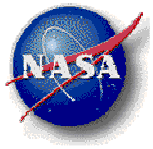

Computation of Aggregate Delay Using Center-based Weather Impacted Traffic Index

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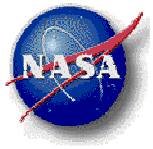
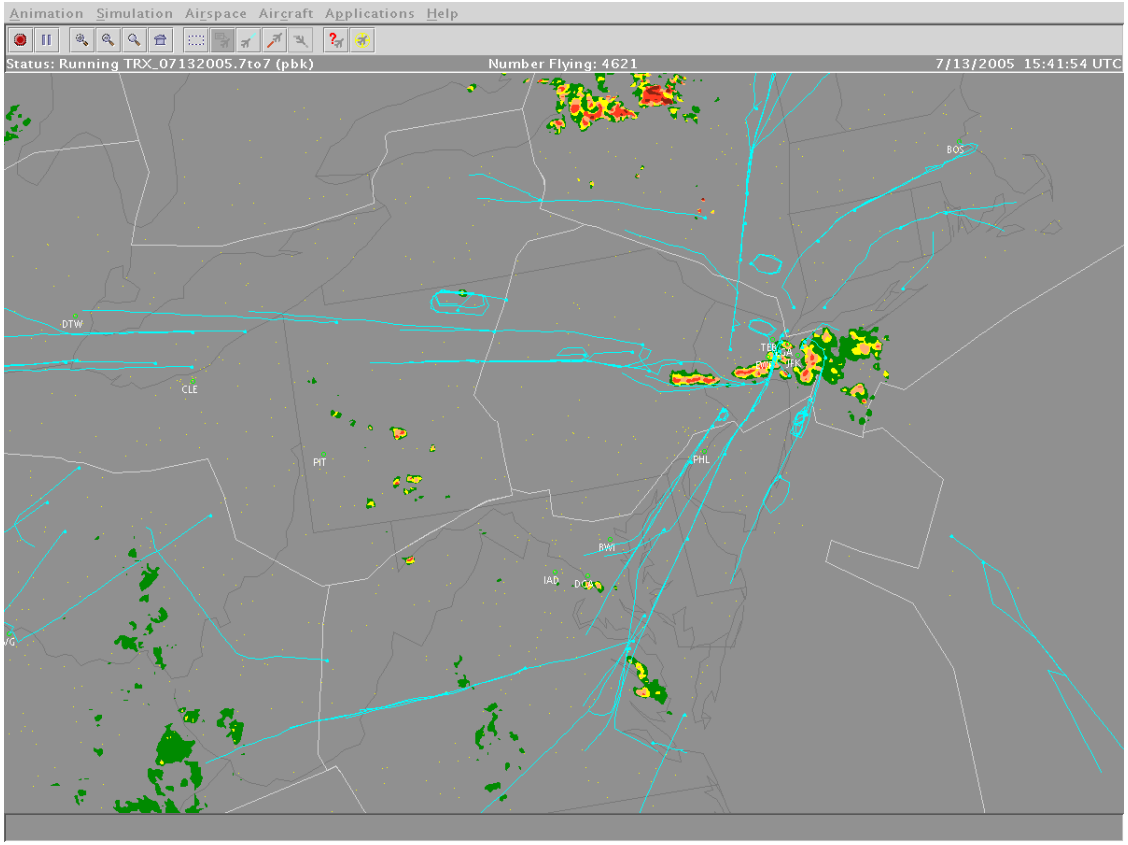
National Airspace System Performance Workshop
Asilomar Conference Grounds
Pacific Grove, CA
September 4-7, 2007



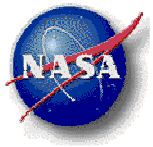
Outline

- Motivation
- Objective
- Weather Impacted Traffic Index
- Delay Prediction Models
- Classification of a day into delay categories
- Results
- Concluding Remarks

Motivation



- **Traffic Flow Management initiatives in response to surface & enroute weather are the major cause of National Airspace System (NAS) delays**
- **Relate the delay performance to the weather conditions**
  - **Assessment using baseline data**
  - **Prediction based on weather forecast**

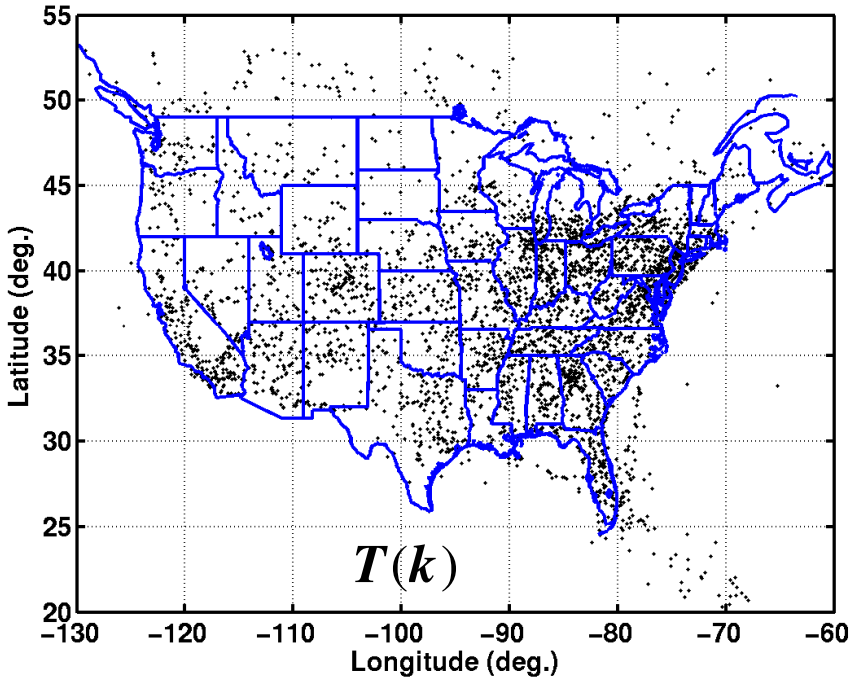


Objectives

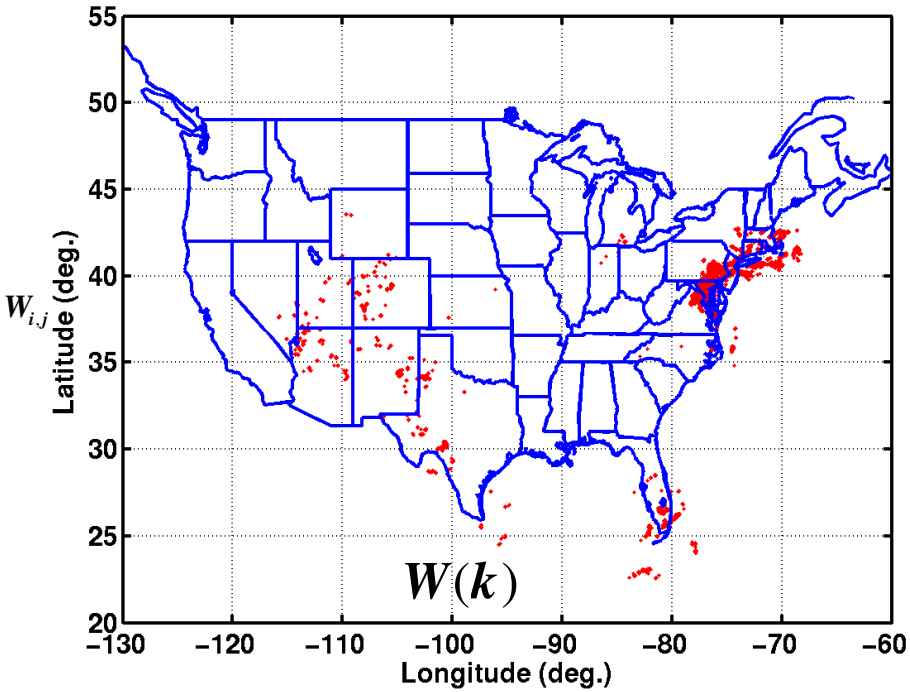
- **Develop a NAS delay estimation models based on expected traffic, and surface and enroute weather**
  - **Linear Model**
  - **Three-piece Linear Model**
- **Compare the accuracy of the two estimation models**

Weather Impacted Traffic Index (WITI)

Aircraft positions grid

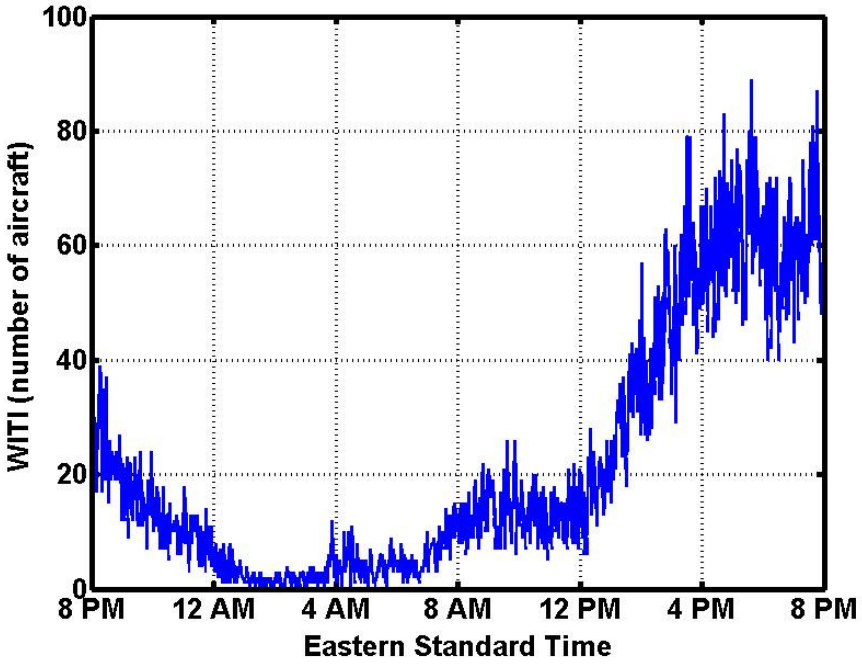


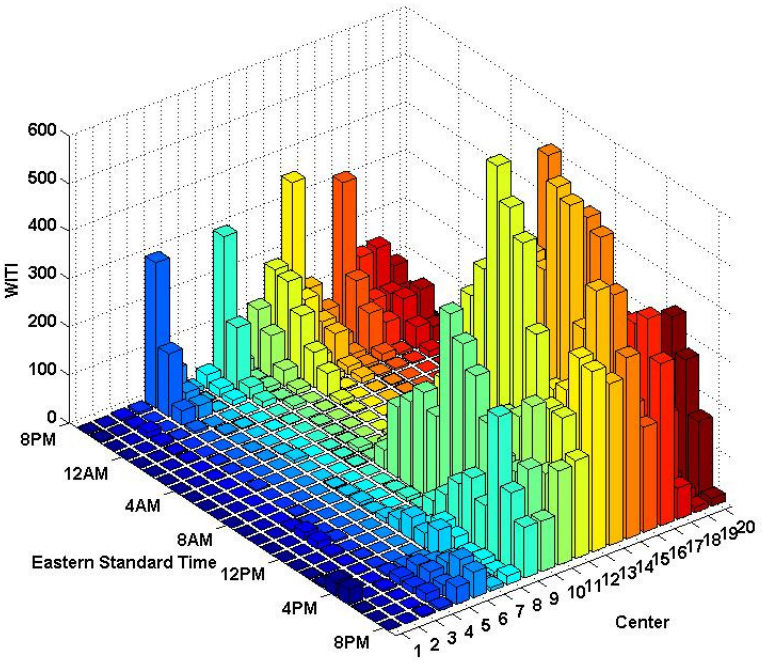
Severe weather grid



$$WITI(k) = \sum_{1 \le j \le m} \sum_{1 \le i \le n} T_{i,j}(k) W_{i,j}(k)$$

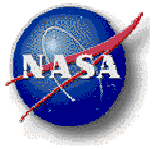
WITI and Center WITIs (16 July 2005)





1	ZSE
2	ZOA
3	ZLA
4	ZLC
5	ZDV
6	ZAB
7	ZMP
8	ZKC
9	ZFW
10	ZHU
11	ZAU
12	ZID
13	ZME
14	ZOB
15	ZDC
16	ZTL
17	ZJX
18	ZMA
19	ZBW
20	ZNY

- **Delay modeled as a linear combination WITI features**



Delay Prediction Models

NAS Delay Estimation

Model

$$\begin{bmatrix} f_1(1) & f_2(1) & \cdots & f_r(1) \\ f_1(2) & f_2(2) & \cdots & f_r(2) \\ \vdots & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ \vdots & & & \vdots \\ f_1(s) & f_2(s) & \cdots & f_r(s) \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_r \end{bmatrix} = \begin{bmatrix} d(1) \\ d(2) \\ \vdots \\ \vdots \\ \vdots \\ d(s) \end{bmatrix}$$

Features (columns) — Delay (right) — Number of Days (rows)

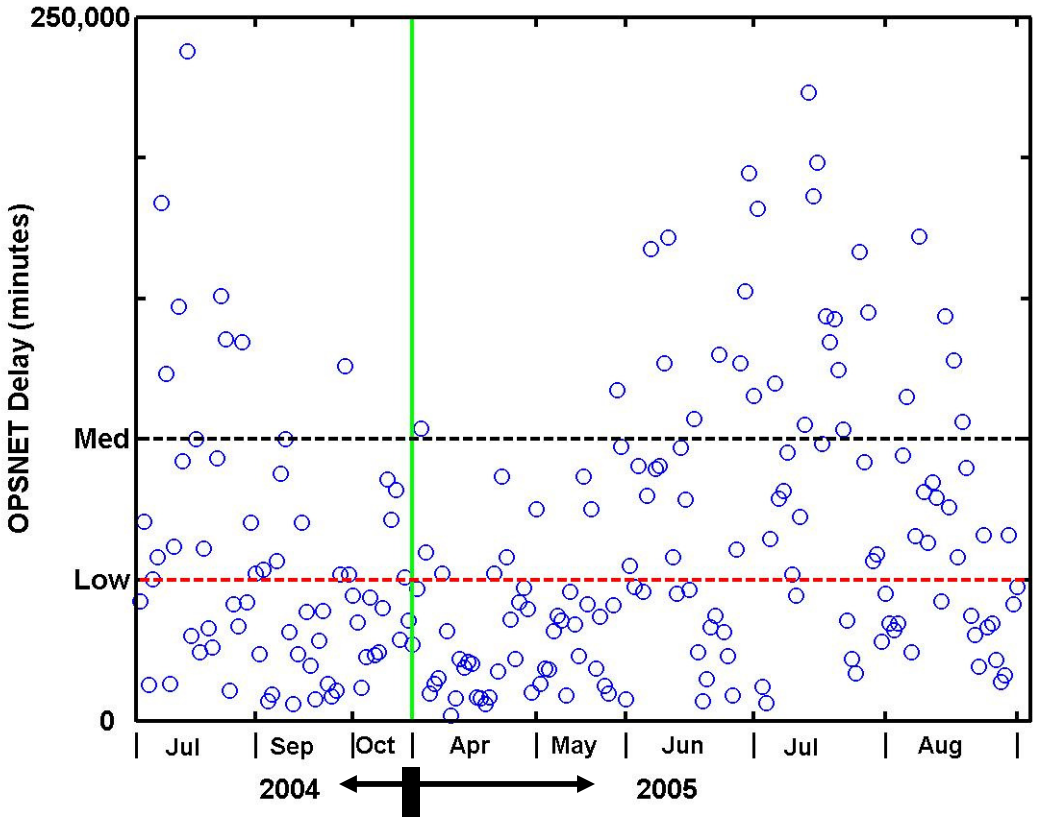
Weights

$$\boldsymbol{w} = (\boldsymbol{F}^T \boldsymbol{F})^{-1} \boldsymbol{F}^T \boldsymbol{d}$$

Delay estimate

$$\hat{d}(p) = \begin{bmatrix} f_1(p) & f_2(p) & \cdots & f_r(p) \end{bmatrix} w$$

Piece-Wise Linear Modeling



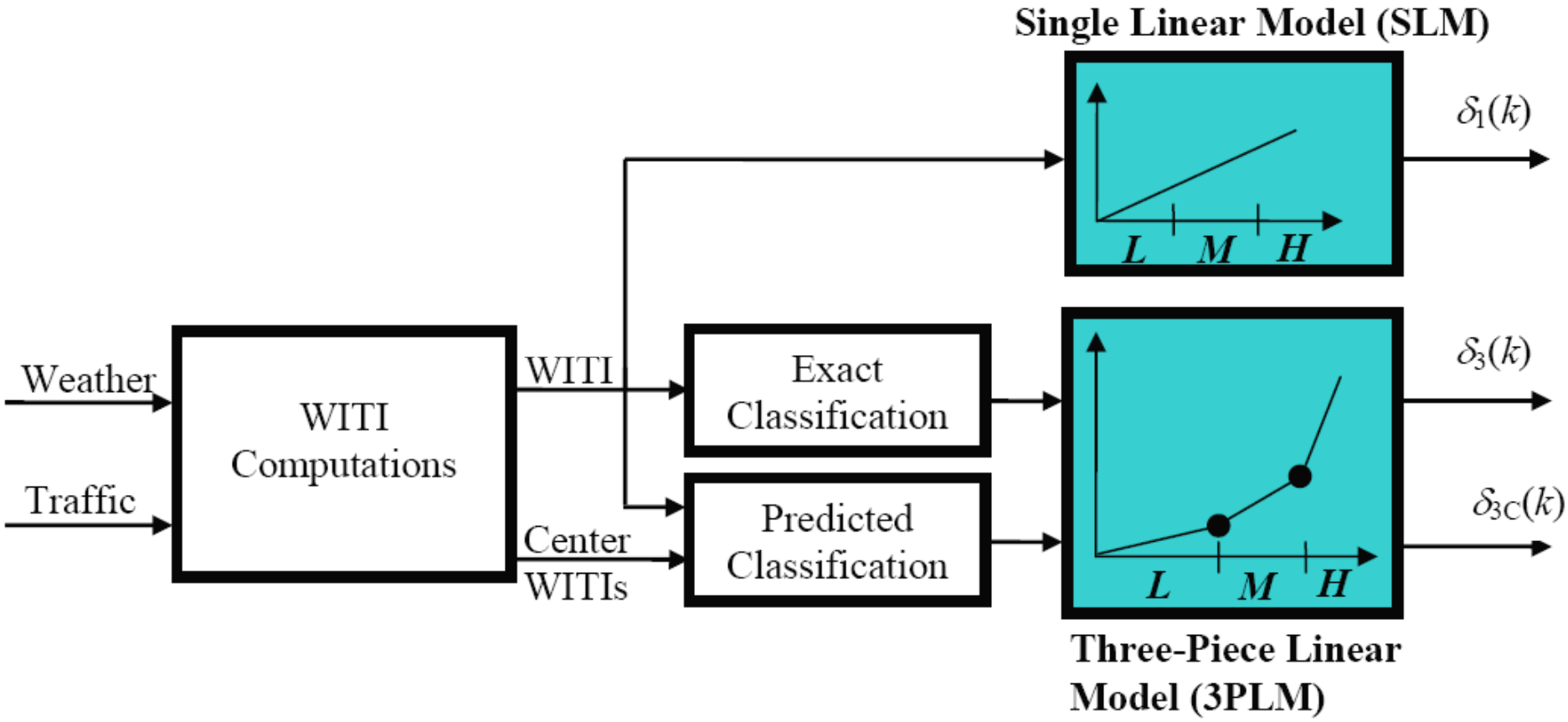
$$F = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} \quad d = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix} \quad w = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}$$

$$w_i = (F_i^T F_i)^{-1} F_i^T d_i$$

$$\hat{d}_i = F_i w_i$$

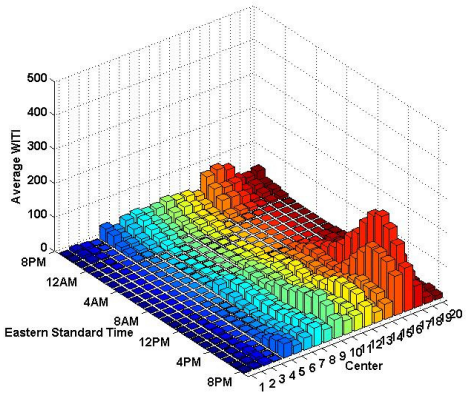
- **Three linear models covering recorded delays**
  - **0 to Low, Low to Medium, and Medium to High regions**

Delay Estimation Models

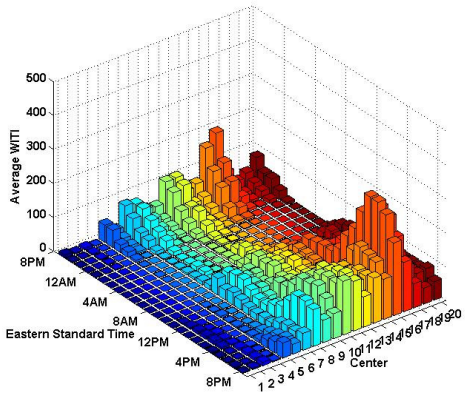


Classification of a day into delay categories

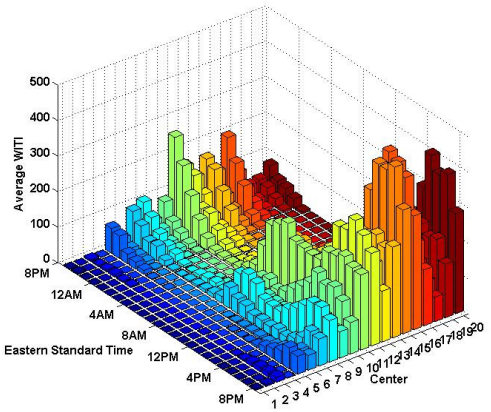
Average Center WITIs by Delay Category



Low

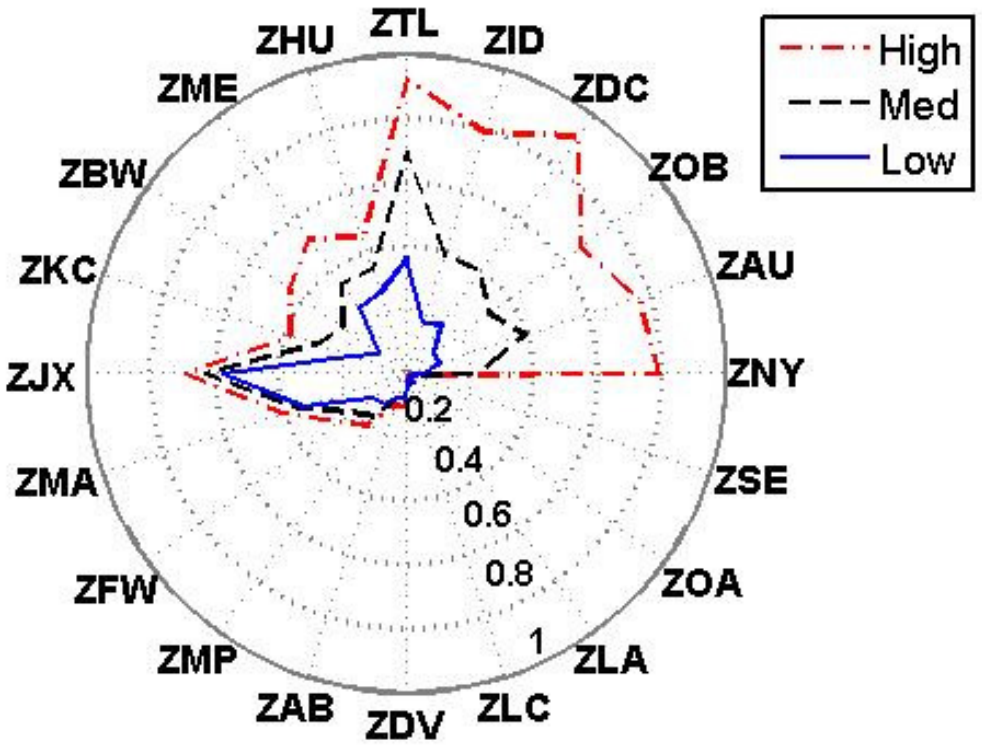


Medium



High

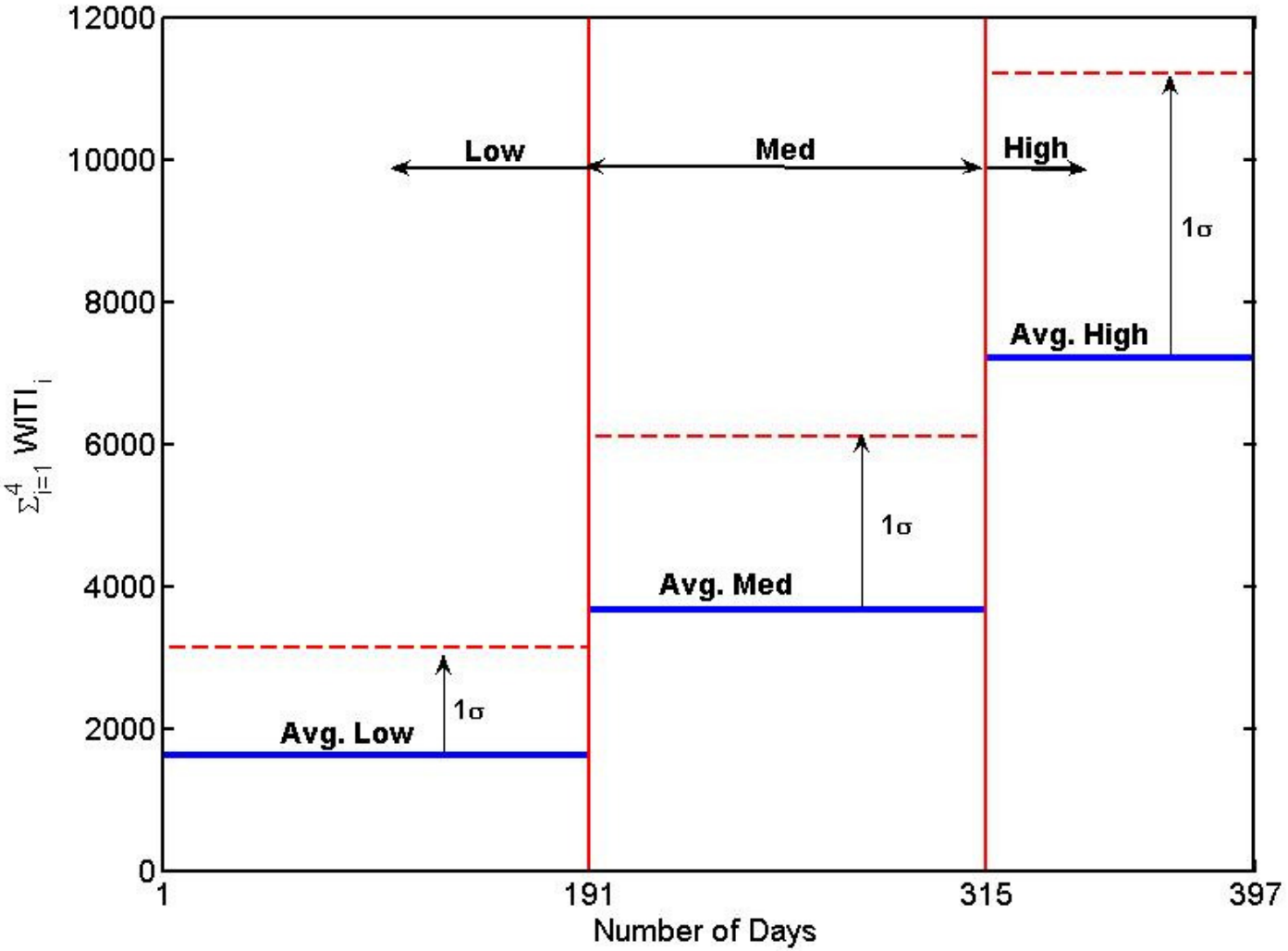
Normalized average center WITIs for 2004, 2005 and 2006



Correlation of Center WITI with OPSNET delays

# of Center	Center Names	Correlation Coefficient
1	ZNY	0.59
2	ZNY ZOB	0.68
3	ZNY ZAU ZDC	0.72
4	ZNY ZAU ZOB ZDC	0.75
6	ZNY ZAU ZOB ZDC ZID ZTL	0.76
9	ZNY ZAU ZOB ZDC ZID ZTL ZHU ZFW ZME	0.73

Average and standard deviation of total WITI values using 4-center configuration



Validation of delay classification using August 2006 data

Date #	1	2	3	4	5	6	7
Actual Delay (min)	9,126	9,843	12,844	24,667	26,290	29,612	33,955
Category in PLM	L	L	L	L	L	L	L
Predicted Category	L	L	L	L	L	L	L

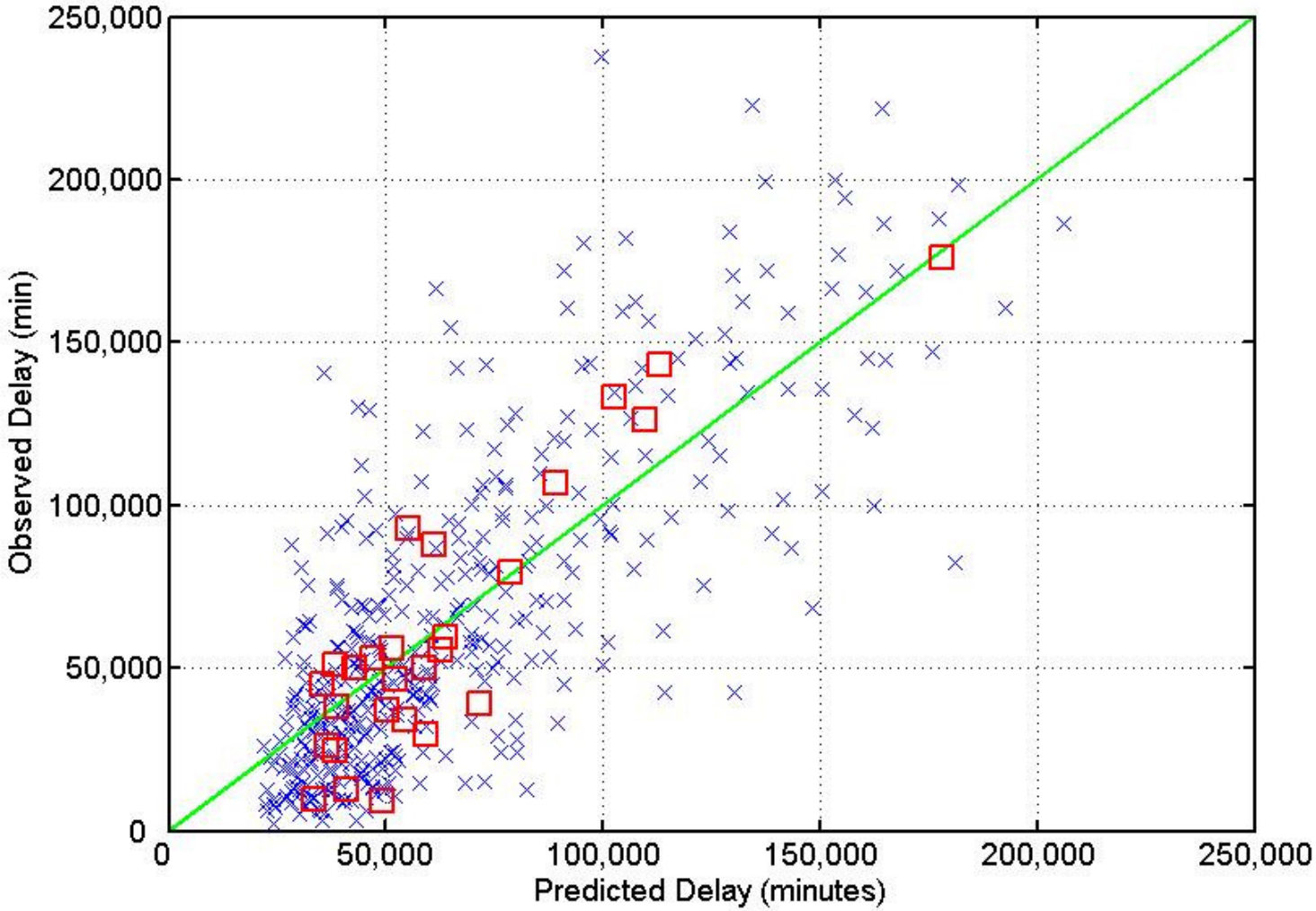
Date #	8	9	10	11	12	13	14
Actual Delay (min)	37,139	37,979	39,220	44,972	46,500	49,812	50,259
Category in PLM	L	L	L	L	L	L	M
Predicted Category	L	L	L	L	L	L	L

Date #	15	16	17	18	19	20	21
Actual Delay (min)	51,010	53,207	55,564	55,858	59,547	79,459	88,077
Category in PLM	M	M	M	M	M	M	M
Predicted Category	M	L	M	M	M	M	M

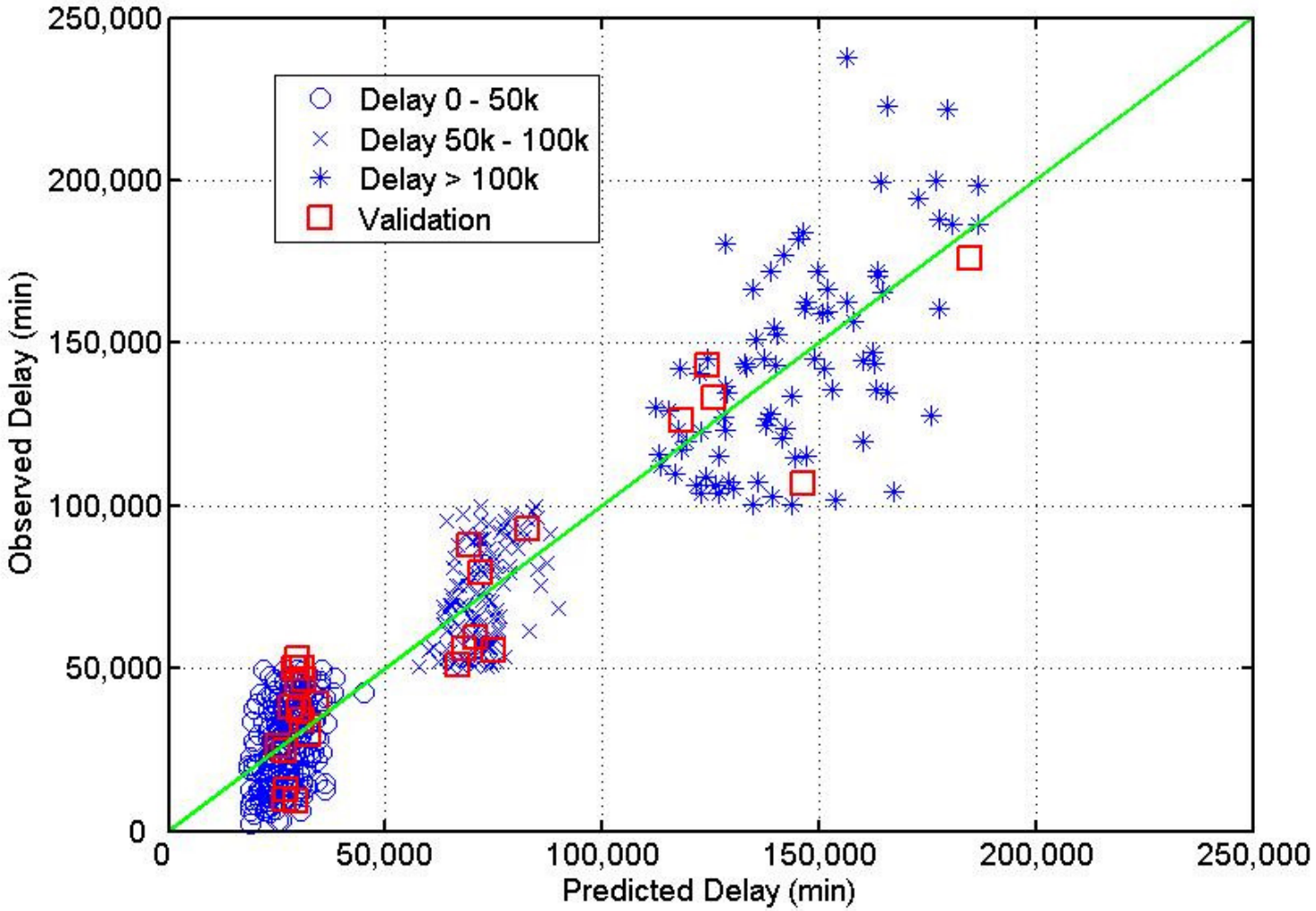
Date #	22	23	24	25	26	27
Actual Delay (min)	93,109	106,606	126,004	133,257	143,173	175,804
Category in PLM	M	H	H	H	H	H
Predicted Category	M	H	H	H	H	H

Results

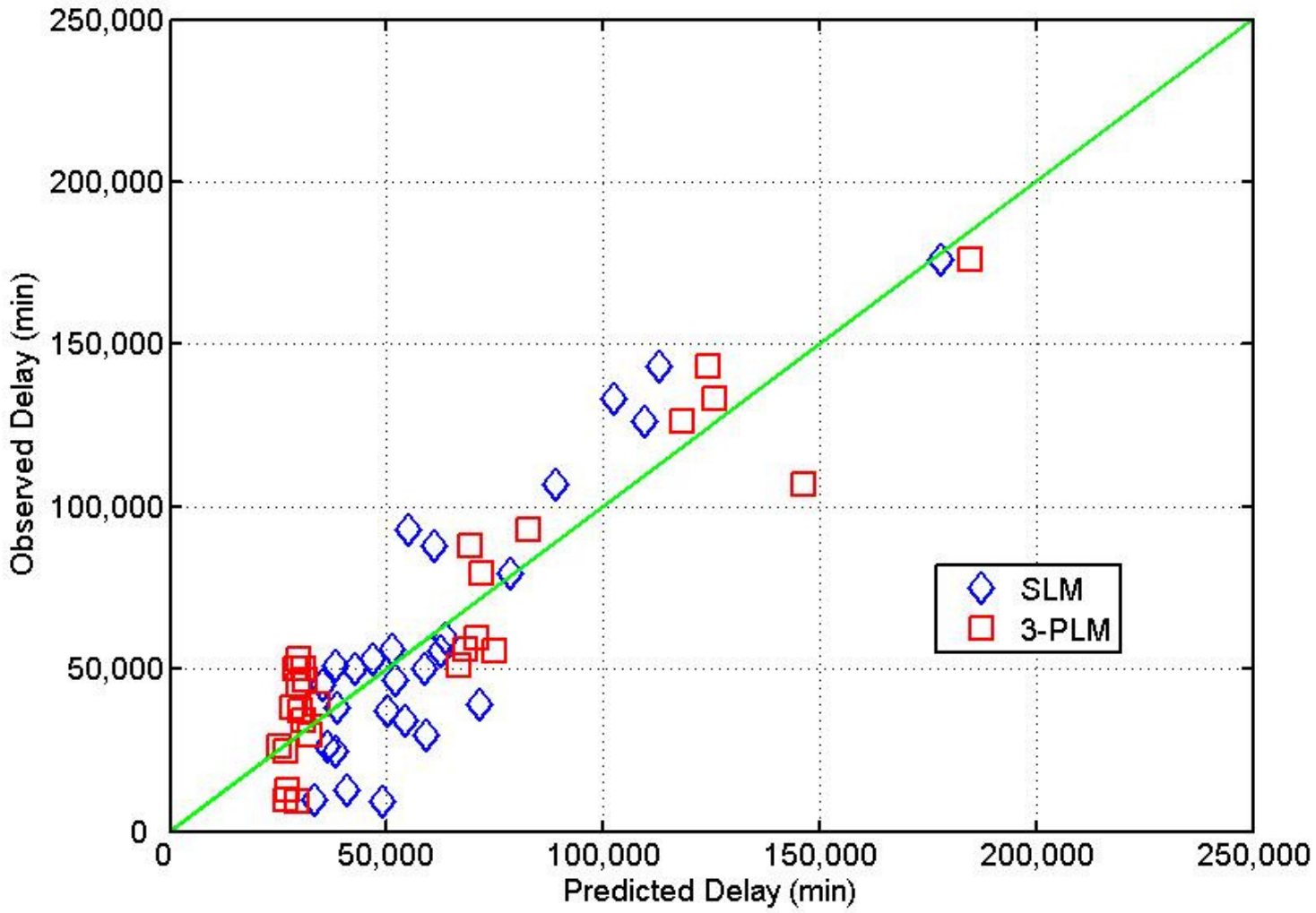
Delay estimation for August 2006 using single linear model



Delay estimation for August 2006 using predicted delay classification



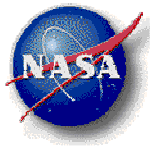
Comparison of delay estimation between single linear model and 3-piece linear model



Delay estimation for August 2006

Methodology	Correlation Coefficient	Standard Deviation (min)		
SLM	0.89	20,400		
3-PLM with exact classification	0.94	12,530	14,820	22,826
3-PLM with predicted classification	0.93	13,769	15,039	22,826

- **Three-piece linear model provides a better estimate of aggregate delay**

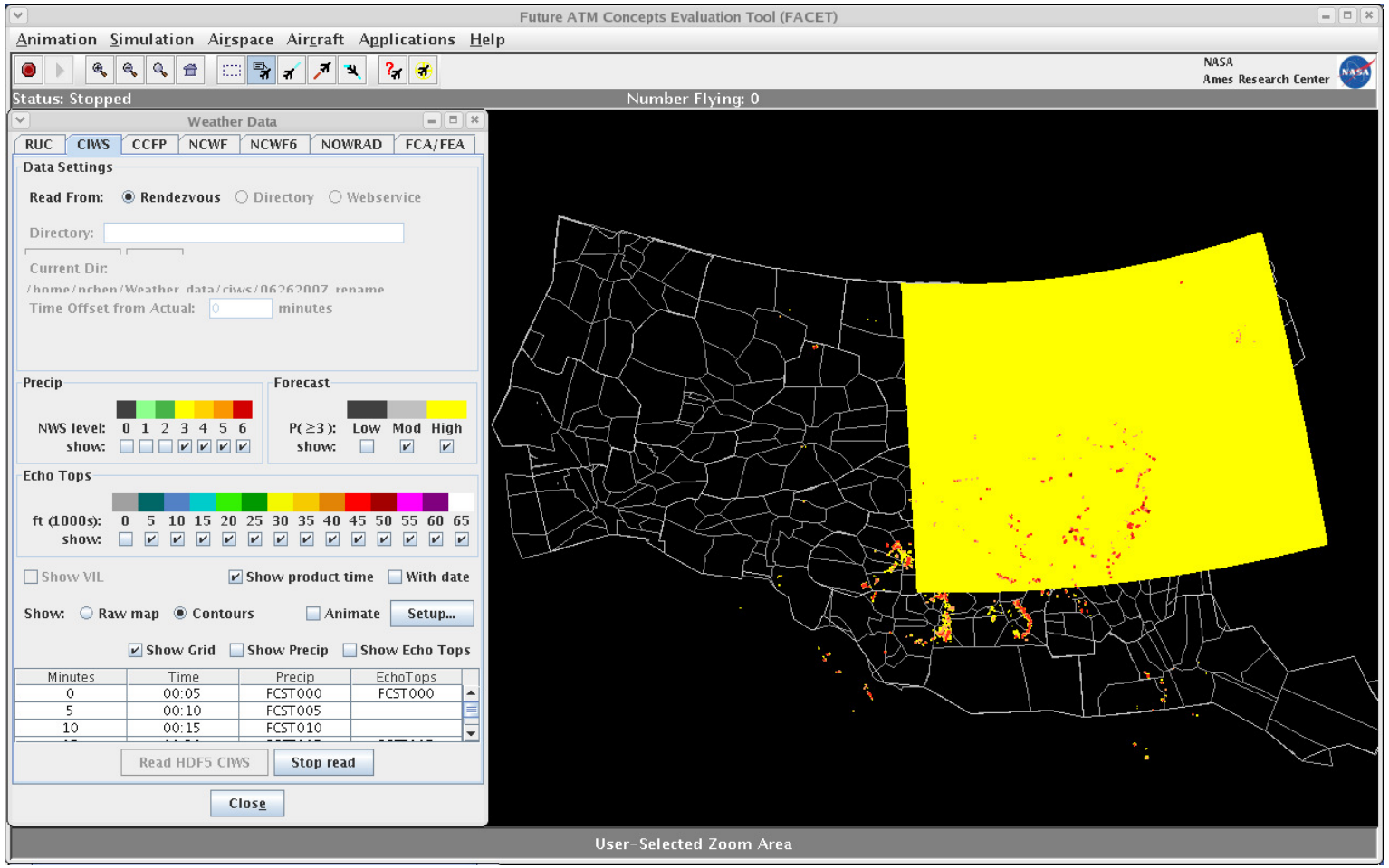


Concluding Remarks

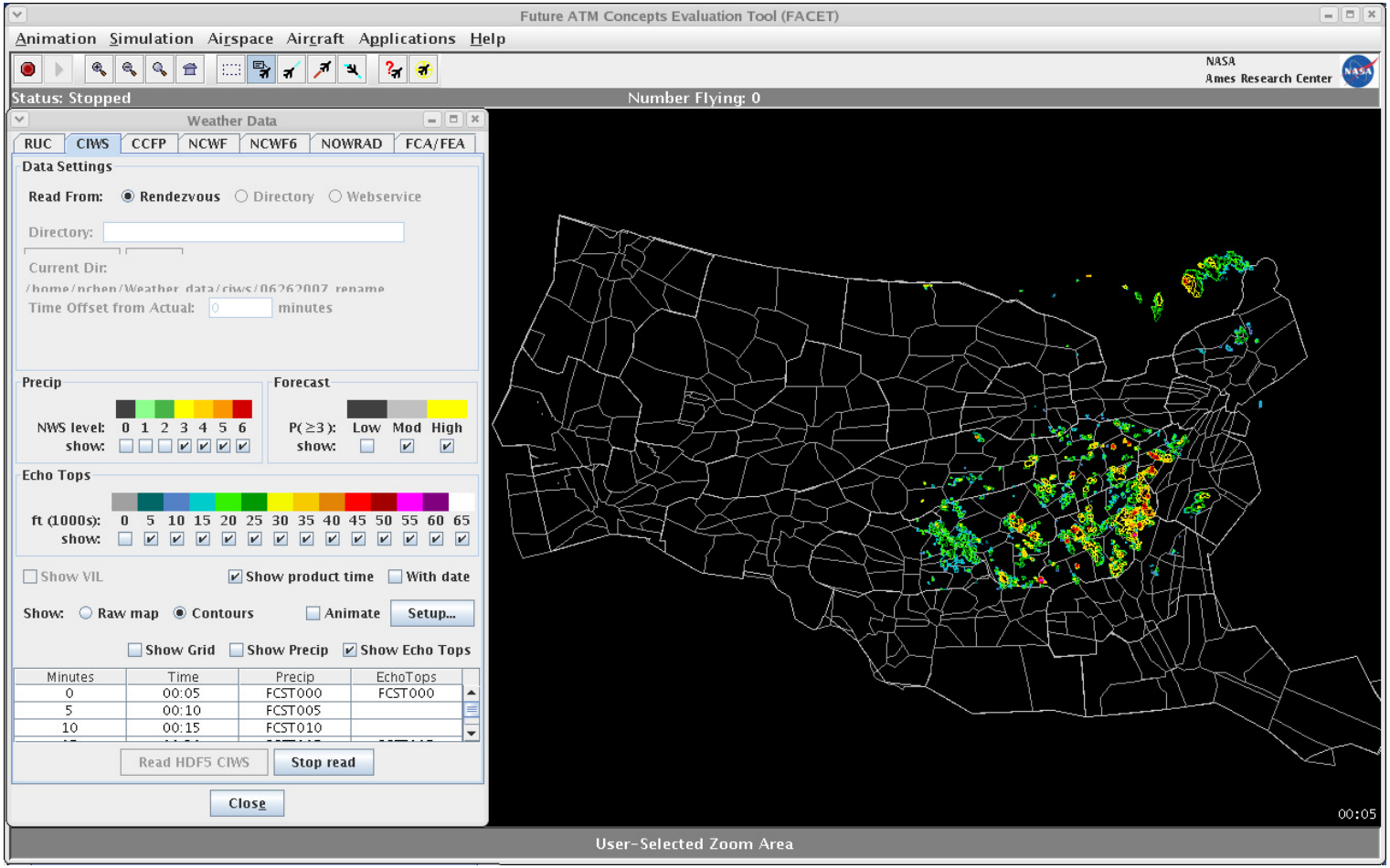
- First attempt to successfully classify days into delay categories based on Center WITI values.
- Developed an integrated method to estimate NAS aggregate delay as a function of weather and traffic
- Three-piece linear model provides significantly better estimates of delay
- Future research
  - Improvement of delay classification using different techniques
  - Use of three-dimensional information in the computation of WITI
  - Use of Aviation System Performance Metrics (ASPM)

Additional Viewgraphs

NOWRAD Weather Level 3-6 with CIWS Grid



CIWS Weather Echotop 0626_2006_0005



Computation of WITI