Future Aeronautical Meteorology Research & Development

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The only constant is change.

~ Heraclitus  (approx. 500 BC)
A Changing World

Technology
- Communication
- Computing
- Automation
- Aircraft
- Sensors

Stakeholders
- ICAO, WMO, CAAs
  - Airport & Airlines
    - ATC & ATM
      - GA, UAS
        - Space
        - Defense
        - ANSPs

Weather & Climate

Procedures
- Terminal
- En route
- Oceanic

Discussing weather in a broader context

- Observations
- Process understanding
- Modeling & prediction
• **Air traffic growth**
  - Asia/Pacific & Middle East

  ![World map showing passenger volume growth](image)

  - Approximate passenger volume per month, Q1 2017
    - North America: 3.0% (3,430,000)
    - South America: -1.0% (1,240,000)
    - Asia Pacific: 5.4% (3,470,000)
    - Middle East: 4.8% (3,470,000)
    - Europe: 6.1% (2,170,000)

  Travel between Asia Pacific and the Middle East surged 13.4% CAGR over the last two years.

• **New entrants**
  - business jets
  - unmanned systems
  - space travel
  - supersonic flight

  ![Business jets and spacecraft images](image)

  **New weather requirements?**

• **Stakeholders**
  - ICAO, WMO, CAAs
  - Airport & Airlines
  - ATC & ATM
• **International coordination**
  - ICAO/WMO roadmap
  - major programs lead way

- **Stakeholders**
  - ICAO, WMO, CAAs
  - Airport & Airlines
  - ATC & ATM

- **Weather roadmap**

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- Communication
- Computing
- Automation
- Aircraft
- Sensors

• Computing
  - exponential growth in computing
  - cloud computing
  - data analytics

• Aircraft
  - propulsion, fuel
  - avionics, automation
  - communication

High weather sensitivity
• Communication
• Computing
• Automation
• Aircraft
• Sensors

Technology

• **Infrastructure**
  - GPS-based position
  - position communication
  - connectivity & interoperability

Security concerns
- **Efficiency & capacity**
  - performance-based navigation
  - trajectory-based operations
  - time-based management
  - collaborative decision making
  - greener skies

Metrics

<table>
<thead>
<tr>
<th>KPA</th>
<th>EFFICIENCY</th>
<th>CAPACITY</th>
<th>PREDICTABILITY</th>
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</thead>
<tbody>
<tr>
<td>FOCUS AREASI</td>
<td>ADDITIONAL FLIGHT TIME &amp; DISTANCE</td>
<td>ADDITIONAL FUEL BURNS</td>
<td></td>
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<tr>
<td>CORE KPIs</td>
<td>KPI02 Taxi-Out Additional Time</td>
<td>KPI09 Airport Peak Arrival Capacity</td>
<td>KPI03 Departure punctuality</td>
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<tr>
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<td>KPI13 Taxi-In Additional Time</td>
<td>KPI10 Airport Peak Arrival Throughput</td>
<td>KPI14 Arrival Punctuality</td>
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<tr>
<td>ADDITIONAL KPIs</td>
<td>KPI04 Filed Flight Plan en-Route Extension</td>
<td>KPI16 Additional fuel burn</td>
<td>KPI07 ATFM delay</td>
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<tr>
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<td>KPI05 Actual en-Route Extension</td>
<td>KPI11 Air Traffic Capacity Utilization</td>
<td>KPI18 ATFM slot adherence</td>
</tr>
<tr>
<td></td>
<td>KPI08 Additional time in terminal airspace</td>
<td>KPI12 Airport/ Terminal ATFM Delay</td>
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</table>

- **Terminal**
- **En route**
- **Oceanic**
- **Traffic management initiatives**
  - range of tools available
    - airspace flow program
    - ground delay program
    - ground stop
    - miles/minutes in trail
    - traffic management advisor
    - plus many others

- **Wake separation**
  - on ground & in air

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- Terminal
- En route
- Oceanic

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**Effective use of weather is key**
- Observations
  - new satellites (GOES-16, Himawari-8, JPSS, etc.)
  - radar & lightning
  - in situ (basic meteo, turbulence, etc.)
  - field experiments (BAIRS, HAIC/HIWC, ICICLE, etc.)

- Prediction
  - increasing resolution yields improved atmospheric processes representation
  - ensembles for capturing prediction uncertainty & probabilistic forecasting

Essential for process understanding & model initiation/validation/verification
- **Safety**
  - range of weather hazards
  - including volcanic ash & space weather

- **Climate change**
  - weather impacts are changing

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**Weather & Climate**

- Process understanding
- Modeling & prediction

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**Need to appreciate weather/climate impacts on aviation operations**

**Need to appreciate aviation operations on environment (e.g., noise & emissions)**
Emerging Concepts & Tools

- **Weather integration & impact translation**
  - weather translation to operational constraints
  - understanding constraints in operational context
  - mitigation of avoidable impacts (efficiency & safety)
  - applies to planning & execution, & all phases of flight

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**Level 0**
- No Weather Integration
  - Displayed independently
  - Cognitive interpretation
  - Manual use & application

**Level 1**
- Weather “On-the-Glass”
  - Displayed with traffic
  - Cognitive interpretation
  - Manual use and application

**Level 2**
- Weather Translation
  - Weather Translation Outputs
    - NAS Constraints
    - Threshold Events

**Level 3**
- Impact Identification
  - Impact Identification Outputs
    - NAS Impacts
    - NAS State Changes

**Level 4**
- Impact Resolution
  - Impact Resolution Outputs
    - Tactical TFM Solutions
    - Strategic TFM Solutions

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**MITRE**

- **Monitor**
  - Data

- **Identify Constraint**
  - Hypothetical Capacity

- **Analyze Impact**
  - Demand vs. Capacity

- **Plan**
  - Criteria

- **Act**
  - Consider Alternatives
  - Prioritize
  - Reassess

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• **Probabilistic capacity estimation**
  - translation of weather ensemble into probabilistic capacity
  - applicable to airspace & runways

(a) User Perspective Missing from Analysis

Weather hazard,

Forecast #1  Forecast #2  Forecast #3

averaging weather ensembles

How many air lanes may fit?

Most likely 2 air lanes will fit!

(b) User Perspective Central to Analysis

2 air lanes  2 air lanes  2 air lanes

ensembling user-relevant information

(a) Probabilistic 9-h Impact Forecast

<table>
<thead>
<tr>
<th>Runway Capacity</th>
<th>Departures</th>
<th>Arrivals</th>
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<tr>
<td></td>
<td>180</td>
<td>140</td>
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<tr>
<td></td>
<td>120</td>
<td>100</td>
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<tr>
<td></td>
<td>60</td>
<td>100</td>
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<tr>
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<td>0</td>
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Likelihood of 30% Reduction in E-W Direction

0  20  40  60  80  100 %
Weather avoidance routing
- trajectory-based operations
- considering multiple hazards
  > route varies depending on hazards & intensity considered

Avoiding moderate or greater convection (red) but not turbulence (orange)

Time: 13:00 UTC
TO IAF: 15:08 UTC

18 November 2015 flight from Houston, TX to Norfolk, VA
• **Weather in cockpit**
  - enhancing shared situational awareness
    > dispatch & pilot
  - electronic flight bag with real-time weather
    > multiple weather hazards
    > horizontal & vertical depiction
• **Smart decision support**
  - what-if scenarios for traffic management
    > record of past weather, air traffic, & other data
    > ability to search for “similar events” in past
    > ability to replay situation using different TMIIs
    > ability to simulate conditions into future
  - useful for training & real-time decision making
• **Crowdsourcing**
  - interactive, real-time information about traffic situation
• **World is changing**  
  - speed of change varies by sector (computing >> aircraft design >> climate/weather)  
  - effective change management requires foresight, planning & lead time

• **Future of air traffic management**  
  - significant growth in air traffic (Asia/Pacific, Middle East) & emerging new airspace users  
  - focus on trajectory-based operations, flexible routing, & denser spacing  
  - enablers include satellite-based navigation, connectivity, shared data, etc.

• **Future of weather prediction**  
  - increasing resolution to better resolve atmospheric processes  
  - use of ensembles to capture forecast uncertainty & probabilistic predictions  
  - improved & more observations (both in situ & remote), enhanced algorithms  
  - characterization of weather impacts (translation) along flight path, for flows & domains

• **Future of decision support**  
  - providing enhanced & shared situational awareness (data sharing is key)  
  - enabling consistent flight/flow planning & execution through increased predictability  
  - examination of what-if scenarios in real time yielding smarter decisions  
    > supported by large amounts of data & data analytics  
  - building trust in technology (training)
Thank you

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