Avoidable Delay in The NAS With Perfect Information of Enroute Convective Weather

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Motivation

- Value of perfect information
- Investment requirements for improved weather forecasts
- Performance metrics: observed vs. optimal
- Performance measurements for future system
  - change in the levels capacity/demand

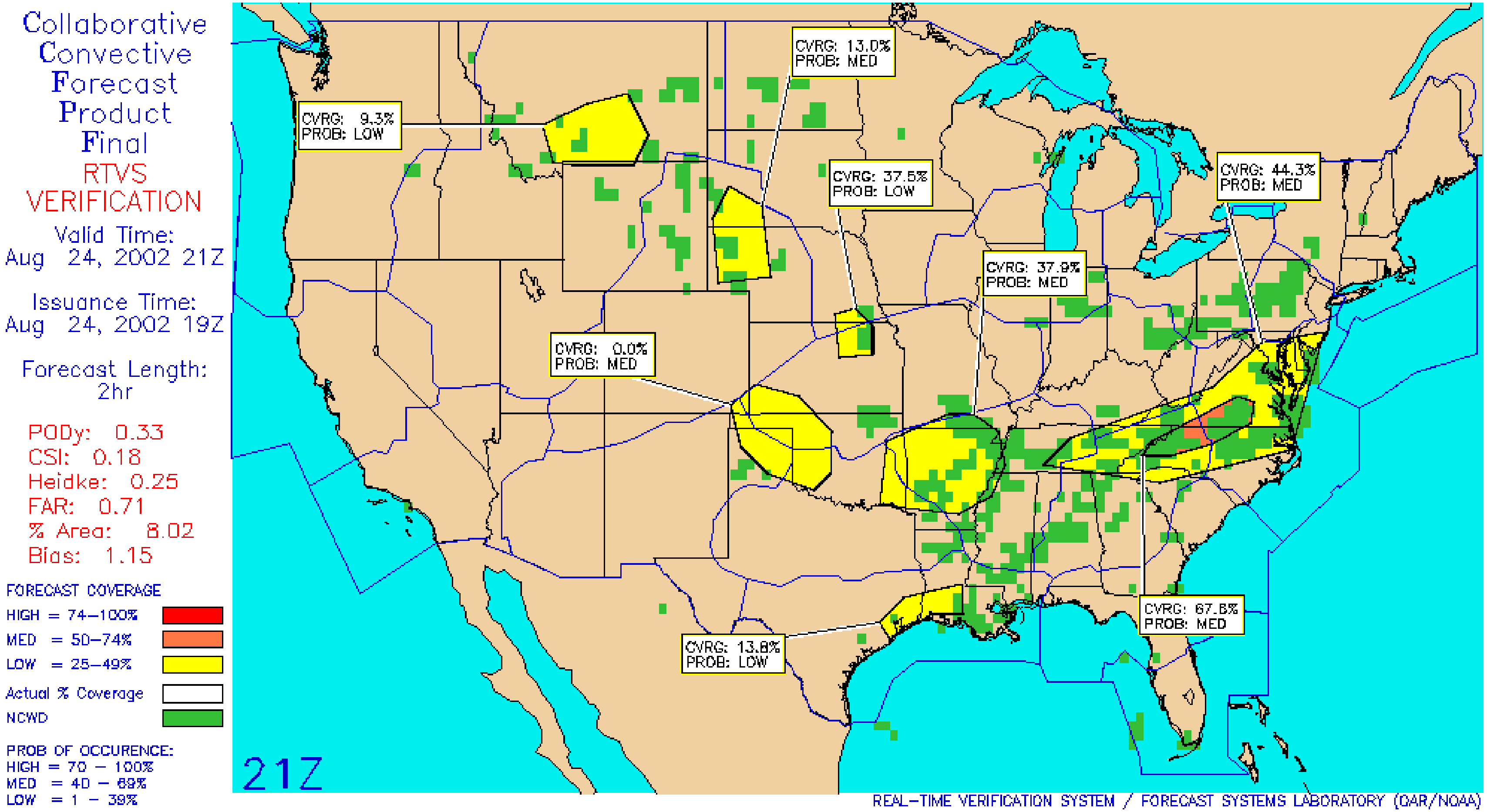
Present Study

- Estimating Benefits of Using Convective Integrated Weather Systems (CIWS) Echo Tops Product
  - Gives the location and altitude of storm cells
  - Ability to fly over storm if the altitude information is known in advance

- Need to determine what would have been done had not the CIWS echo tops product been used to determine that planes could fly over storms

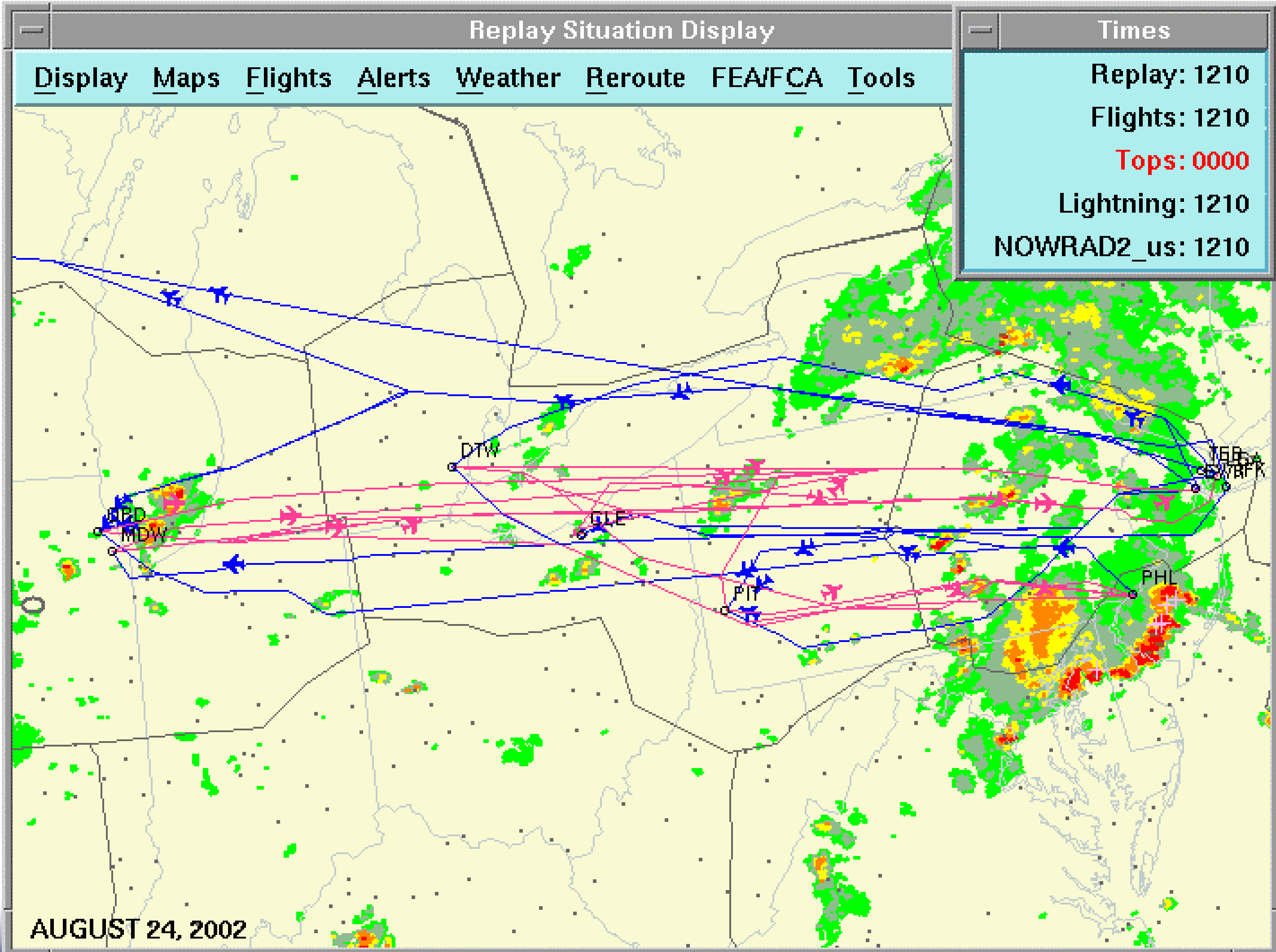
- Case Study: August 24, 2002

CCFP and Validation for 24 August 2002



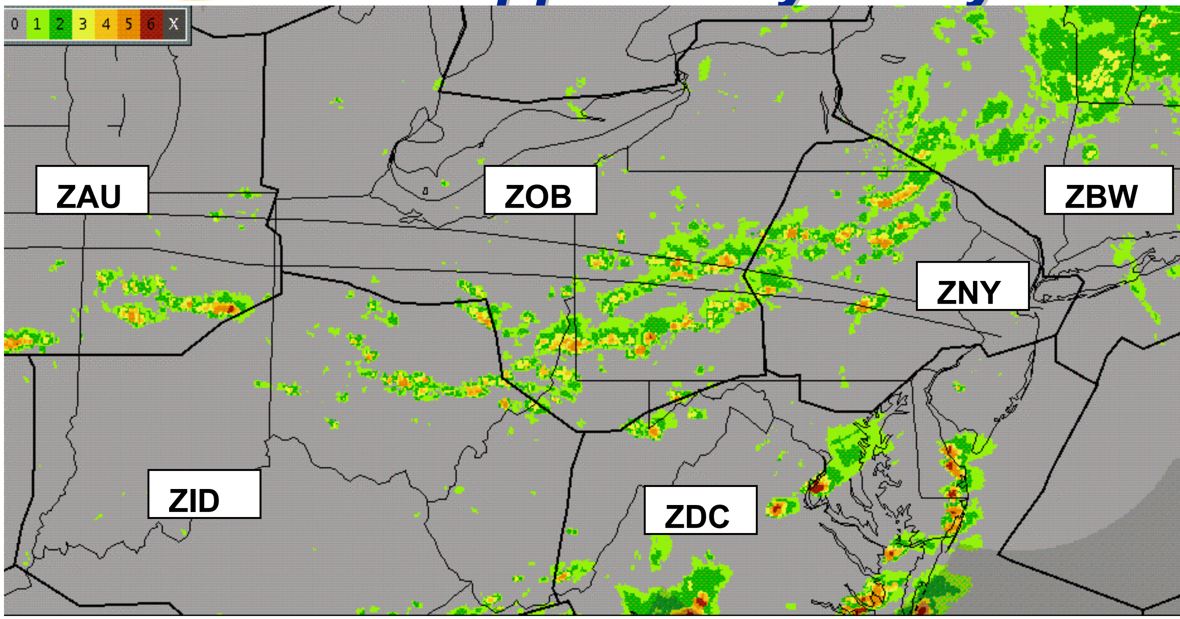
CCFP validation shows significant weather in Pennsylvania. Note also that reroutes south of Pennsylvania would encounter congestion due to severe weather in NC and VA

Case Study: Aug 24, 2002



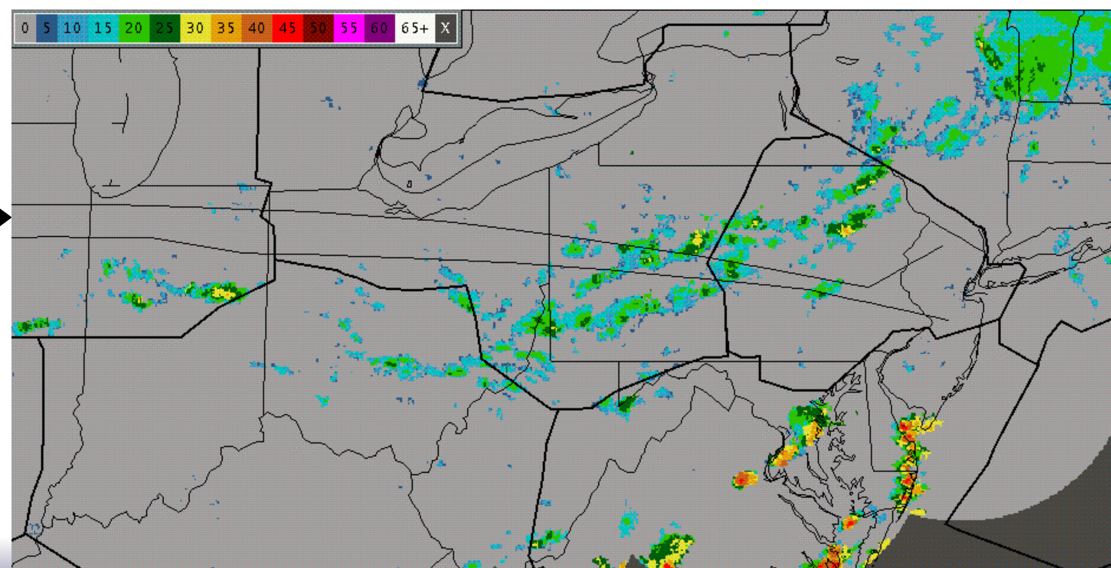
Use of CIWS Echo Tops Map to Identify Opportunity to Fly Over Storms

24 August 2002



NEXRAD VIL

Echo Tops



Methodology

- Optimal decisions under perfect knowledge of weather
  - Need to use decision making tool
  - Air Traffic Flow Management Model (TFMP)
- Comparing optimal delays with and without information about altitude of weather cells
- Comparing the delays from TFMP to what happened in reality

Air Traffic Flow Management Model (TFMP)

- Developed by Bertsimas et al.
  - Integer Programming Model
  - LP relaxation almost always integral
- Used to determine the optimal decisions with perfect knowledge of weather.
- Dynamic and Deterministic.
- Rerouting algorithm

Set of Airports {K};
Set of Sectors {J};
Set of Flights {F};
Set of Preferred Routes Between O-D Airport Pairs rt[f];

Feasible Time Periods: $T_f^j \in T$

Minimum Time Spent By Each Flight in The Sectors in its Flight Path: $l\min[f, j, r]$

Scheduled Departure and Arrival Times;

Cost of Holding a Flight in Air and Ground Per Unit Time Period;

Time Varying Capacities:

Airport Departure, Airport Arrival, Enroute Sectors

Decision Variable: $w_{f,t}^{j,r} \in \{0,1\}$

Ground Hold:

$$gf = \sum_{t \in T_f^k, k=org[f]} t\left(\sum_{r=1}^{rt[f]} \left(w_{f,t}^{k,r} - w_{f,t-1}^{k,r}\right)\right) - df$$

Air Hold:

$$af = \sum_{t \in T_f^k, k=des[f]} t\left(\sum_{r=1}^{rt[f]} \left(w_{f,t}^{k,r} - w_{f,t-1}^{k,r}\right)\right) - rf - gf$$

Objective Function:

$$Minimize : Z = \sum_{f \in F} \left(c_f^g g_f + c_f^a a_f\right)$$

Constraints:

1.Departure Capacity of Origin Airport:

$$\sum_{f:org[f]=k} \sum_{r=1}^{rt[f]} (w_{f,t}^{k,r} - w_{f,t-1}^{k,r}) \leq D_k(t) \qquad k \in K \quad t \in 1..T$$

2.Arrival Capacity of the Destination Airport:

$$\sum_{f:des[f]=k} \sum_{r=1}^{rt[f]} (w_{f,t}^{k,r} - w_{f,t-1}^{k,r}) \leq A_k(t) \qquad \forall k \in K, t \in 1..T$$

3.Sector Capacities:

$$\sum_{f \in F\_Sect[j]} \sum_{r=1}^{rt[f]} (w_{f,t}^{j,r} - w_{f,t}^{next(j,path\_F[f,r]),r}) \leq S_j(t) \qquad \forall j \in J, t \in 1..T$$

4.Sector Connectivity:

$$w^{j',r}_{f,t+l^r_{f,j}} - w^{j,r}_{f,t} \le 0 \begin{Bmatrix} \forall f \in F, r \in 1..rt[f], j \in path\_F[f,r] \\ t \in T^j_f, j' = next(j, path\_F[f,r]) \end{Bmatrix}$$

5.Time Connectivity:

$$w^{j,r}_{f,t} - w^{j,r}_{f,t-1} \ge 0 \quad \forall f \in F, r \in 1..rt[f], j \in path\_F[f,r], t \in T^j_f$$

6.Reroute:

$$w^{j}_{f,t} = \sum_{rt[f]} w^{j,r}_{f,t} \qquad \forall f \in F, j \in path\_F[f,r], t \in T^j_f$$

6.No Cancellation:

$$\sum_{r=1}^{rt[f]} w^{k,r}_{f,Tm^k_f} = 1 \qquad \forall f \in F, r \in 1..rt[f], k = des[f]$$

TFMP Continued…..

- Inputs to the model
  - Set of Flights, Airports, Enroute Sectors
  - Time varying capacities of various NAS components
  - Set of preferred routes/available routes between each O-D airport pair.
  - Scheduled departure and arrival times of the flights.
  - Minimum time required to spend by each flight in the sectors in its flight path.

TFMP continued….

- Objective: Minimize Overall Delay Cost
  - Ground Hold and Enroute Delay

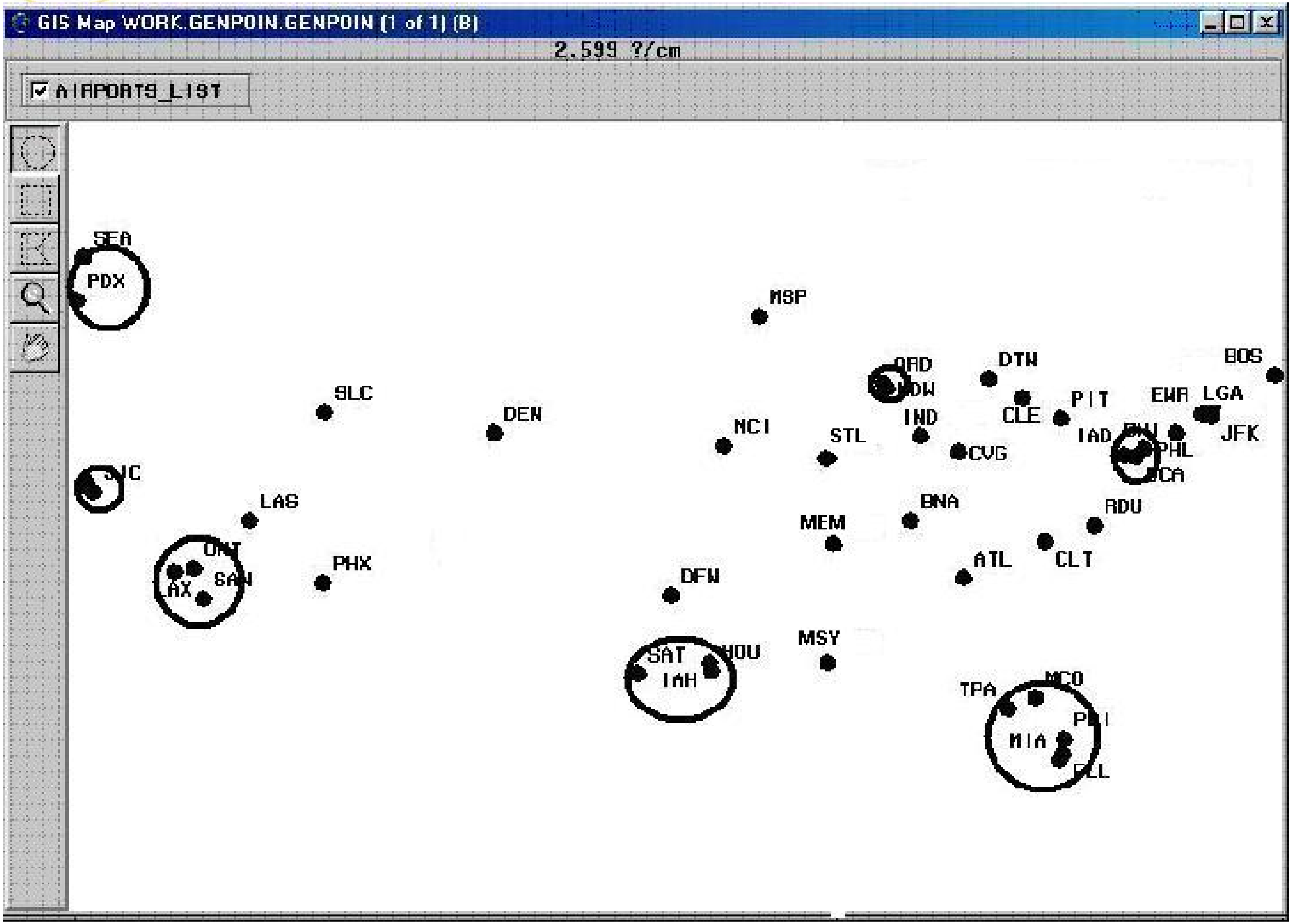
- Constraints of Bertsimas Model
  - Airport departure and arrival capacities
  - Enroute sector capacities
  - Sector connectivity
  - Time connectivity (minimum time spent in a sector for a flight)

- Optimal Decisions: Ground delay, route choice and enroute delay for each flight

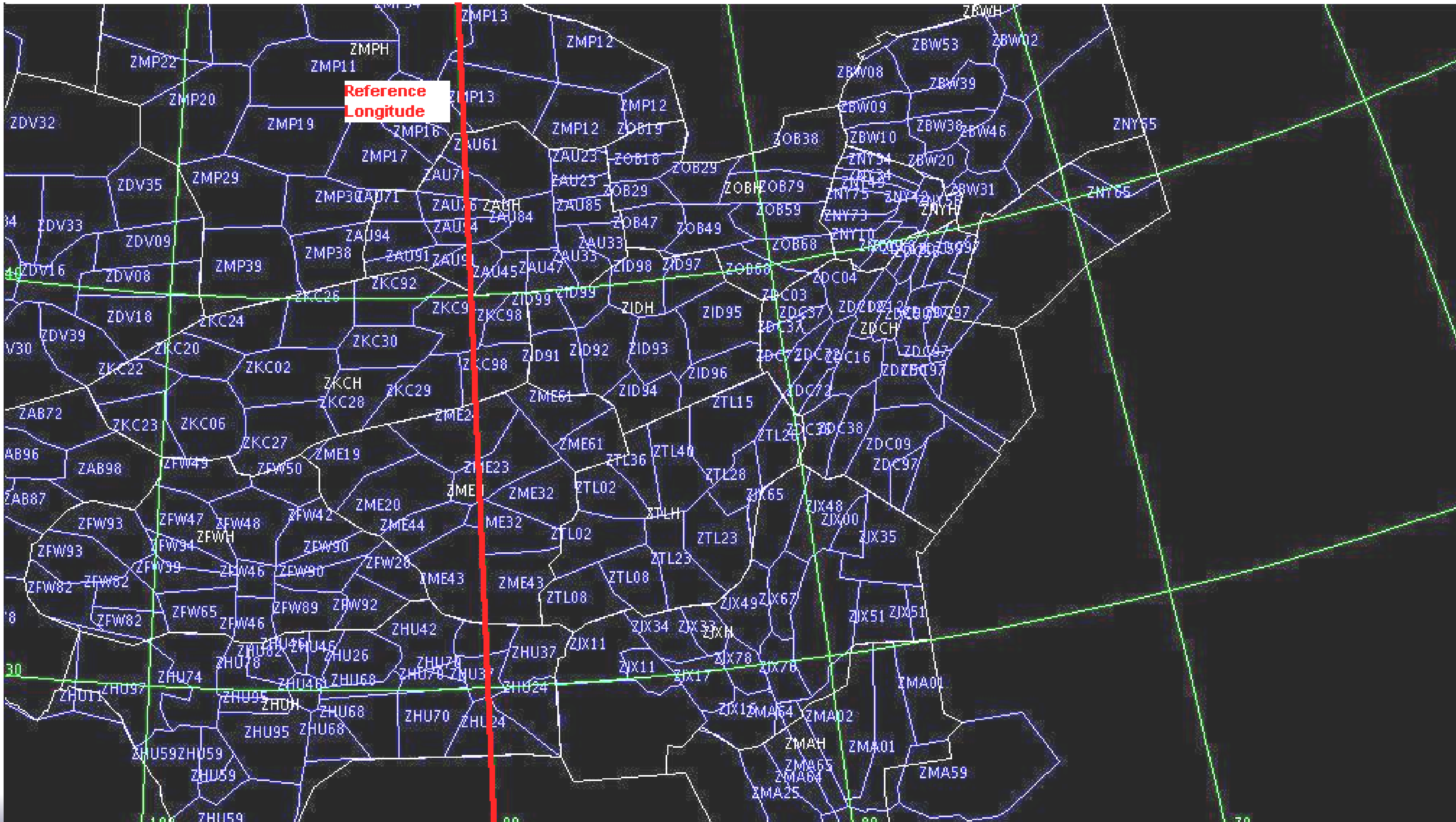
Data Availability

- Individual Flights Data from FAA-ASPM
  - Scheduled departure and arrival times
  - Flight numbers, Origin, Destination
- FAA- Coded Departure Routes Database (CDR)
  - Preferred Routes Between O-D Pairs
- Sector Configuration and Good Weather Capacities
  - FAA, NASA Ames
- Airport Capacities from ASPM Database

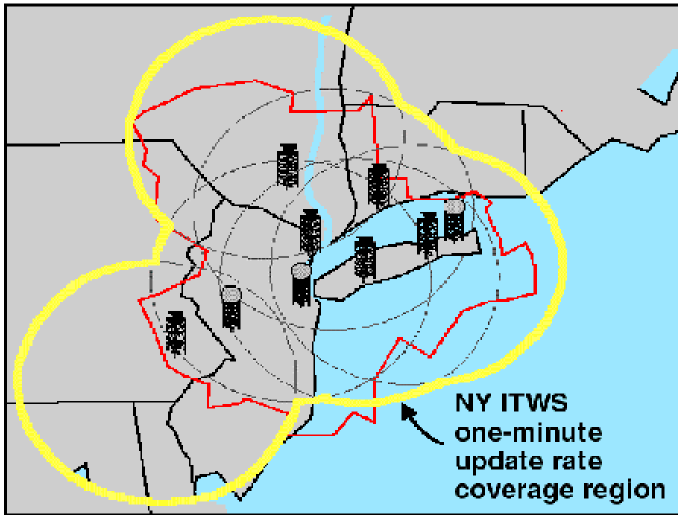
Airports Selected



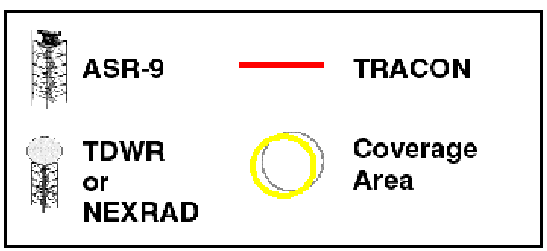
Sectors Considered



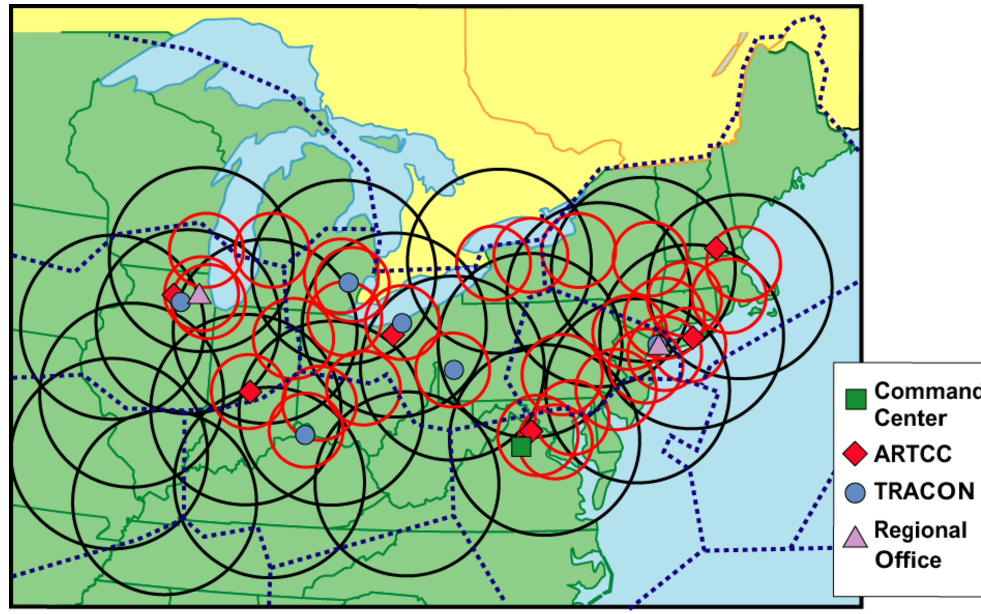
Weather Data Availability



TRACON



NY Integrated Weather System (ITWS)

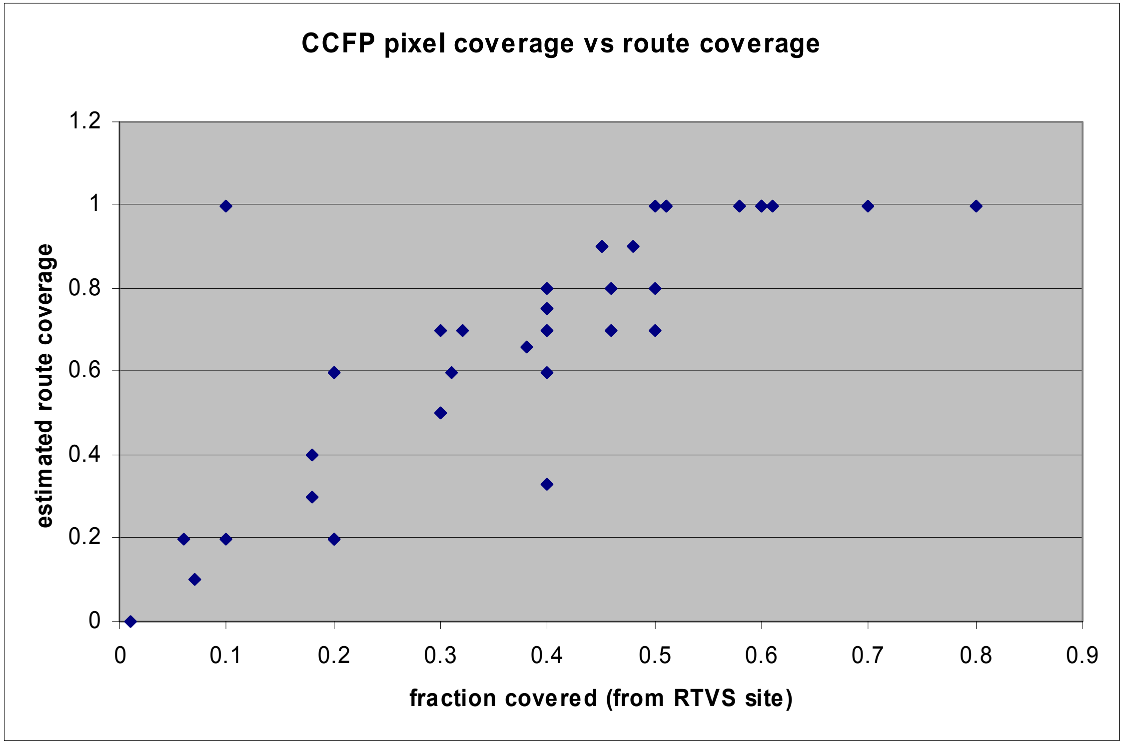


ASR-9 (60 nmi) NEXRAD (124 nmi [230 km])

Corridor Integrated Weather System (CIWS)

Estimating Sector Capacities from Weather Coverage

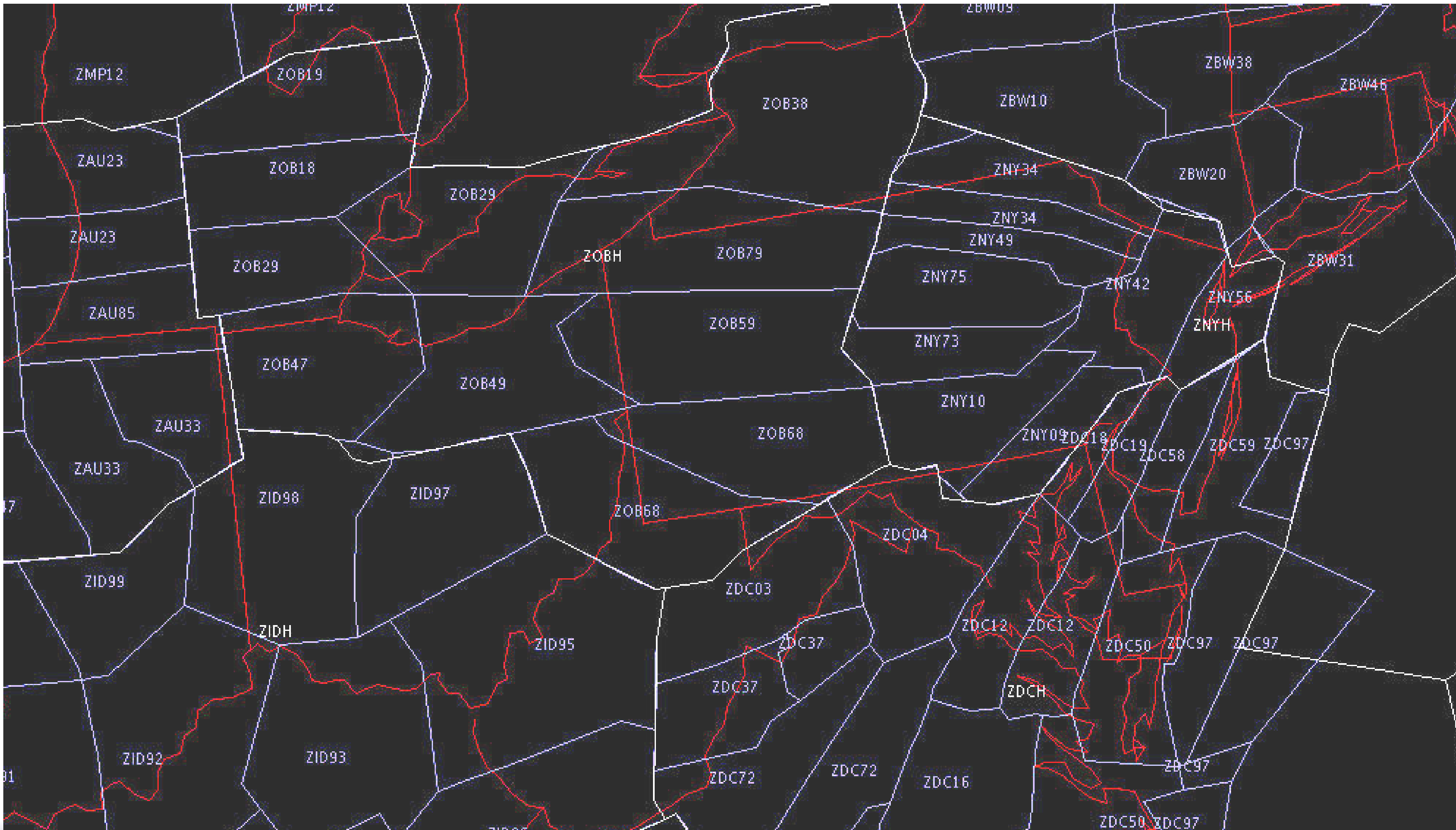
- Routes blocked due to weather
- Lookup function



Source: Jim Evans

$$SectorCapacity_t = (1 - \min(1, c \times percentage\_coverage_t)) \times Max\_Capacity$$

Capacity Estimation Contd..

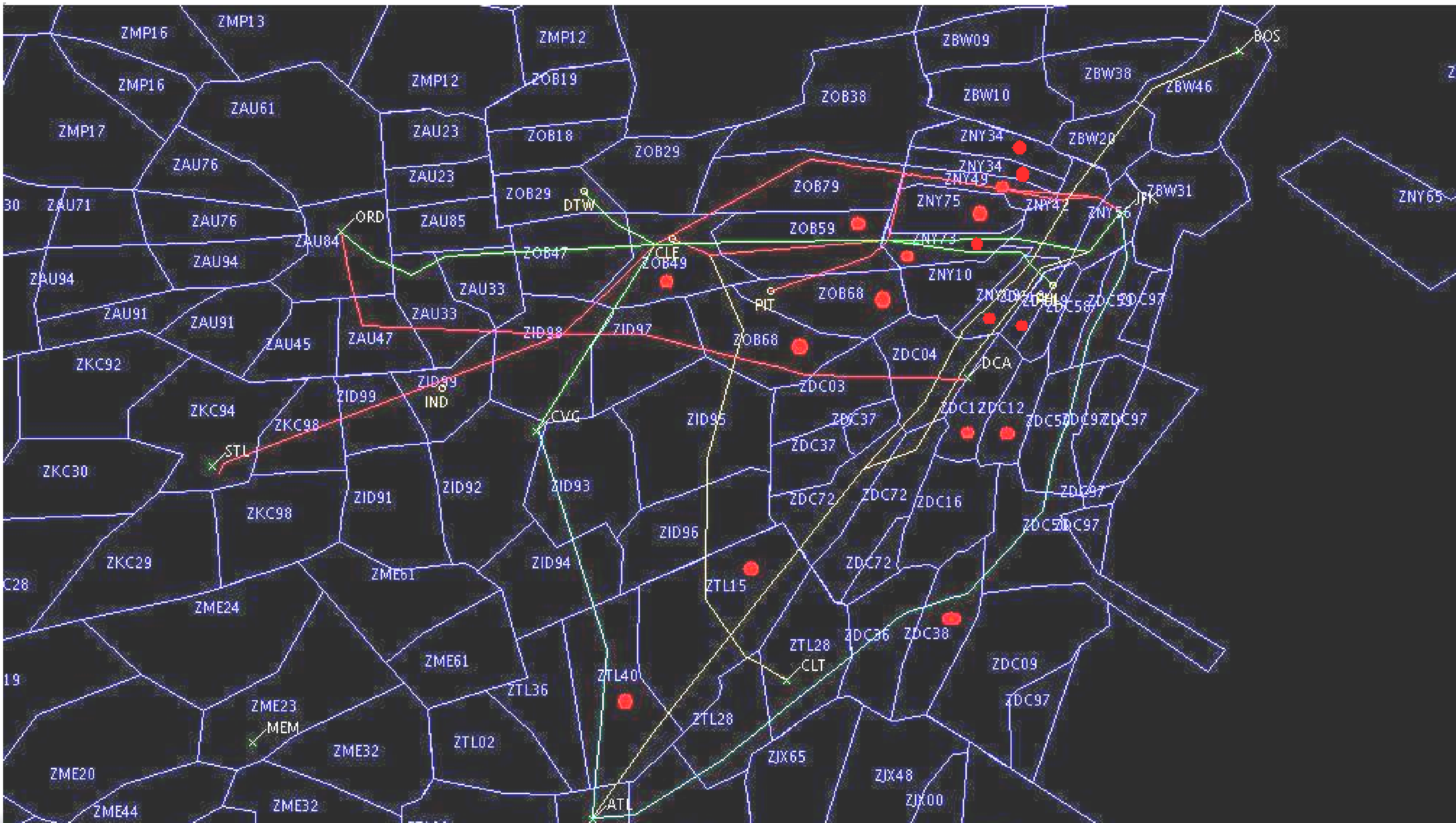


Optimization Model

- Weather Data Available for 4 Hours: 18Z to 21Z
- Time Window for Flights Selection: 18:00 to 24:00 Zulu
- Run in Two Tiers
  - 1st tier: Long Distance and Earlier Flights: Total of 1013 Flights
  - Sector Capacities and Airport Operation Rates Reduced to Count for the Earlier Flights
  - 2nd tier: Flights Within Time Window (18 – 24Z): 1387 Flights
- CCFP Validation Used to Capture the Effects of Weather In South (Over Atlanta)

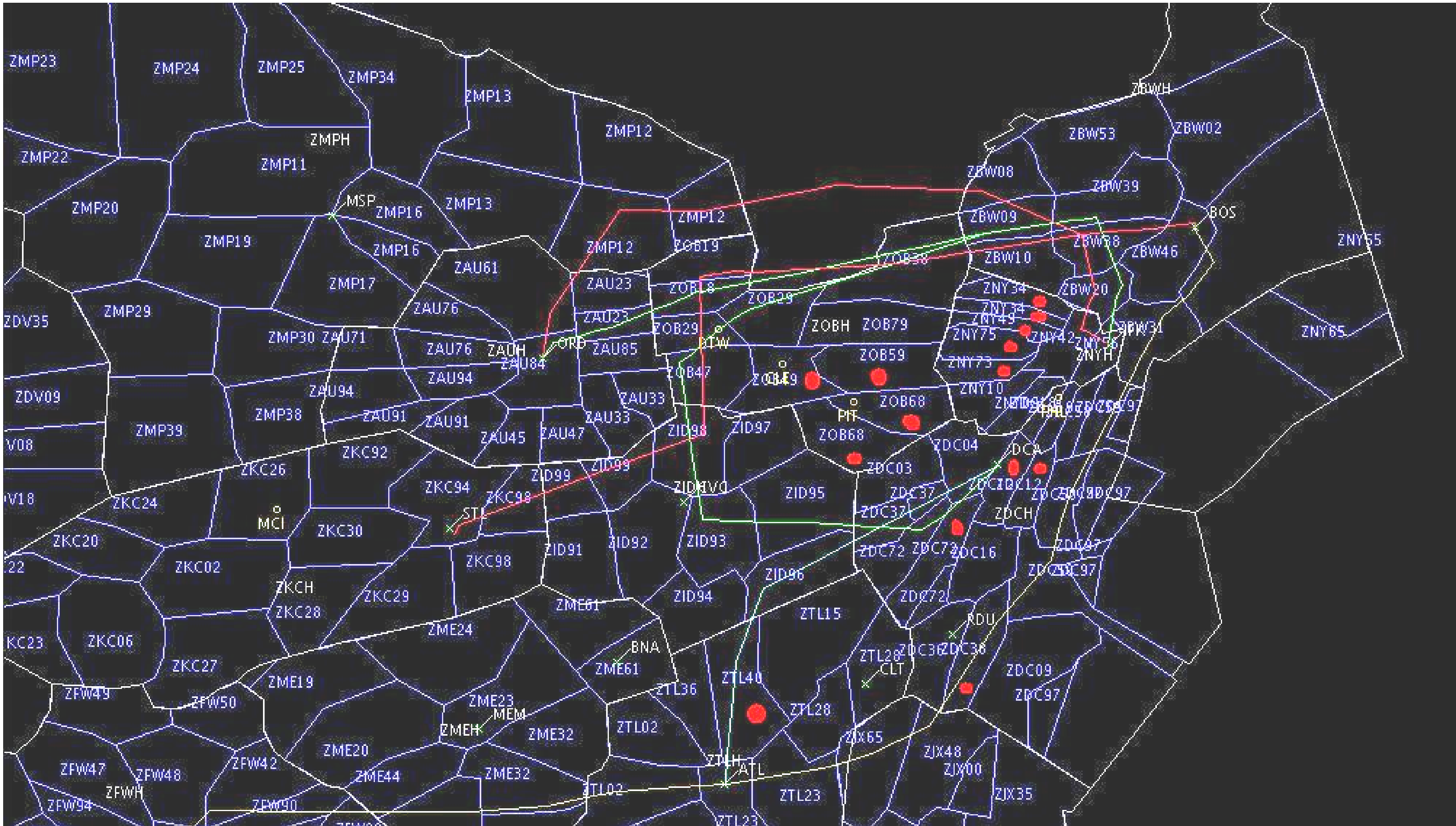
NEXTOR

Primary Routes Between some O-D pairs



NEXTOR

Additional Routes for Some O-D Pairs



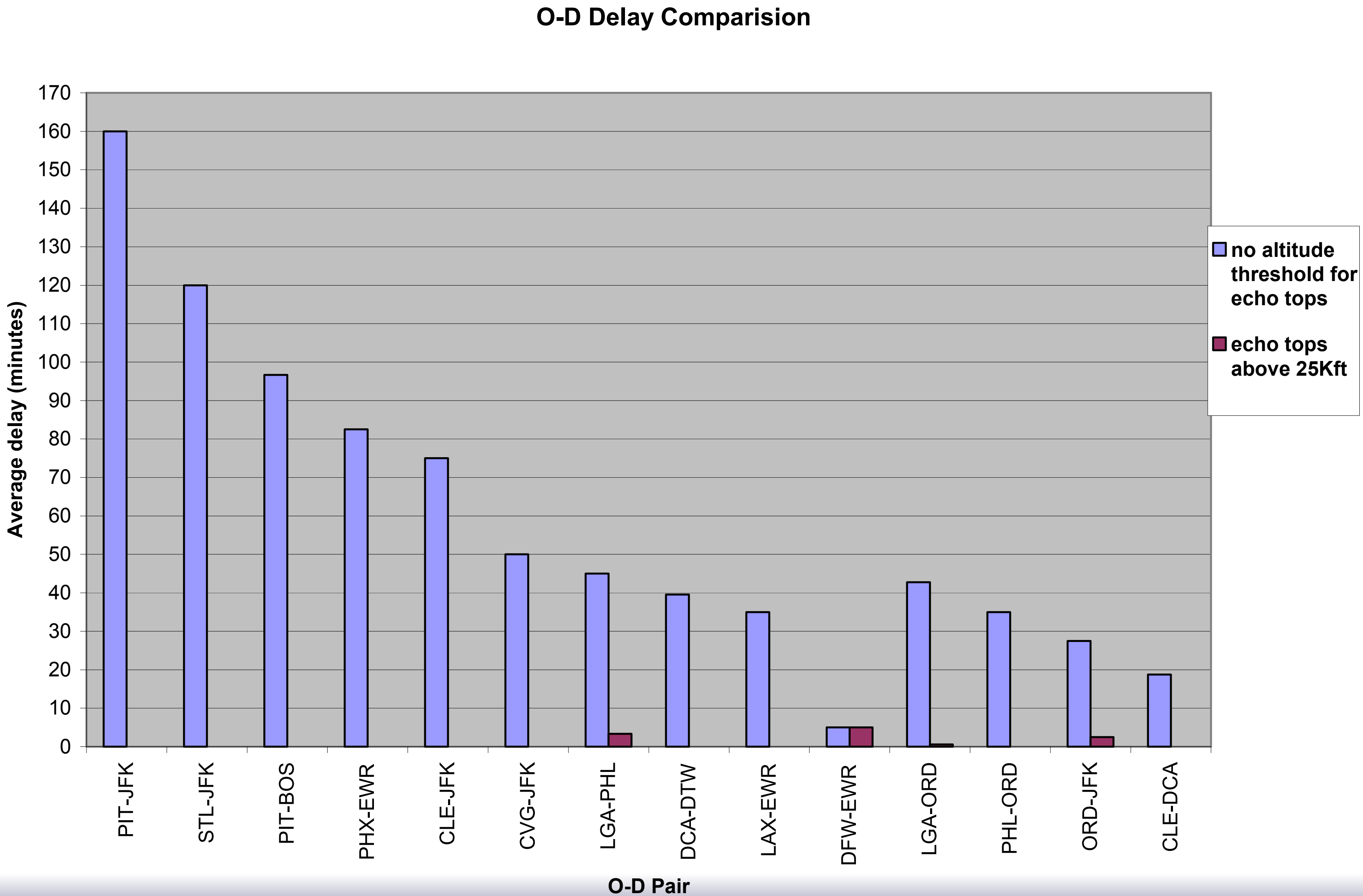
Key Results

- Average Delay from Bertsimas et al. TFMP without Information on Altitudes of Echo Tops: 6.42 minutes/flight

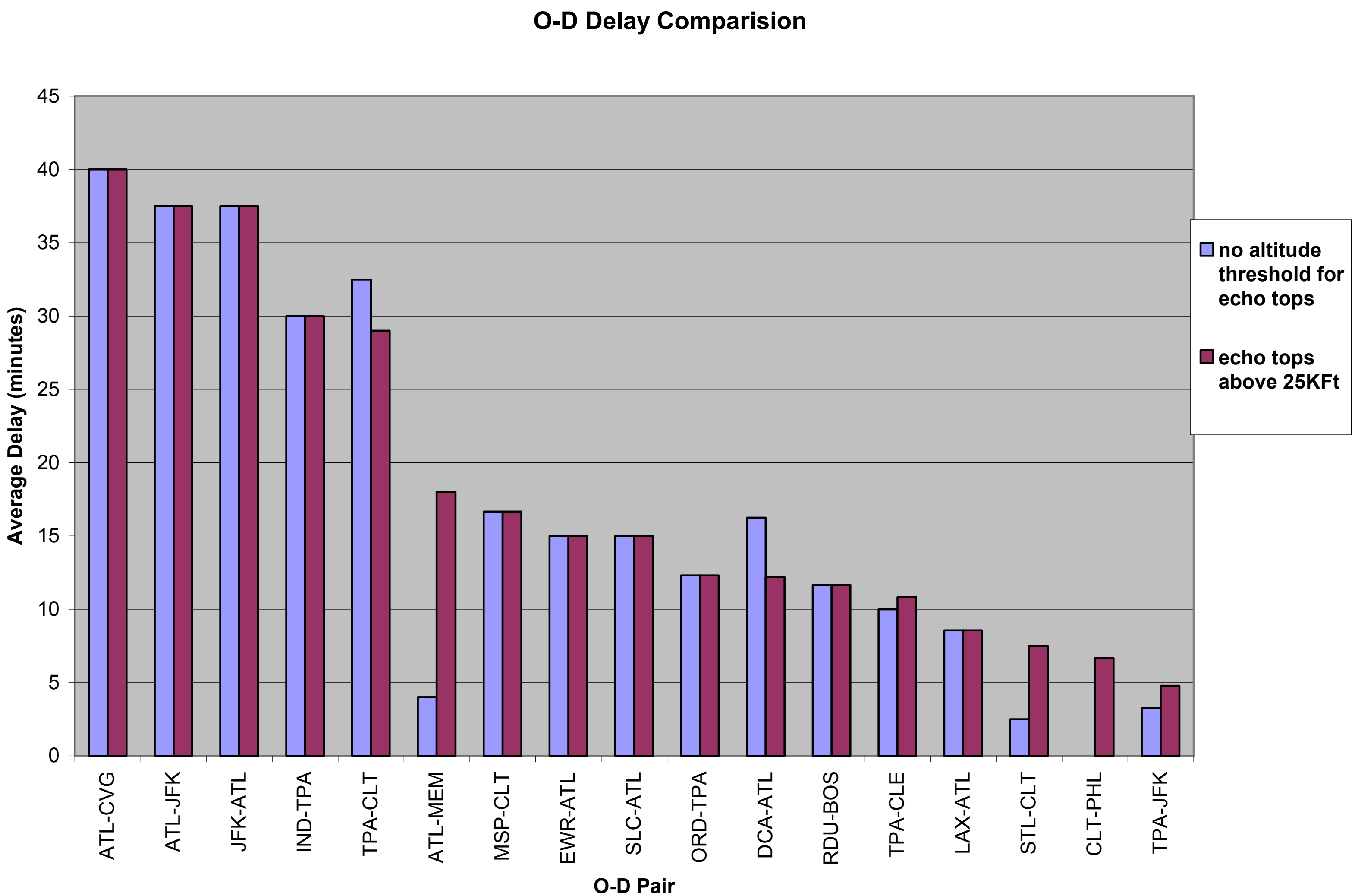
- Average Delay from With Echo Tops Above 25Kft: 2.46 minutes/flight

- Average Delays from ASPM
  - 0.62 minutes/flight for flights selected on Aug 24th
  - -7.07 minutes/flight on a good weather day: Aug 7th

O-D Delays (East West)

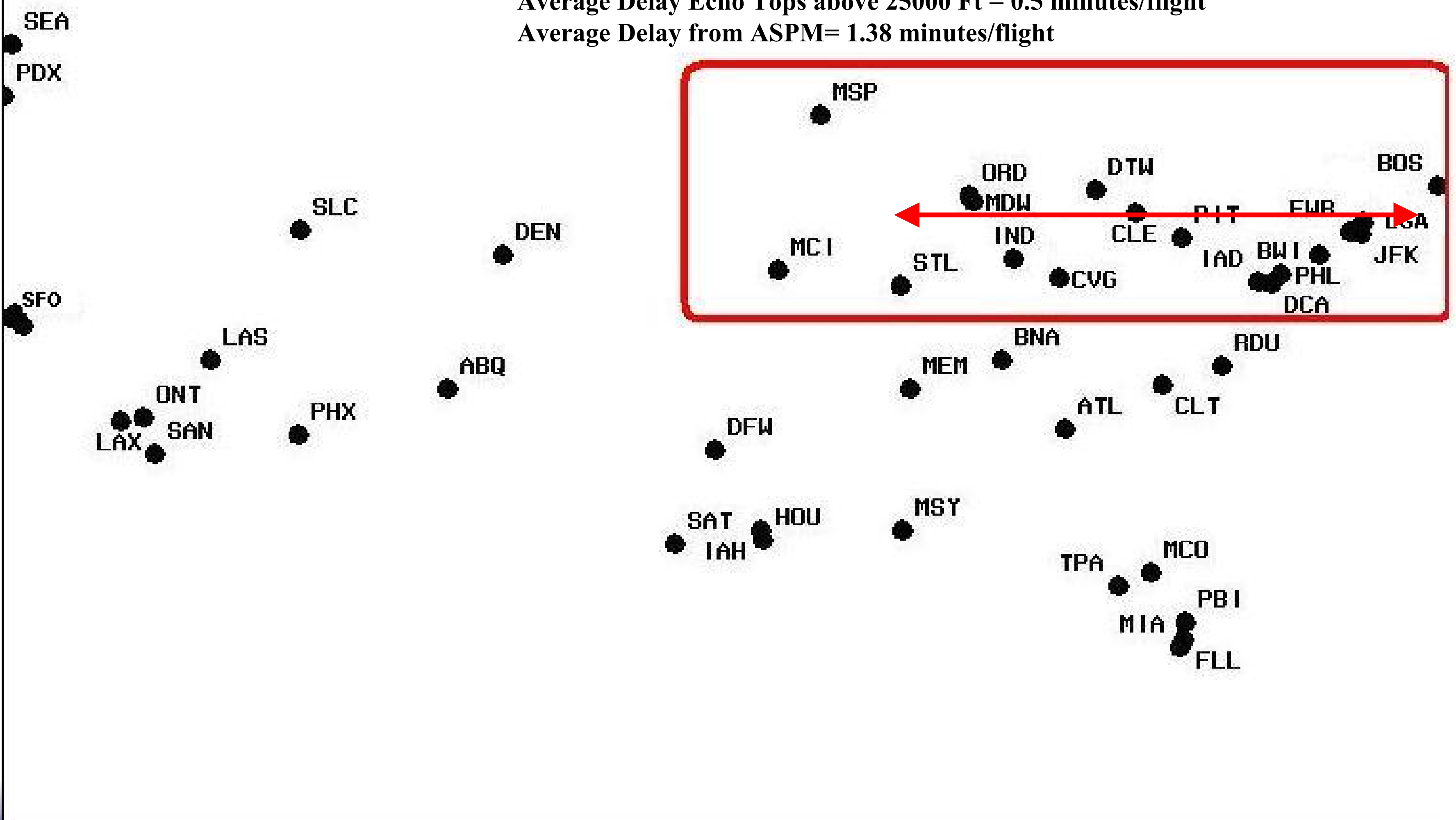


O-D Delays (North-South)



Average Delays for Regional Flights

Number of Flights = 700
Average Delay without Altitude Threshold of Echo Tops = 10.2 minutes/flight
Average Delay Echo Tops above 25000 Ft = 0.5 minutes/flight
Average Delay from ASPM= 1.38 minutes/flight



Future Work…

- Using FACET to obtain actual sector counts from ETMS data.
- Compare sector loads obtained from Bertsimas et al. TFMP with that obtained from ETMS data.
- Compare individual flights delay between TFMP results and ASPM
- Non carrier, GA flights
- Sector capacity estimate from wx coverage

Acknowledgements

- This work was jointly funded by FAA and the MIT – Lincoln Lab
- NASA Ames
  - FACET
  - Data for use in TFMP
- Lincoln Lab
  - Weather data
  - ETMS data

Questions