Air Traffic Management : MET Requirements

(from Data to Ensemble Modeling)

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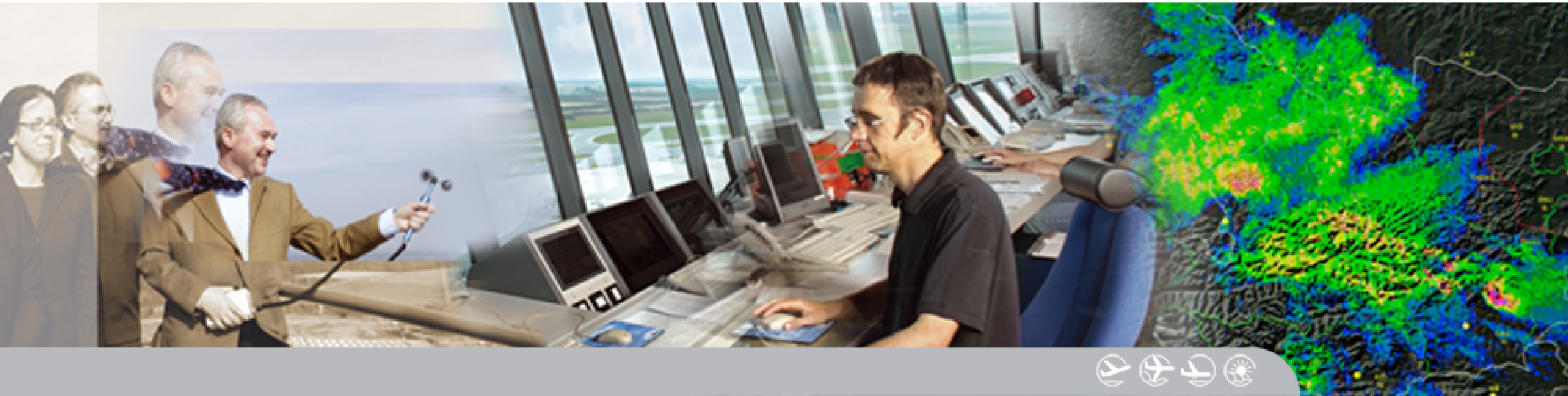


From Legacy ATC to TBO-based ATM

- ICAO Global Air Navigation Plan:
  - Transition from current situation (Aviation System Block Upgrade 0) with improved legacy systems
  - To SWIM-Based system with enhanced ATM and MET (ASBU 1)
  - And finally fully interoperable, consistent , trajectory based operations (ASBU 2),
  - With continued adaptation and perfection in ASBU 3

Current System: ATM Domains

- Network Manager – large national airspace, multi-national airspace (NAS, ECATS, Russian Federation, CARATS, China)
- Flow Management Position in Area Control Center (ACC)
- APCH
- TWR
- Ground

All have specific information requirements and time horizons!

(European) SESAR Categories for weather events

- **Nominal** weather conditions, which are the conditions in which the airport operates in more than 90% of time and where the declared capacity for scheduling purposes is based on. Nominal conditions translate in conditions like no storms, no snow, no visibility constraints etc.
- **Adverse,** degraded**,** weather conditions within the operational envelope of the airport, which have a significant negative impact on operations unless an appropriate response is organised; Adverse weather conditions may be reduced visibility conditions (e.g. Cat II, CAT III) or strong and gusting wind.
- **Disruptive** weather, adverse conditions which are very unlikely to occur and would have a severe impact on airport performance but the airport cannot be expected to provide resources to mitigate the condition like snow at a Mediterranean airport.

Specific space and time scales

Space/time Domain	Network Manager	Flow Management	ACC	APCH	TWR	Ground
0-30 min 100 -150 Miles	-	*	*	**	***	**
30-90 min 300 miles	*	**	***	***	**	*
1,5 -4 hrs 500-1500miles	***	***	**	*	*	-
4 – 9hrs 2000M	***	**	**	*	*	-
9-30hrs	**	*	*	*	*	-
1-7days	**	*	*	-	-	-

Explanation

- - : No significant influence on operations except extreme events
- * : Used for staff deployment planning, consideration of contingency
- **: Used in day-centric operational planning, strategic planning, direct consequences on processes
- *** : Information used for tactical, pre-tactical and strategic decisions, CDM decisions

Event Classification

User domain/ MET event	Network Manager	FMP	ACC	APCH	TWR	Ground
LVP	**	-	-	**	***	***
AP Sensor failure	*	-	-	**	***	**
Winter Weather	** - ***	* - **	*	***	***	***
S&D Storm	**_***	*_ **	*	***	***	***
Local CB/TS	* - **	* - **	**	** - ***	** - ***	** - ***
MCS/TC/ VA	** - ***	***	***	***	***	***

Explanation

- - : No immediate reaction expected
- * : Required for early planning, CSA
- ** : CDM process launched, stakeholder action required
- *** : Significant impact, STAM considered, CDM essential

ICAO Approach

- FF- ICE Document : Manual on Flight and Flow – Information Management for a Collaborative Environment (Doc 9965) AN/483
- TBO Concept by the ICAO ATMRPP
- Based on the principle of information sharing for trajectory operations
- Performance orientation
- MET information contains "performance limiting aspects"
- Cornerstone of the Global ATM Operations Concept

Role of MET information in Performance Management

- DCB (Demand Capacity Balancing) allows early action to minimize negative impact of weather events on regularity
- MET phenomena ranked differently in different climates and airspace segments (frequency and severity of occurrence of individual phenomena)
- BUT: organized convection always a show stopper!

Matching needs and capabilities

- Tactical, In-Flight Decisions: Deterministic, accurate, relevant information on winds, CB, Turb, Icing , mostly obs&Ncst
- Arrival Manager, TBS, RWY selection, line-up:
  - Low level winds accurate, deterministic, mean & max,Obs and Ncst
- APCH: Location & intensity of convective systems, determ. preferred, prob. acceptable

Matching cont…

- FMP, STAM: Max impact MCS/Lines > Fl 300
- Depending on ATM System localization near critical way points relevant
- Mitigation requires flexible sector operations (incl. staffing), thus Calibrated probability fcst useful >T+2hrs
- NM: Classical DCB 4 NETWORK, suited to PROB information, calibration essential

Validation and Key Performance Indicators (KPI)

- Performance Improvements of the ATM System depend not only on the quality of the MET information, but its suitability, relevance for the problem at hand, and finally use by ATM units and operators
- Key Performance Indicators compare "expected" performance degradation if no MET information is available to the "mitigated" one using the information
- Must be developed together with users!

Examples of suitable Key Performance Indicators

- Comparing “historic” degradation of capacity in similar weather situation to actual one – open to discussions…
- Run a simulation with and without MET information: Sophisticated, but hard to do
- Run real operations in parallel with Mock-up: High Cost
- Expressed in terms of time saved, capacity gained, risks avoided

Requirements for Input data and observations

Met Observations serve a triple purpose:

- As direct input to decision support and warning systems
  - METAR (Wind,VIS, WX, Cloud,TEMP,Pressure) at RWY
  - Wind Shear Alert Systems (WXR, LIDAR, LLWAS)
  - Wake Vortex Detection and Risk assessment
  - Lightning Activity (Ground Activity shut-DOWN)
  - WXR coupled to detection algorithms for Sev WX (e.g. ITWS)

Observations…

- As input to Nowcasting, VSRF and NWP methods and systems
- Off-line as ground truth for validation and verification purposes, and for establishing aerodrome and environs climatologies
- Around TMA, new sources essential:
  - TDWR, Lidar, Mode-S winds, GPS-moisture profiles, AMDAR profiles, wind profilers…

Now-casting Systems (WXR-Based)

- Ranging from simple linear extrapolation to complex, dynamically weighted blending with HR models
- Trend to clustering, feature/scenario type detection
- Inclusion of non-convective weather (stratiform rain/snow, ceiling and vis, wind fields
- Limited time horizon in stand-alone mode

Deterministic High Resolution Models

- Horizontal Resolution O (1 km)
- Improved handling of forced flows in complex topography
- Assimilation of WXR data as source of humidity, vertical motion
- Assimiltion of GPS moisture, Mode-S winds
- High update rates
- Residual uncertainty particularly in convection

HR Ensemble modeling

- Computationally expensive
- Choice of IC variations critical
- Variation of physical schemes?
- Calibration of probabilities of significant events?
- Seamless transition from Nowcasting – blending?

Sources of uncertainty – data and model!

- High-impact weather strongly depends not only on winds and temperature fields, but also on humidity and its sources (advection, evapo-transpiration from ground and vegetation, vertical distribution)
- In complex terrain, such data are hard to come by
- Complex interactions between radiation, cloudiness &wind create local convergence/ divergence of moisture fluxes, which are difficult to model explicitly or in parametric form
- While errors from IC uncertainty will grow slowly, but surely over time, model errors may have an early impact
- Design of ensembles (multi-model vs. single model) needs to encompass all factors

Needs and Methods for calibration of forecast probabilities

- Need to compute statistics over an extended calibration period to reduce systematic errors in the data (establish stable relationship between observed and forecast probabilities)
- Challenge to find best possible estimates for the calibration of the extreme values of important high impact weather parameters (extremes by definition rare events, thus large samples required)
- Requires estimate if calibration is sufficiently uniform and stable over domain, seasons, and scenario types
- For statistically infrequent events (e.g. heavy snowfall in Mediterranean, or MCS in NW Europe,), this may require several season's worth of information to be assessed (Historic data?).
- For risk assessment of extreme and rare events, users to provide critical threshold values, providers proof of predictability

Ensemble vs probability forecast

- An Ensemble Prediction System (EPS) has two possibilities of output:
  - A probability forecast; or,
  - An Ensemble forecast.
- For a *probability forecast*, the output would typically be a percentage risk of a certain event, often relative to a specific threshold.

Aviation users of ensemble information may be able to use the full range of forecast data directly to calculate a range of ATM impacts, to be entered in a decision support system

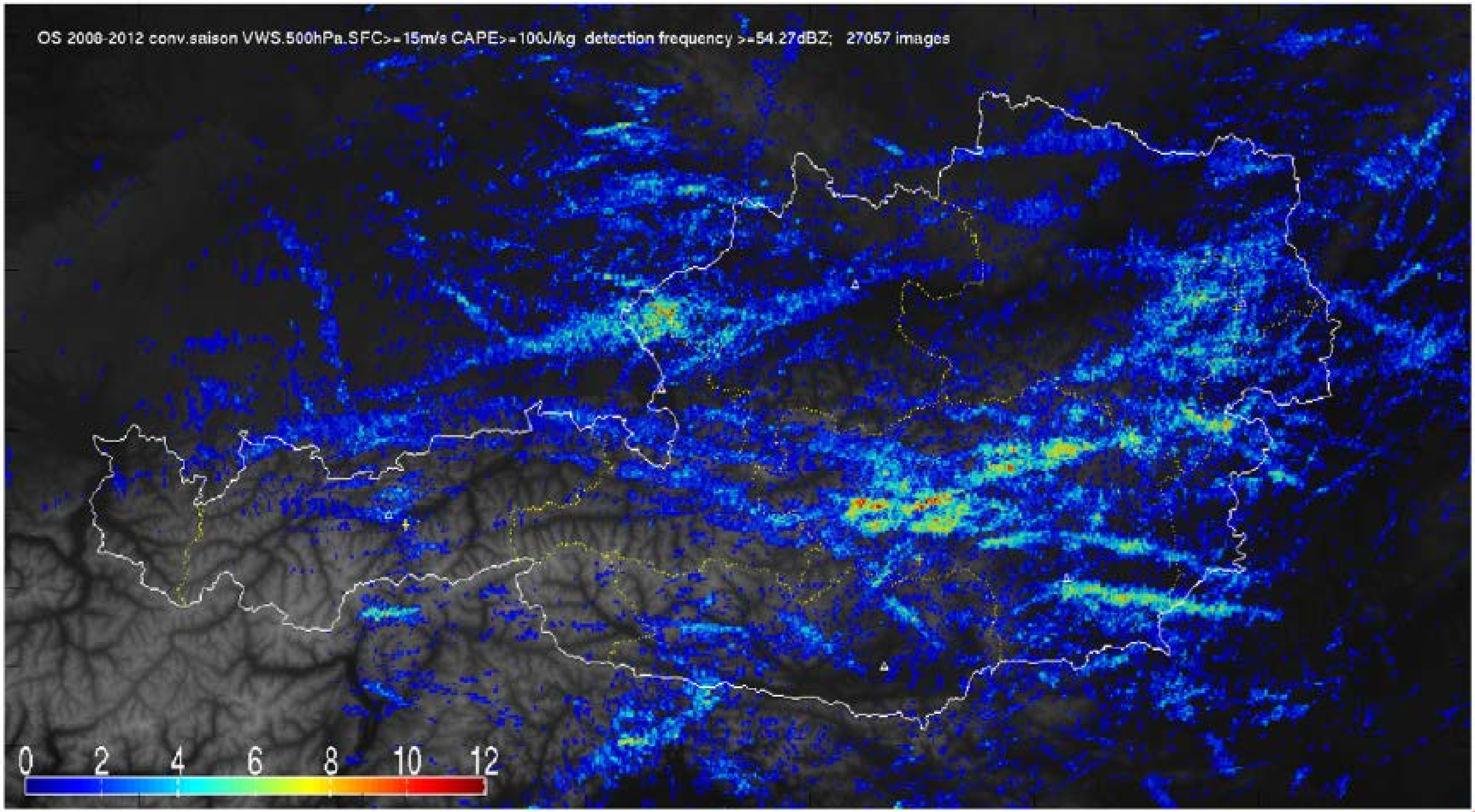
Spread and chance of "hitting the significant event"

- Individual, deterministic forecasts may miss a significant event
- "Shotgun approach" has higher chance of identifying the risk of an extreme event, but
  - Multi-model ensembles may have a better chance of hitting the target (if single model has a systematic weakness)
  - The rarer the event, and the larger model bias, the harder is calibration
  - Larger spread of IC increases likelihood of identifying, but not necessarily exact estimate of risk
  - Best suited for reasonably homogenous domain
- Use of "mean" forecast likely to eliminate information about small, but important risks
- Use of "translated impact" tempting for end users, requires rather good understanding of underlying principles

Use of conditional Climatologies in complex topography

- 4 Years of WXR data from Austrocontrol Composite (4 sites)
- Selection of strong convective events (Max Reflectivity >54db)
- Stratified by vertical shear BL - 5 km

Strong shear case



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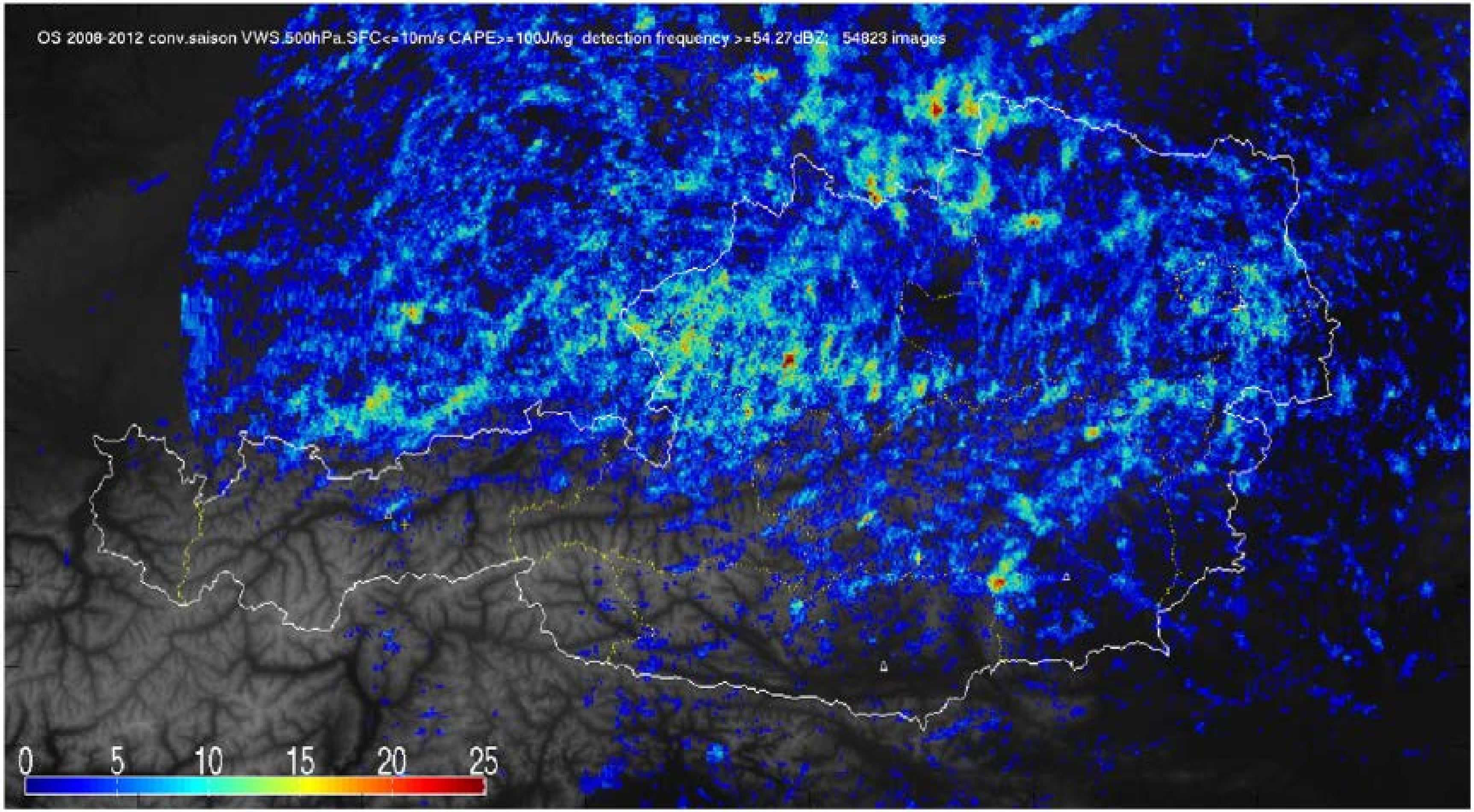

OS 2008-2012 conv.saison VWS.500hPa.SFC<=10m/s CAPE>=100J/kg detection frequency >=54.27dBZ: 54823 images
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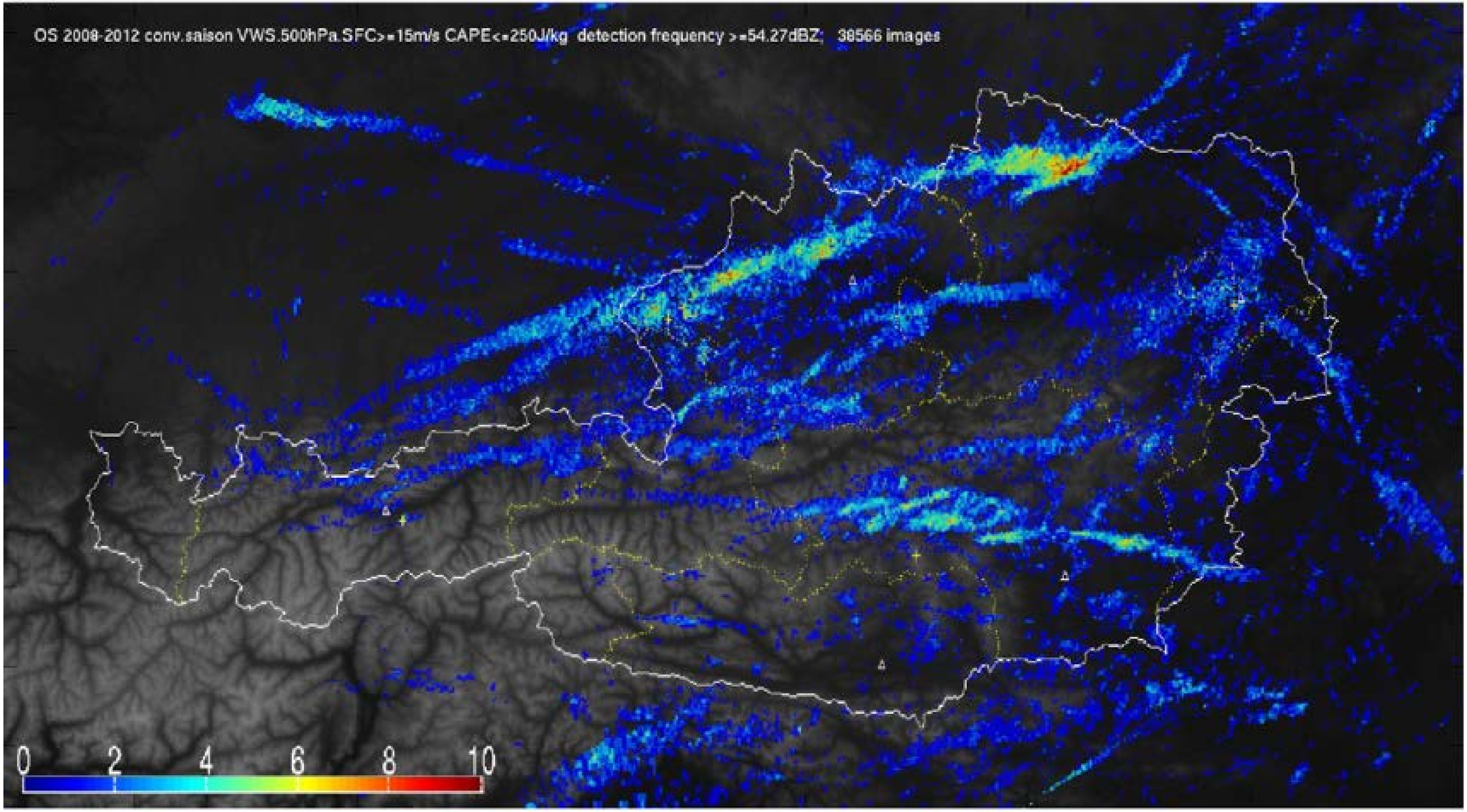
OS 2008-2012 conv.saison VWS.500hPa.SFC>=15m/s CAPE<=250J/kg detection frequency >=54.27dBZ; 38566 images
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Verification and Calibration

- Both Nowcasting Systems and HR models typically developed for limited domain
- Frequent model/system cycle upgrades reduce number of significant events to be verified
  - Use of re-analysis and stored data for runs?
  - Likelihood of reaching statistically significant numbers of cases for reliable calibration???
  - ATM Impact analysis depending on ATM system used – changes and upgrades?

Example of ATM ensemble prediction

- NextGen (Steiner et. al., 2010) approach of using high-resolution, ensemble-based numerical weather prediction model data for weather-related, probabilistic aviation impact forecasting.
- Ensembles of aviation-relevant information (e.g. maps of potential throughput as measured by the available flow capacity ratio). EPS output with statistical analysis (left); and, secondly, creating aviation-relevant EPS output.

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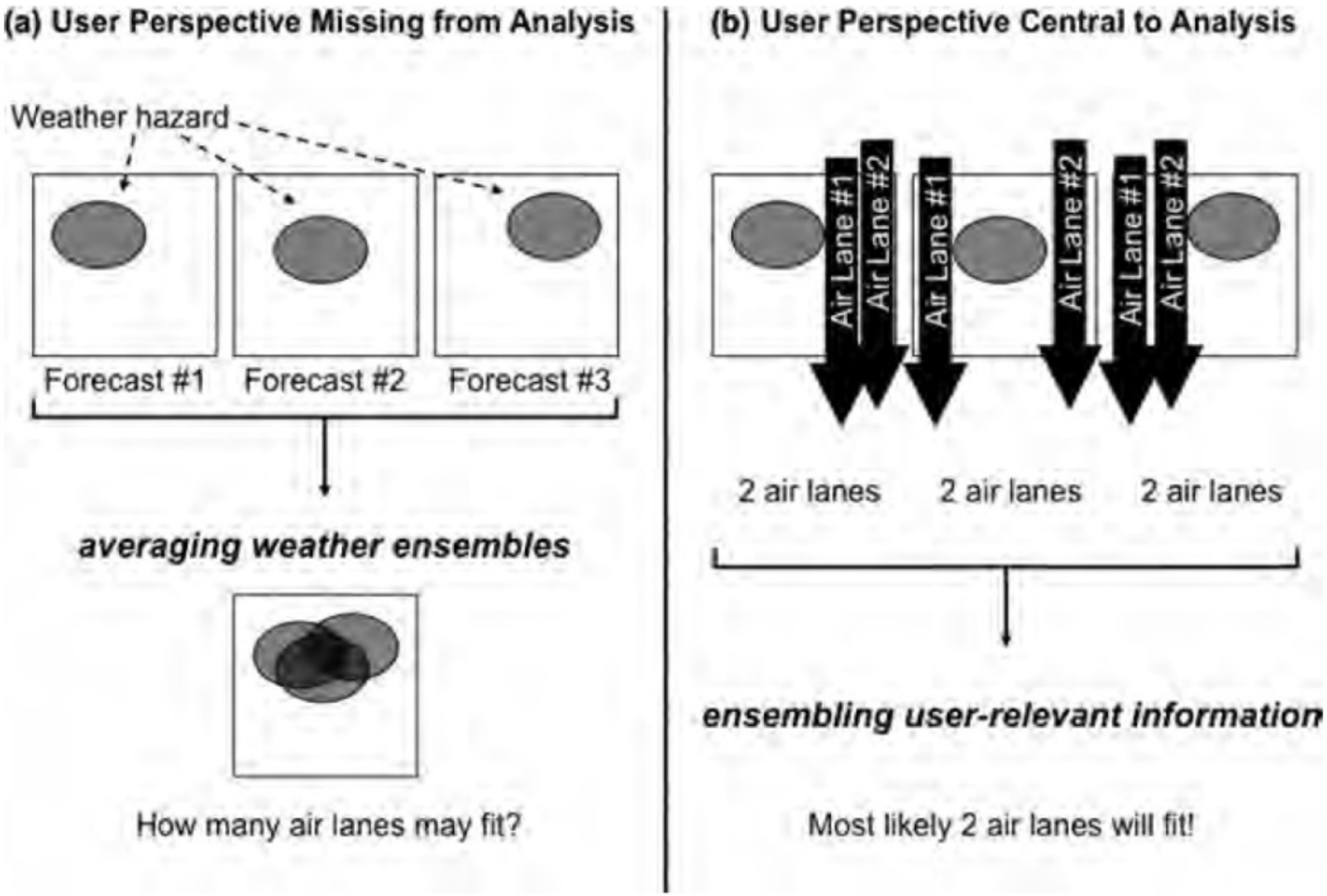
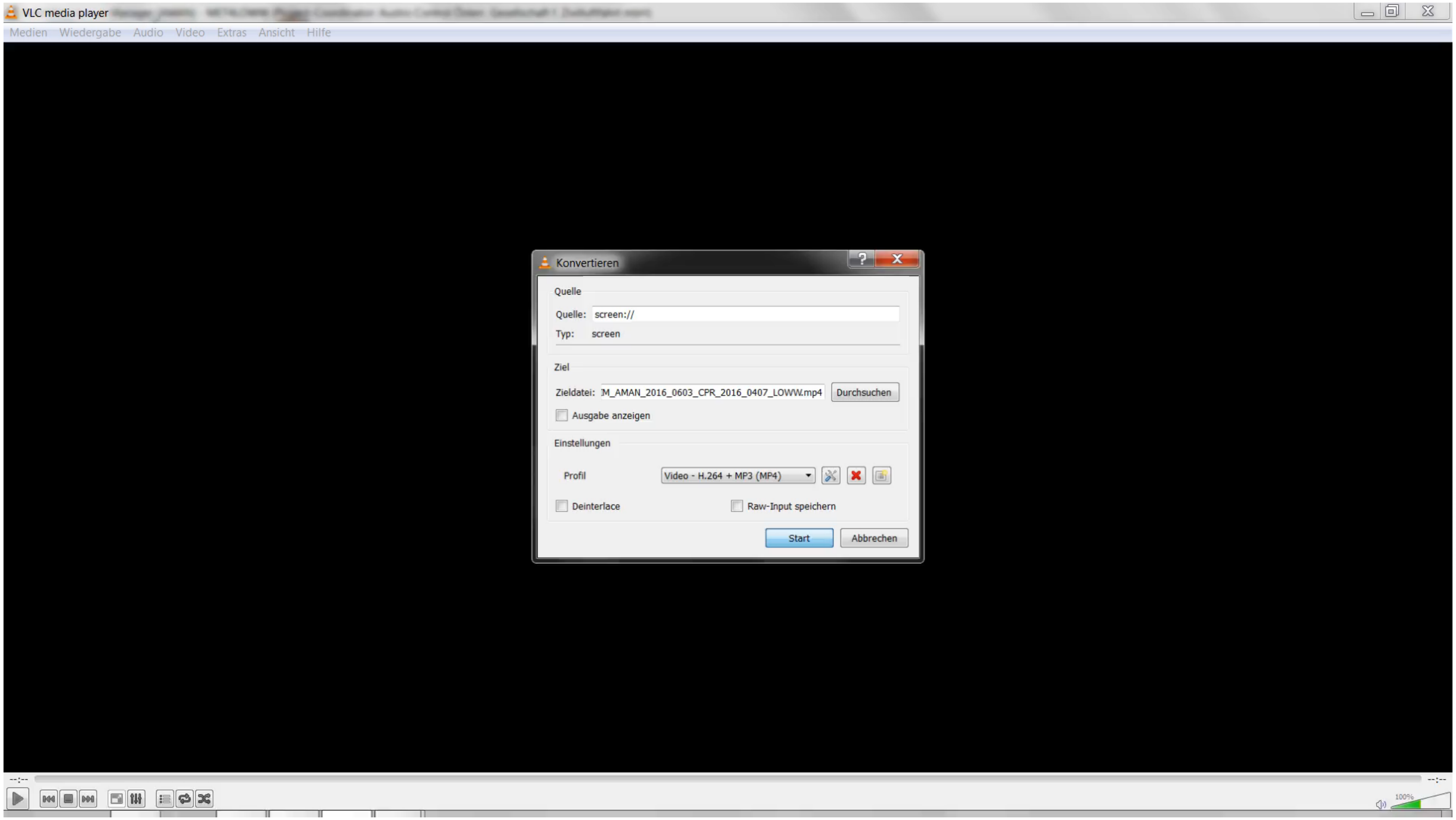


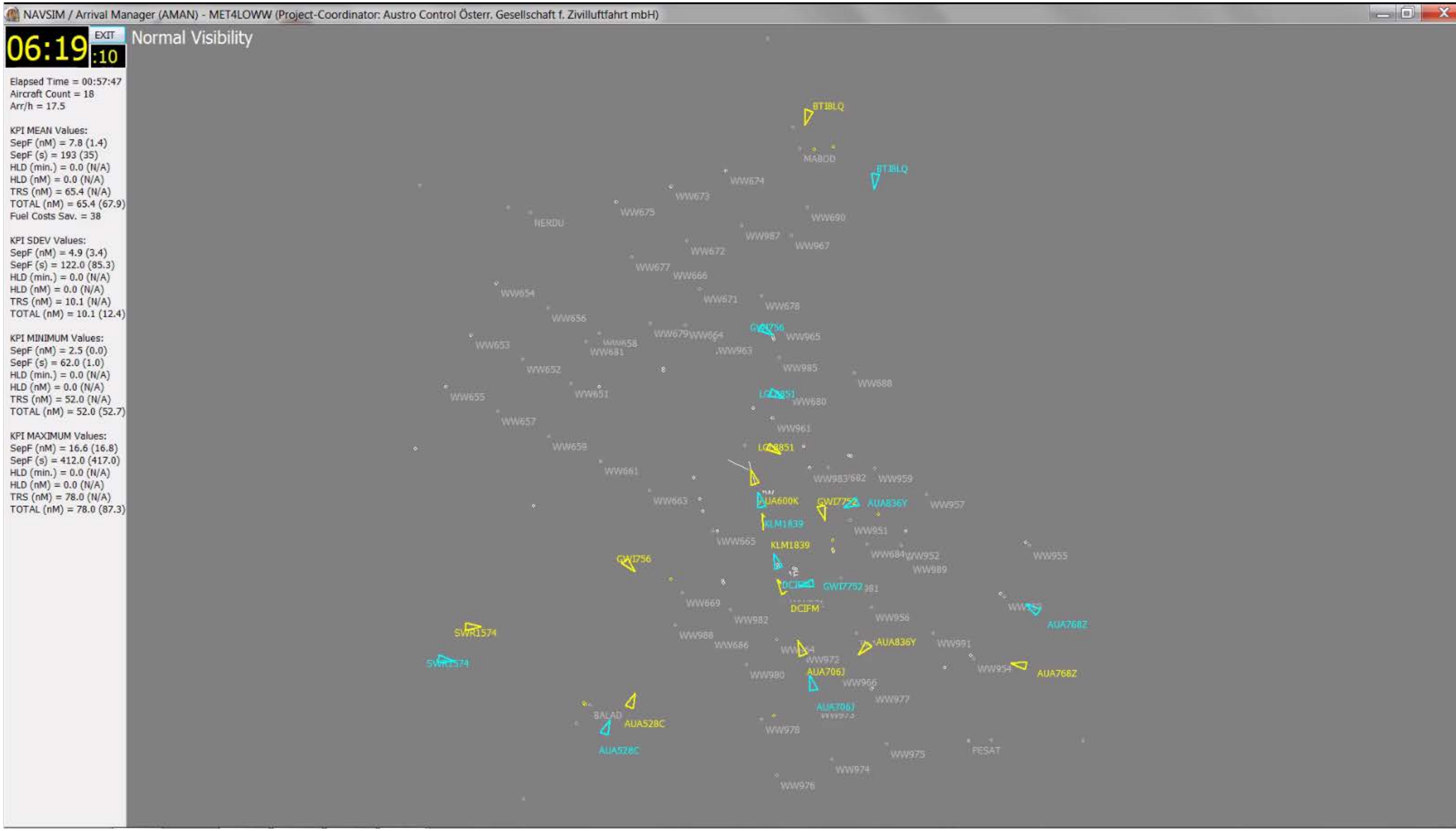
Air Traffic Simulation

- University of Salzburg implements LOWW approach procedures and weather into the air traffic simulator NAVSIM
- First validation shows very good agreement of simulation and actual flown flight tracks
  - ATCOs certifies widely realistic behaviour of simulator



yellow: CPR; blue: simulated

Simulator evaluation
snapshot



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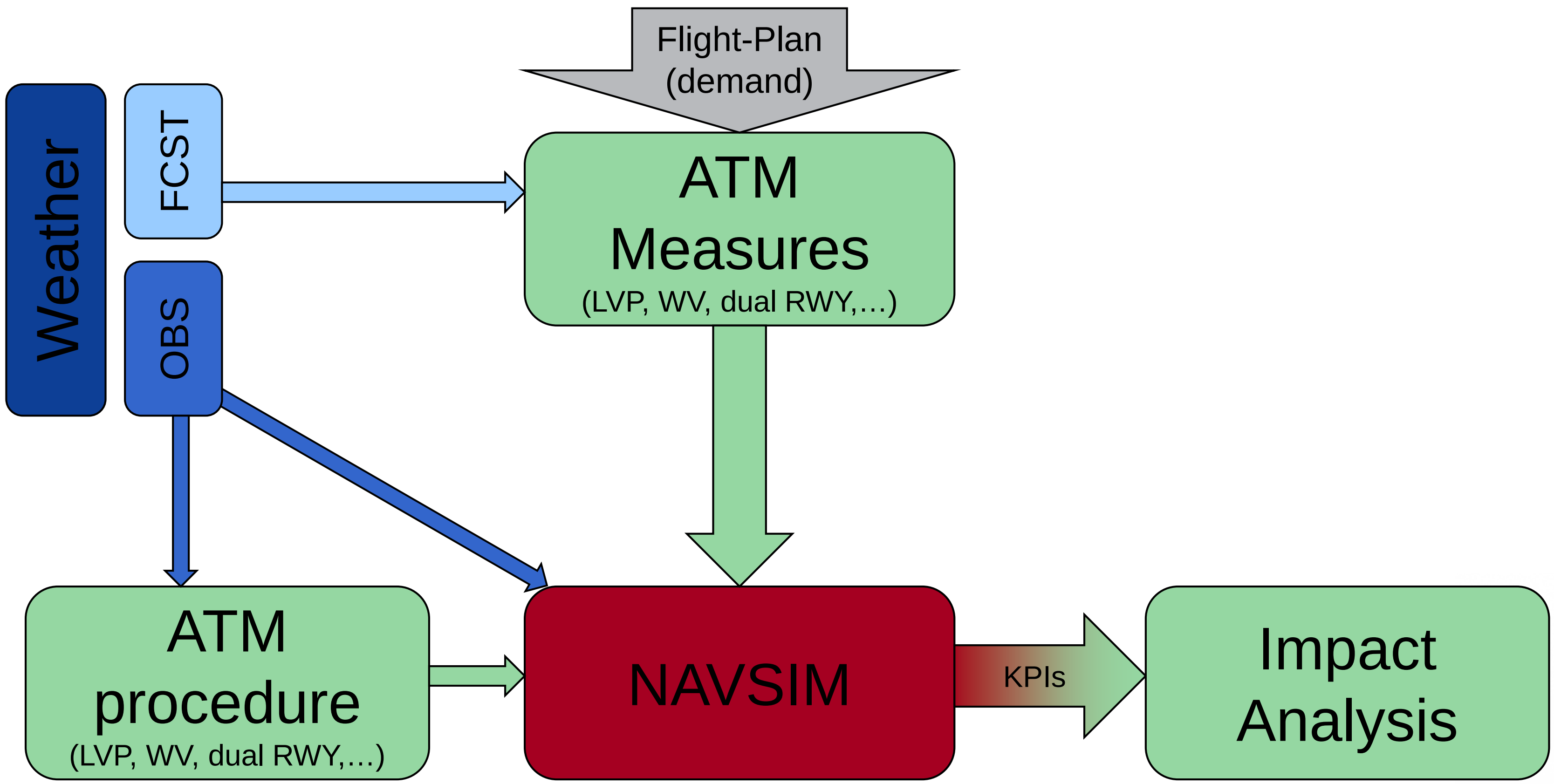
Weather impact analysis



Performance requirements per use case

- Specific ATM mitigation options determine performance requirements for MET information in terms of
  - Lead time
  - Accuracy
  - Reliability
  - Sharpness
  - Robustness

Achievable benefits

- Safety: Demand </= Capacity, manageable complexity, tolerable stress level for all operatives (ATCO, Pilots, APOC) depends on predictability of system under MET events
- Regularity: Limited mitigation potential, mostly in FMP, APOC (winter weather) by timely increasing resources (staff, equipment)
- Economy: Highly complex considerations!

Overall Economy considerations

- Cost of disruption is manifold:
  - ACFT and Crew time cost
  - Alternate / Return cost
  - PAX time cost
  - ATM, APOC staffing / operating cost
  - Lost rotations/connections
  - Fuel cost in non-optimal trajectories, holdings

    Contingency/alternate fuel

Achievable Mitigation per use case and Met performance

- LVP

Action	Lead time	Cost/loss	Acc/Rel
Holding, speed red. Vs alternate	30 ‘ – 1 hr	**	***
GDP	1-6hrs	* - **	** - ***
Clearance by cat	1 – 6hrs	* - **	***

Use cases…

- FMP

Action	Lead Time	Cost Loss	Acc/Rel
Increase sectors	2-6hrs	***	**
STAM/GDP	1 -6 hrs	* -**	**

Use cases…

- APCH

Action	Lead Time	Cost Loss	Acc/Rel
Change STAR	30’ to 1 hr	***	***
STAM	1 -3 hrs	* -**	***

Use cases…

- APOC – Winter weather/ Snow&Ice

Action	Lead Time	Cost Loss	Acc/Rel /Diff
Increase staff resources	12 – 24 hrs	** - ***	**
Rwy closure > STAM	30’ to 1hr	*	* - **

Conclusions:

- Required accuracy and reliability of MET information strongly dependent on use cases
- Impact translation important, but not necessarily sufficient for prioritization of stakeholder action
- Mitigation potential strongly dependent on external factors, stakeholder cooperation, predictability of MET events
- CBA etc have limited shelf life due to climate change!

Thanks to:

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- You, the audience, for your attention, patience and tolerance