# *Classification of Weather Translation Models for NextGen*
## *Jimmy Krozel, Ph.D., Rafal Kicinger, Ph.D., and Mark Andrews*
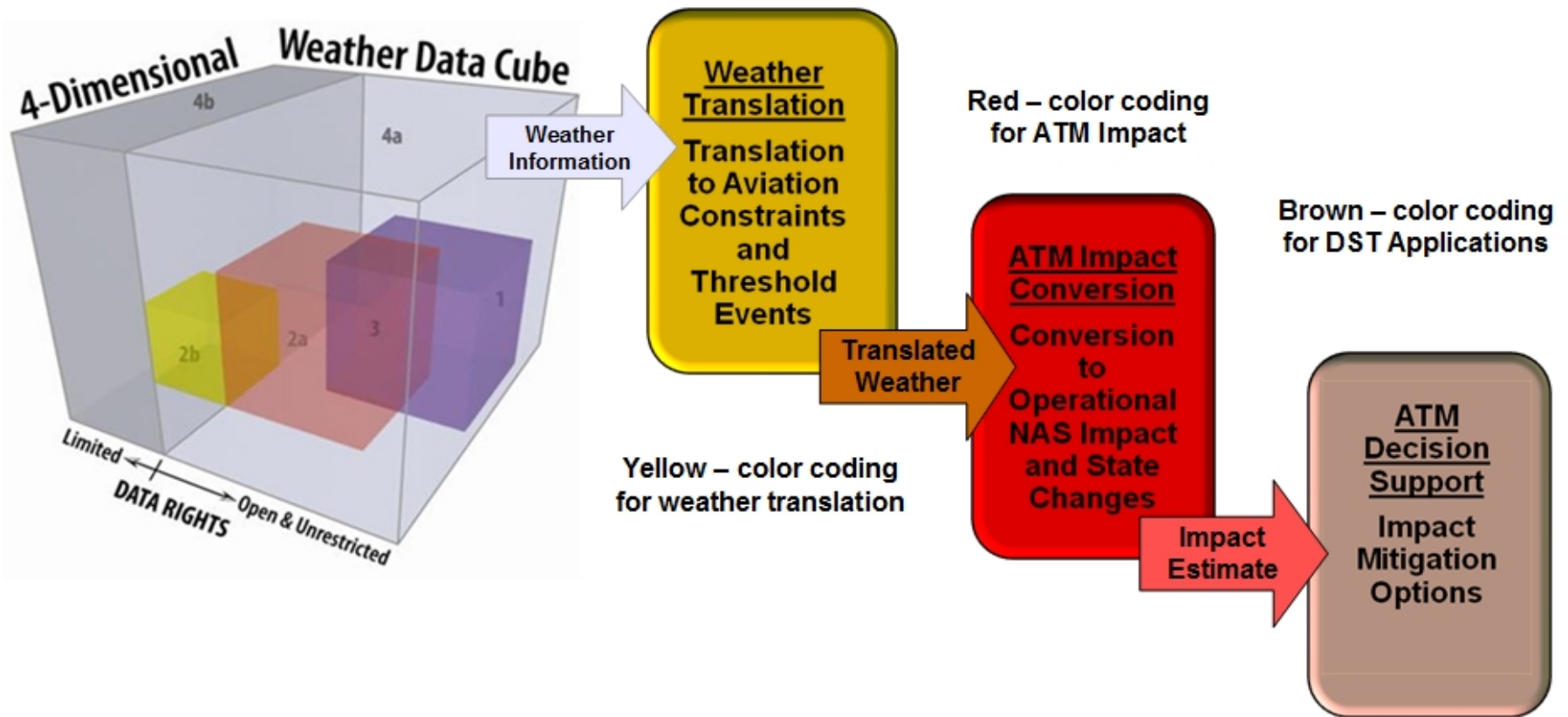### *15th Conf. on Aviation, Range & Aerospace Meteorology*

**Aug. 3, 2011 – Los Angeles, CA**

# List of Acronyms

| | |
|---|---|
| **ATC** | **Air Traffic Control** |
| **ATM** | **Air Traffic Management** |
| **C&V** | **Ceiling and Visibility** |
| **CWAM** | **Convective Weather Avoidance Model** |
| **IFR** | **Instrument Flight Rules** |
| **MVFR** | **Marginal Visual Flight Rules** |
| **NAS** | **National Airspace System** |
| **NextGen** | **Next Generation Air Transportation System** |
| **VFR** | **Visual Flight Rules** |
| **WAF** | **Weather Avoidance Field** |

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# NextGen Weather Integration Concept



See: Bradford, S., Pace, D.J., Fronzak, M., Huberdeau, M., McKnight, C., and Wilhelm, G., "ATM-Weather Integration and Translation Model," *Second Aviation, Range and Aerospace Meteorology Special Symposium on Weather-Air Traffic Management Integration,* AMS, Seattle, WA, Jan., 2011
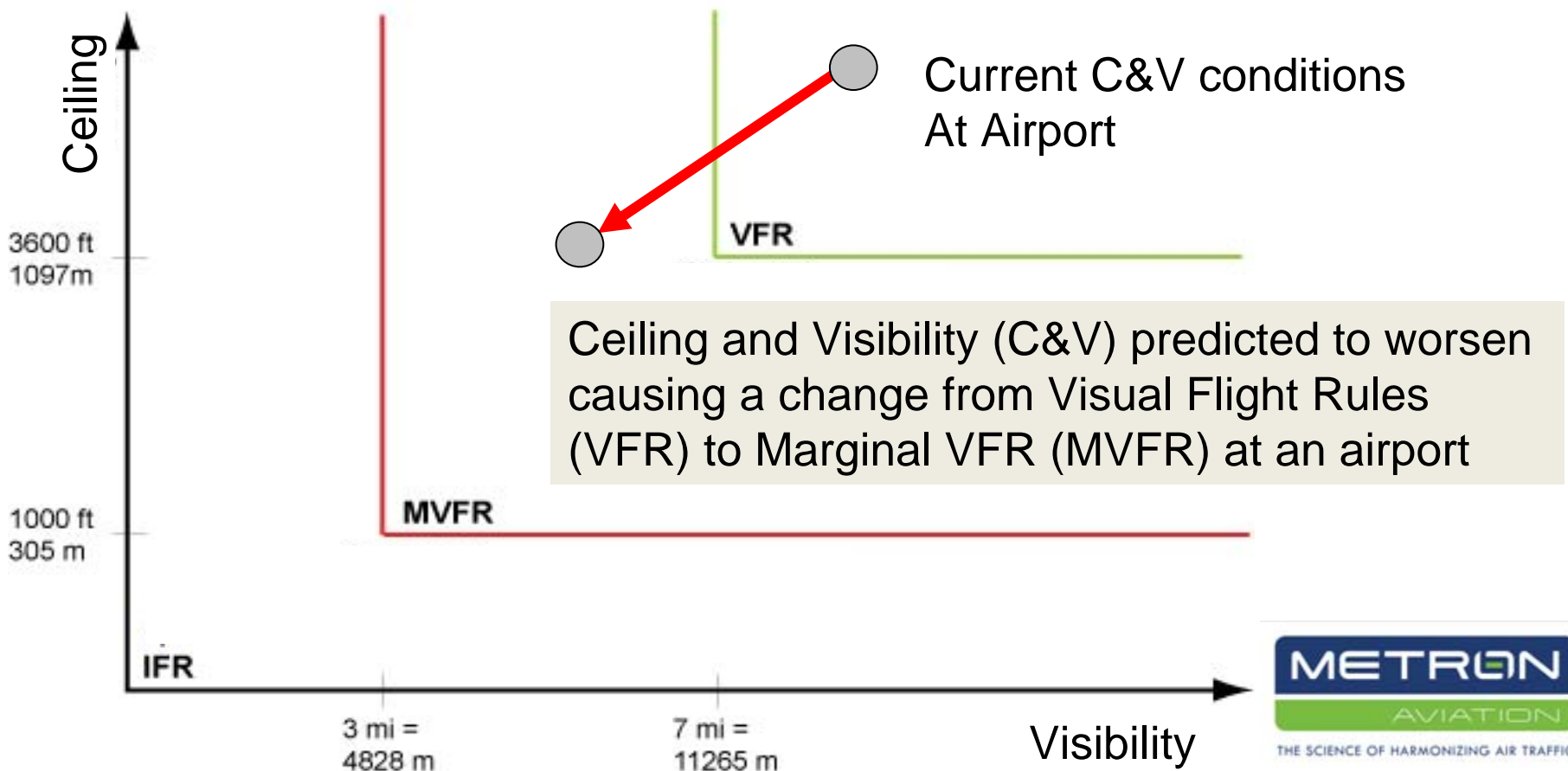
# What is a Weather Translation Model?

- **Weather translation models transform weather forecast data into:**

    - Characterizations of weather-related NAS constraints,
    - Threshold events, and
    - Expected resource performance characteristics

- **Independent of actual ATM operational state (actual system demand, Special Activity Airspace (SAA) schedule) and ATM application**

- **Does not account for ATC/ATM operational constraints (Flow Constrained Areas (FEAs), staffing, system outages)**

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# Types of Weather Translation Outputs
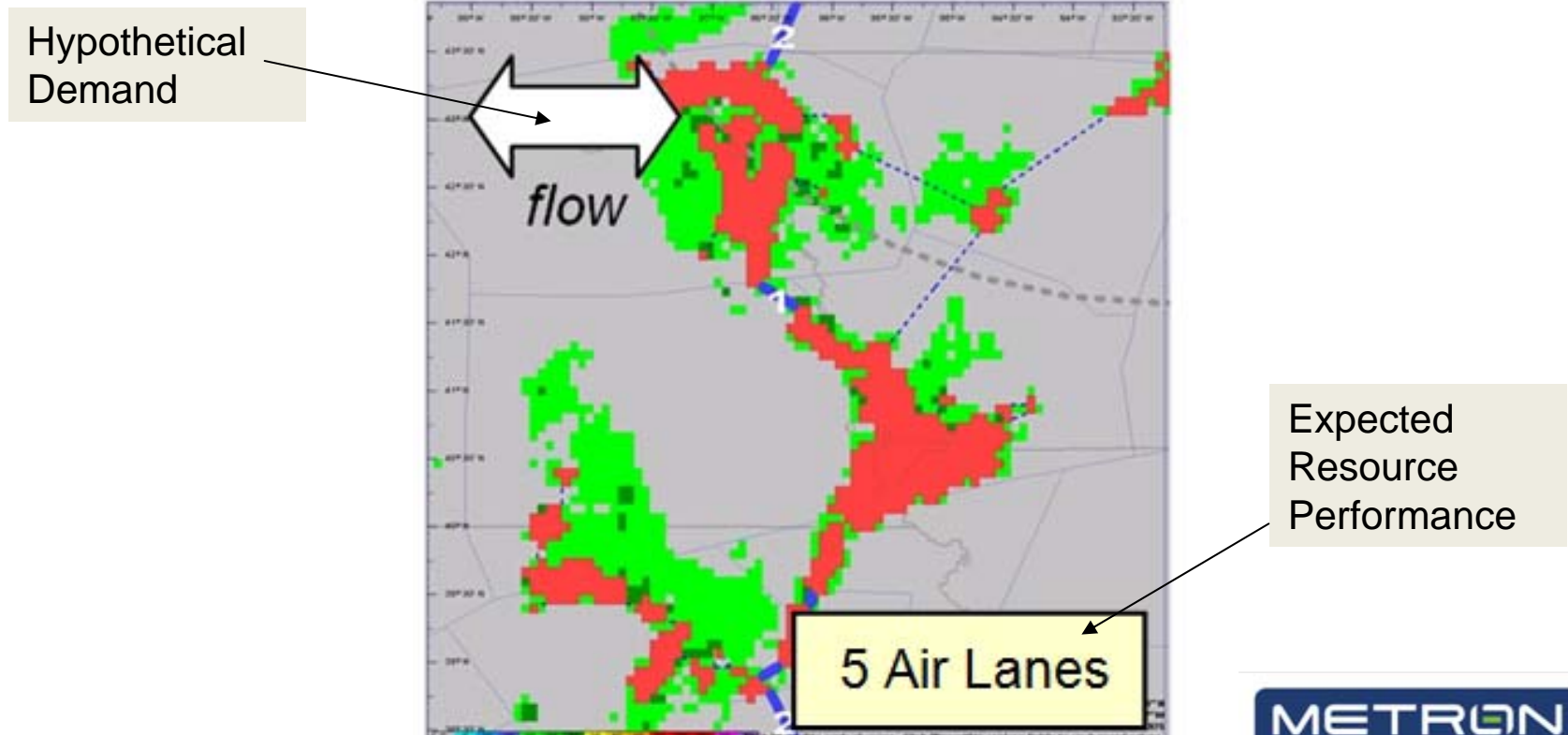
## Threshold Events

Non-hazardous atmospheric parameter crosses a regulatory or operational threshold and may result in an associated change in the state of the affected NAS element.



Current C&V conditions At Airport

Ceiling and Visibility (C&V) predicted to worsen causing a change from Visual Flight Rules (VFR) to Marginal VFR (MVFR) at an airport

# Types of Weather Translation Outputs

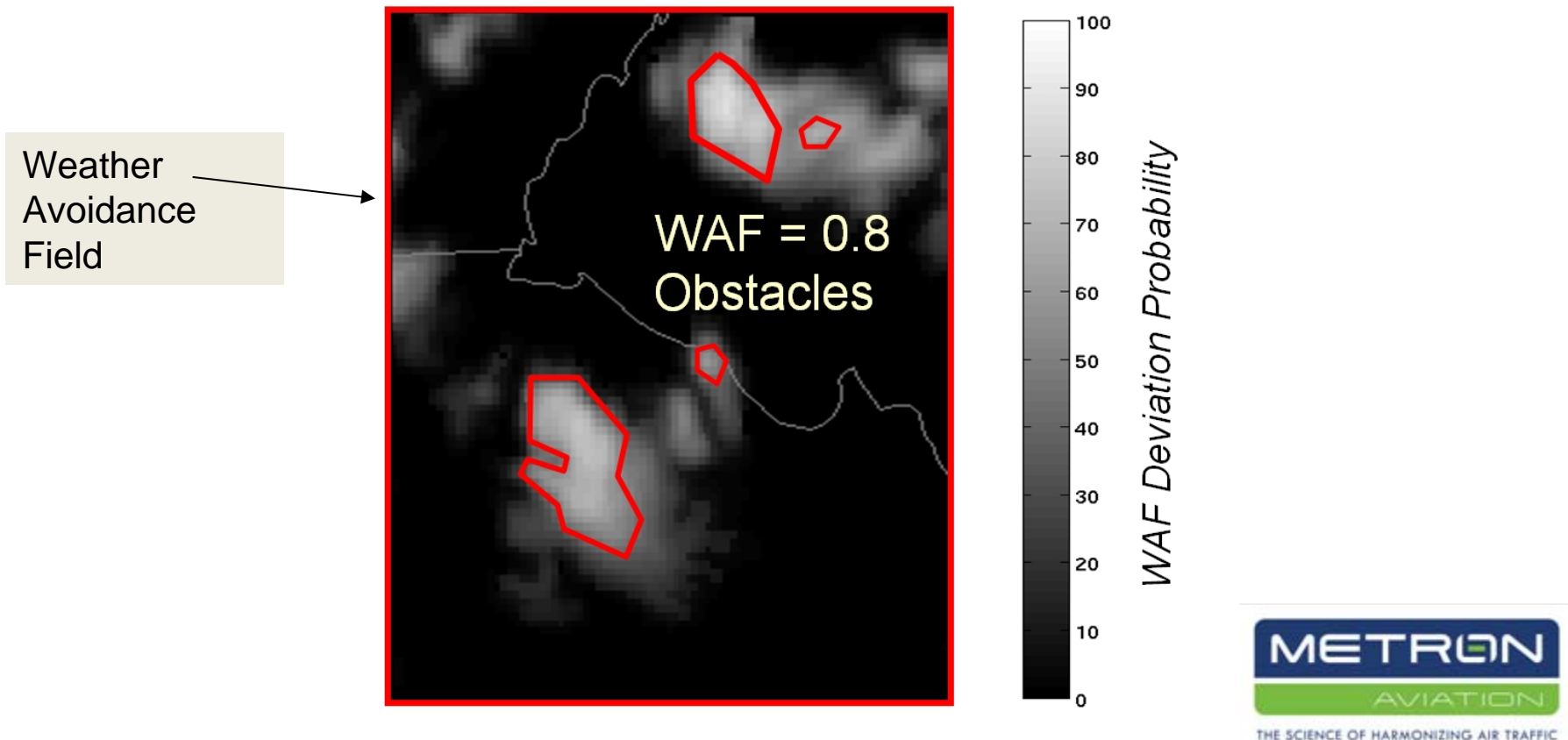**Expected Resource Performance**

Weather-impacted performance characteristics (e.g., capacity, permeability) of a NAS element <u>independent</u> of the ATM operational state and ATM application.

Hypothetical Demand

flow

Expected Resource Performance

5 Air Lanes

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# Types of Weather Translation Outputs

## Characterizations of Weather-Related NAS Constraints

Meteorological phenomena which are potentially hazardous to aircraft; Reflect the degree to which the weather hazard would constrain the affected NAS element; Expressed in non-meteorological terms and conveyed using representations such as avoidance fields.

Weather Avoidance Field

WAF = 0.8 Obstacles

WAF Deviation Probability

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# What is an ATM Impact Model?

- **Converts outputs from Weather Translation model(s) combined with the actual ATM operational state to produce:**
    - Resource performance estimates (e.g., capacities)
    - Characterizations of operational NAS constraints (e.g., NAS elements with identified demand-capacity imbalances)

- **Provides estimates of weather impact on resource performance considering actual demand and existing ATM operational constraints**

- **Provides Decision Support Tools (DSTs) with 4D representations of an airspace region with identified imbalances which will require some form of mitigation**
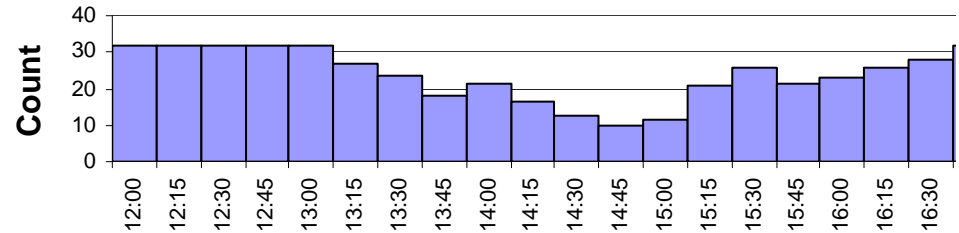
# Types of ATM Impact Conversion Outputs

## Resource Performance Estimates

An estimate of the operational performance (e.g., capacity) of a specified resource. It <u>depends</u> on a given ATM operational state and actual demand expected to use this resource.



Convective weather expected to impact ZAU75
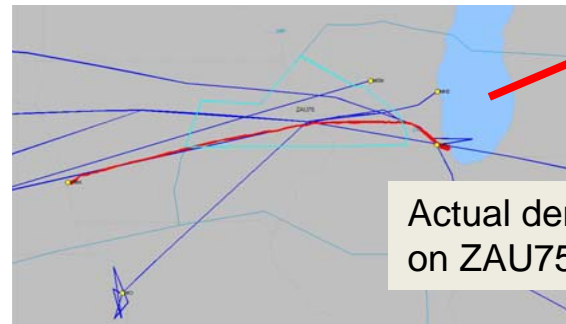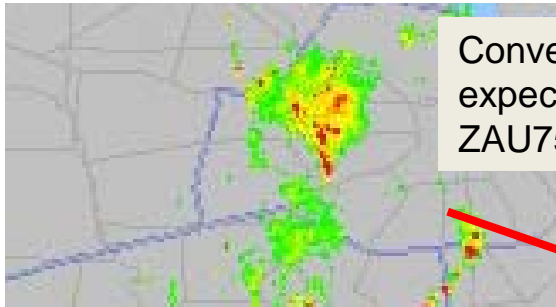
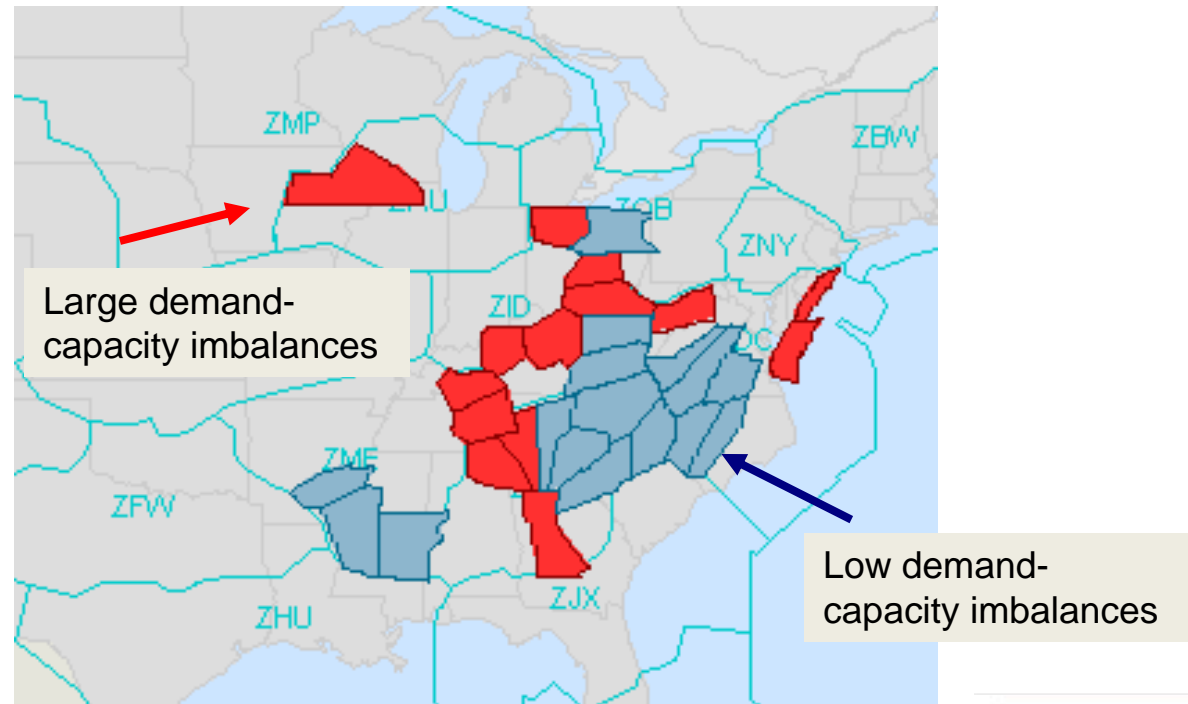ATM impact conversion models define ZAU75 capacity profile showing the impact of convective weather



Actual demand on ZAU75



**ZAU75 Time-based Performance Estimate**

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# Types of ATM Impact Conversion Outputs

## Operational NAS Constraints

Spatially and temporally relevant 4D representation of an airspace region in which actual demand is expected to exceed available airspace capacity. The degree to which demand exceeds capacity define the imbalance of the constraint.
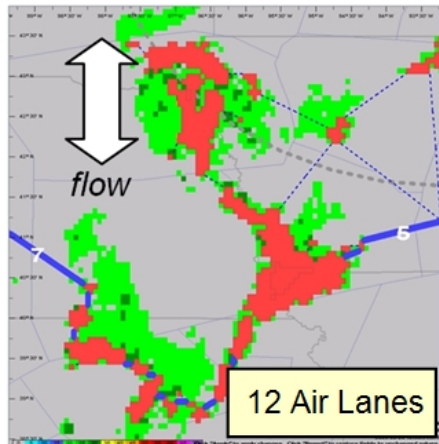
Identified operational NAS constraints as a result of convective weather impact.
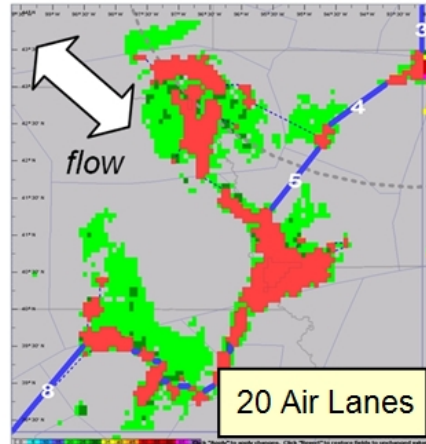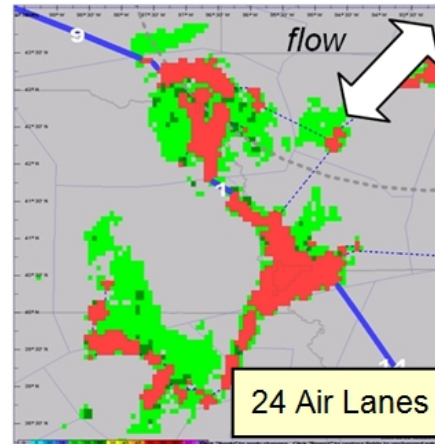
Large demand-capacity imbalances

Low demand-capacity imbalances

# Examples

# Directional Permeability



(a) North-South — 12 Air Lanes
(b) South-East — 20 Air Lanes
(c) North-East — 24 Air Lanes
(d) East-West — 5 Air Lanes
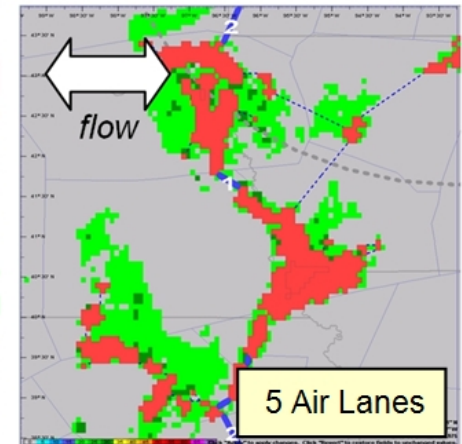
- **Airspace Permeability –** determines the throughput of an airspace, given a definition of a weather hazard and requirements for safe passage of traffic through the airspace.
- Airspace permeability is a property of the weather hazards, and not dependent on pilot or controller workload limits or ATM operational state
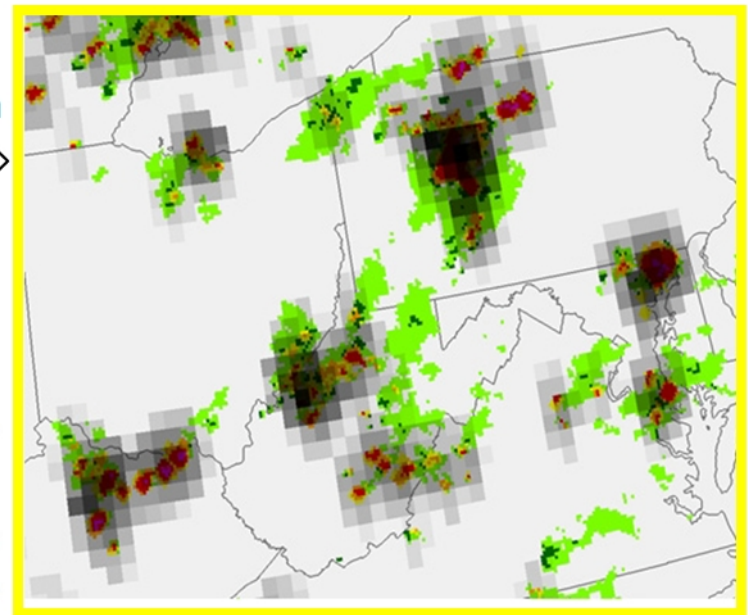
See: Zou, J., Krozel, J., Krozel, J., and Mitchell, J.S.B., "Two Methods for Computing Directional Capacity given Convective Weather Constraints," *AIAA Guidance, Navigation, and Control Conf.*, Chicago, IL, Aug., 2009.

# Directional Permeability Weather Translation Module



Weather Translation
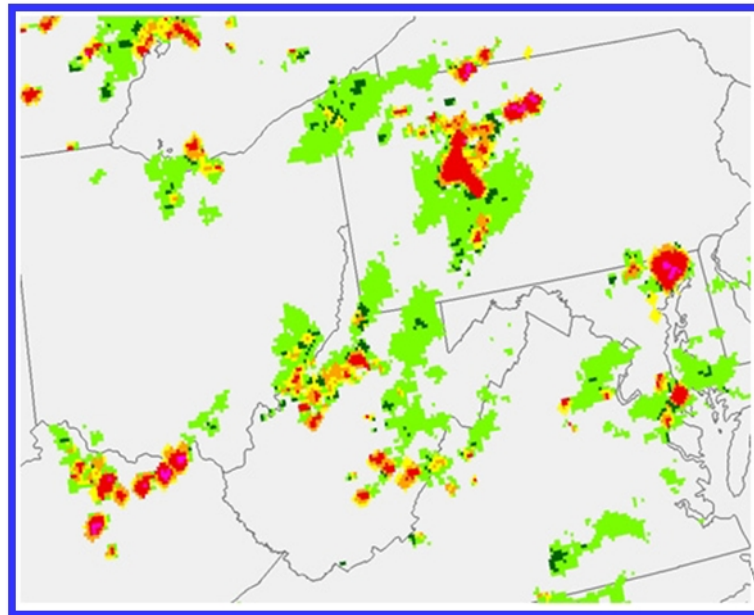
(a) Weather Forecast – information in standard weather units; useful for a wide variety of aviation as well as non-aviation applications
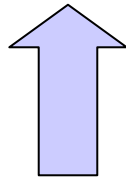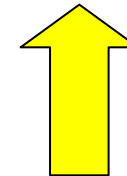
Capacity Reduction

0%
33%
66%
100%

(b) Expected Airspace Resource Performance – data overlays the weather forecast and displays information relevant to NAS operations
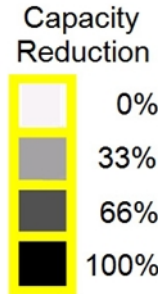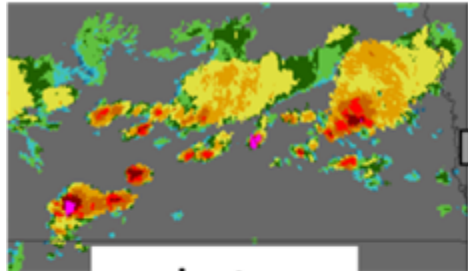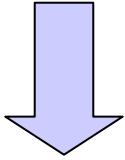
Weather Information
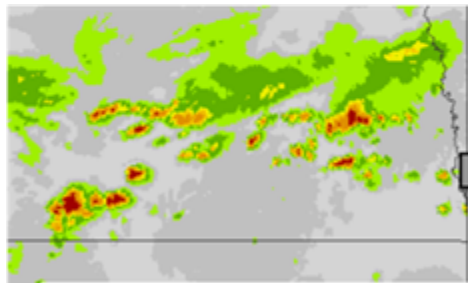
Weather Translation

See: Zou, J., Krozel, J., Krozel, J., and Mitchell, J.S.B., "Two Methods for Computing Directional Capacity given Convective Weather Constraints," *AIAA Guidance, Navigation, and Control Conf.*, Chicago, IL, Aug., 2009.

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# CWAM Weather Avoidance Fields (WAFs)

Weather Information

Weather Translation



CWAM

echo tops

precipitation intensity

extract predictors

**Deviation Probability**

deviation probability lookup

WAF

35 kft

31 kft

27kft

deviation probability

Observe 1000s of flights and classify as deviate or non-deviate
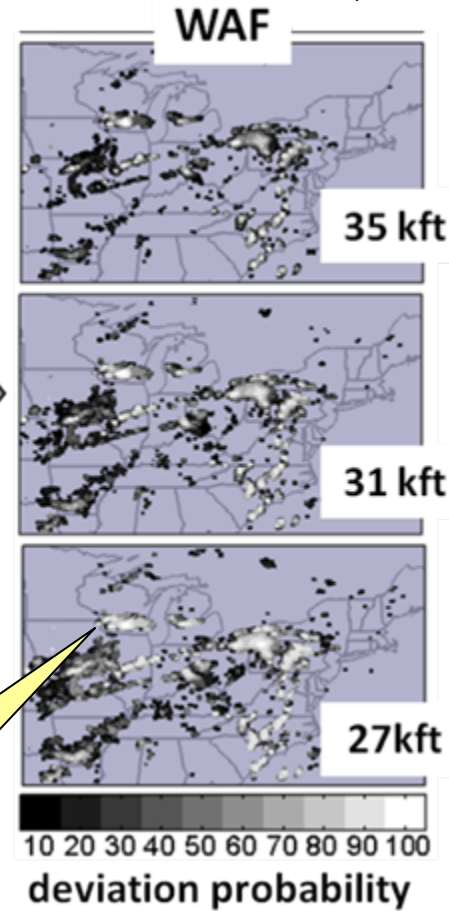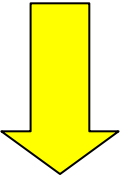
En Route models differ from Terminal models

*Results of MIT-Lincoln Laboratory*

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# Space Weather Translation Model
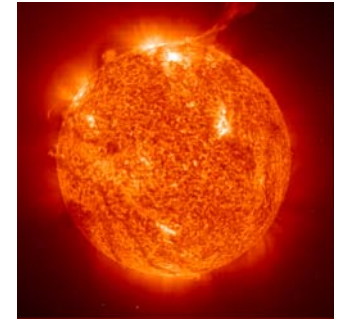
- **Solar Flares – Tactical FL adjustment; Crew has 7-8 min to respond**

- **CME – Reroute to Polar Route 4 or NO routes used; 2-3 days to reach the Earth and respond**

| | | |
|---|---|---|
| **Solar Flare** → **Increase Atmospheric Radiation** → Solar Radiation Level ≥ 3 → **Polar Flights Limited to FL310 or Below** → **Limited Airspace Resources** | | |

**Coronal Mass Ejection** → **Communication and Navigation System Degradation**

Geomagnetic Storm Level < 4 And Radio Black Out Level = 3 → **May Only Use Polar Route #4** → **Limited Airspace Resources**

Geomagnetic Storm Level ≥ 4 Or Radio Black Out Level ≥ 4 → **Polar Routes Not Permitted** → **Unusable Airspace**

Weather Information

Weather Translation

# Route Availability (Convection)



En Route WAF Needed

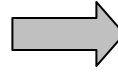Route Availability

Weather Information
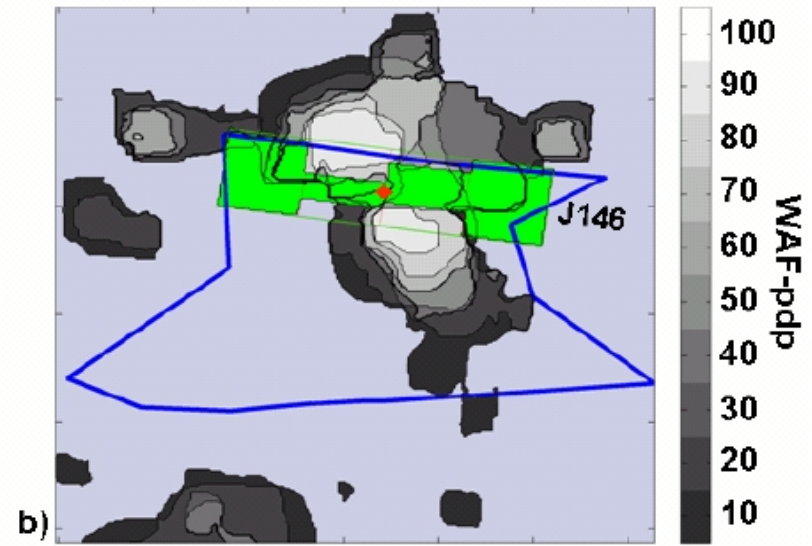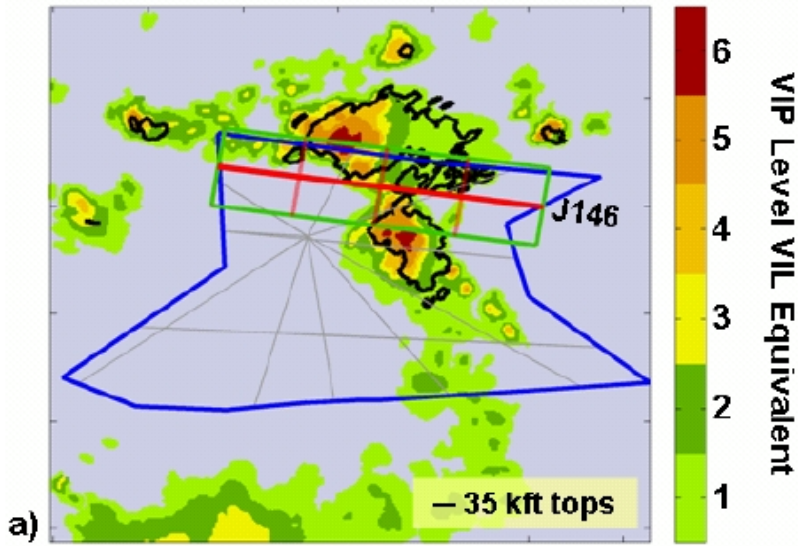
Weather Translation

*Results of MIT-Lincoln Laboratory*

# Route Availability (Convection) and FCAs

Weather Forecast Data ⟹ Route Availability



ATM-Impact
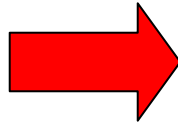
*Results of MIT-Lincoln Laboratory*
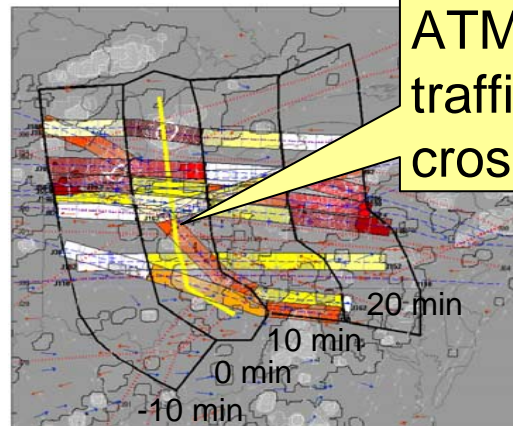
ATM – Impact considers actual traffic reductions along routes crossing FCAA05

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# Re-Distribution of Traffic due to Weather Impacts

Weather Information

Weather Translation
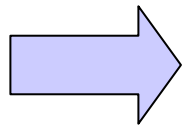
Weather Forecast → Available Capacity
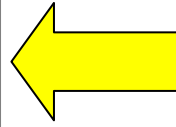
ATM-Impact

Predicted Traffic Flow relative to Available Capacity

Predicted change in traffic counts due to weather
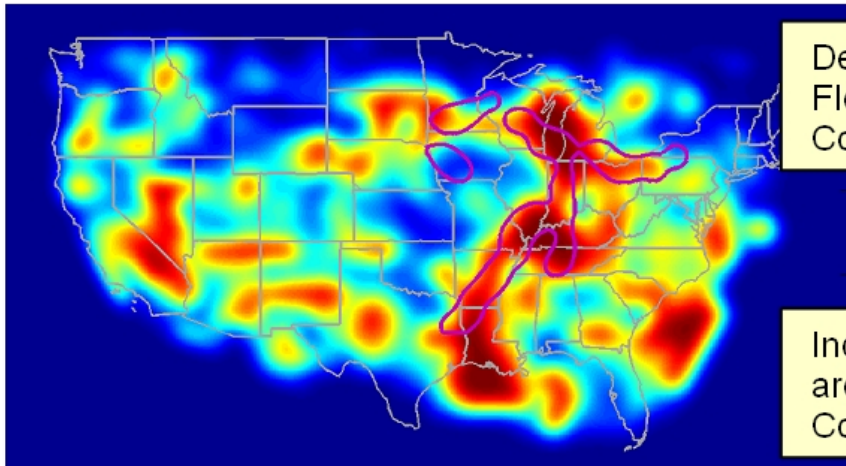
Decreased Traffic Flow inside Weather Constraints

Increased Traffic Flow around Weather Constraints



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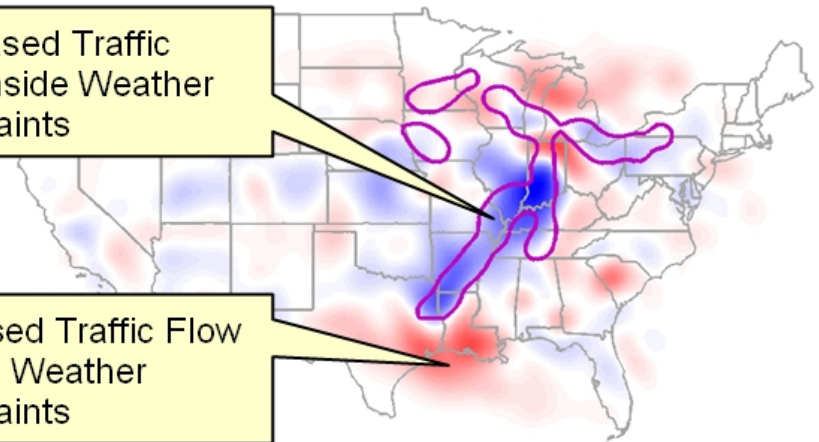
# NextGen Weather Integration Concept – Refined Model
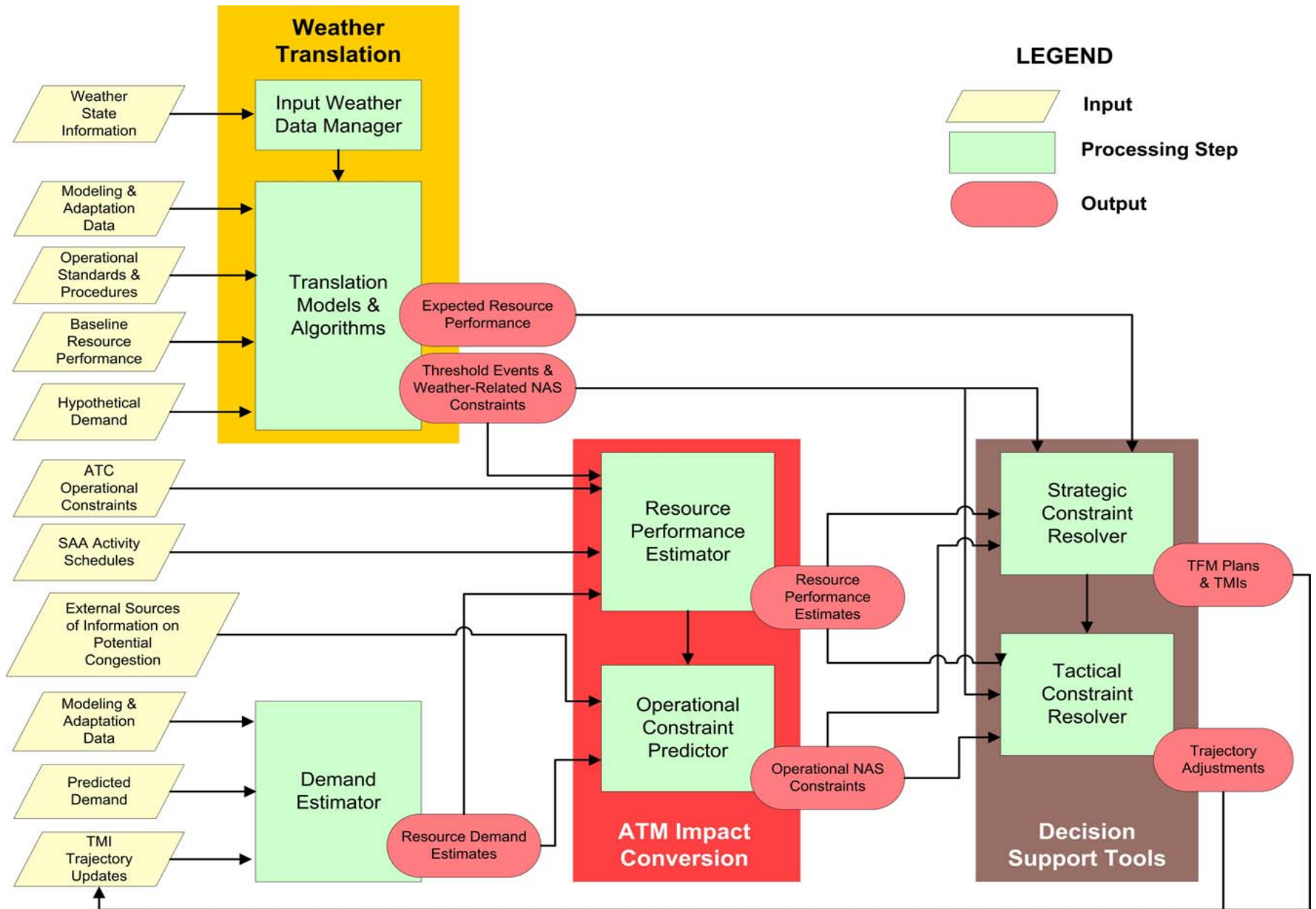
# Categorization Color Scheme

| Color | Name | Description |
|---|---|---|
| Yellow | Weather Translation (TRA) | Pure weather translation models resulting in threshold events and/or characterizations of weather-related NAS constraints |
| Orange | Weather Translation and ATM Impact (TRA/IMP) | Can be used as both translation and ATM impact conversions models |
| Red | ATM Impact (IMP) | Pure ATM impact conversion model processing actual demand |
| Brown | DST Application (DST) | Assisting human in making decisions on identified operational NAS constraints |

# Technology Classification Results

| Technology Name | 0. Classification (TRA, IMP, DST) |
|---|---|
| B-1.1 En route Convective Weather Avoidance Modeling | TRA |
| B-1.2 Terminal Convective Weather Avoidance Modeling | TRA |
| B-1.3 Mincut Algorithms to determine Maximum Capacity for an Airspace | TRA, IMP |
| B-1.4 Weather-Impacted Sector Capacity considering CWAM and Flow Structure | TRA, IMP |
| B-1.5 Route Availability in Convective Weather | TRA, IMP |
| B-1.6 Directional Capacity and Directional Demand | TRA, IMP |
| B-1.7 ATM Impact based on the Weather Impacted Traffic Index | IMP |
| B-1.8 Weather-Weighted Periodic Auto Regressive Models for Sector Demand Prediction | IMP |
| B-1.9 ATM Impact in terms of a Stochastic Congestion Grid | IMP |
| B-1.10 ATM Impact in terms of Network Flow Adjustments | IMP |
| B-1.11 Translation of Ensemble Weather Forecasts into Probabilistic ATM Impacts | TRA,IMP |
| B-1.12 Translation of a Deterministic Weather Forecast into Probabilistic ATM Impacts | TRA,IMP |
| B-1.13 Sensitivity of NAS-wide ATM Performance to Weather Forecasting Uncertainty | IMP |
| B-1.14 Use of Probabilistic Convective Weather Forecasts to Assess Pilot Deviation Probability | TRA |

| Technology Name | 0. Classification (TRA, IMP, DST) |
|---|---|
| B-1.15 Integrated Forecast Quality Assessment with ATM Impacts for Aviation Operational Applications | TRA |
| B-1.16 Conditioning ATM Impact Models into User-relevant Metrics | TRA,IMP |
| B-1.17 Integration of the Probabilistic Fog Burn Off Forecast into TFM Decision Making | TRA, IMP |
| B-1.18 Mincut Algorithms given Hard/Soft Constraints to determine Maximum Capacity | TRA, IMP |
| B-1.19 ATM Impact of Turbulence | TRA, IMP |
| B-1.20 Tactical Feedback of Automated Turbulence electronic Pilot Reports | TRA, IMP |
| B-1.21 ATM Impact of Winter Weather at Airports | TRA, IMP models needed |
| B-1.22 Weather Impacts on Airport Capacity | TRA, IMP |
| B-1.23 ATM Impact of In-Flight Icing | TRA, IMP |
| B-1.24 ATM Impacts Derived From Probabilistic Forecasts for Ceiling and Visibility and Obstructions to Visibility | TRA,IMP |
| B-1.25 Improved Wind Forecasts to predict Runway Configuration Changes | TRA,IMP |
| B-1.26 Improved Wind Forecasts to facilitate Wake Vortex Decision Support | TRA,IMP |
| B-1.27 Impact of Winds Aloft on the Compression of Terminal Area Traffic Flows | TRA,IMP |
| B-1.28 Oceanic/Remote Weather Integration | TRA,IMP |

| Technology Name | 0. Classification (TRA, IMP, DST) |
|---|---|
| B-1.29 Translation of Volcanic Ash Plume Hazards onto Airspace and Airport Impacts | TRA,IMP |
| B-1.30 Translation of Atmospheric Effects into Environmental and ATM Impacts | TRA,IMP |
| B-1.31 ATM Impact of Space Weather | TRA,IMP |
| B-1.32 ATM Impact of Weather Constraints on General Aviation Access to the NAS | TRA,IMP |
| B-2.1 Sequential, Probabilistic Congestion Management for addressing Weather Impacts | DST |
| B-2.2 Sequential Traffic Flow Optimization with Tactical Flight Control Heuristics | DST |
| B-2.3 Airspace Flow Programs to address 4D Probabilistic Weather Constraints | DST |
| B-2.4 Ground Delay Program Planning under Capacity Uncertainty | DST |
| B-2.5 Contingency Planning with Ensemble Weather Forecasts and Probabilistic Decision Trees | DST |
| B-2.6 Probabilistic Traffic Flow Management | DST |
| B-2.7 A Heuristic Search for Resolution Actions in Response to Weather Impacts | DST |
| B-2.8 Integrated Departure Route Planning with Weather Constraints | DST |
| B-2.9 Tactical Flow-based Rerouting | DST |
| B-2.10 Tactical On-Demand Coded Departure Routes (CDRs) | DST |

**Legend:**
Translation (TRA) | Translation or Impact (TRA, IMP) | Impact (IMP) | Decision Support Tool (DST)

# Conclusions

- **The NextGen weather integration process requires a clear distinction between the data, information, models, and algorithms that are included in:**
  - 4D Weather Data Cube
  - Weather Translation
  - ATM Impact Conversion
  - Decision Support Modules
- **Existing weather integration technologies often blur the line between translation and ATM impact conversion**