Avoidable Delay In The NAS, Caused Due to Uncertainty in Convective Weather Forecasts

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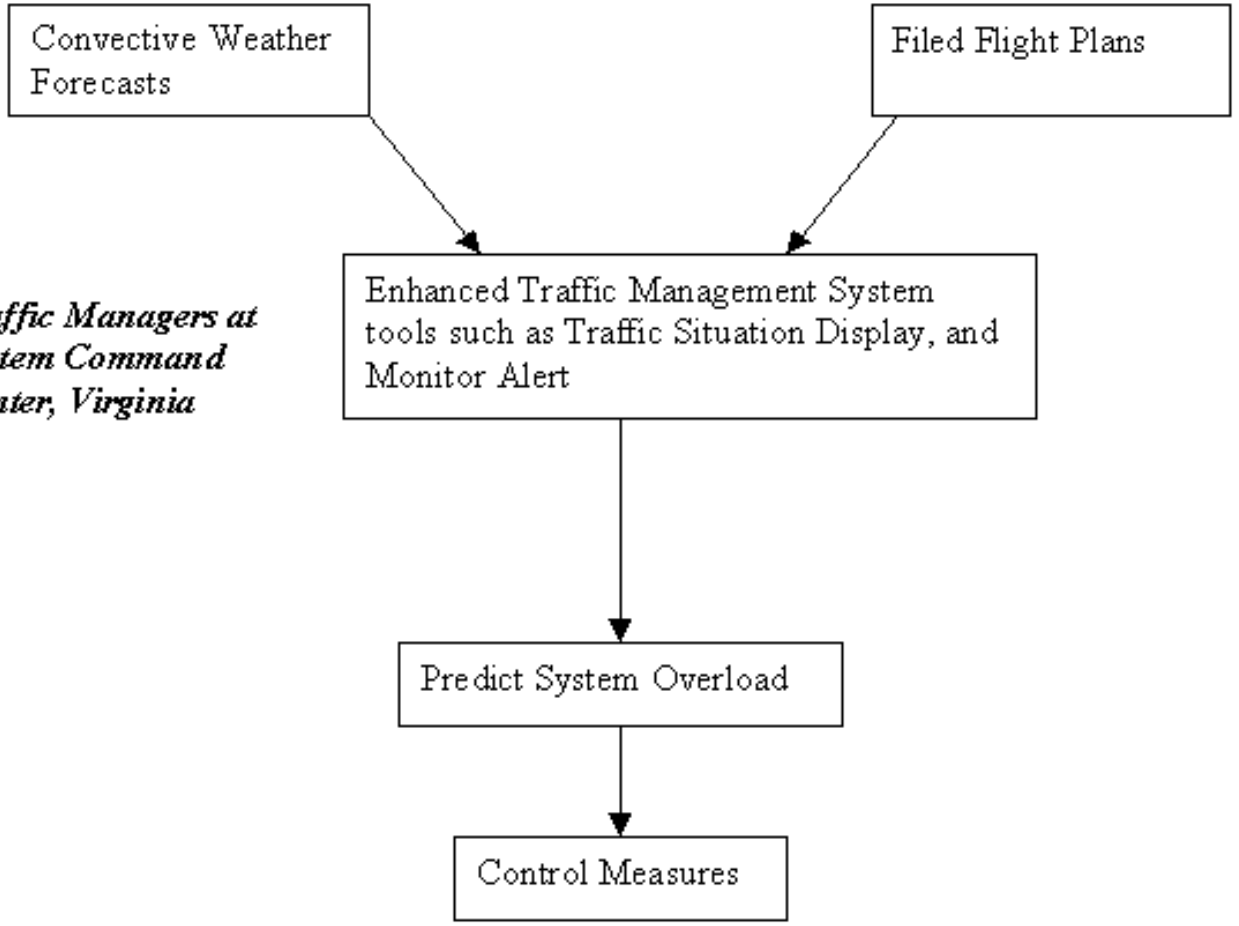
Role of Weather Forecast Products in Air TFMP



Traffic Managers at System Command Center, Virginia

Control Measures in Case of Overload

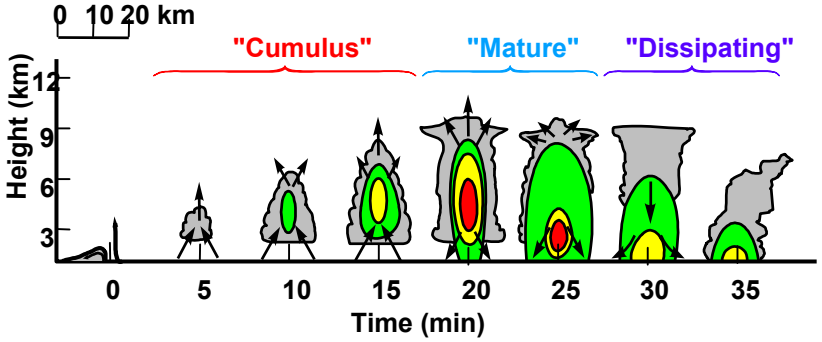
- Ground Delay Programs: aircrafts given expected departure clearance times (EDCT)
- Ground Holds: short term congestion at destination airport; no EDCT given
- Metering
- Rerouting

NEXTOR

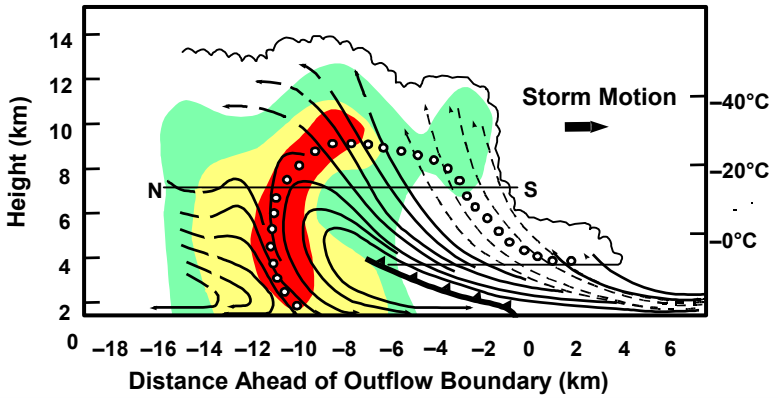
Convective Weather

Model of Storm Type

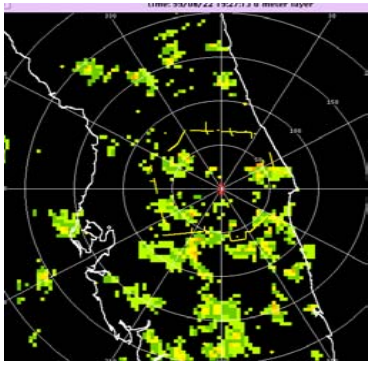
Isolated or "Airmass" Storms

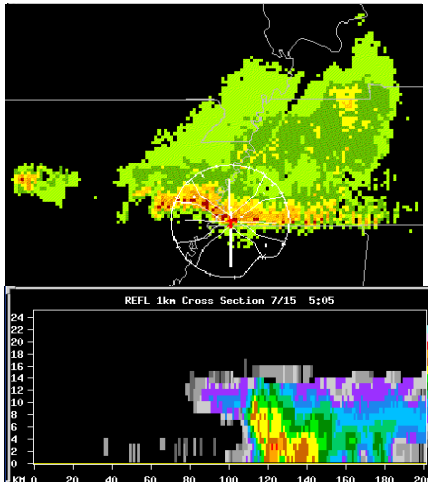


Multi-cell or "Line" Storms

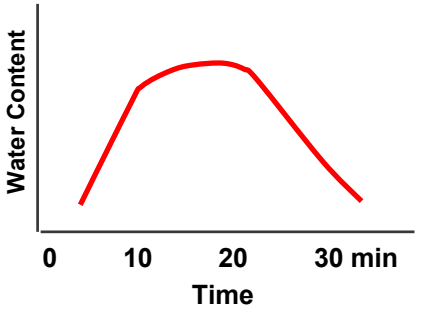


Appearance in Radar Data

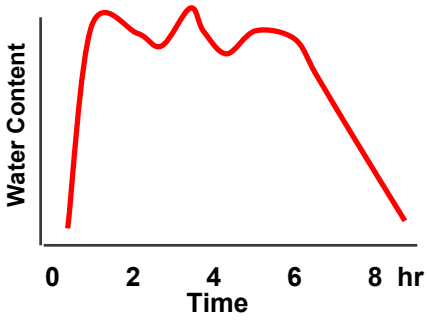




Storm Life Cycle



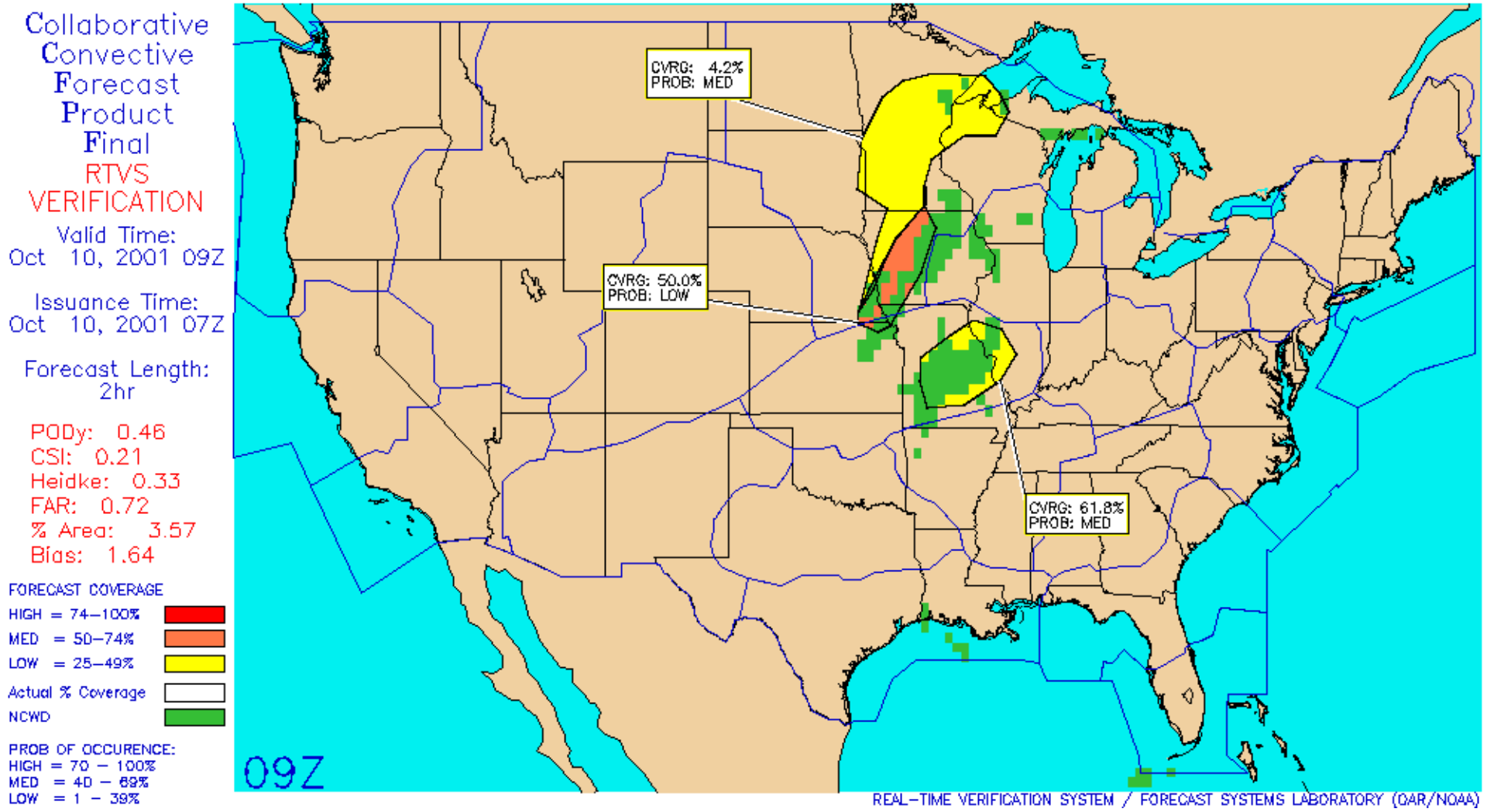
- Diurnal forcing
- Short-lived
- Largely disorganized

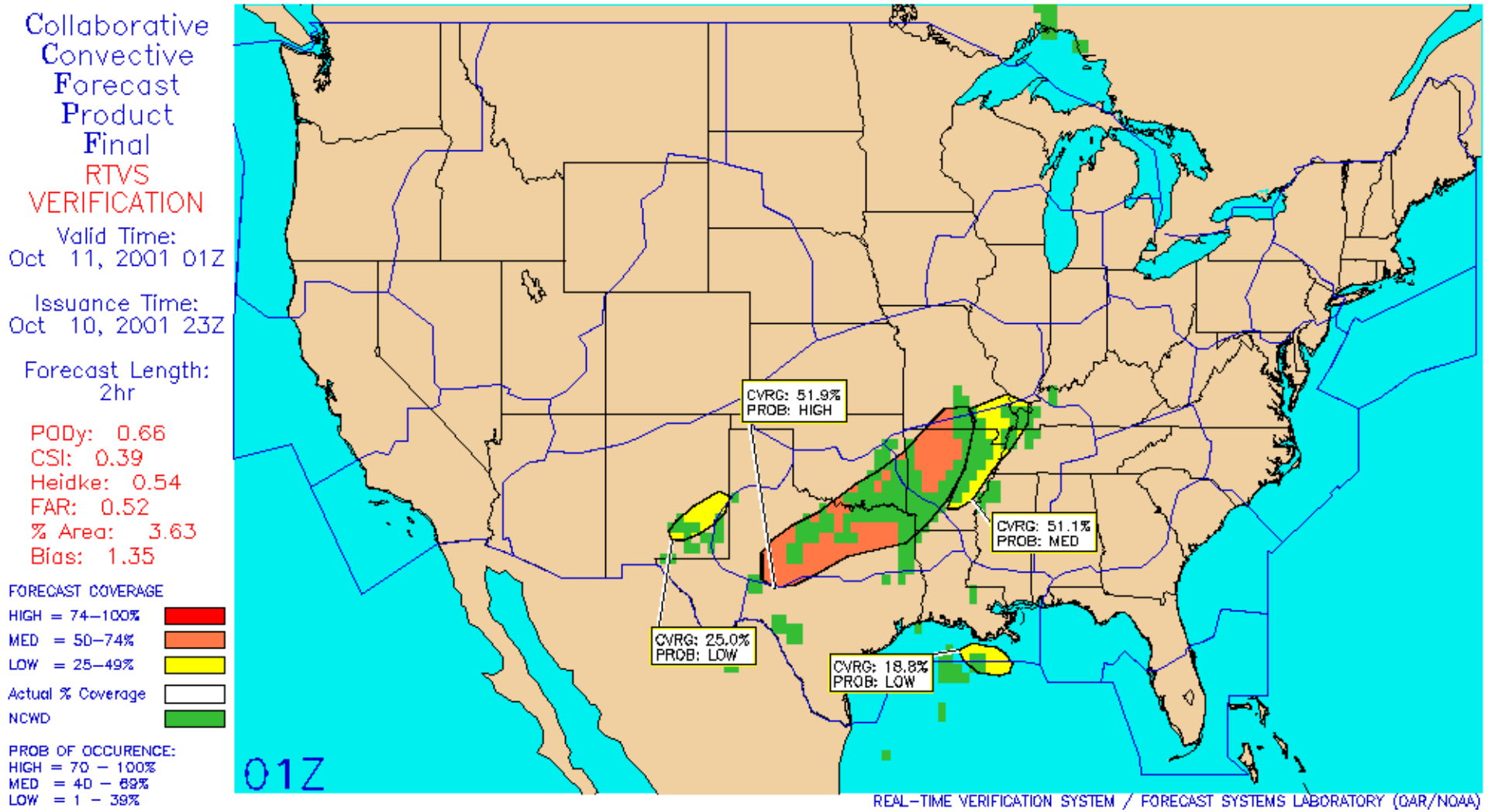


- Large scale forcing
- Long-lived
- Highly organized

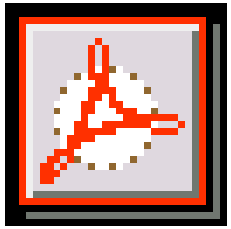
Convective Weather Forecast Products

- Collaborative Convective Forecast Products (CCFP)
  - Forecasts available five times a day, for next 2,4 and 6 hours
  - Coverage and Prob. Of Convection
  - Will be available in 2 hour frequency from this summer
- National Convective Forecast Products (NCWF): Updated Every 5 min.


Collaborative
Convective
Forecast
Product
Final
RTVS
VERIFICATION
Valid Time:
Oct 10, 2001 09Z
Issuance Time:
Oct 10, 2001 07Z
Forecast Length:
2hr
PODy: 0.46
CSI: 0.21
Heidke: 0.33
FAR: 0.72
% Area: 3.57
Bias: 1.64
FORECAST COVERAGE
HIGH = 74–100%
MED = 50–74%
LOW = 25–49%
Actual % Coverage
NCWD
PROB OF OCCURENCE:
HIGH = 70 – 100%
MED = 40 – 69%
LOW = 1 – 39%
CVRG: 4.2%
PROB: MED
CVRG: 50.0%
PROB: LOW
CVRG: 61.8%
PROB: MED
09Z
REAL–TIME VERIFICATION SYSTEM / FORECAST SYSTEMS LABORATORY (OAR/NOAA)


Collaborative
Convective
Forecast
Product
Final
RTVS
VERIFICATION
Valid Time:
Oct 11, 2001 01Z
Issuance Time:
Oct 10, 2001 23Z
Forecast Length:
2hr
PODy: 0.66
CSI: 0.39
Heidke: 0.54
FAR: 0.52
% Area: 3.63
Bias: 1.35
FORECAST COVERAGE
HIGH = 74–100%
MED = 50–74%
LOW = 25–49%
Actual % Coverage
NCWD
PROB OF OCCURENCE:
HIGH = 70 – 100%
MED = 40 – 69%
LOW = 1 – 39%
CVRG: 51.9%
PROB: HIGH
CVRG: 51.1%
PROB: MED
CVRG: 25.0%
PROB: LOW
CVRG: 18.8%
PROB: LOW
01Z
REAL-TIME VERIFICATION SYSTEM / FORECAST SYSTEMS LABORATORY (OAR/NOAA)

Available Gaps Between Areas of Convective Weather



Research Objectives

- TFMP under perfect knowledge of weather
- Comparing delay under optimal decisions made under deterministic knowledge of weather with what happened in reality
- Identifying extraneous factors affecting delays
- Usage of gaps in weather

Modeling Flow with Perfect Knowledge of Weather

- Air Traffic Flow Management Model developed by Bertsimas et al.
  - Dynamic and Deterministic
  - Decision variable binary: w[f,j,t]
  - Rerouting algorithm

TFMP contd.

- Objective: Minimize Overall Delay Cost
- 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)

Set of Airports {K};
Set of Sectors {J};
Set of Flights {F};
List of Preferred Routes Between O-D Airport Pairs;

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

Minimum Time Spent By Each Flight in The Sectors in its Flight Path:

Scheduled Departure and Arrival Times; $l \min[f, j]$

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

Time Varying Capacities:

Airport Departure, Airport Arrival, Enroute Sectors

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

Ground Hold:

$$gf = \sum_{t \in T_f^k, k = orig[f]} t(w_{f,t}^k - w_{f,t-1}^k) - df$$

Air Hold:

$$af = \sum_{t \in T_f^k, k = dest[f]} t(w_{f,t}^k - w_{f,t-1}^k) - rf - gf$$

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:

$$\sum_{f:orig[f]=k} \left(w^{k}_{f,t} - w^{k}_{f,t-1}\right) \le D_k(t)$$

2.Arrival Capacity of the Destination Airport:

$$\sum_{f:dest[f]=k} \left(w^{k}_{f,t} - w^{k}_{f,t-1}\right) \le A_k(t)$$

3.Sector Capacities:

$$\sum_{f \in F\_Sect[j], j1=nextj[f]} \left(w^{j}_{f,t} - w^{j1}_{f,t}\right) \le S_j(t)$$

4.Sector Connectivity:

$$w^{j1}_{f,t+l\min[f,j]} - w^{j}_{f,t} \le 0 \left\{ \begin{array}{l} t \in T^{j}_{f}, j \in F\_Sect[j] \\ j1 = nextj[f] \end{array} \right\}$$

5.Time Connectivity:

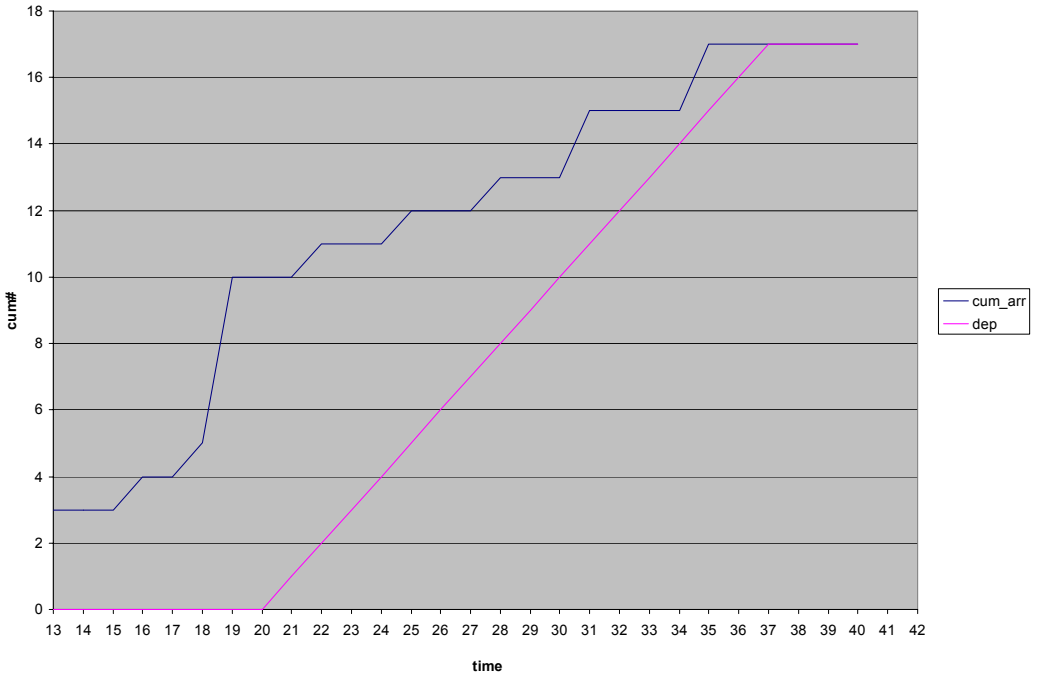
$$w^{j}_{f,t} - w^{j}_{f,t-1} \ge 0 \left\{ \forall f \in F, j \in (J \cup K), t \in T^{j}_{f} \right\}$$

Modeling Issues

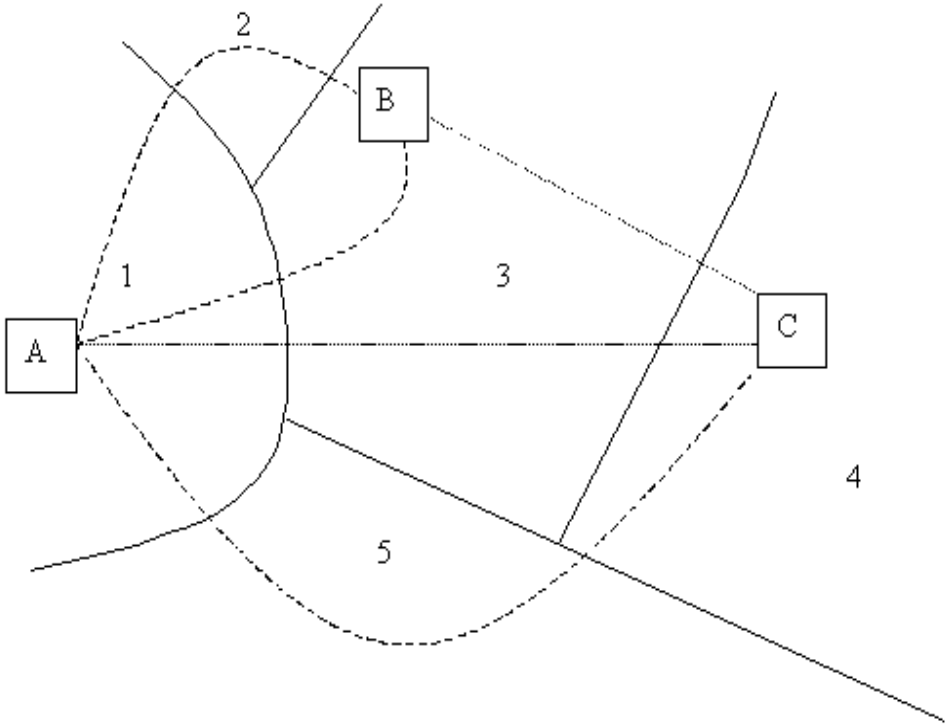
- Model Testing
  - Varying the costs of ground hold and enroute hold
  - Varying departure and arrival capacities
- Verification with large data set
  - 131 Flights, 12 Airports, 90 Sectors, 4 hr time period
  - Queuing Analysis

Queuing Analysis

- Dep. Capacity of Boston made 0 for the first 2hr 30 min
- Average Delay from queuing analysis: 34.4 min
- From Bertsimas's Model: 34.7 min



Rerouting Strategy

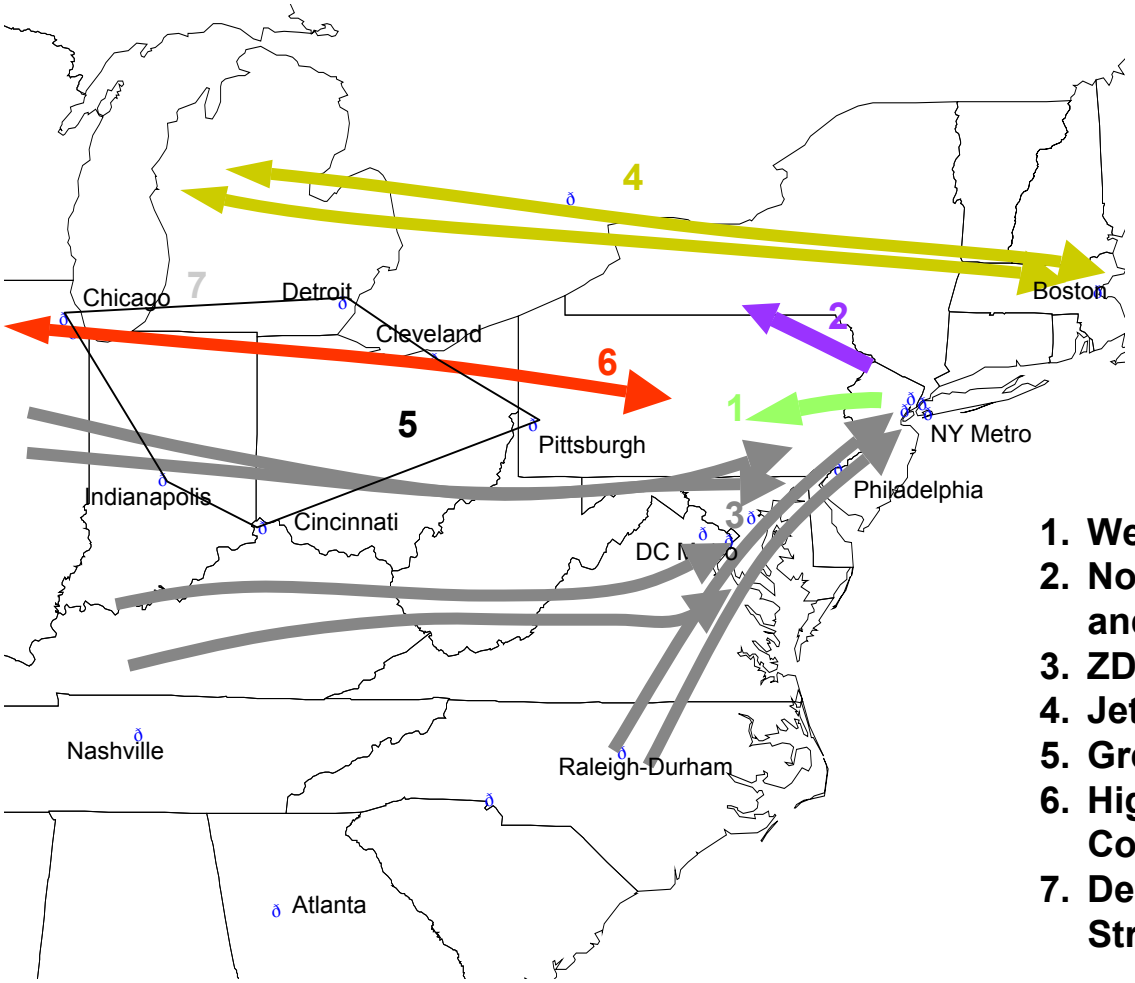


- 16 Flights
- Ideal conditions
  - No ground/air holds
  - A- C flights travel via. Sector 3
- Capacity of Sector 3 Low
  - A – C flights travel via Sector 5
  - A – B flights doesn't travel via sector 2

Softwares and Tools

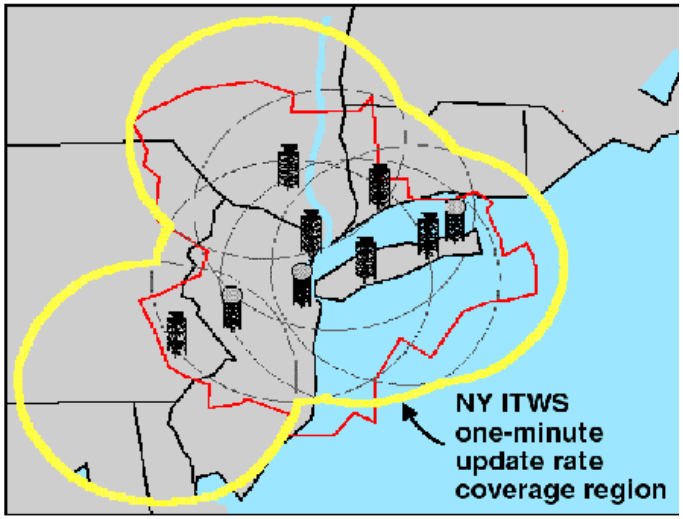
- AMPL/CPLEX for TFMP
- Use of FACET in Data Gathering
  - Time varying sector capacities for different weather scenarios
  - Overlay weather over the sector layer and identify the sectors affected
  - Input to the model the NAS components: sectors, airports, preferred routes between O-D pairs, minimum time spent by a flight in the sectors in its flight path

Current NAS Chokepoints

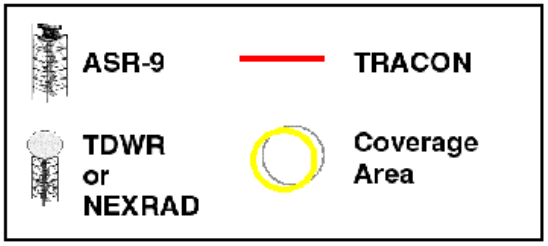


1. **Westgate Departures, NY TRACON**
2. **Northgate Departures, NY TRACON and ZNY**
3. **ZDC - Mid-Atlantic Sectors**
4. **Jet Route 547 Westbound**
5. **Great Lakes Corridor**
6. **High Altitude Holding for East Coast Arrival Streams**
7. **Departure Access to Overhead Streams**

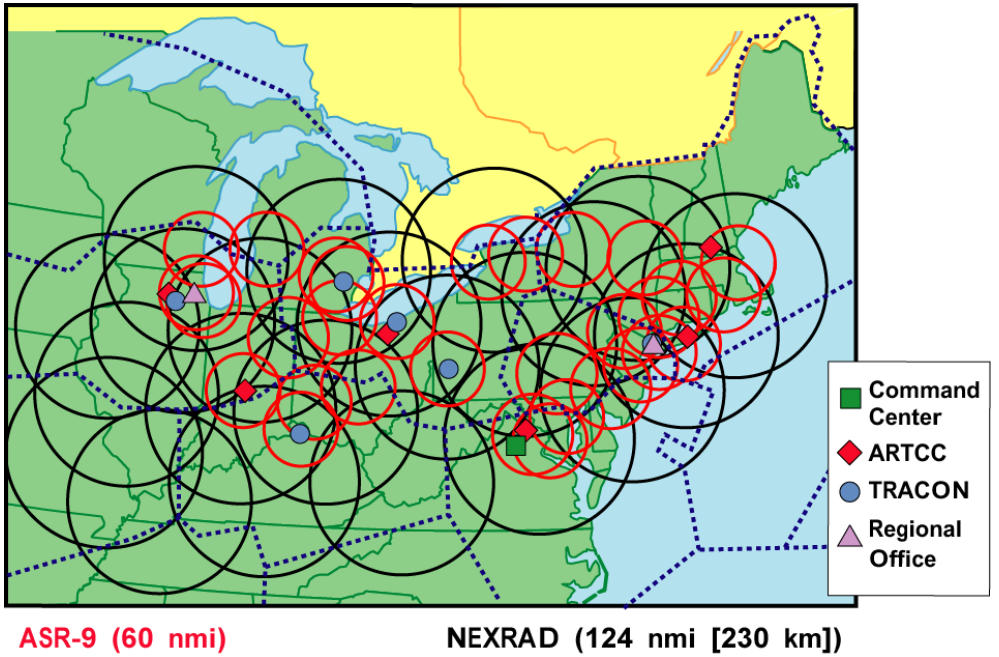
Data Availability



TRACON



NY Integrated Weather System (ITWS)

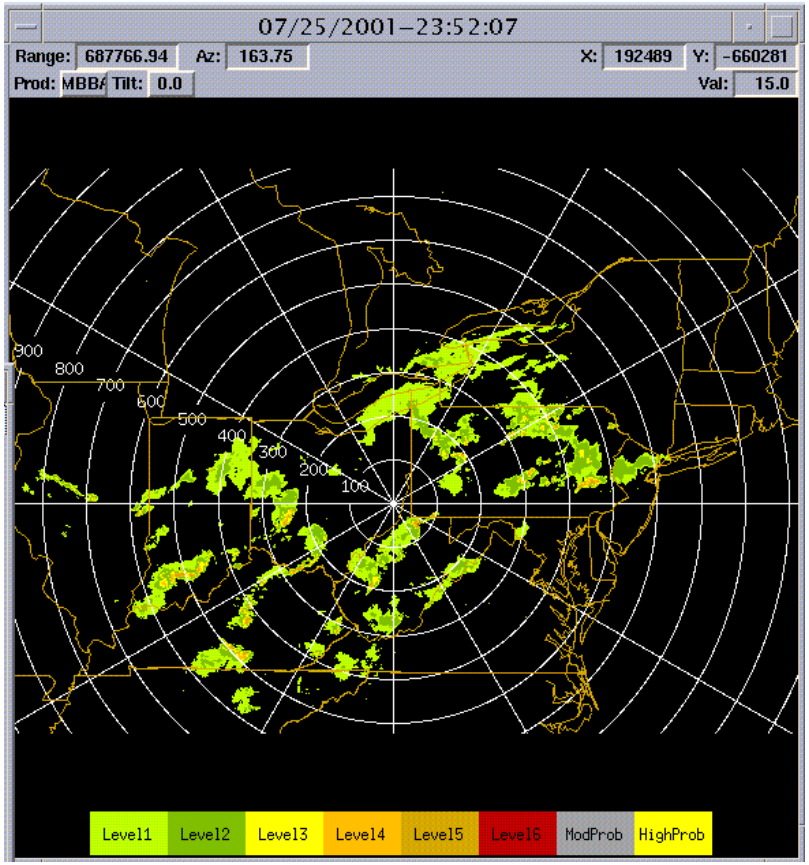


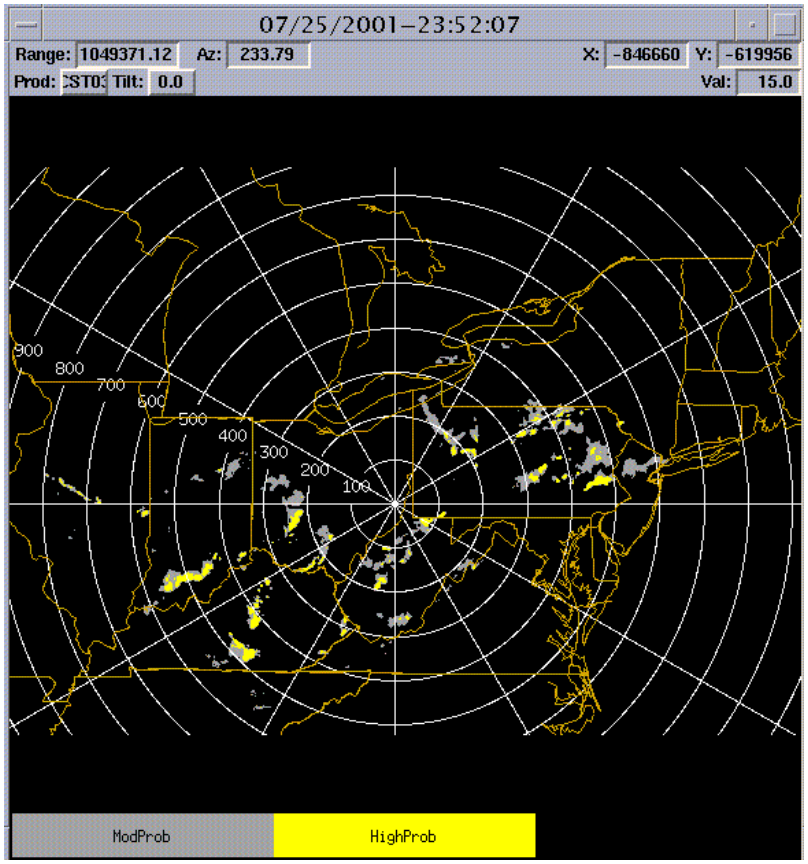
Corridor Integrated Weather System (CIWS)

Data to be provided for study:

- Storm locations and tops
- Facility observations
- Flight tracks
- Forecasts

Weather Data: MIT Lincoln Lab CIWS Products





What Happened in Reality ?

- Use of FACET
  - Playback ETMS data
  - Overlay weather forecasts and/or actual weather over flight tracks
  - Observe re-routing strategies
  - Identify unused gaps between weather
- Actual delays from ASPM database

Factors Affecting Delay

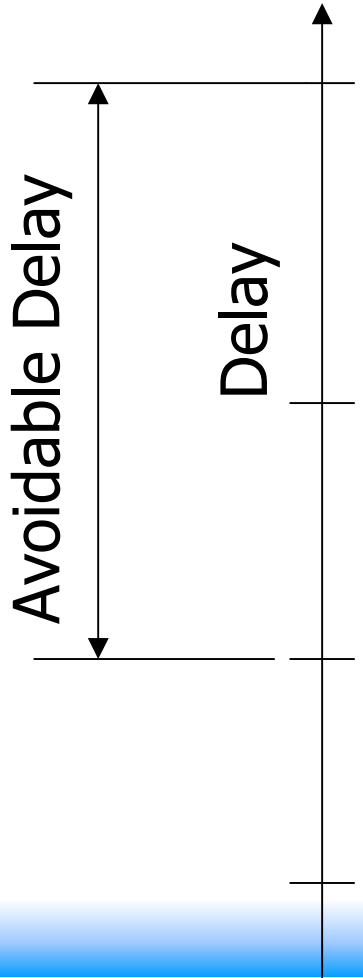
- Enroute weather
- Origin airport congestion
- Load factor of flights
- Queuing delay at destination airport
- Weather at destination airport

Avoidable Delay

- Compare results from the model by Bertsimas et. al. to what happened in reality
- Identify and normalize for factors other than weather uncertainty that affects delay
- Value of improved forecasts

Questions

Avoidable Delay



Delay due to uncertainty in weather forecasts

Delay due to uncertainty in weather forecasts after improvements in forecast tools

Delay with TFMP under enroute weather uncertainty

Delay under perfect information of weather