

# Airspace Capacity Estimation: Flow Constraint Index (FCI)

Ken Fenton

Forecast Impact and Quality Assessment Services Branch

NOAA/OAR/Global Systems Laboratory (GSL)

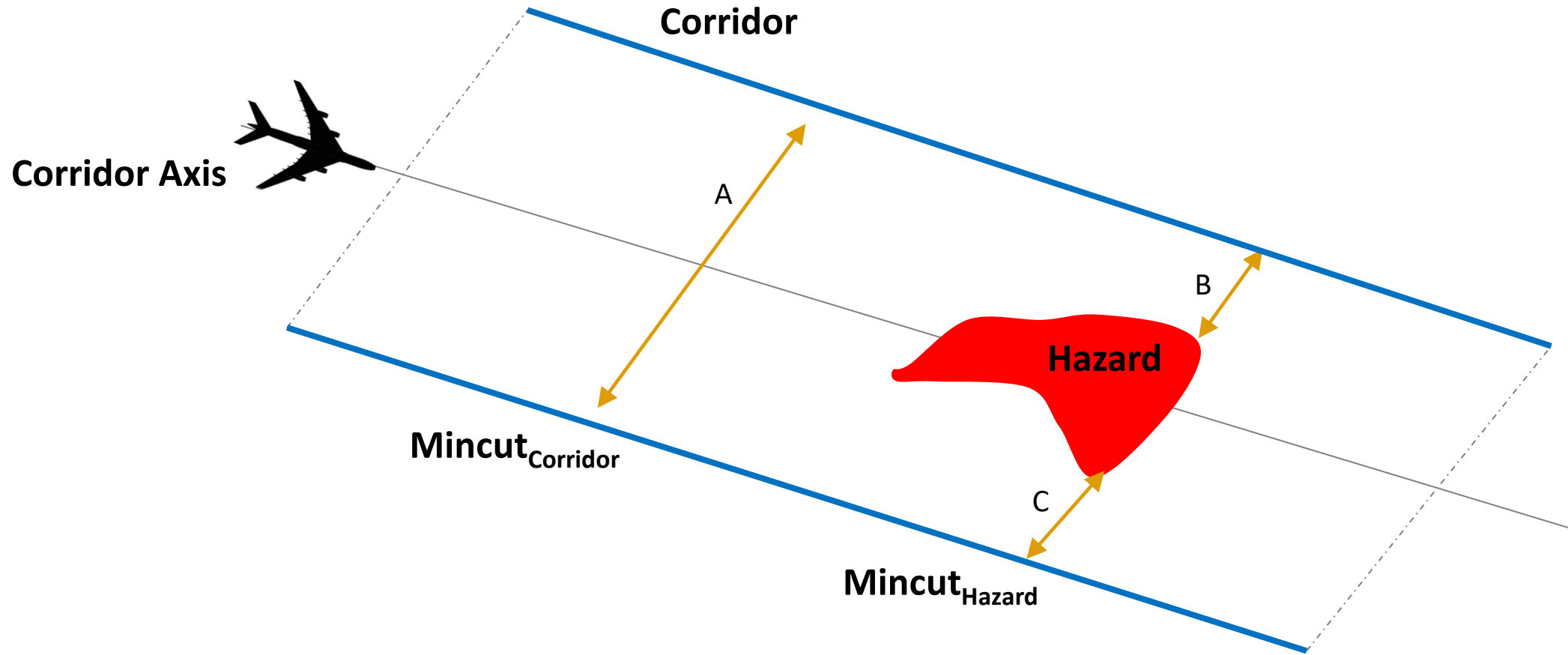
CIRA Award Number NA14OAR4320125, CIRES Award Number NA17OAR4320101



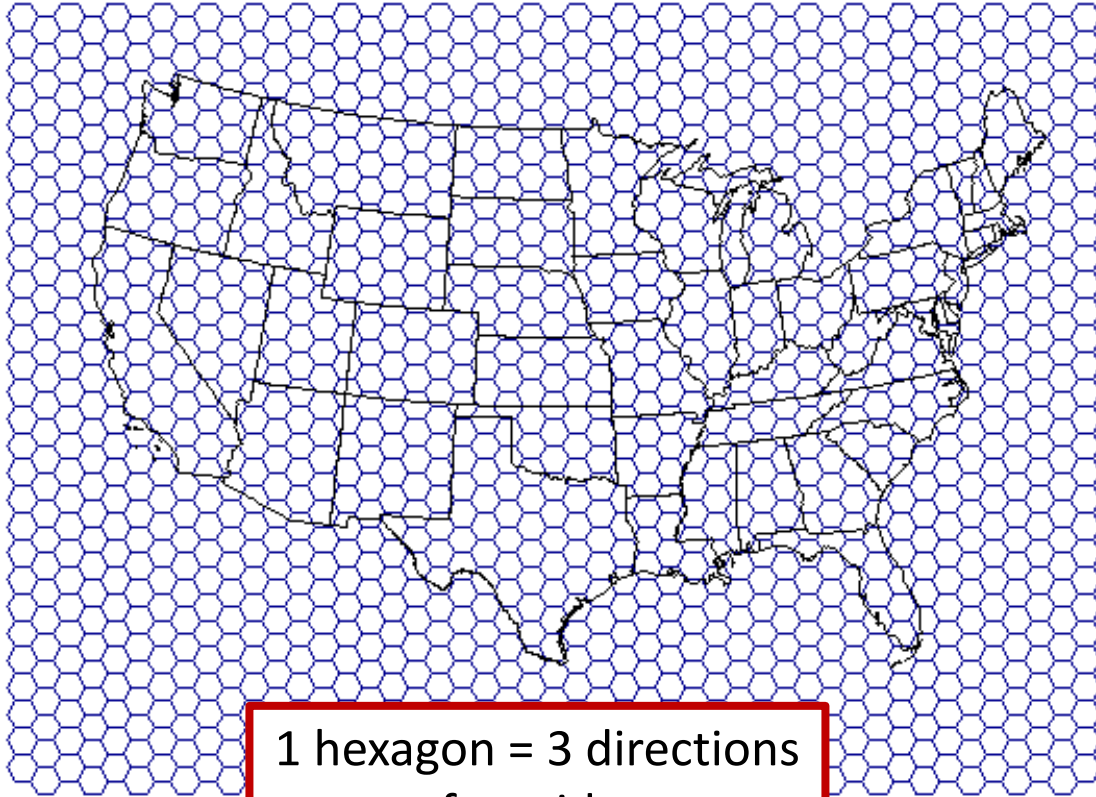
# Problem Statement

- How to objectively determine locations where air traffic will be constrained?
- How to optimize traffic flow given weather scenarios?
- Need to recognize that no forecast is perfect, so look at ensembles, probabilities, and multiple model solutions

# Flow Constraint Index (FCI)

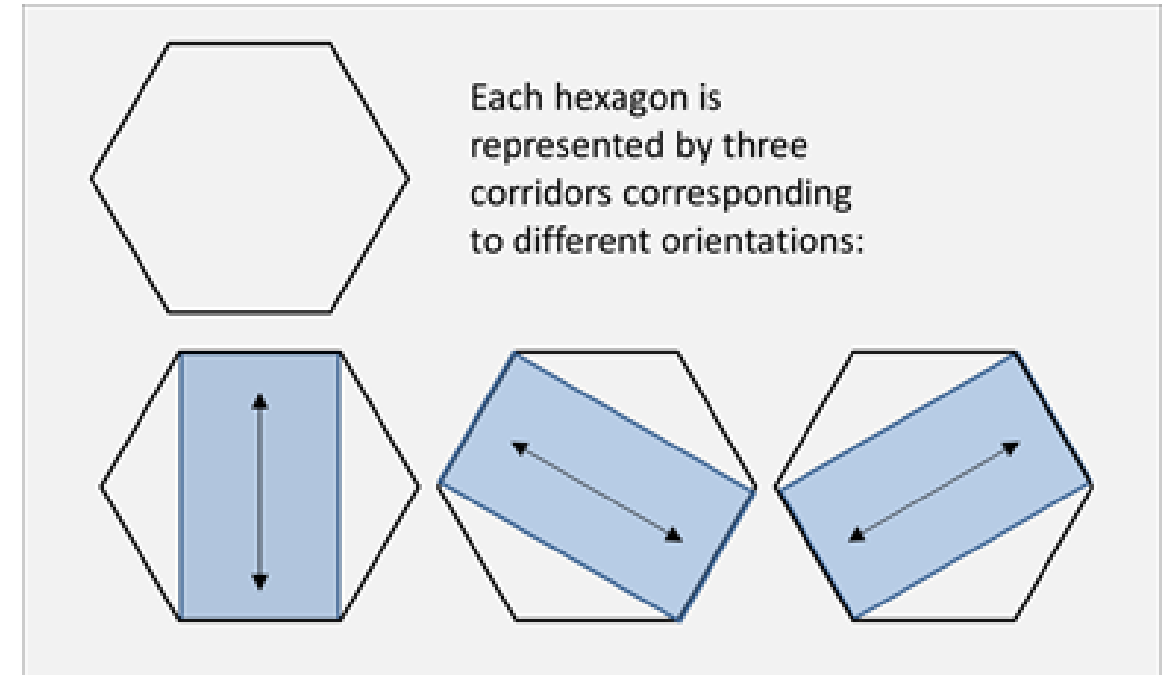


# Flow Constraint Index (FCI)

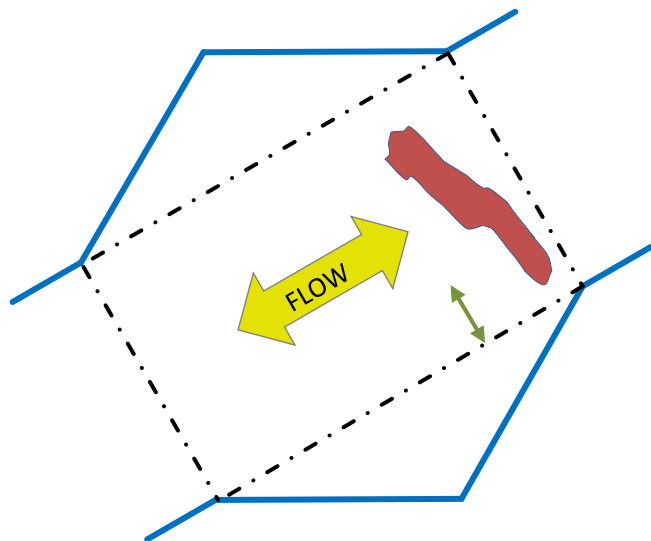


1 hexagon = 3 directions  
of corridors  
Supports computation  
of traffic in any direction

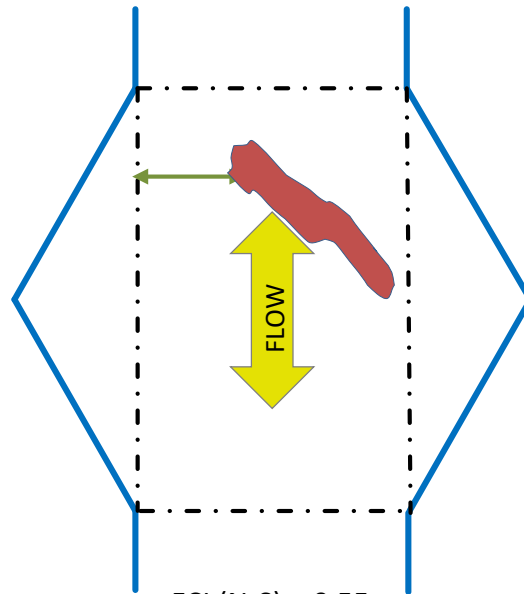
- Hexagonal Grid with 80 x 40 nmi corridors
  - Approximates width of jet routes
  - Captures sensitivity to orientation of hazard
  - Allows FCI aggregation over any desired region (e.g., ARTCCs, potential TCF polygons)



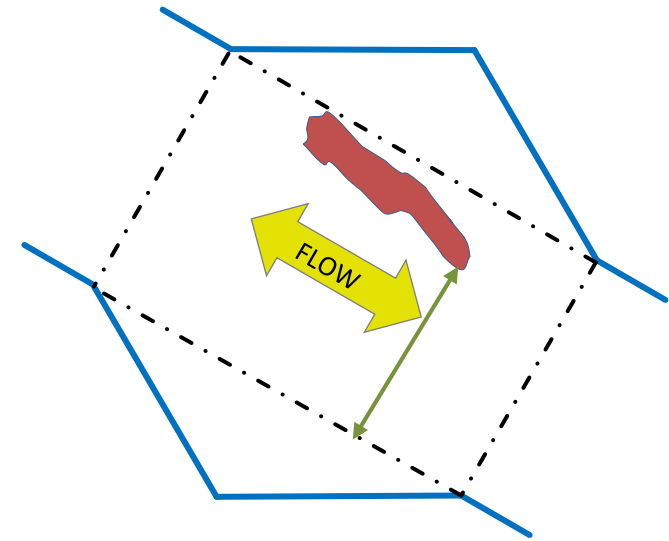
# Flow Constraint Index (FCI)



FCI (SW-NE) = 0.75

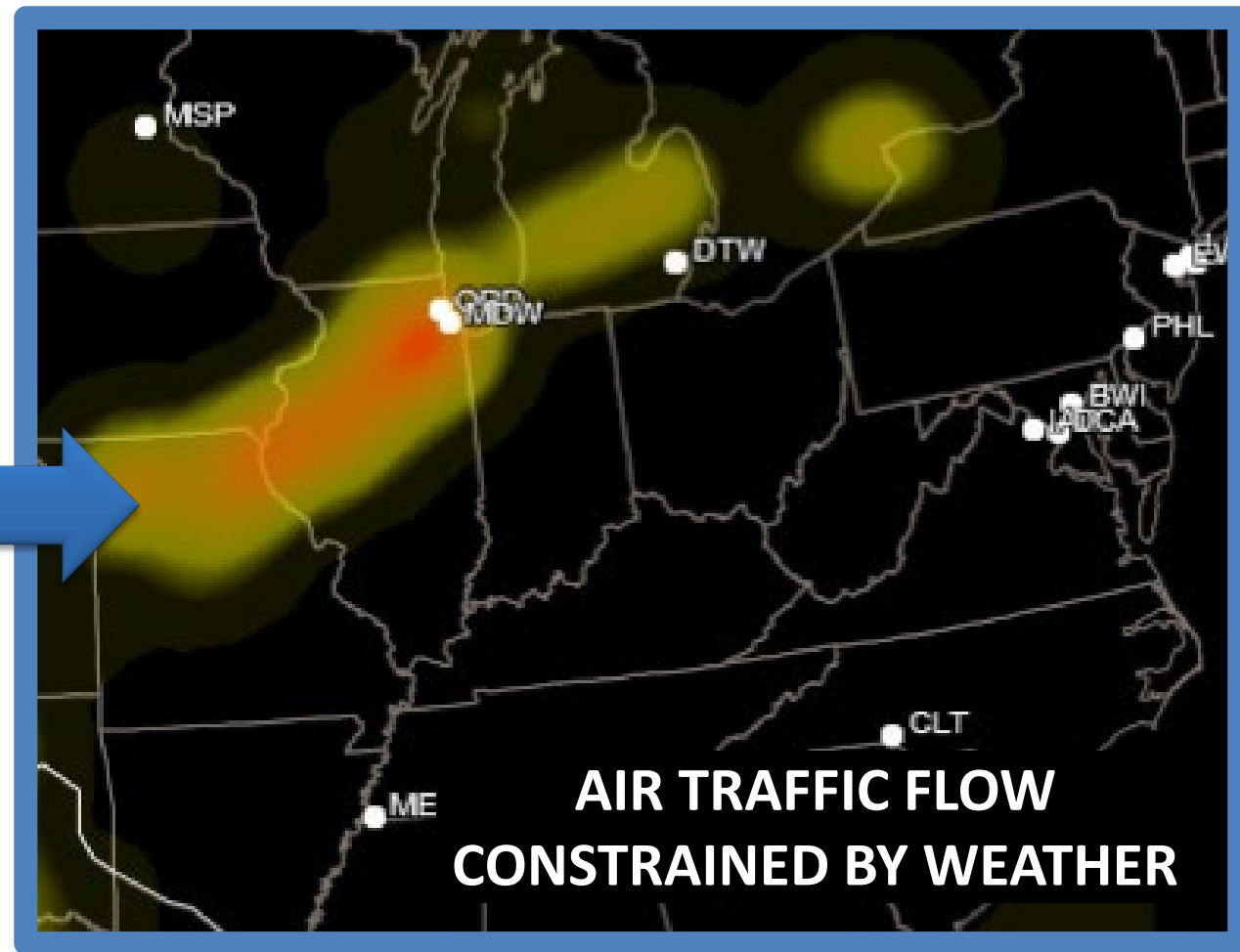
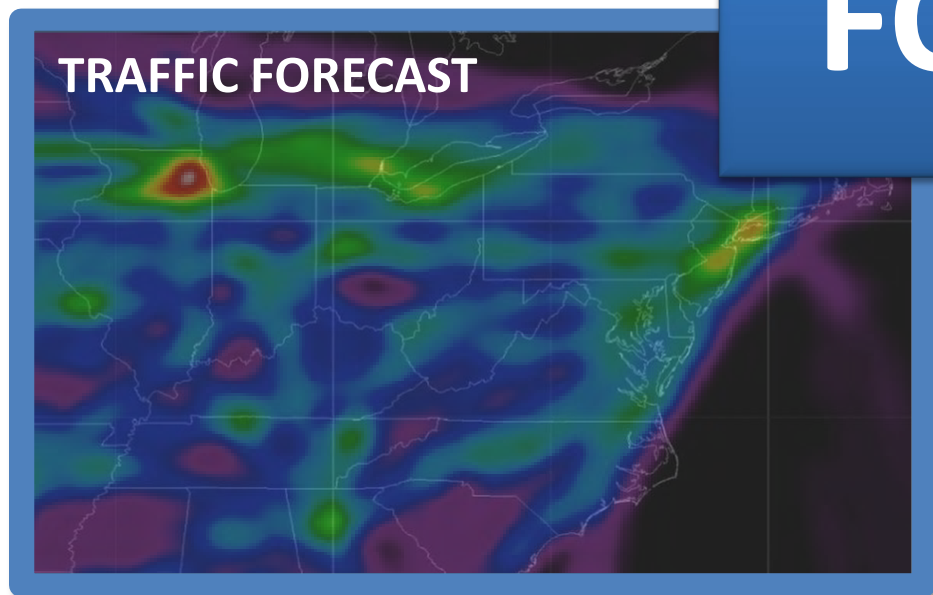
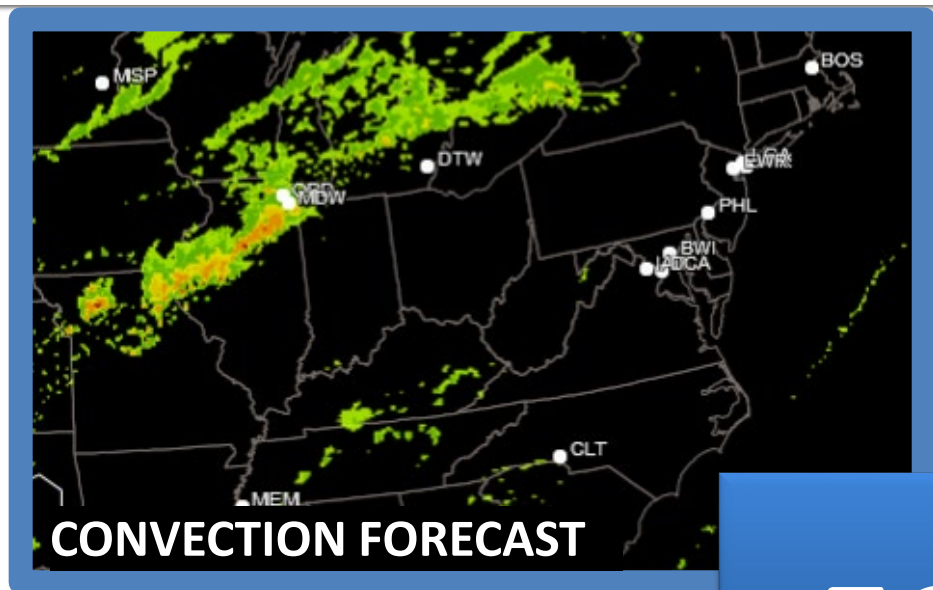


FCI (N-S) = 0.55

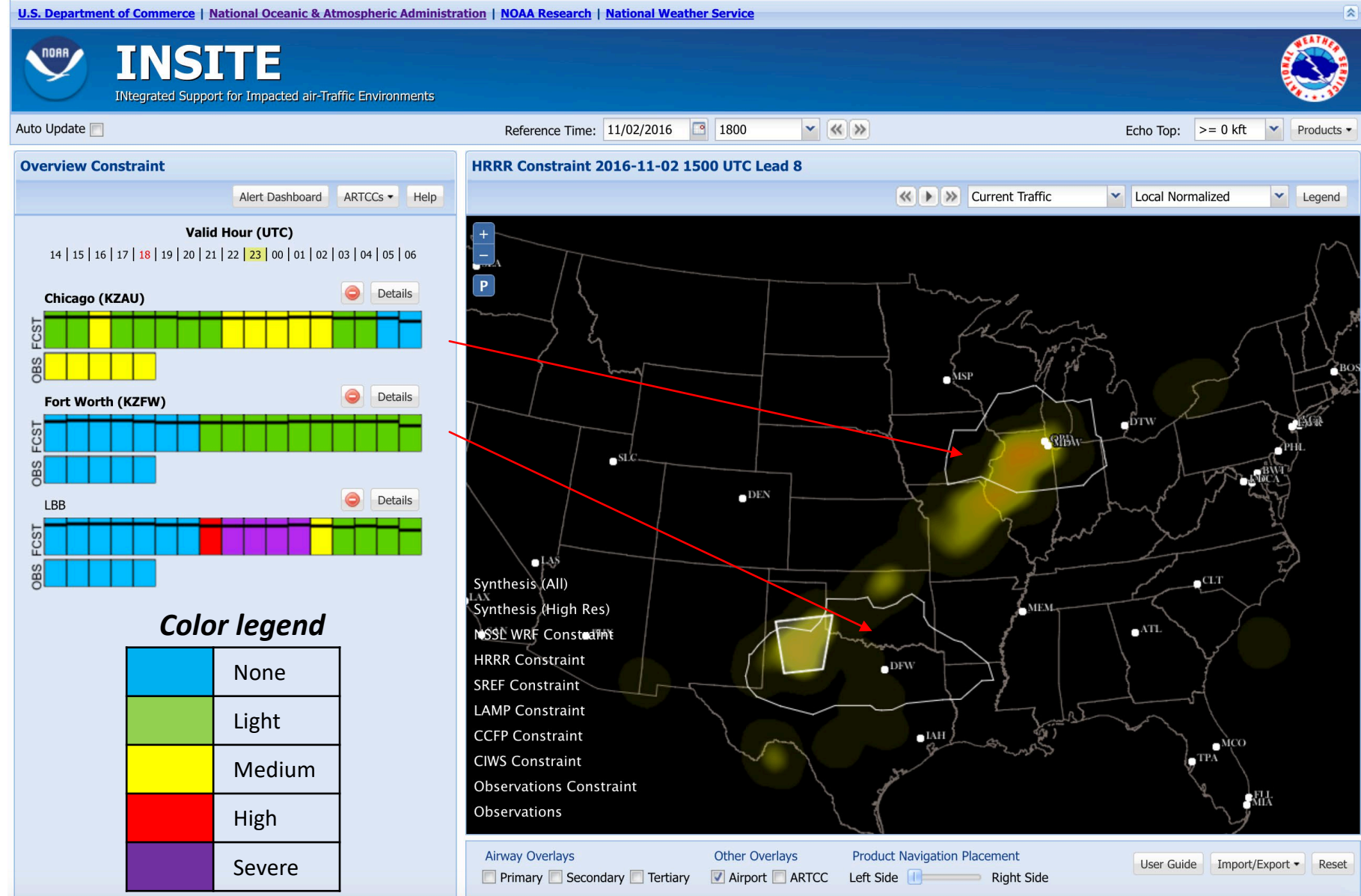


FCI (NW-SE) = 0.20

# FCI – Combining Weather with Traffic



- Constraint over ARTCCs



- Constraint over ARTCCs
- Constraint over user-drawn polygon

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research | National Weather Service

**INSITE**  
INtegrated Support for Impacted air-Traffic Environments

Auto Update  Reference Time: 11/02/2016 1800 Echo Top: >= 0 kft Products

### Overview Constraint

Alert Dashboard ARTCCs Help

Valid Hour (UTC)  
14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 00 | 01 | 02 | 03 | 04 | 05 | 06

**Chicago (KZAU)** Details

OBS FCST

**Fort Worth (KZFW)** Details

OBS FCST

**LBB** Details

OBS FCST

**Color legend**

	None
	Light
	Medium
	High
	Severe

### HRRR Constraint 2016-11-02 1500 UTC Lead 8

Current Traffic Local Normalized Legend

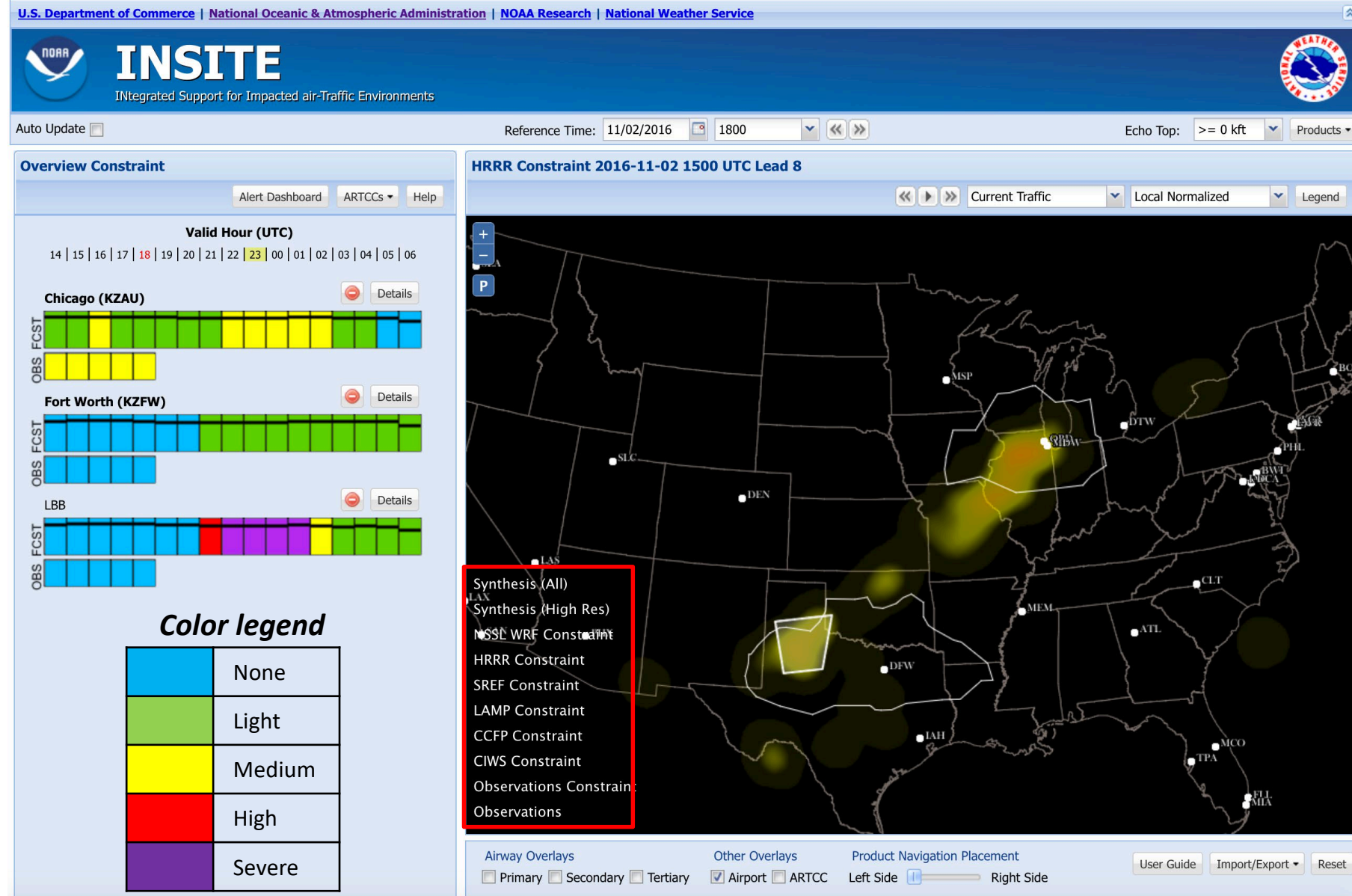
Synthesis (All)  
 Synthesis (High Res)  
 NSSL WRF Constraint  
 HRRR Constraint  
 SREF Constraint  
 LAMP Constraint  
 CCFP Constraint  
 CIWS Constraint  
 Observations Constraint  
 Observations

Airway Overlays:  Primary  Secondary  Tertiary  
 Other Overlays:  Airport  ARTCC  
 Product Navigation Placement:  Left Side  Right Side

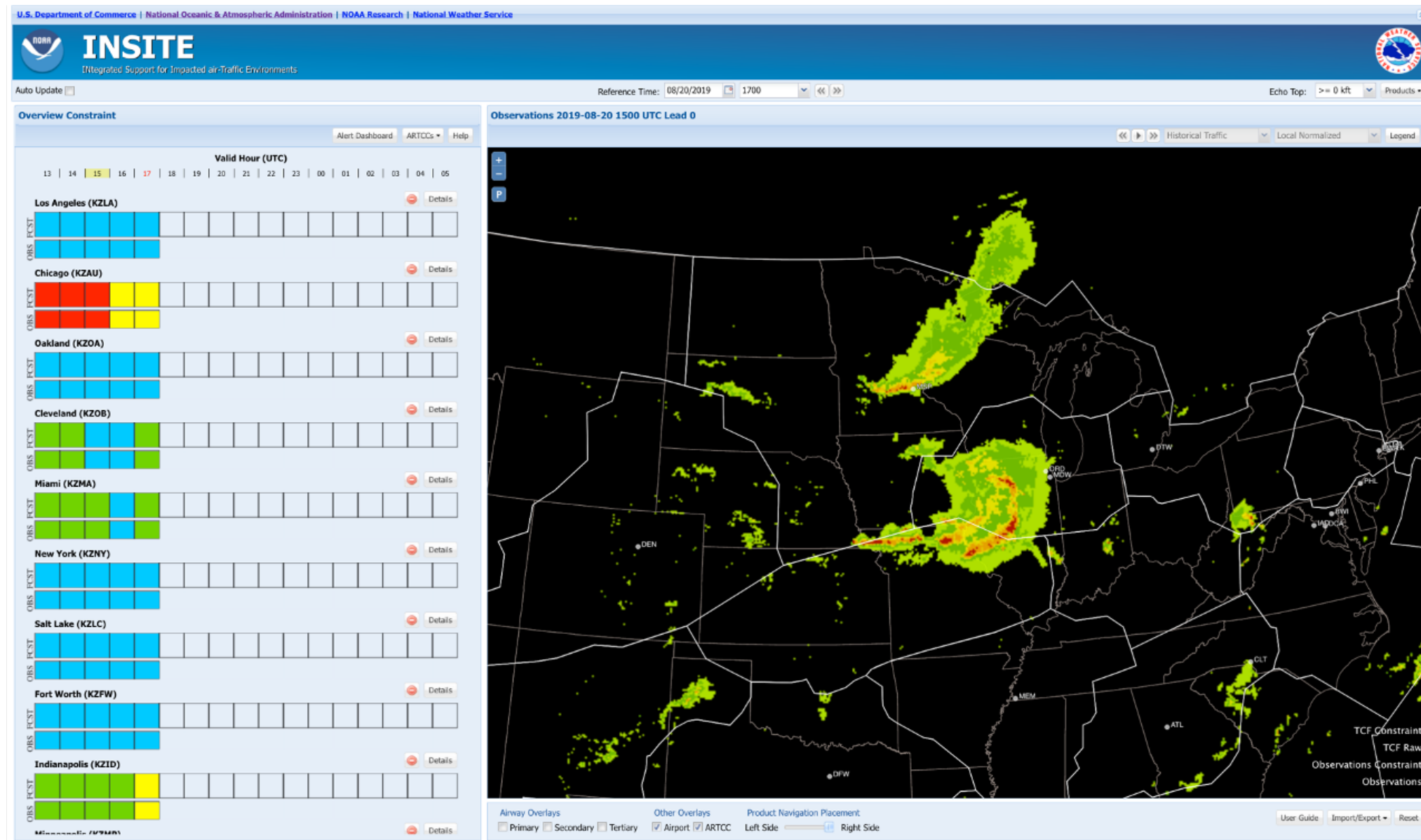
User Guide Import/Export Reset



- Constraint over ARTCCs
- Constraint over user-drawn polygon
- Constraint for a host of forecast products
  - Hi-resolution deterministic
  - Probabilistic
  - Synthesis

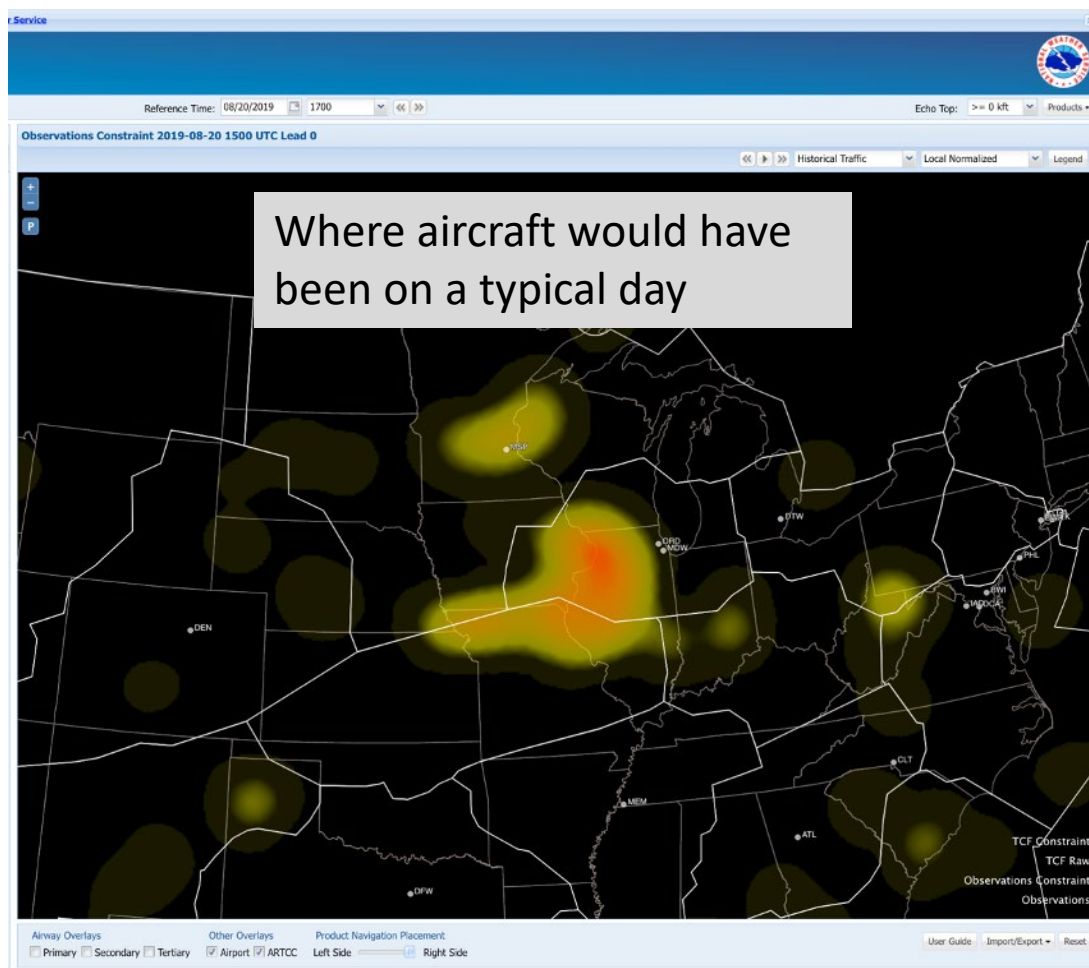


# Integrates Historic and Current Traffic

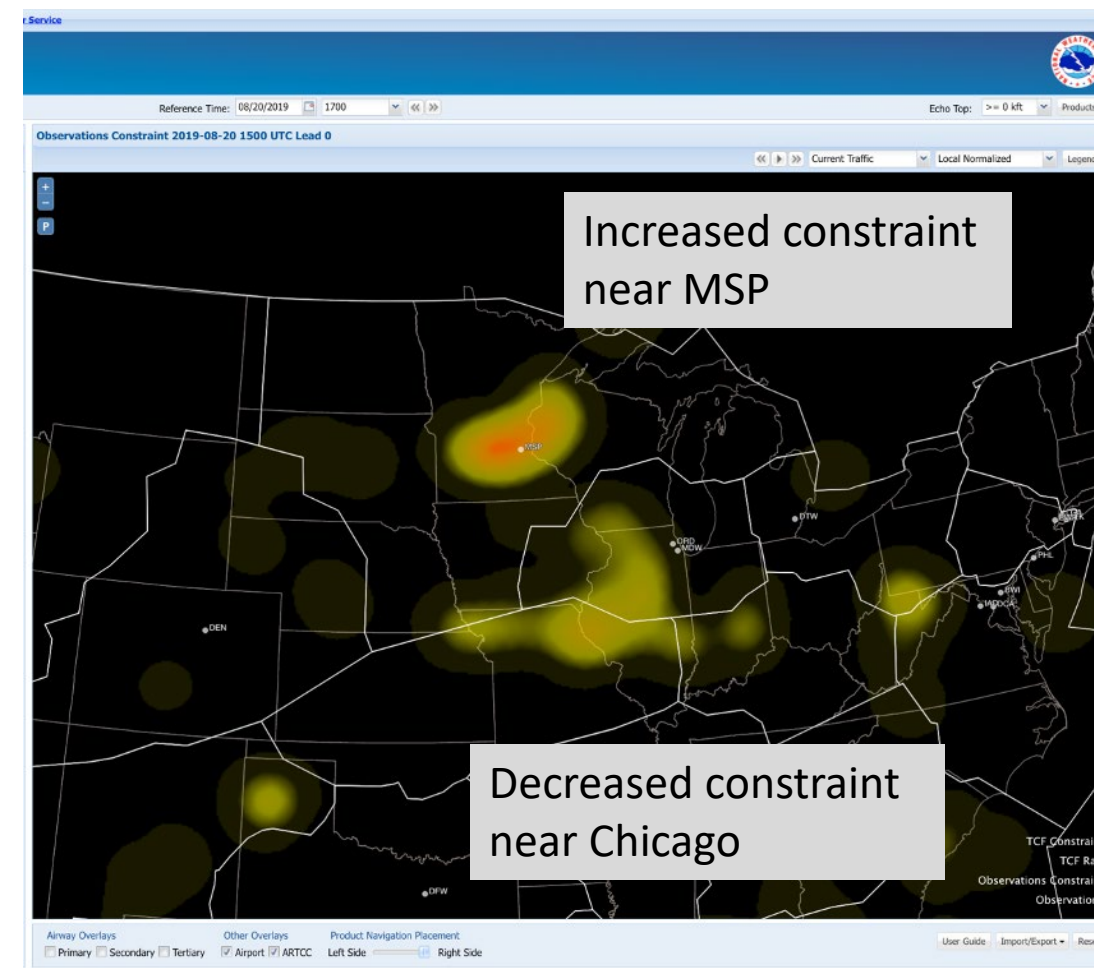


# Integrates Historic and Current Traffic

Historic Traffic



Current Traffic

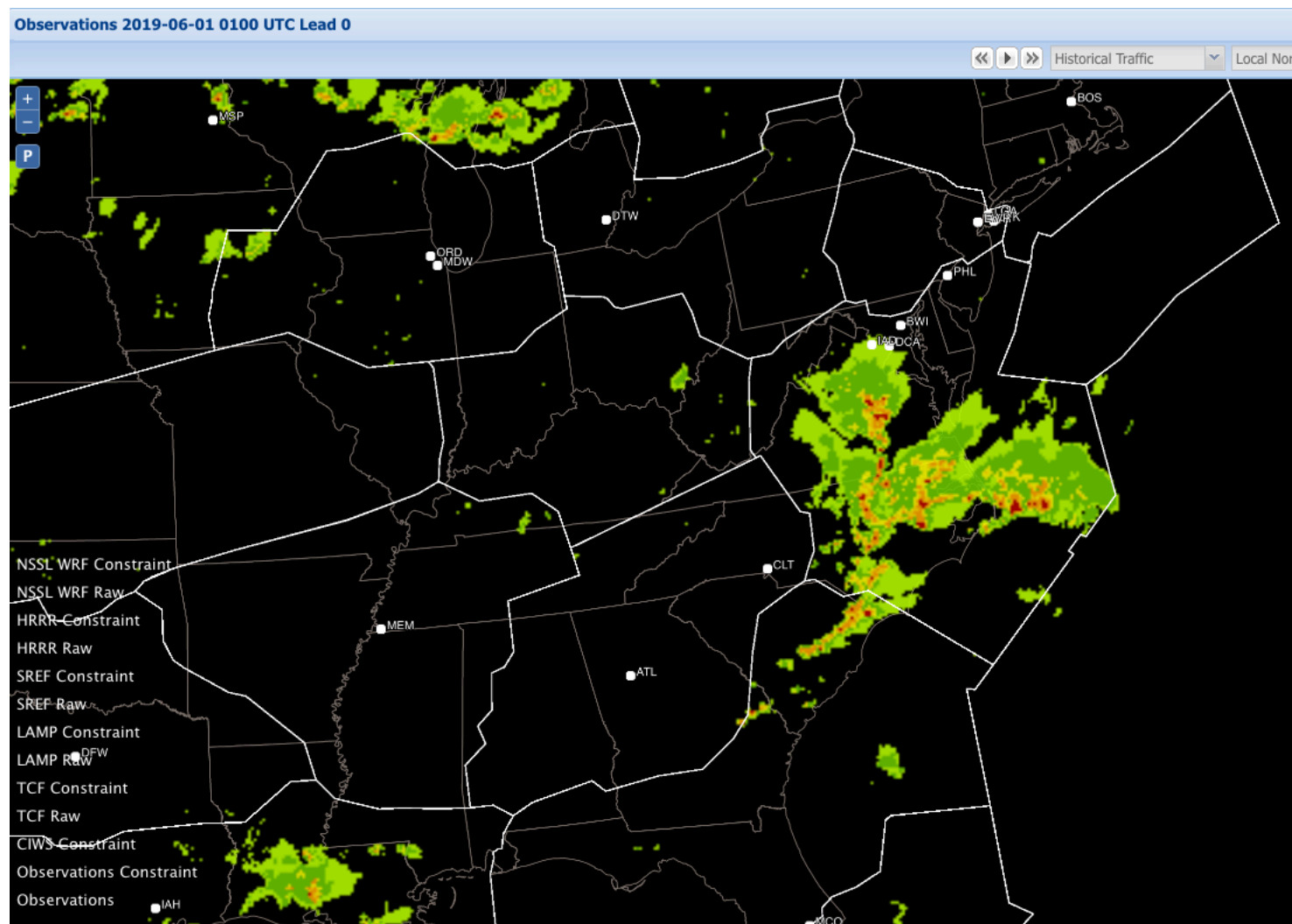


# Ideas for Future Airspace Capacity Estimation

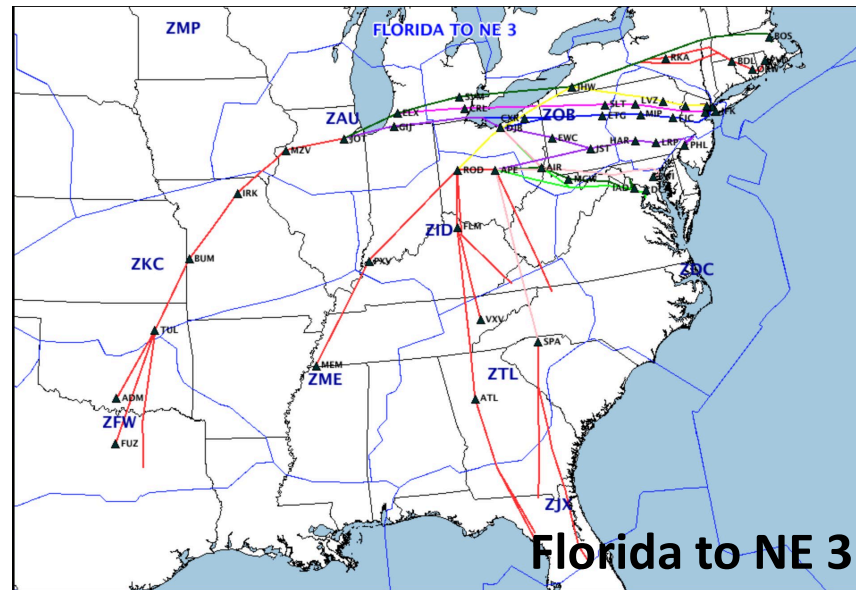
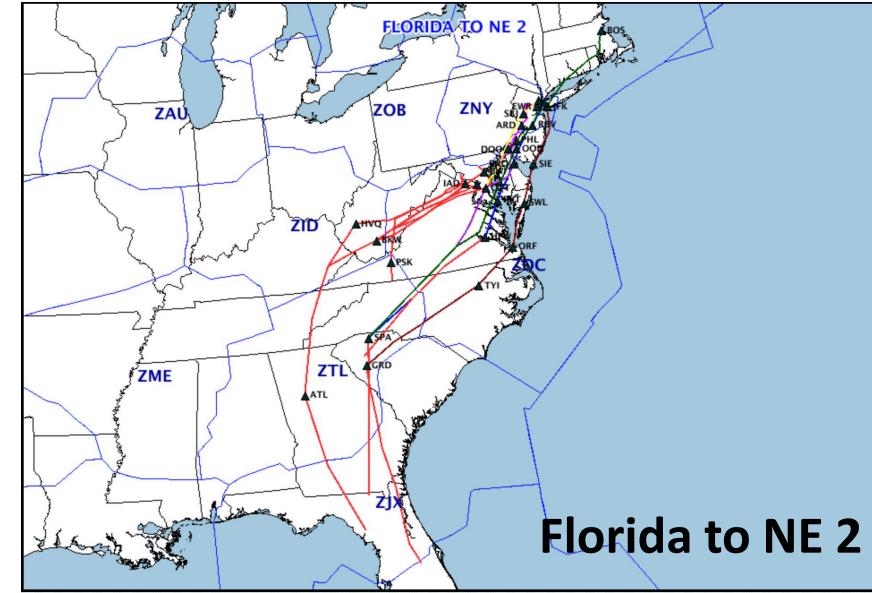
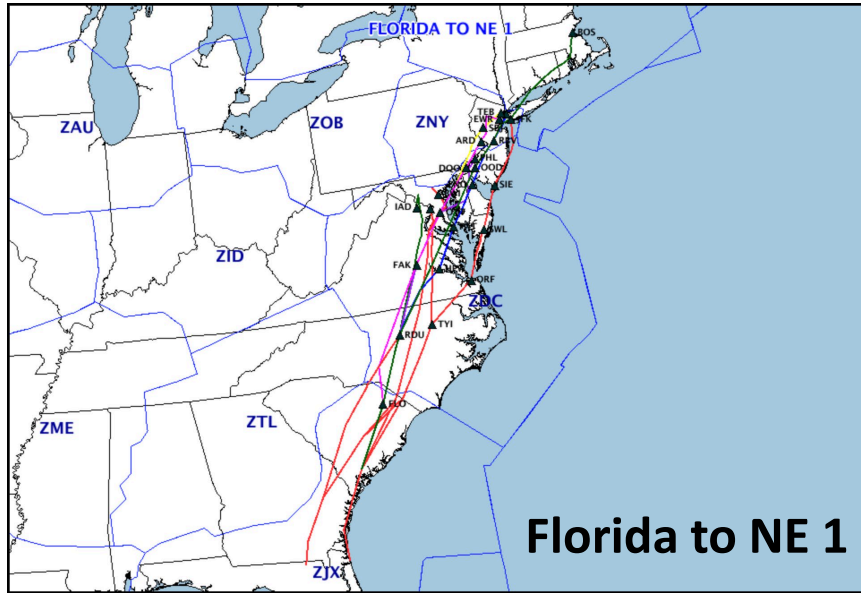
- Playbook selection by rank ordering impacts from weather
- Model optimal free flight around hazards
  - Flow Constraint Mitigation
- Calculate capacity and constraint in the terminal area on approach

# Playbook Recommendation

Area of thunderstorms in Virginia and the Carolinas, blocking north-south traffic along the eastern seaboard.



# Playbook Recommendation



# Playbook Recommendation

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research | National Weather Service

**NOAA INSITE**  
INtegrated Support for Impacted air-Traffic Environments

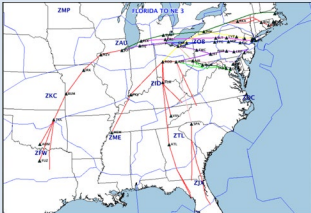

Auto Update

**Overview Constraint > Atlanta (KZTL)**

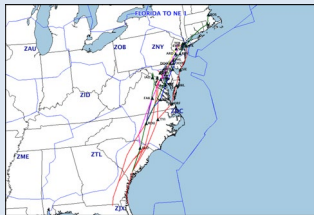

Alert Dashboard Options Help

Valid Hour (UTC)  
15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07


**#1 Playbook: Florida to NE 3**



**#2 Playbook: Florida to NE 2**

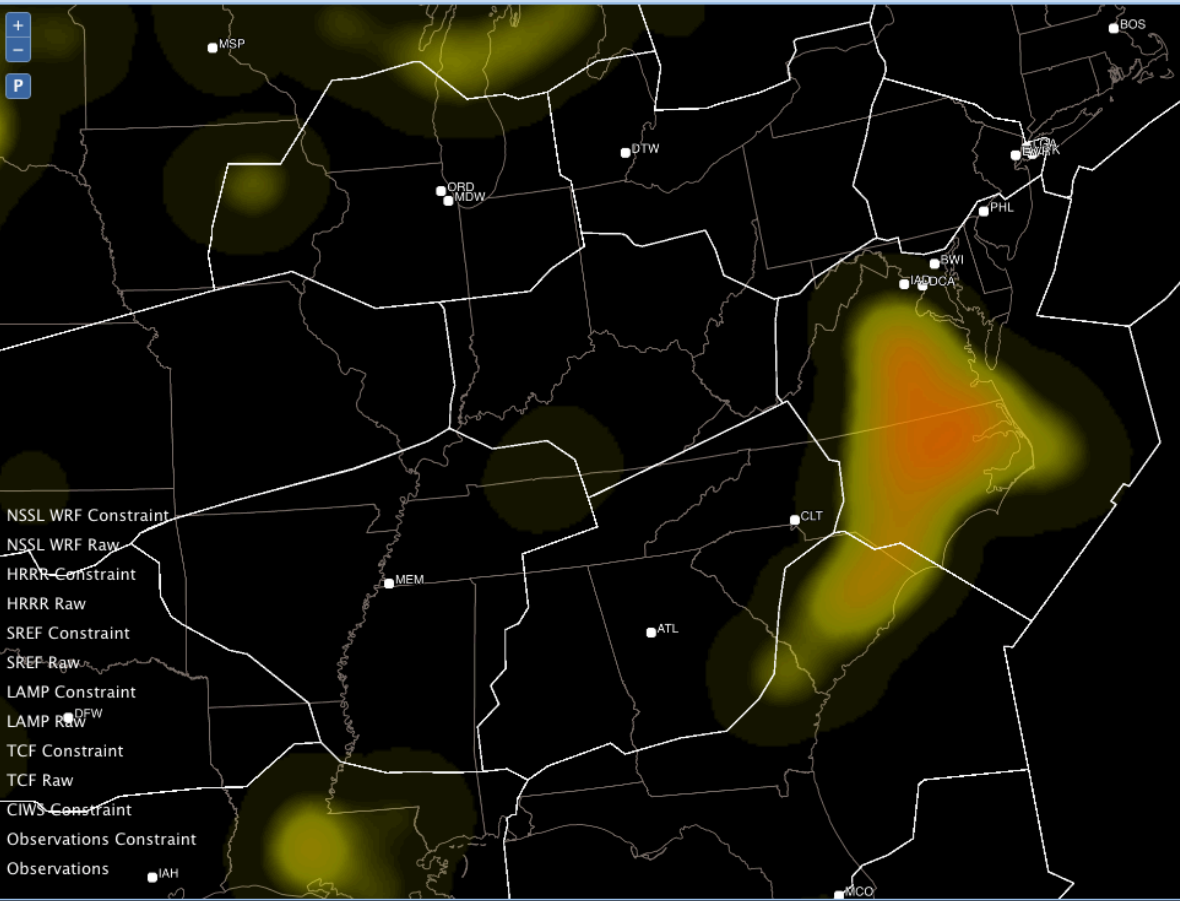


**#3 Playbook: Florida to NE 1**



Select All Select None Apply

Observations Constraint 2019-06-01 0100 UTC Lead 0



Historical Traf

NSSL WRF Constraint  
NSSL WRF Raw  
HRRR Constraint  
HRRR Raw  
SREF Constraint  
SREF Raw  
LAMP Constraint  
LAMP Raw  
TCF Constraint  
TCF Raw  
CIWS Constraint  
Observations Constraint  
Observations

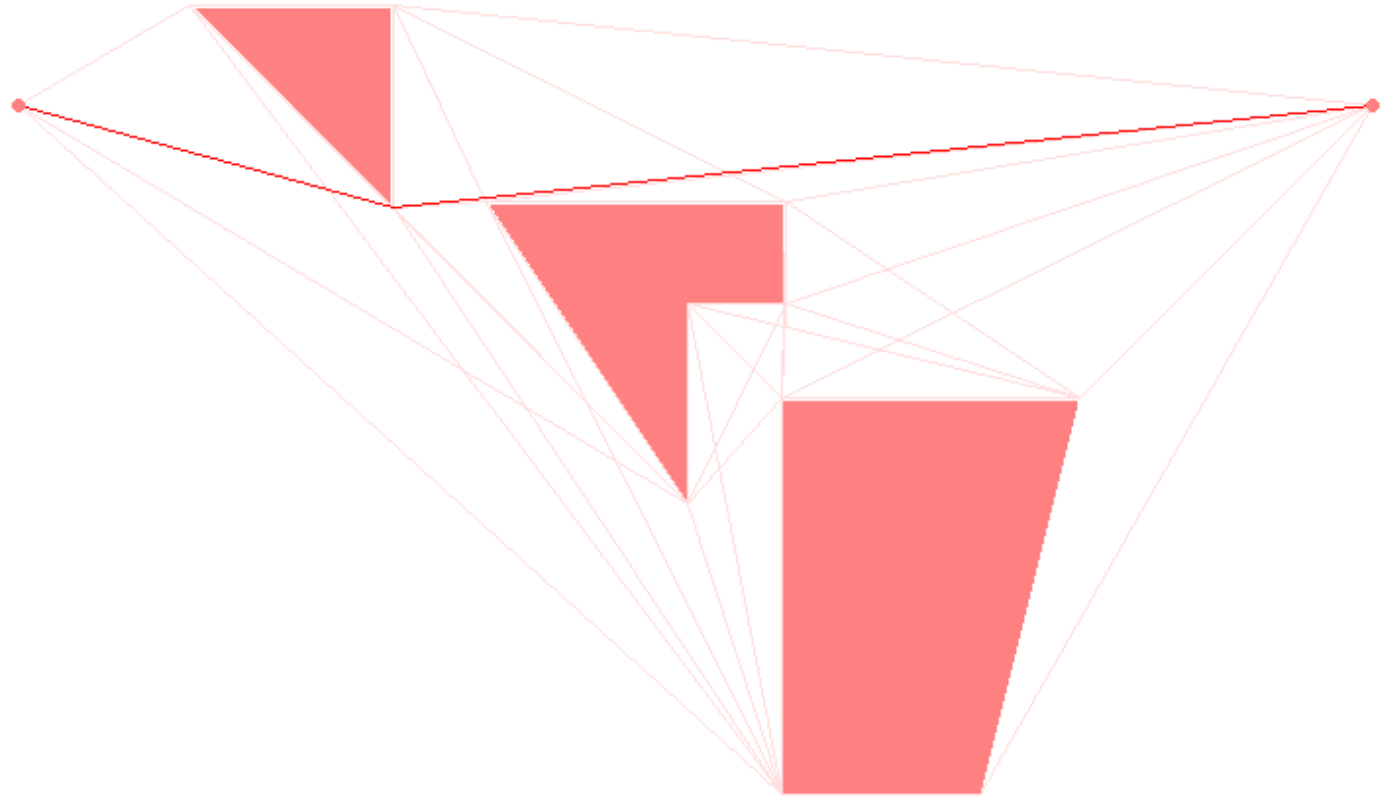
Airway Overlays Other Overlays Product Navigation Placement  
 Primary  Secondary  Tertiary  Airport  ARTCC Left Side Right Side

User Guide Import/Export Reset

javascript:insite.app.getController('Common').displayOverview();

# Modeling Optimal Free Flight

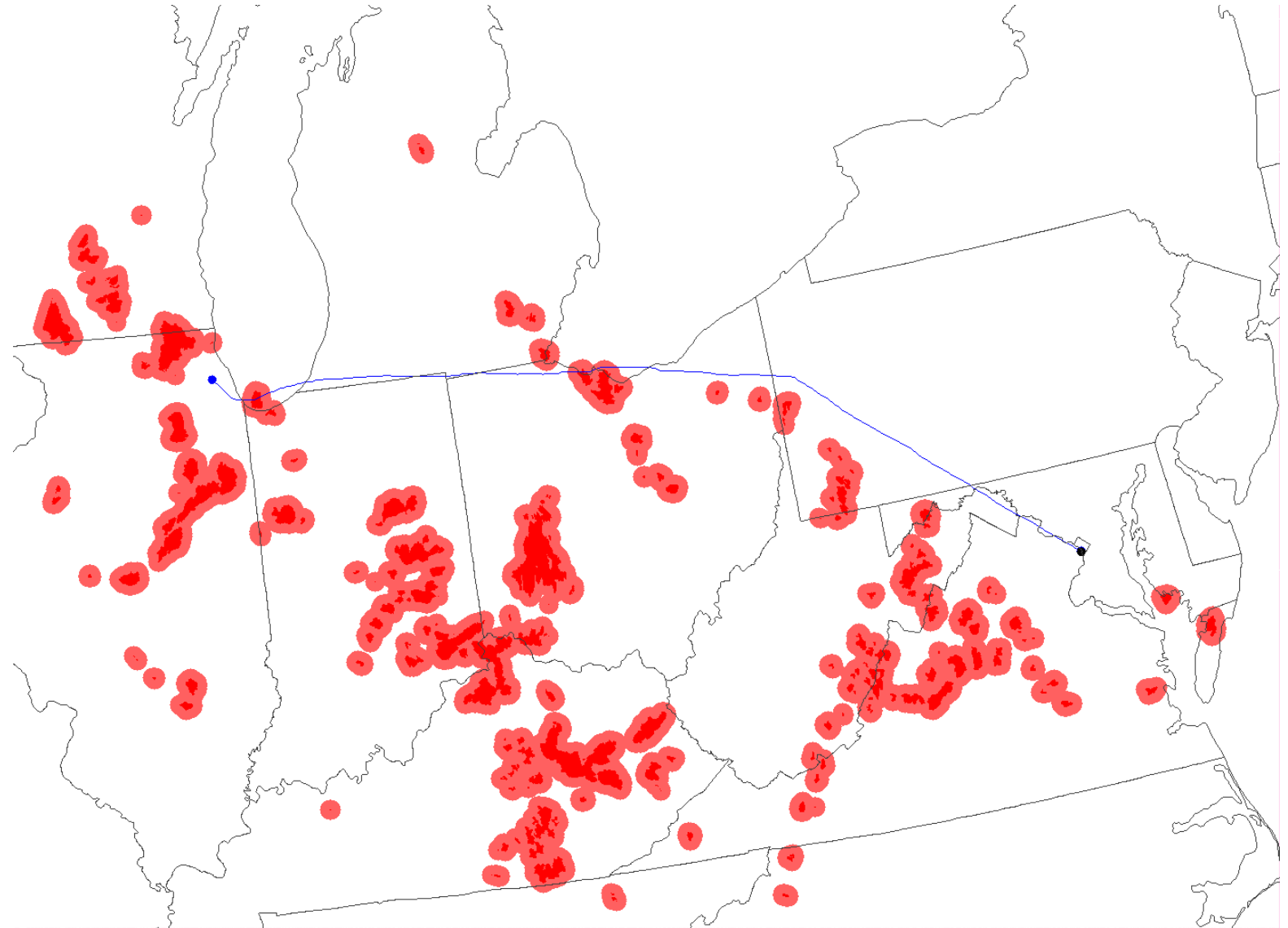
- Construct a Graph
  - Each vertex of an object is a Node
  - Edges are defined between all Nodes if the connection does not pass through any object
  - Source and Sink represent the departure and arrival airport
- Use a Shortest Path algorithm to solve
- Differences in Graph as compared to FCI
  - Each object is a Node
  - Edges are shortest path between objects
  - Source and Sink of the corridor sides





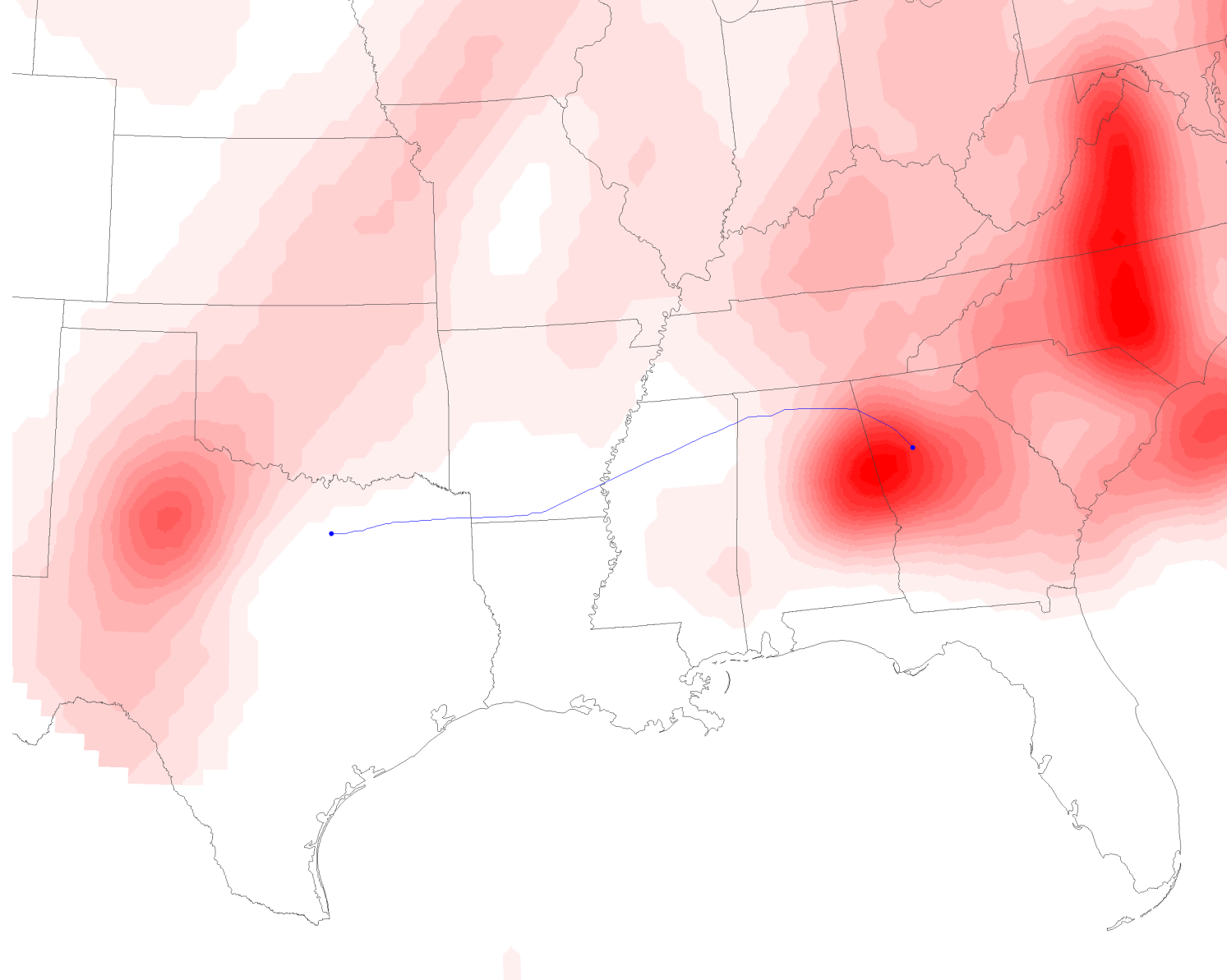
# Modeling Optimal Free Flight

Accounts for storm motion by matching the timing of aircraft position with observation or model forecast times



# Modeling Optimal Free Flight

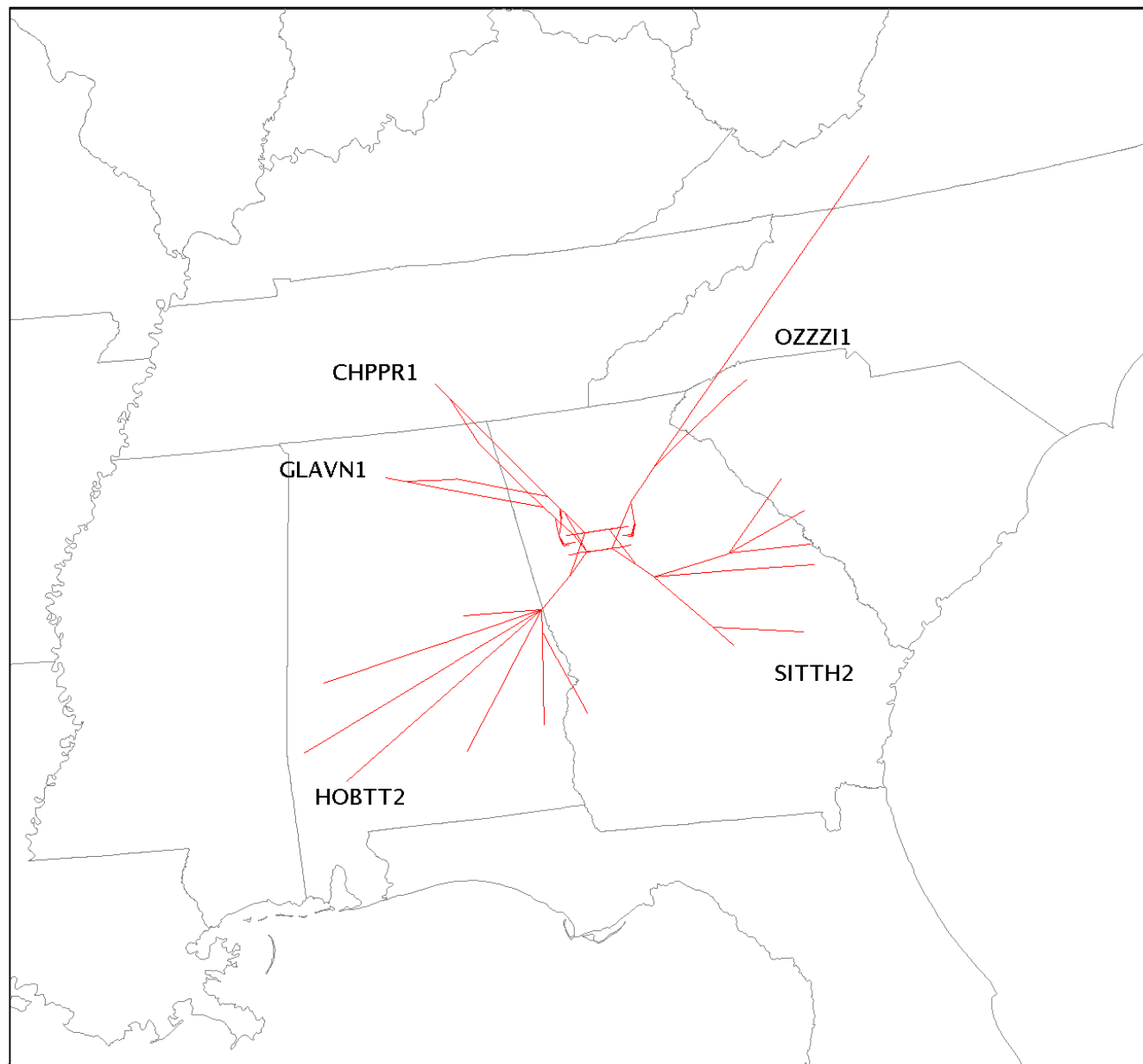
Optimizes the trade-off between additional flight distance and probability of encountering a hazard



# Terminal Area Capacity and Constraint

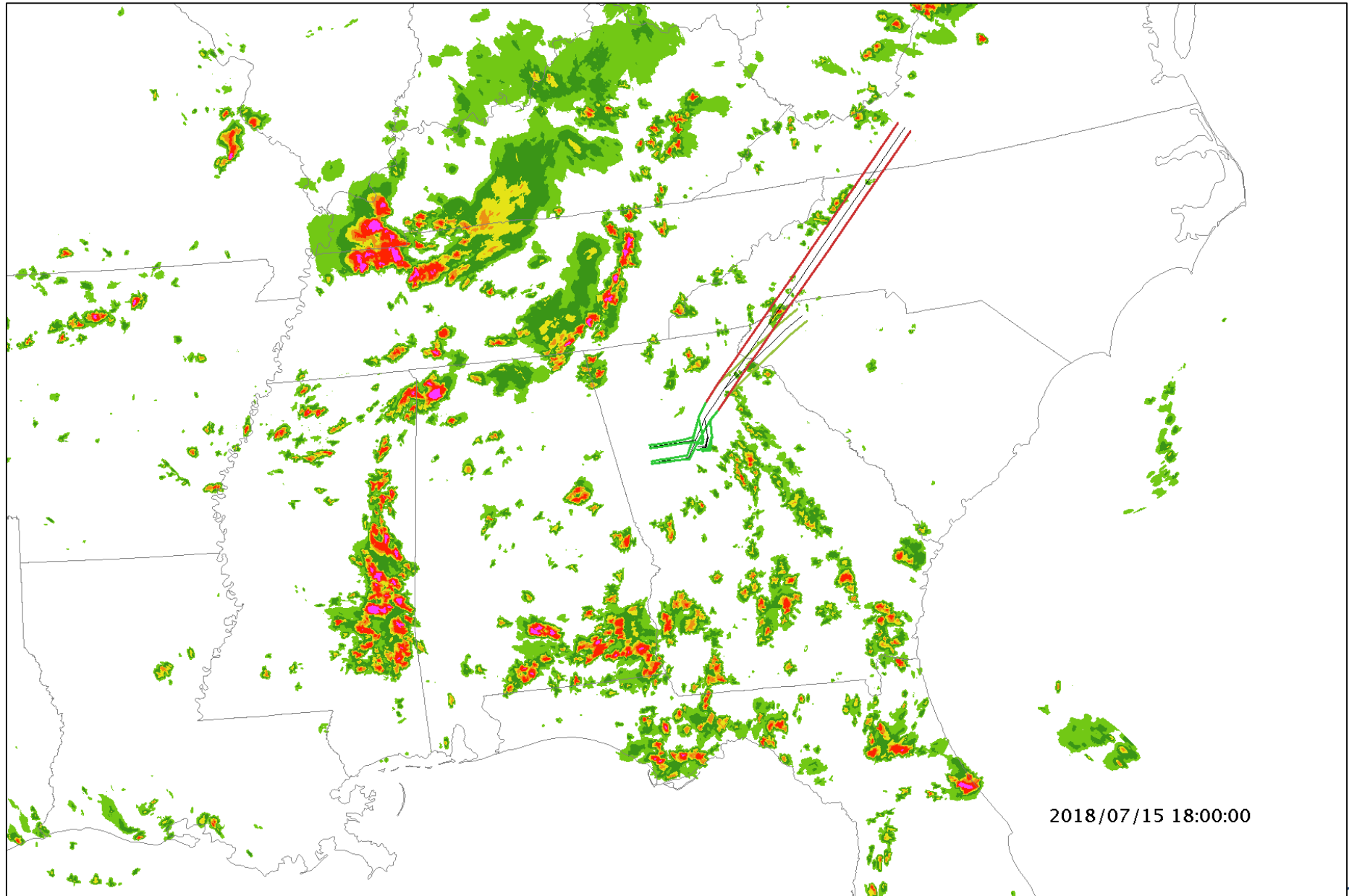
FCI works better en route, it doesn't make as much sense near the terminal.

Divide this space into narrow corridors for STARs/SIDs and weighted sum of traffic on approach into airports.



# Terminal Area Capacity and Constraint

Forecast verification –  
does the forecast give  
you good information  
about near terminal  
operations



# **Alternative Approach based on Convective Weather Forecast**

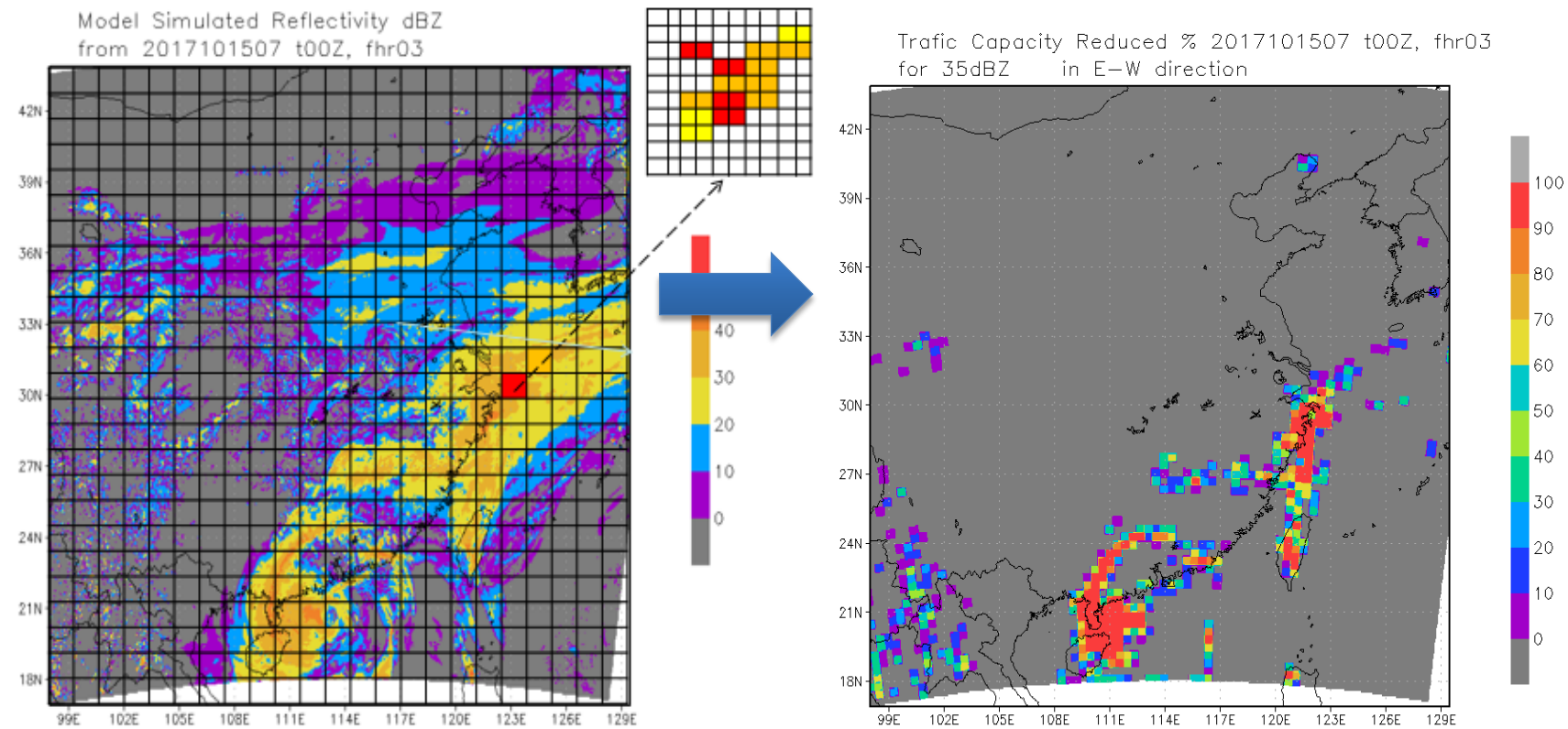
(4/29/2021)

Le Jiang (IMSG)

- Directly apply Min-cut theory using high res. numerical forecast/ nowcast
- ✓ Square Box built over forecast/nowcast grids to estimate flow capacity deduction rates in 8 directions
- ✓ Square Box is scalable based on forecast resolution and FCA
- ✓ One or multiple convection fields can be applied by setting appropriate thresholds (e.g. radar reflectivity, echo top, convection precipitation, icing, turbulence, etc.)
- ✓ The thresholds can be easily tuned (based on validation)
  
- Flow capacity reduction rate for Route Segments, Waypoints, and Sectors
- ✓ Step 1: translate weather forecast to capacity reduction rate forecast
- ✓ Step 2: estimate capacity rate reduction in Route Segments, then Way-points and Sectors (using aggregation)
  
- With or without (historical or current) flight data: In case of no flight data, capacity reduction rate is purely due to weather impact (same weighting in all directions)
  
- Performance depends on weather model performance
- ✓ Sensitive to convection weather field thresholds
- ✓ Easy validation if flight data are available

Example: Mesoscale Model – NMMB reflectivity 3 hour forecast over East China (left) is translated to 3 hour capacity reduction rate forecast in East-West direction with composite reflectivity threshold > 35 DBZ (right)

- Capacity reduction rate forecast in other directions can be done as well.
- Base on the projections over all directions, capacity reduction rates in various route segments, waypoints, and sectors can be estimated



GRADS: COLA/IGES

2018-03-08-16:03

✓ Validation was done in comparison to GSL's FCI-based approach, close match