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# **Temporal Deviations from Flight Plans: New Perspectives on En Route and Terminal Airspace**

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# Acknowledgements

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- **Seminal ideas from**
  - Ed Meyer, FAA
- **Helpful comments from**
  - Dave Knorr, FAA
  - James Bonn and Joe Post, CNA Corp.
  - Mike Ball, U Maryland
  - Bob Hoffman, Metron Aviation
  - American Airlines OR group
- **Financial support from**
  - FAA Free Flight

# How this all got started...

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Q: I wonder, how long does it take to fly from A to B?

A: It varies a lot.

Q: Is this a problem?

A: Yes. Consistency is an important service metric.

Q: Why does the time vary so much?

A: Some of the variation is predictable, but a lot is surprising and troublesome.

Q: How can we quantify the surprises?

A: Look at deviations from flight plans.

Q: Do the deviations reflect en route problems?

A: Mostly. But there are also systemic effects, like correlations across different routes, or problems with flights going to the same destination from many origins.

Q: How can we trace the deviations to their various sources?

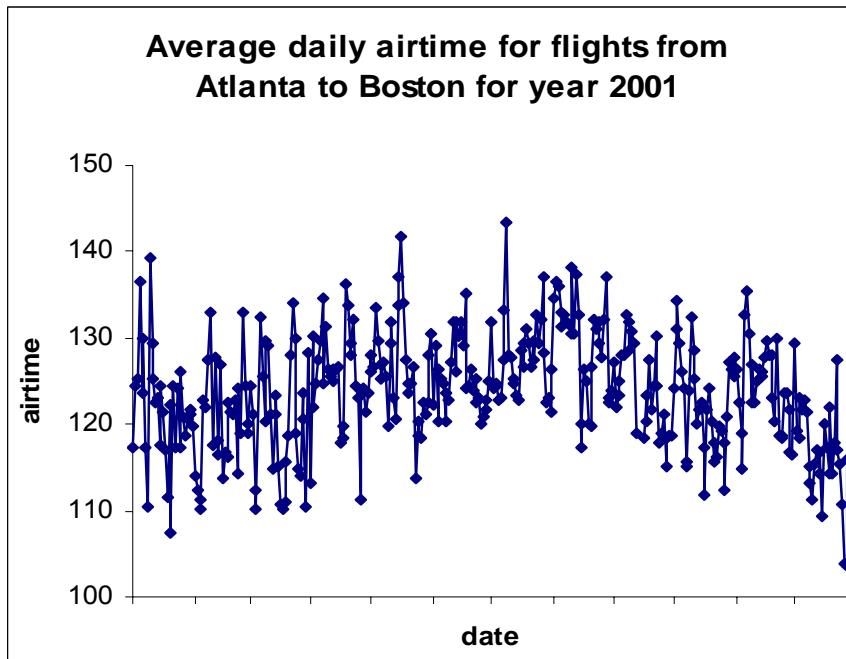
A: Invent a **new way of analyzing ASPM data**.

# Agenda

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- Deviations from flight plans
  - Sources of deviations
  - Row+column analysis to estimate deviations
  - System implementation
  - Samples of system outputs
- Alternative approach using new ASPM En Route data
  - Row+column analysis of excess en route distance
  - Evidence of ripple effect back from runway congestion to excess en route distance flown

# Variation in flight times



← Average airtime fluctuates (due to winds aloft, weather and congestion in airports, etc.)

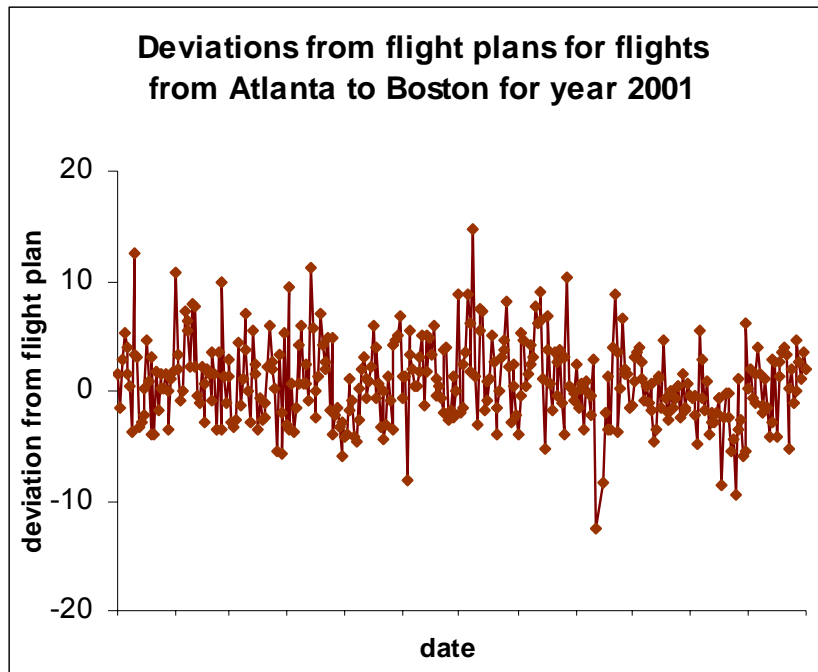
← Flight plans anticipate “normal problems”

↓ Shift attention to

Deviation = Actual Airtime – Planned Flight Time

2 types of Deviations: “ETE” and “G2G”

# Deviations from flight plans



- ← Deviations from flight plans measure unanticipated problems, or “surprises”
- ← Common factors for different flights are considered as systemic sources of deviations

- ↓ Decompose deviations into four sources:

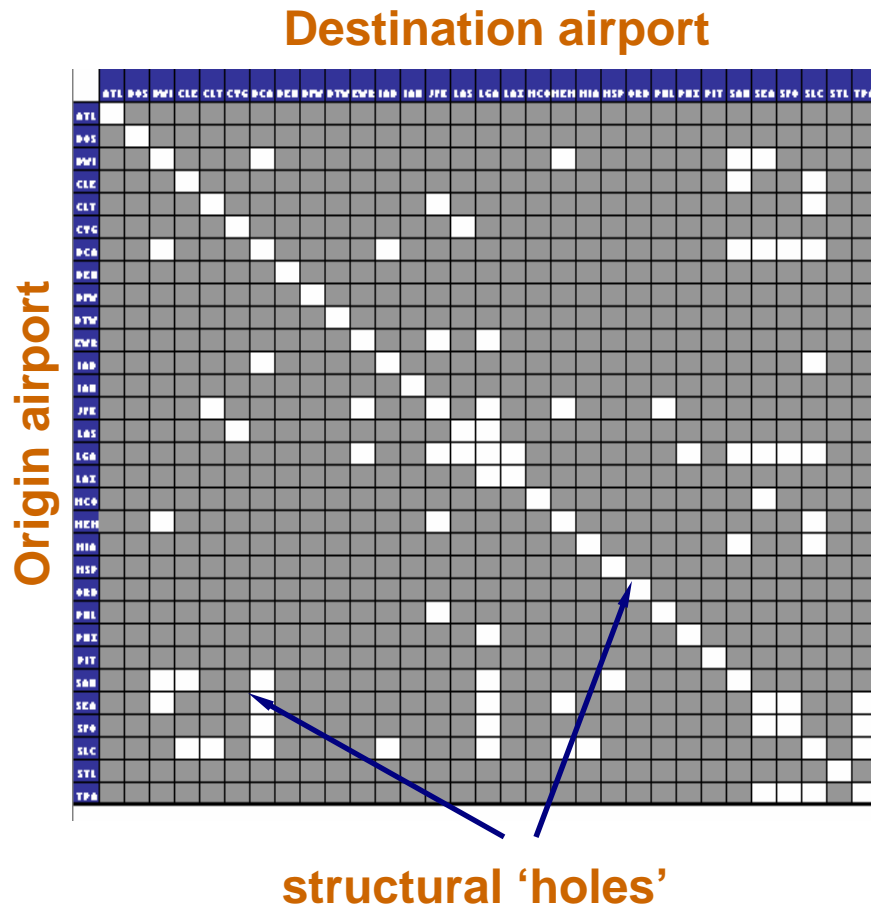
System + Origin airspace + Destination airspace + En route airspace

# Sources of deviations

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- System effects
  - 9/11 attacks, bias in data collection system
- Origin effects
  - restricted departure gates, runway configuration
- Destination effects
  - LAHSO unavailable, reduced AAR
- En route effects
  - convective weather, MIT, circular holding

# FAA data as a two-way table



- 31 major US airports
- Each table represents one day of operations
- One observation per cell, averaging over all flights on route
- Analyzed ASPM data for January '01- June '03
- Presence of structural 'holes' and outliers complicates estimation problem



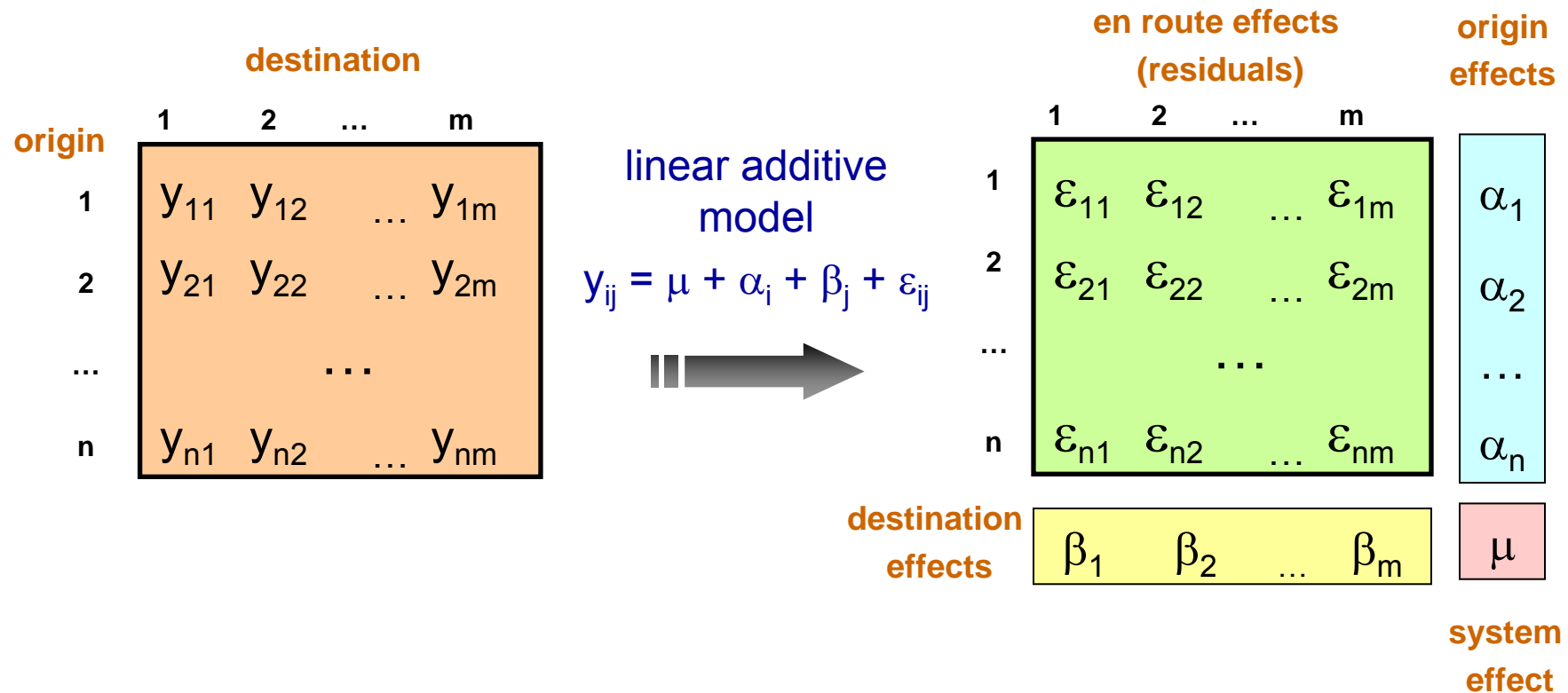
# Fragment of the table

Destination airport

Origin airport

	ATL	BOS	BWI	CLE	CLT	CVG	DCA	DEN	DFW	DTW	EWB	IAD	IAH
ATL	.	6.33	3.93	-0.80	6.33	2.36	6.80	-3.47	0.93	2.50	-1.74	0.22	-4.00
BOS	4.50	.	3.30	0.20	5.43	-2.71	4.67	2.43	2.00	-1.25	-7.71	7.88	-2.17
BWI	4.71	0.45	.	7.55	0.13	8.40	.	-0.17	1.00	15.17	-5.29	4.20	-1.27
CLE	1.27	7.80	7.40	.	0.83	-1.08	2.75	0.00	4.80	0.08	-12.8	8.50	1.
CLT	3.31	-2.00	1.43	5.00	.	4.25	7.33	1.67	3.00	8.00	0.36	18.80	-3.
CVG	5.40	2.67	-1.25	-2.45	-4.88	.	7.40	7.40	0.00	5.78	-11.1	11.38	-4
DCA	6.53	-0.84	.	2.00	-0.73	3.75	.	-4.00	1.54	8.29	-16.5		
DEN	4.25	7.86	7.00	-6.25	3.25	1.50	.	.	2.80	3.50	3.31		
DFW	5.03	-7.92	9.17	-2.33	1.85	4.22	5.18	-0.37	.	3.92			
DTW	5.06	4.75	-2.50	2.71	-0.33	1.57	-1.14	0.13	4.67				
EWB	-2.46	-9.48	4.83	-1.57	0.40	-1.80	-3.						
IAD	3.06	-0.09	.	-0.33	-5.00	1.							
IAH	5.00	-10.0	-1.17	-1.17	0.								

# Row + Column analysis



# Toy example of row+column analysis

Avg Deviations		Destination					
		ORD	CVG	CLE	DTW	PIT	
Origin	ORD		1	6	3	2	1
	CVG	12		5	3	-1	0
	CLE	12	-3		0	-1	-2
	DTW	13	2	4		0	1
	PIT	24	4	7	7		4
		10	-2	3	0	-2	2

$$24 = 2 + 4 + 10 + 8$$

En route Effects		Destination				
		ORD	CVG	CLE	DTW	PIT
Origin	ORD		0	0	0	1
	CVG	0		0	1	-1
	CLE	2	-1		0	1
	DTW	0	1	-2		-1
	PIT	8	0	-2	1	

# System implementation

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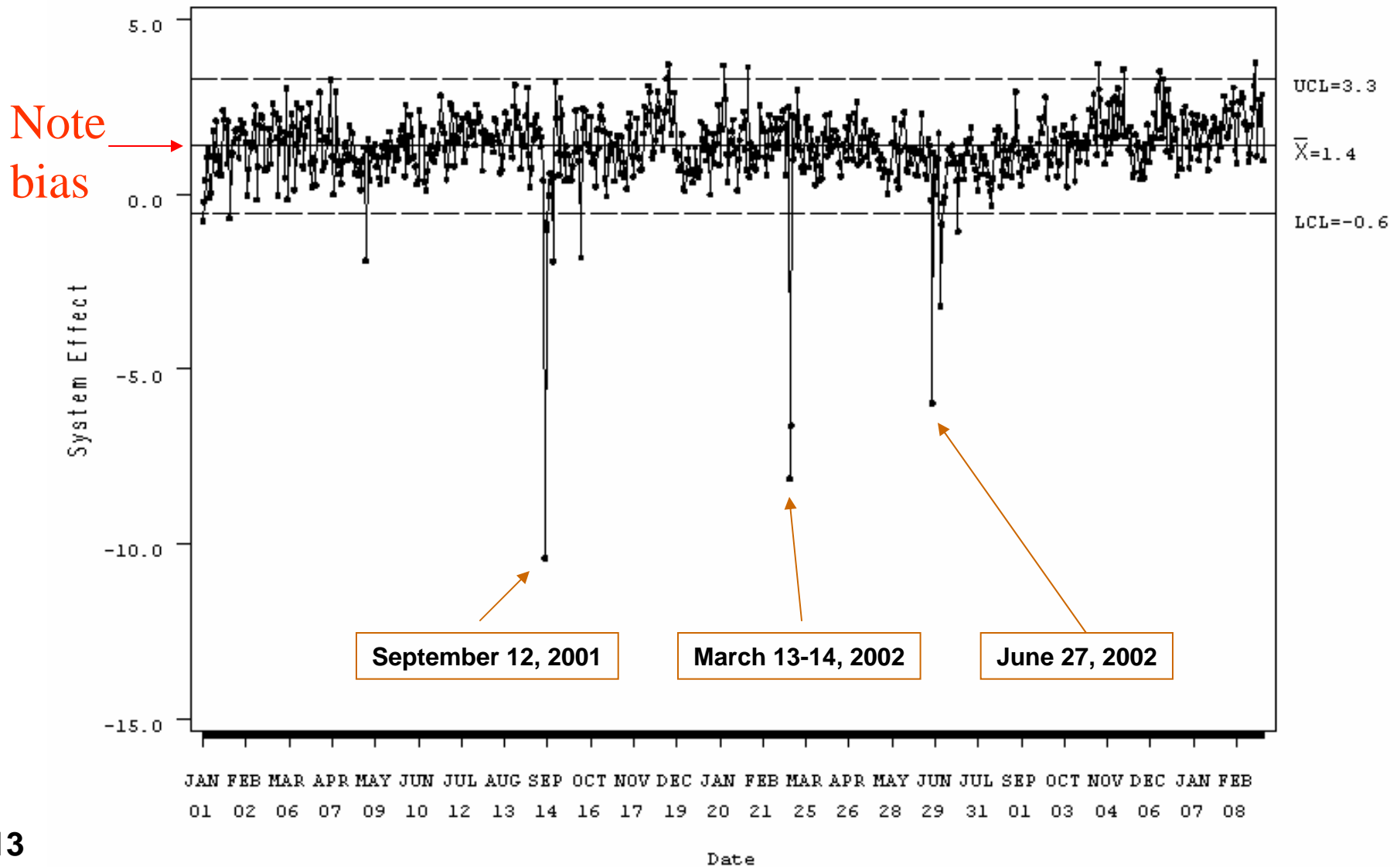
We created a turnkey system implemented in SAS that produces:

- Detection of outliers for next-day analysis of NAS operations
- Map-based displays
- Statistical graphics
- Datasets for further analysis in one-off statistical studies

Examples of system outputs follow.

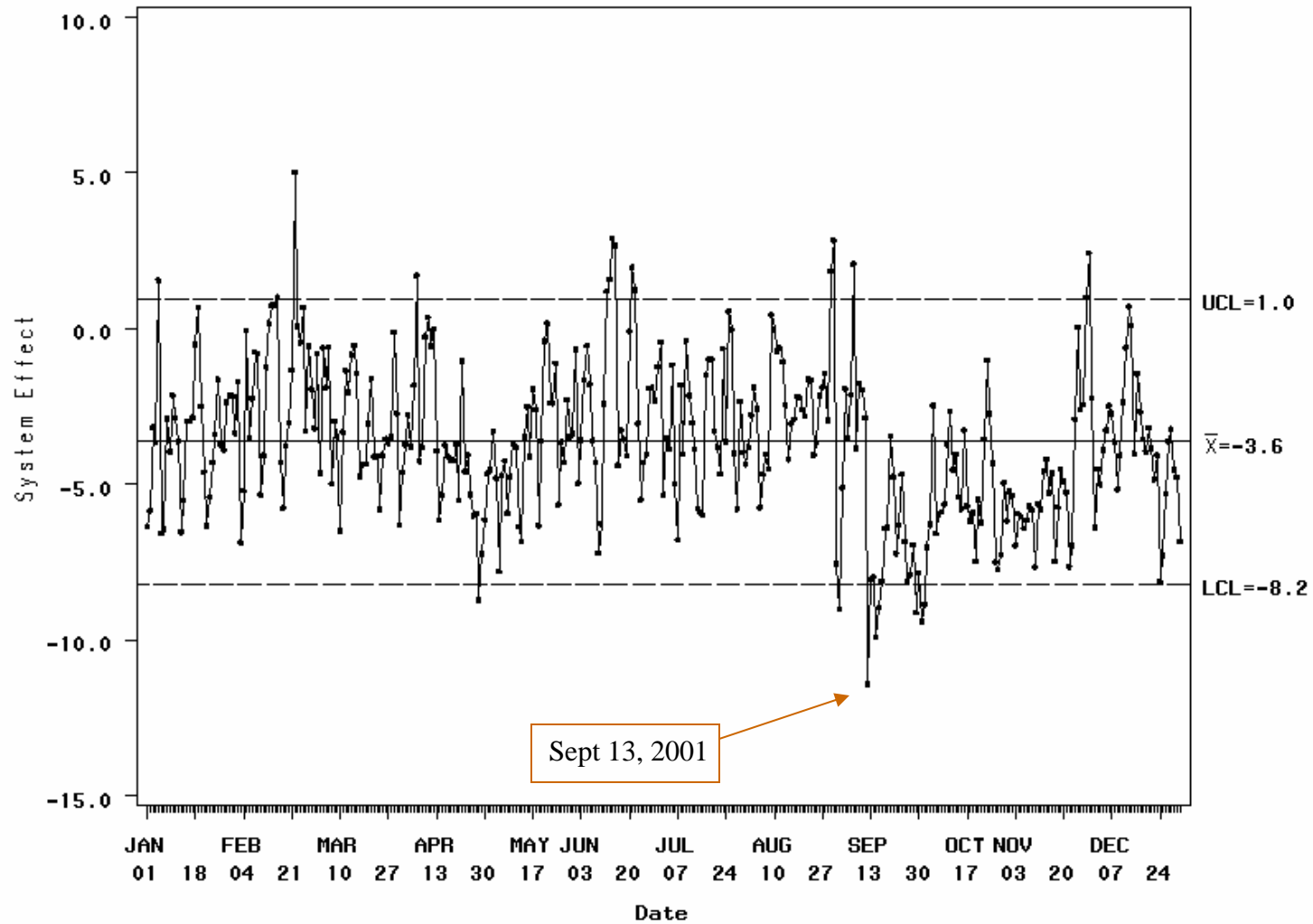
# Timeplot of system effects (ETE)

Timeplot of System Effects (UCL and LCL are based on 3 sigma)  
Computations are based on ETE data from ASPM



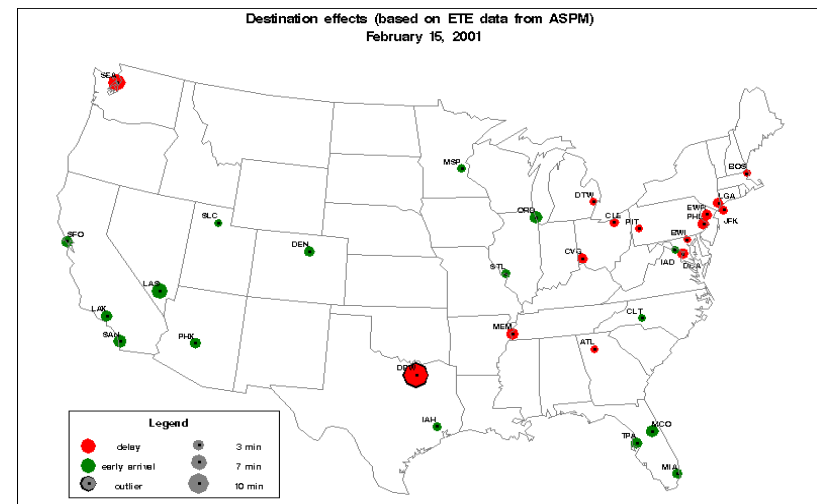
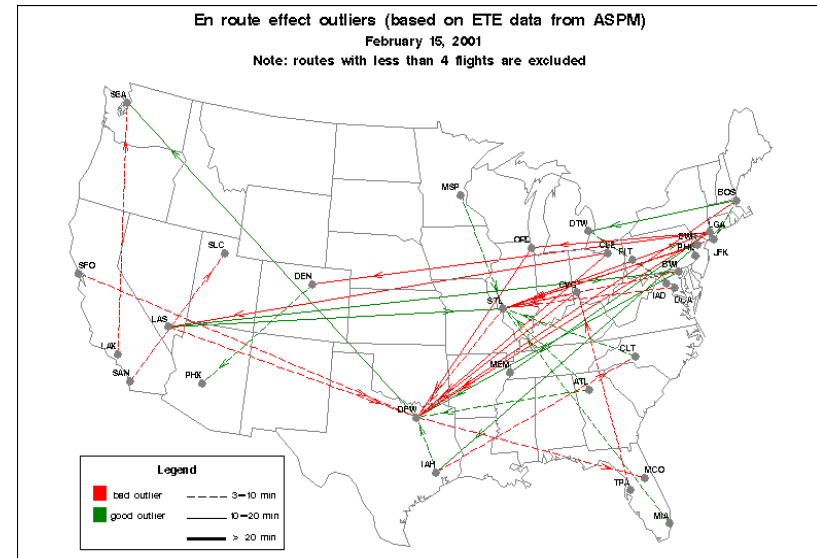
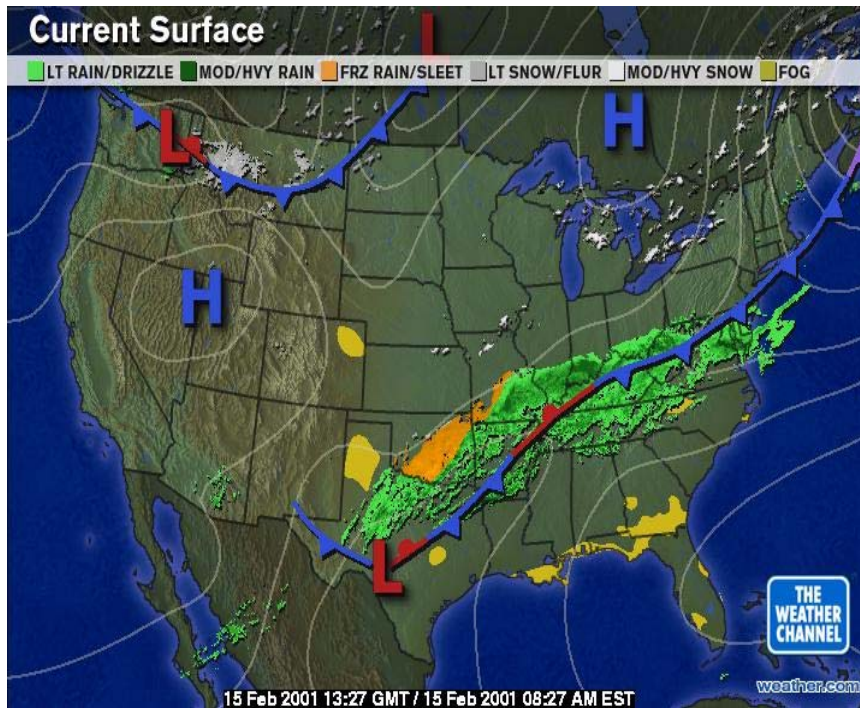
# Timeplot of system effects (G2G)

Timeplot of System Effects (UCL and LCL are based on 3 sigma)  
Computations are based on G2G data from ASPM  
Date of computation is February 20, 2002



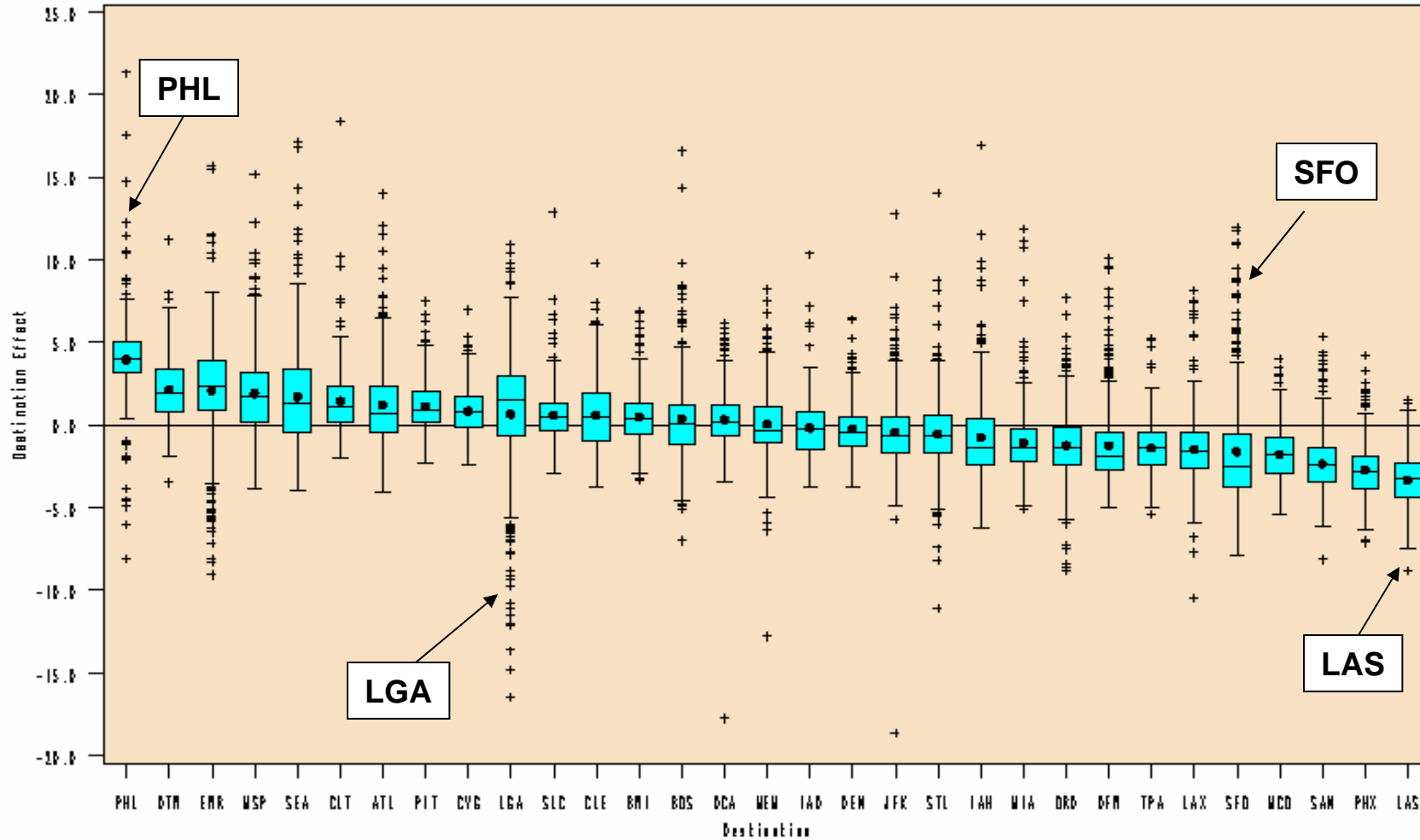
# Outlier detection for next-day analysis

February 15, 2001



# Boxplots of destination effects, 2001

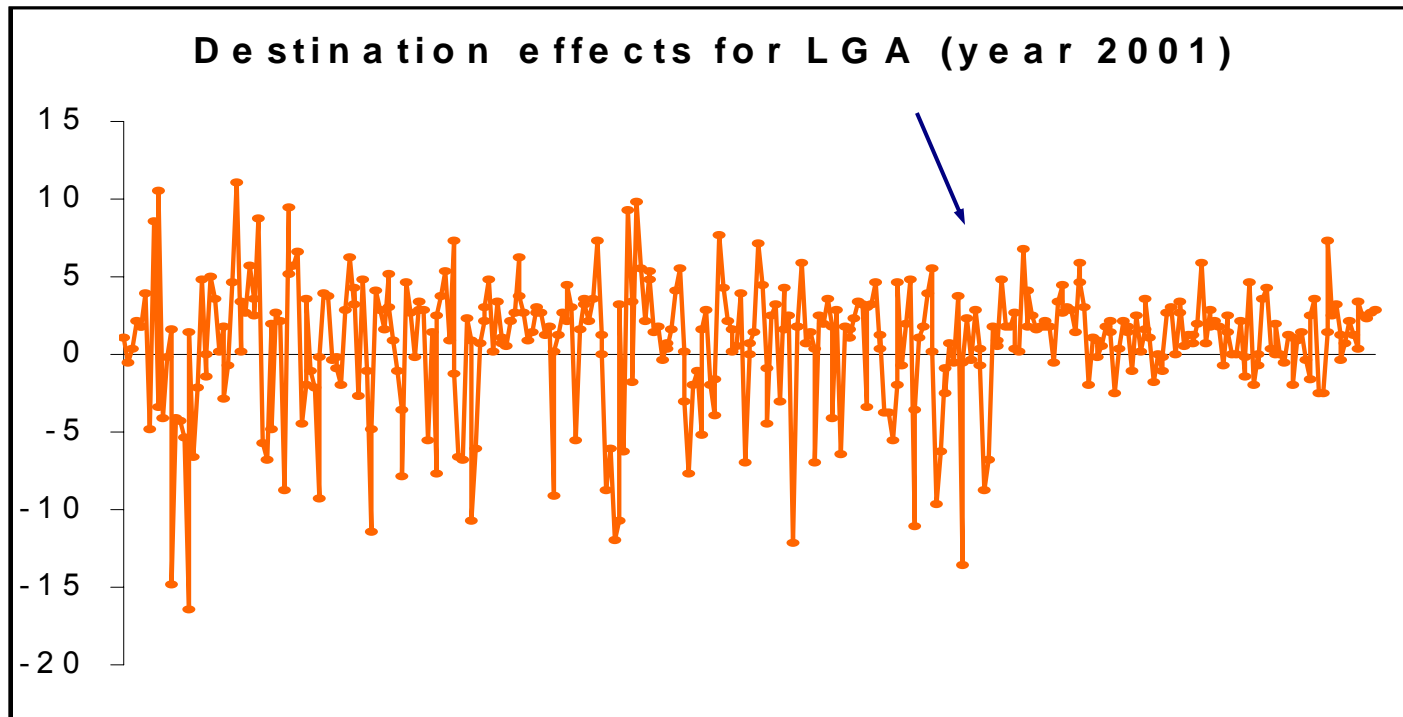
Distributions of Destination Effects (based on ETE data from ASPM)  
Date of computation is November 8, 2002



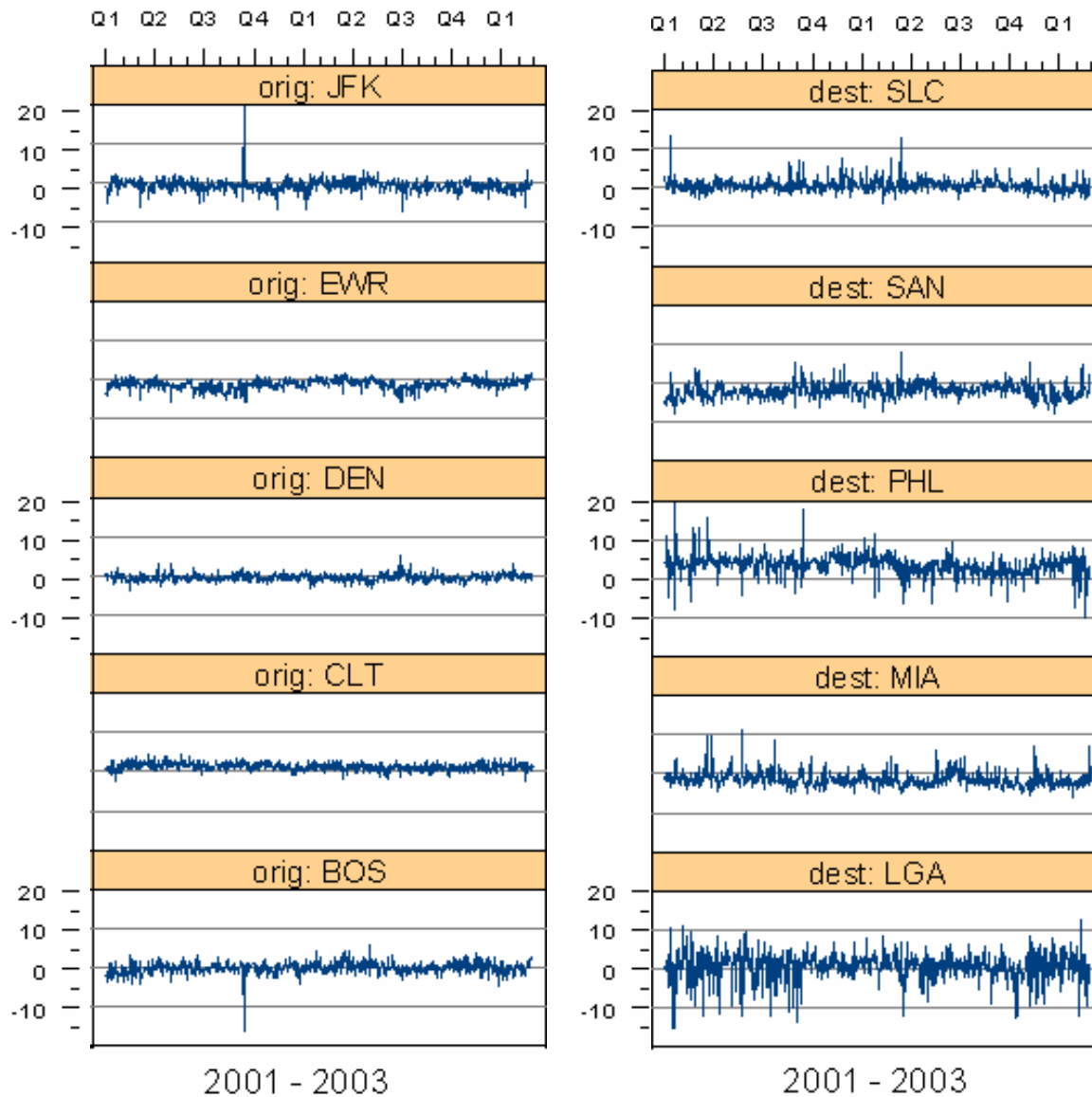


# Timeplot of destination effects at LGA

Why the sudden reduction in variability?  
Why did we lose all the “good” numbers?



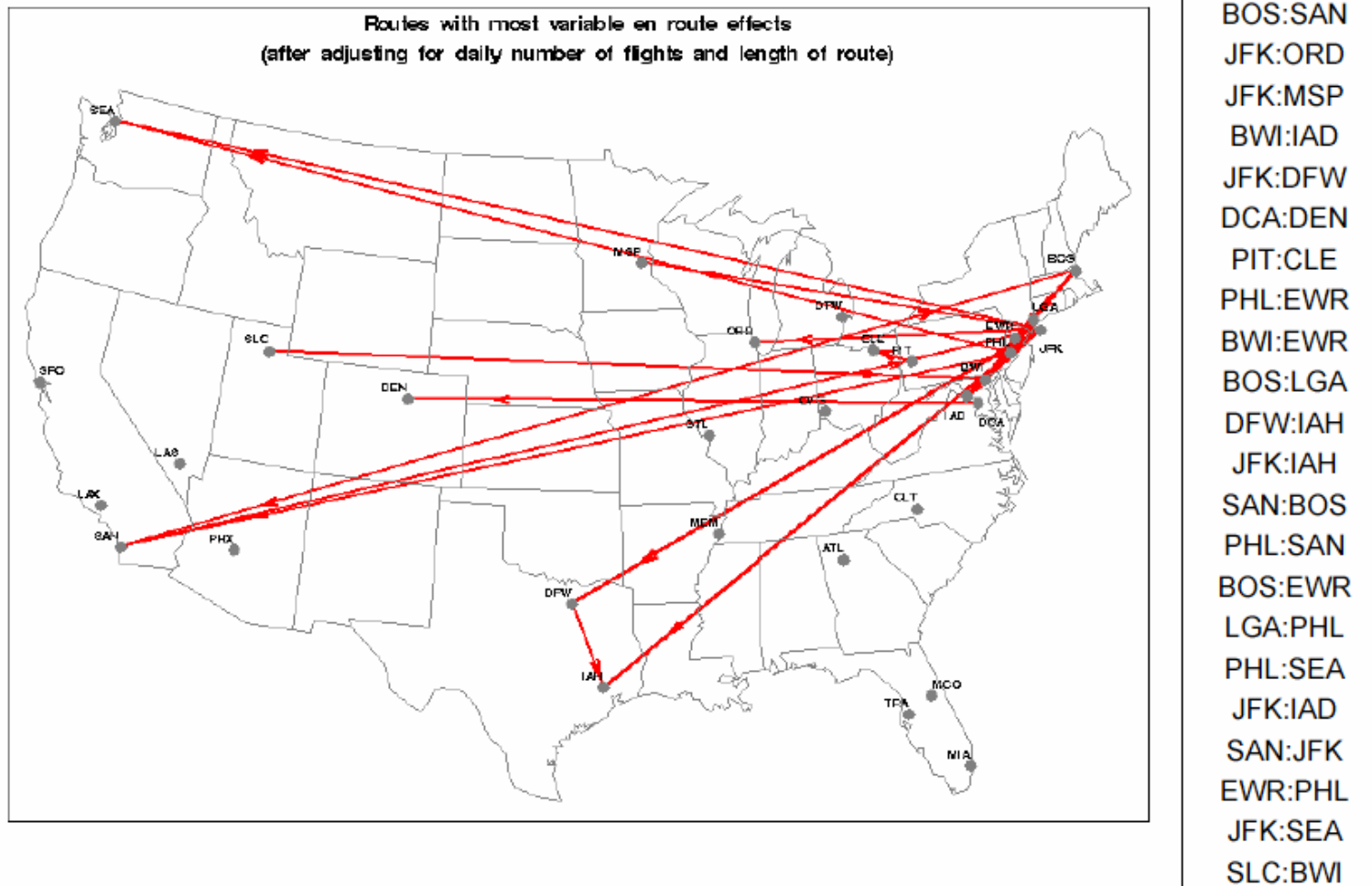
# Timeplots of origin and destination effects





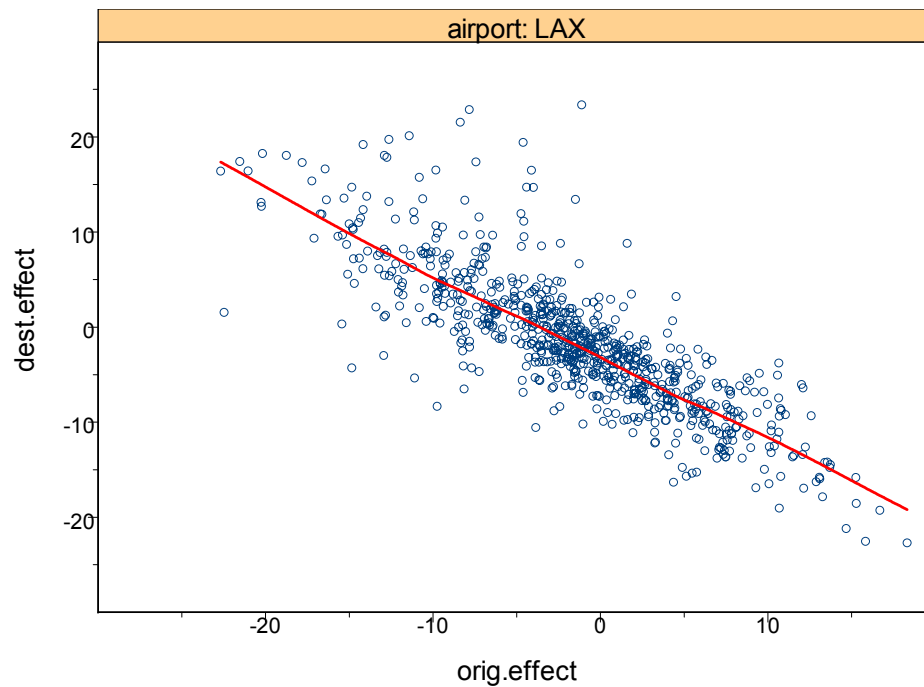
# Routes with most en route variation

Exhibit 7.26. Twenty two routes with highest standard deviations of en route effects after adjusting for daily number of flights and length of route

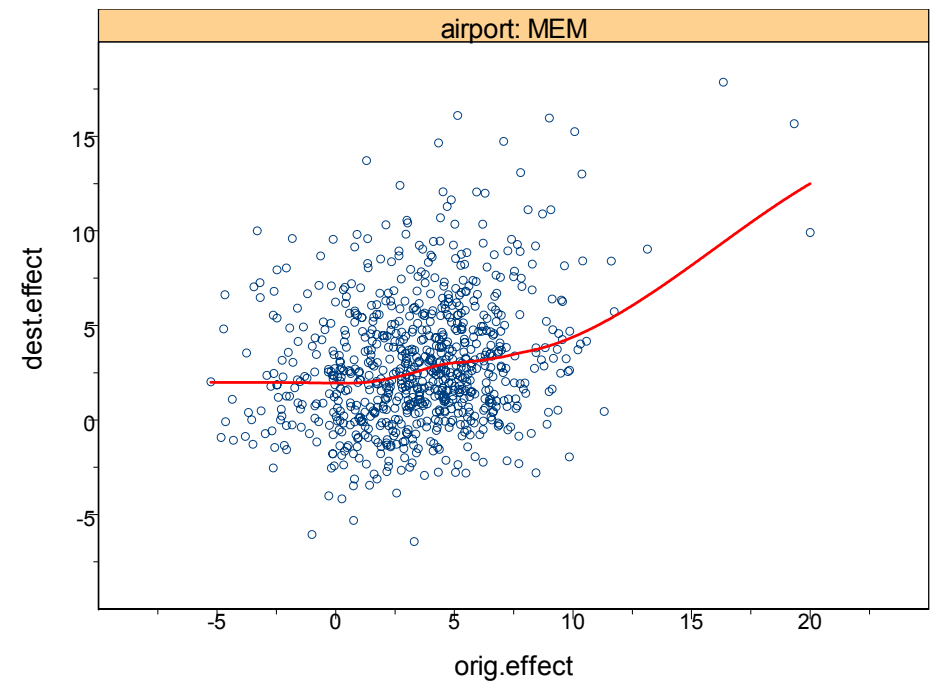


# Two types of airport operation

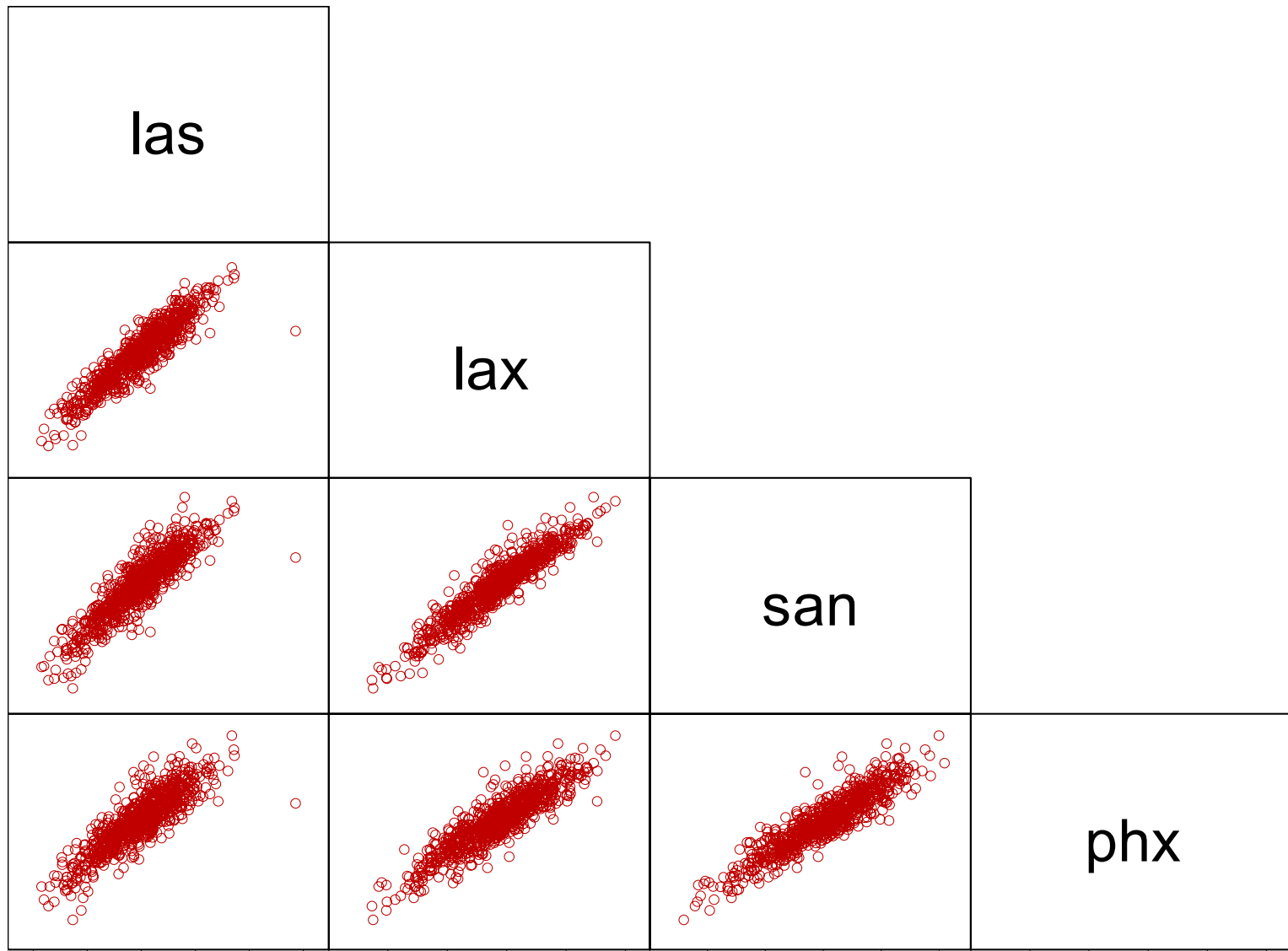
↓ Origin versus destination effects for LAX (G2G): negative correlation



↓ Origin versus destination effects for MEM (G2G): no correlation



# Regional patterns in G2G origin effects



## Alternative approach using new ASPM data

- ASPM now provides data based on crossing lines at {0, 40, 100, 200, mid, 200, 100, 40, 0} miles along the GCR between origin and destination.
- “En route”  $\equiv$  100 to 100 mile portion.
- Comparison with analysis of deviations
  - Advantage: Reduces effect of terminal airspace on en route data (but still some spillover).
  - Disadvantage: Fails to reduce effects of anticipated en route problems (e.g., wind) on en route data.
  - Same: Can also apply row+column analysis to “pure” en route data.
- Enables new analyses, such as
  - Exposing the link between terminal airspace congestion and en route performance
  - Use of opposite direction flights to compare variability from wind vs variability from en route ATC (not shown here).

# Row+column analysis of excess en route miles

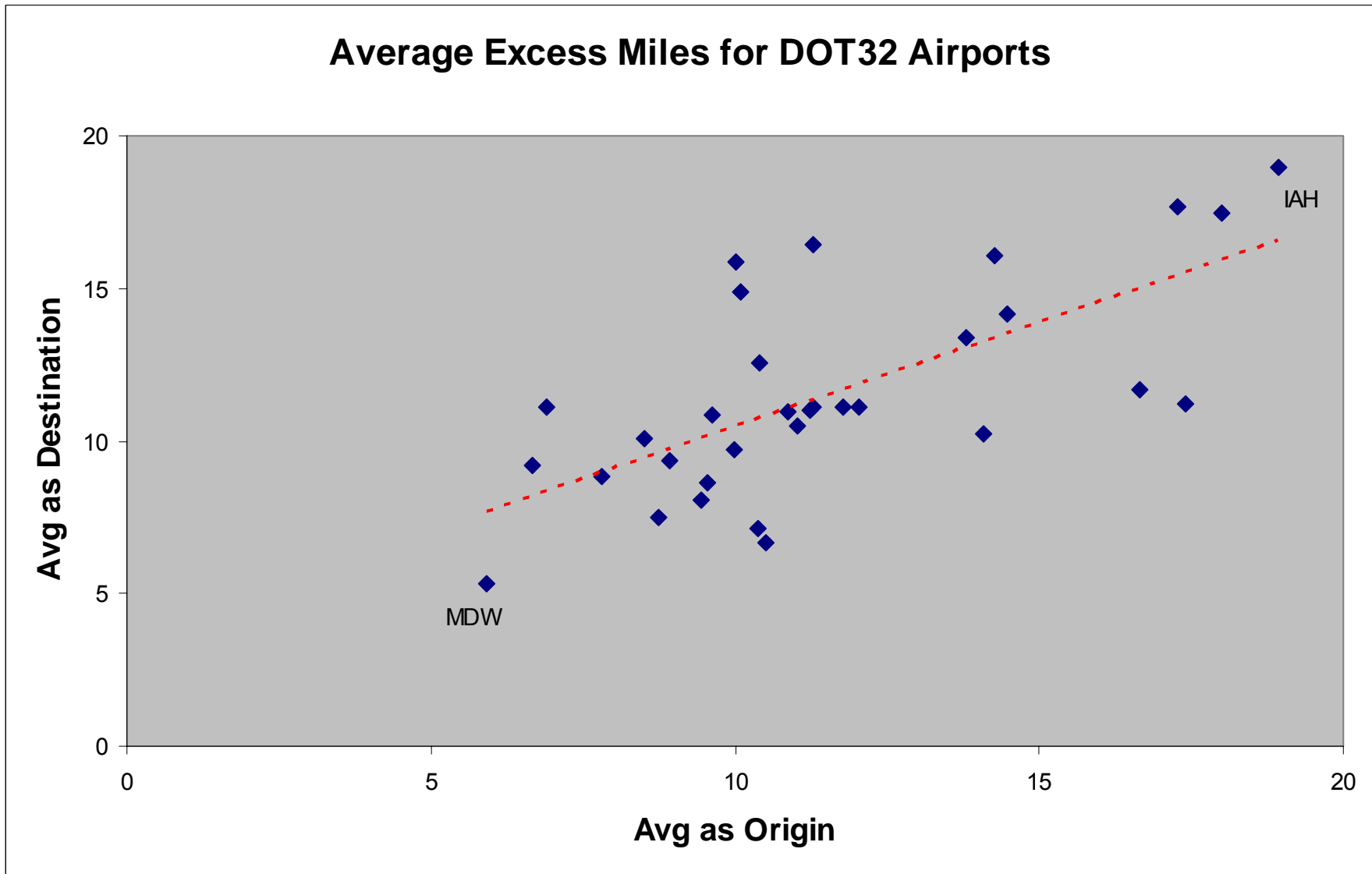
## DOT 32 Airports on 01Oct03

Average of ExcessMiles

Origin	Destination																															Grand Total	
	ATL	BOS	BWI	CLT	CVG	DCA	DEN	DFW	DTW	EWR	FLL	IAD	IAH	JFK	LAS	LAX	LGA	MCO	MDW	MIA	MSP	ORD	PDX	PHL	PHX	PIT	SAN	SEA	SFO	SLC	STL	TPA	
ATL	22	4		2	2	8	6	4	6	6	3	7	17	14	12	9	3	3	4	16	10	15	6	18	2	29	40	15	10	17	2	10	
BOS	4		1	3	14	2	22	40	5		20	1	24		22	45		15	15	36	12	5		14	2		18	50	12	32	23	17	
BWI	1	1		1	2		14	5	5		60		28		18	23		15	11	29	22	24		14			34	26	8	10	17		
CLT		13	2				15	10	3	5	9		16		12	17	3	1	7	6	17	12		3	10	3		19		9	2	9	
CVG	4	12	4			5	7	13		19	12	4	28	15	8	8	17	2		17	20		17	4	9		12	8	12	7		11	
DCA	2	1			4		6	7	7		20		19					14	6	11	10	10		9			13			6	7	9	
DEN	8	4	17	13	5	6		3	11	7	30	8	6	2	2	7	6	9	3	31	4	8	6	7	5	8	3	6	2	1	5	8	
DFW	9	28	2	5	10	4	4		18	21	20	26		45	2	23	62	11	4	14	5	6	8	8	8	13	17	6	20	5	2	16	8
DTW	9	3	9	5		10	5	17		1	11	11	23	3	6	11	1	6		9	5			11	10		8	7	11		13	6	8
EWR	3			1	10		22	12	4		10		19		14	28		11	1	12	9	9			22	23	27	24	19	7	16	14	
FLL	6	16	30	20	22	17	13	23	11	22		6	40	8	10	12	25		6		3	19		19	65	17					4	18	
IAD	1	2			4		19	5	9		2		14		9	12			13		14	15	10		22		13	7	28	13	8	9	11
IAH	10	40	22	9	8	7	6		9	29	59	23		53	13	9	32	9		26	15	12	6	31	3	54	6	7	24	13	11	6	19
JFK	4				5		14	5	6		9		20		24	27		15		7	9	6		14		13	29	39	17	5	17	14	
LAS	8	4	10	8	11		1	4	24	14	14	13	25	11				8	3	22	4	9	4	7		6		5	12	1	9	12	10
LAX	7	9	19	9	9		5	10	16	14	4	16	7	19				18	8	13	4	16	2	14	1	5		2	7	12	17	10	
LGA	3			2	10		15	10	4		9		26					14	1	13	10	8									8	16	10
MCO	4	10	9	9	9		6	14	6	9		11	6	11	29	11		4		4	24		15	27	5				24	4		11	
MDW	7	3	12	11		9	2	5		2	9				6	5	1	10		7	1			8	7	2	6	5	8		4	6	
MIA	5	22	22	20	15	11	12	14	9	27		15	11	11	22	36	29		4		20	29		10	34	11	11	27		3	17	7	
MSP	17	13	14	10	14	12	2	6	5	9	17	11	13	8	5	8	9	13	9	18			2	12	8	6	12	3	14	6	4	20	10
ORD	8	2	9	10		12	3	8		1	8	10	11	3	6	6	1	12		11			4	7	8	2	13	4	8	8		5	7
PDX	24				29		3	5	6	17			14		10	7					6	6			18		6		1	3	14	11	
PHL	2			1	2		11	11	5		6		21		12	10			13	2	12	20	7		7		20	56	18	9	6	14	12
PHX	15	9	12	4	7	17	4	8	21	19	43	10	6	17		2		30	4	67	3	9	17	12		7		22	9	4	5	23	14
PIT	3	4		4			12	12			12		42		11	12		3	1	20	8	1		8		11	5	17		2	3	10	
SAN	14	6			10		9	11	47	9		15	16	18				10			7	16	6	6		7	2	1	2	11		11	
SEA	8	14			25		6	3	9	21		8	9	19	12	8			5	16	6	7		25	17	11	3	1	3	3		10	
SFO	10	12	17	10	6		10	14	7	10		17	26	17	12			18	4	24	14	12	0	15	10	7	5	1	8	8		11	
SLC	12	10			15		1	6		9		3	15	7	2	7		7		9	6		2	8	1	2	1	8		9		7	
STL	3	10	9	8		15	6	6	8	26	11	5	14	21	8	6	19	8		4	5		4	10	10	1	9	16	8	6		9	12
TPA	4	21	10	1	12		13	11	12	5	12	13	45	19	10	17	13		4		8	8		7	18	6			3		3		9
Grand Total	7	11	12	7	10	9	9	10	10	13	17	11	19	16	11	15	16	11	5	18	10	11	7	11	14	9	11	13	16	9	8	11	12



# Some airports are consistently good or bad



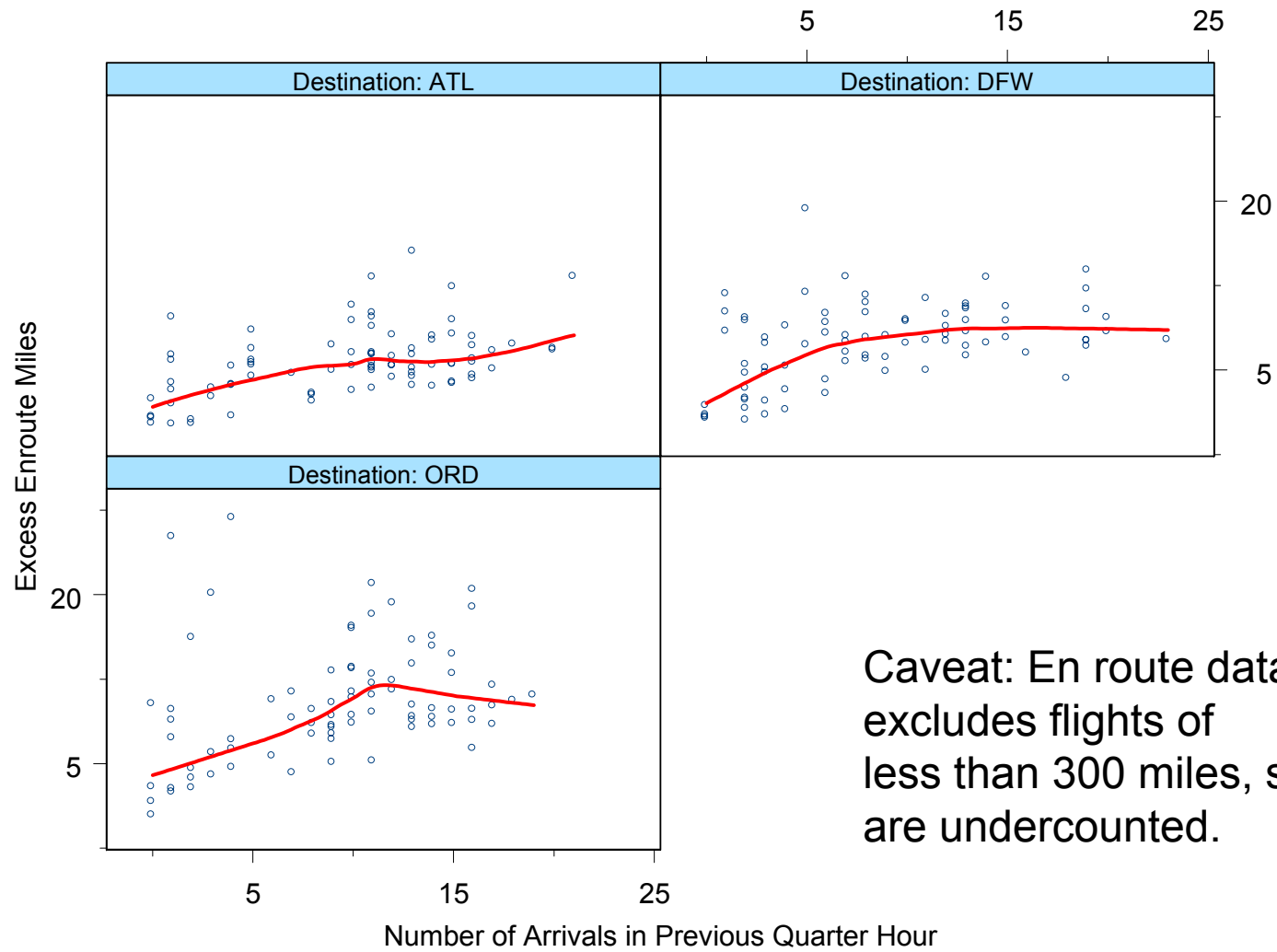
# Residuals show out-of-pattern routes

Identify best and worst 1% of routes for further analysis

**Residuals**

Origin	Destination																															
	ATL	BOS	BWI	CLT	CVG	DCA	DEN	DFW	DTW	EWR	FLL	IAD	IAH	JFK	LAS	LAX	LGA	MCO	MDW	MIA	MSP	ORD	PDX	PHL	PHX	PIT	SAN	SEA	SFO	SLC	STL	TPA
ATL	12	-7	-7	-7	-6	0	-3	-5	-6	-11	-7	-10	2	4	-2	-6	-7	-2	-12	7	0	9	-4	5	-6	19	29	0	2	10	-8	
BOS	-9	-17	-10	-2	-13	8	24	-11	-3	-16	-1		5	24		-2	4	13	-4	-12				-6	-13		-1	28	-3	18	6	
BWI	-11	-16	-12	-13		0	-10	-11	-37	4		2	3			-2	1	6	7	8				-5	-1			12	12	-5	-7	
CLT	4	-7				9	2	-5	-6	-6	0		4	5	-10	-7	4	-9	10	4			-5	-1	-3			5		4	-7	
CVG	-3	1	-7		-4	-2	4		6	-5	-6	9	0	-2	-6	2	-9		0	10		11	-7	-5		1	-4	-3	-2	1		
DCA	-3	-8			-4	0	0	-1		5	2					6	4	-4	3	1			-3			3				1	-2	
DEN	5	-3	9	9	-1	0		-3	4	-2	17	1	-9	-11	-5	-5	-6	2	2	17	-2	0	3	0	-5	3	-5	-2	-10	-4	1	0
DFW	-1	14	-12	-5	-3	-8		-8	6	5	0	13		26	-11	5	43	-3	-4	-6	-7	-8	-2	-6	-8	2	4	-10	1	-6	-8	3
DTW	5	-5	1	1		4	-1	10		-10	-3	3	7	-10	-1	-1	-11	-2		-5	-2		3	-1		0	-3	-2		8	-2	
EWR	-7			-8	-3		11	0	-8		-10		-2		1	11		-2	-6	-8	-3	-4		5		10	12	6	8	-3	3	
FLL	-8	-2	12	6	5	1	-3	6	-5	2		-12	15	-15	-7	-9	2		-6		-13	2		1	46	2					-11	
IAD	-6	-9			-6		11	-4	-1		-14		-5		-2	-2		2		-3	6	0		9		3	-5	13	4	1	-1	
IAH	-5	22	3	-6	-10	-10	-11		-9	8	34	5		30	-5	-14	9	-10		1	-2	-7	-8	12	-19	38	-12	-13	0	-3	-5	-13
JFK	-6			-8		3	-8	-7		-11		-2		11	10				-14	-4	-8			-3		0	14	20	5	-6	3	
LAS	3	-5	1	2	2		-6	-4	16	2	-1	4	8	-4			-1	0	7	-3	0	-1	-2		0	-5	-3	-6	3	3		
LAX	1	0	9	3	0		-3	1	8	2	-12	7	-10	5			8	4	-4	-4	-7	-3	4	-12	-2		-9		-1	6	7	
LGA	-3			-4	1		8	2	-5		-7		8				5	-2	-3	2	-1									2	7	
MCO	-3	-1	-2	2	-1	-1	-3	4	-3	-4		0	-13	-5	1	15	-5		-1		-5	13		4	13	-3			15	-4		
MDW	6	-3	6	9		6	-1	1		-6	-3				1	-4	-9	5		-5	-3			2	-1	-1	1	-2	-3		-2	
MIA	-8	5	4	7	-1	-4	-3	-2	-7	8		-1	-14	-11	6	15	8		-7		5	12		-7	14	-3		-7	5		-10	
MSP	12	3	4	4	5	4	-5	-3	-4	-3	1	1	-4	-7	-4	-5	-6	4	5	1			-3	3	-4	-1	2	-8	0	-2	-3	10
ORD	5	-4	2	7		7	-1	3		-7	-5	4	-3	-8	0	-4	-10	6		-2			2	0	-1	-2	7	-4	-4	3	-2	
PDX	18				20		-5	-4	-3	5		-4			0	-7				-3	-4			4		-4					7	
PHL	-6			-7	-9		2	0	-5		-12		2	0	-6			2	-4	-6	10	-5				8	43	1	-1	-2	3	
PHX	5	-5	-3	-6	-6	5	-8	-5	8	3	23	-4	-16	-2		-16		16	-4	46	-9	-5	7	-2		6	-10	-8	-6	9		
PIT	-2	-5		-2		5	4			-4		25		2	2	-1		-6	-2	4	1	-8				2	-5	2		-4	-6	
SAN	7	5			0		1	1	38	-4		5	-2	2				5		-3	6	-1	-5		-2		-10	-7	3			
SEA	2	4			15		-1	-6	0	8		-2	-9	4	2	-6			1	0	-3	-3		15	4	4	-7	-14	-6	-4		
SFO	3	1	6	3	-4		1	4	-3	-3		6	7	1	2		8	-1	6	5	1	-6	4	-4	-1	-6	-11	-4	-1	0		
SLC	9	4			9		-3	1	0		-3	1	-4	-4	-3		1		-1	6	5	-1	0	2	-8	-4	-7	-4	5			
STL	-2	1	-1	3		7	0	-2	0	15	-4	-4	-2	7	-1	-7		6	-1		-11	-3		0	1	-2	-6	0	5	-7	-1	0
TPA	-3	9	-2	-6	1	3	2	2	-5	-2		2	26	3	-1	2	-3		-2		-2	-3		-4	4	-3				-5		

# Runway congestion ripples back to en route



# Summary

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- Have data sources and analysis tools to monitor en route problems using multiple metrics
  - Use existing ASPM datasets
  - Both air time vs ETE and block time vs G2G
  - Excess en route distance and time
  - Row+column analysis applies to both data sources
- Have multiple uses
  - Next-day analysis of troubles in NAS for ATCSCC
  - Analysis of longer-term issues at airports or routes
  - One-off scientific studies

# More importantly...



Go Pats!

