Translation of probabilistic weather forecast into impact for aviation stakeholders
Overview

• From monitoring to forecast: seamless and continuous prediction

• Probability aspects: local-Lagrangian and fuzzy-logic approach

• From MET to ATM: from information to impact

• Example: thunderstorm nowcast in the cockpit

Credits

• Arnold Tafferner, Kirstin Kober, Caroline Forster, Dennis Stich, Martin Köhler
Meteorological advisory for the air transportation system

- Use of **seamless** MET information to plan, re-plan, adjust, and execute flights
- **Continuous** consideration of planned and real data for flight planning and execution taking into account the reduced uncertainties when time proceeds
Predictability in a chaotic system

- Prediction skill
- Forecast lead time

- Observation & Nowcast (meas. data)
- Short-term Forecast (assim. data)
- Forecast (num. data)

- < 60 min
- 30 min – 4h
- 3h + for strong convection

- Nowcast
- Numerical Weather Prediction, NWP
Predictability in a chaotic system

For **seamless** and **continuous** prediction of aviation-relevant weather features:

- **seamless**: no gaps or jumps in the steps  Monitoring – Nowcast – Forecast
- **continuous**: permanent availability of information for a certain purpose
  a user receives automatically the most actual observation and prediction

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**Forecast skill**

- **Cb**: Cb/Rad-TRAM
- **Ww**: WHITE
- **Cb-LIKE**: Cb-LIKE
- **COSMO-DE**: COSMO-DE

**Forecast lead time**

- < 60 min for strong convection
- 30 min – 4h
- 3h +

**Observation & Nowcast (meas.data)**

**Short-term Forecast (assim. data)**

**Forecast (num. data)**

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**Numerical Weather Prediction, NWP**

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T.Gerz, DLR, at UFO Dissemination Workshop, 23.0415 Amsterdam,
 Decrease of descriptive detail over forecast time

1 Analysis
3D Object
Intensity
Trend
Attributes

2 Nowcast < 30 min
2D Object
with bottom and top
Extrapolation with trend
Attributes

3 Nowcast 30-60 min
2D Object
Extrapolation
Attributes

4 Nowcast > 60 min
2D Objects
Cb-Probability
Severity
Observation & Nowcast (meas. data) → Short-term Forecast (assim. data) → Forecast (num. data)
Cb-TRAM: **Cumulonimbus Tracking and Monitoring**
observation – translation - nowcast

Rad-TRAM: **Radar Tracking and Monitoring**
Rad-TRAM - Radar Tracking and Monitoring

Using European precip. radar composit (DWD):
37 dBZ reflectivity for deriving bottom contours
• detected contours in black
• 60 min nowcast in white
• moving direction by arrows
lightning obs. superimposed (LINET by nowcast GmbH)
Observation & Nowcast (meas. data) → Short-term Forecast (assim. data) → Forecast (num. data)
Probabilistic forecasts in Rad-TRAM

Local Lagrangian:
- temporal evolution of precipitation field is correlated to spatial variability
- fraction of pixels > 19dbZ
- shifting with displacement vector
- size search area ~ lead time
- forecasts up to 4 hrs in 15min steps

Germann and Zawadzki, 2004
Rad-TRAM-prob: 12.08.2007 23:15UTC

Kober & Tafferner 2009
Rad-TRAM-prob: 12.08.2007 23:15UTC

+30min

Kober & Tafferner 2009
Rad-TRAM-prob: 12.08.2007 23:15UTC

T. Gerz, DLR, at UFO Dissemination Workshop, 23.04.15 Amsterdam,

Kober & Tafferner 2009
Rad-TRAM-prob: 12.08.2007 23:15UTC

Observation & Nowcast (meas.data) → Short-term Forecast (assim. data) → Forecast (num. data)
Cb-LIKE - Likelihood of thunderstorms

- extension of Cb nowcasting scale to short-term forecasting scale
- use of model output data
- selection of the best member from an ensemble forecast
- combination of four model output quantities using fuzzy logic approach
  - vertical velocity, omega
  - convectively available potential energy, CAPE
  - synthetic radar data, SYNRRAD
  - cloud top temperature, CTT

M. Köhler 2015: Cb-LIKE Cumulonimbus Likelihood: Thunderstorm forecasting with fuzzy logic. Subm. to Meteorologische Zeitschrift
M. Köhler 2015: Dissertation an der Ludwig-Maximilians-Universität München

<table>
<thead>
<tr>
<th>Parameter</th>
<th>x-Bereich</th>
<th>Fuzzy-Input Sets</th>
<th>Überlappung</th>
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</thead>
<tbody>
<tr>
<td>Temperatur an Wolkengrenze</td>
<td>200 bis 280 K</td>
<td>nied.: 200 bis 230 K mod.: 220 bis 260 K hoch: 250 bis 280 K</td>
<td>220 bis 230 K 250 bis 260 K</td>
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<tr>
<td>(IR 10.8)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Radarreflektivität</td>
<td>0 bis 60 dBZ</td>
<td>nied.: 0 bis 25 dBZ mod: 15 bis 45 hPa/h hoch: 35 bis 60 hPa/h</td>
<td>15 bis 25 dBZ 35 bis 45 dBZ</td>
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</table>
Determination of Cb intensity by fuzzy logic: input data sets
Determination of Cb intensity by fuzzy logic: Cb indicator

![Fuzzy Output Sets Diagram](image_url)
Cb-LIKE: Cb likelihood forecasts up to 6 hrs, indicator 50
Fuzzy logic combination of CAPE, 500 hPa vertical velocity, synthetic satellite and radar data from the DWD COSMO-DE model

Cb 6 hrs forecast for 21 June 2012 18:00 UTC
Cb-LIKE: Cb likelihood forecasts up to 6 hrs
Fuzzy logic combination of CAPE, 500 hPa vertical velocity, synthetic satellite and radar data from the DWD COSMO-DE model

Cb observation 21 June 2012 18:00 UTC

Pink contours: Rad-TRAM cells
Blue crosses: Lightning data (LINET)
Translation of “likelihood” into “probability”

Statistical measures for thunderstorm occurrence:

<table>
<thead>
<tr>
<th>Indikator</th>
<th>Mittleres FAR</th>
<th>Gewitterwahrscheinlichkeit</th>
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<tbody>
<tr>
<td>20</td>
<td>0,47</td>
<td>53 %</td>
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<tr>
<td>30</td>
<td>0,40</td>
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<tr>
<td>40</td>
<td>0,35</td>
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<td>50</td>
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<td>60</td>
<td>0,18</td>
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<td>70</td>
<td>0,14</td>
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<tr>
<td>80</td>
<td>0,10</td>
<td>90 %</td>
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From statistics based on summer 2012 evaluations
From MET to ATM

How to use the meteorological information in aviation?

From info to impact

How good is good enough?

Depends on the user’s business case

courtesy by Dave Pace, FAA
Use cases

Cb-TRAM: objects for aircraft en-route, encountering thunderstorms
Rad-TRAM: objects for airports / air traffic control when TS approach

Bottom: Rad-TRAM
weather radar data analysis
→ take-off and landing

Top: Cb-TRAM
satellite data analysis
→ en-route

on-board radar range
From MET to ATM: What are the impacts of adverse weather to aviation?

Who are the stakeholders in aviation?

- Airlines (operation centres, flight crew, …)
- Air navigation safety providers (air traffic control, air traffic management)
- Airports (operation centres, ground handling, …, side-business)
- …
- Flying citizen (safety, punctuality, service, comfort)
- Non-flying citizen (comfort, noise, pollution)

These stakeholders have very different, conflicting interests!
How good is good enough?

“Carrying an umbrella or getting wet”

Dave Pace, FAA

- man: doesn’t like to carry an umbrella unnecessarily
- woman: hates to get wet hair

Nota bene:
- Both use the same forecast to make decisions resulting in different actions
- There is no gray area, each yes/no decision is objective and repeatable, based on predetermined criteria
- The costs/risk to getting wet and to carrying umbrellas are known
  - For the man, carrying an umbrella has a higher cost
  - For the wife, getting her hair wet has a higher cost
- Both choose their own probability thresholds for their decisions
Options

1) Fly direct and hope for the best
   a) If succeed, 729 miles, direct
   b) If deviate, 342+320+442 = 1104 miles (151%)

Courtesy: Dave Pace, FAA
Options (cont)

2) Plan a strategic reroute around the weather
   a) If the weather appears, 519 + 442 = 961 miles (132% of the direct route)
   b) If the weather does not appear, still 132%

Courtesy: Dave Pace, FAA
# Cost of decisions and outcomes

<table>
<thead>
<tr>
<th></th>
<th>Weather Yes</th>
<th>Weather No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic Reroute Yes</td>
<td>961 miles (132%)</td>
<td>961 miles (132%)</td>
</tr>
<tr>
<td>Strategic Reroute No</td>
<td>1104 miles (152%)</td>
<td>729 miles (100%)</td>
</tr>
</tbody>
</table>

Courtesy: Dave Pace, FAA
Cost of decisions

- If this route is flown on 100 typical days maybe 30 times there will be weather, and 70 times there will not be weather.
- Making the same decision every day will result in the following costs:

  | Strategic Reroute | 1104 miles (152%) | 729 miles (100%) | 30*1104+70 *729 = 84150 miles |

- In general, the probability threshold for rerouting is:

  \[ \text{Threshold} = \frac{\text{reroute} - \text{direct}}{\text{deviate} - \text{direct}} \]

So here, if the probability of blocking weather is > 61.9 %, do a strategic reroute to reduce long-term costs.

- Conclusion: with a 30% probability of weather, do not reroute.
test of innovative met-tools in the cockpit: in-flight uplink of Cb-TRAM
first successful data link tests
cooperation DLR - DLH

Lufthansa GADCom project (Ground Air Data Link Communication):

Real time link of Rad-TRAM and Cb-TRAM data in 5 EFBs (Electronic Flight Bags) of Lufthansa Cityline aircraft via mobile network on the ground and later in 5 EFBs of Lufthansa aircraft via FlyNet during cruise-flight
The Test Flight: Rio de Janeiro to Frankfurt, February 2013

“According to the charts: Business as usual at the ITCZ”
Thunderstorm scenario in the ITC, flight tracks and flown route

For a detailed report please contact Capt. Andreas Ritter (andreas.ritter@dlh.de)
Summary

Meteorology:

• Seamless and continuous observation and prediction on different scales increases forecast skill

• Data tailored to the user’s needs: simple unambiguous information (translation)

• Probabilities can be delivered “…but are they good enough?”

Aviation:

• Develop impact scenarios for various stakeholders

• Derive business cases to tailor MET info to the user’s needs, “…to know when it’s good enough!”