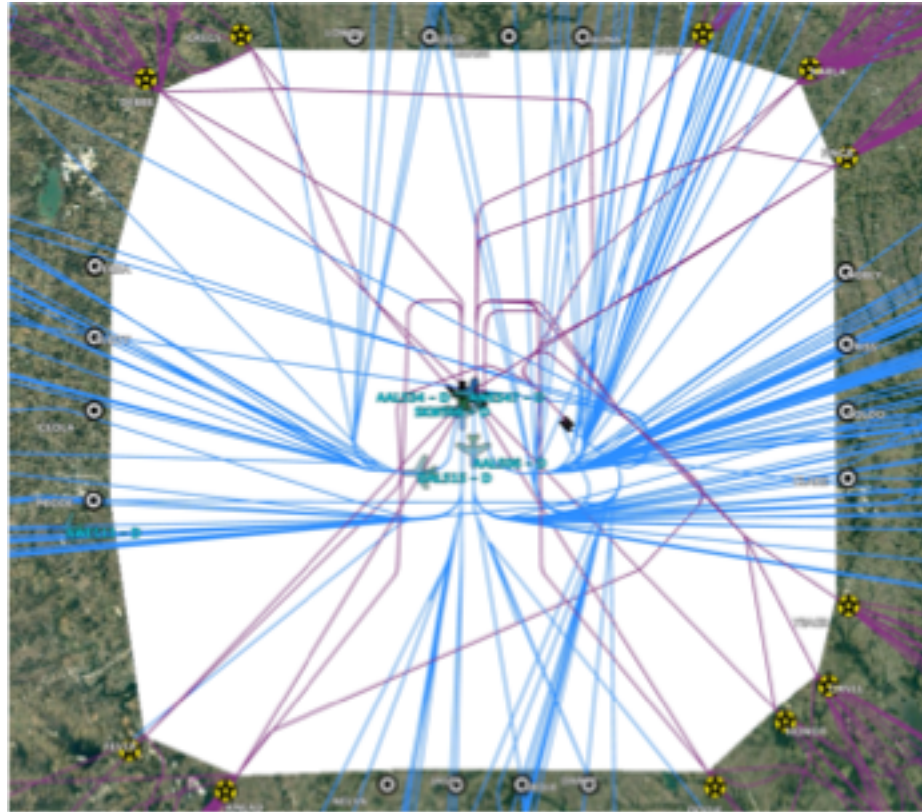


Detection Only

Exercising New Capabilities

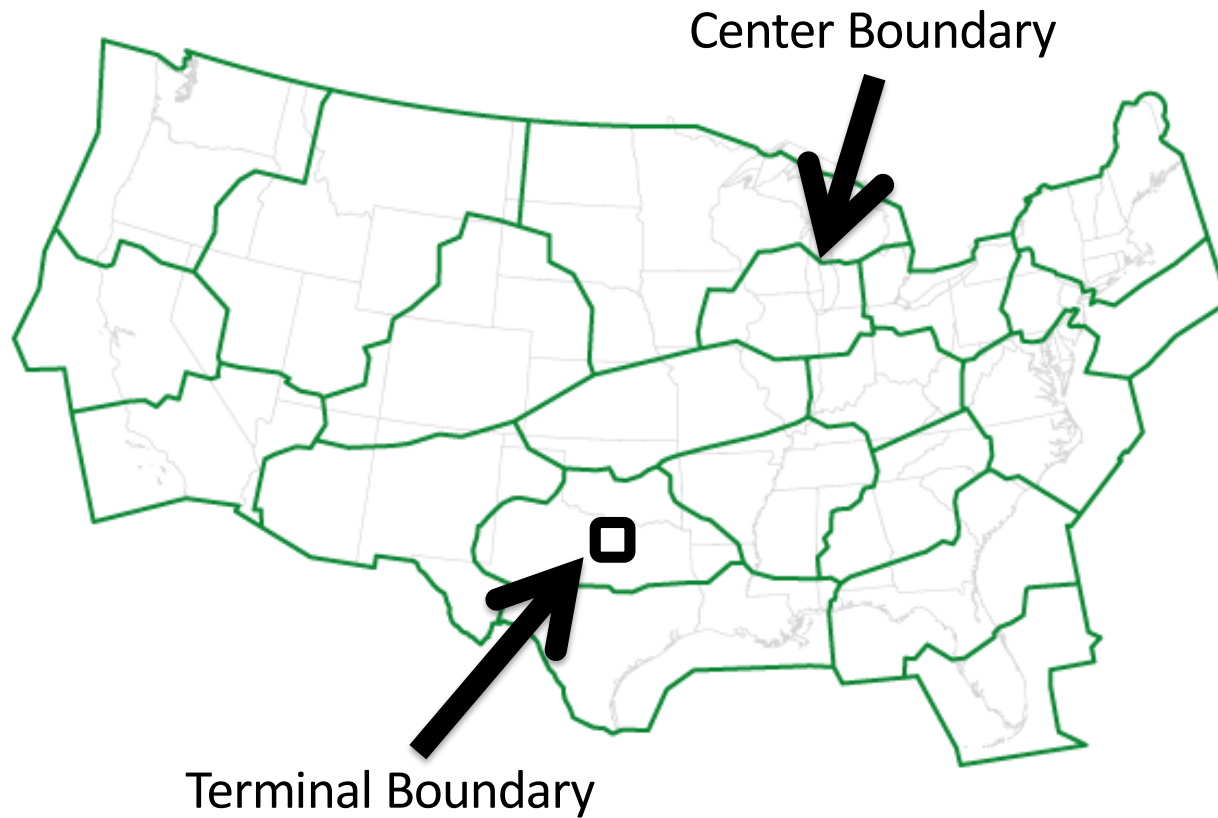


Dallas (D10) TRACON

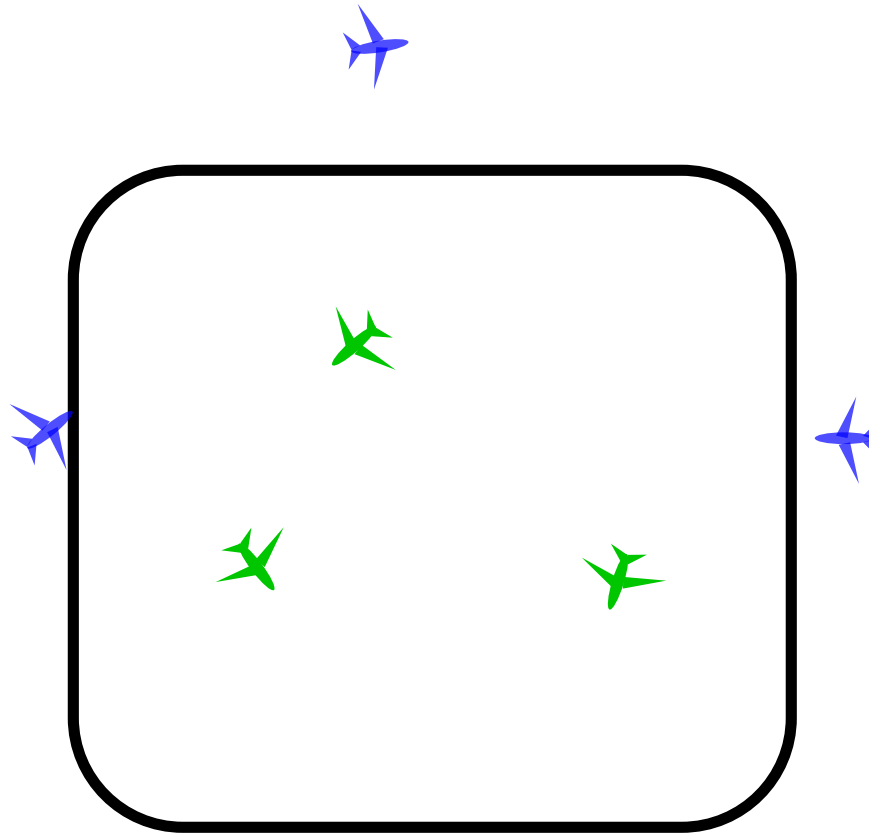


Simulated Traffic in D10;
350 Flights at Present Day
Demand Levels

Coordinated Enroute and Terminal Operations

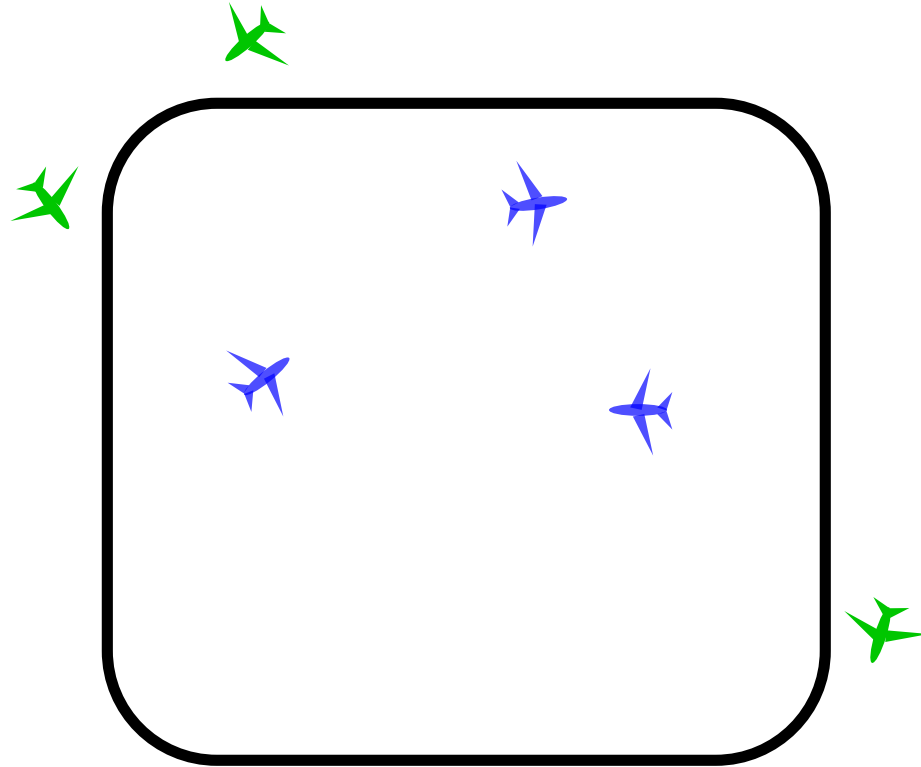


TRACON Visibility and Control



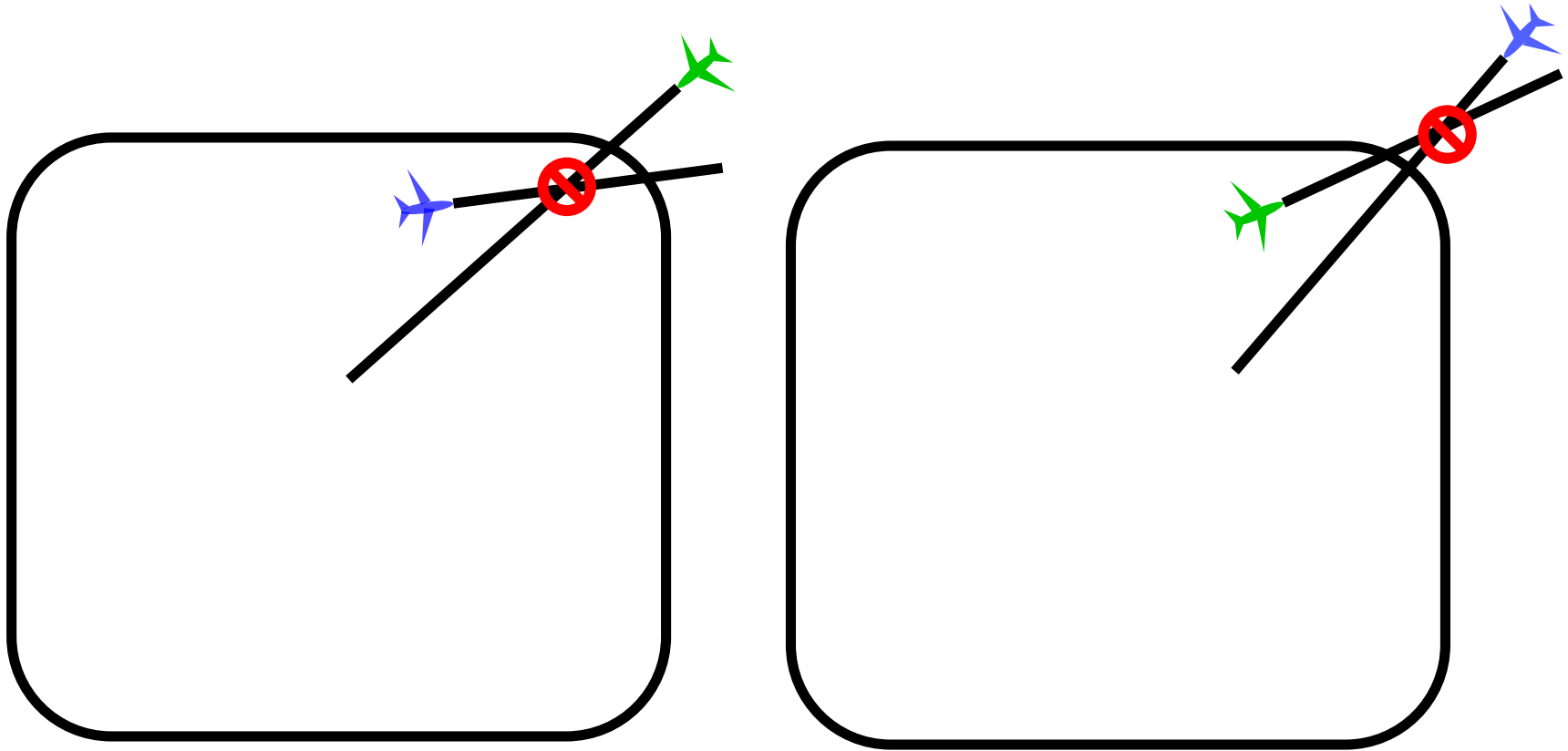
Green = Controlled
Blue = Visible

Enroute Visibility and Control

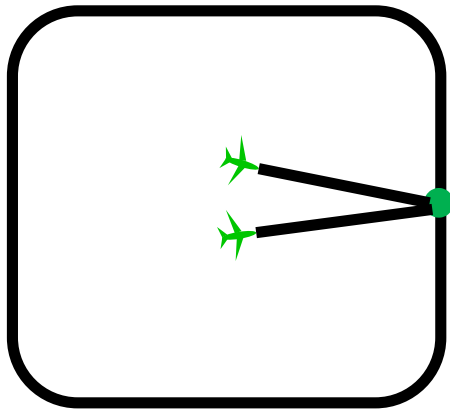


Green = Controlled
Blue = Visible

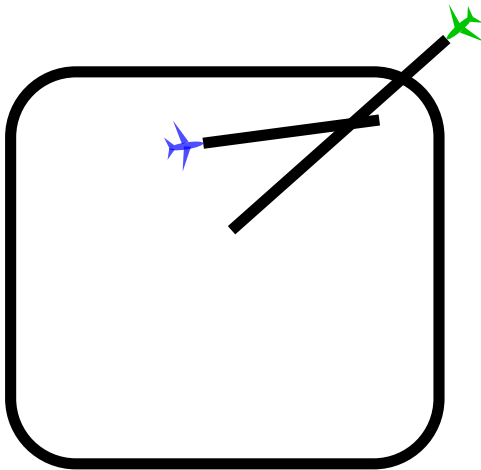
Losses of Separation Near Boundaries



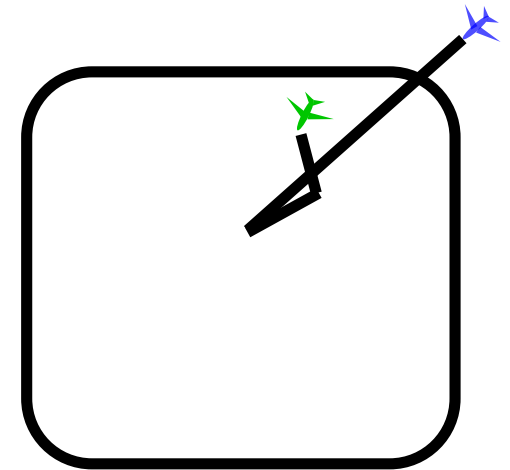
Coordination Rules



Use Enroute
Separation

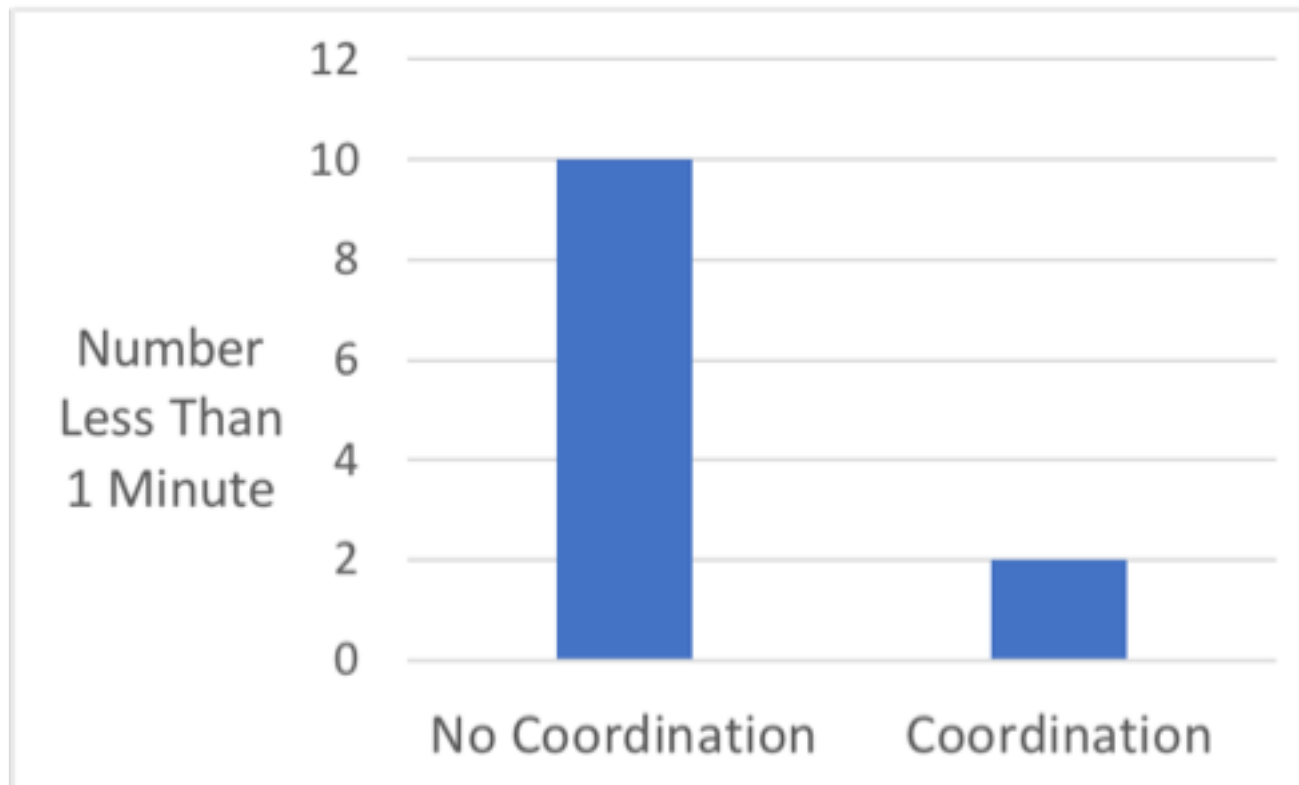


Enroute Ensure
Conflict Free
Across Boundary

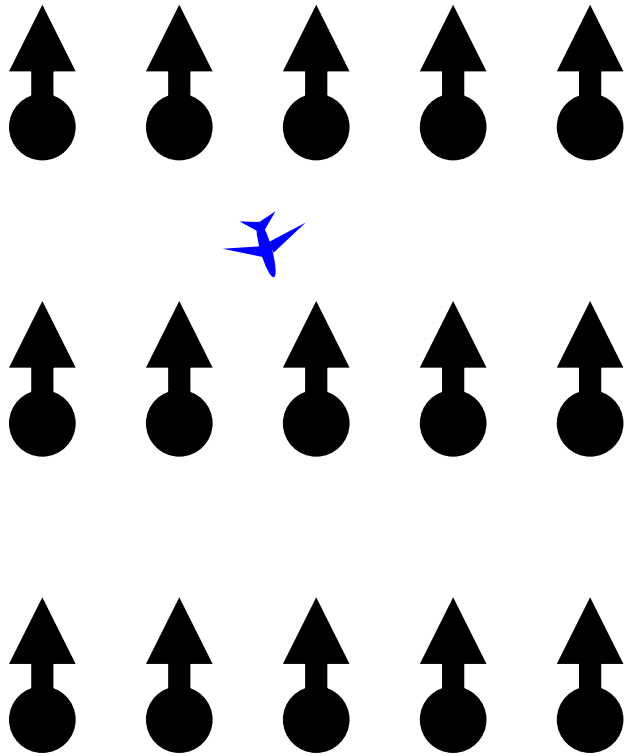


Terminal Assumes
“Frozen” Enroute
Trajectories

Conflicts Detected with Less than 1 Minute to Loss of Separation

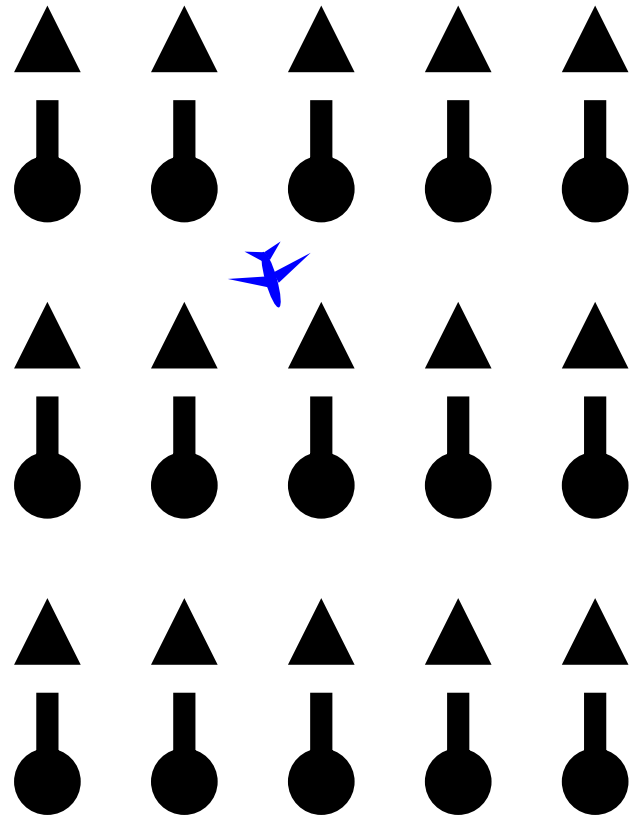


Wind Field Errors



Actual Winds

(Constant 25 knots from the South)

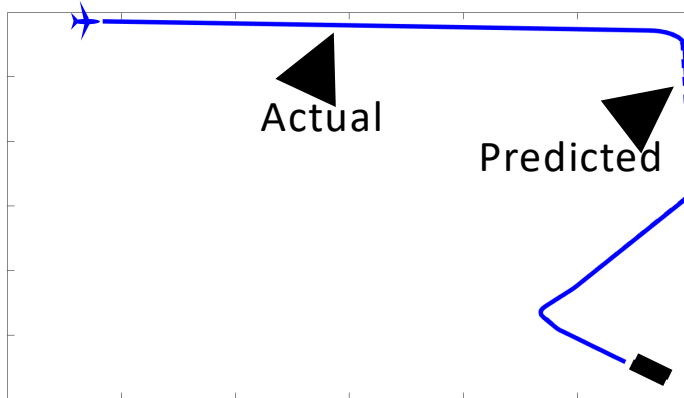


Predicted Winds

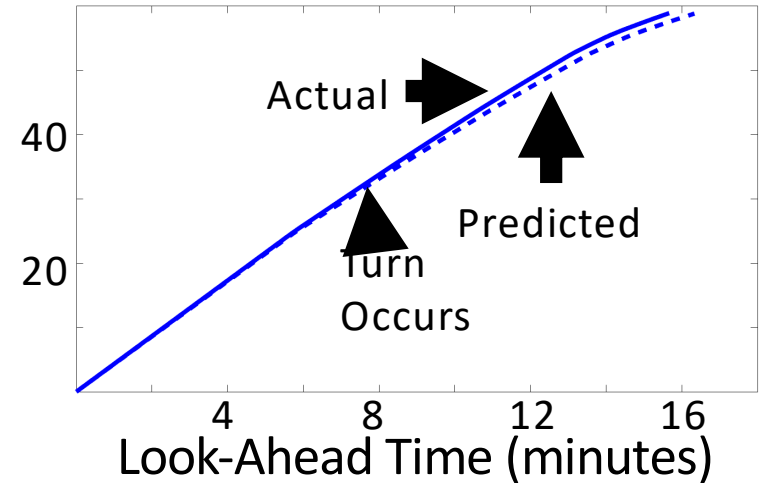
(150% Actual Magnitude)

Example Trajectories

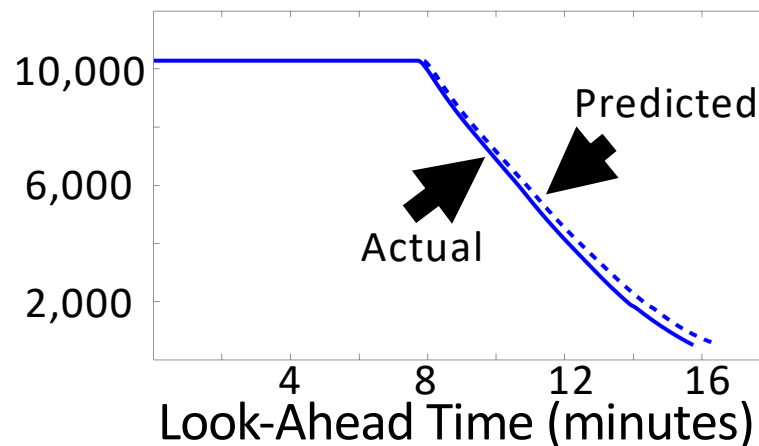
Latitude v. Longitude



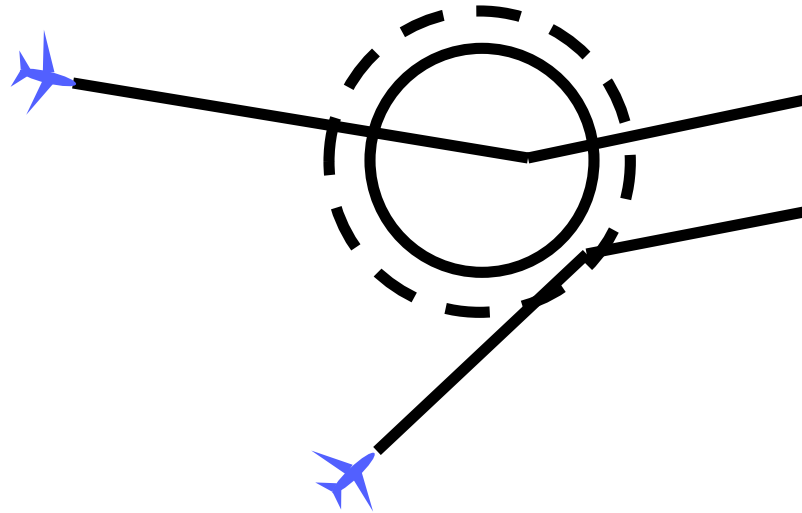
Along-Track Distance (nmi)



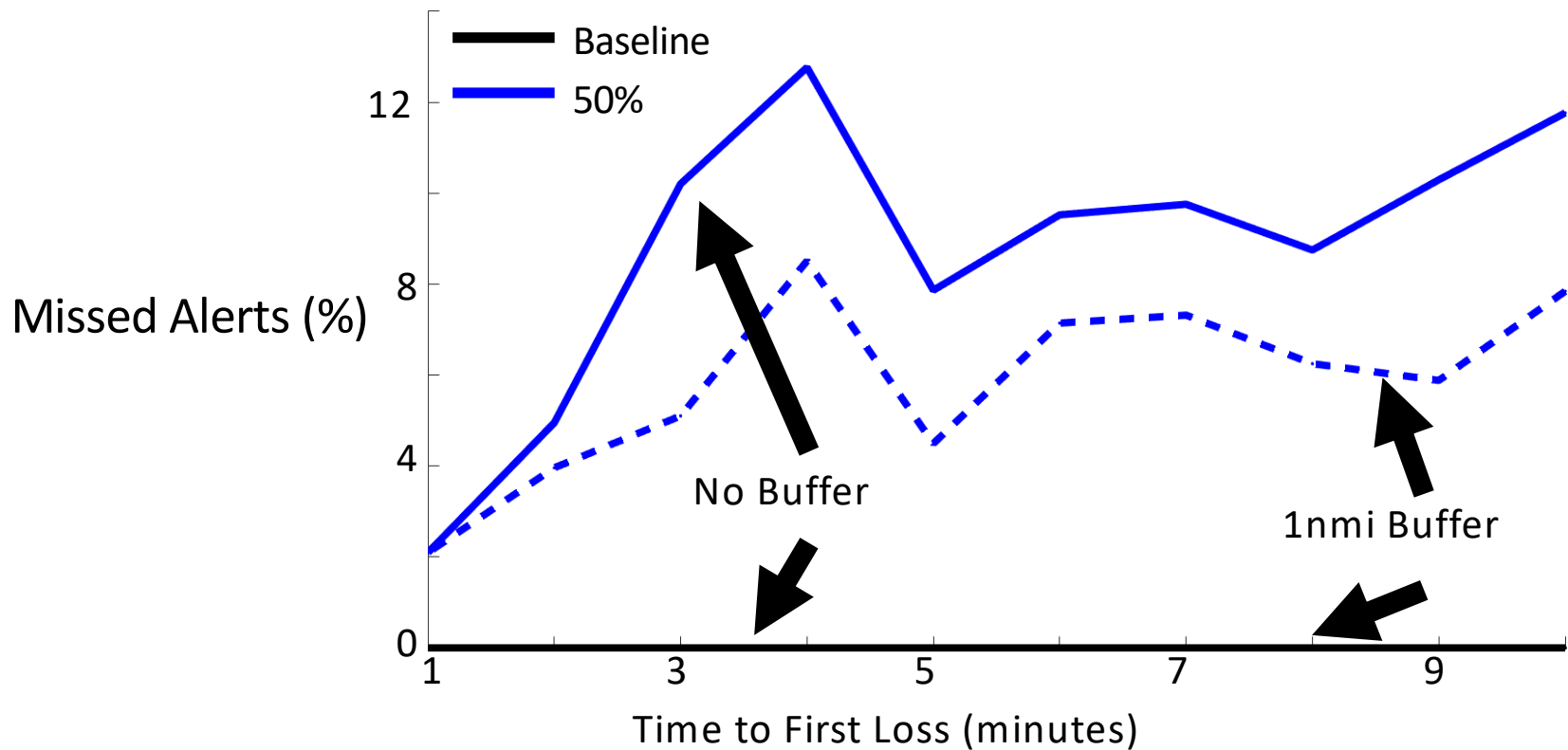
Altitude (ft)



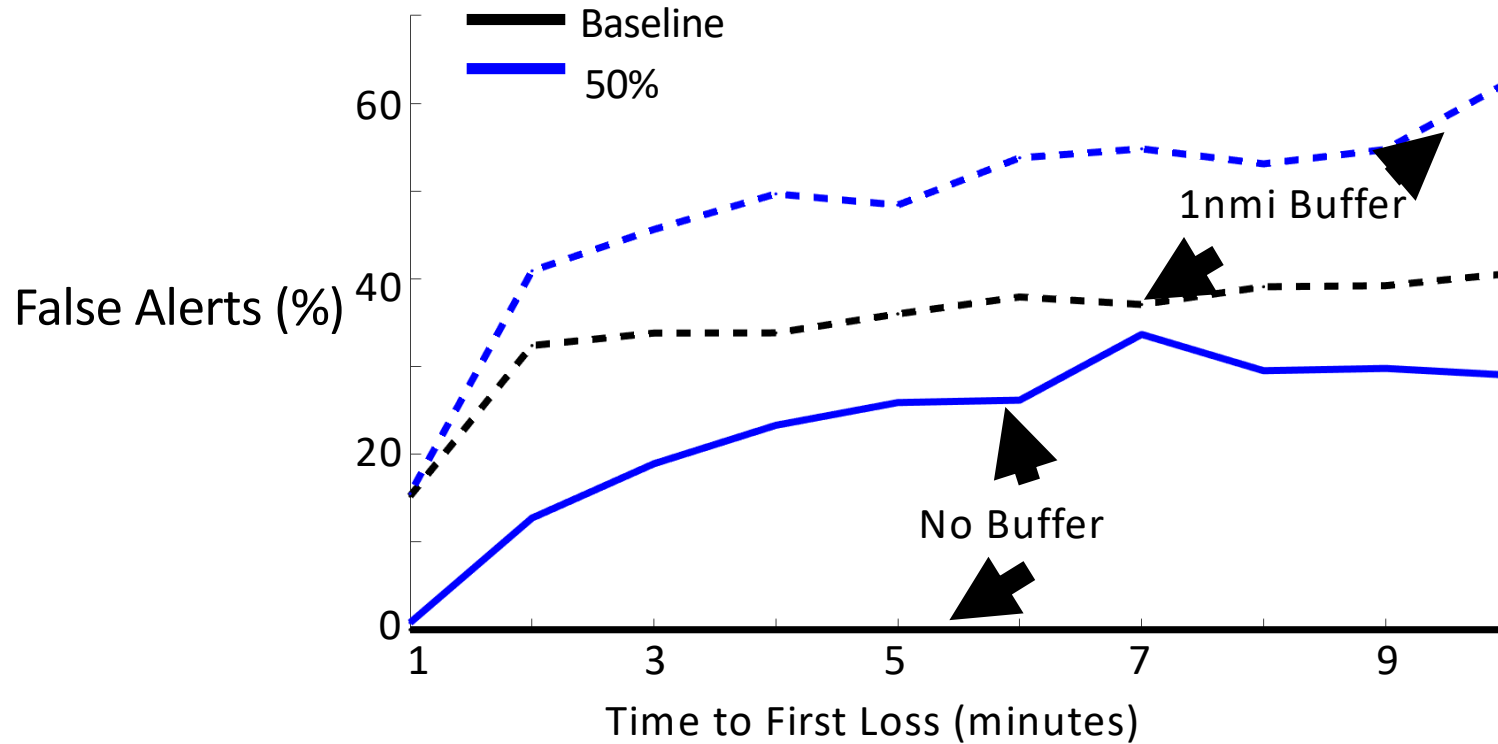
Detection Buffer



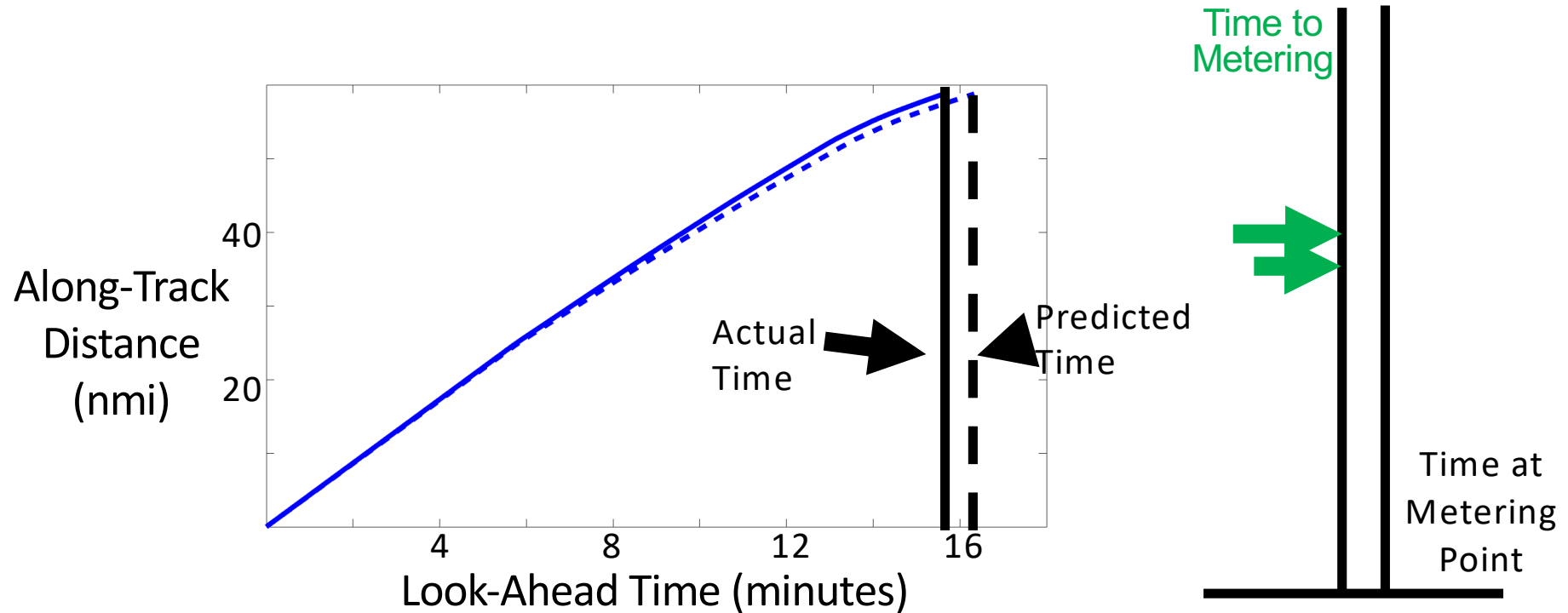
Missed Alerts



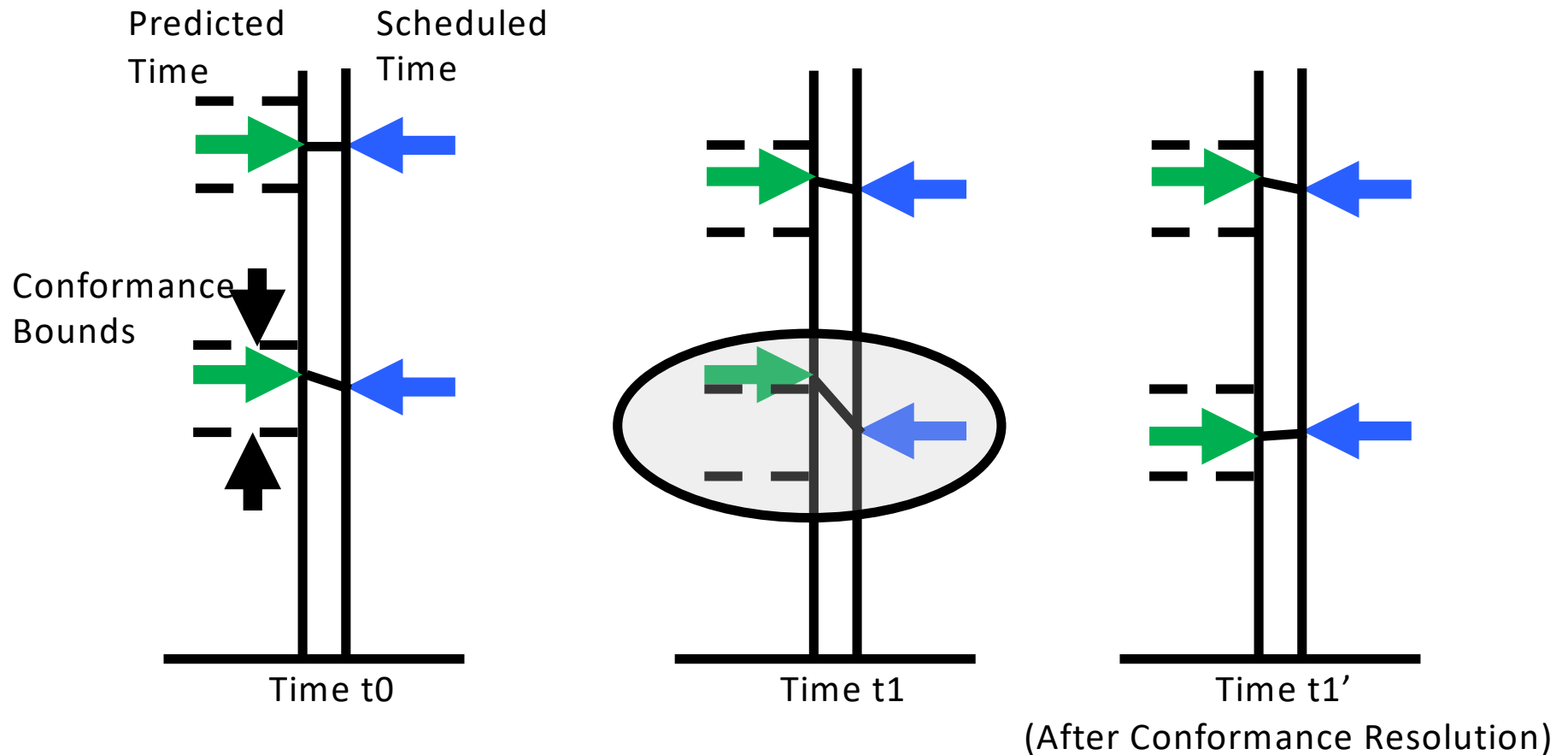
False Alerts



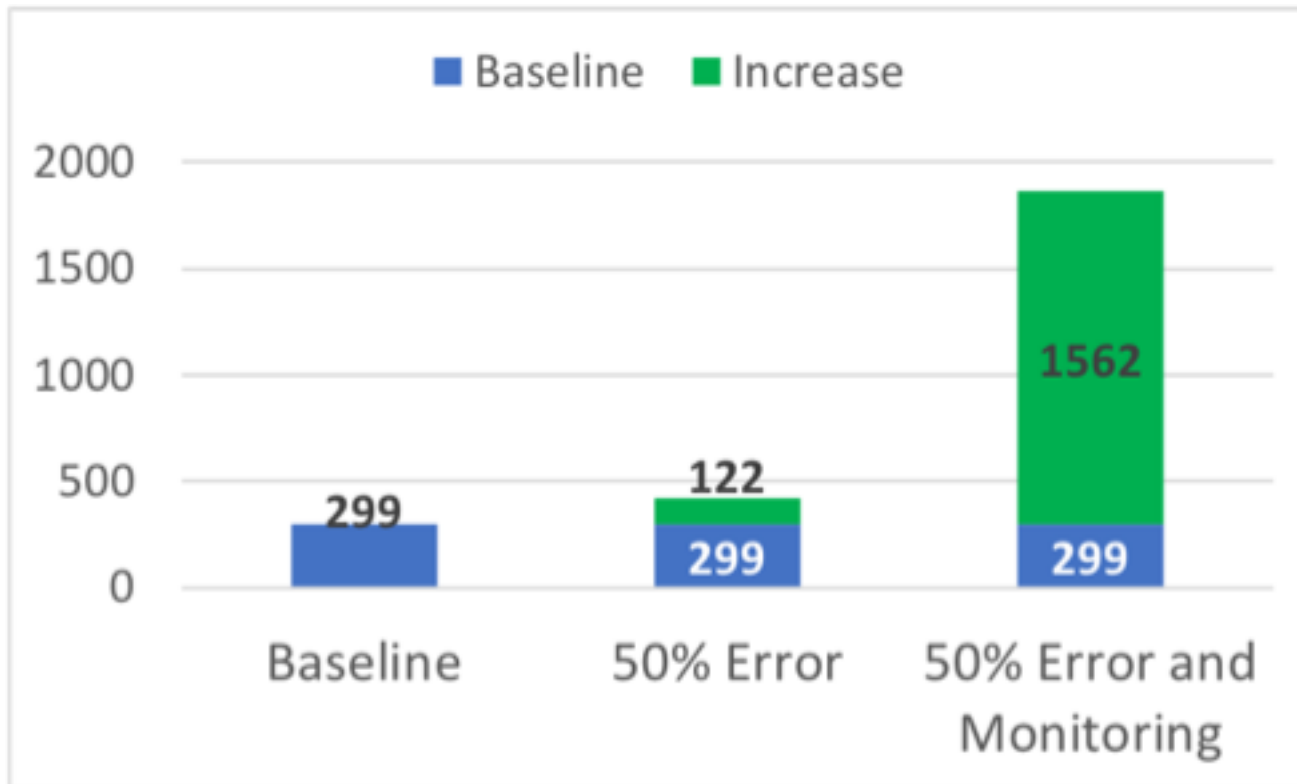
Errors and Arrival Scheduling



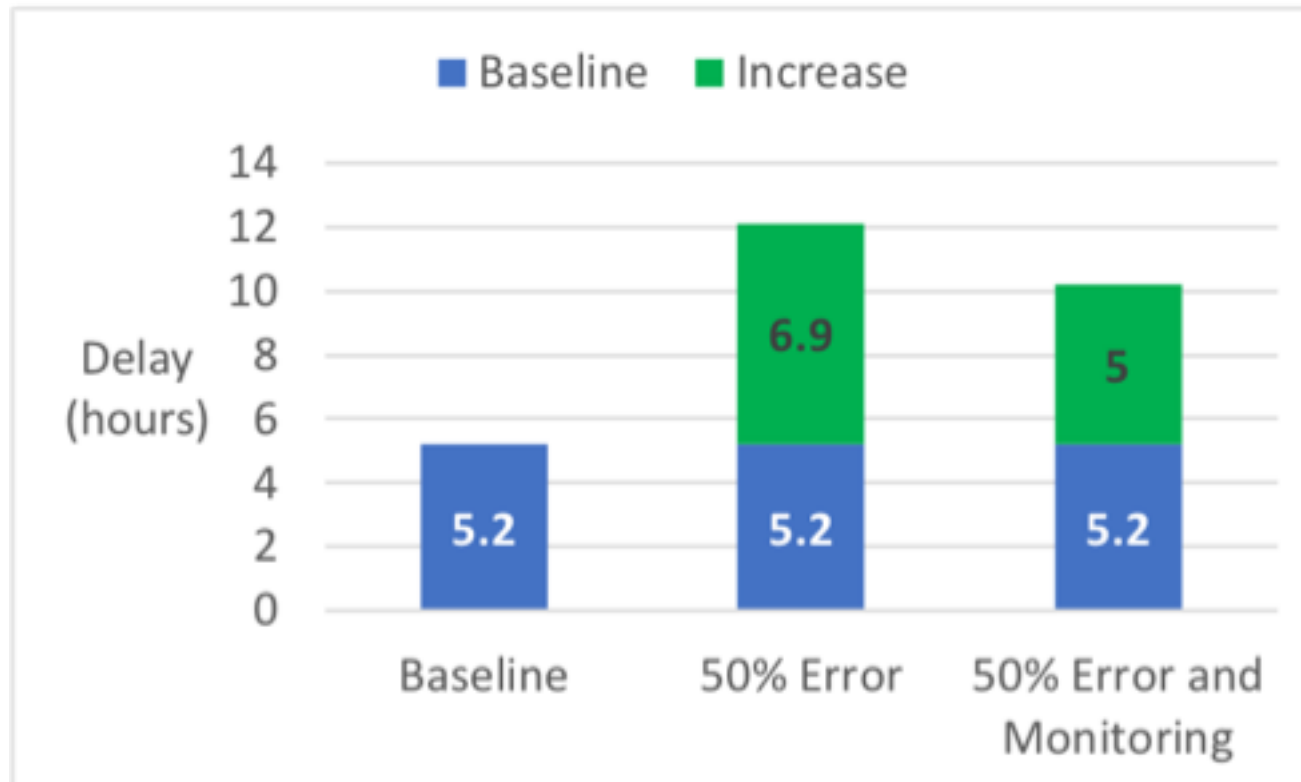
Arrival Schedule Conformance Monitoring



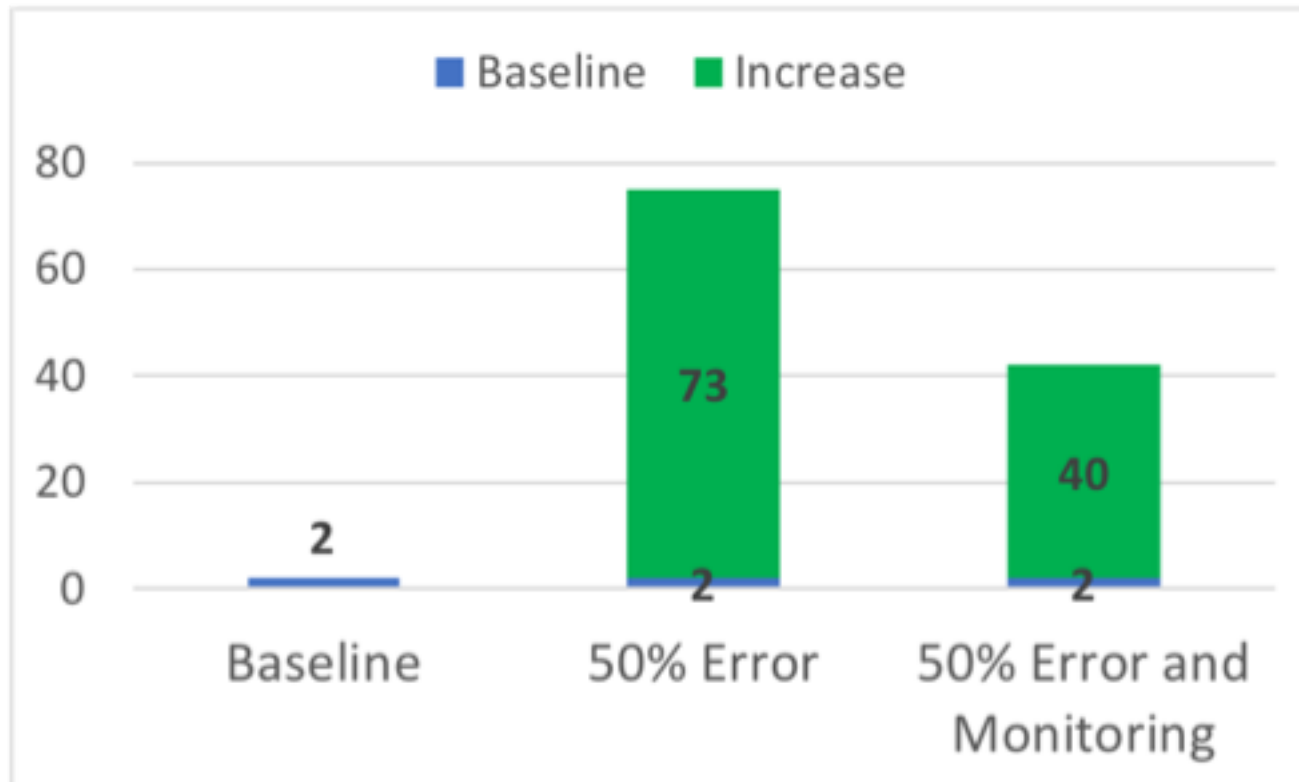
Number of Resolutions



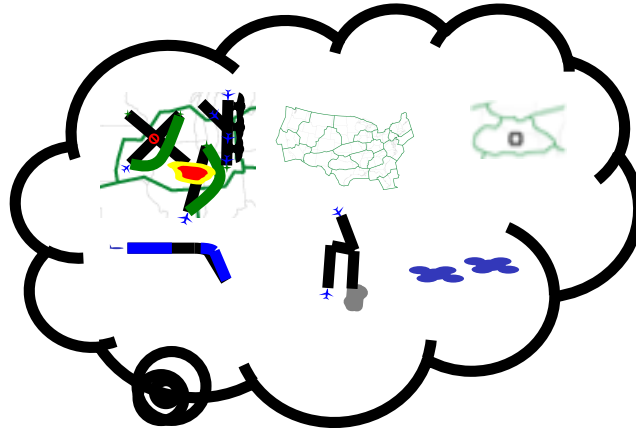
Total Delay



Number of Schedule Changes



Conclusions



- Coordinated operations in multiple types of airspace were demonstrated in the presence of trajectory prediction errors
- Simple rules were demonstrated that enabled coordination across control boundaries
- Arrival schedule conformance monitoring reduced delay significantly at the cost of significantly more resolutions