From minutes to days:
Seamless prediction of airspace capacity degradation for air traffic management

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Outline

- Introduction / Motivation

- Operational ATM product – SigWX Bulletin

- Current research:
  - Nowcast
  - NWP forecast
  - Forecaster Intervention

- Results

- Summary / Outlook
Introduction / Motivation
Weather and Air Traffic Management (ATM)

- Weather is an important factor in the ATM-system

- Weather can’t be changed, but accurate forecasts help to be prepared and allow to minimize its impact, i.e. forecasts enhance *situational awareness*

- Deep convection has particularly high impact on flight safety and ATM – efficiency

- Exact time and location of deep convection is hard to predict

- Location makes a big difference for ATM:
  - a single convective cell on the final approach path or at a holding pattern location causes major disruptions
  - while the same cell has negligible impact if it is located 10 km away
Weather and Air Traffic Management (ATM)
A visualization

- Flight tracks and weather radar image over Austria
Operational ATM Product
Classification of horizontal structure of convection in airspace sectors (green / yellow / orange / red)
Manually generated by forecasters
Significant Weather Bulletin

**Approach**

- **1h**
  - No significant deep convection
  - ISOL or OCNL TS or FRQ/SQL TCU
  - FRQ TS or SQL TS

**Area Control Center**

- **2h**
  - No significant deep convection
  - ISOL TS
  - OCNL TS

- **6h**
  - No significant deep convection
  - FRQ TS or SQL TS
Significant Weather Bulletin

- Includes also forecasts for other hazards than convection and Low Visibility Procedures (LVP) at Vienna Airport

- Manual creation
  - Advantages
    - For short range convection forecasts with demand for high temporal and spatial precision human forecaster experience is invaluable
    - Product is monitored and can be amended in case of significant changes (including telephone briefing)
  - Disadvantages
    - Resources are limited, so product only feasible for limited area (i.e. Wien FIR) and forecast range
Current research
AAA4ATM – research project
Analysis of Available Airspace for ATM

- Funded by the Austrian Research Promotion Agency (FFG)

- Objectives
  - Development of an analysis and forecasting system for impact of deep convection on ATM
  - Analysis and nowcasting based on image processing algorithms for
    - object- and structure-detection
    - tracking and extrapolation
  - Blending of nowcasting to NWP forecasts supported by forecaster intervention to resolve inconsistencies
Object-Detection

- The Watershed algorithm was identified as promising improvement over threshold based object detection algorithms

- Basic idea:
  - Consider image as topographic relief (pixel value is interpreted as altitude)
  - There are 3 types of points in such a topography
    - Points of regional minimum
    - Points from where a drop of water would fall to a single minimum (catchment basin)
    - Points from where a drop of water could fall to more than one minimum (divide lines or watershed lines)
Object-Detection

- The Watershed algorithm:
  - Evaluate seed points (positions of maximum intensity of smoothed image)
Object-Detection

- The Watershed algorithm:
  - Evaluate seed points (positions of maximum intensity of smoothed image)
  - Flood 3D topography from seed points. Where the rising water of distinct catchment basins would merge, a dam is built → These dam boundaries correspond to the watershed lines.
Structure-Detection

- Feature Based Clustering
  - Group cells based on properties
  - Properties considered:
    - area
    - cell top
    - eccentricity
    - orientation
    - maximum reflectivity
    - maximum reflectivity location \((x,y)\)
    - maximum reflectivity altitude
    - mean reflectivity
  - Results with different feature weighting are evaluated
Structure-Detection
Feature Based Clustering

Watershed Regions
Structure-Detection
Feature Based Clustering

<table>
<thead>
<tr>
<th>Cell Centers</th>
<th>Cluster data: Position</th>
</tr>
</thead>
</table>

![Image of cell centers and cluster data](image_url)
Structure-Detection

Feature Based Clustering
Structure-Detection
Feature Based Clustering

Weights:
- eccentricity \( W = 0.5 \)
- orientation \( W = 1 \)
- max reflectivity \( W = 2 \)
- max location X \( W = 2 \)
- max location Y \( W = 2 \)
- cell top \( W = 1 \)
Tracking and Extrapolation

- Evaluation of popular tracking algorithms
  - Optical flow (“Cross-Correlation”)
  - TRACE3D (Handwerker 2002)
- Alternative approach
  - contour based segmentation

2D contours derived from Max-CAPPI image

3D contours derived from CAPPI images using Marching Cubes algorithm
Tracking and Extrapolation

- Evaluation of popular tracking algorithms
  - Optical flow (“Cross-Correlation”)
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Contours are matched between time steps using *Dynamic Time Warping*
(Every contour point of an image has a matching point in the subsequent image).

Cell centre tracks (white) and extrapolated paths (red)
Airspace classification from NWP forecasts

Simple parametrization

- Simple parametrization of classification
  - Based on the area fraction of the airspace sector covered by 1h-ly (convective) precipitation
  - Showalter index is used to distinguish between deep convection and shallow convection/stratiform precipitation
  - currently used with global deterministic model (ECMWF, 16km)
  - can be easily applied to other models and ensemble prediction systems

Histograms of sector mean Showalter index for SigWX classifications
(Based on ECMWF data for all SigWX forecasts in range 201308 - 201407)
Airspace classification from NWP forecasts
Based on object- and structure detection

- Object- and Structure detection algorithms developed for radar-images applied to NWP-fields
  - spatial and temporal (1h-ly post processing time step) scale of global model probably to coarse for this approach
  - better suited for high-resolution LAM model (< 3 km)
  - synthetic radar images from model would be a good basis
In order to provide a consistent seamless prediction the nowcast (+0 - +2) and NWP forecast (+1 – several days) must be blended.

To support automatic blending algorithms, especially in case nowcast and forecast are considerably different forecaster intervention tools are developed.

These tools ensure the forecasters can add value where the automatic systems have weaknesses (e.g. cell initiation, cell weakening or where model resolution is not sufficient – e.g. Alpine valleys).

The ultimate goal of the Field Modification is that forecasters work on the weather (=fields) and not on products. Products will be generated from a 4D-weather database which combines nowcasting, NWP models and the forecaster input.
Field Modification – Forecaster Intervention

Modification tools

- Field modification is implemented in Visual Weather, the meteorological workstation in use at Austro Control

- Modification tools, e.g.:
  - polygon tool: change field inside a polygon (incremental, multiplicative, absolute)
  - line tool: change field along a line and spread these changes inside a polygon (incremental, multiplicative, absolute)
  - merge tool: merge fields from observation or nowcasting (e.g. precipitation) into forecast
Field Modification – Forecaster Intervention
Consistency restoration rules (CRR)

- after every modification the CRR are applied to make sure fields stay consistent, e.g.:
  - surface temperature is changed to be below freezing: zero degree line and snow line need to be consistent
  - TS is added: precipitation is added; clouds must be present; lability is decreased
Results
Airspace classification
Monitoring different sources
Airspace classification
Monitoring different sources
Airspace classification
Monitoring different sources

Classification
Lightning data
Airspace classification
Monitoring different sources
Airspace classification

Monitoring different sources
Airspace classification
Monitoring different sources
Airspace classification
Monitoring different sources

Line currently only captured by forecaster
Convection sometimes not captured in NWP
Airspace classification
Verification

- Contingency tables comparing the operational product and the NWP classification against the classification based on the WXR-images have been generated for the period 1.8.2013 – 31.7.2014

- Result for sector east:

  Performance of NWP-Classification looks comparable to forecaster product
Airspace classification

Verification

- Contingency tables comparing the operational product and the NWP classification against the classification based on the WXR-images have been generated for the period 1.8.2013 – 31.7.2014

- Result for sector east:

  - Performance of NWP-Classification looks comparable to forecaster product

  However:
  - Specially for high classifications quite different
  - Reference based on WXR-images is flawed as no structure detections (lines!) is yet included
Summary / Outlook
Summary

- Deep convection has major impact on airspace capacity.
- An operational product created by forecasters proved very valuable as support for ATM planning.
- A new product based on nowcasting algorithms and NWP-forecasts, supported by forecaster intervention is under development.
- Development is still on-going, but a first prototype is under evaluation and shows promising results.
Outlook

- Improvement of
  - nowcasting algorithms
  - classification based on WXR (structure detection)
  - classification based on NWP

- In depth analysis of weather impact on ATM process based on flight trajectories
  - relevant WXR reflectivity thresholds
  - relevant structures: space between cells, cell tops

- Refine product for ATM
  - add more detail for short lead times:
    e.g. is traffic flow only affected in particular direction
  - move towards probabilistic forecasts for longer lead times