
Scoring of Convective Precipitation Forecasts Used for Air Traffic Flow Decision Making

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30 July 2002

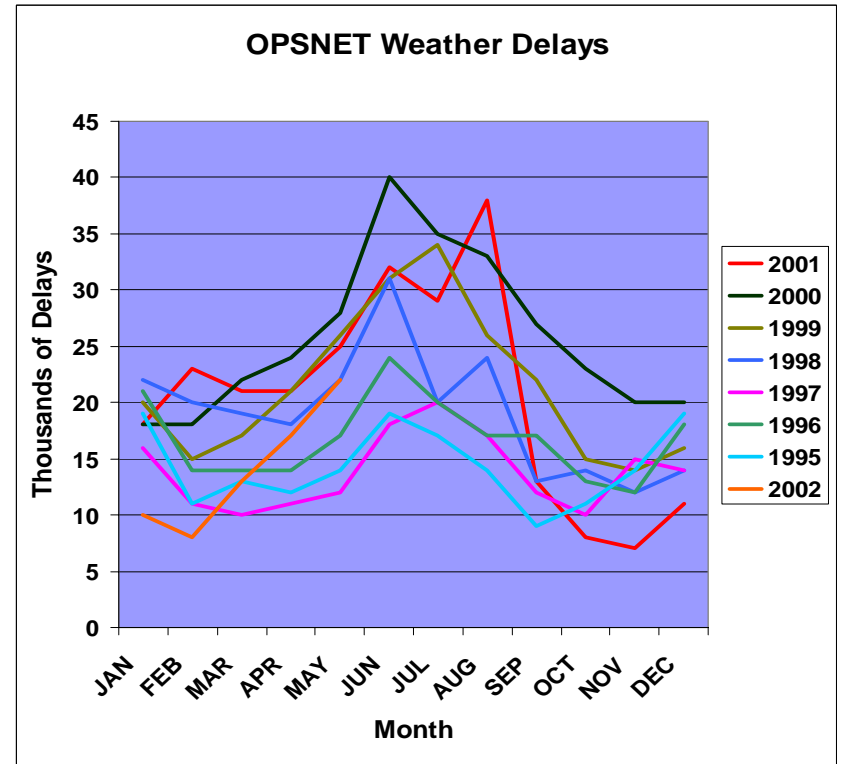
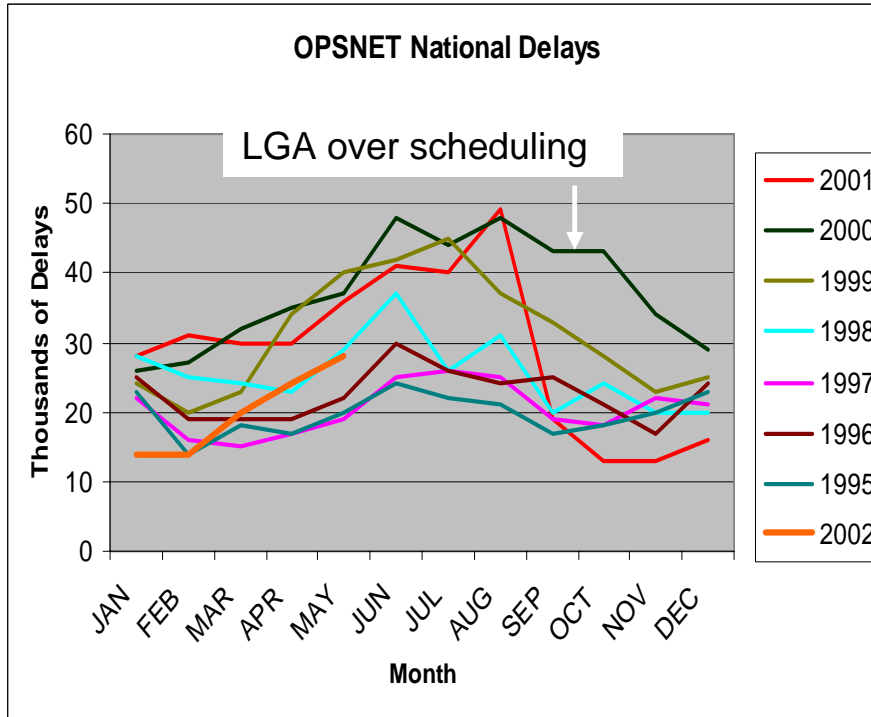


Outline

- **Background**
 - Why problem is an important one
 - What has been done to create multi-hour forecasts to date
 - Example of plane encounters with weather
 - Operational use of the forecasts today
- **Route impacts versus pixel based scoring**
- **Next steps**
 - Expectations for accuracy of future forecasts
 - Probabilistic forecasts
 - Issues associated with use of probabilistic forecasts
- **Summary**



Trends in Aviation Delays

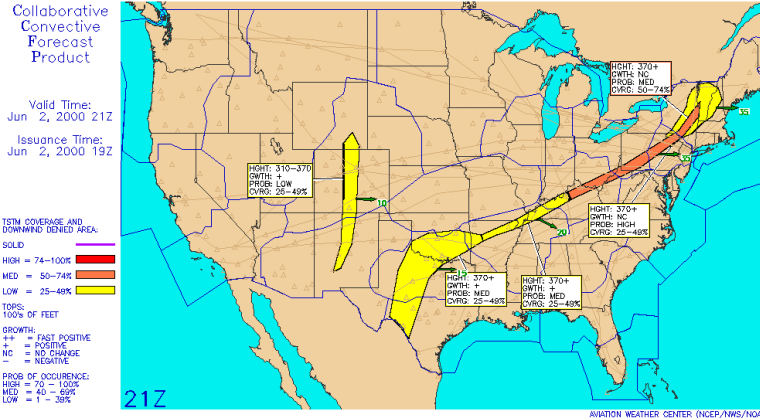


Note that delays have primarily gone up in months characterized by “disorganized” thunderstorm activity which is the hardest to forecast accurately hours in advance



FAA/Airline “Spring 2K to 2K+2” Plans

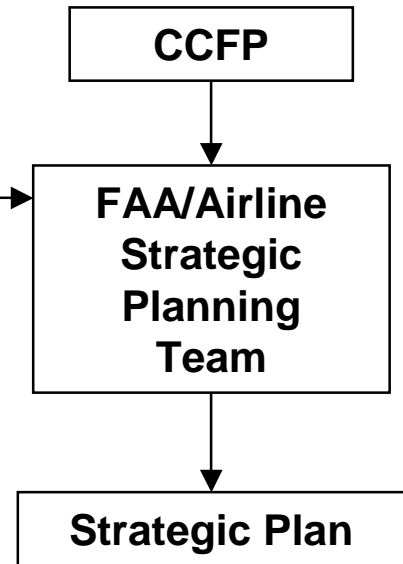
Collaborative Convective Forecast Product (CCFP)



“Play book”

Play book is response to “impenetrable” wx

Strategic Planning



Teleconference Every 2 hours

2, 4 and 6 hour predictions generated by FAA/NWS/airline meteorologist collaboration every 2-4 hours

Each region of predicted convective activity has estimates of:

Thunderstorm coverage (median) = 100, 87, 62 or 37%

Probability of occurrence (median) = 85, 55 or 22%

(note: probability of occurrence is now regarded as an expression of confidence in the coverage forecast)



Frequency of Various CCFPs in 2001

Predicted coverage

	“low” 25-49%	“medium” 50-74%	“high” 75-100%
Prob. Wx will Occur At Forecast time “low” 1-30%	50.6%	1.4%	0.0%
“medium” 30-74%	39.6%	6.3%	0.1%
“high” 75-100%	1.4%	1.1%	0.1%

The vast majority of all CCFPs (over 90%) suggest that the airspace inside the CCFP is likely to be partially usable at the forecast time, but do not provide guidance on which routes within the CCFP will be usable



Example of “inaccurate” CCFP in a critical location

Green is actual level 3 or higher weather

Collaborative
Convective
Forecast
Product
Final
RTVS
VERIFICATION

Valid Time:
Aug 10, 2001 15Z

Issuance Time:
Aug 10, 2001 11Z

Forecast Length:
4hr

PODy: 0.37
CSI: 0.19
Heidke: 0.30
FAR: 0.72
% Area: 3.33
Bias: 1.35

FORECAST COVERAGE

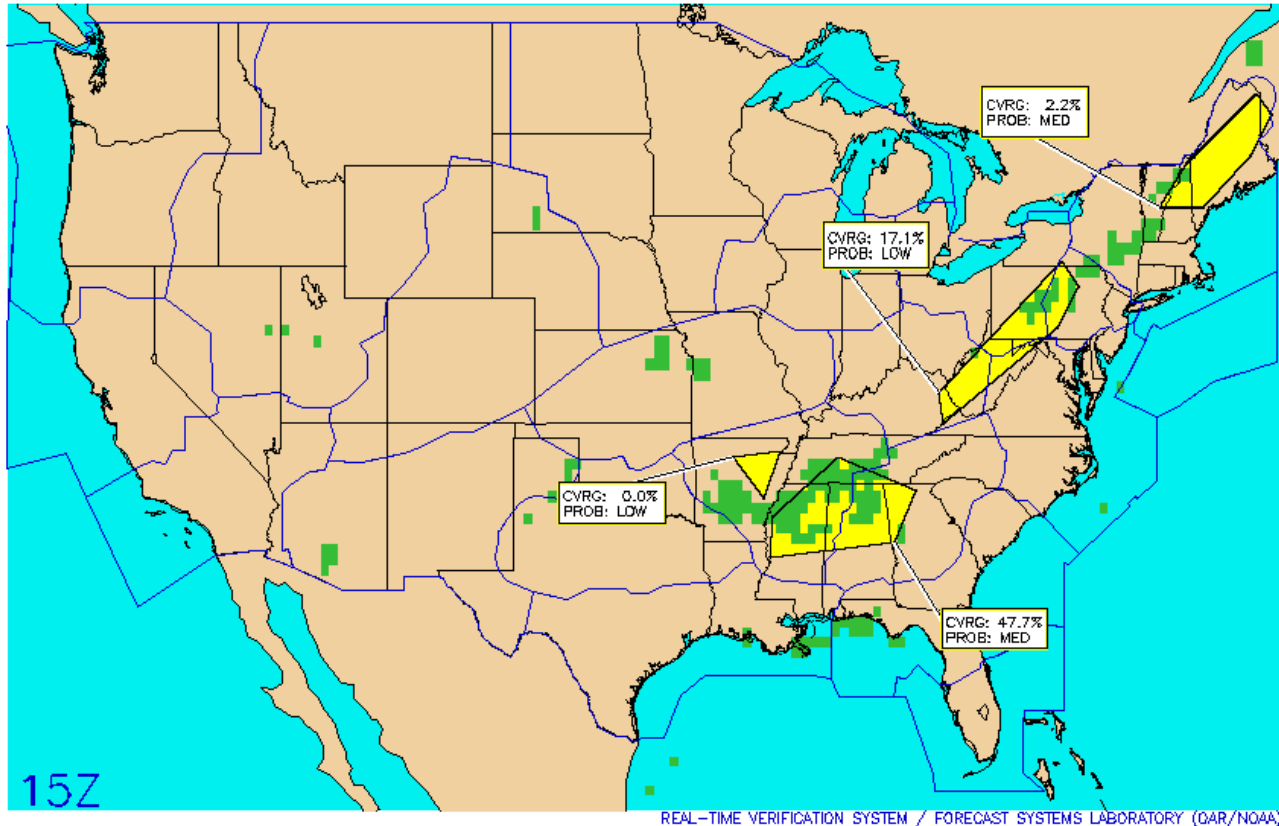
HIGH = 74–100%	
MED = 50–74%	
LOW = 25–49%	

Actual % Coverage

NCWD

PROB OF OCCURENCE:

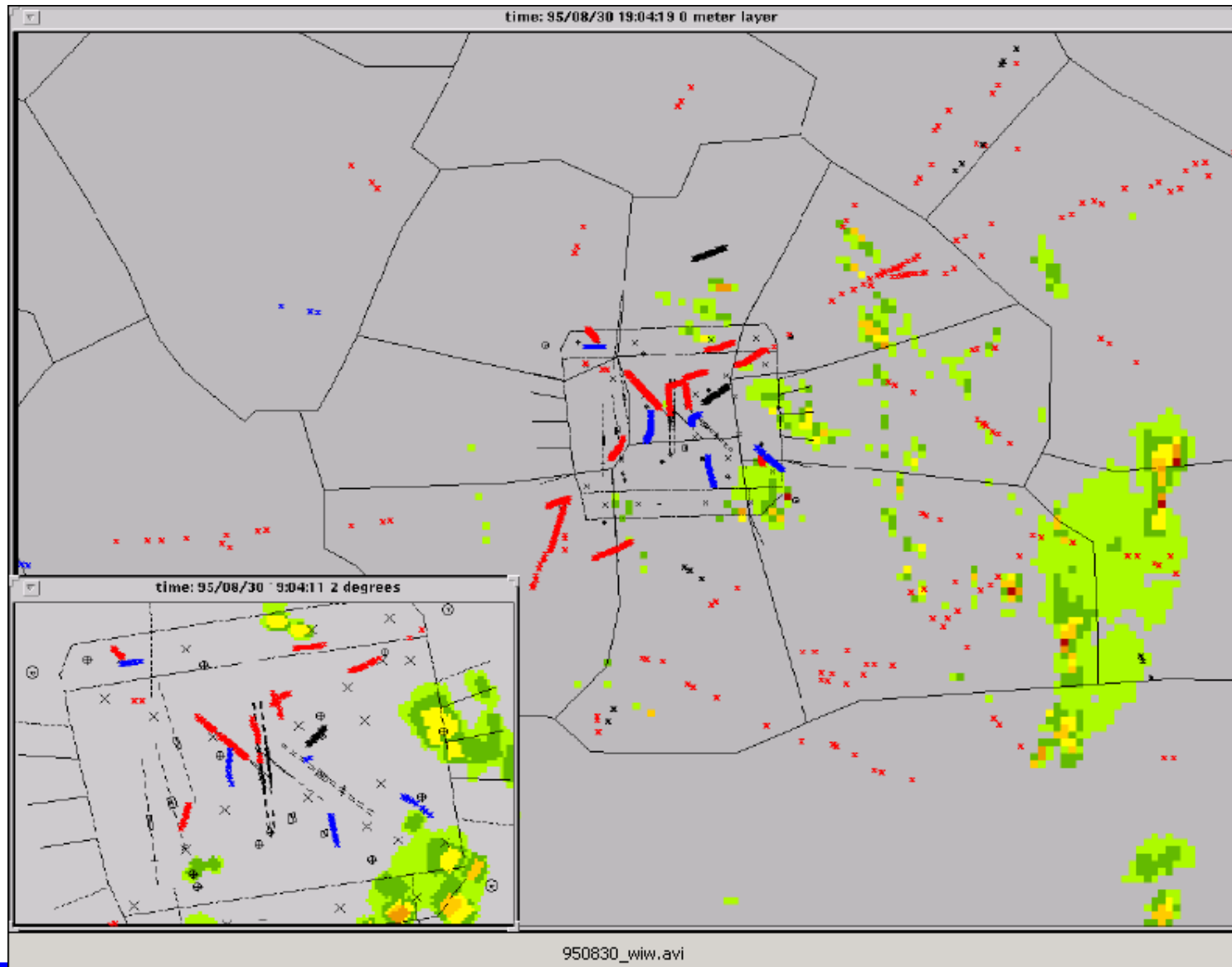
HIGH = 70 – 100%
MED = 40 – 69%
LOW = 1 – 39%



**Significant weather north of WV to PA forecast region;
not much weather in forecast region**



Flight Tracks and Storms at DFW 1995





Actual Decisions Given CCFP

- Avmet Applications/METRON looked at operational flight decision making for 7 instances of “low coverage” CCFPs in 2001 (see Appendix A for more details)
- Actual coverage % (according to RTVS) was 0, 10,12,34,40,42,46 %
- Percentage of fair weather demand that was “strategically” rerouted was 5,8,9,16,18,24,33,40 %
- “Good” to strategically reroute 64 % of time, “bad” 36% of time
- “Good” to not reroute 50% of time, “bad” 50 % of time
- Conclusions: “Low coverage” CCFPs definitely are not being used as “no fly” zones and should be scored accordingly (e.g., as a classification estimation problem)

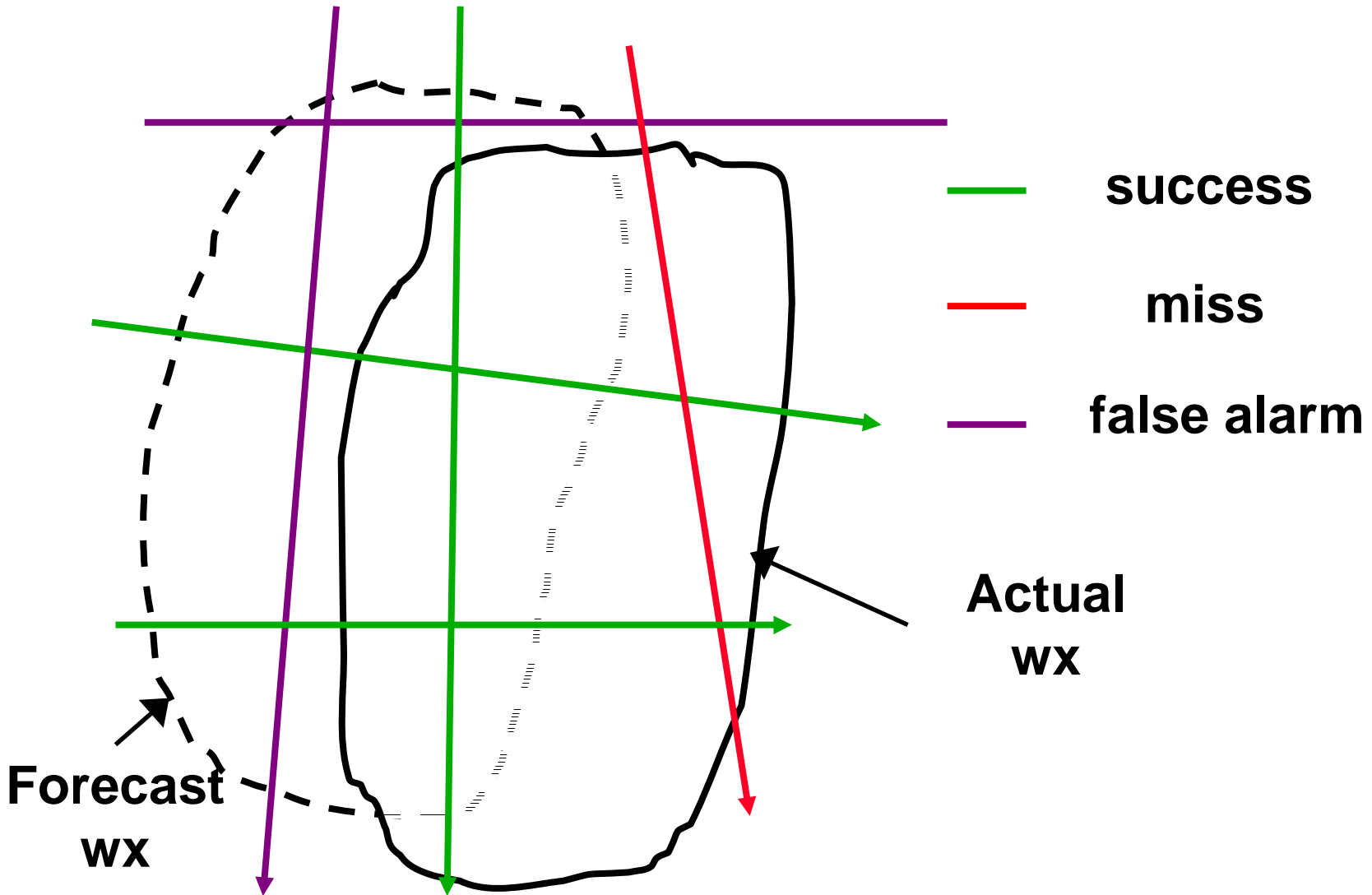


Scoring of forecast accuracy

- **Scoring to date (RTVS, LL) of contemporary forecasts has been by pixel overlap criteria**
 - Scoring boxes that look in 10 km radius around predicted weather
 - “Blooming” of actual weather on 4 km grid to 40 km
- **Problems with this approach**
 1. Interpretation as a binary decision (P_d , P_{fa} , CSI, ...) is not appropriate given operational use of CCFP and, the complicated impact of “misses”
 2. Aviation users are more interested in route impacts than pixel impacts (except when near an airport !)
- **Relationship of pixel impacts to route impacts depends on spatial correlation of the precipitation process**
- **Merritt and Brasunas (1983) investigated route based scoring using randomly located flight segments**



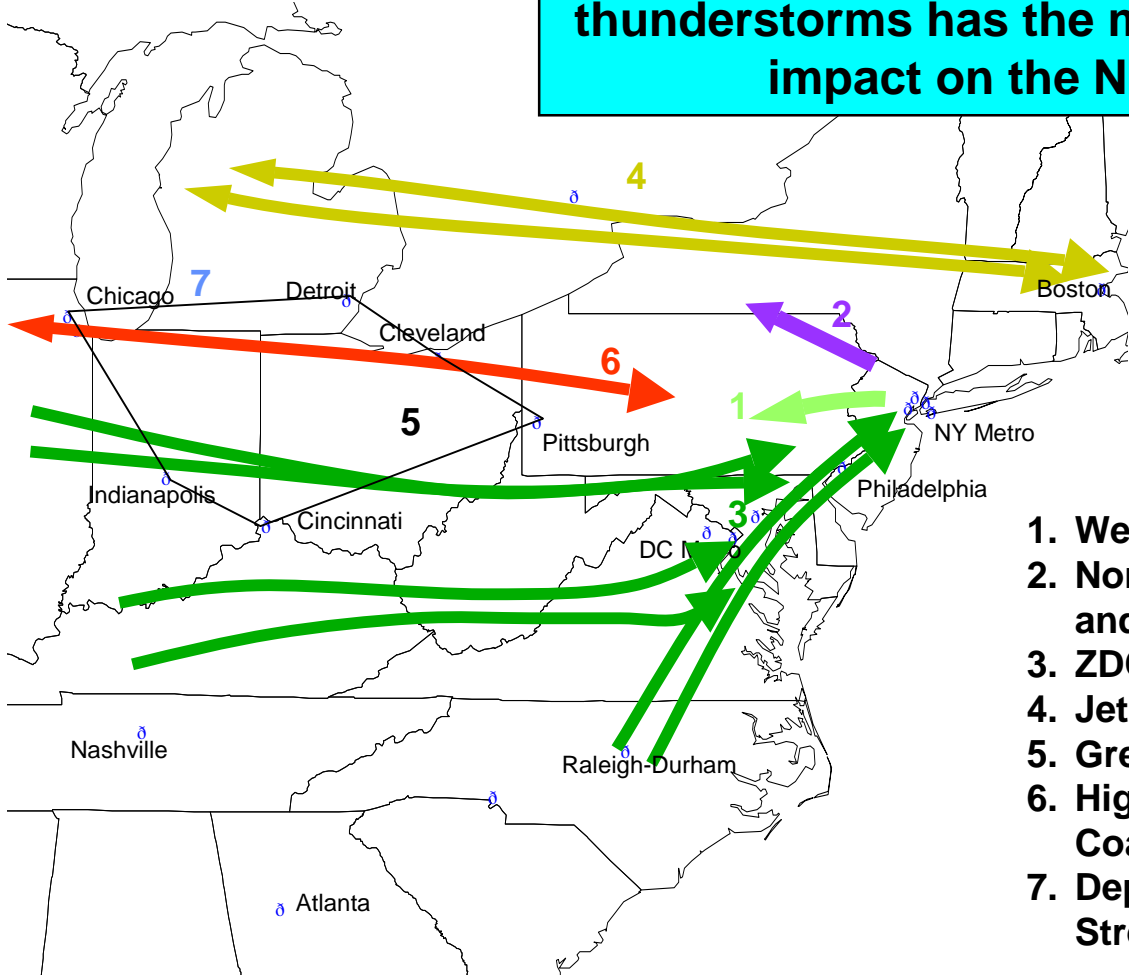
Flight Path Impact vs Pixel Overlap





Current National Airspace Choke Points

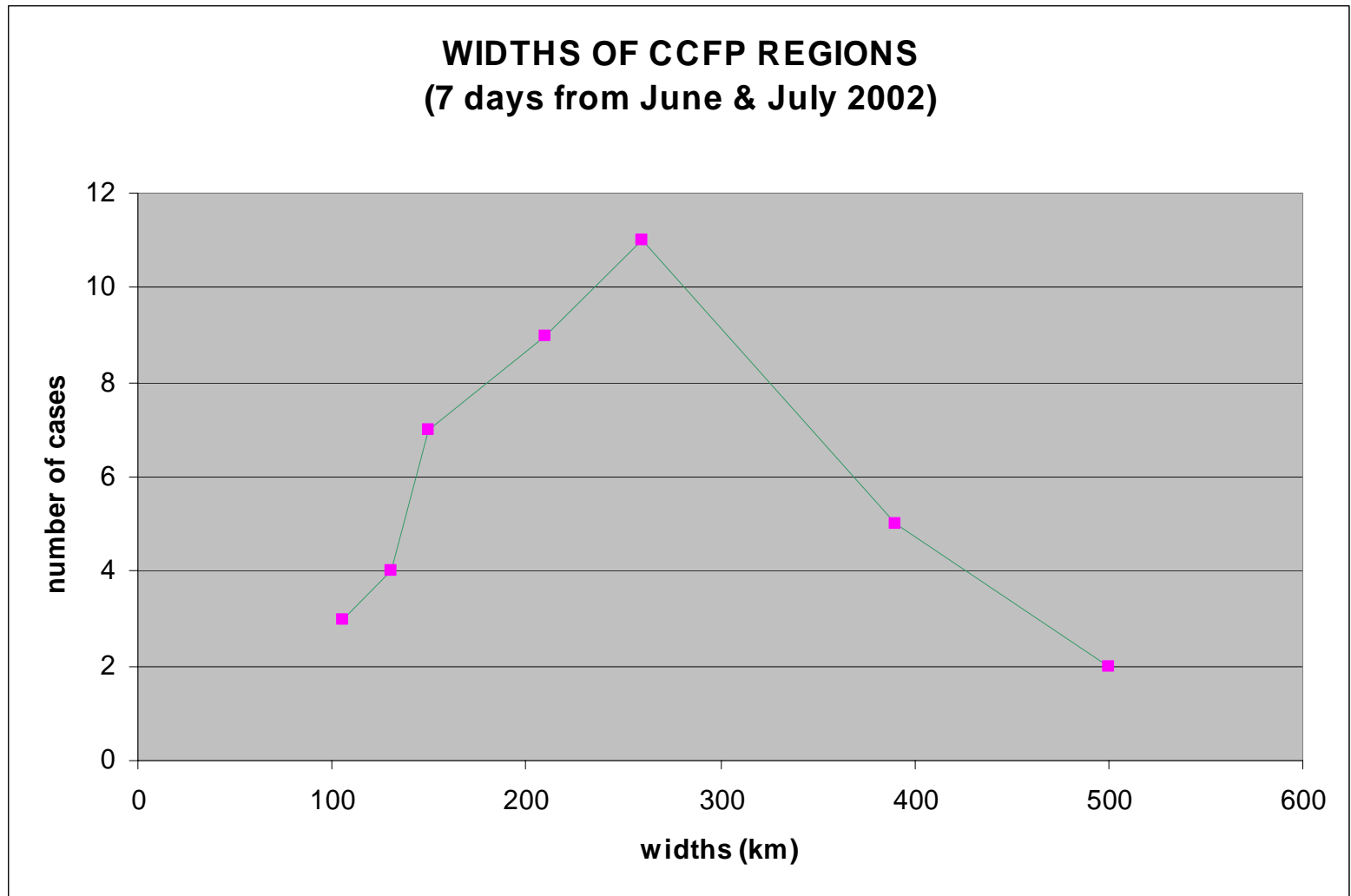
Accuracy is most important when loss of capacity due to thunderstorms has the most severe impact on the NAS



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



Widths of CCFPs in Key Corridors





Computing Route Wx Coverage from Pixel Wx Coverage

- **Simple assumption: 40 km pixel impacts are independent (“popcorn convection”)**

- **Then probability of route not being impacted is approx.**

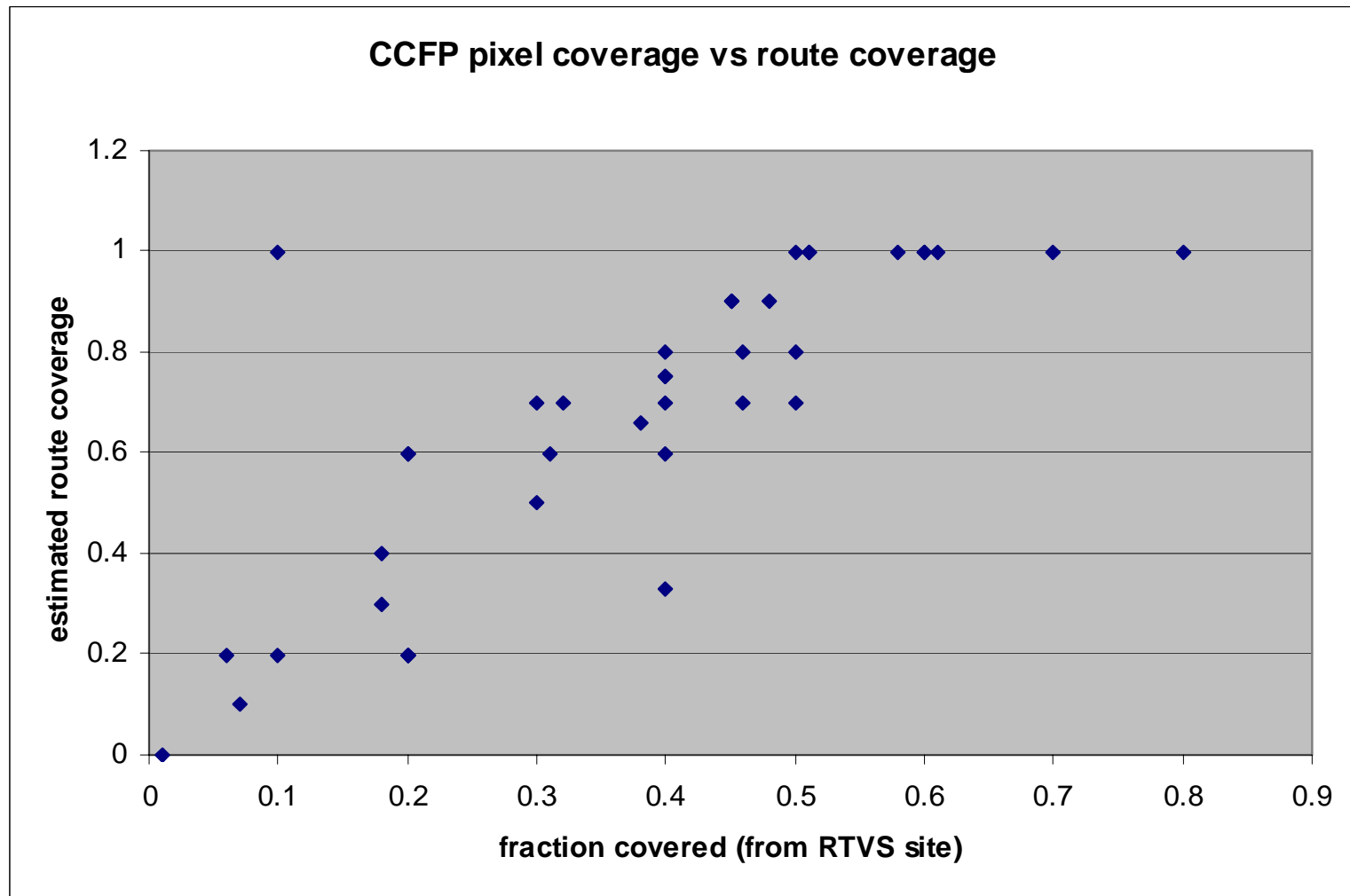
$$(1 - \text{fraction of pixels covered})^{(\text{width}/40 \text{ km})}$$

- **Applying this to observed pixel coverage of about 30% for “low coverage” CCFPs and, the observed CCFP region widths yields route impact of about 90% for the most common width of 260 km**
- **Need to look at the actual weather coverage of routes to get insights into weather spatial probability structure**



Pixel Wx Coverage vs Route Wx Coverage

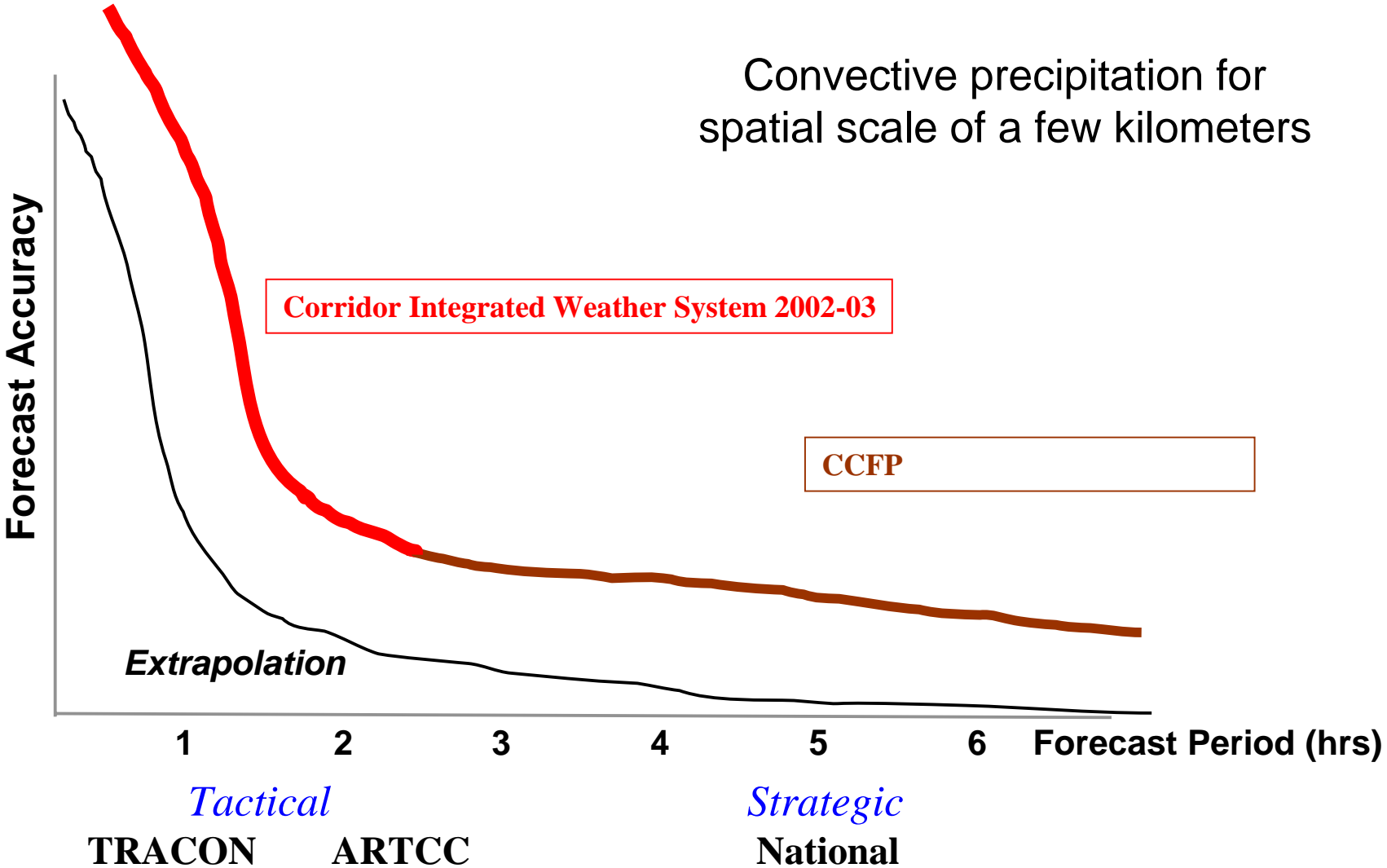
(7 days in June and July 2002)



Route wx coverage ~ twice pixel wx coverage

Projection of near term capability by FAA Av. Weather Research Convective Weather Product Development Team

Convective precipitation for
spatial scale of a few kilometers



Modified from Browning, 1980

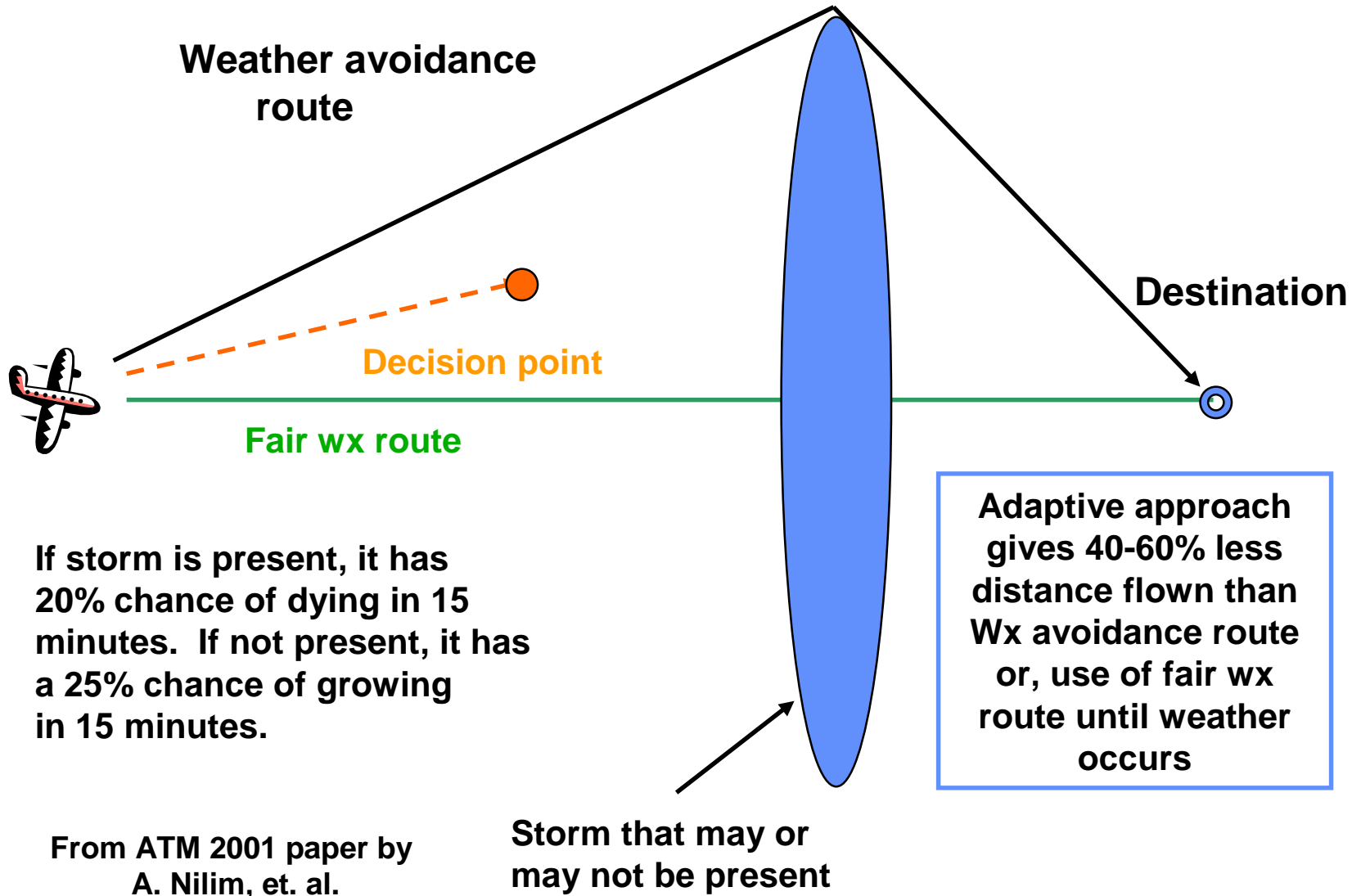


Looking Ahead

- **Start with the assumption that**
 - Convective weather will continue to cause major variations in en route and terminal capacity, and
 - We cannot expect to accurately predict the precise locations of all significant convective cells hours in advance
- **Actual decision process is sequential in the sense that the planned routes can be adjusted in real time based on the latest weather situation and forecasts**
- **Statistical forecasts will be used to decide on**
 - Initial choice of routes
 - Estimating the capacity
 - Deciding how much fuel to load on the plane
 - Dynamic rerouting
- **Need to treat problem as one of risk management with policies that are statistically optimal as opposed to searching for a “guilty party” on the “unlucky” cases**

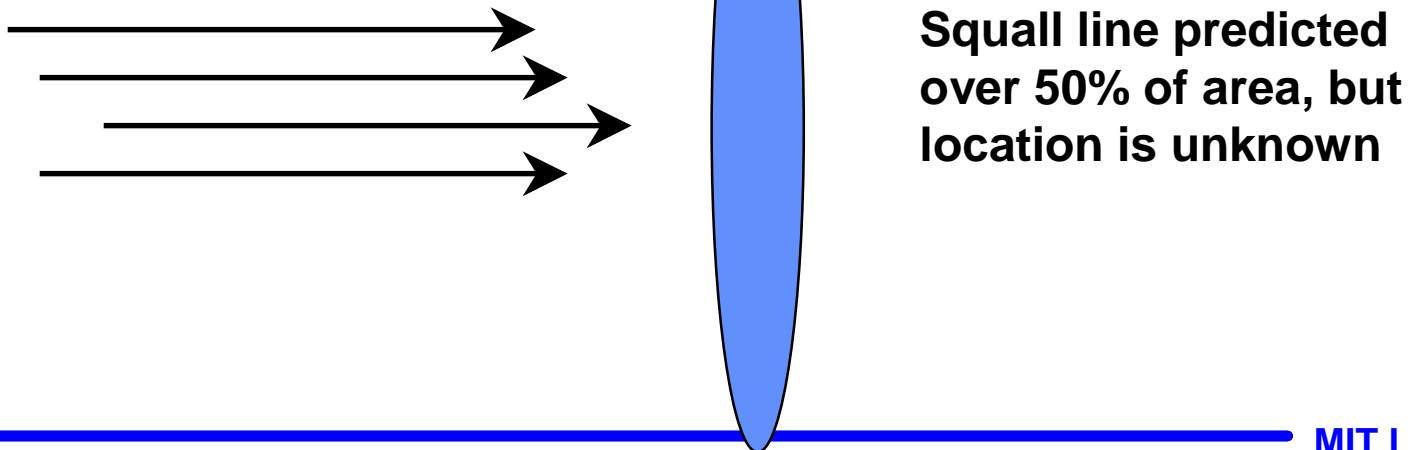
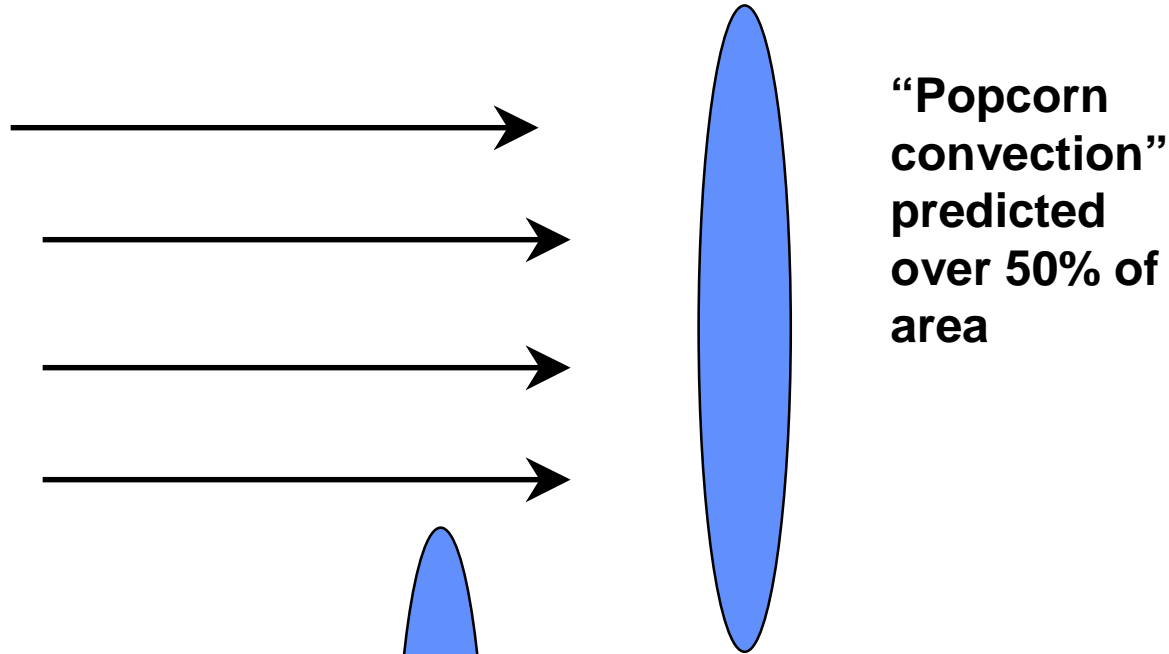


Strategic Planning for a Tactical Adjustment: Example 1



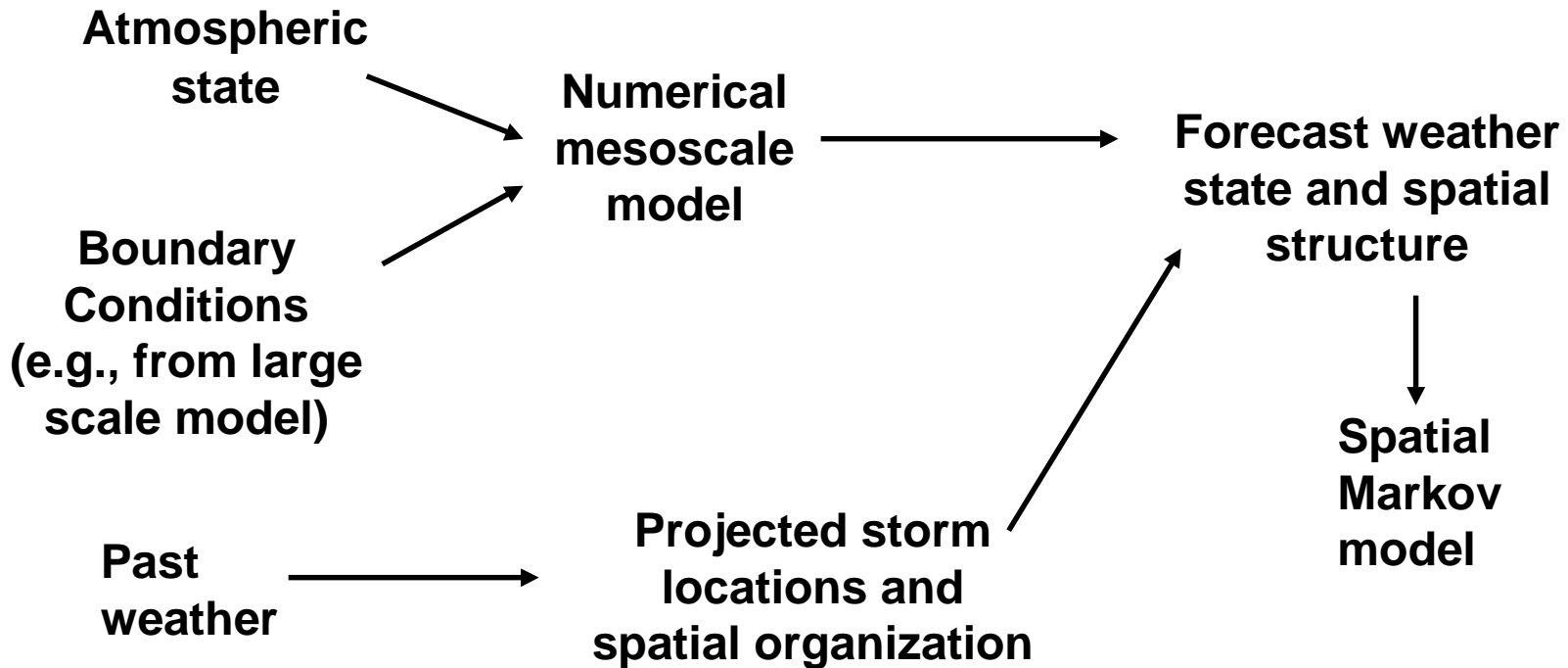


A Flight Distribution Conjecture





Markov Modeling of Future Weather



Markov model:

Prob [P(t)] is a function only of S(t) and P(t-1), that is the precipitation process is conditionally Markov

Challenges:

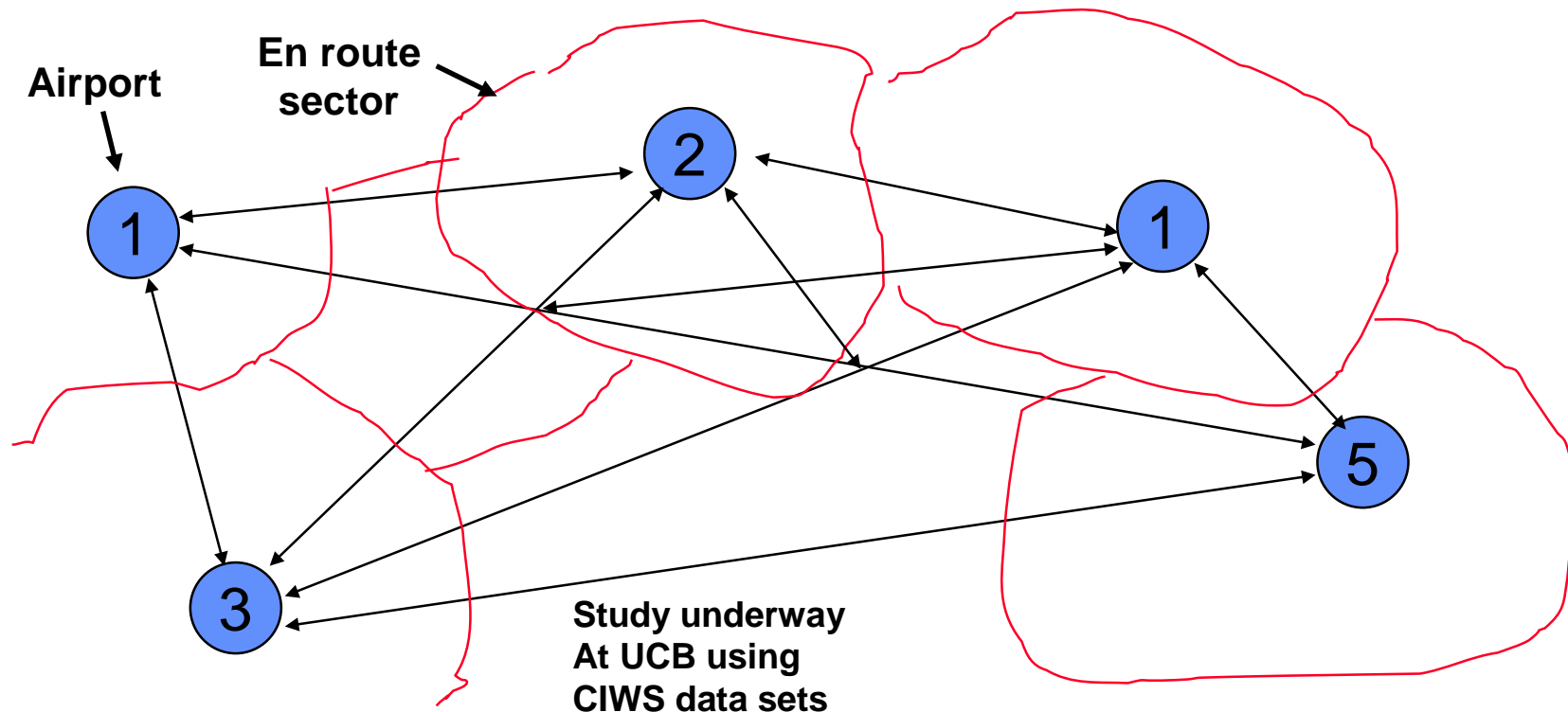
1. Very large state space for Markov process (e.g., 4×10^6) in subsequent ATM calculations
2. Estimating and **validating** parameters for Markov process



Estimating the Effective Capacity

We can bound capacity by assuming perfect forecasts plus optimized routing of aircraft through sectors and airports whose capacity is time varying.

Study in progress uses a linear programming routing algorithm by Bertsimas of MIT in which planes may hold on ground and/or in air as well as use alternative routes





Summary

- **Convective weather has become a major factor in the growth of aviation delays. Problem is most severe in congested airspace.**
- **Users seek to make multi-hour strategic plans on the basis of the forecasts**
 - Current forecasts (e.g., CCFP) are partially probabilistic and need to be scored accordingly (e.g., joint distributions, stratification,...)
 - Handling of “misses” needs to consider ATC impact
- **Users will seek to use forecasts to estimate likelihood of route availability and effective “tactical” capacity**
 - Route wx impacts are different than pixel wx impacts and warrant separate scoring
 - Don’t forget the major airports
 - Capacity estimation given weather distribution is poorly understood
- **Many opportunities for creative research contributions**
 - Handling of storm tops plus precipitation
 - Probabilistic modeling of weather coupled to air traffic management (ATM) algorithms
 - How to characterize forecast uncertainty for ATM use
 - Validation of probabilistic models



References

1. Evans, J., "Tactical Weather Decision Support To Complement "Strategic" Traffic Flow Management for Convective Weather", The Fourth International Air Traffic Management R&D Seminar ATM-2001 in Santa Fe (New-Mexico, USA) December 3rd-7th, 2001. Paper and presentation available at <http://atm2001.eurocontrol.fr/>
2. Rhoda, D.A., E.A. Kocab, M.L. Pawlak, 2002: "Aircraft encounters with convective weather in en route vs. terminal airspace above Memphis, Tennessee," 10th Conference on Aviation, Range, and Aerospace Meteorology, Amer. Meteor. Soc., Portland, OR.
3. Rhoda, D.A. and M.L. Pawlak, "An Assessment of Thunderstorm Penetrations and Deviations by Commercial Aircraft in the Terminal Area," Massachusetts Institute of Technology, Lincoln Laboratory, Project Report NASA/A-2, 3 June 1999.
4. Case illustrating tremendous sensitivity of delays in congested corridors to apparently small changes in traffic handling: http://www.caasd.org/proj/delay/scenario_a.html
5. Case illustrating congestion due to en route severe weather:
http://www.caasd.org/proj/delay/scenario_b.html



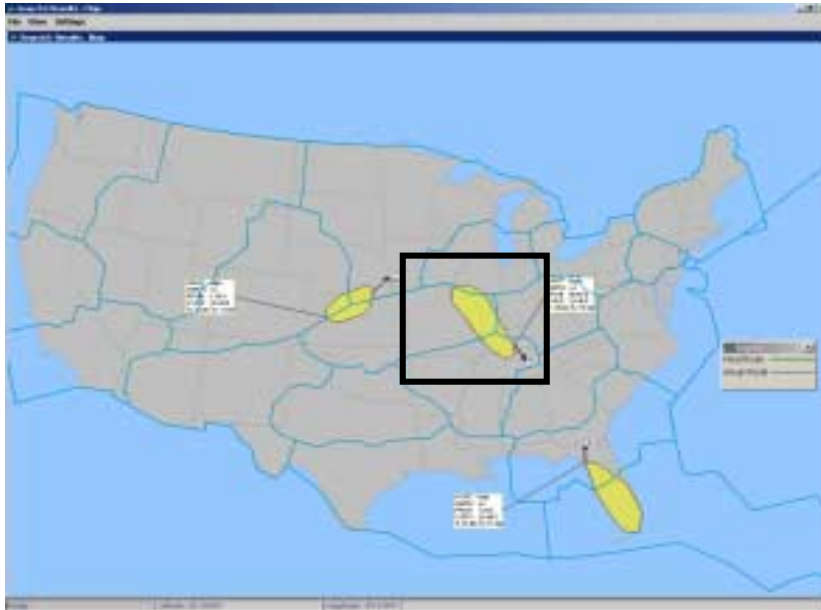
Appendix A Details on CCFP Calibration & Operational Study

The following 6 slides were very kindly provided by Mark Phaneuf of AvMet, Incorporated (phaneuf@avmet.com)

They provide details on a number of the issues discussed in slide 8.

The bulk of these slides are from a presentation at the Second Workshop on Aviation Weather for ATM held at the MITRE Corporation July 23-25, 2002.

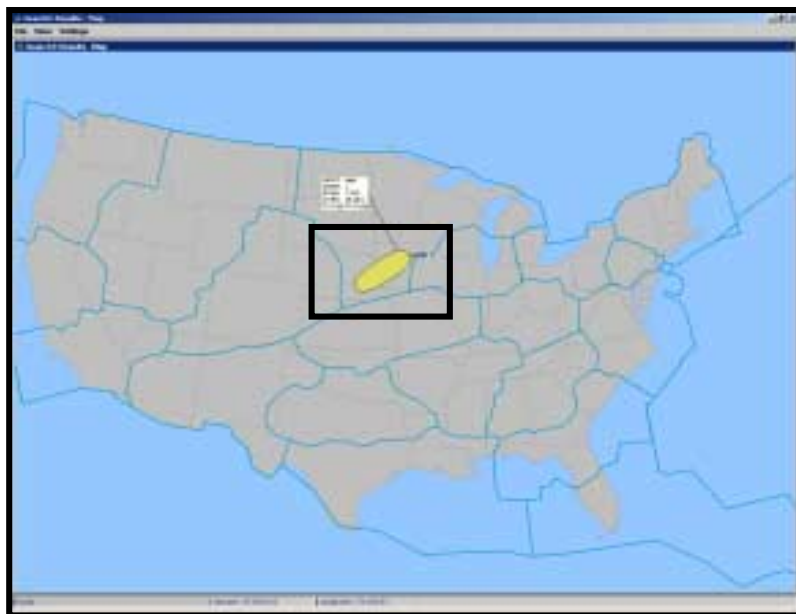
Flight Route	Reroute Decision
Scheduled, Filed and actual flight routes go through forecast area and do not differ	No Reroute
Scheduled and/or filed route goes through forecast area, Amended route goes around forecast area prior to CCFP issue time	Strategic Before Forecast
Scheduled and/or Filed route goes through forecast area, Amends around known forecast area before take off or prior to 2 hours before the issue time	Strategic
Filed route goes through forecast area, Amends around the known forecast area after take off	Tactical
Not enough flight information	Unclear



7-19 1500 for 1700 CCFP forecast
 Low Coverage, Medium Probability Forecast
 Weather verified at 34.4%.

Baseline Traffic Days	Number of Flights
4/12/01	293
4/19/01	346
4/26/01	346
5/10/01	338
5/24/01	358
6/7/01	349
6/28/01	360
7/5/01	323
7/12/01	322
7/26/01	355
8/16/01	354
Average # of Flights on Baseline Days	340
Maximum	360
Minimum	293
Standard Deviation	20.3
Forecast Date	Number of Flights
7/19/01	226
Average Traffic Reduction	34%
Maximum Traffic Reduction	37%
Minimum Traffic Reduction	23%

CCFP Present, Weather Did Not Develop



Baseline Traffic Days	Number of Flights
4/12/01	134
4/19/01	116
4/26/01	150
5/24/01	135
6/28/01	148

Average # of Flights on Baseline Days **136.6**
Maximum **150**
Minimum **116**
Standard Deviation **13.6**

Forecast day	Number of Flights
5/10/01	124

Average Traffic Reduction **9%**
Maximum Traffic Reduction **17%**
Minimum Traffic Reduction **-7%**

5-10 1500 for 1900 CCFP forecast
 Low Coverage, Low Probability Forecast
 Weather verified at 0.0%

Percentage of Strategic Reroutes for Each Forecast

Date/Valid Time	Forecast	% Verified by FSL	% of Flights
5/3/2001 1700	Low Coverage, Low Probability	42.3%	24%
5/3/2001 1900	Low Coverage, Low Probability	39.1%	8%
5/10/2001 1900	Low Coverage, Low Probability	0.0%	18%
8/2/2001 1700	Low Coverage, Low Probability	47.6%	5%
8/9/2001 1700	Low Coverage, Low Probability	40.0%	9%
6/14/2001 1700	Low Coverage, Medium Probability	12.2%	40%
7/19/2001 1700	Low Coverage, Medium Probability	34.4%	16%
8/23/2001 1500	Low Coverage, High Probability	10.2%	33%

Low Coverage = 25-49%

Medium Coverage = 50-74%

High Coverage = 75-100%

% of flights = fraction of flights that were probably rerouted on the basis of the CCFP

% verified = percentage of CCFP area covered by actual weather

Number of Flights by Outcome of Reroute Type



5/3/2001 1900, 6/14/2001 1700, 8/9/2001 1700, 8/23/2001 1500

		Outcome			
		<i>Good</i>	<i>Bad</i>	<i>Needed To Reroute-Bad</i>	<i>Total</i>
Type of Reroute	<i>No Reroute</i>	341	340	-	681
	<i>Strategic</i>	56	68	65	189
	<i>Unclear</i>	-	-	-	53
<i>Total</i>		397	408	65	923

Good decision not to reroute **50%**

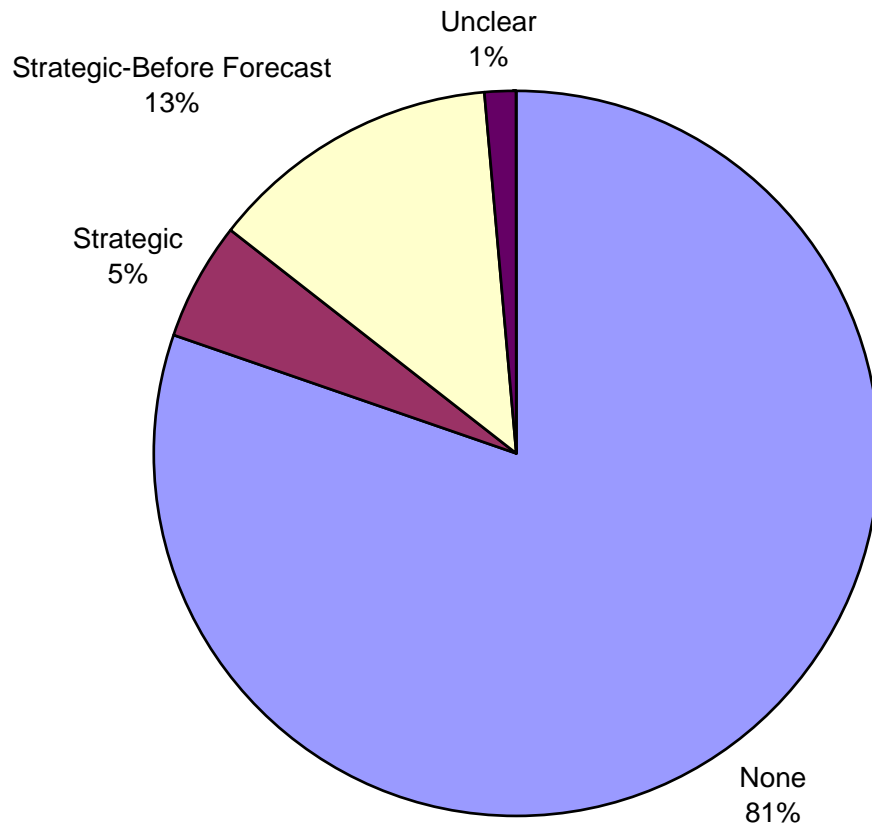
Bad decision not to reroute **50%**

Good decision to strategically reroute **64%**

Bad decision to strategically reroute **36%**

Type of Reroutes on 5/10/2001

Low Coverage, Low Probability Forecast at 1900
Verified at 0.0%



Additional case not presented at workshop.