The impact of airborne wind and water vapour lidar measurements on ECMWF analyses and forecasts

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Motivation

above oceans:
hardly any radiosondes
aircraft at cruise level
low accuracy of passive instruments
low resolution and height errors

lidars can measure various atmospheric quantities in remote regions with high accuracy and high resolution either from satellites or aircraft

goal: estimate benefit with impact studies
DLR lidar instruments

Differential Absorption Lidar (DIAL)
λ~920-945 nm, 100 Hz, 2 W
parameter: water vapour molecule number
nadir or zenith pointing
horiz. resolution: 2 - 40 km
vert. resolution: 500 - 2000 m

scanning coherent 2 µm Doppler lidar:
conical scans with 24 positions
→ 24 LOS observations (~30/54 s)
→ vertical profile of 3-D wind vector
horiz. resolution 5 - 40 km
vert. resolution 100 m
range: 0.5-12 km
4 flights in "sensitive areas" (targeting)
1 flight for Greenland Tip Jet
1 flight for intercomparison ASAR and lidar
2 transfer flights

8 flights, 1600 wind profiles, 40 000 lidar measurements, 49 dropsondes
Observations on 25 November 2003

ECMWF sensitivity plot and 500 hPa

Iceland

Ireland

http://www.sat.dundee.ac.uk/
Comparison: 33 Wind profiles
> 500 Measurements

Error Lidar (u,v):
RMS = 0.75-1 m/s
Assigned errors

Error lidar: 0.75-1 m/s

Representativeness error (Frehlich & Sharman 2004) < 0.5 m/s

Total error lidar: 1-1.5 m/s

Total error Dropsonde/Radiosonde: 2-3 m/s

Total error AMV 2-5 m/s
6 experiments 14-30 November 2003
- lidar, ~10 km, Std = 1 m/s
- lidar, ~40 km (2 averaging types), Std = 1 m/s
- lidar, ~40 km, Std =1.5 m/s
- ~100 dropsondes (from 10 flights)
- control run

thinning to grid points (40 x 40 km, 60 levels)
- ~ 80% not used
- ~ 3000 used measurements
- 5 million operational measurements used per day
- lidar = 0.005% additional measurements

4 un-cycled experiments to investigate targeted observations (forecast sensitivity)
Background departure = difference background and observation

\[(\text{Std(bg-dep)})^2 = (\text{Std}_{\text{obs}})^2 + (\text{Std}_{\text{bg}})^2\]
observation influence (Cardinali et al. 2004):
0 --> no influence of observations
1 --> no influence of background
mean global observation influence = 0.15

<table>
<thead>
<tr>
<th></th>
<th>Lidar u, v</th>
<th>Dropsonde u, v</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation influence</td>
<td>0.63</td>
<td>0.45</td>
</tr>
<tr>
<td>Number of observations</td>
<td>758</td>
<td>388</td>
</tr>
<tr>
<td>Information content</td>
<td>477.5</td>
<td>174.6</td>
</tr>
</tbody>
</table>
Reduction of forecast error at 500 hPa - 48 h

Diff in RMS of fc-Error: RMS(fc_en5t - an_eiz3) - RMS(fc_eiz3 - an_eiz3)
Lev=500, Par=z, fcDate=20031115-20031128 00/12 UTC, Step=48
NH=-0.55 SH= 1.19 Trop= 0.35 Eur=-4.52 NAmer= 4.2 NAtl= -2.94 NPac= -3.65

(gpdm)
Reduction of forecast error at 500 hPa - 72 h

Diff in RMS of fc-Error: RMS(fc_en5t - an_eiz3) - RMS(fc_eiz3 - an_eiz3)
Lev=500, Par=z, fcDate=20031115-20031128 00/12 UTC, Step=72
NH=-2.37 SH= 2.87 Trop= 0.31 Eur=-11.42 NAmer= 5.12 NAtl= -1.61 NPac= -8.24
Reduction of forecast error at 500 hPa - 96 h

Diff in RMS of fc-Error: RMS(fc_en5t - an_eiz3) - RMS(fc_eiz3 - an_eiz3)
Lev=500, Par=z, fcDate=20031115-20031128 00/12 UTC, Step=96
NH=-4.14 SH= 6.82 Trop= 0.05 Eur=-14.54 NAmer= -6.13 NAtl= 2.84 NPac= -7.9

area: 17 x 10^-6 km^2

(gpdm)
Mean reduction over Europe, averaged over 29 forecasts (2 weeks)
black: experiments with lidar, gray: experiment with 100 dropsondes
Comparison to mean reduction of NWP error

Reduction of forecast error of 500 hPa geopotential height:
Lidar 72 h: ~ 1 m (3.5%)

Simmons and Hollingsworth 2002:
72 h: 10 m in 10 years
Analysis influence of lidar data

Analysis difference of lidar experiment and control run
26 November 2003, 00 UTC
Reduction of forecast error at 100 hPa - 72 h

Diff in RMS of fc-Error: RMS(fc_en5t - an_eiz3) - RMS(fc_eiz3 - an_eiz3)
Lev=100, Par=z, fcDate=20031115-20031128 00/12 UTC, Step=72
NH=-0.75 SH= 0.96 Trop= 1.25 Eur=-8.54 NAmer= 3.1 NATl= -0.04 NPac= -5.53

highest lidar observations at 250-300 hPa
Reduction of forecast error - 48, 72, 96 h
Relative reduction of RH forecast error - 48, 72, 96 h

→ Reduction of u, v, z, rh, and t forecast errors
A-TReC targeting campaigns

Cut off low; heavy precipitation in SE-Spain

20031115 at 18 Step42

DLR

NOAA

20031115 at 18 Step42

Heavy rain/strong wind in Portugal and NW-Spain

20031120 at 18 Step54

Smaller winds – northwest Europe

20031122 at 18 Step66

Strong winds – northwest Europe

20031122 at 18 Step66

Heavy rain, Scotland and Norway

20031125 at 18 Step30
The influence of targeted observations

- Contribution to FCE  Obs Rel Num

Airep  Lidar  Temp  Drop
ATReC 2003111518

Airep  Lidar  Temp  Drop
ATReC 200112018

Airep  Lidar  Temp  Drop
ATReC 2003111218

Airep  Lidar  Temp  Drop
ATRec 2003111518
The problem of case studies ...

statistical problem --> larger sample
practical restrictions --> better planning

28 forecasts
14-28 November
Impact outside the verification area

impact outside of verification area --> larger areas
improved sensitivity predictions - Kalman Filter
no compromise between sensitive areas calculated by different models
DIAL lidar water vapour observations

Transfer flights to 4 field campaigns during 2002 - 2005
Transfer Germany --> Oklahoma, IHOP 2002

Flentje et al. 2005
Stratospheric DIAL observations
Impact of lidar H2O-observations (preliminary)

Assigned errors: 4 - 10%

Mean relative background departure:
2400 observations
Std = 44%
Bias < 1%

Reduction of TCWV first guess error (lidar - control)
Conclusions

first assimilation of "real" Doppler lidar measurements in global NWP model

lidar measurements have a smaller error than all other operational wind observations
  --> analysis influence is 50% higher than that of dropsonde obs.
  information content is three times higher

lidar wind measurements reduce the average forecast error of u, v, z, rh, and t over Europe
average reduction of the 48 - 96h forecast error over Europe ~3%

propagation of the information into the lower stratosphere through 4D-Var

limitations of targeted observations
need for more cases, larger verification area, systematic decisions

ongoing water vapour studies

emphasizes the potential airborne and spaceborne lidars (ADM-Aeolus, possible future water vapour DIAL satellite)

Cost estimates

**ADM-Aeolus**
- Launch: 2009
- 300 Mio. Euros for 3 years
- 3000 LOS-profiles per day
- 100 Euros per LOS-profile
- Std 2-3 m/s
- Vert. resolution 500-1000 m
- Horiz. resolution 50/200 km
- No modification after launch
- Stratospheric winds
- Regular spacing

**Radiosonde/drops.**
- 10-20 Mio. Euros for >3 years
- 650 wind profiles per day
- Two wind components
- 15-30 Euros per LOS-profile
- Std 1-1.5 m/s
- Vert. resolution 100 m
- Horiz. res.: 50 km (up to 5 km)
- No signal in very clear air
- Could be operated longer

500-1000 Euros
Std 2-3 m/s
Also T, q, p