Airport Capacity Prediction Considering Weather Forecast Uncertainty

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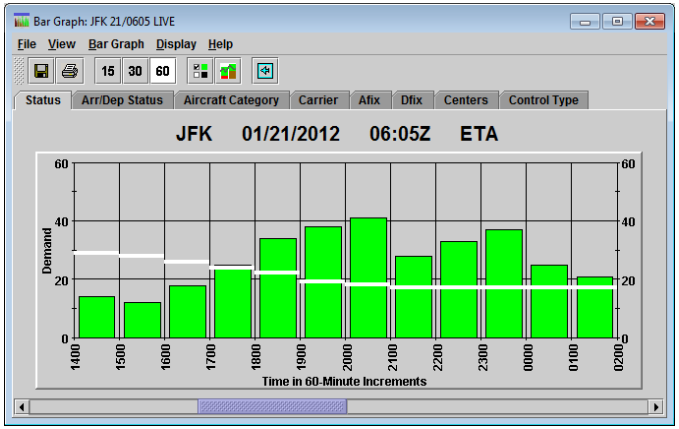
Objectives

- **Develop an analytical model that explicitly incorporates weather forecasts, and their uncertainty, in estimating airport capacity**
  - Focus on providing decision support for strategic Air Traffic Flow Management (ATFM) planning and long-term probabilistic effects

- **Validate probabilistic airport capacity predictions against actual arrival and departure throughput**

- **Investigate the impact of different methods of representing weather uncertainty on airport capacity predictions**



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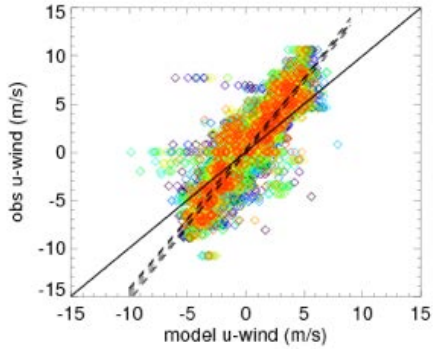
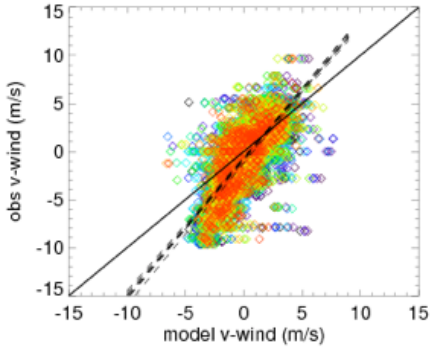
Weather Uncertainty Representation

- **Statistical error modeling**
  - Empirical parameter fitting for wind, ceiling & visibility by airport



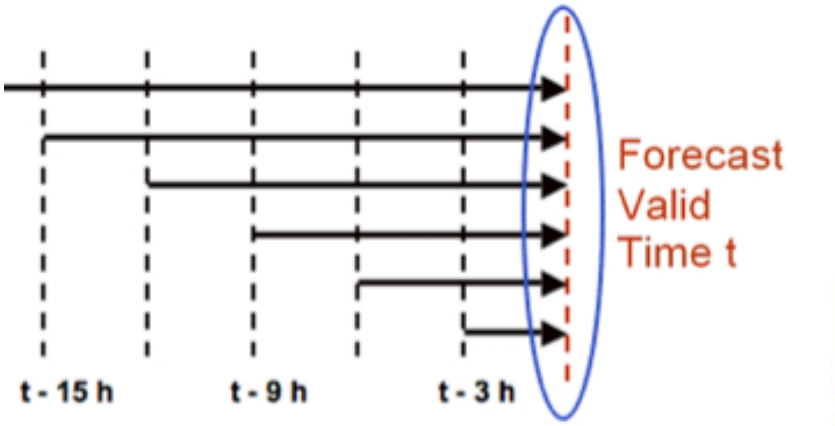


$$U_c = \alpha_u(a,\tau)U_{raw} + \beta_u(a,\tau)$$

$$V_c = \alpha_v(a,\tau)V_{raw} + \beta_v(a,\tau)$$

	March 2011				August 2011			
Airport	α_u	β_u	α_v	β_v	α_u	β_u	α_v	β_v
ATL	0.3	1.5	-0.7	1.5	-0.1	1.4	-0.8	1.1
DFW	0.1	1.1	0.1	1.4	0.0	0.7	2.0	0.7
ORD	-0.7	1.4	-0.9	1.4	0.1	1.3	-0.2	1.3
DEN	-0.3	1.1	0.3	1.0	0.9	0.7	0.4	0.8
	October 2011				**December 2011**			
Airport	α_u	β_u	α_v	β_v	α_u	β_u	α_v	β_v
ATL	-0.2	1.4	-0.1	1.4	-0.1	1.5	-0.3	1.5
DFW	0.0	1.1	0.0	1.3	0.3	1.3	-0.4	1.3
ORD	-0.2	1.4	-0.1	1.4	0.2	1.5	-0.2	1.5
DEN	0.5	1.0	0.7	1.3	0.4	1.2	0.2	1.4

- **Time-lagged HRRR**
  - o With or without spatial filtering (latter provides for smoother PDFs)



Integrated Airport Capacity Model (IACM)

Ensemble Weather Forecasts
- Ceiling & Visibility
- Surface Winds
- Precipitation & Echo Tops

Predicted Demand
- Hourly Arrival & Departure Counts
- Aircraft Types

Integrated Airport Capacity Model (IACM)

Terminal Capacity Model (TCM)

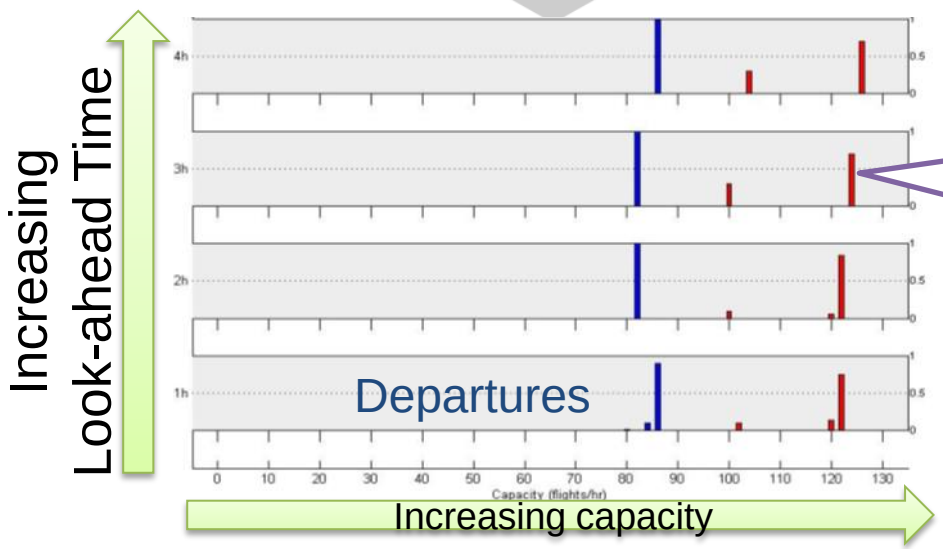
Airfield Capacity Model (ACM)

Runway Configuration Estimator (RCE) ⇔ Runway Capacity Model (RCM)

Multi-criteria Capacity Forecast Integrator (MCFI)

Airport Adaptation
- Layout and Geometry
- Runway Configurations
- Runway Occupancy Times
- Approach Speeds

Operational Standards & Procedures
- Arrival and Departure Separations
- Ceiling and Visibility Thresholds
- Wake Vortex Separations
- Crosswind and Tailwind Thresholds



The height of each bar represents an estimated probability of achieving this capacity value

STAR

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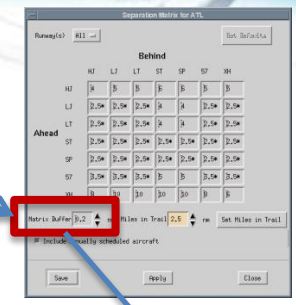
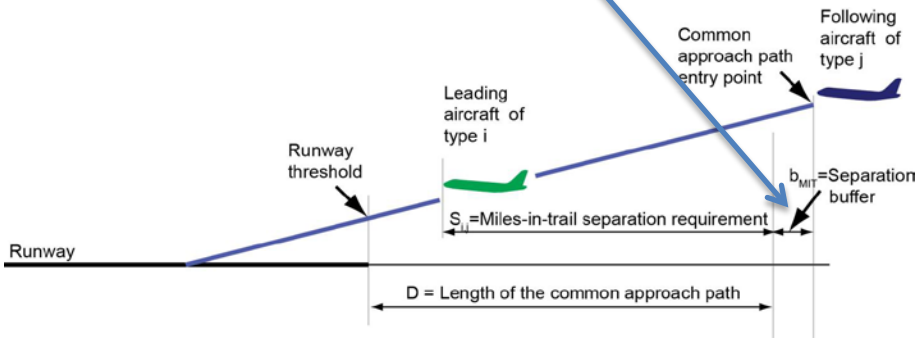
Sensitivity Analysis and Validation Studies

- **Parameters studied:**
  - Final approach separation buffer b_{MIT}
  - Separation buffer for departure release b_{REL}
  - Separation buffer for consecutive departure release b_{DEP}
- **ASPM arrival and departure counts**
- **Types of weather inputs**
  - METAR observations
  - Deterministic forecasts
  - Deterministic forecast and forecast error models (Monte Carlo)
  - Ensemble forecasts (time-lagged HRRR)
- **Scatterplots and Theil inequality coefficients based on IACM outputs**
  - Grouped by operation type (arrivals and departures)
  - Grouped by airport meteorological conditions: Visual Meteorological Conditions (VMC), Marginal VMC (MVMC), and Instrument Meteorological Conditions (IMC)

TMA "matrix buffer" settings at ATL





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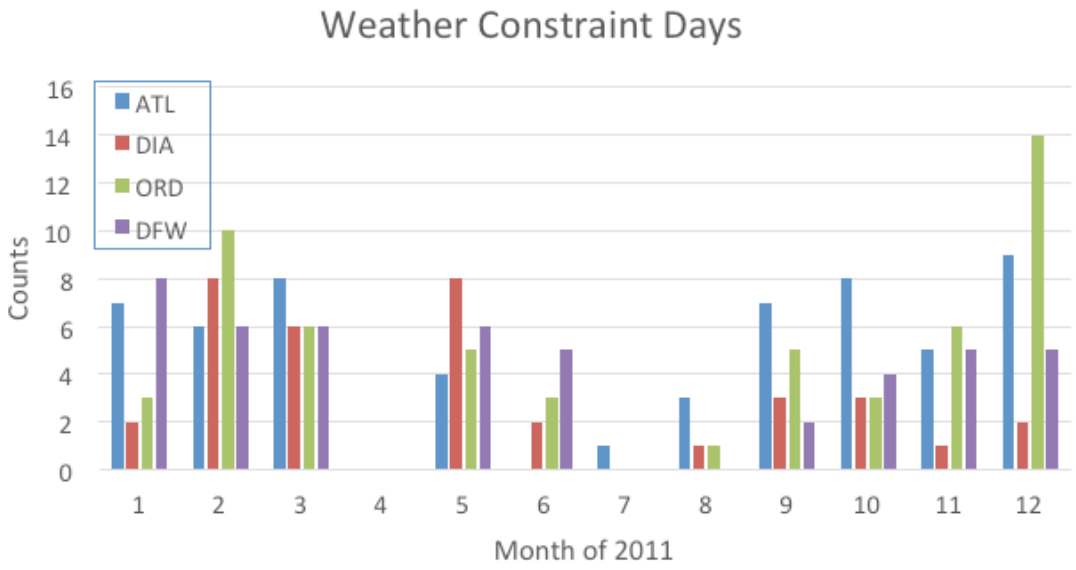
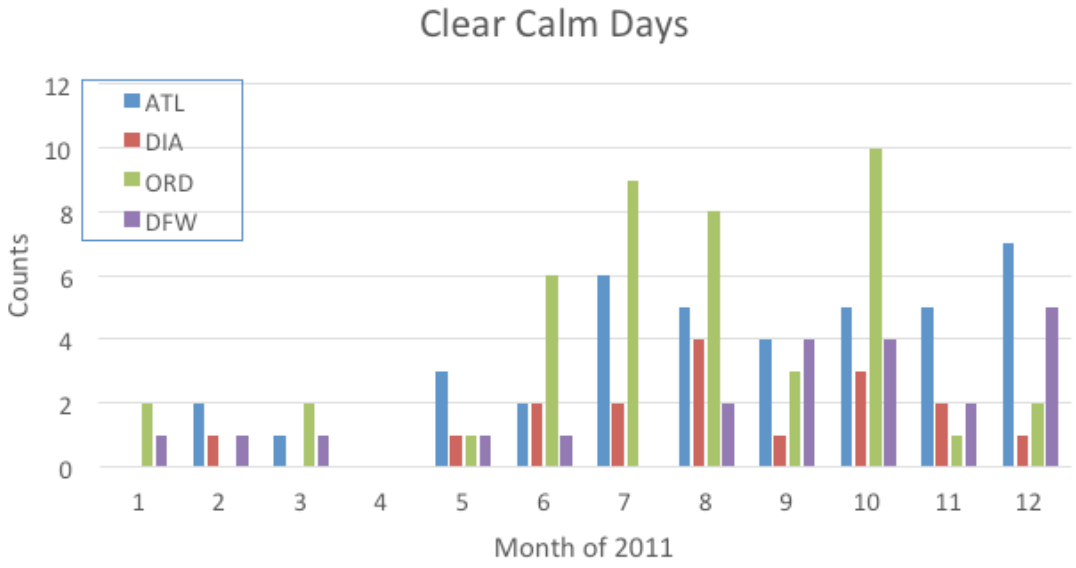
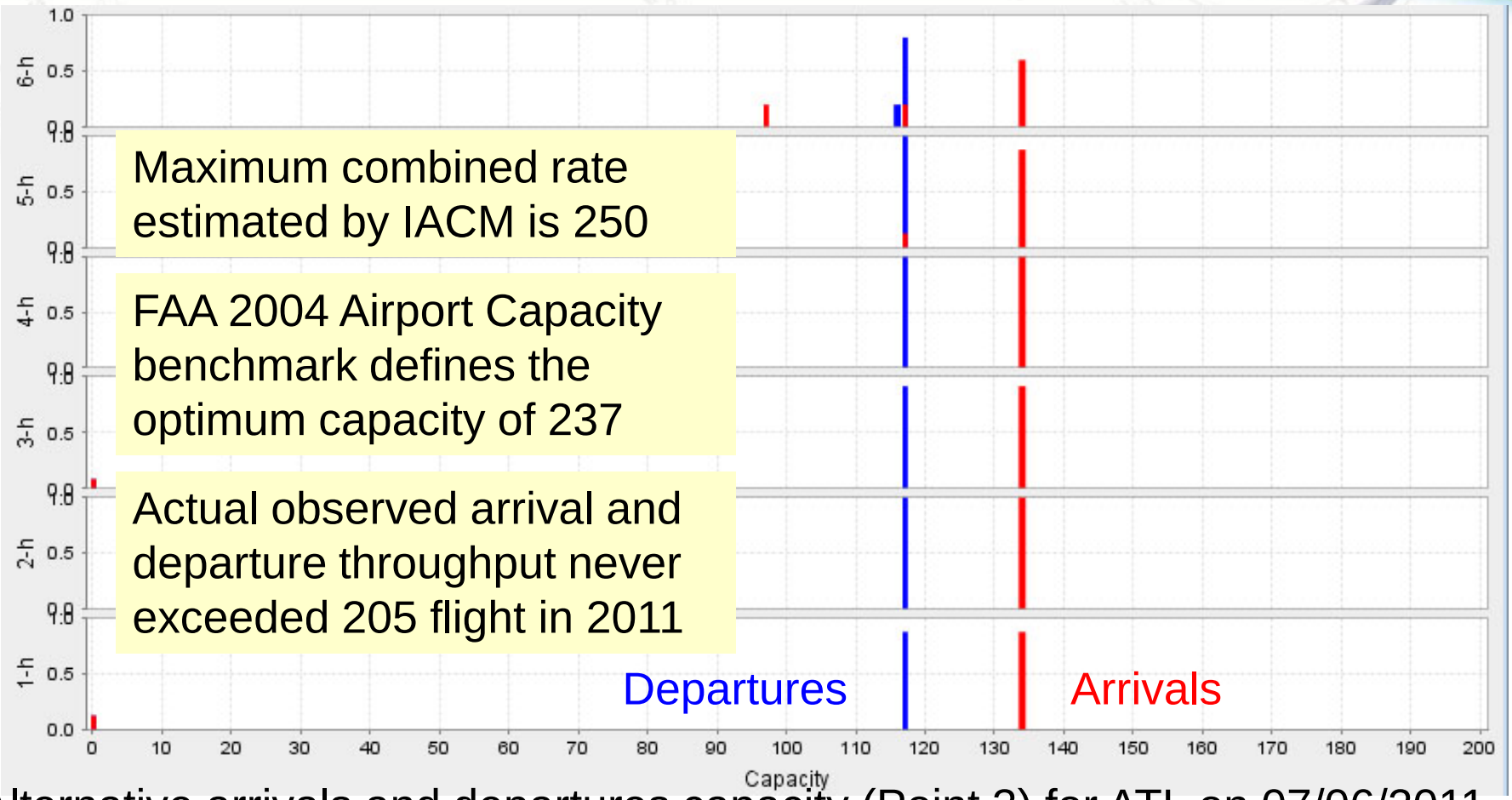
Weather Days

- **Selection of Days**
  - Representative cases for IACM simulations
  - Multiple airports & seasons
- **Weather Constraints**
  - Seasonal variation
    - Low in summer
    - High in fall & winter
  - Geographical variation
    - ORD high in Feb & Dec
- **Clear & Calm Days**
  - Seasonal variation
    - High in summer & fall
  - Geographical variation
    - ORD high in Jul, Aug & Oct





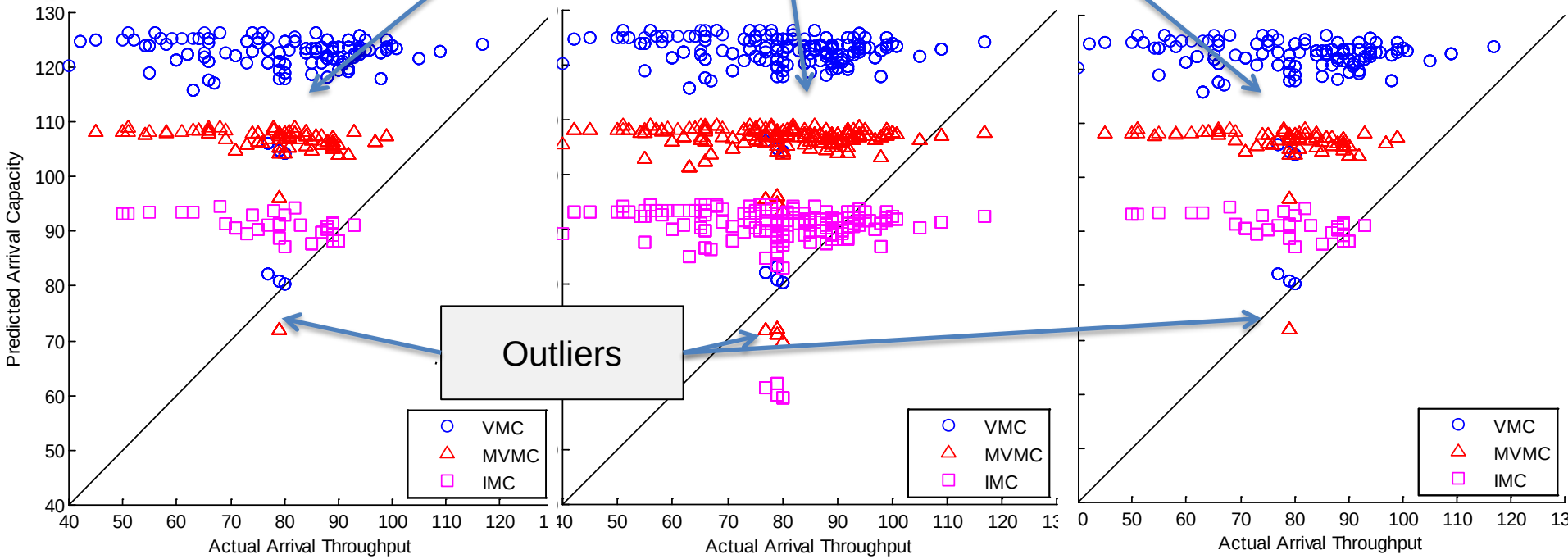
Qualitative Validation



Alternative arrivals and departures capacity (Point 3) for ATL on 07/06/2011 11:00Z for runway configuration 26R 27L 28 | 26L 27R 28

Qualitative Validation Cont.

Stratification due to meteorological conditions



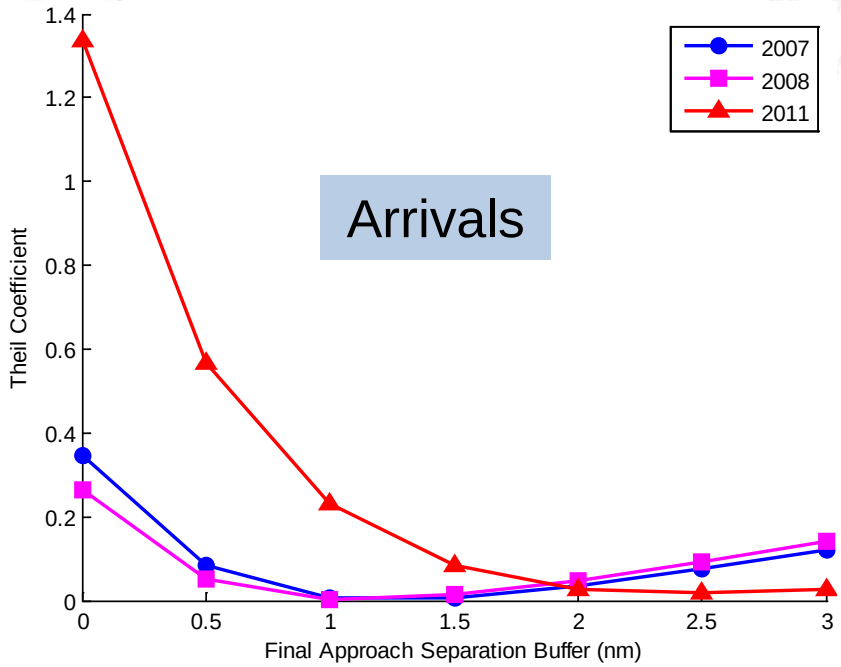
Outliers

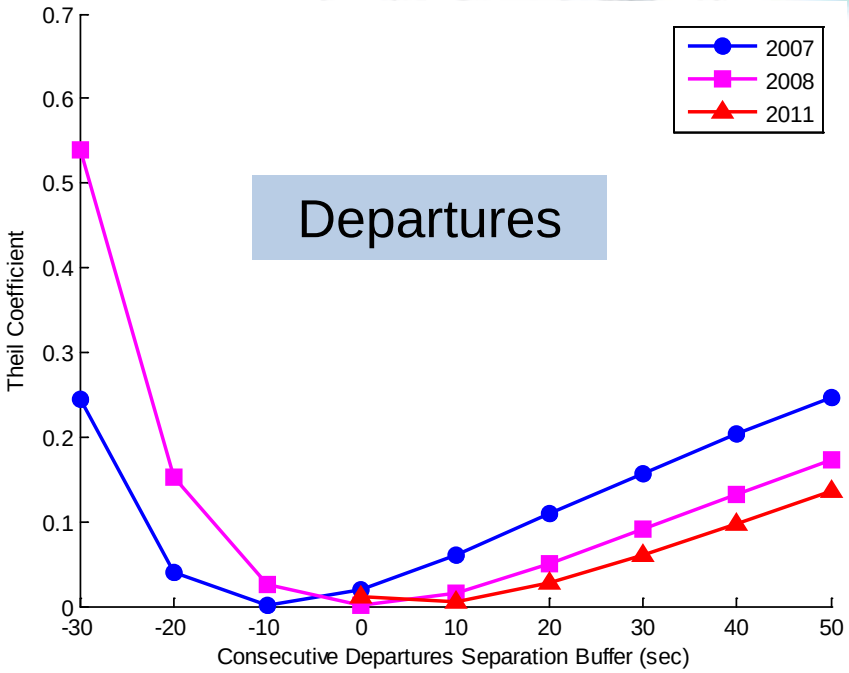
Deterministic

Forecast Error Models

Ensemble

Sensitivity Analysis

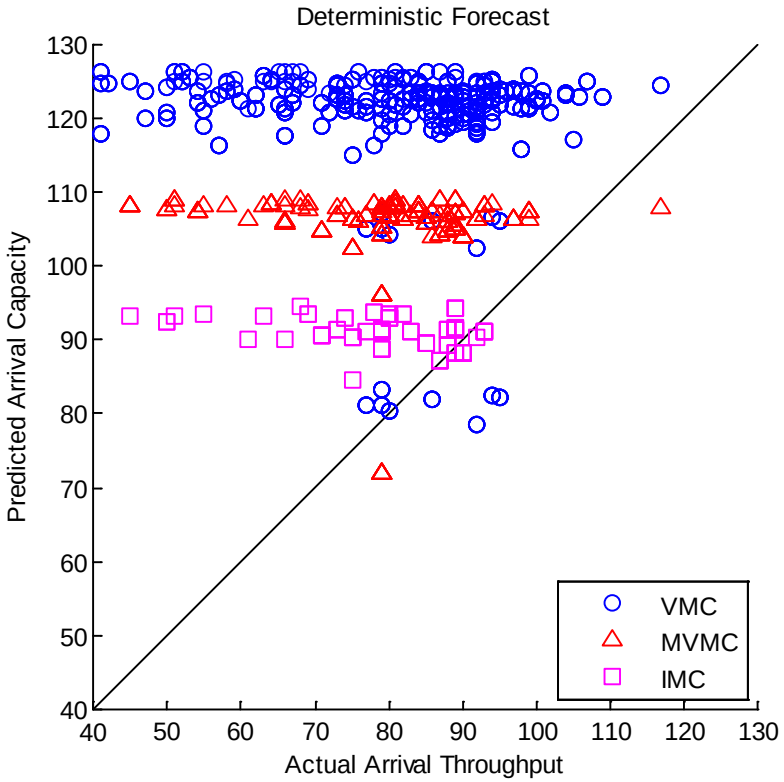




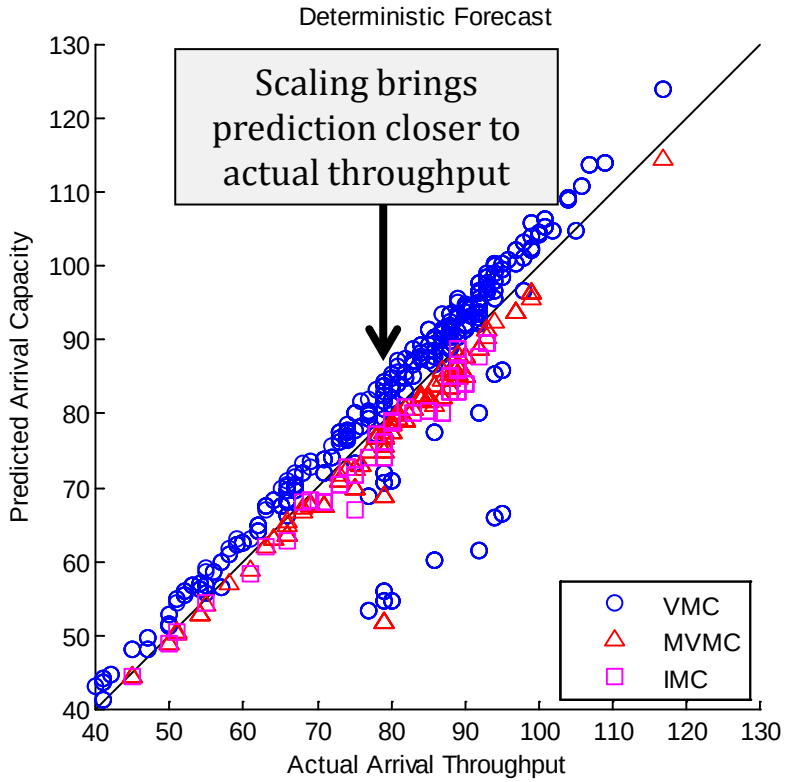
The impact of the final approach separation buffer b_{MIT} (left) and separation buffer for consecutive departure release b_{DEP} on the accuracy of arrival and departure capacity predictions for VMC conditions

Validation with Scaled 2011 Demand

- **Determine ratio of current demand to baseline demand**
  - Use mean of 2007 & 2008 demand as baseline
- **Multiply computed prediction with ratio to get scaled prediction**



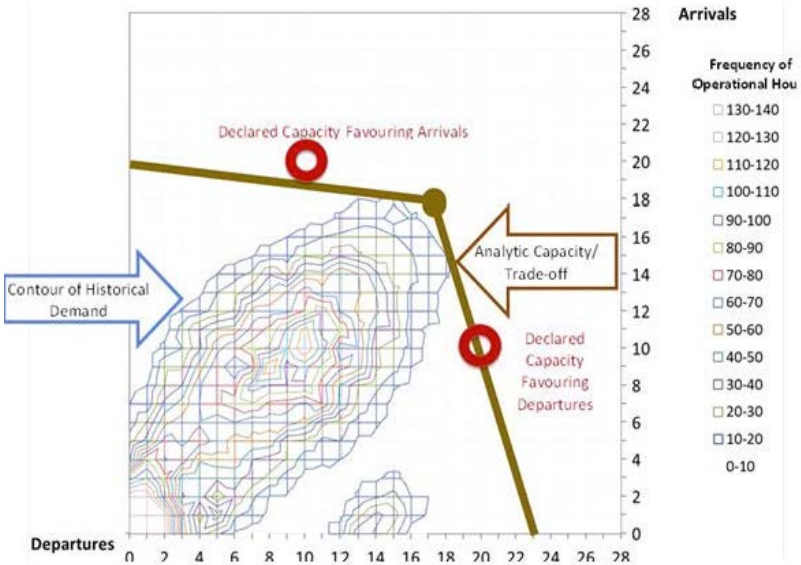
Unscaled prediction



Scaled prediction

Conclusions

- **IACM explicitly integrates weather information and its uncertainty to estimate airport capacity**
- **It supports various types of weather inputs and operational constraints**
- **Validation study performed to evaluate predicted accuracy of IACM for ATL**
- **Validation results and operational feedback indicate that IACM produces fairly accurate predictions of theoretical maximum airport capacity**



IACM has also been used to support Airside Capacity Enhancement study for several South African airports

Future Research

- Extending the set of supported airport to the Core 30 airports
- Developing web interface for real-time airport capacity prediction
- Enhancing the analytical models for airports with complex runway geometries
- Integrating Terminal Capacity Model with Airfield Capacity Model to predict convective weather impact on terminal airspace/corner posts

Backup slides

Theil Statistics

- **Quantify airport capacity prediction accuracy using Theil inequality coefficient:**

$$T = \frac{\sum_i (P_i - A_i)^2}{\sum_i A_i^2}$$

- **It can be decomposed into 3 components:**
  - Bias or error in central tendency T_m

$$T_m = \frac{(\bar{P} - \bar{A})^2}{\frac{1}{n}\sum_i^n (P_i - A_i)^2}$$

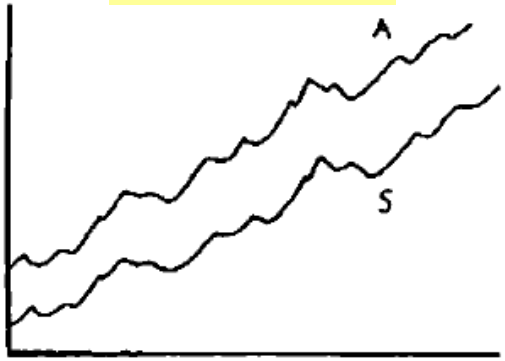
  - Unequal variation T_s

$$T_s = \frac{(s_P - s_A)^2}{\frac{1}{n}\sum_i^n (P_i - A_i)^2}$$

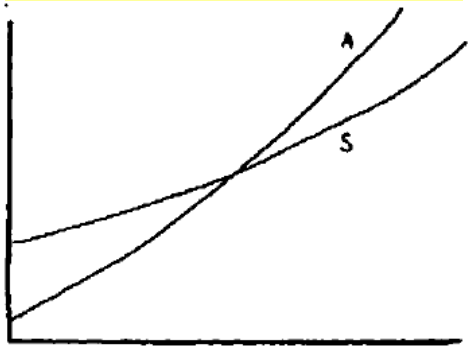
  - Incomplete covariation T_c

$$T_c = \frac{2(1 - r)s_P s_A}{\frac{1}{n}\sum_i^n (P_i - A_i)^2}$$

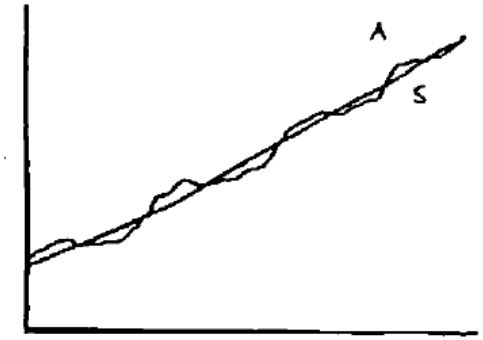
Bias



Unequal Variation



Incomplete Covariation



Source: (Sterman 1984)