Representation of ozone in the ECMWF model

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1) Ozone in the ECMWF model
2) Ozone in the ECMWF analysis system
3) Validation of the ozone field
4) Bias correction for ozone
5) Monitoring of new data
6) Summary and outlook
1) Ozone in the ECMWF model

- Ozone mass mixing ratio is **prognostic variable** in IFS

\[
\frac{dO_3}{dt} = RO_3
\]

- **Simple chemistry parametrization** *(Cariolle and Déqué, 1986)*

\[
RO_3 = c_0 + c_1(O_3 - \overline{O}_3) + c_2(T - \overline{T}) + c_3\left(\sum O_3 - \sum \overline{O}_3\right) + c_4Cl_{eq}^2O_3
\]

  - \( c_i \) relaxation rates
  - photochemical equilibrium values, \( f(\text{lat}, p, \text{month}) \)
  - \( Cl_{eq} \) equivalent chlorine content of stratosphere, \( f(\text{year}) \)

T < 195 K
2) Ozone in the ECMWF analysis system

- Ozone included *univariately* in analysis system (minimize effect of ozone on the rest of analysis system)
- Assimilation of retrieved ozone columns and partial columns
- No interaction with radiation at present
- Stable ozone field, no trend
- *Model bias* at certain times of year, e.g. positive bias in NH in winter/spring.
Ozone assimilation in ERA-40 (3D-Var) and operations (4D-Var)

**ERA-40:**
- Ozone assimilation included for years after 1978
- 6-hour 3D-Var assimilation system, $T_L159$ ($\approx 125$ km)

**Operations:**
- Assimilation of ozone retrievals since April 2002
- 12-h 4D-Var assimilation system $T_L511$ ($\approx 40$ km)
Ozone data used in ERA-40 (1)

- **TOMS (Total Ozone Mapping Spectrometer):**
  - Total column ozone
  - nadir viewing instrument
  - 35 FOV along 1 scan
  - 6 wavelengths: 312, 317, 331, 340, 360, 380nm
  - ca. 200000 obs daily (≈20000 used)

- **SBUV (Solar Backscatter UltraViolet):**
  - 6 ozone layers:
    - 0.1-1 hPa, 1-2 hPa, 2-4 hPa, 4-8 hPa
    - 8-16 hPa, 16hPa – surface
  - nadir viewing instrument
  - instantaneous FOV
  - 12 wavelengths: 252 (256), 273, 283, 288, 292, 298, 302, 306, 312, 318, 331, 340 nm
  - ca. 1400 obs daily (1200 used)

- Daylight measurements only
- Daily global coverage
- Both datasets have been reprocessed
# Ozone data used in ERA40 (2)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Satellite</th>
<th>Year</th>
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<tbody>
<tr>
<td>TOMS</td>
<td>Nimbus-7</td>
<td>12/78 - 5/93</td>
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<tr>
<td>TOMS</td>
<td>Meteor-3</td>
<td>4/93 - 12/94</td>
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<td>SBUV</td>
<td>Nimbus-7</td>
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<td>NOAA-9</td>
<td>1/95 - 2/98</td>
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<td>NOAA-11</td>
<td>1/91 - 10/94, 1/98 - 5/01</td>
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<tr>
<td>SBUV</td>
<td>NOAA-16</td>
<td>5/01 -</td>
</tr>
</tbody>
</table>
Ozone data assimilated operationally since 9 April 2002

• **GOME** (Global Ozone Monitoring Exp.):
  - On ERS-2
  - Total column ozone
  - Spectral range: 240 – 790 nm
  - NRT retrievals from KNMI (version FD 3.1)
  - approx. 20000 obs daily (14000 used)

• **SBUV/2 (NESDIS retrievals):**
  - NOAA-16
  - NOAA-14 passive
  - NOAA-17 passive (since 20020804,18z)
  - 6 ozone layers:
    0.1-1 hPa, 1-2 hPa, 2-4 hPa, 4-8 hPa, 8-16 hPa, 16hPa - surface
  - approx. 1400 obs daily (1200 used)

• **Blacklist criteria:**
  - at solar elevations < 10°
  - at latitudes > 40° in NH
  - at latitudes < -50° in SH
  - QC flag > 0

• **Blacklist criteria:**
  - at solar elevations < 6°
  - QC flag > 0
Background error covariance matrix for ozone

- Determines how analysis increment from column observations is spread in vertical
- Calculated with analysis ensemble method
- Anti-correlations between stratosphere and troposphere in original covariances (used in ERA-40 between 1991-10/1996)
- Modified covariances used in ERA-40 before 1991 and after 10/1996. Also used in operational system.
- Problems with vertical ozone profiles in situations when analysis increment is large
Original background error covariance matrix

Increment created by 1 TOMS obs

Wavenumber averaged vertical correlation matrix for ozone

Ozone observation of 247 DU, 66 DU lower than background
**Modified background error covariance matrix**

Increment created by 1 TOMS obs

Wavenumber averaged vertical correlation matrix for ozone

Ozone observation of 247 DU, 66 DU lower than background
3) Validation of the ozone field

Total ozone (Dobson units)

Barrow 71N 157W

57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02

Plot produced by Adrian Simmons

VTPR data

Begin o3 assim.

No o3 assim.
Total column ozone validation

Total ozone (Dobson units)

Plot produced by Adrian Simmons

Bismarck 47N 101W

Year

VTPR data

Begin o3 assim.

No o3 assim.
Total column ozone validation

Total ozone (Dobson units)

Plot produced by Adrian Simmons

Mauna Loa 20N 156W

Year

VTMR data

Begin o3 assim.

No o3 assim.
Total column ozone validation

Total ozone (Dobson units)

Plot produced by Adrian Simmons

VTPR data
Begin o3 assim.
No o3 assim.

Amundsen-Scott 90S

Year

100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500

57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02
Total column ozone - Ozone hole

No O3 assim.

With O3 assim

TOMS

30 Sept. 1990
South Pole ozone profiles: April 1964

Ozone profiles from sondes and 0020
Amundsen-Scott (Lat = -90.0)
Month = 196404 (7 sondes)

Temperature profiles from sonde and 0020
Amundsen-Scott (Lat = -90.0)
Month = 196404 (7 sondes)

Ozonesonde data obtained from WOUDC
South Pole ozone profiles: October 1965

Ozone profiles from sondes and 0020
Amundsen-Scott (Lat = -90.0)
Month = 196510 (9 sondes)

Temperature profiles from sonde and 0020
Amundsen-Scott (Lat = -90.0)
Month = 196510 (9 sondes)

Ozonesonde data obtained from WOUDC
NH mid-latitudes ozone profiles

• **1967–1969:** Before assimilation of satellite data

• **1973–1975:** Assimilation of VTPR data

• **1979–1981:** Assimilation of TOMS and SBUV from Nimbus-7; modified covariances

• **1992–1993:** Assimilation of TOMS from Nimbus-7 and SBUV from NOAA-11; old covariances

Ozonesonde data obtained from WOUDC
Summary NH mid-latitude ozone profiles

• Ozone profiles reasonable during large part of year

• Bias during winter/spring months:
  O3 values below the maximum too large

• Bias worse when VTPR data are assimilated

• Assimilation of ozone retrievals improves profiles, except at times when biases are present

• Bad profiles when ozone retrievals are assimilated in presence of bias
Summary NH mid-latitude ozone profiles

Old covariances:
Remove ozone below O3-maximum and add in troposphere

Modified covariances:
Remove ozone near O3-maximum

Model bias
4) Developing a bias correction for ozone

- Bias between model and observations violates underlying assumption of DA that obs and fg are unbiased

- **Model AND ozone data** can have bias

  - Understand model bias
  - Correct model bias

  - Transport?  Chemistry?

- Develop a bias correction for ozone data, based on **independent** observations

- Use **ground-based** Brewer and Dobson observations (obtained from WOUDC: http://www.msc-sms.ec.gc.ca/woudc)
Developing a bias correction for ozone

**Linear fit:**
\[ y = 3.5 - 0.1 \times \]

Use independent observations to develop bias correction

Apply at SZA <75

Relative difference between GOME and Brewer obs. (1999)
Developing a bias correction for ozone

GOME

Mean: -10.3
Stdv: 20.9

Bias corrected GOME

Mean: -4.0
Stdv: 21.3

First-guess departures in DU (Period: 20021010 - 20021015)
Developing a bias correction for ozone

Profiles at Ny-Aalesund on 20021011 from 3 experiments

Improvement when bias corrected data are assimilated

Both passive
BCOR active
KNMI active
O3 sonde
4) Monitoring of new data

• Use assimilation system to evaluate
  ▪ Data quality
  ▪ Biases
  ▪ Instrument and algorithm stability

• ENVISAT retrievals are currently monitored passively
  ▪ SCIAMACHY total ozone
  ▪ MIPAS ozone, temperature, water vapour profiles
  ▪ (GOMOS ozone, temperature, water vapour profiles)
SCIAMACHY total ozone

SCIAMACHY Total fields (30N-30S) GOME

SCIAMACHY about 25 DU lower than GOME
MIPAS ozone data

Global means: 1.5.-15.5.2003

Departures

Obs and Ana
MIPAS water vapour data

Global means: 1.5.-15.5.2003

MIPAS moister than ECMWF analysis
MIPAS water vapour data: 1.3.-30.4.2003

20-65S

Obs and Ana (6-10 hPa)

65-20N

Departures larger in SH than in NH

19.-25.5.2003
5) Summary

- Ozone is prognostic variable in ECMWF model
- Cariolle and Déqué chemistry parametrization
- Ozone included uni-variately in 3D-Var and 4D-Var
- Ozone retrievals from TOMS and SBUV/2 are assimilated in ERA40 (3D-Var)
- Ozone retrievals from GOME (KNMI, v. FD 3.1) and SBUV/2 are assimilated operationally since 9 April 2002 (4D-Var)
Summary

Total column

- Good total ozone field when ozone observations are assimilated
- Realistic seasonal cycle, interannual variability, Antarctic ozone hole
- Total column ozone field also reasonable in earlier years of ERA-40
- Some biases, particularly in NH winter/spring.
- Biases worse after 1972 (when VTPR data are assimilated)
- Total column ozone over Antarctica too low before 1979
Profiles

- Ozone profiles reasonable during large part of year
- Bias during winter/spring months:
  - O3 values below the maximum too large
- Bias worse when VTPR data are assimilated

- Assimilation of ozone retrievals improves profiles, except at times when biases are present
- Bad profiles when ozone retrievals are assimilated in presence of bias

Monitoring

- Assimilation system is powerful tool for data monitoring. Can help to detect biases, instrument/algorithm changes, assess data quality

Need for bias correction. Need to understand model bias. Background error covariances?