Validation of En Route Capacity Model with Peak Counts from the National Airspace System

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11 November 2010

*** This work is sponsored by the Federal Aviation Administration under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the author and are not necessarily endorsed by the United States Government.**

Overview

- Airspace capacity estimates are important
  - sector design
  - air traffic management
- Current model accounts only for ‘transit’ workload
  - hand-offs at sector crossings

- New model adds key workload components
  - conflict avoidance
  - recurring tasks

- We have estimated capacities for 20 NAS* Centers
  - ~ 800 sectors

Capacities differ significantly center to center

Local Capacity << Inherent Capacity

* U.S. National Airspace System

Outline

- **Review of Capacity Model**
- **Regression Process**
- **Center Capacities**
- **Conclusions**

Workload Event Rates

Workload grows with three critical traffic-dependent event rates

Transit (boundary crossing) rate

$\lambda_t = N/T$

sector aircraft count N

mean sector transit time T

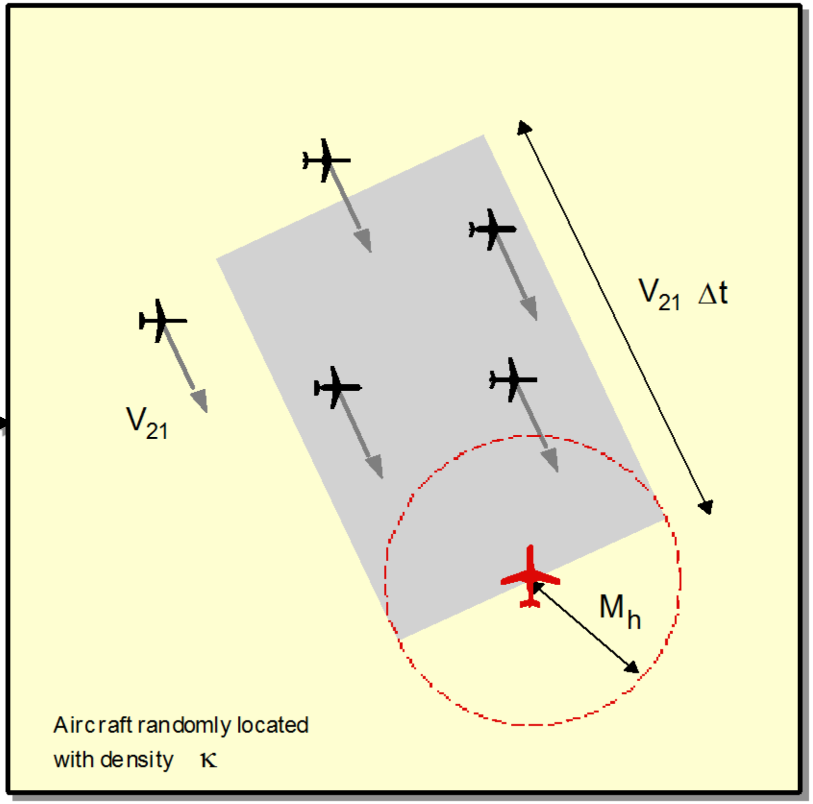
Conflict rate

$\lambda_c = (2\, N^2/Q)\, M_h\, M_v\, V_{21}$

sector airspace volume Q

miss distances **M_h and M_v**

mean closing speed V_{21}



Recurring (scanning/monitoring) rate

$\lambda_r = N/P$

recurrence period P

Workload Intensity

Workload Intensity
(fraction of controller time)

$$G = G_t + G_c + G_r$$

transit — conflict — recurring

Service Times
(empirical)

$$G_t = \tau_t \; [N/T]$$

$$G_c = \tau_c \; [(2\, N^2/Q)\, M_h\, M_v V_{21}]$$

$$G_r = \tau_r \; [N/P]$$

occurrence rates
(calculated from airspace parameters)

Determining the unknown service times

- Live approach
  - Measure controller performance
- Regression approach
  - Observe Peak daily counts *Np* for many sectors
  - Calculate corresponding Model capacities *Nm*
  - Find service times that best fit *Nm* to *Np* bound

Conflict Distance

Conflict Workload Intensity

$$G_c = \tau_c \left[(2\, N^2/Q)\, M_h\, M_v V_{21}\right]$$

Global closing speed V_{21} is also unknown

Fit the product $\tau_c V_{21}$

(separation lost while resolving a conflict)

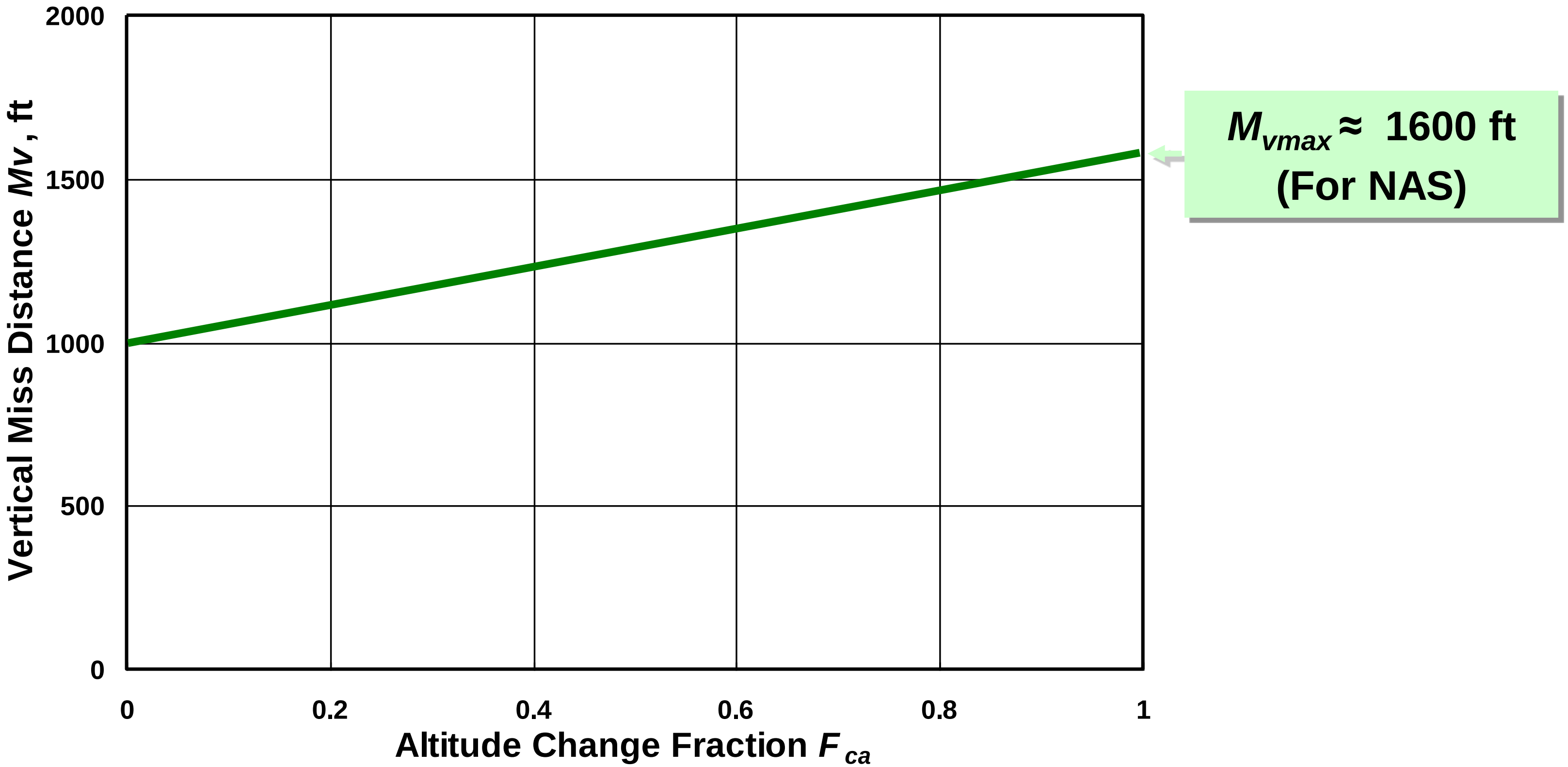
$\tau_c V_{21}$ ~ 2 nautical miles (for NAS)

Effect of Altitude Changes

Aircraft with vertical rates cause increased uncertainty

Adapt by increasing vertical miss distance M_v

- **Determine fraction F_{ca} of aircraft with ≥2000 ft altitude change**
- **As F_{ca} grows, increase M_v linearly from 1000 ft to M_{vmax}**



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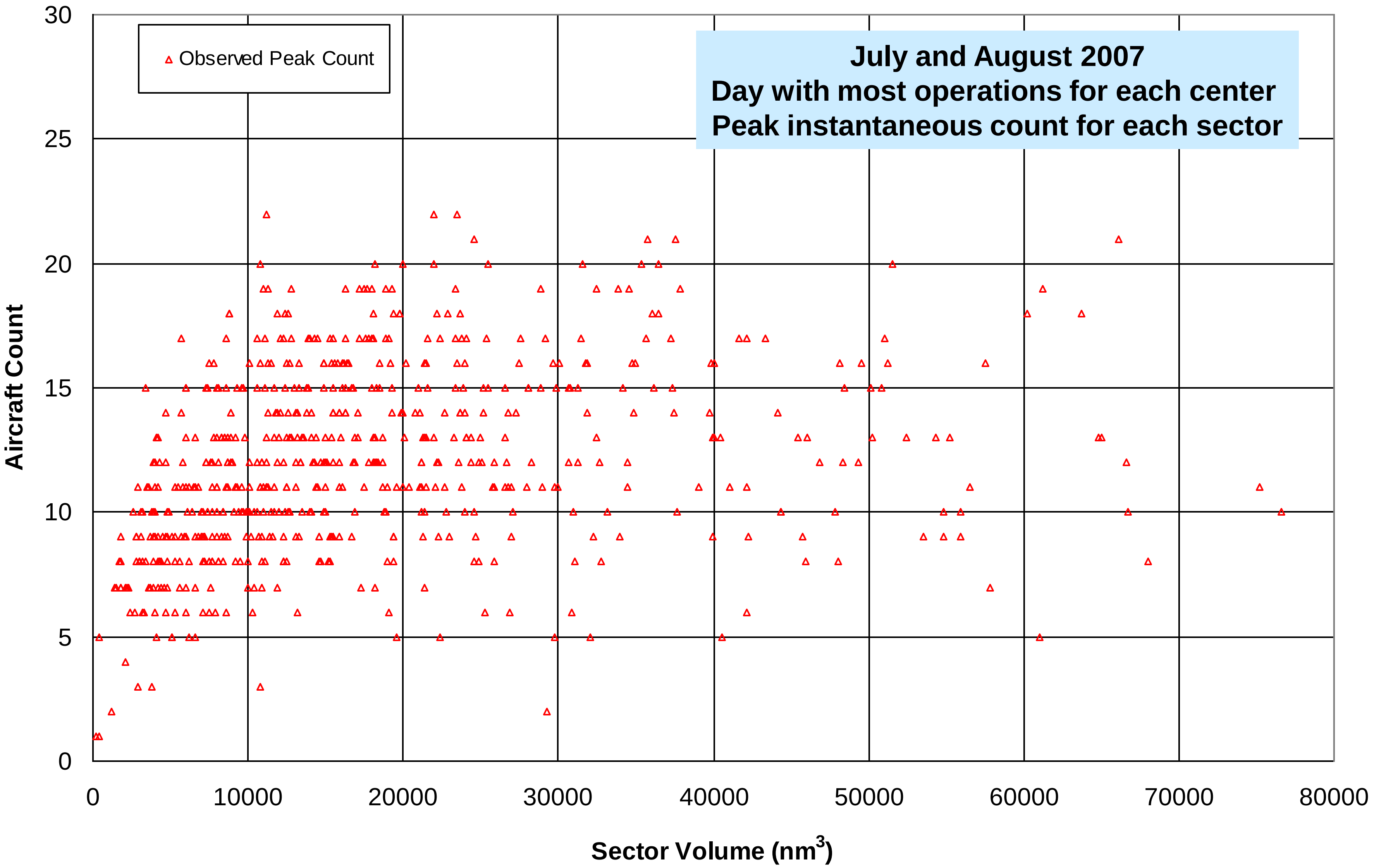
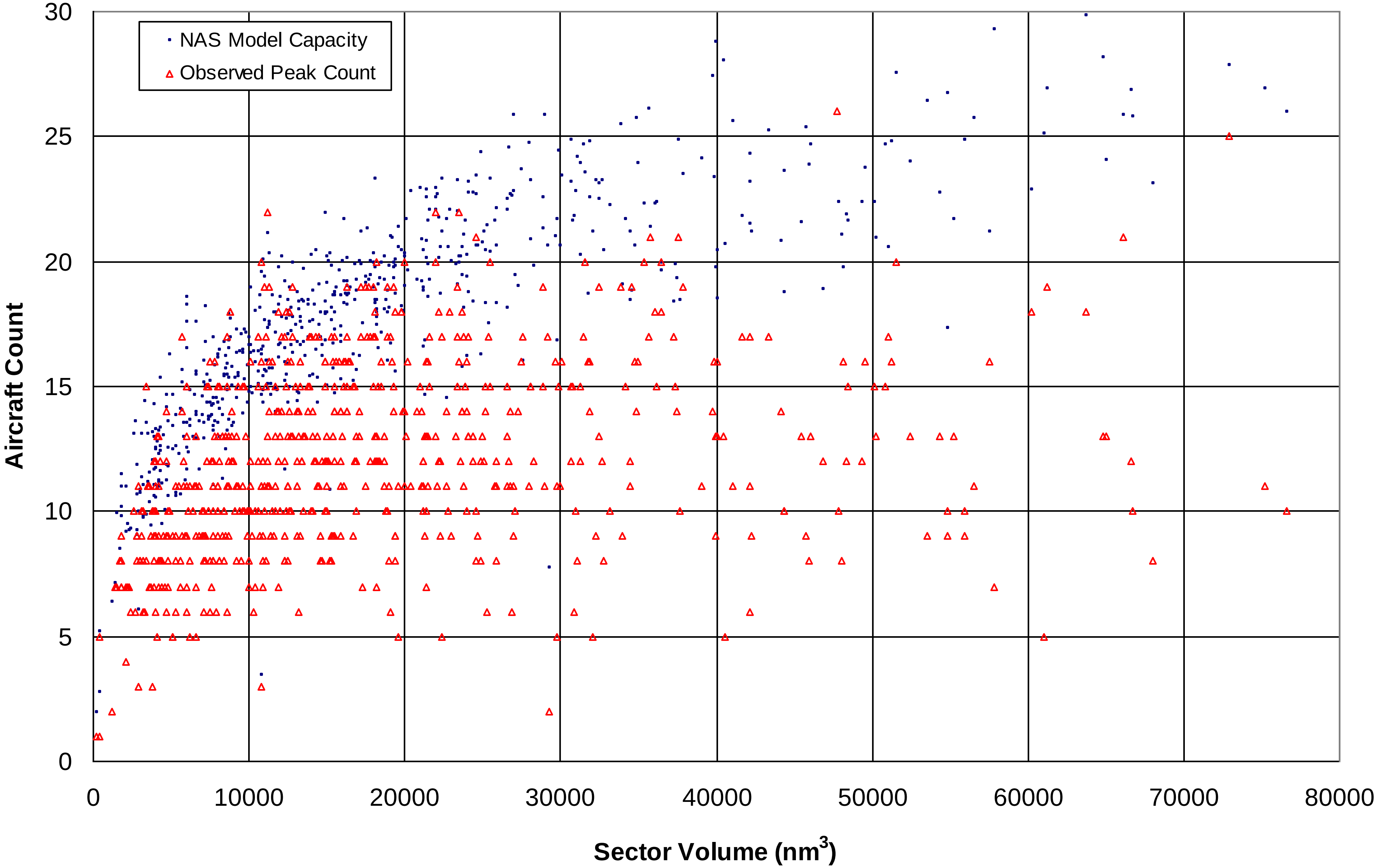
Peak Daily Counts

(790 NAS Sectors)

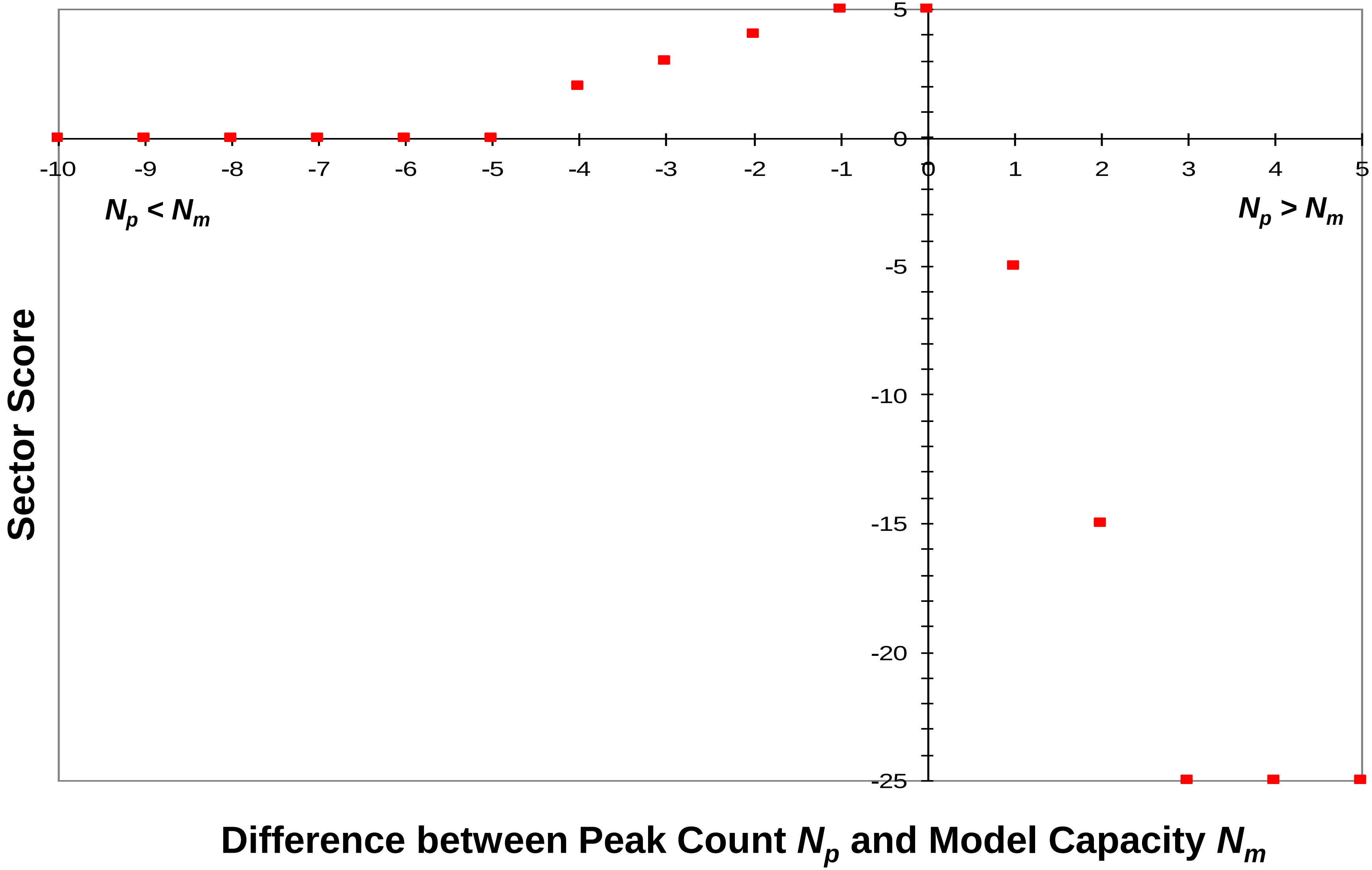


Peak Daily Counts and Fitted Capacities

(790 NAS Sectors, July–August 2007)



Asymmetric Objective Function
(Fits Model to Peak Count Bound)



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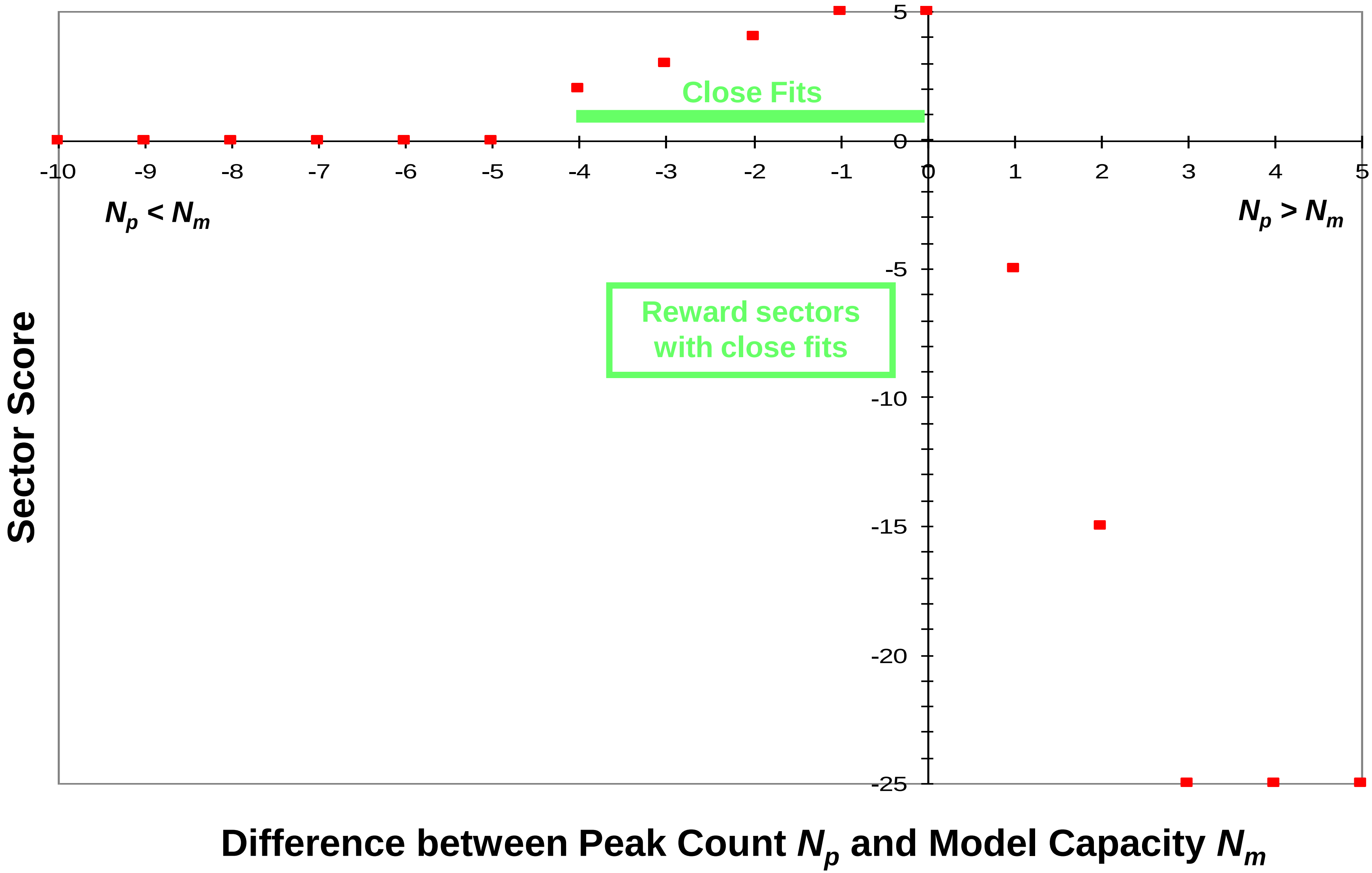

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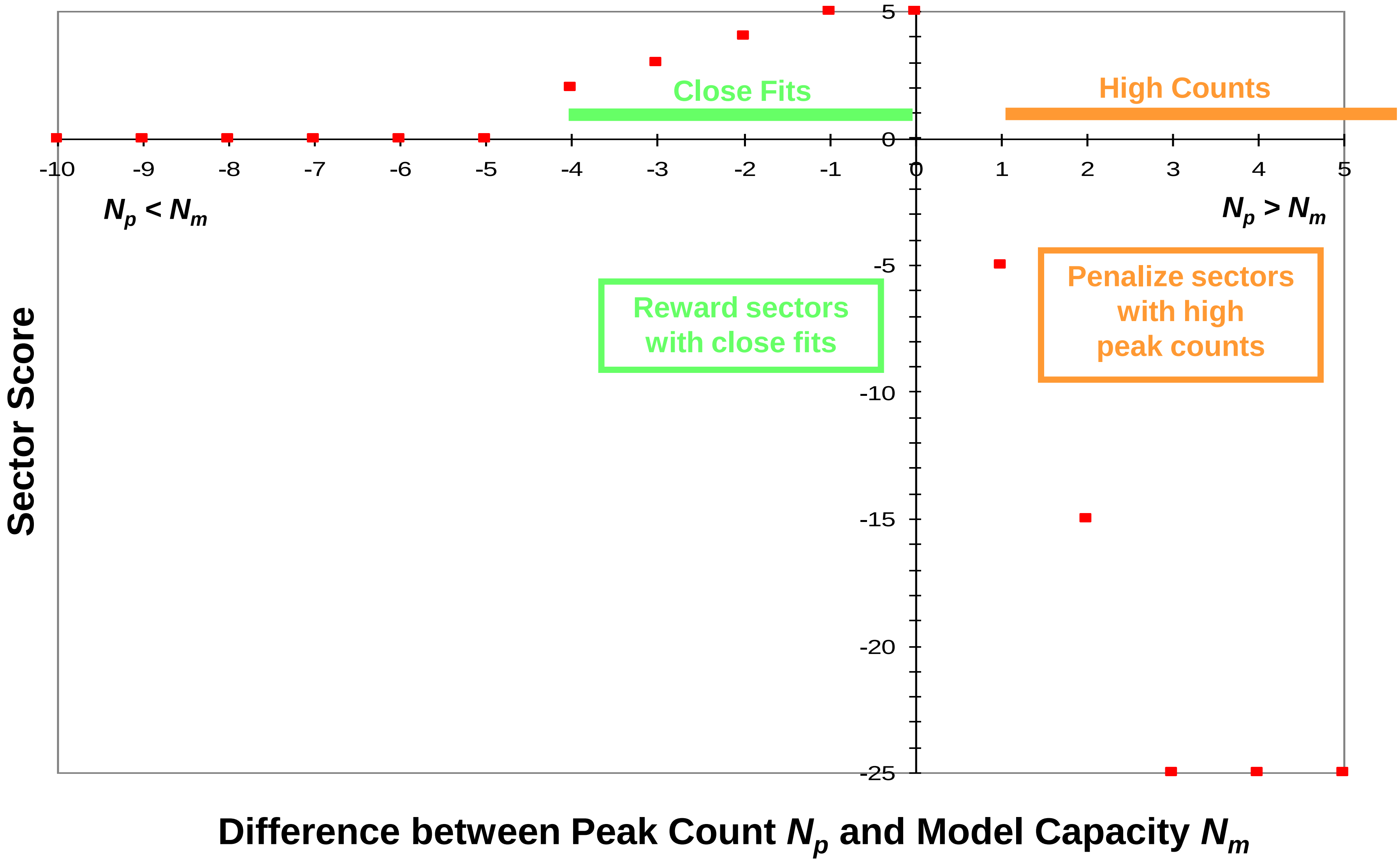

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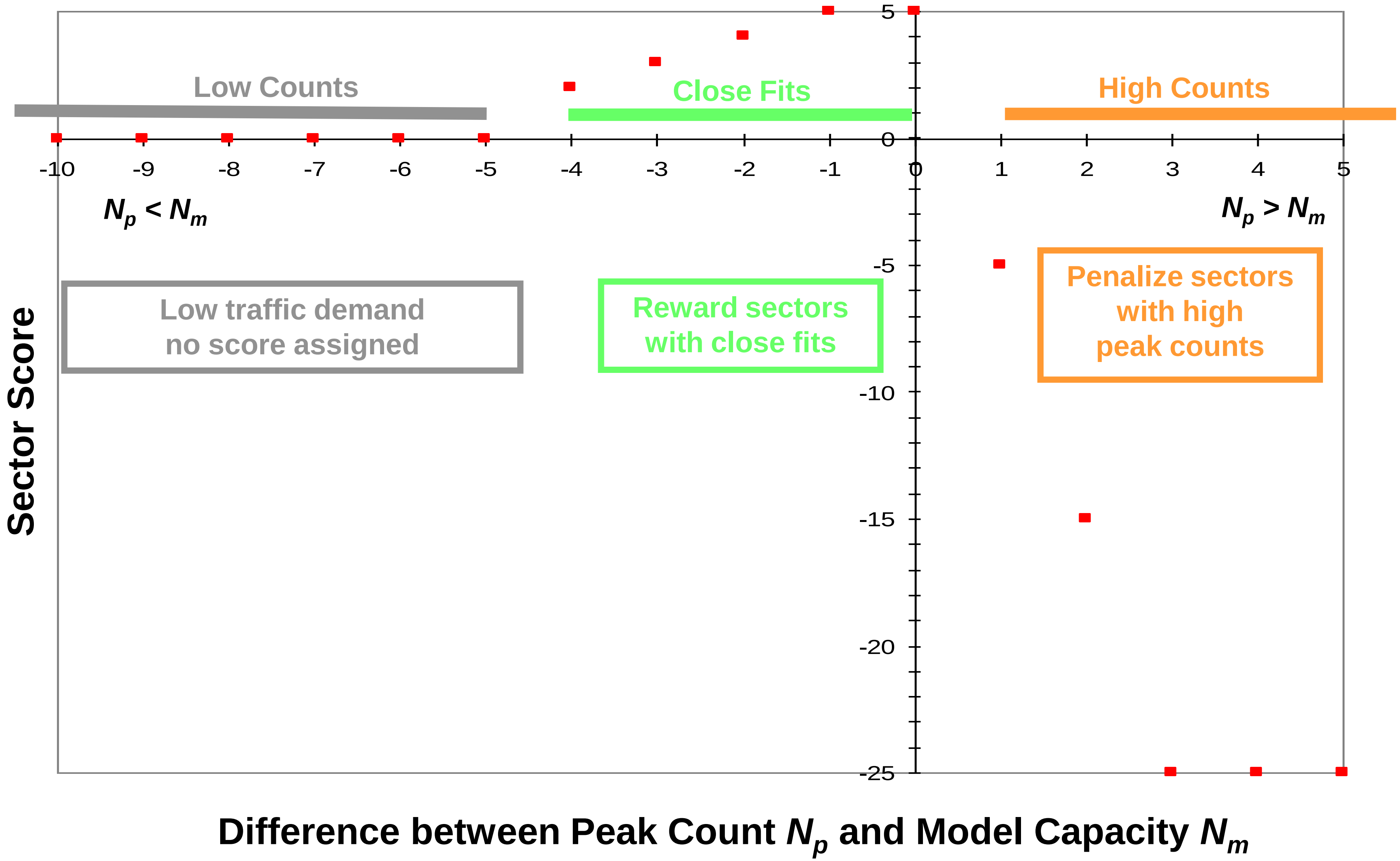
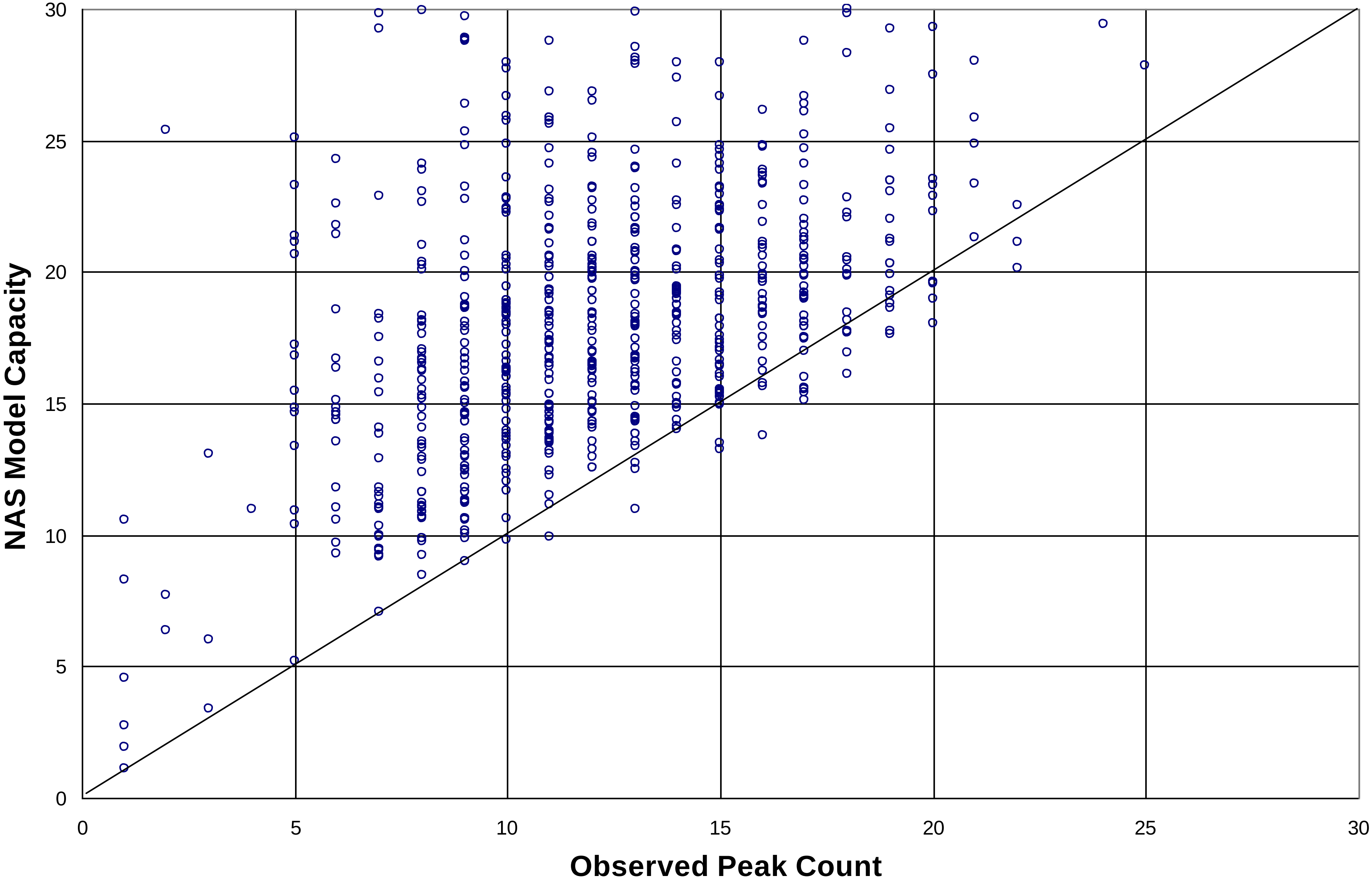


Fitted Capacities versus Peak Counts

(790 NAS Sectors July – August 2007)



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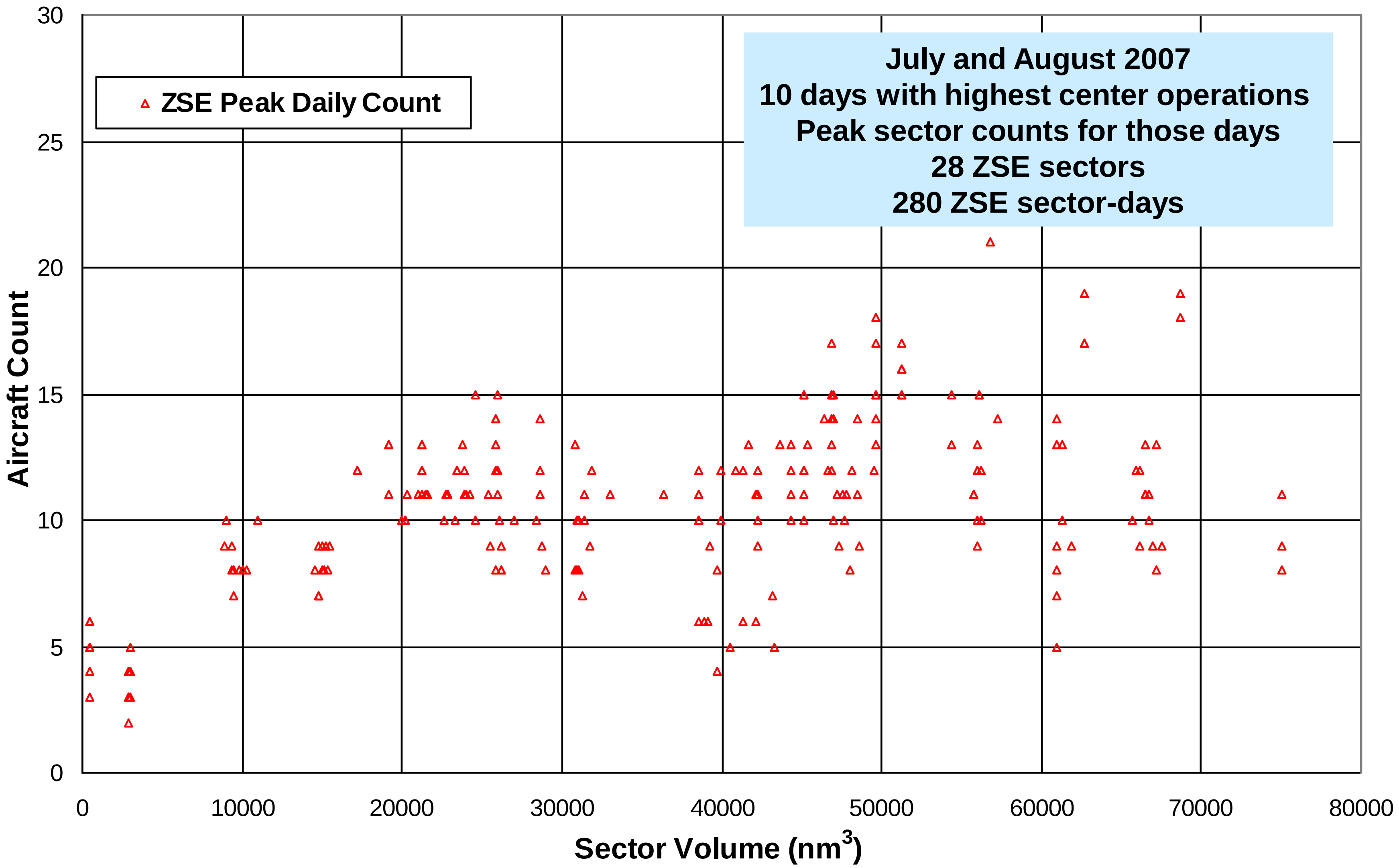
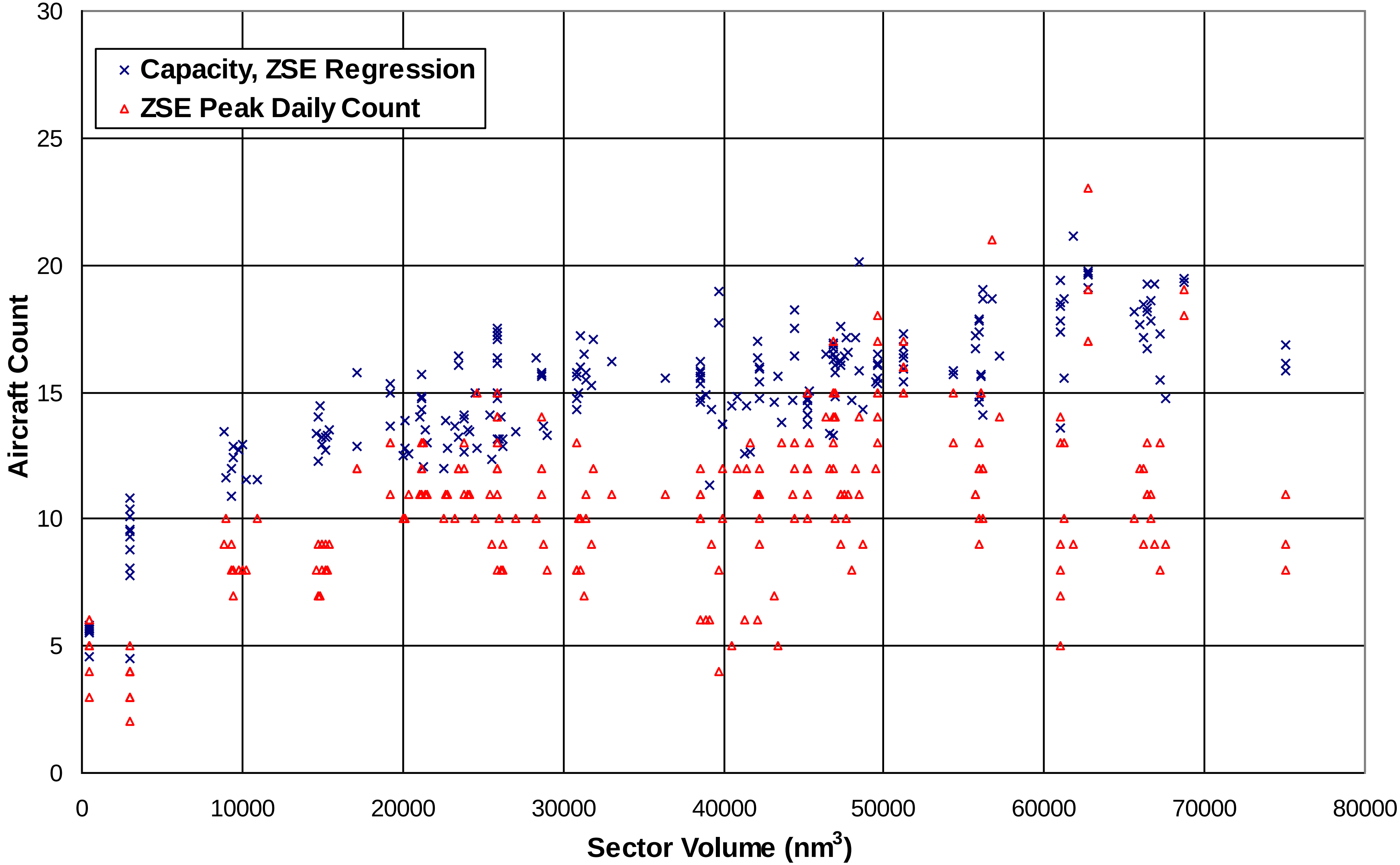
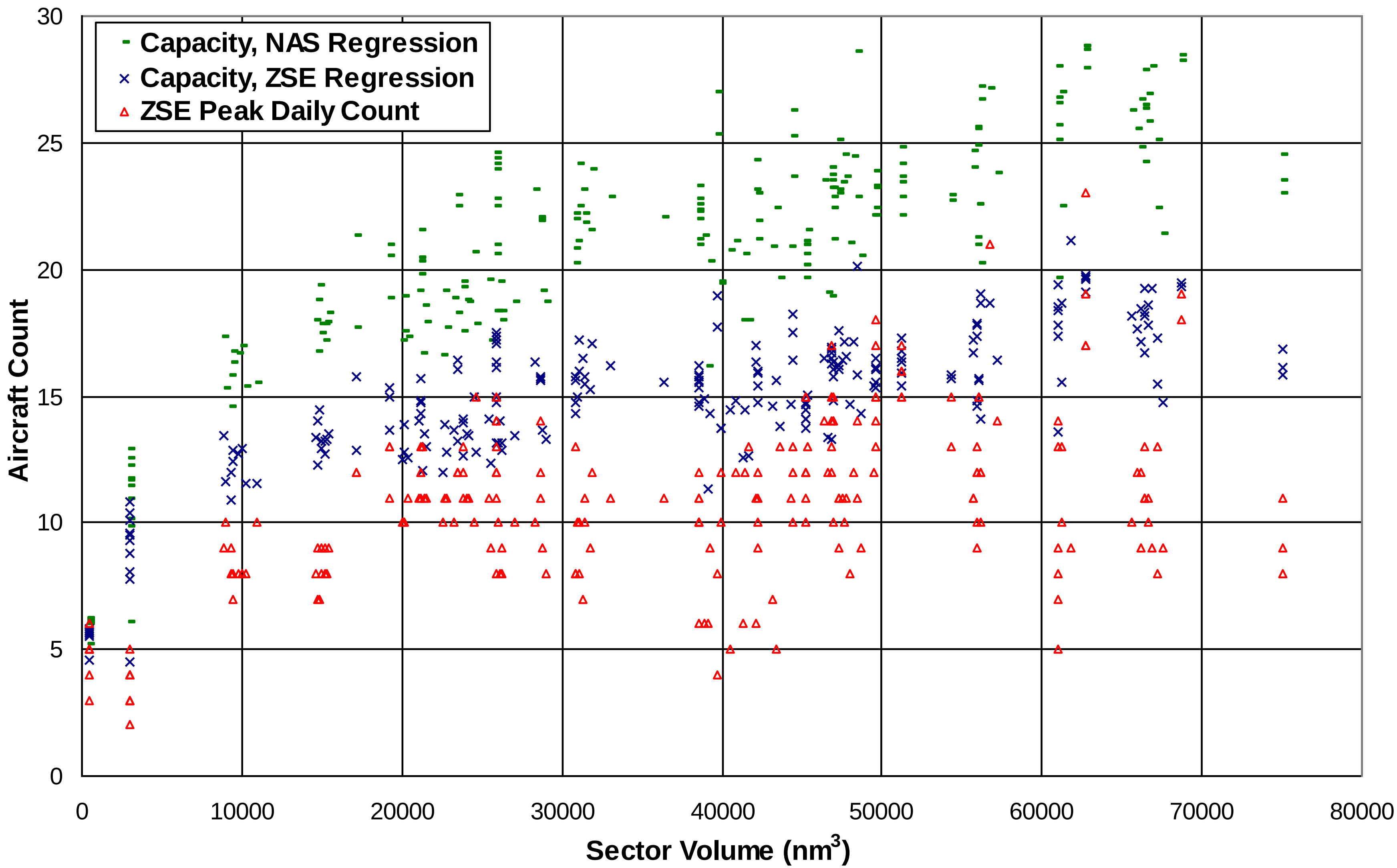
Peak Sector Counts, Seattle Center (ZSE)



ZSE Sector Capacity from ZSE Regression



ZSE Sector Capacity from NAS Regression



Normalized Capacity Density

- **Local center capacities differ significantly**
- **Meaningful capacity comparisons must normalize for**
  - **center size**
  - **sector count**

Normalized capacity density

$$K_{NC} = \Sigma_{CS} / Q_Z / N_S$$

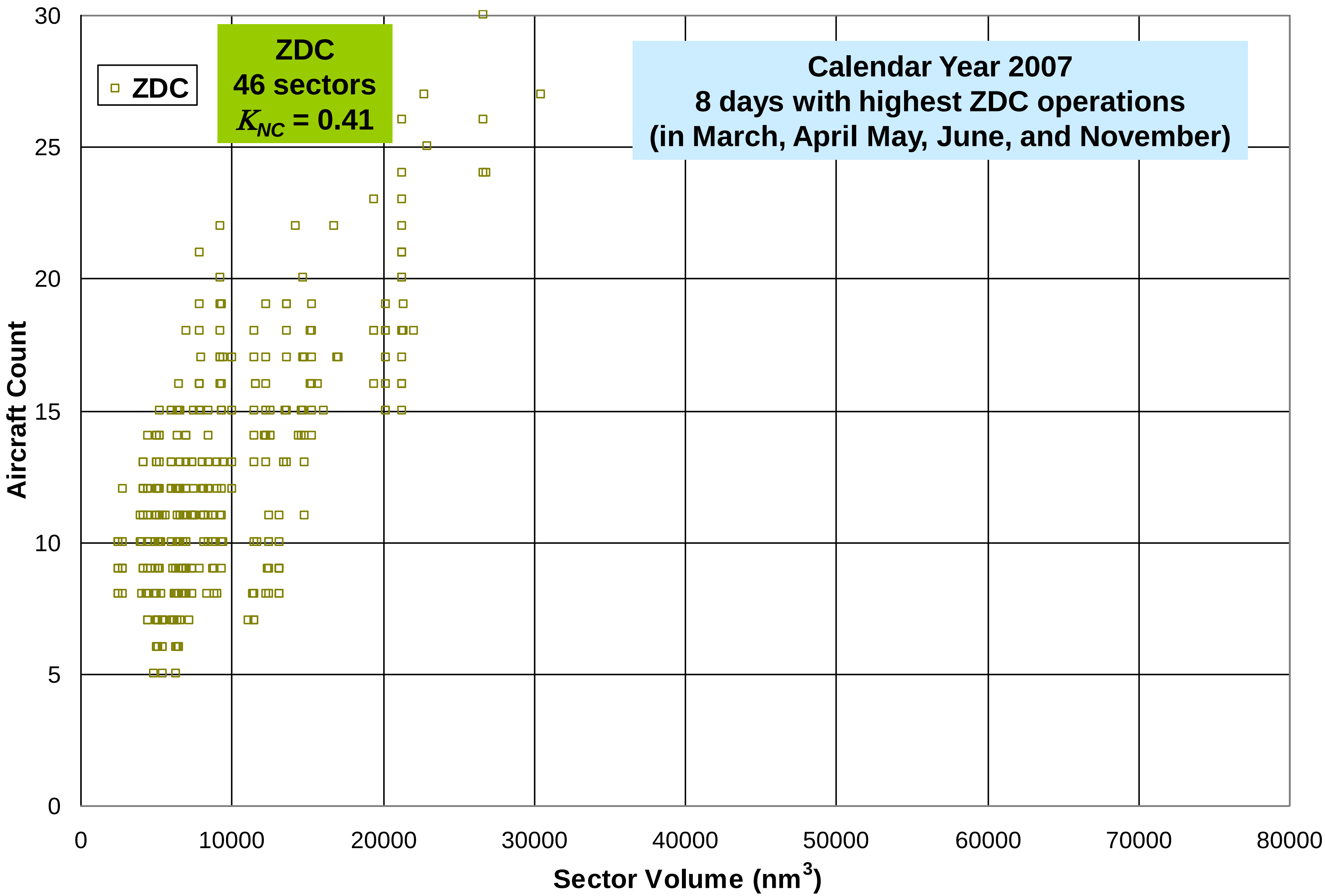
Σ_{CS} **= Sum of local capacities of all sectors**

Q_Z **= Center airspace volume (10,000 nmi^3)**

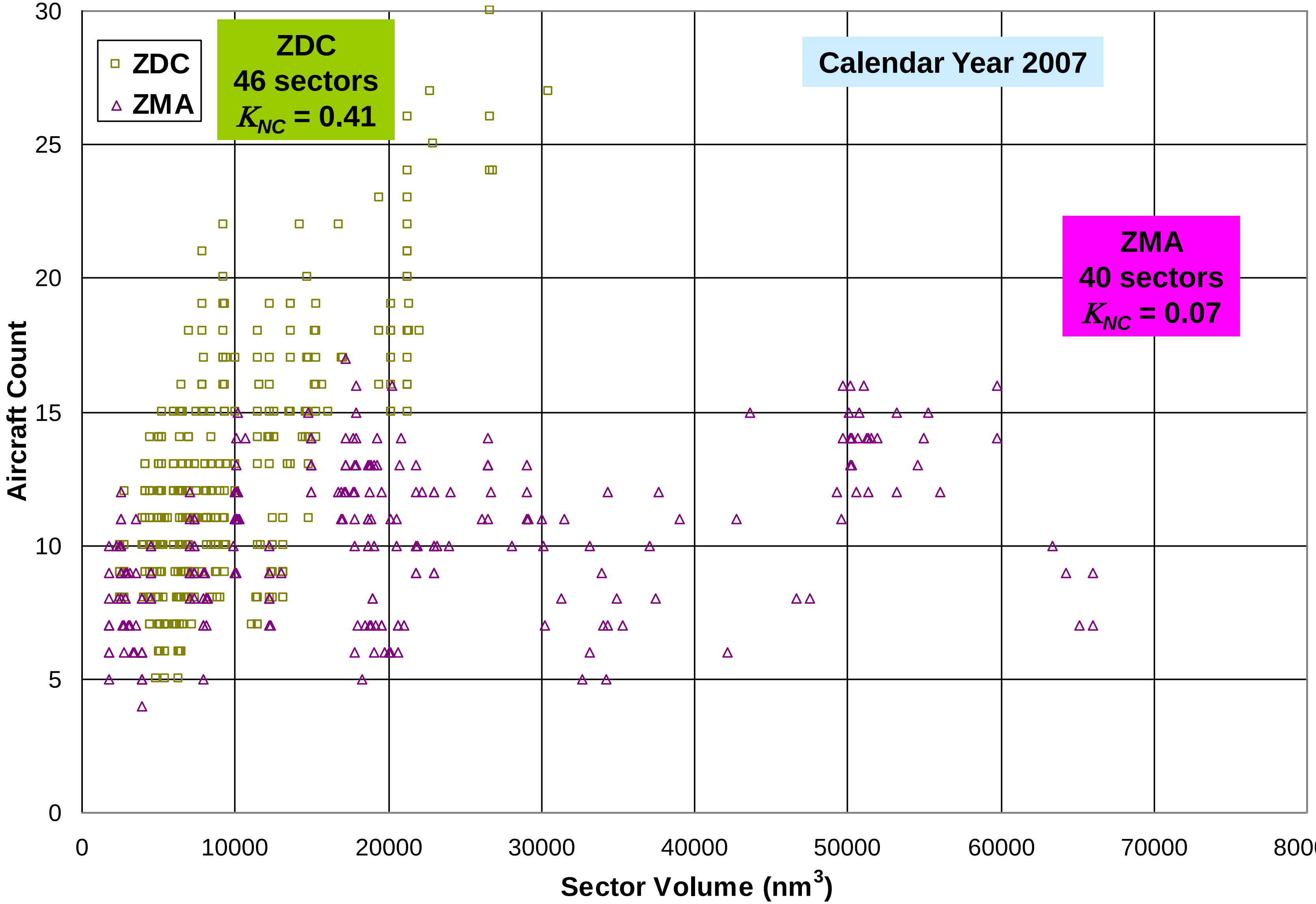
N_S **= Sector count**

(K_{NC} for Seattle is 0.11 aircraft per 10,000 nmi^3)

Peak Counts
Washington DC Center

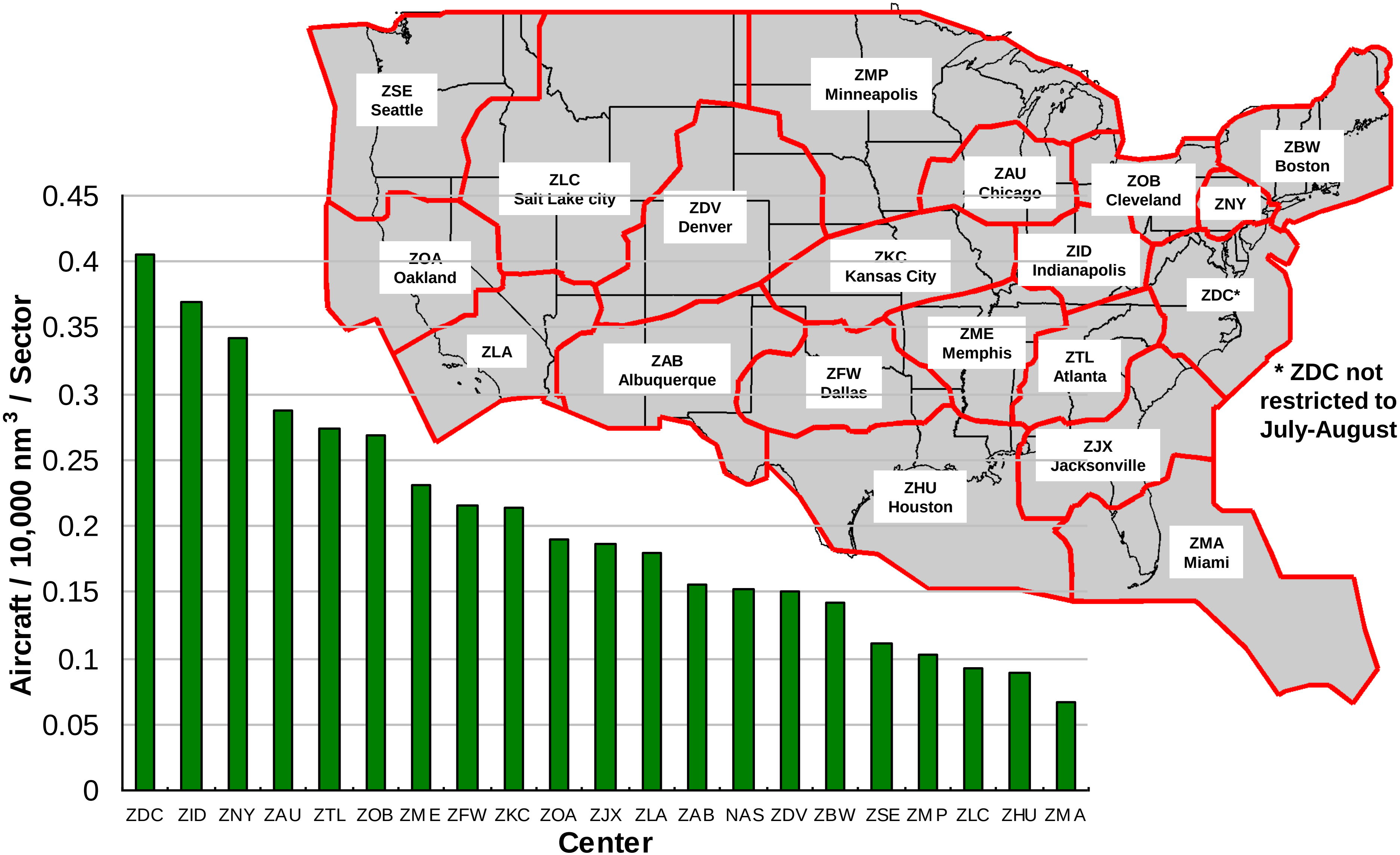


Peak Counts
Washington DC and Miami Centers



Normalized Capacity Density

NAS En Route Centers (July – August 2007)



Equation for NAS Sector Capacity

Sector Capacity

$$N_m = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

where

- a = 5.4(1+0.6 F_{ca})/Q, b = (a + 0.013 + 13/T), c = -0.7
- F_{ca} = fraction of daily sector flights with ≥2000 ft altitude change
- Q (nm^3) = sector volume based on min and max daily altitudes
- T (s) = mean transit time for aircraft in sector at time of peak

Conclusions

- NAS regression provides inherent sector capacity
- Individual center regressions provide local sector capacity
  - can be significantly less than inherent capacity
- Peak count data reflect wide range of
  - Complexity
  - Demand
  - Airspace characteristics
- Single set of capacity parameters cannot capture current operations
  - Individual center regressions necessary

- July - August 2007 peaks do not give peak demand for all Centers
  - Southern operations peak in winter
- We plan to refine capacity calculations
  - Choose actual peak demand periods for all centers
  - Increase data sets in all regressions

End