

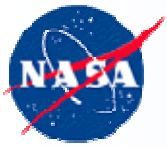
Integration of Weather Avoidance and Traffic Separation

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Airspace Systems Program
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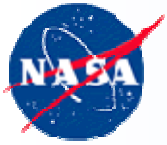
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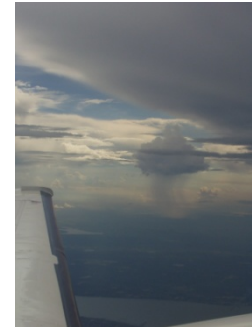
Outline and Participants

- Presentation topics
 - The challenges of weather and weather modeling for Air Traffic Management (ATM) systems and concepts
 - Integrating weather avoidance with trajectory-based ATM
 - Implementing weather avoidance logic
 - Testing an integrated weather avoidance and traffic separation algorithm
 - Modeling weather patterns and onboard weather radar in simulations
 - Preliminary testing results
 - Summary and future work
- Researchers are Maria Consiglio (PI), Jim Chamberlain (Co-PI), and Sara Wilson
 - Many others deserve credit: David Wing, Mike Guminiski, Ed Searce, Jim Sturdy, Bob Vivona, Dave Roscoe, David Karr, Clay Hubbs, Troy Landers, Joey Ponthieux and numerous other CSAOB & ATOL staffers



The Challenge of Weather

- Weather is a significant source of uncertainty and potential delay for ATM systems and concepts
- In particular, dynamic convective weather avoidance poses challenges for en-route trajectory-based ATM concepts
 - Current and future states of weather cells are imprecisely known
 - They don't broadcast their "intent!"
 - Operators (e.g., flight crews) use data from multiple sources to build "best guesses" about hazardous weather's current and future states
- When building conflict-free trajectories, ATM automation should
 - Compensate for these weather uncertainties and, ideally,
 - Do so in a way that matches the operators' "best guess" avoidance preferences

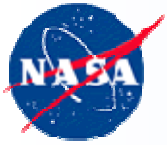




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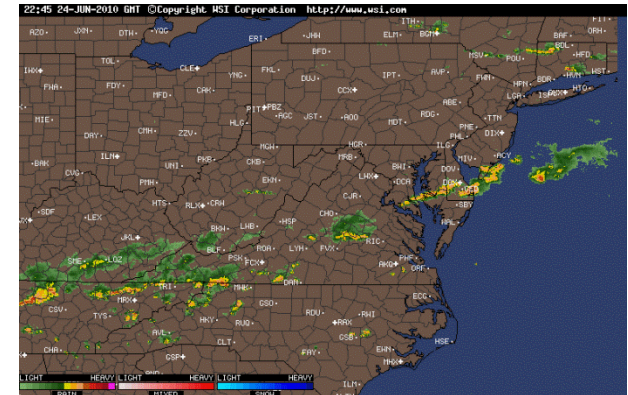
Legend: LIGHT, HEAVY LIGHT, HEAVY, LIGHT HEAVY

Map showing precipitation intensity across the Eastern United States, including major cities and airports. The map displays a large area of heavy precipitation (red) in the Northeast, particularly around New York City and Philadelphia, with lighter precipitation (green and yellow) extending westward and southward.



The Challenge of Weather Modeling

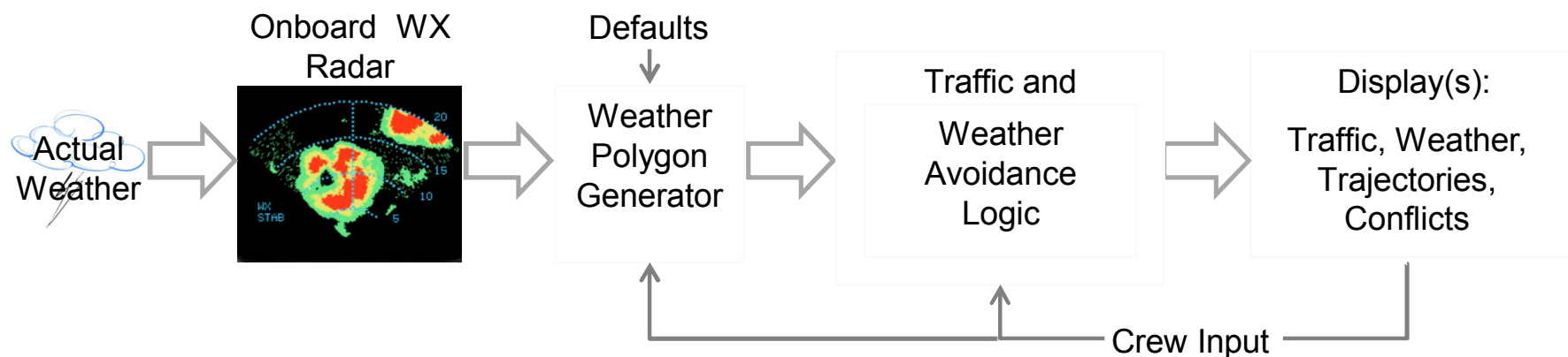
- Simulation testing of weather-avoiding ATM concepts presents additional challenges:
 - Modeling of weather cell “morphing” and motion
 - Modeling of opening and closing weather gaps
 - Modeling of weather sensor limitations (e.g., onboard weather radar)



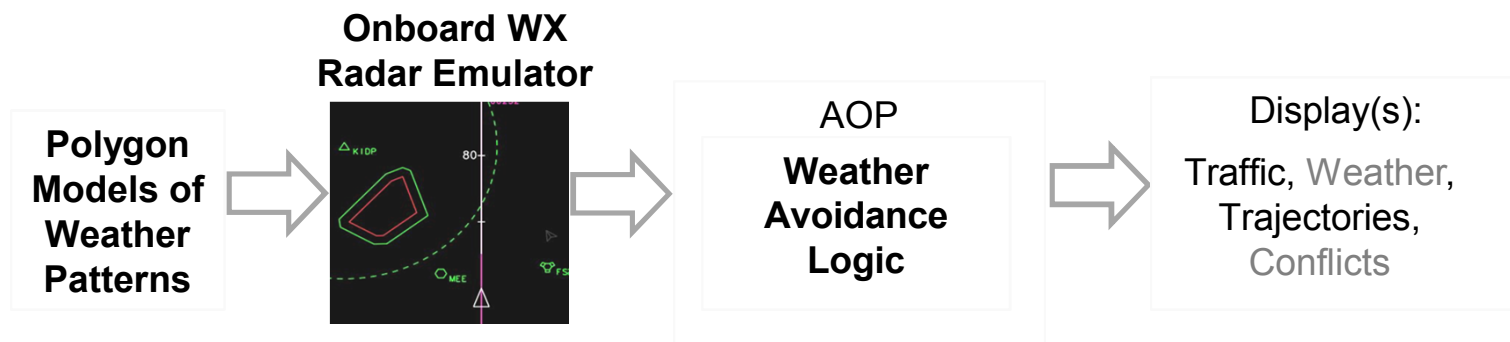


Integrating Weather and Traffic Avoidance

A candidate architecture:



Our current focus:

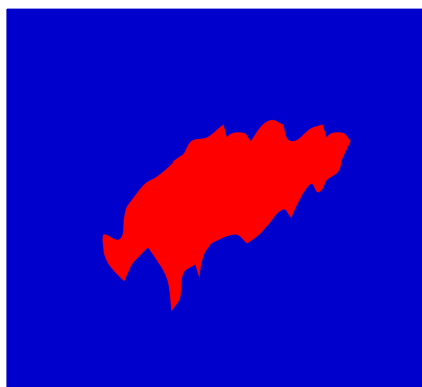




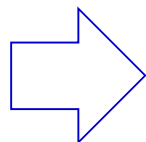
Weather Avoidance Implementation

Weather Representation

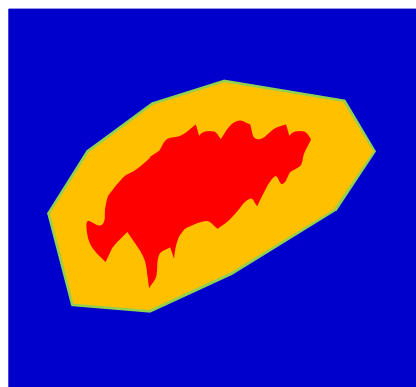
Weather Cell, **Core Polygon** and **Avoid Polygon**



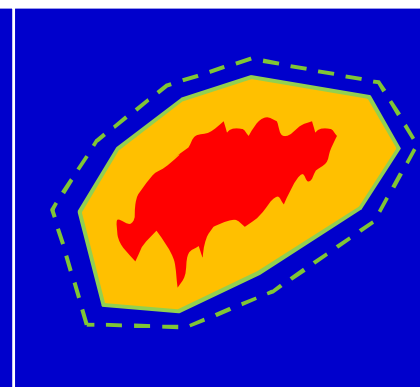
Weather Cell



Polygon
Generator



Core Polygon:
Weather Cell plus a
defined safety distance
(e.g., 20 nm)



Avoid Polygon:
Core Polygon plus an
additional configurable
distance for avoidance
implementation

Core and Avoid Polygon sets are dynamically updated & provided to AOP as new weather cell source data become available



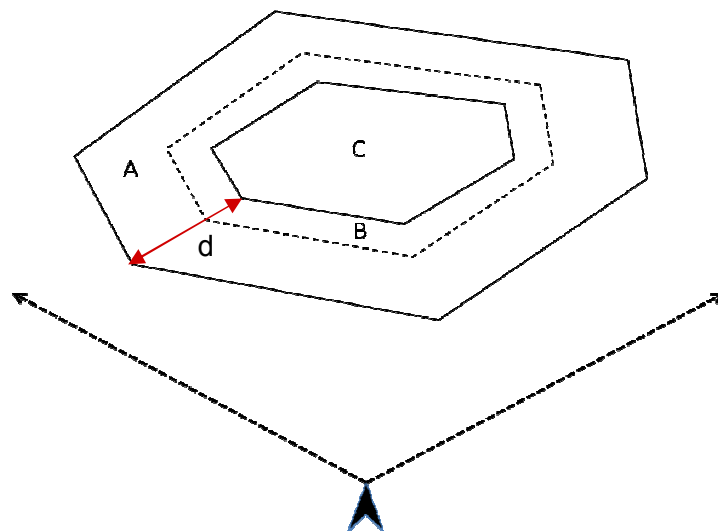
Weather Avoidance Implementation

Avoidance Logic

Logic will seek and provide trajectories that are conflict-free with both traffic and Core Polygons (hard constraints).

If available, logic will provide trajectories that are also conflict-free with Avoid Polygons (soft constraints).

Avoid Polygon size
“d” is a study
parameter



C = Core Polygon
A = Avoid Polygon
B = AOP-internal
resolution buffer

Large values of “d” minimize Core Polygon penetrations.
Small values of “d” maximize trajectory & airspace efficiency.

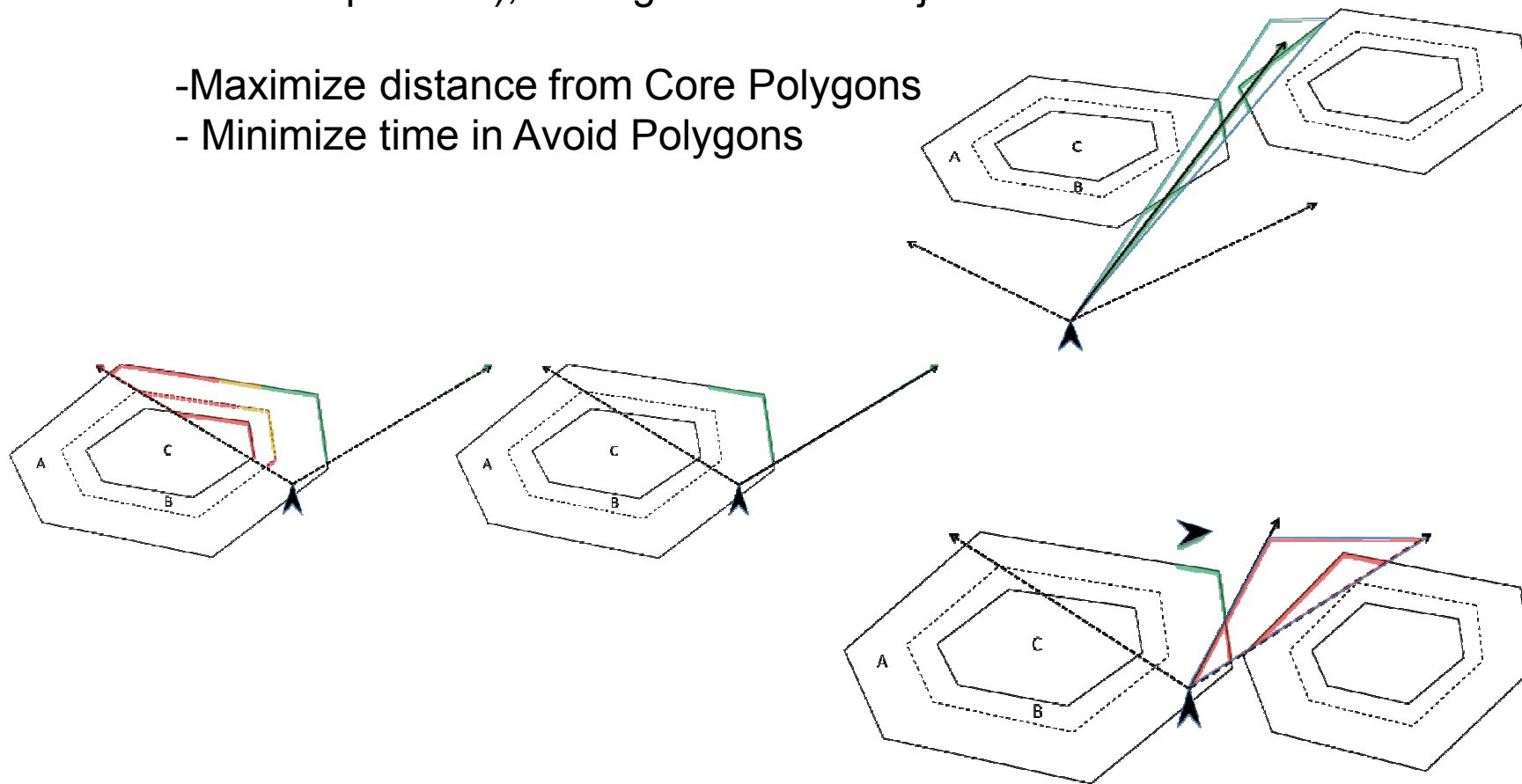


Weather Avoidance Implementation

Avoidance Logic cont'd

If Avoid Polygons must be penetrated (due to hard constraints, or because the updated weather polygons move over the aircraft's position), the logic will seek trajectories that:

- Maximize distance from Core Polygons
- Minimize time in Avoid Polygons





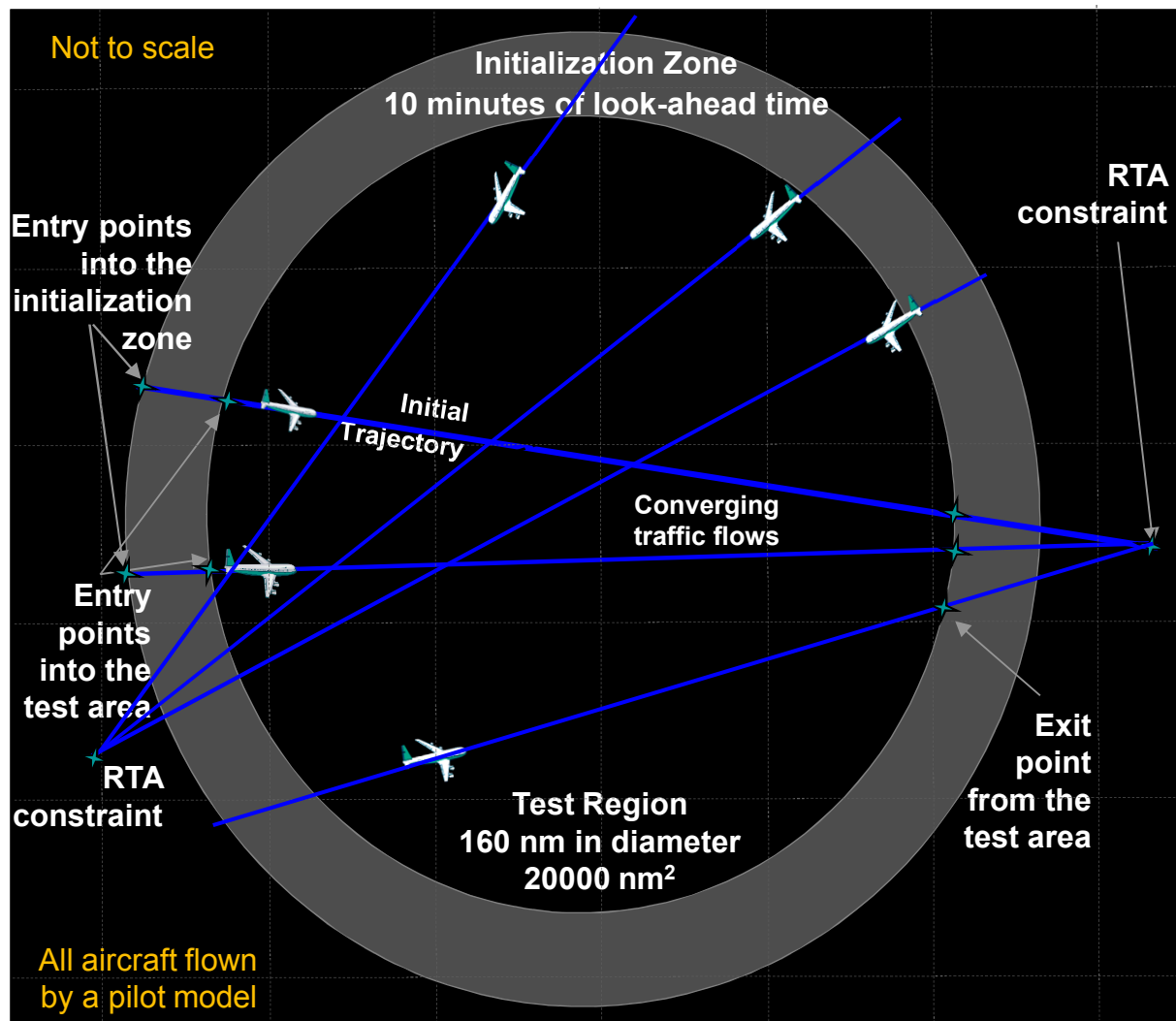
Stress-Testing the Integrated Weather Avoidance and Traffic Separation Algorithm

- Batch-mode testing performed in NASA Langley's Air Traffic Operations Laboratory (ATOL)
 - Medium-fidelity simulation of each aircraft: 6-DOF motion model, FCC, EFIS, FMS, ADS-B Out/In, AOP, plus a simple onboard weather radar model
 - For batch-mode testing, each aircraft is “flown” by a rule-based Pilot Model
 - Extensive data collection and analysis capabilities
- Test area is generic, circular en-route airspace
 - 160 nm diameter x 10000' (FL290 – FL390)
 - Aircraft on random routes across test area converging to a set of meter fixes
 - Approximately 75 aircraft (~ 2x current traffic density) concurrently in test area
 - Different weather polygon patterns introduced into test area
 - All aircraft use AOP to self-separate from other traffic and weather polygons



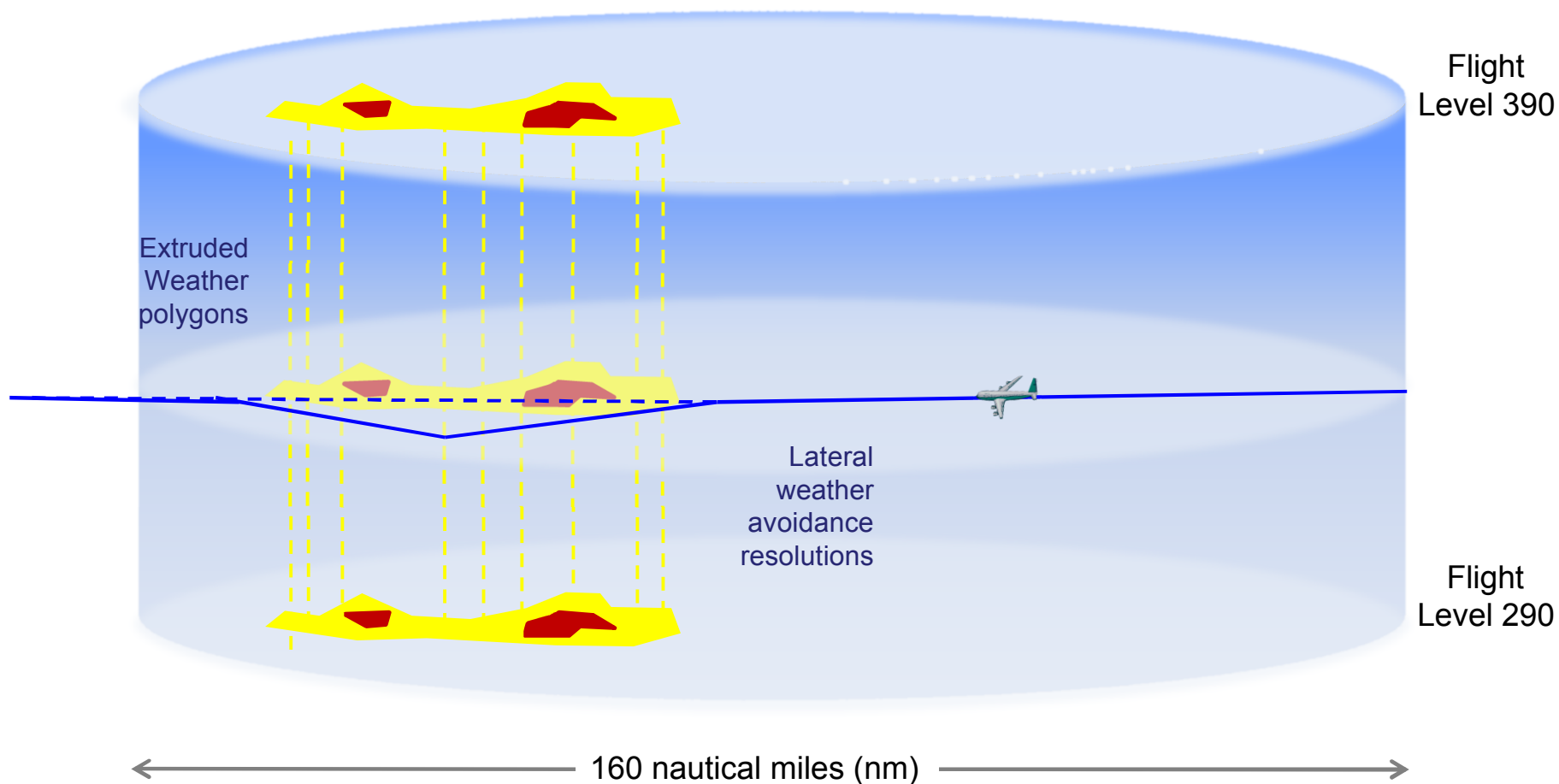


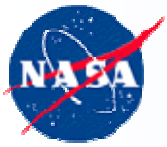
Top View of Test Area





Lateral View of Test Area



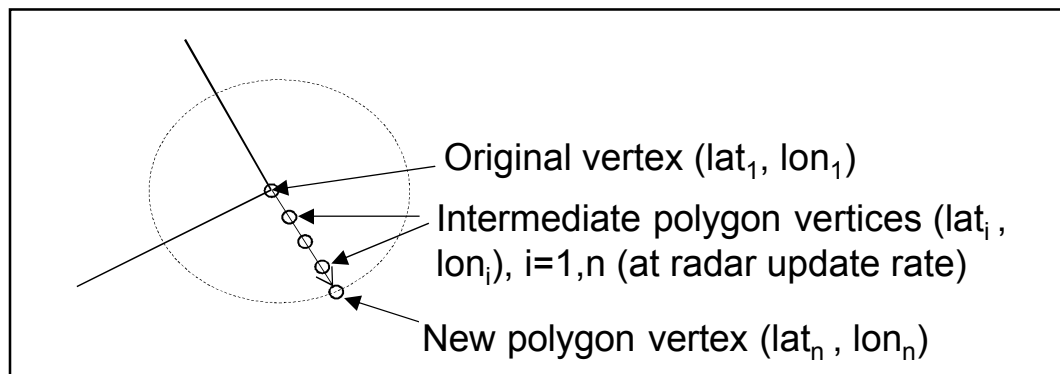
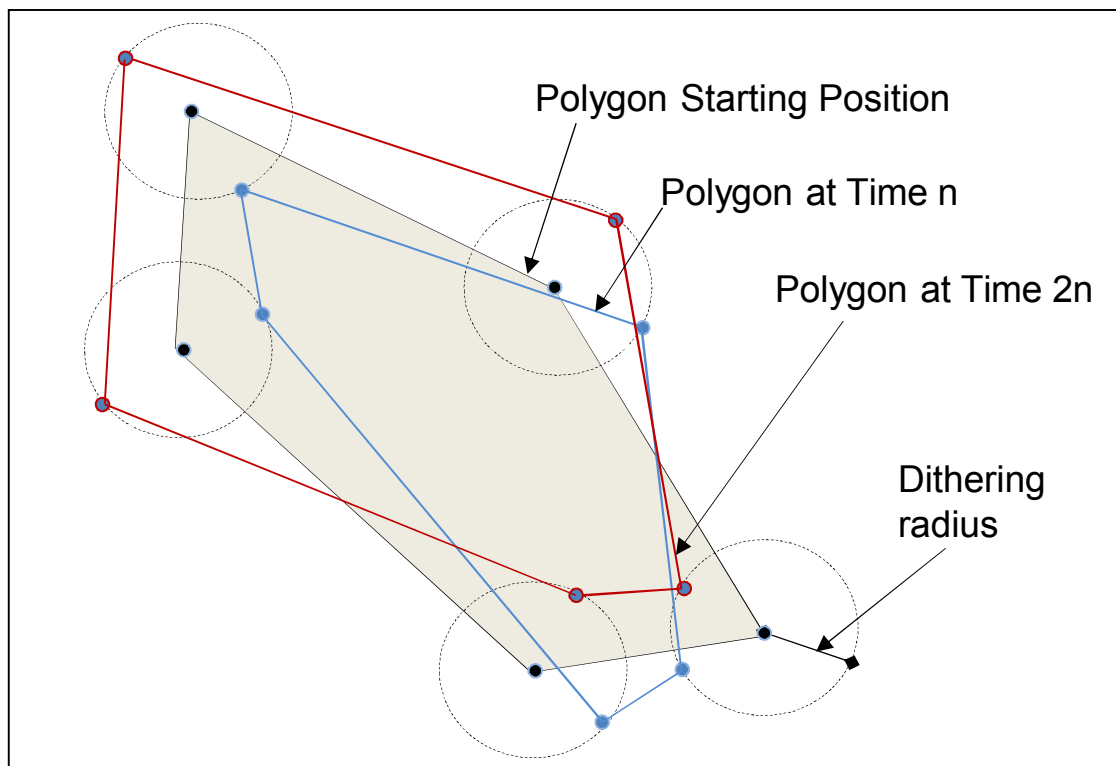


Polygon-Based Weather Model

- Provides a simple means to build weather polygon scenarios for stress-testing ATM concepts
- Scenarios built from one or more experimenter-defined weather cells or polygons
- Highly parameterized, including:
 - Cell sizes and polygon distances from cells
 - Polygon velocity and magnitude/rate of pseudo-random “morphing”
 - Placement and number of polygons (e.g., to build opening/closing weather gaps)



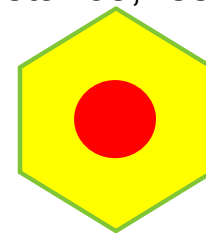
Polygon “Morphing” Implementation





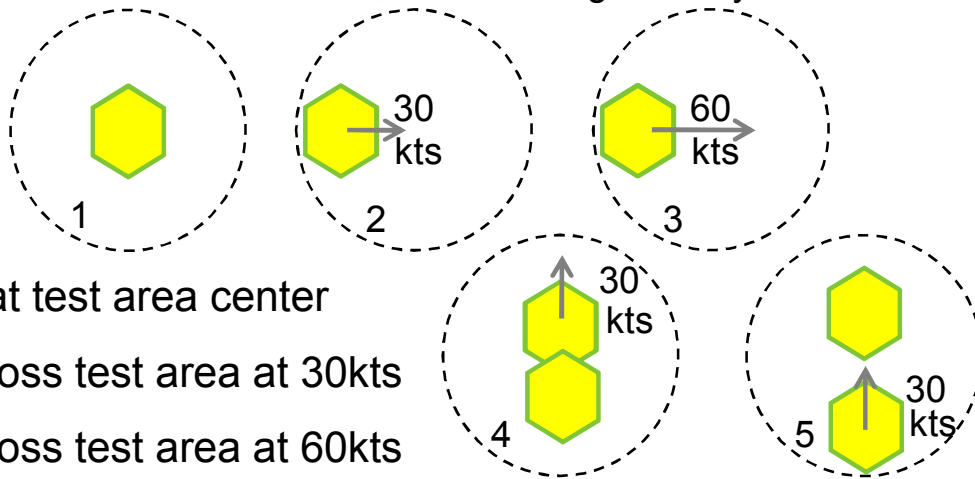
Weather Patterns for the Batch Testing

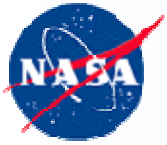
- Each pattern built up from the same simple weather polygon:
 - Assumes a 10nm circular weather cell and a 20nm safety distance, resulting in a 50nm circumscribed-diameter polygon
 - Polygon “morphs” by randomly moving the vertices
 - Each vertex remains within ± 3 nm of its original position
 - Each vertex’s speed varies from 0 to ~ 70 kts; rate is changed every 5 minutes



- Five patterns tested:

1. Single stationary cell at test area center
2. Single cell moving across test area at 30kts
3. Single cell moving across test area at 60kts
4. Two initially overlapping cells; one moves away at 30kts (creates a gap)
5. Two separated cells; one moves toward the other at 30kts (closes a gap)



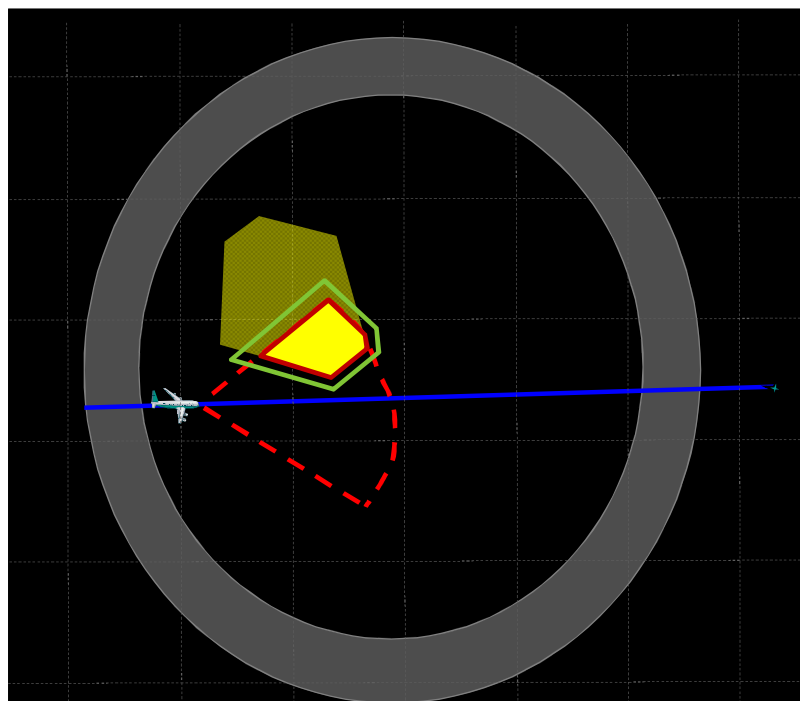


Modeling Onboard Weather Radar

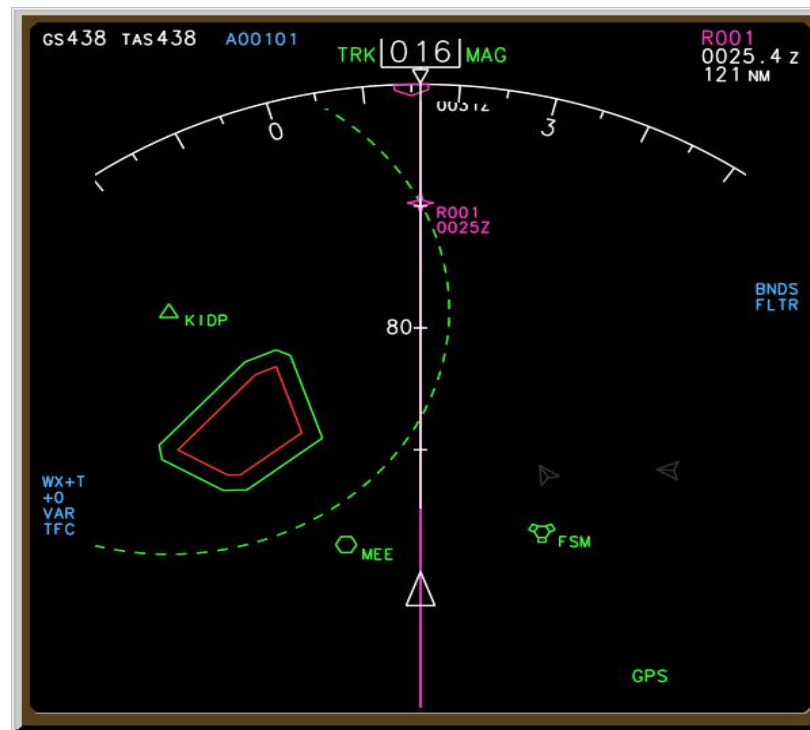
- Each aircraft's radar will “see” a different view of the weather
- High-fidelity onboard weather radar modeling is quite complex
 - Tilt, beam spread, attenuation, shadowing, terrain returns, etc.
- Simple model used for algorithm stress-testing
 - Assumes optimal tilt for detecting weather at current altitude, no beam spread
 - Parameters for range and azimuth limits, with clean cutoff at limits
 - Each aircraft builds its own Core and Avoid Polygons based on its view of the weather
 - Update rate (from radar model to AOP) set at 30 seconds



Weather Radar Range/Azimuth Cropping



Top view of test area and weather polygon



Cropped view of weather polygon on aircraft ND

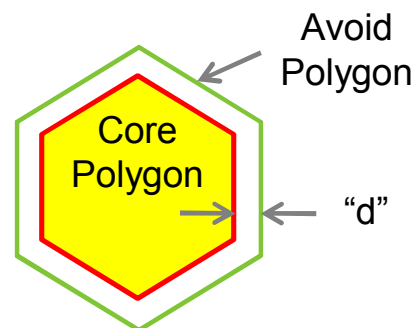


Preliminary Results at a Glance

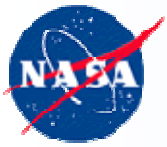
- Approximately 40000 flight hours over 180 runs; analysis ongoing

- Six Avoid Polygon sizes were tested:

“d” = 9, 7, 5, 3, 2, and 1 nm



- *First look at results:*
 - Core Polygon incursion rates are quite low overall (~0.6% of baseline rate with weather avoidance disabled) and zero in many cases
 - Weather avoidance appears effective with “d” as small as 2-3 nm
 - The “closing gap” weather pattern shows slightly more Core Polygon incursions
 - Traffic separation performance does not appear to degrade when weather polygons are present



Summary and Future Work

- Initial Observations
 - Weather avoidance logic performance results look promising
 - Traffic separation performance appears robust in the presence of dynamic weather
 - Weather polygon & onboard weather radar models are useful for stress-testing ATM concepts
- Future Work
 - Investigate trajectory efficiency, RTA performance, additional weather patterns
 - Implement weather “memory” and resolution buffers
 - Develop & evaluate crew weather presentations and interfaces
 - Explore options for mapping weather source data to polygons
 - Investigate integration of ground-based weather sources

