



Analysis of Excess Flying Time in the National Airspace System (Paper #32)

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Overview

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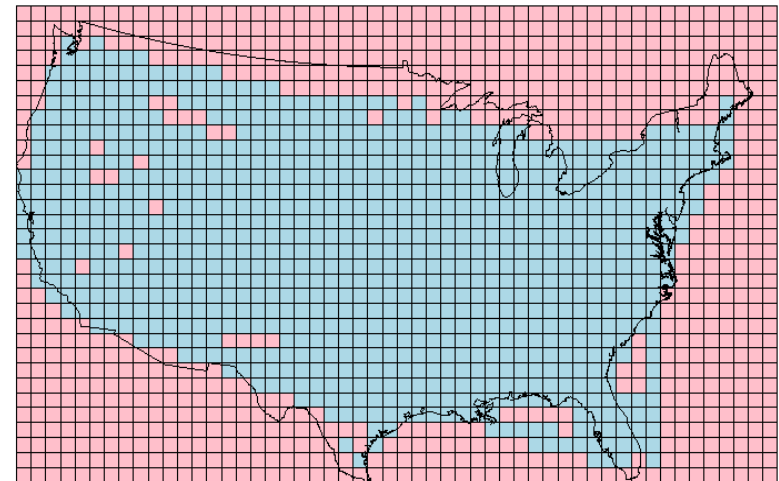
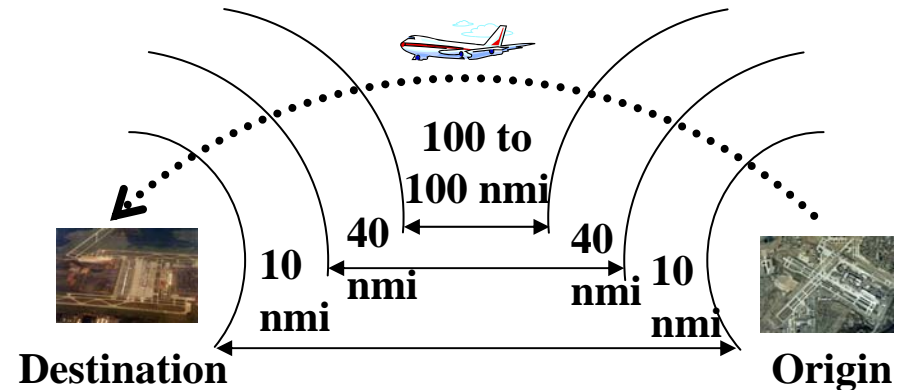
Purpose of this Project

- The Center for Advanced Aviation System Development (CAASD) has been tasked with exploring the potential benefits available from future enhancements
- The focus of this task is the estimation of the extent to which flights take longer in the *air* than some minimal time (i.e., “Excess Flying Time” [EFT])
- Other areas where benefits may be gained (e.g., fuel burn savings, workload savings, etc.) are not explored
- Important for many reasons
 - Gaining perspective: are benefit(s) claimed by various programs *reasonable* and achievable?
 - Determine best location: *where* are the efficiency gains needed?
 - Decide best time: *when* will enhancements be most needed?
- **Not all of this excess flying time is recoverable!**



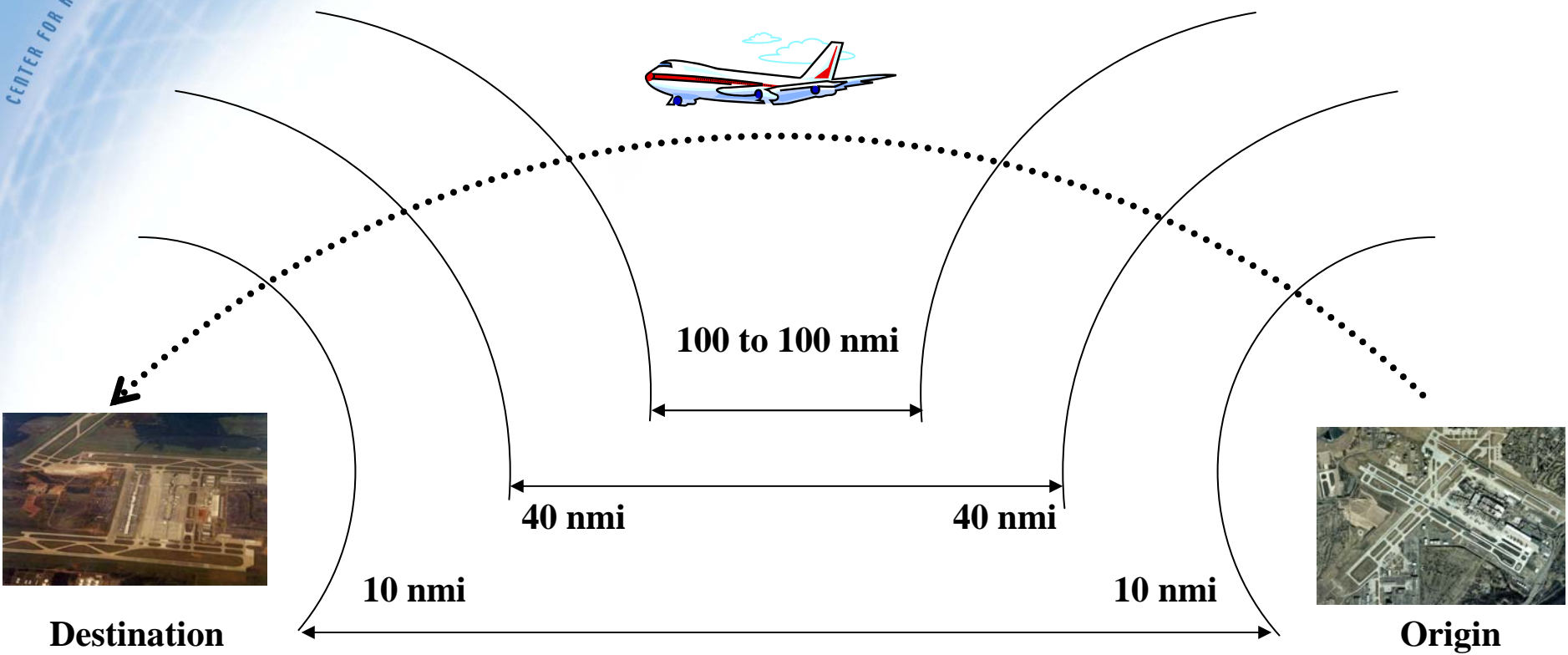
Two Approaches Followed

- **Flight-Based Method:**
Computed excess flying time (EFT) in the U.S. National Airspace System (NAS) on a *per flight* basis
 - Analyses performed on 100/100, 40/40, and 10/10 datasets (e.g., 100 nautical miles (nmi) from origin to 100 nmi from destination)
- **Cell-Based Approach:**
Computed EFT by *geographic location*
 - Summarized results by ARTCC and grid location





Flight-Based Method





Flight-Based Method Overview

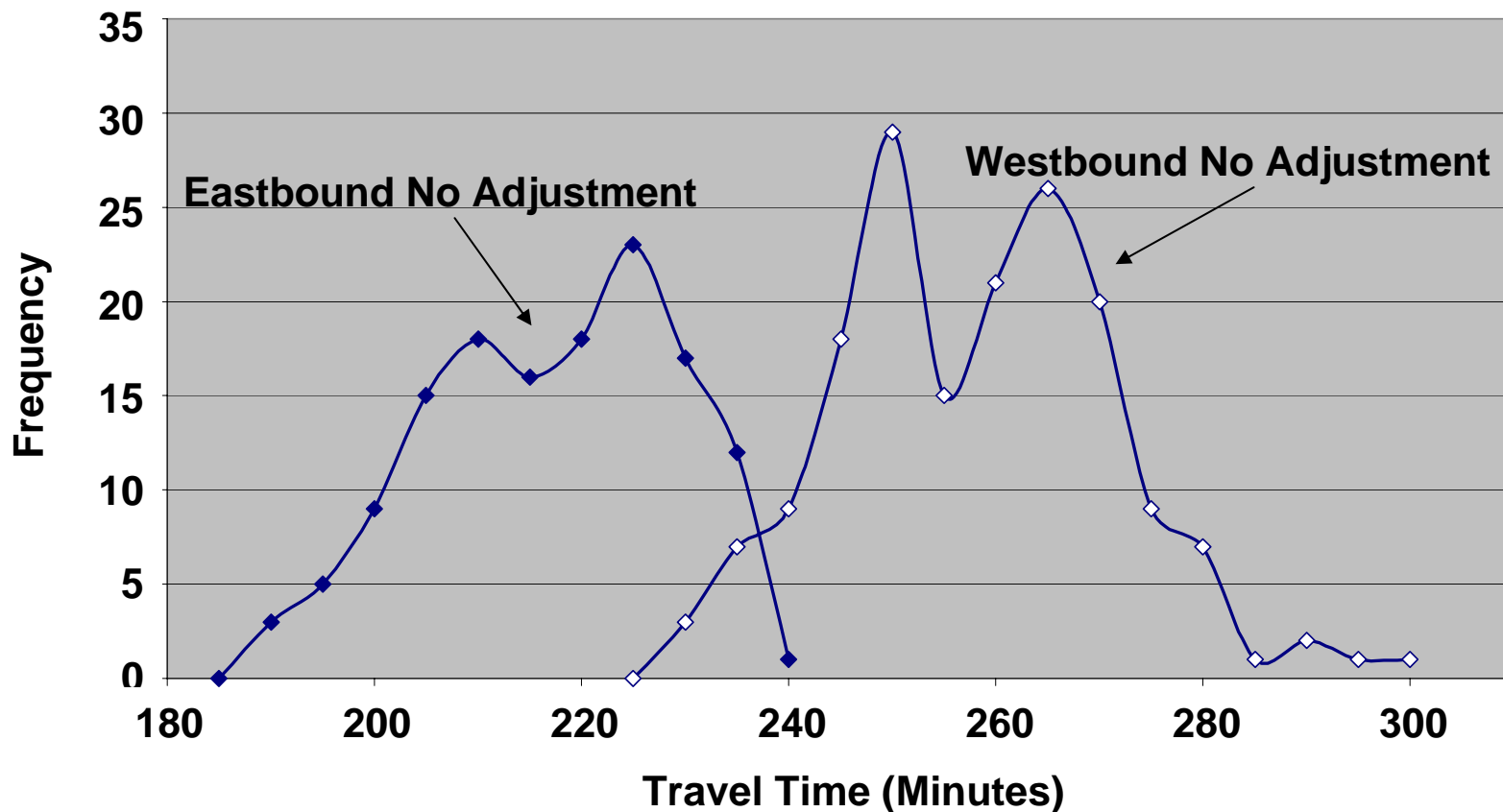
- **Two time frames studied**
 - **Good weather analysis:** based on 30 good weather days (Jan – Aug). 15 from 2001 and 15 from 2002 (as determined by “Misery Index”*)
 - **Full year analysis:** based on Calendar Year (CY) 2003
- **Flight times based upon**
 - **Origin and Destination** (direction matters: A to B is different from B to A)
 - **Aircraft type** (as specified in Enhanced Traffic Management System (ETMS) [397 types])
- **Actual flight times were adjusted for “wind effects” on **daily** basis (using opposing traffic method)**
- **Flights with **minimum adjusted** flight time were compared to other flights to determine excess flying time (data filtering/validation also applied)**
- **Analysis was performed for varying numbers of days**
 - **Calculated EFT on individual days, as well as groups of 2, 3, ... 30 days**
- **Based upon actual performance data, not modeled data**

* %Cancellations + 2x%Diversions + %Departure Delays Over 30 Minutes



Before Applying Adjusted Speeds: To and From LAX and IAD

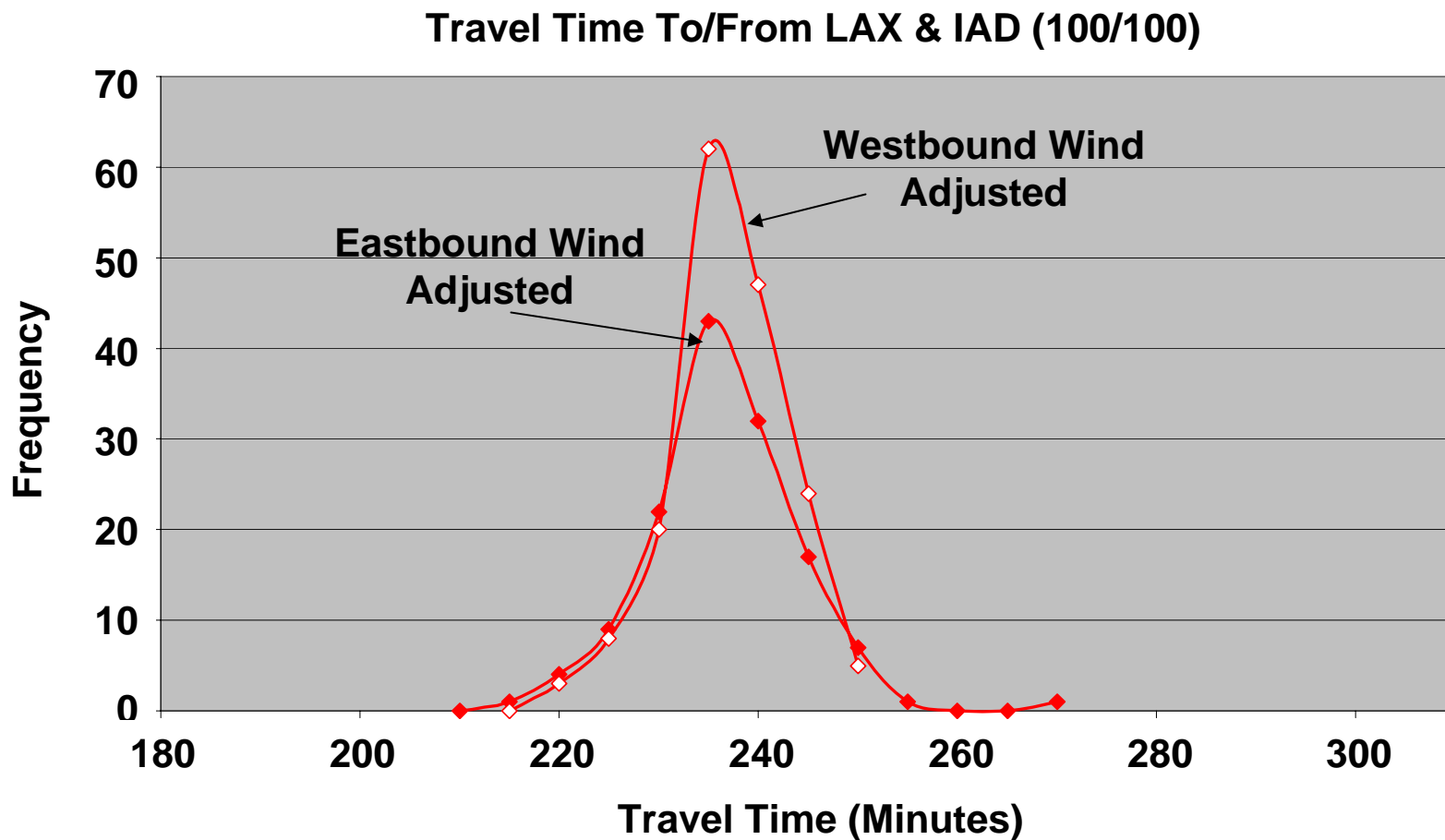
Travel Time To/From LAX & IAD (100/100)



30 days of data; number of flights: 137 eastbound; 169 westbound



After Applying Adjusted Speeds: To and From LAX and IAD



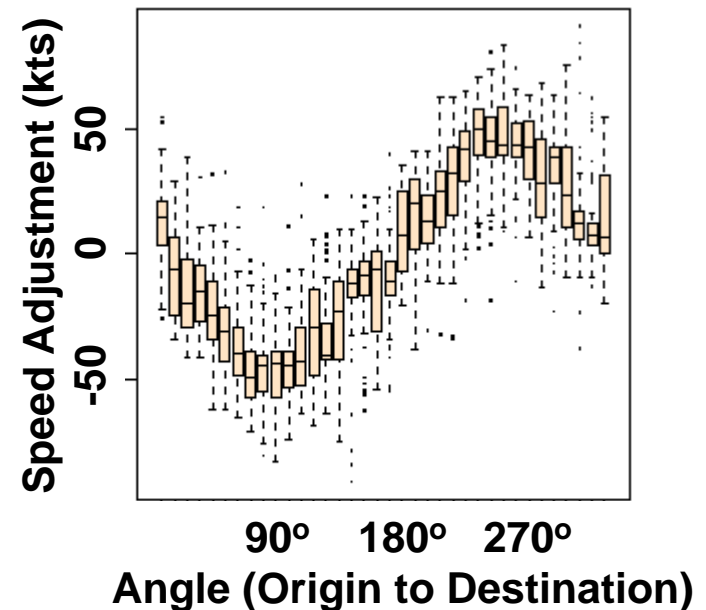
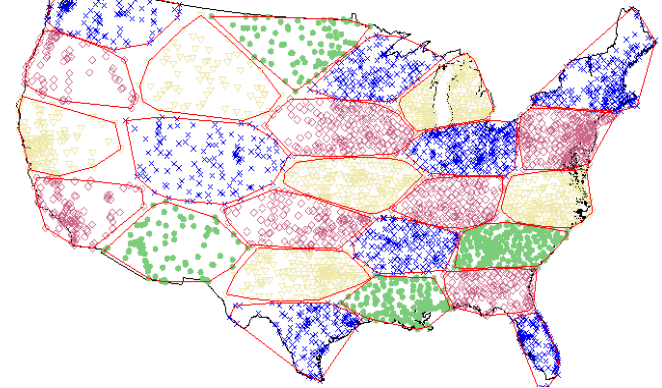
Note: Flights whose flight times could not be adjusted were omitted from further analysis.
30 days of data; number of flights: 121 eastbound; 128 westbound



Clustering of 3628 Airports

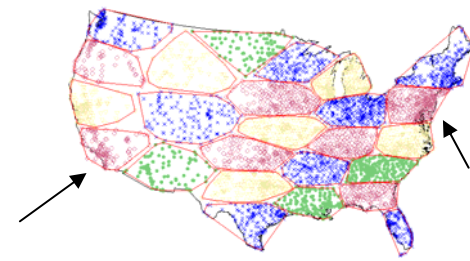
- Winds and their effects differ day to day, so wind adjustments need to be applied on a **daily** basis
- In order to apply the opposing traffic methodology, **adequate traffic needs to exist** between the origin and destination pairs
- The tradeoff is between the number of flights captured and the “fineness” of wind adjustment applied

25 Clusters

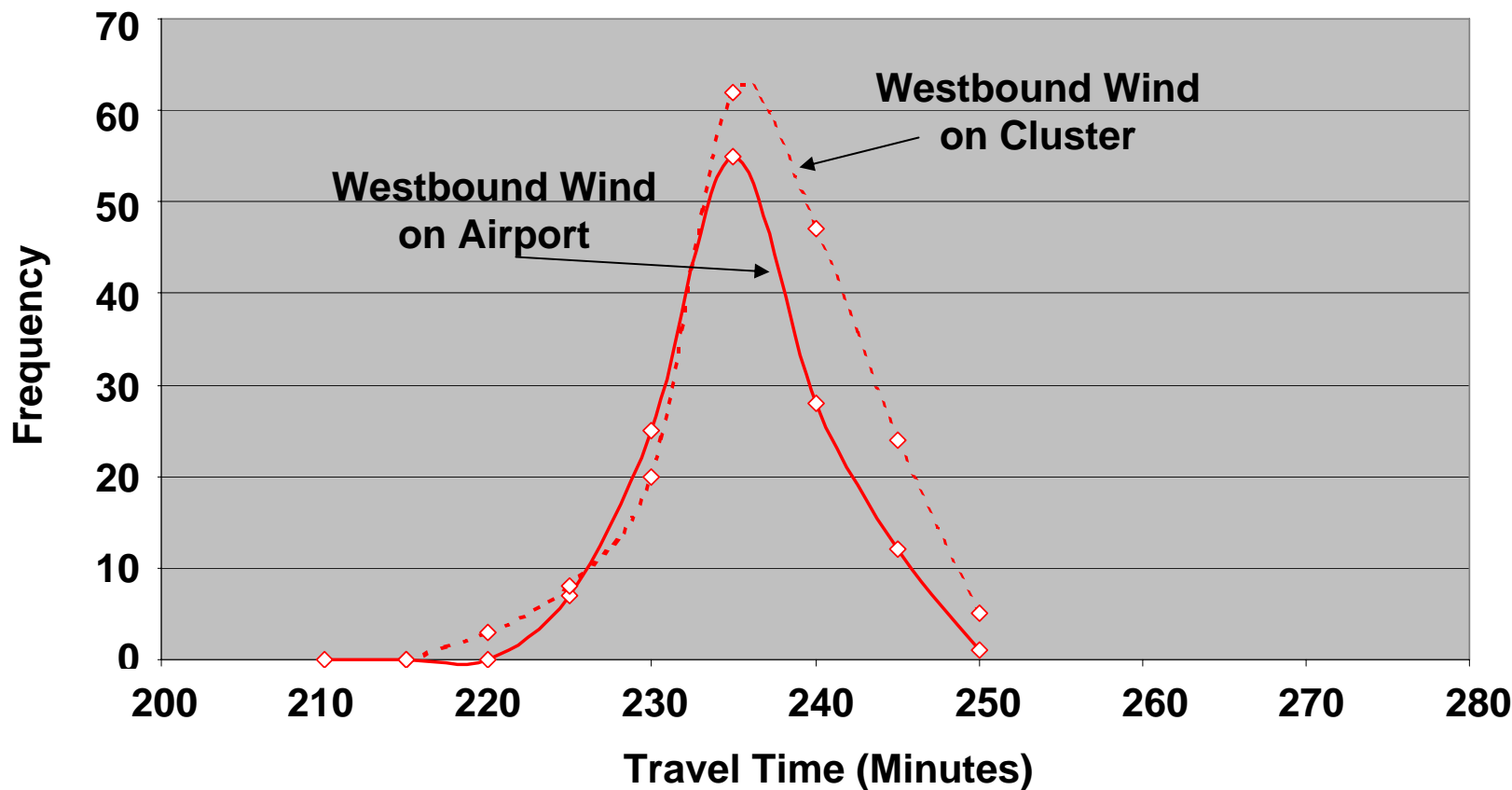




With Airport Clustering Are We Really Accounting for Winds?



Travel Time To LAX From IAD (100/100)

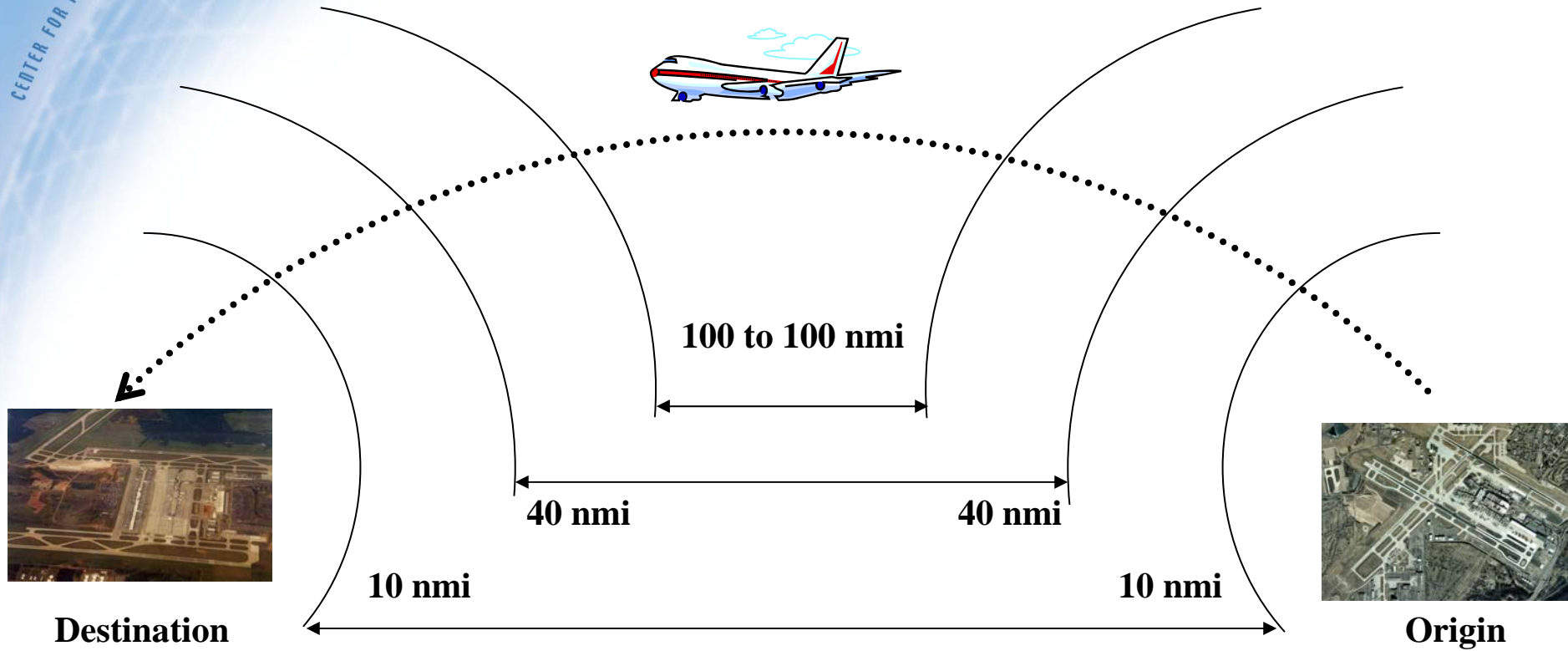


30 days of data; number of flights: 128 flights airport adjusted; 169 cluster adjusted





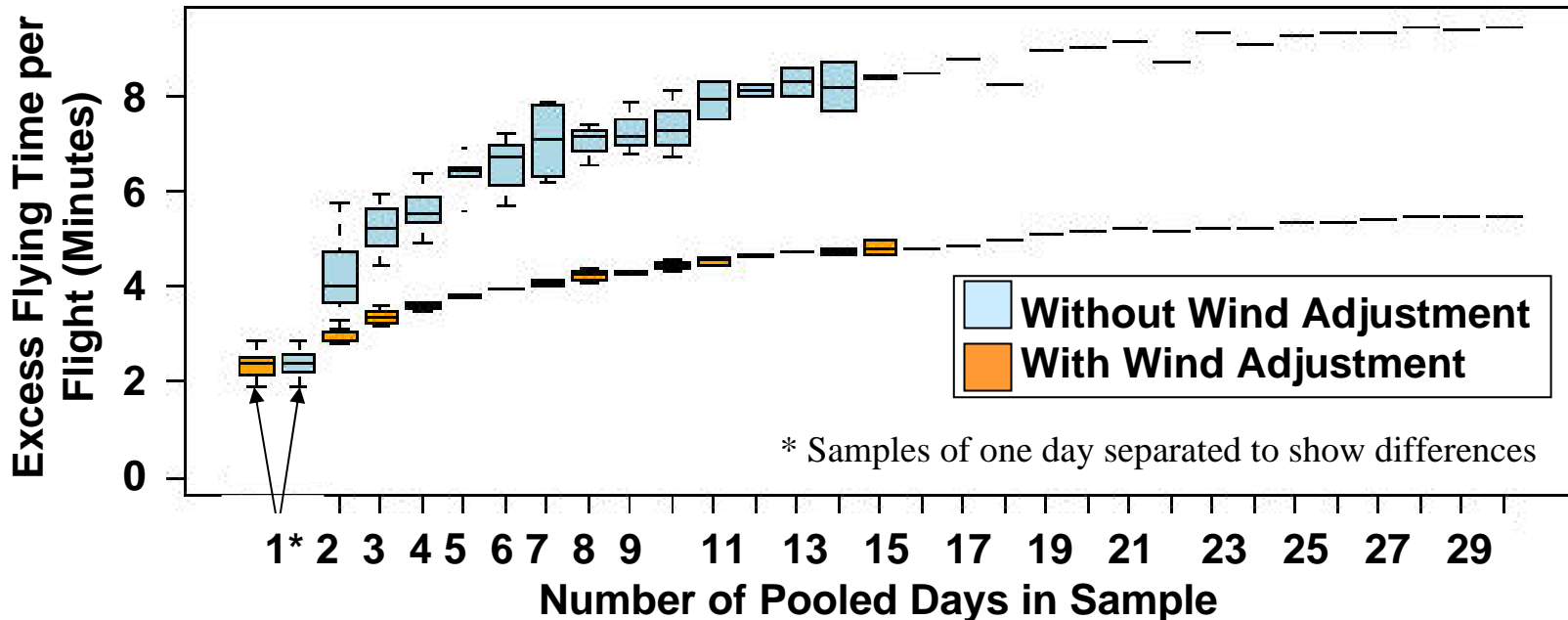
Flight-Based Results





Flight-Based Method Results: Good Weather Analysis for 100/100 Dataset

Excess Flying Time vs. Number of Sampled Days: 100/100 Dataset

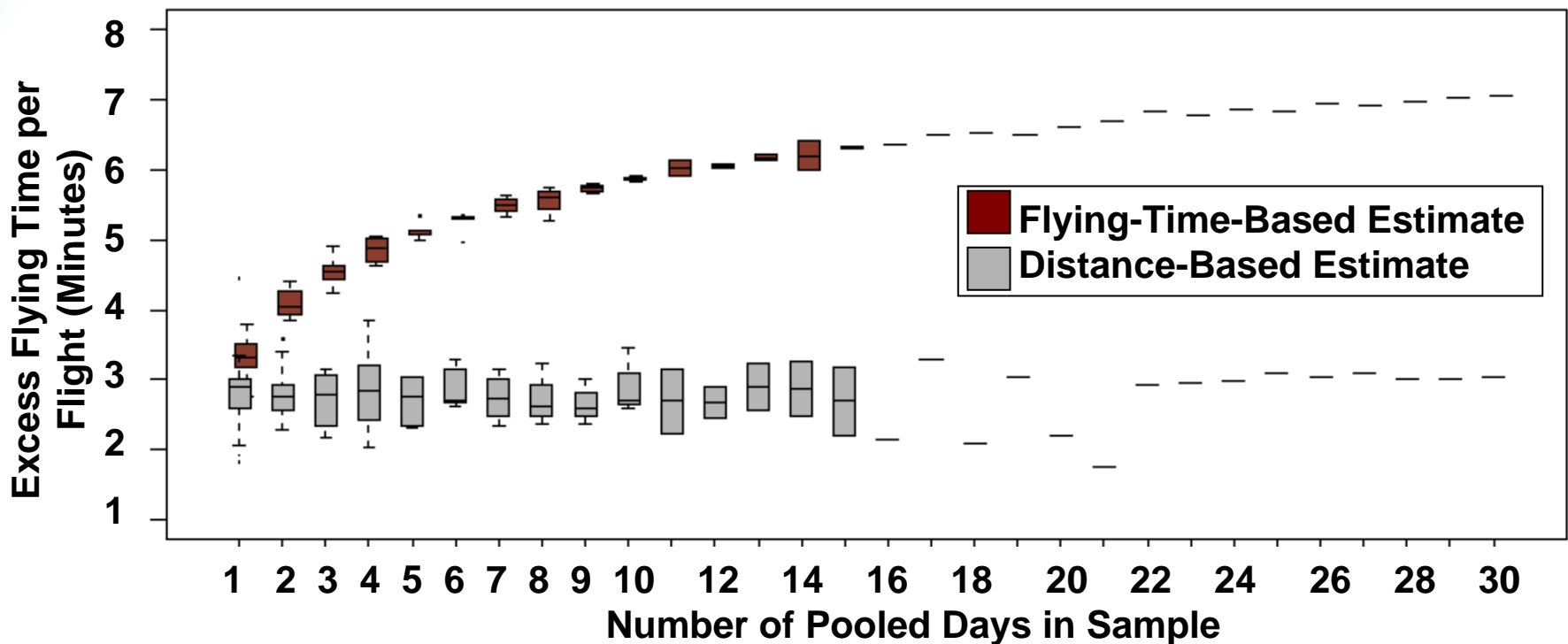


- Results indicate approximately 4 – 5 minutes of EFT exists during good weather days using the 100/100 dataset
- Adjusting for wind effects is most important when looking across days
- EFT grows with larger numbers of pooled days as new minimums are found



How Do These Results Compare to Distance-Based Results?

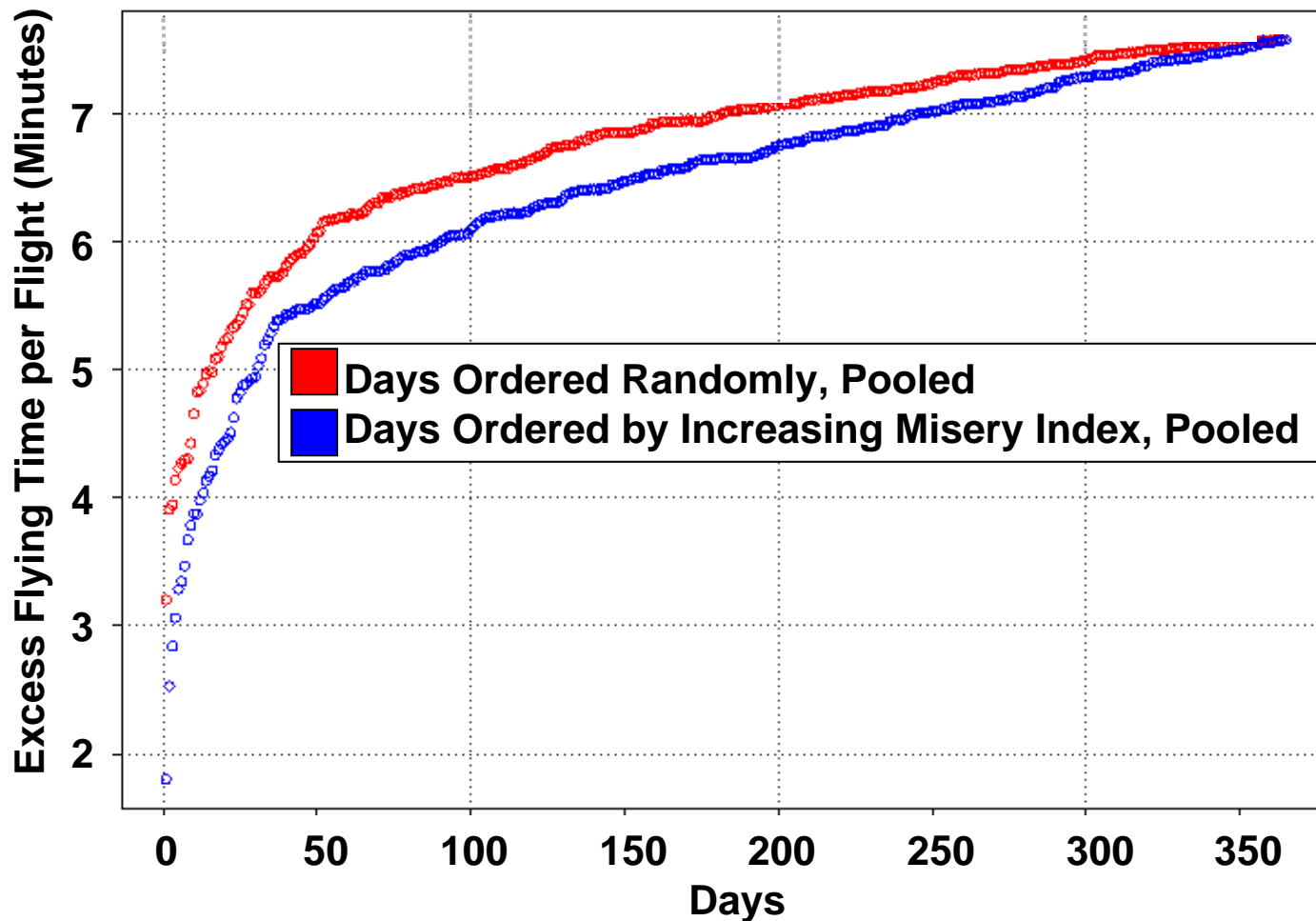
Excess Flying Time (Minutes) vs. Number of Sampled Days: **10/10** Dataset



- A simple distance-based estimate comparing track length to great circle distance yields around 2 – 3 minutes of EFT
- Approximately 2 additional minutes of EFT were measured with the 10/10 dataset compared to the 100/100 dataset



Flight-Based Method Results: Full Year (CY2003) Analysis for 100/100 Dataset, Regardless of Weather



- Indicates 7.5+ minutes EFT considering all days
- Results of 30 'best' days consistent with good weather study from '01 and '02 (e.g., 4+ minutes)
- Mixing good and bad days grows EFT more quickly

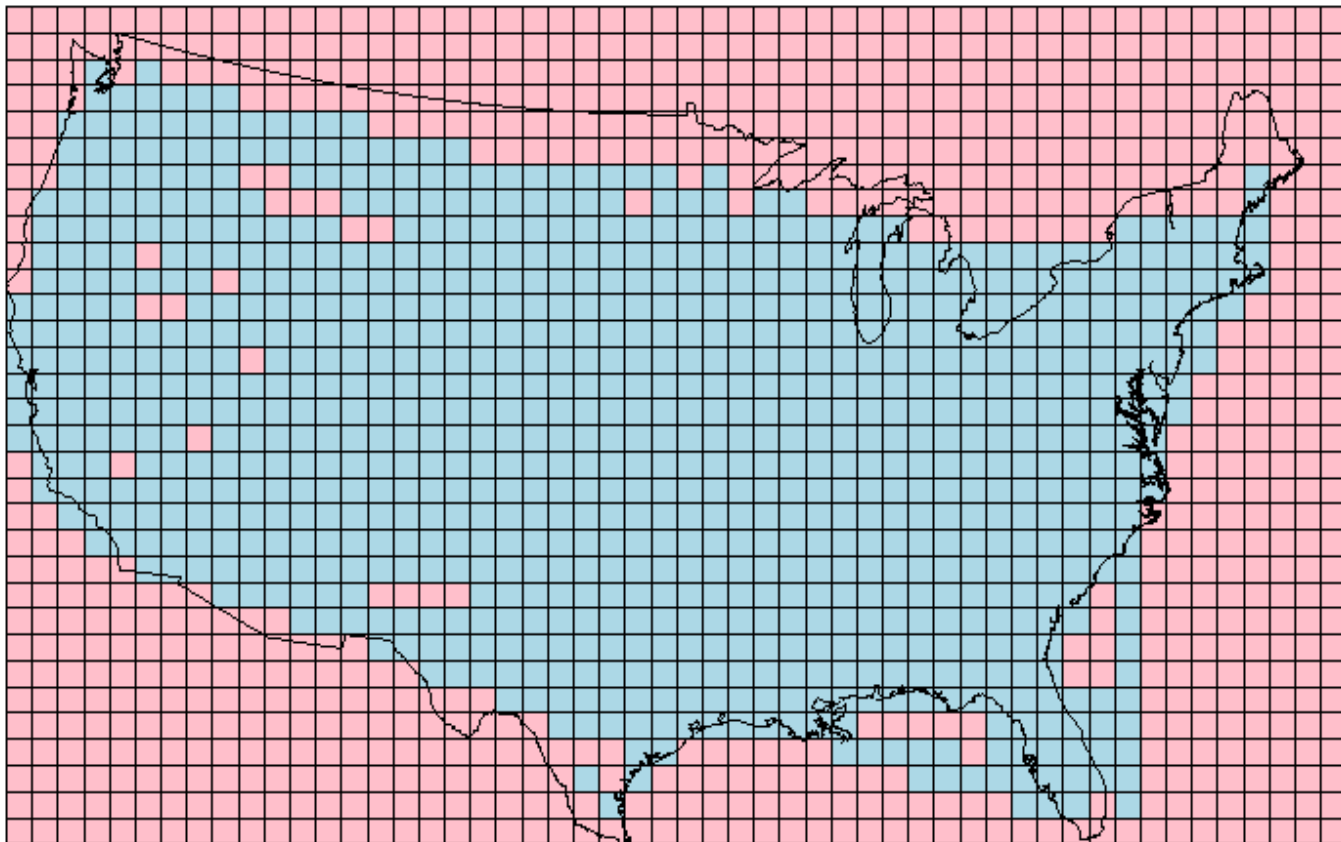


Other Questions We Have Addressed (And Are Happy to Discuss With You)

- **Are results valid in light of potential errors in the data?**
 - *Yes. Sensitivity tested using several sources of error.*
- **Why use a shortest time and not a low percentile as minimum value?**
 - *Minimal time flights are not outliers.*
- **Does time of day matter?**
 - *To a small extent. Results vary on the order of 10%.*
- **Are we really accounting for winds?**
 - *Yes. Tested against various levels of wind adjustment.*
- **Does any particular day stand out regarding the number of minimum values obtained on that day?**
 - *No. Removing days with the most minimum values had little effect.*
- **Where are the minimums occurring?**
 - *Different locations day to day.*
- **Were excess flying times different in 2001 and 2002?**
 - *Yes. On the order of 10 – 14 seconds.*



Cell-Based Approach





Cell-Based Approach Overview

- The Flight-Based Method does not address the question “Where is EFT being experienced?”
 - Compute EFT for each 50 nmi x 50 nmi cell (versus each flight)
- Time frame studied: 22 good weather days from each January – October in 2000 and 2004 (based upon misery index)
- Flight times based upon
 - Direction of flight (versus origin and destination)
 - Aircraft type (as specified in ETMS)
 - Altitude (low, medium, and high altitudes): 0 to 18,000 feet mean sea level (MSL), 18,000 feet MSL to flight level 290 (FL290), above FL290
- Actual flying **speeds** through cells were adjusted for wind effects on daily basis (using opposing traffic method)
- Flights with **greatest adjusted speed** were compared to other flights to determine “deficit speed” (data filtering/validation applied; minimum flight distance of 25 nmi through cell required)
- Deficit speed translated to excess flying time
- Based upon actual performance data, not modeled data



Compute Wind-Speed Adjustment ("Clustering" Cells)

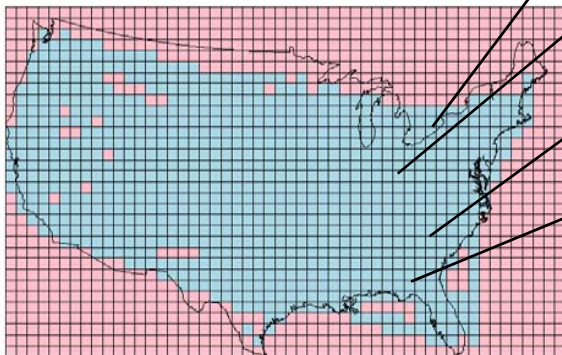
- To satisfy minimum sample size requirement of flights in both directions
 - Search subject cell plus neighborhood of subject cell (if required)
 - Stop search when sample size is adequate
- Analysis showed that searching just one "tier" beyond subject cell (called "tier 1") generally satisfied sample size requirement

Tier Values Relative to Subject Cell				
2	2	2	2	2
2	1	1	1	2
2	1	Subject Cell 0	1	2
2	1	1	1	2
2	2	2	2	2



Compute Wind-Speed Adjustment (Sample Adjustments)

- Example look-up table for January 1, 2000
- For cell (40, 8), aircraft type Airbus 320, direction NNW, altitude above FL290, the wind-speed adjustment is +0.177153 nmi/minute



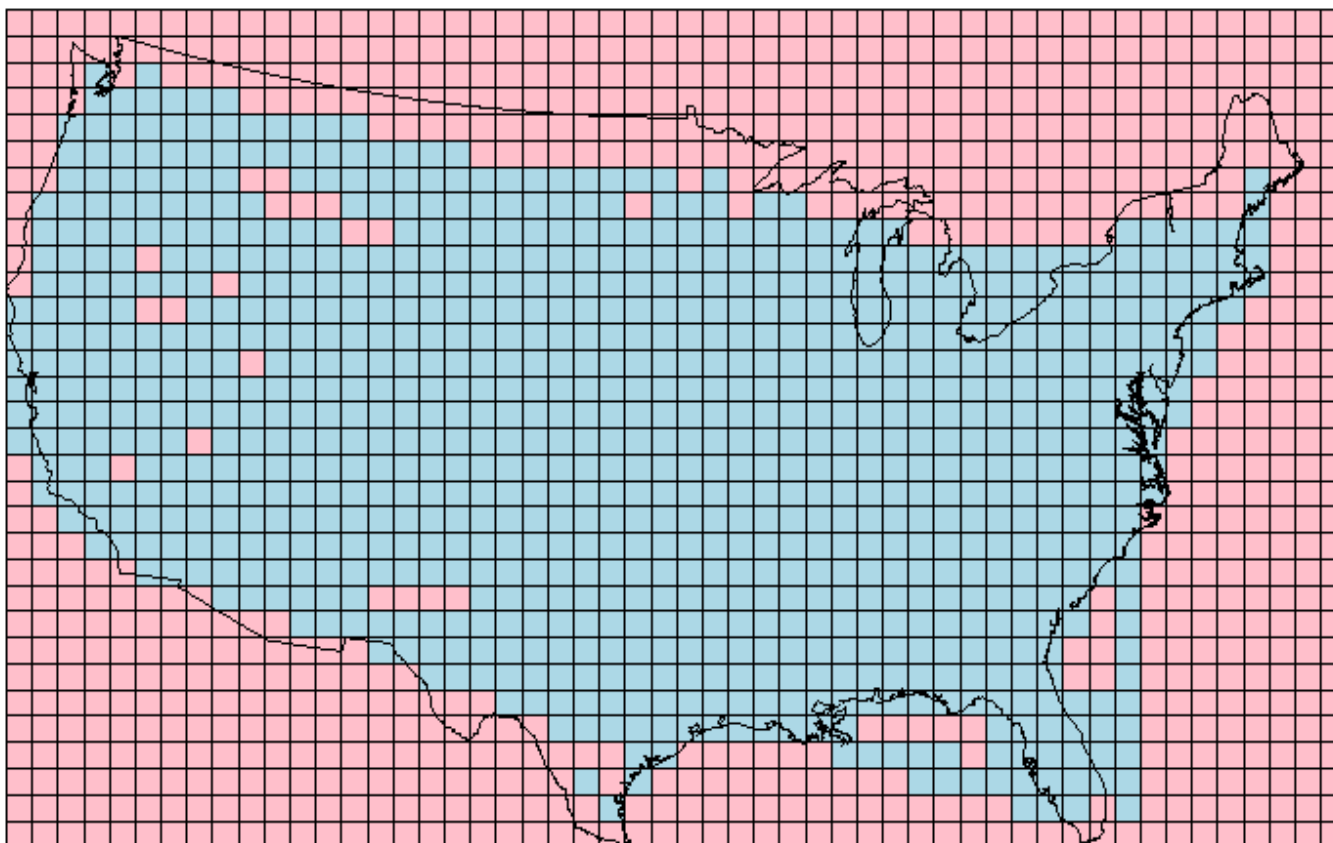
X Cell	Y Cell	Aircraft Type	Direction of Flight	Altitude Stratum	Speed Adjustment (nmi/min.)
40	8	A320	NNW SSE	Hi Hi	+0.177153 -0.177153
37	13	CRJ7	NNW SSE	Hi Hi	+0.000434097 -0.000434097
39	3	A319	SSE NNW	Lo Lo	-0.477839 +0.477839
4	19	B733	SSW NNE	Med Med	+0.789066 -0.789066

- For flights traveling in opposing directions, the sign of the wind adjustment is reversed
 - Example from first row: speed adjustment for A320 headed SSE in high altitude stratum of cell (40,8) is -0.177153; but for A320 headed NNW, speed is increased by 0.177153
 - (X Cell, Y Cell) values uniquely identify the cells, e.g., (40, 8)

Each cell combo is a row in the look-up table



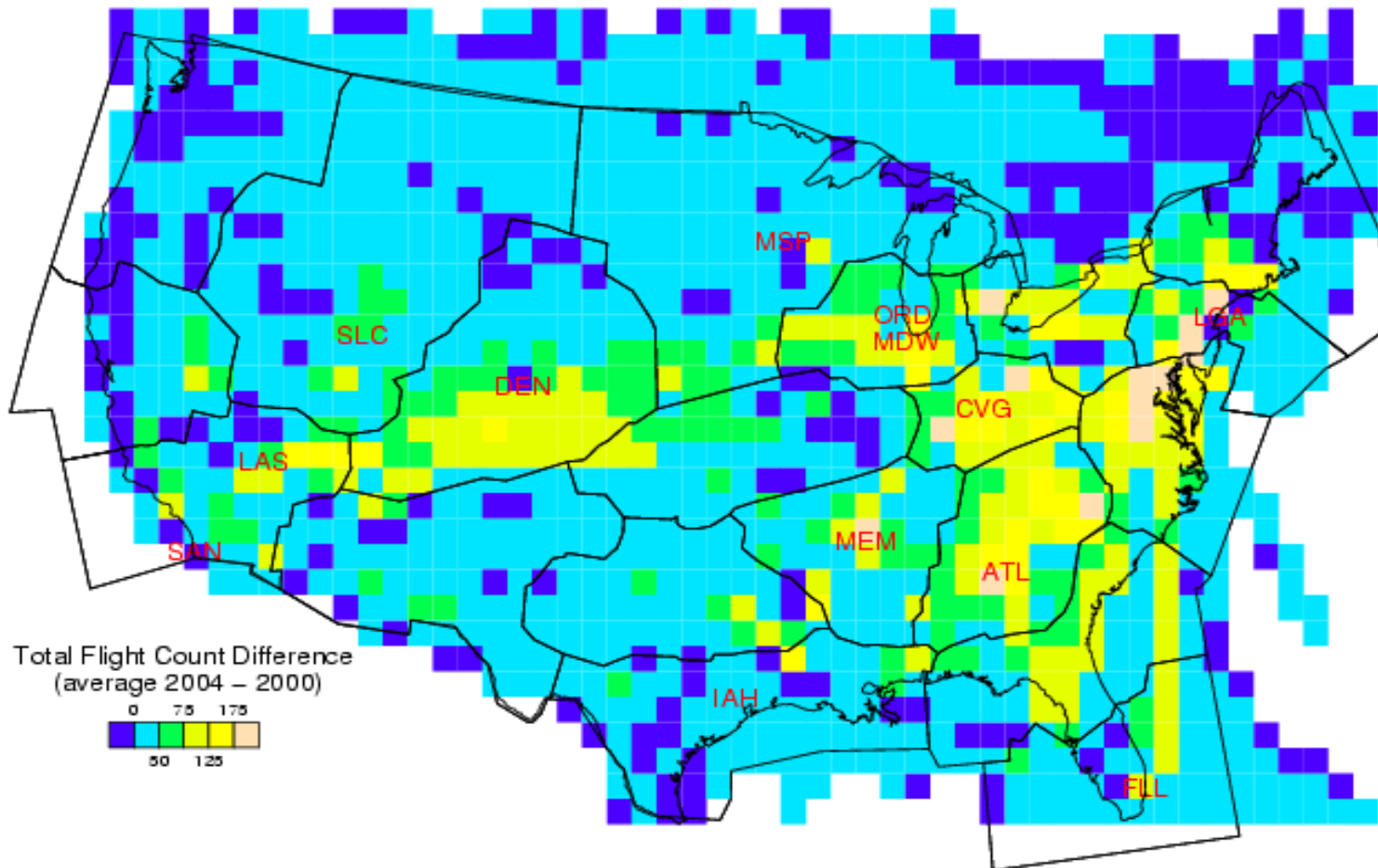
Cell-Based Results





Yearly Differences in Daily Averages of *Total Flight Counts* For Each Cell: 2004 – 2000

- Based on 2 x 22 good-weather weekdays, all directions, all altitudes*

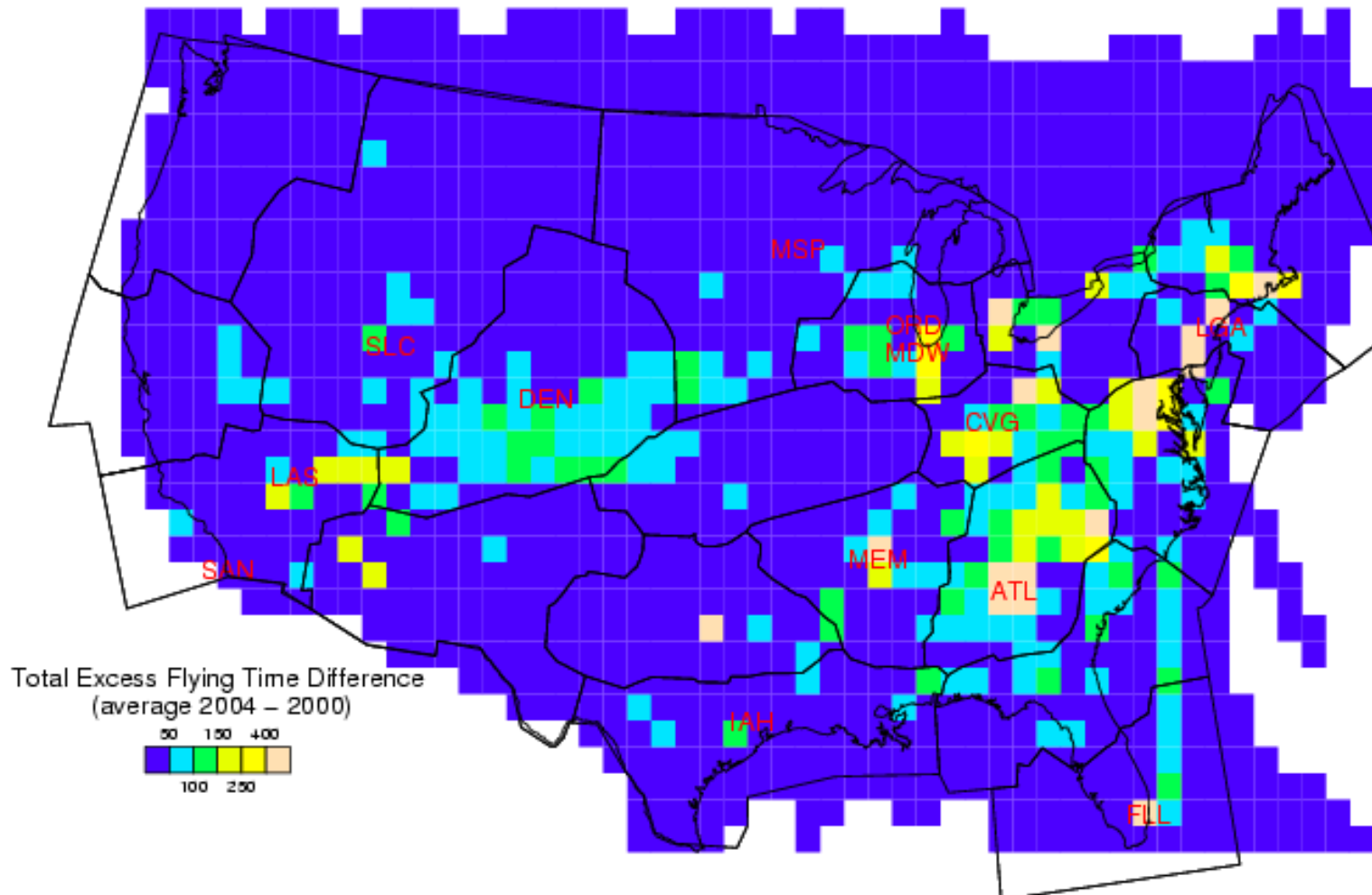


*Airports shown in red had higher levels of traffic in FY04 than in FY00



Yearly Differences in Daily Averages of *Total Excess Flying Time* in Minutes for Each Cell: 2004 - 2000

- Based on 2 x 22 good-weather weekdays, all directions, all altitudes*

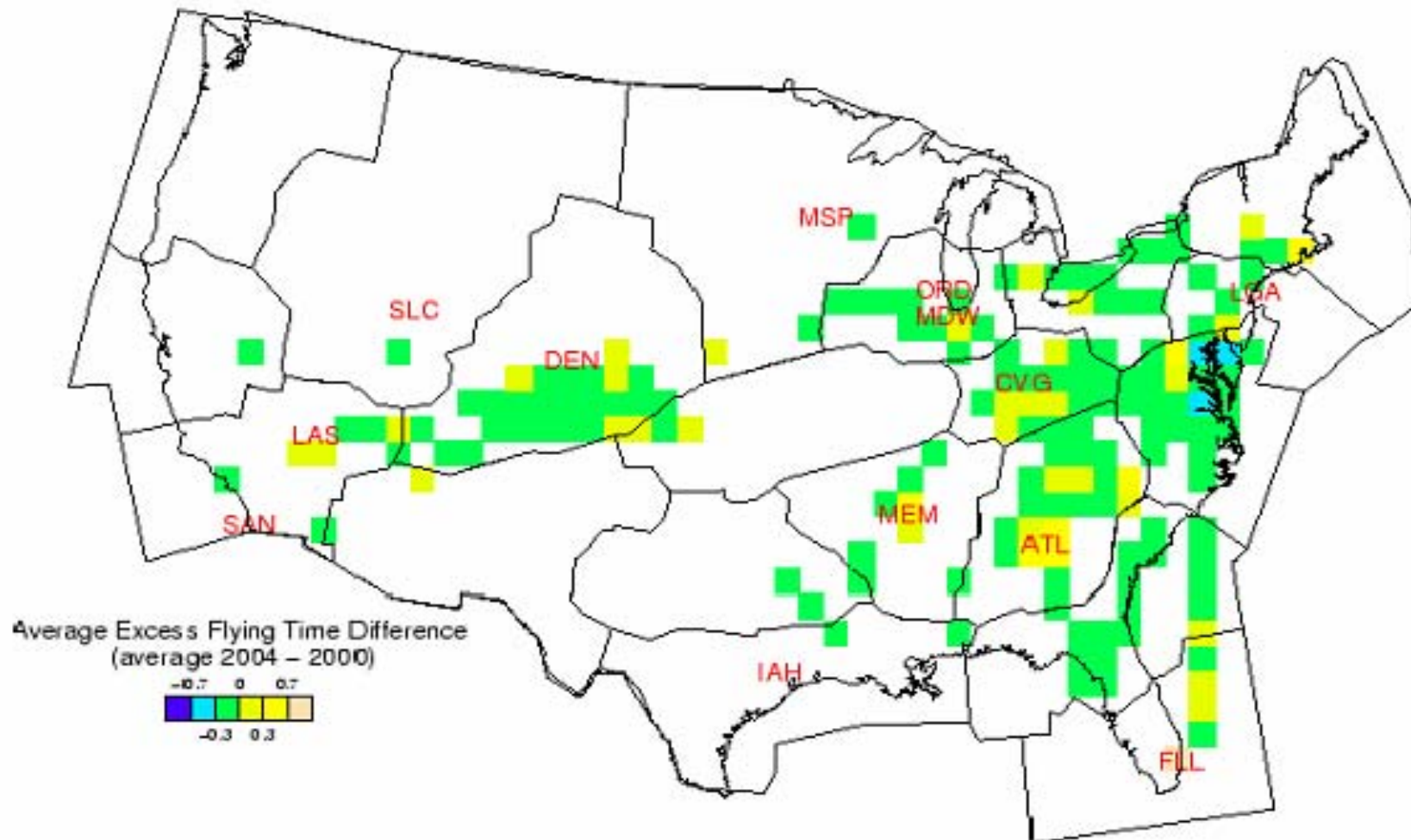


*Airports shown in red had higher levels of traffic in FY04 than in FY00



Average per Flight *Excess Flying Time* Difference for High-Difference Traffic Count Cells, Daily Average 2004 Minus 2000 (Units are Minutes)

- Based on 2 x 22 good-weather weekdays, all directions, all altitudes*



*Airports shown in red had higher levels of traffic in FY04 than in FY00



Estimated Daily Averages for All Altitudes Combined

ARTCC	Grid Count	Traffic Volume		Total EFT (minutes)		EFT per Flight-Cell		EFT per Sub-Flight	
		2000	2004	2000	2004	2000	2004	2000	2004
ZAB	72	15,808	17,294	21,212	20,407	1.34	1.18	7.05	6.15
ZAU	30	18,049	20,065	32,429	33,241	1.80	1.66	4.47	4.19
ZBW	54	5,990	6,927	12,509	13,465	2.09	1.94	4.30	4.16
ZDC	44	16,882	20,822	29,444	34,280	1.74	1.65	5.26	5.16
ZDV	78	18,163	22,262	21,317	24,685	1.17	1.11	6.11	5.89
ZFW	49	13,344	14,680	24,104	23,832	1.81	1.62	5.07	4.77
ZHU	70	9,054	10,186	14,992	14,519	1.66	1.43	4.71	4.23
ZID	21	12,742	14,958	18,186	20,008	1.43	1.34	3.15	2.99
ZJX	58	13,855	16,627	19,401	20,791	1.40	1.25	5.15	4.61
ZKC	52	16,858	17,905	22,535	20,045	1.34	1.12	5.38	4.93
ZLA	53	13,407	15,021	25,652	25,961	1.91	1.73	5.06	4.80
ZLC	131	11,335	13,851	12,726	15,055	1.12	1.09	4.84	4.89
ZMA	44	5,144	6,170	9,575	10,325	1.86	1.67	3.81	3.79
ZME	39	12,230	14,131	15,240	17,201	1.25	1.22	3.77	3.80
ZMP	118	13,370	15,603	19,360	20,266	1.45	1.30	5.16	4.96
ZNY	26	11,943	13,270	30,461	31,242	2.55	2.35	4.19	4.06
ZOA	35	8,259	8,673	14,127	12,640	1.71	1.46	4.54	3.91
ZOB	29	19,829	21,866	32,750	33,801	1.65	1.55	4.41	4.39
ZSE	73	7,171	7,125	11,822	10,595	1.65	1.49	5.40	5.06
ZTL	45	19,381	23,449	29,141	36,086	1.50	1.54	4.15	4.50
TOTAL	1,121	262,812	300,885	416,985	438,445	NA	NA	NA	NA
MEAN	56	13,141	15,044	20,849	21,922	1.62	1.48	4.80	4.56

Note: EFT per Flight-Cell and EFT per Sub-Flight are both in minutes



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Conclusions



Summary and Conclusions

- **Flight-Based Method**
 - **Good weather results: about 4 to 5 minutes EFT, per flight, in the 100/100 dataset, a potential reduction of 8% – 10%**
 - **Full year results: about 7.5 minutes EFT when considering all days and the 100/100 dataset**
 - **Not all of this excess flying time is recoverable via efficiency initiatives: it represents an upper bound in today's NAS**
- **Cell-Based Approach**
 - **Some areas of the country, especially east of the Mississippi, had more traffic in 2004 than in 2000**
 - **During the best weather days**
 - **Leading to *more* excess flying time**
 - **However, although there is more excess flying time (due to higher traffic levels), the *average* EFT per cell has *decreased***
 - **EFT per 'Sub-Flight' (within an ARTCC) has also *decreased* (2004 versus 2000)**
 - **Some exceptions exist. For example, ZTL has higher average EFT as well as more EFT per Sub-Flight**



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Backup Slides



How Estimates of Daily Averages In Slide 24 Are Computed

- A cell is in an ARTCC (such as ZAU) if its midpoint is in that ARTCC
- A flight is in an ARTCC cell if it flies in the cell for at least 25 nmi
 - A flight may traverse multiple cells of various ARTCCs
- Traffic volume of an ARTCC = number of flights in cells of the ARTCC
 - Traffic volume of an ARTCC is in units of flight-cells, and counts each flight once for each cell in which the flight travels at least 25 nmi
- Total EFT in an ARTCC = sum of EFTs for all flight-cells of the ARTCC
 - Counts only those portions of flights with at least 25 nmi per cell
- Mean EFT in an ARTCC
 - Per flight-cell – already adjusted for different ARTCC geographic areas
 - Per sub-flight – estimates mean EFT for the entire portion of each flight in the ARTCC
 - Called “sub-flight” because for each flight in the ARTCC the EFT estimate includes only those cells in which the flight traveled at least 25 nmi and for which there were enough flights to compute a wind adjustment
- Grid count of an ARTCC is the number of cells in the ARTCC



Average Excess Flying Times for 15-Day Pools With Wind Adjustment

Dataset	Average Minutes Excess	Average Percent Excess
10/10	6.4	9.5
40/40	4.9	10.0
100/100	4.7	8.1



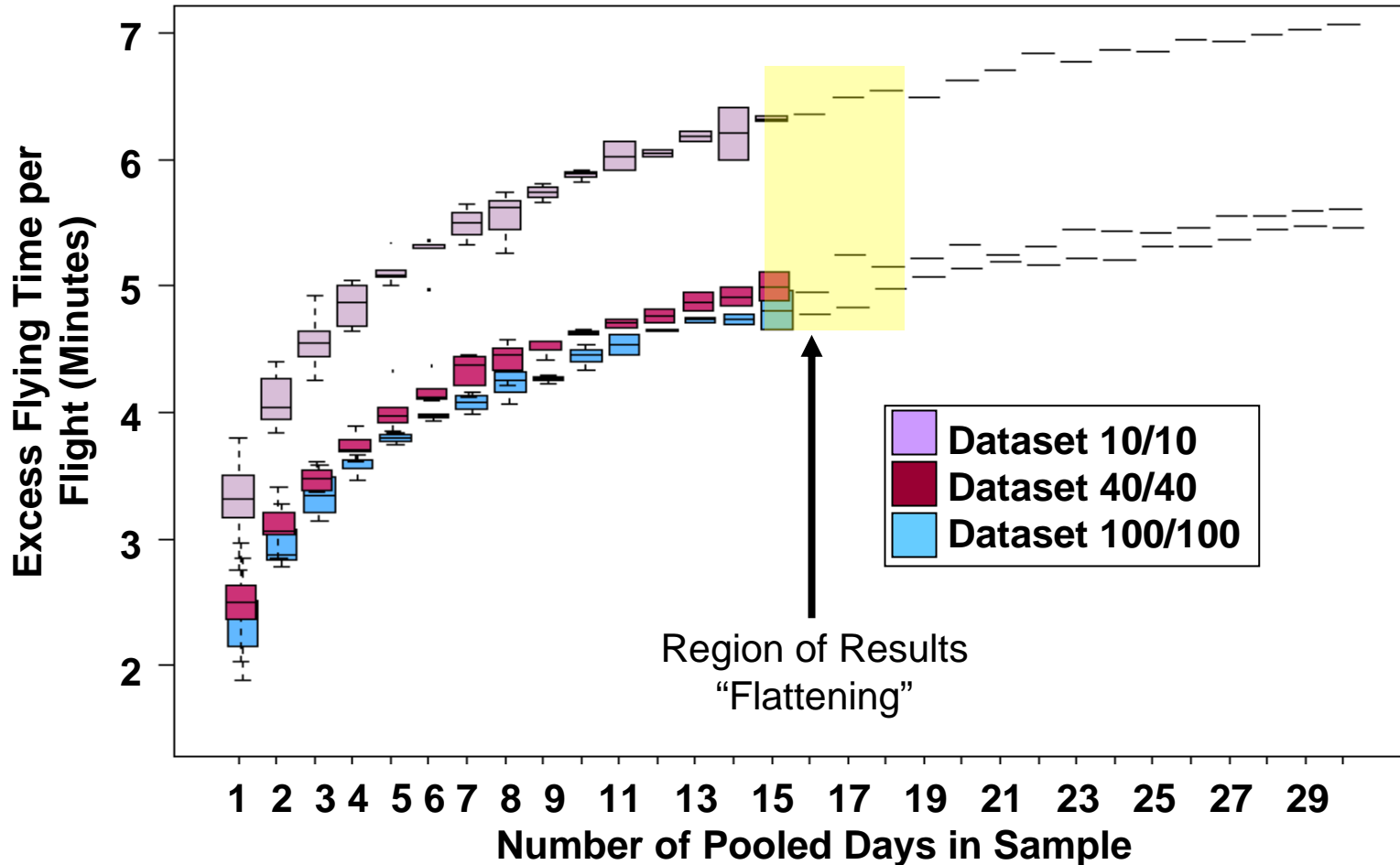
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Additional Backup Slides



Summary of Results: All Datasets

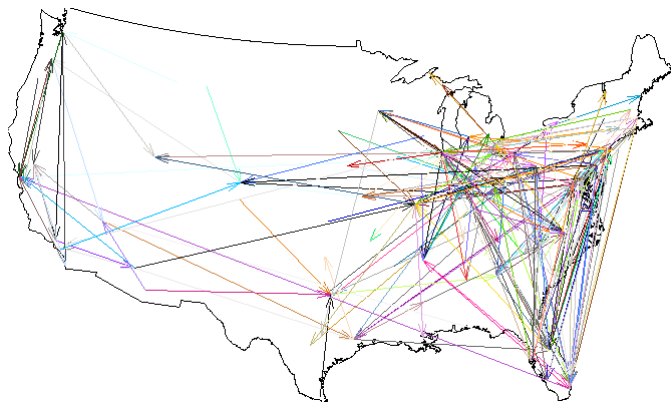
Excess Flying Time vs. Number of Sampled Days: All Datasets



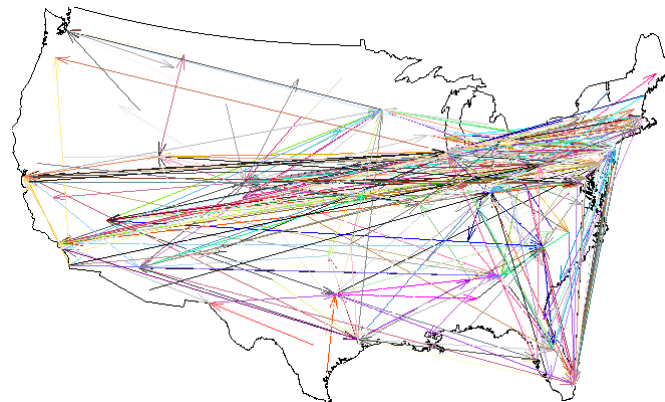


Where are the Minimums Occurring? Different Parts of the System Perform Best On Different Days

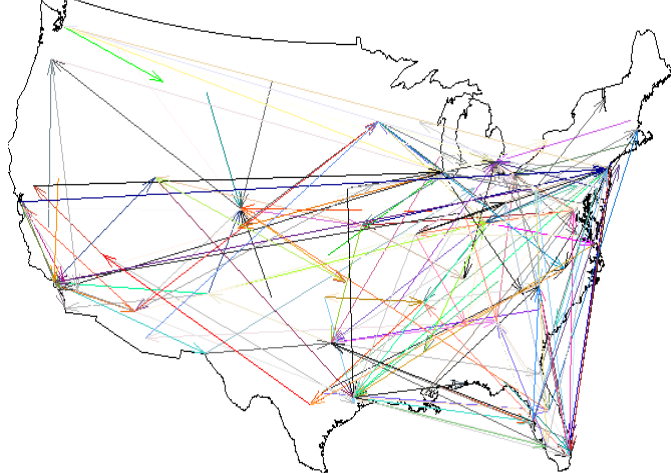
5/8/2001 East Coast Minimums



4/22/2002 Trans Con Minimums



3/29/2002 NAS-Wide Minimums



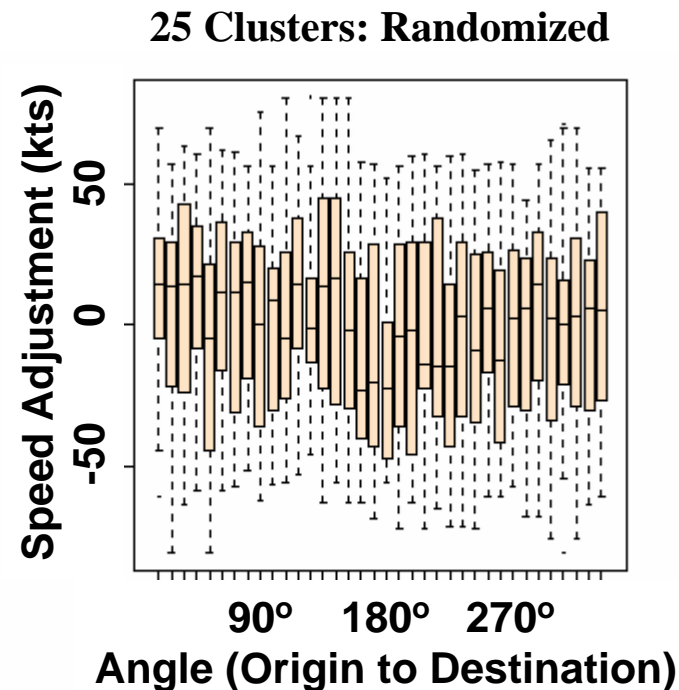
2/16/2002 East and SW Minimums





Are We Really Accounting for Winds? Results Using Random Adjustments

- **Wanted to understand how strongly our results depended on the wind adjustments being made**
- **As a test we took the wind adjustment data and randomly shuffled it for each day and performed the same analysis as before**
 - **Chart on right shows effect of randomly shuffling the wind adjustment data**
- **Results were dramatically different and stable, indicating wind adjustments were performing as expected**
 - **Wind Adjusted Results: 5.61 minutes; 11.41%**
 - **Random Analysis Results (3 runs of 40/40 dataset; 30 pooled days): 12.80, 12.87 and 12.86 minutes; 25.42, 25.58, 25.57%**

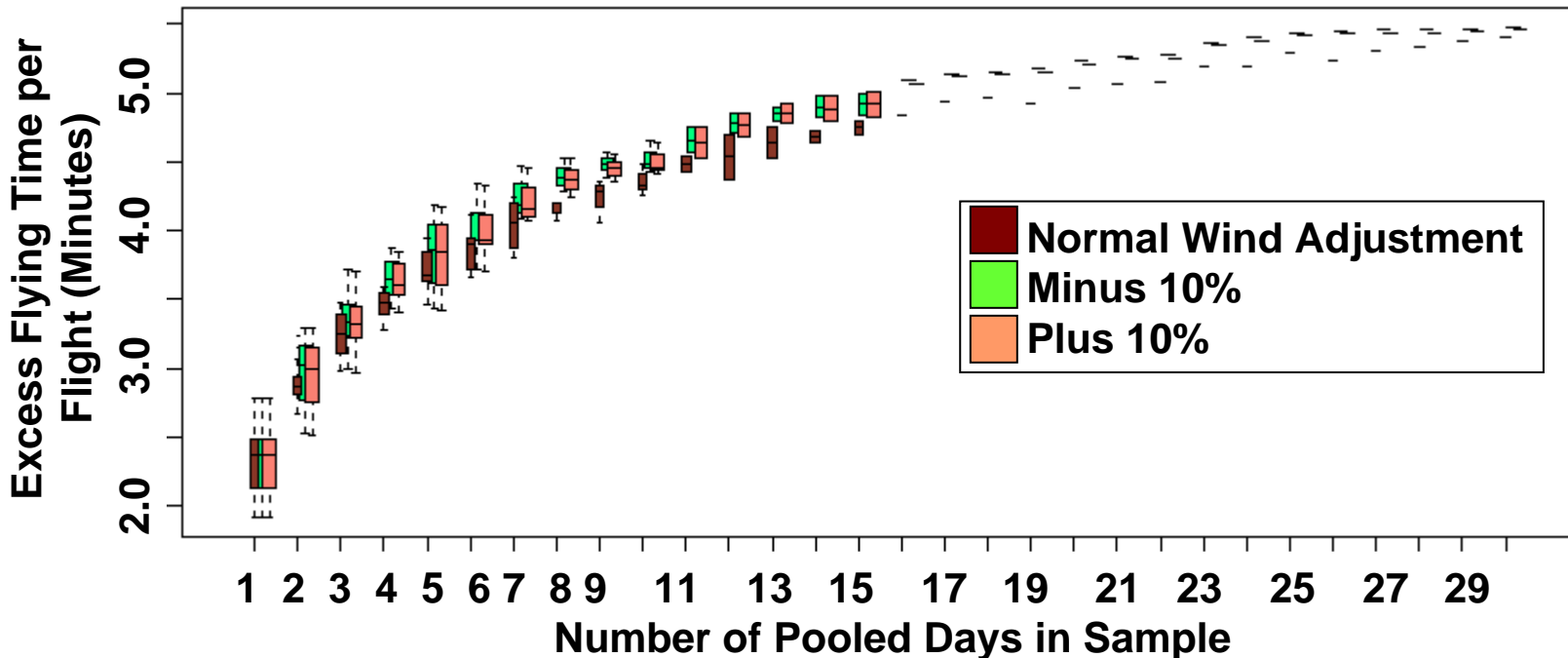




Are We Really Accounting for Winds? Results Using Modified Adjustments

- **Wanted to know how sensitive results are to inaccuracies in wind adjustments**
 - Tested wind adjustments of +10% and -10%
 - Results indicate wind adjustment used minimizes EFT

Excess Flying Time vs. Number of Sampled Days: 100/100 Dataset, Daytime

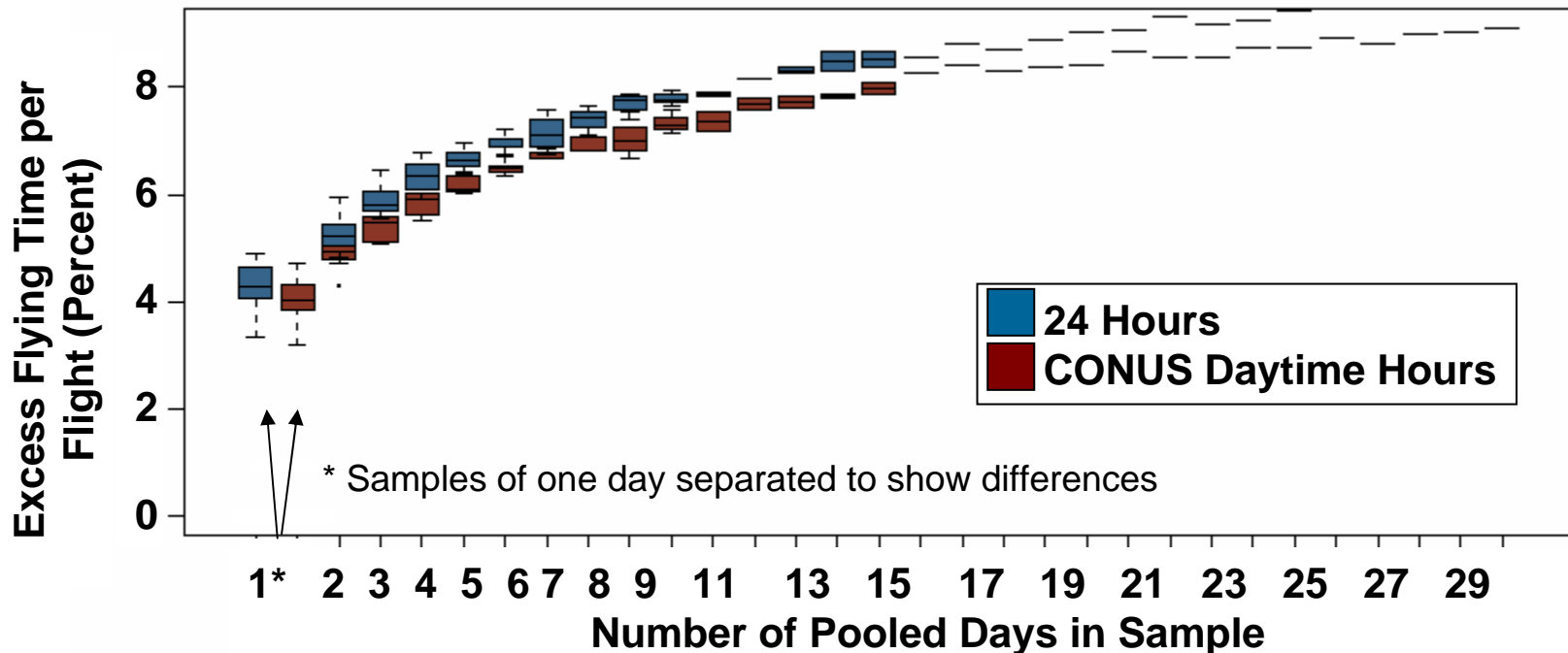




Does Time of Day Matter?

- If many of the minimal flight times were occurring overnight in the non-congested hours, EFT may appear larger than it really is when congestion is considered
 - Tested for this by comparing 24 hours to daytime (16 hours)

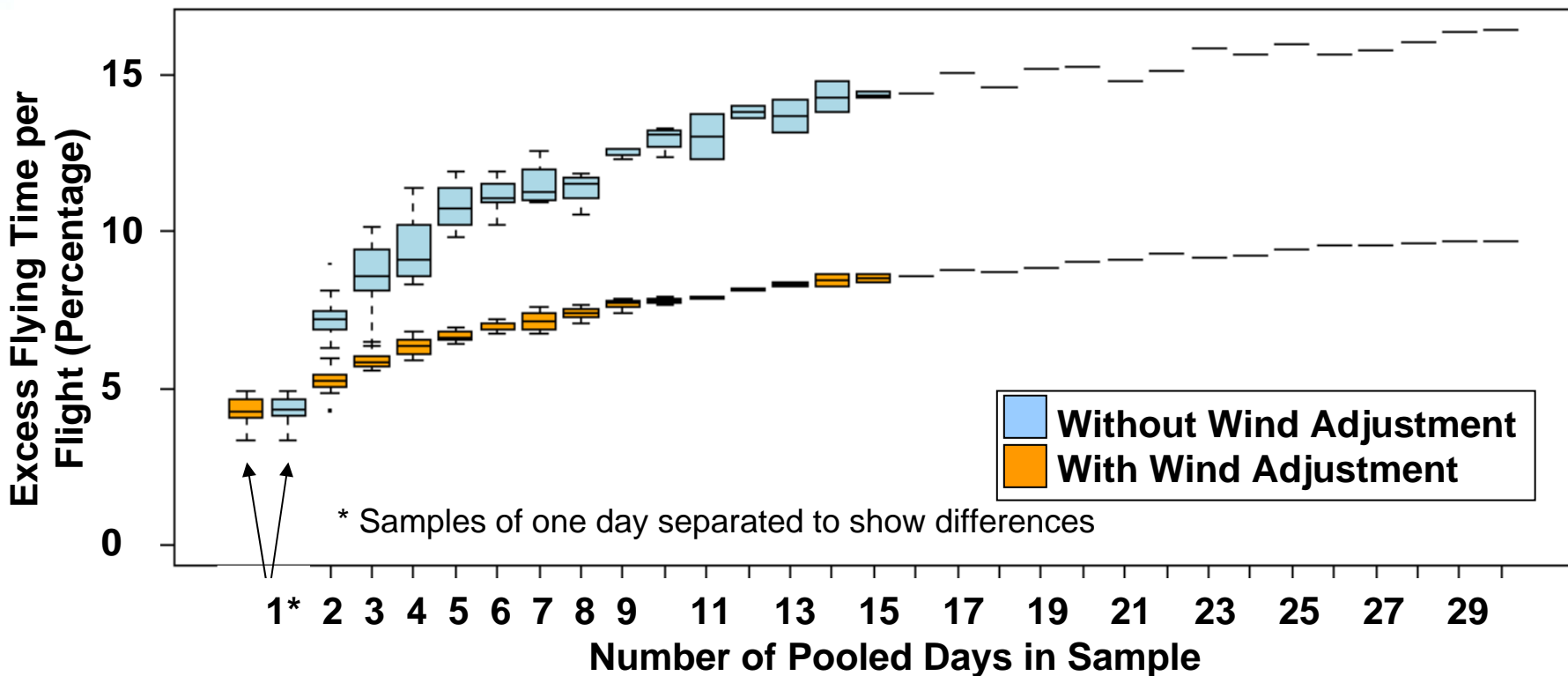
Excess Flying Time (%) vs. Number of Sampled Days: 100/100 Dataset





Flight-Based Method Results: 100/100 Dataset (Percentage)

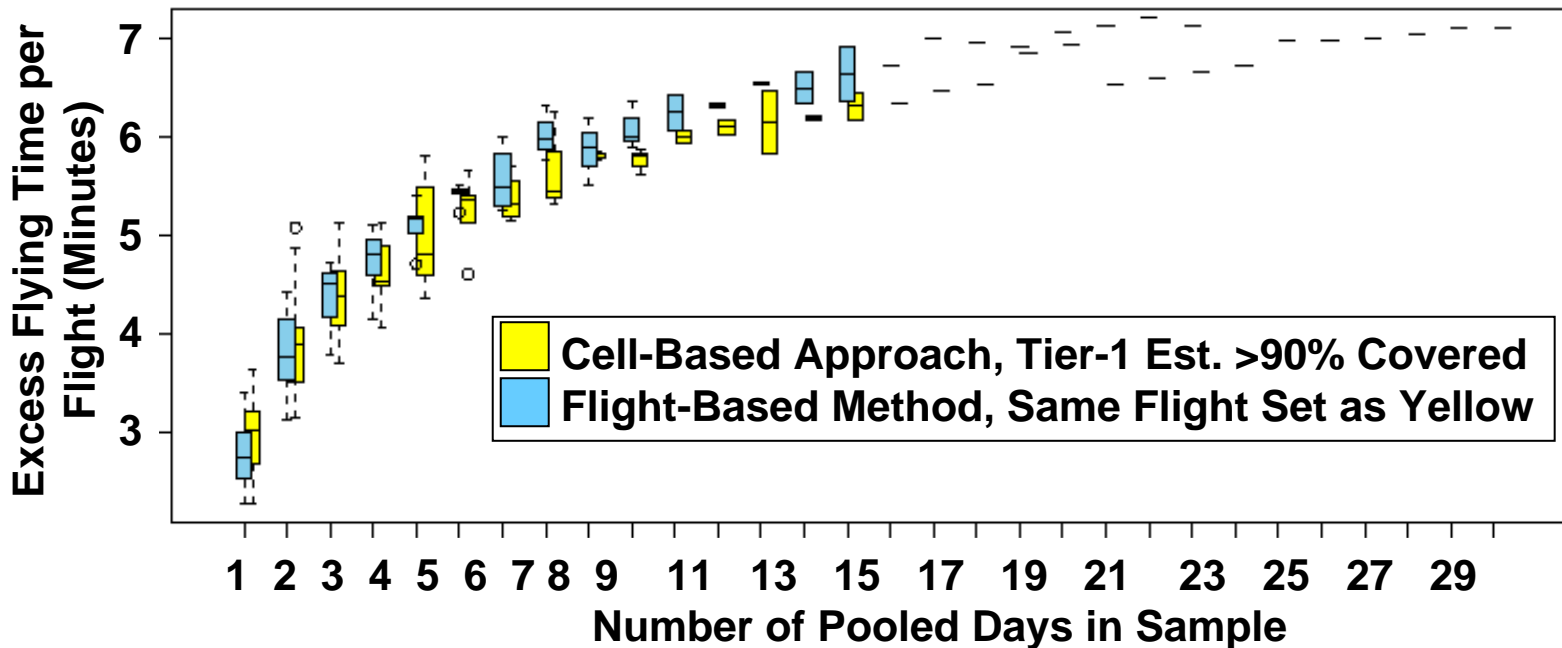
Excess Flying Time vs. Number of Sampled Days: 100/100 Dataset





Comparison of Pooled-Days vs. Excess Flying Time for Various Methods

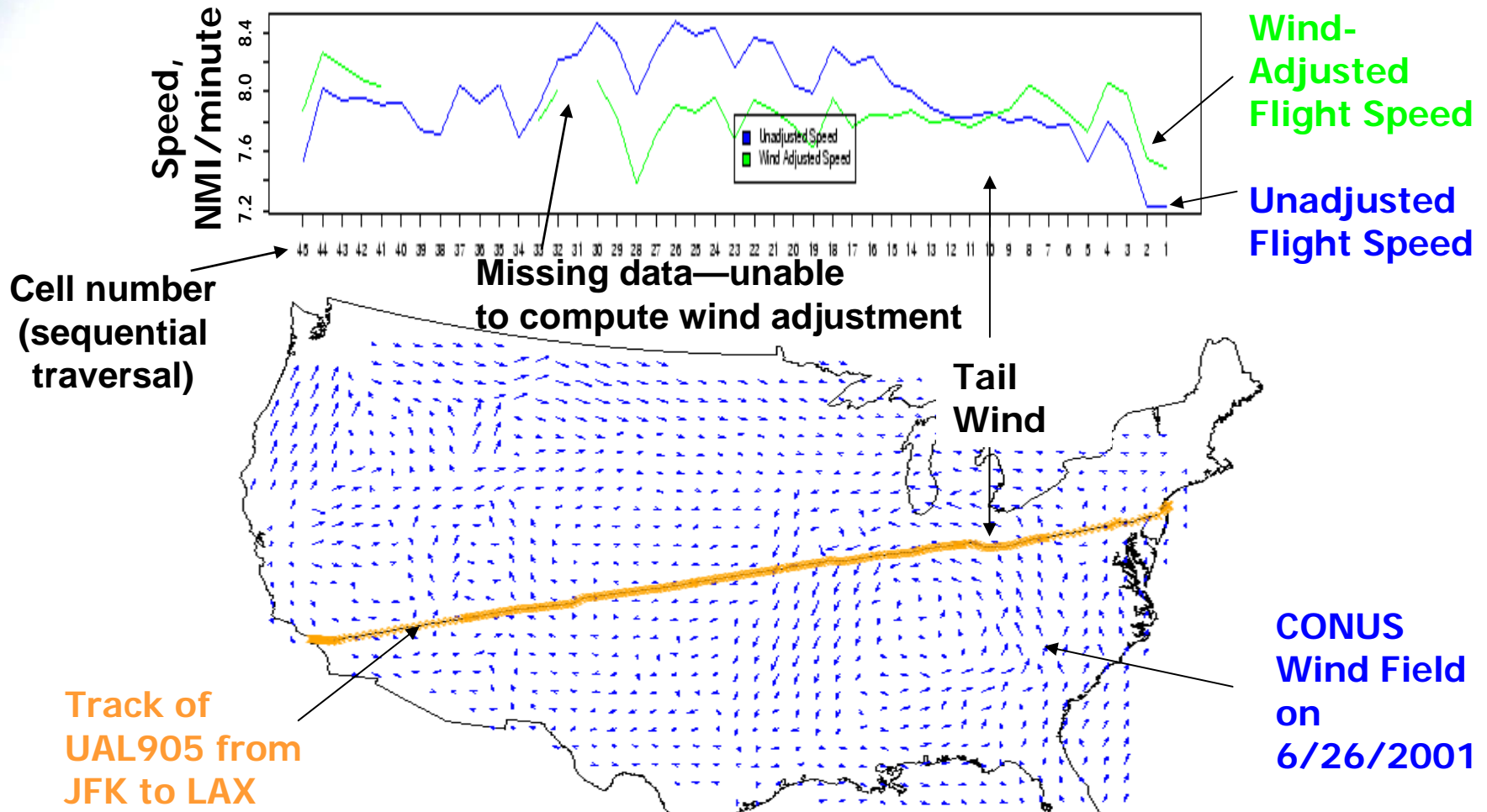
Excess Flying Time vs. Number of Sampled Days: Long Flights Only



Yellow boxes are cell-based approach with Tier value $K=1$, and a discarding of flights when $<90\%$ of their cell penetrations have wind adjustment available. This filter retains long flights. The same flight set for each run (30 runs when pool=1, 15 runs when pool=2, etc.) was repeated using the flight-based method, with acceptably similar results, per agreement of blue and yellow in the figure.



Validation of Computations



When track experiences tail wind, adjusted speed becomes less than unadjusted speed, since track needs relative decrement to make results wind-neutral.



Average per Flight Excess Flying Time Difference, Daily Average 2004 Minus 2000 (Units are Minutes)

