Representation of ozone in the ECMWF model

Antje Dethof
ECMWF

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)

$$RO_3 = c_0 + c_1\left(O_3 - \overline{O}_3\right) + c_2\left(T - \overline{T}\right) + c_3\left(\sum O_3 - \sum \overline{O}_3\right) + \underbrace{c_4 Cl_{eq}^2 O_3}_{T < 195\ K}$$

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

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)

Instrument	Satellite	Year
TOMS	Nimbus-7	12/78 - 5/93
TOMS	Meteor-3	4/93 - 12/94
TOMS	Earthprobe	9/96 -
TOMS	ADEOS-1	10/96-2/97
SBUV	Nimbus-7	12/78-6/90
SBUV	NOAA-9	1/95 – 2/98
SBUV	NOAA-11	1/91 - 10/94, 1/98 – 5/01
SBUV	NOAA-16	5/01 -

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)

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

- **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)

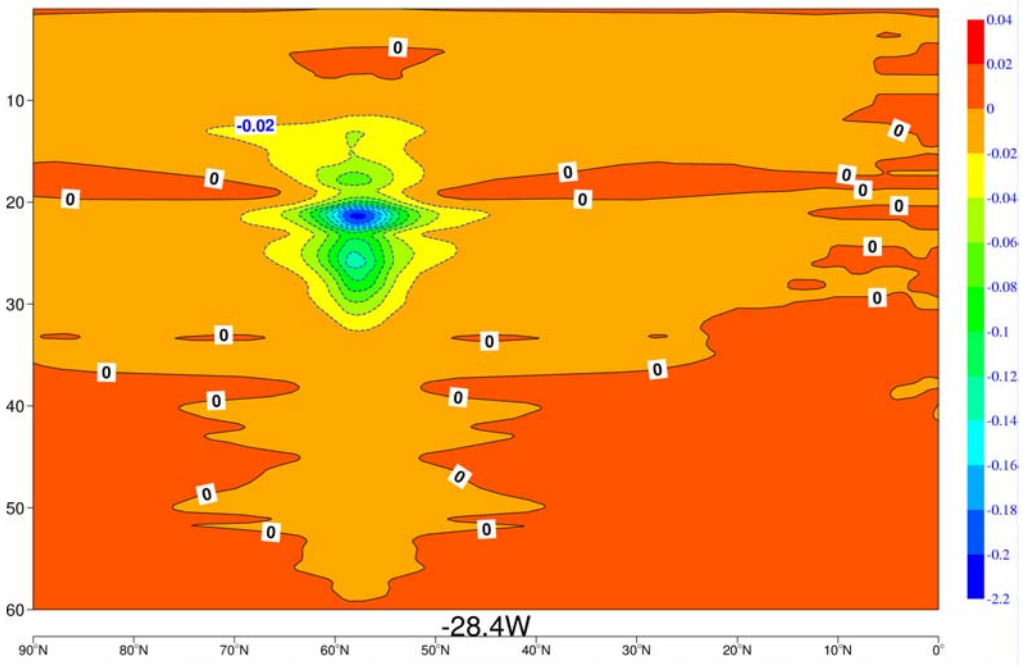
- **Blacklist criteria:**
  - at solar elevations < 6°
  - QC flag > 0

Background error covariance matrix for ozone

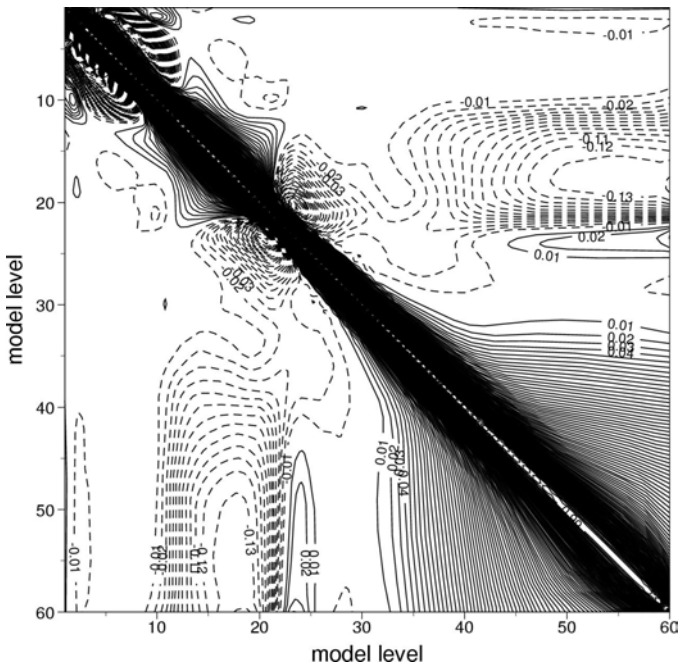
- Determines how analysis increment from column observations is spread in vertical
- Calculated with analysis ensemble method
- Anti-correlations between stratosphere and troposphere in original covariances (used in ERA-40 between 1991- 10/1996)
- Modified covariances used in ERA-40 before 1991 and after 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



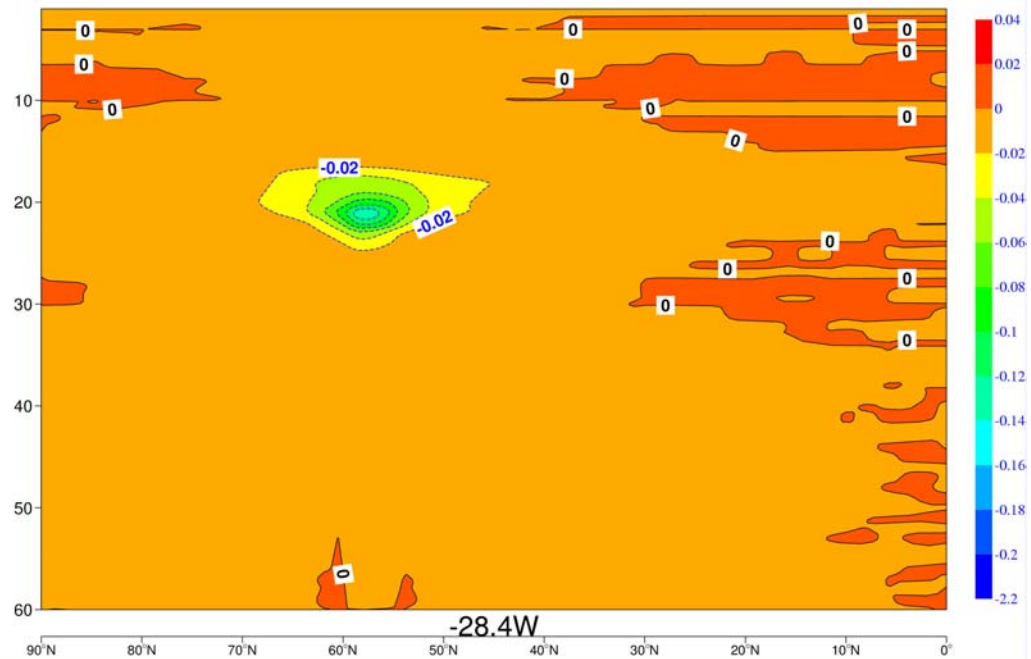
Wavenumber averaged vertical correlation matrix for ozone



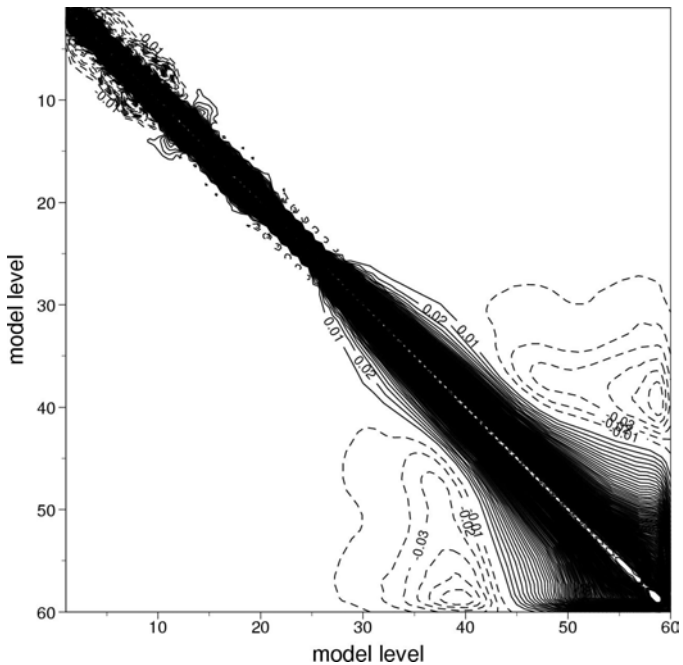
Ozone observation of 247 DU, 66 DU lower than background

Modified background error covariance matrix

Increment created by 1 TOMS obs

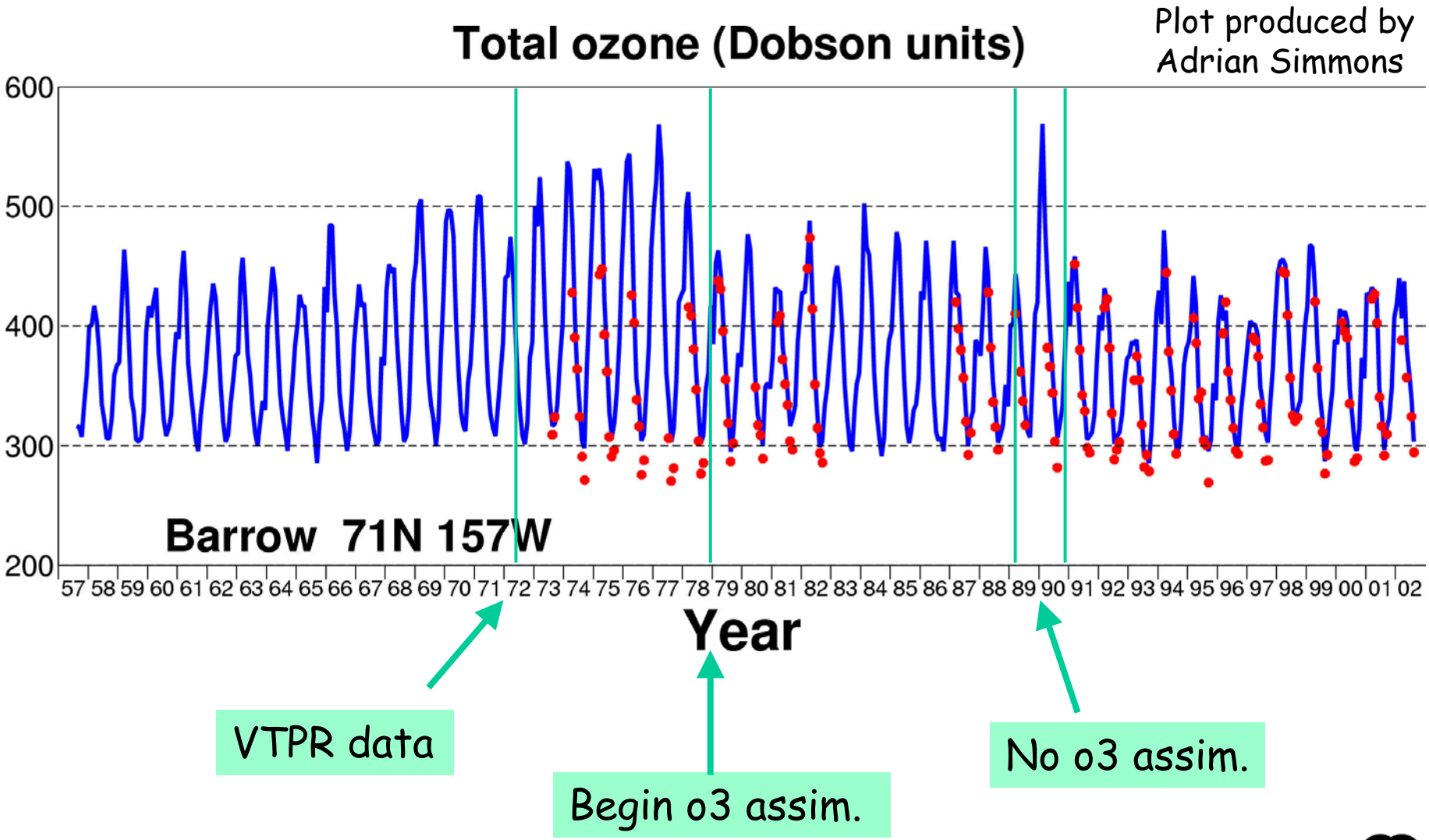


Wavenumber averaged vertical correlation matrix for ozone

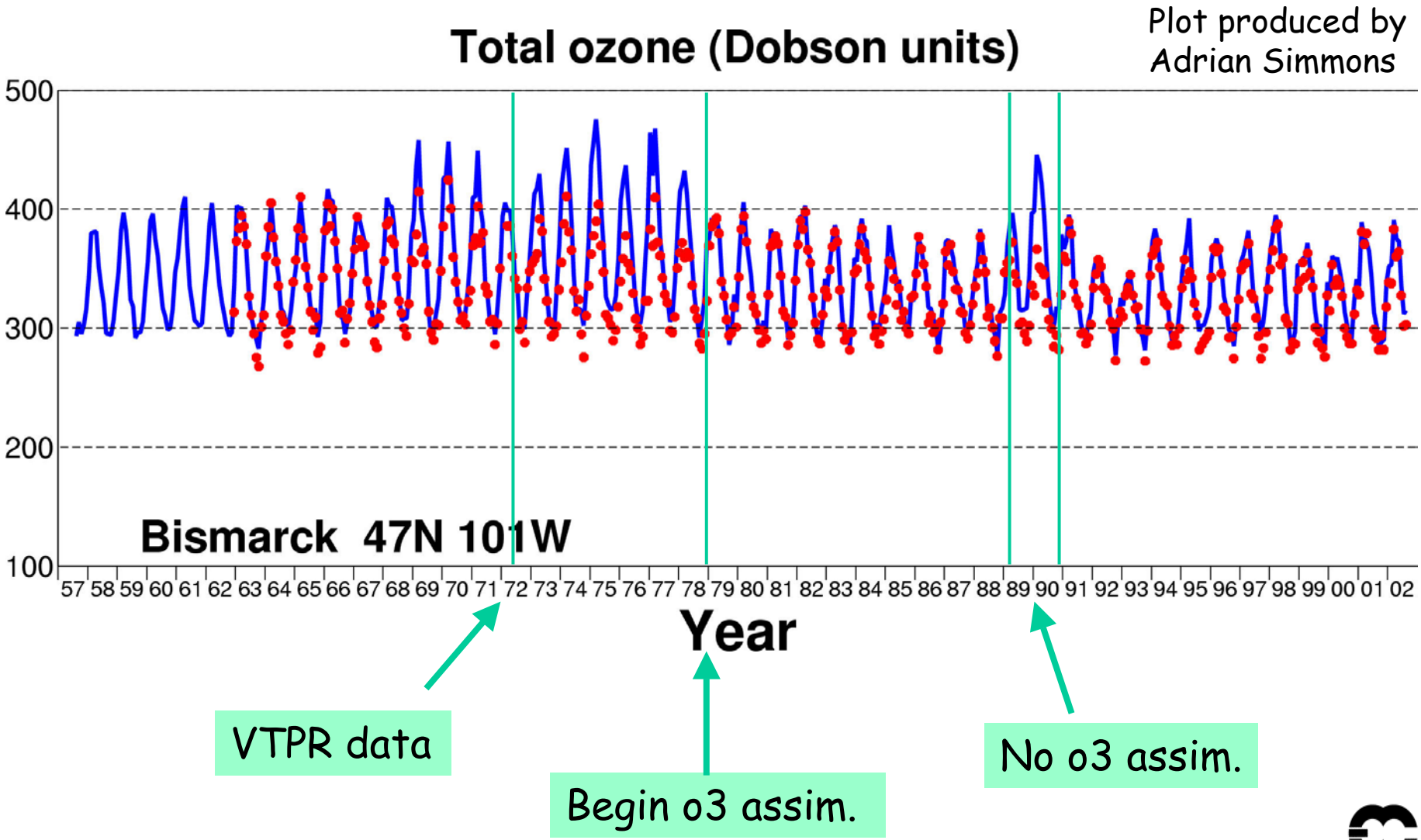


Ozone observation of 247 DU, 66 DU lower than background

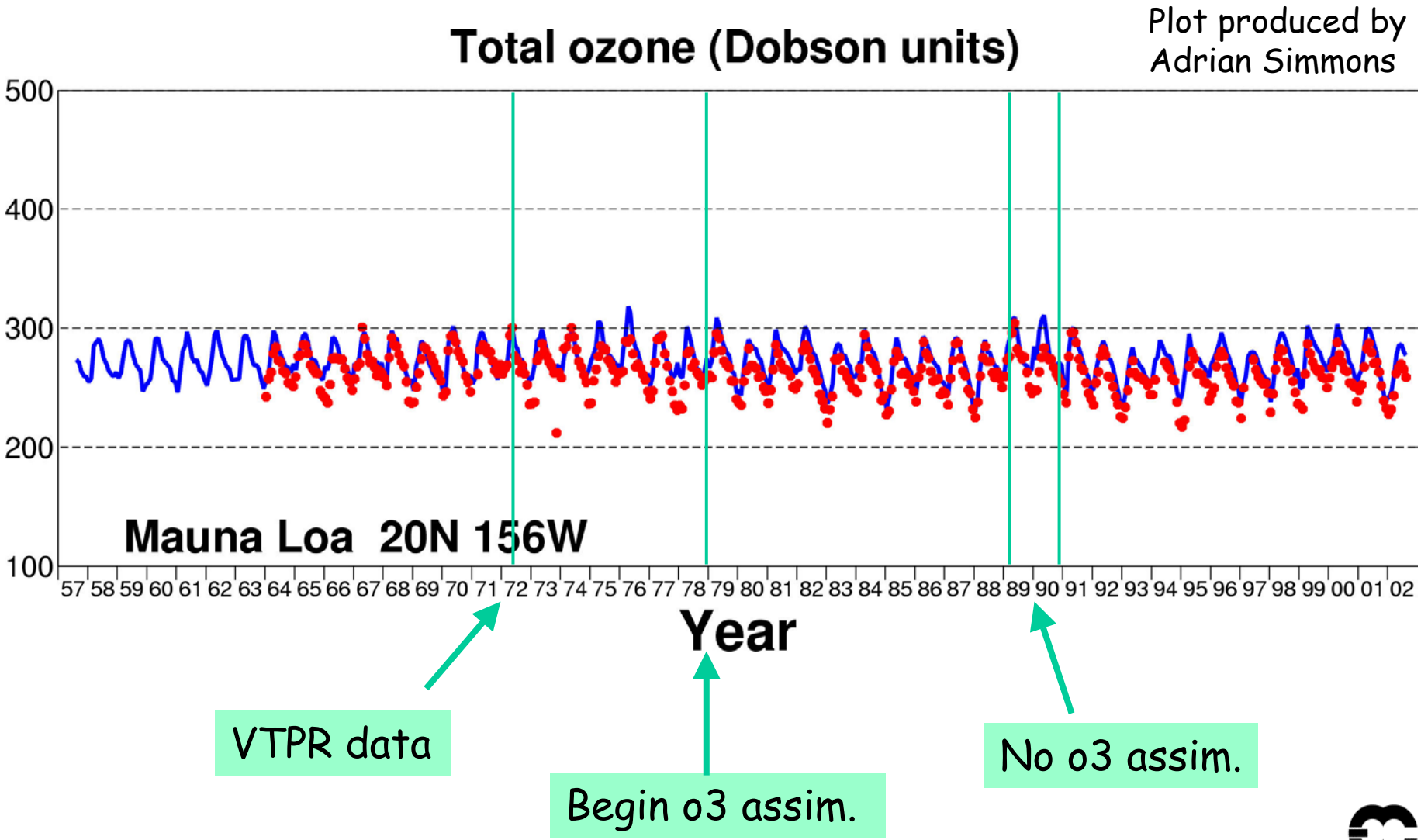
3) Validation of the ozone field



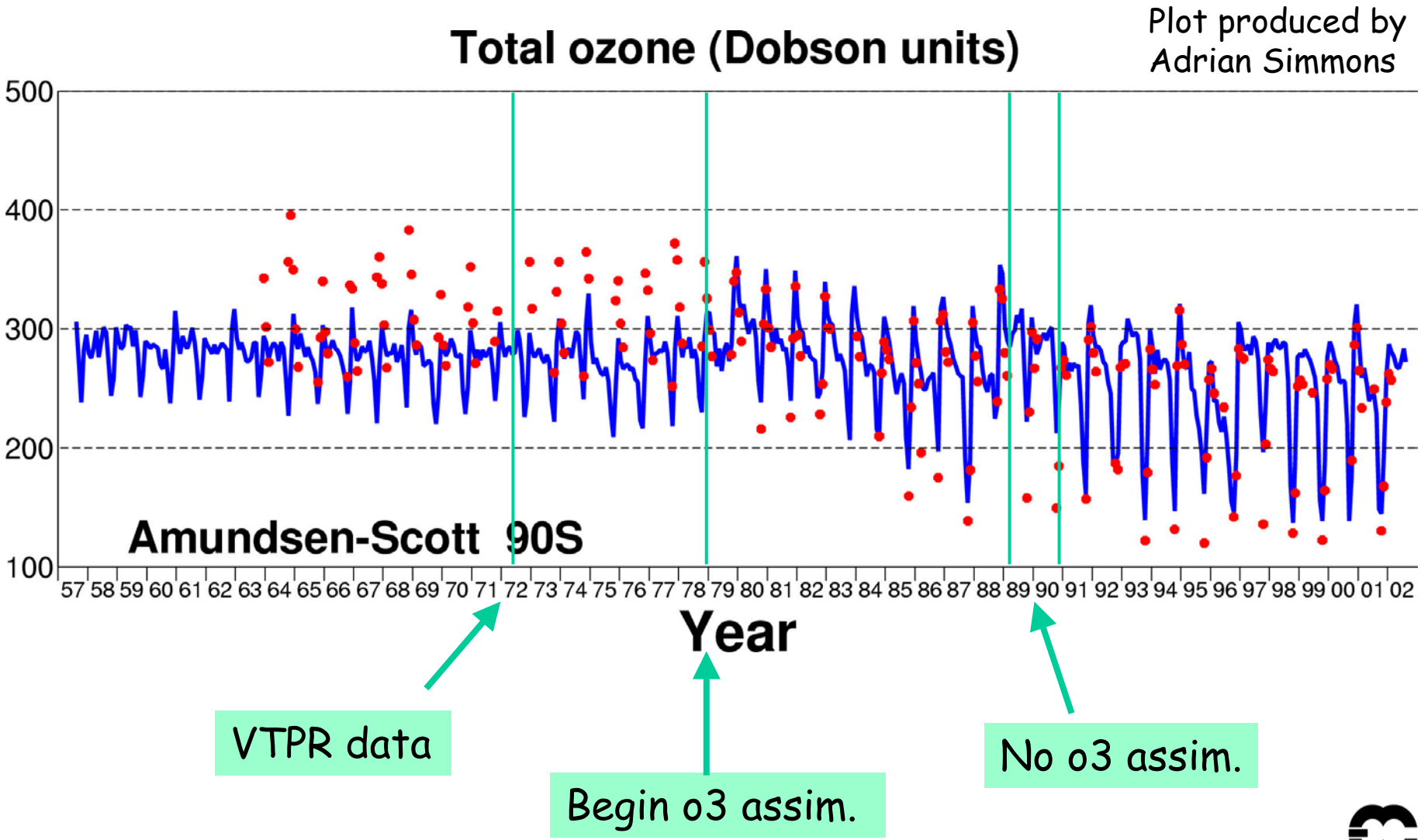
Total column ozone validation



Total column ozone validation



Total column ozone validation

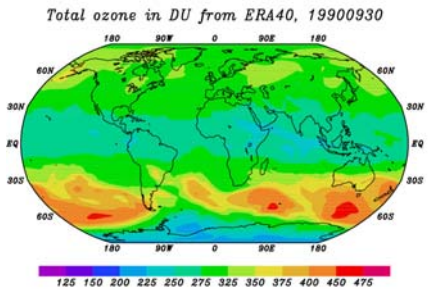


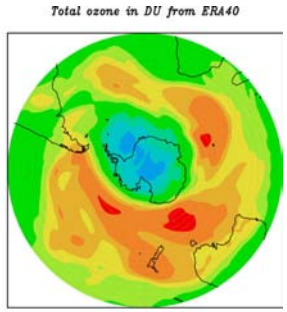
Total column ozone – Ozone hole

No O3 assim.

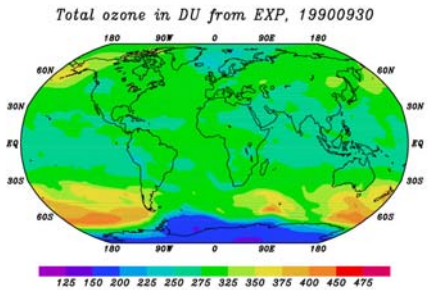
With O3 assim

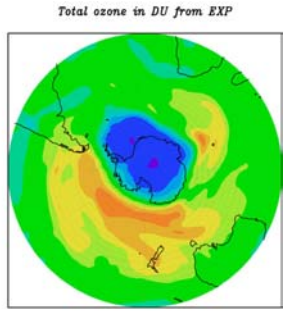
TOMS

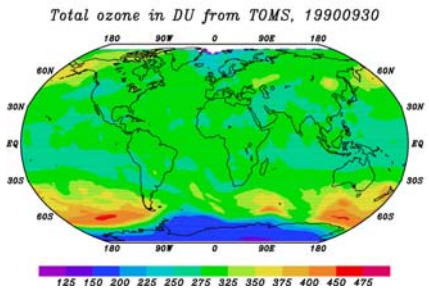


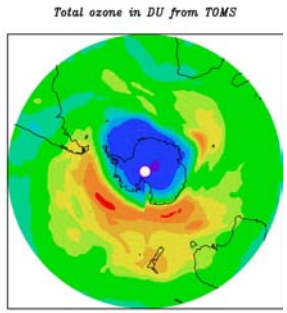


30 Sept. 1990

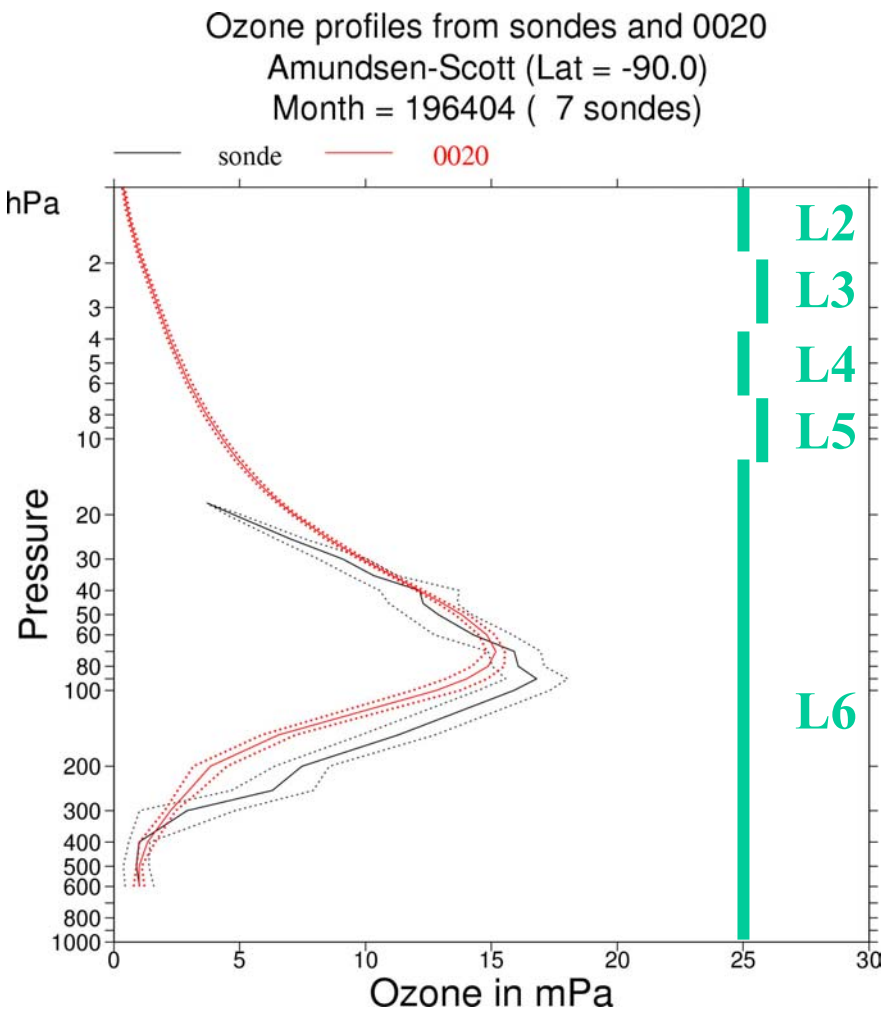


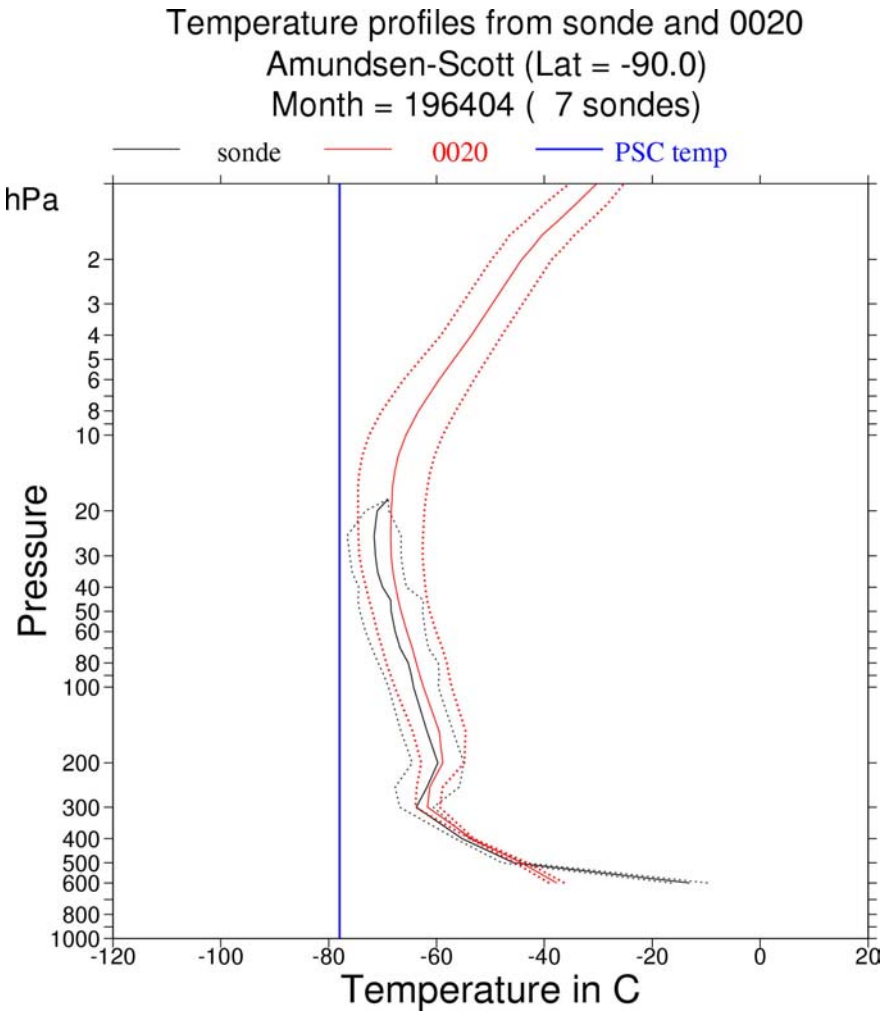






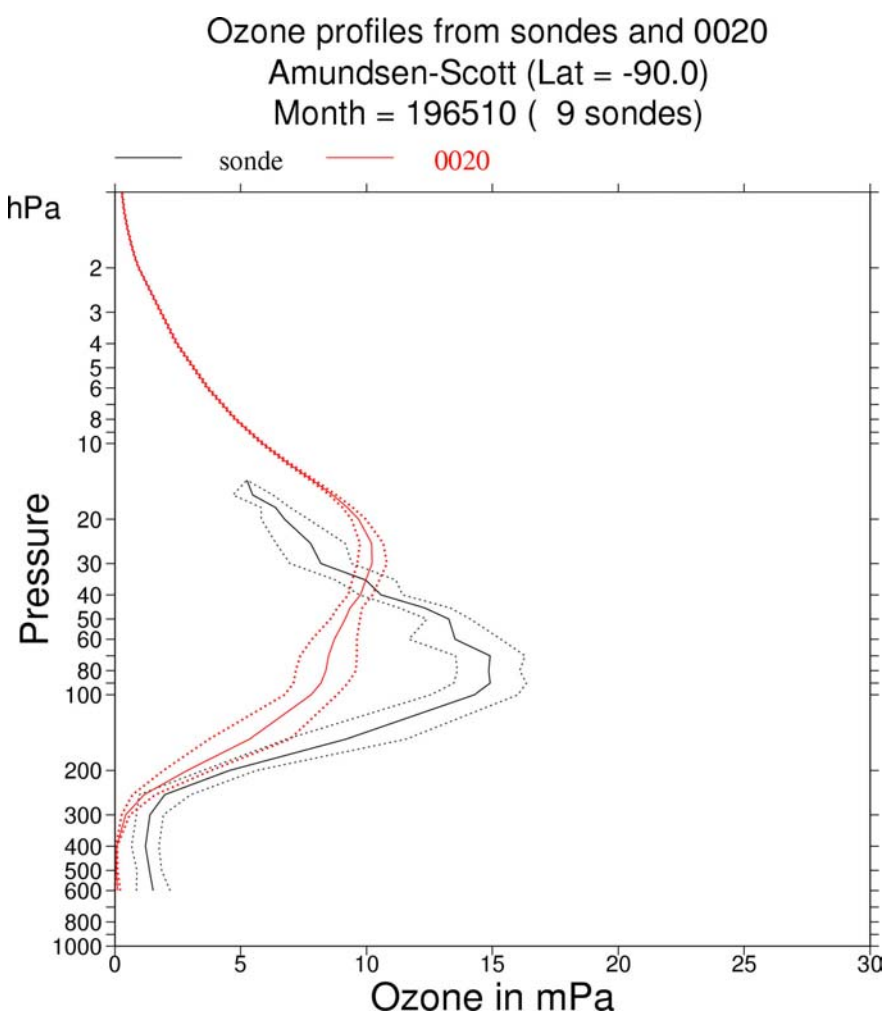
South Pole ozone profiles: April 1964

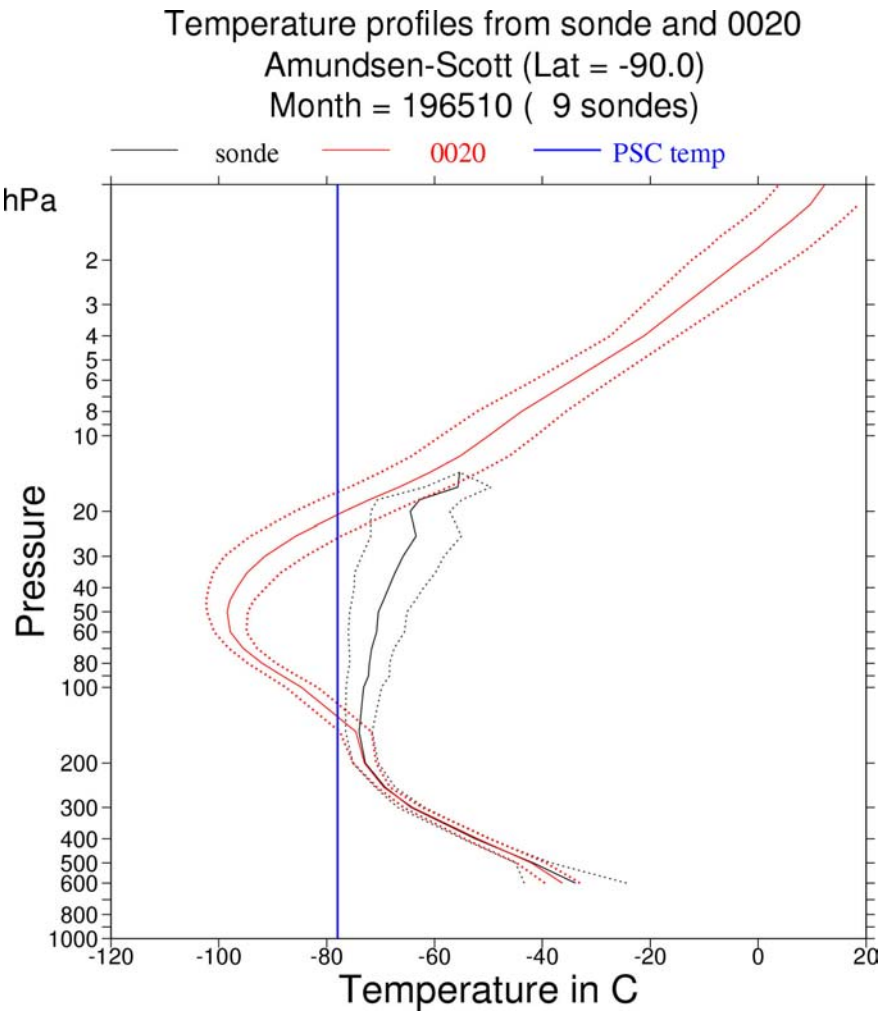




Ozonesonde data obtained from WOUDC

South Pole ozone profiles: October 1965

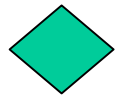




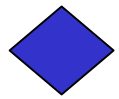
Ozonesonde data obtained from WOUDC

NH mid-latitudes ozone profiles

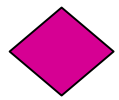
- **1967-1969:** Before assimilation of satellite data



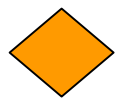
- **1973-1975:** Assimilation of VTPR data



- **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

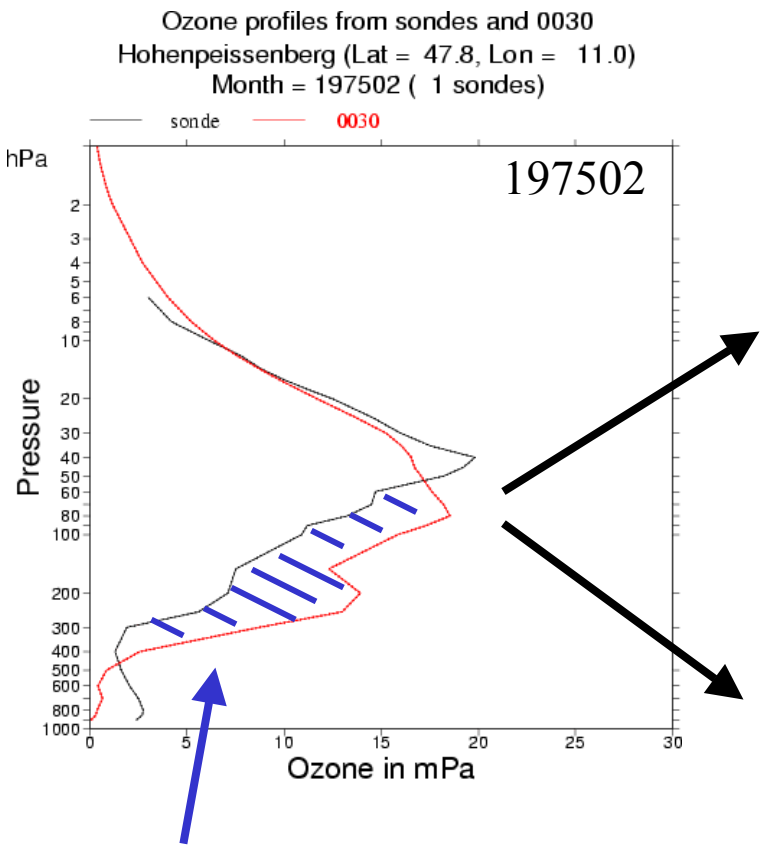


Ozonesonde data obtained from WOUDC

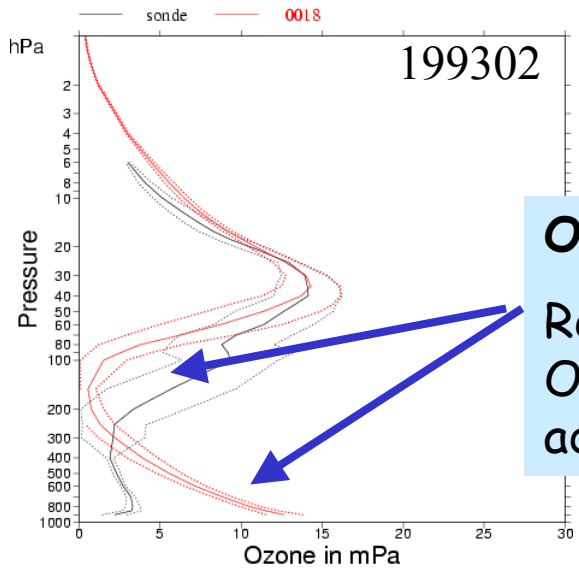
Summary NH mid-latitude ozone profiles

- 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

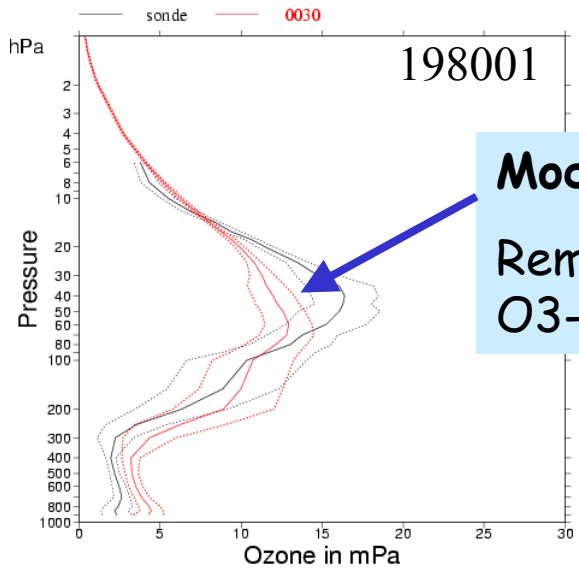


Model bias



Old covariances:

Remove ozone below O3-maximum and add in troposphere



Modified covariances:

Remove ozone near O3-maximum

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

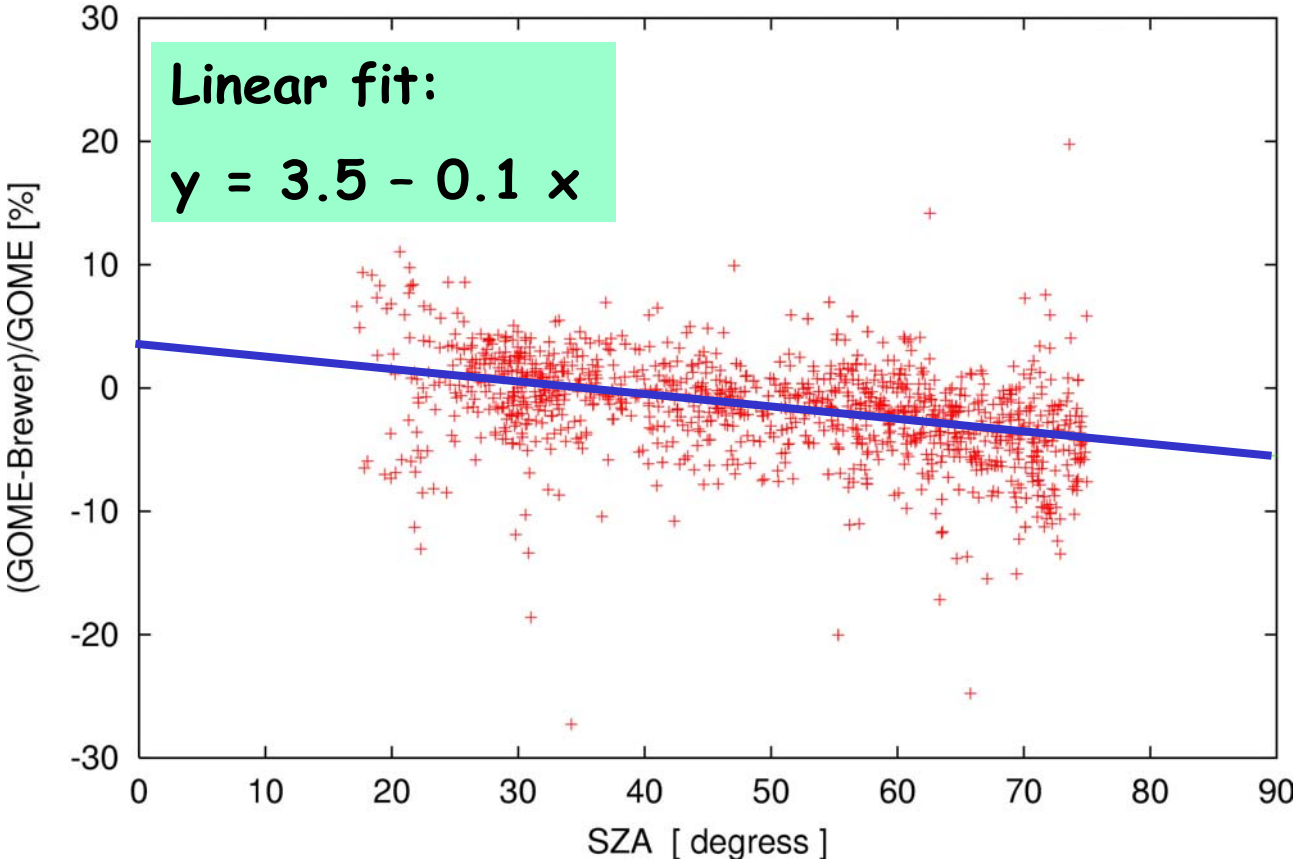
- Understand model bias
- Correct model bias

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



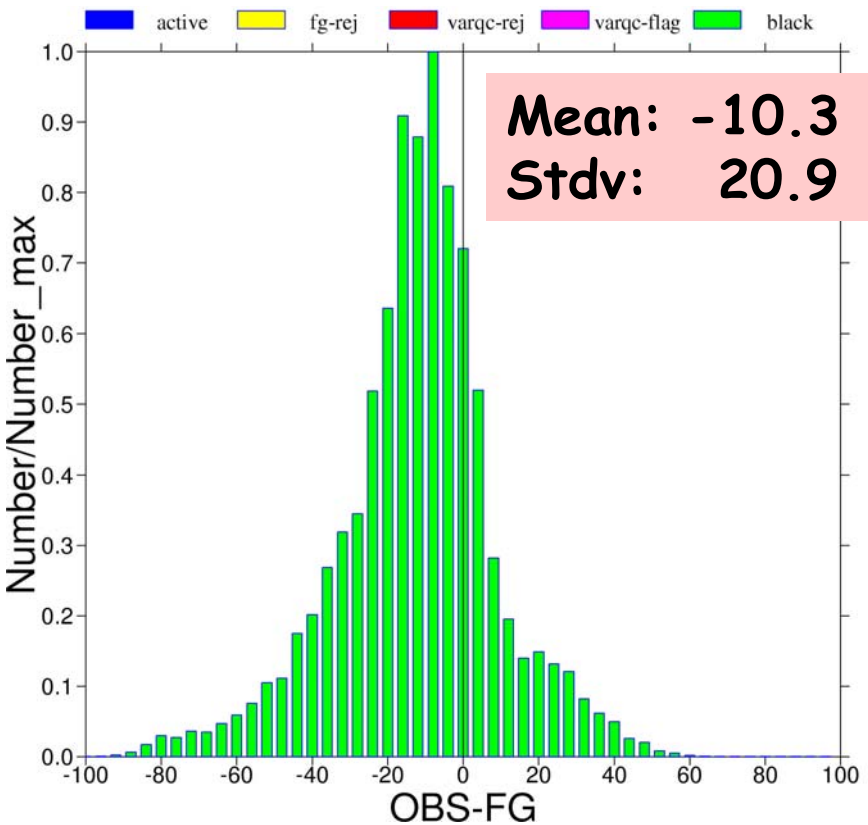
Use **independent** observations to develop bias correction

Apply at SZA <75

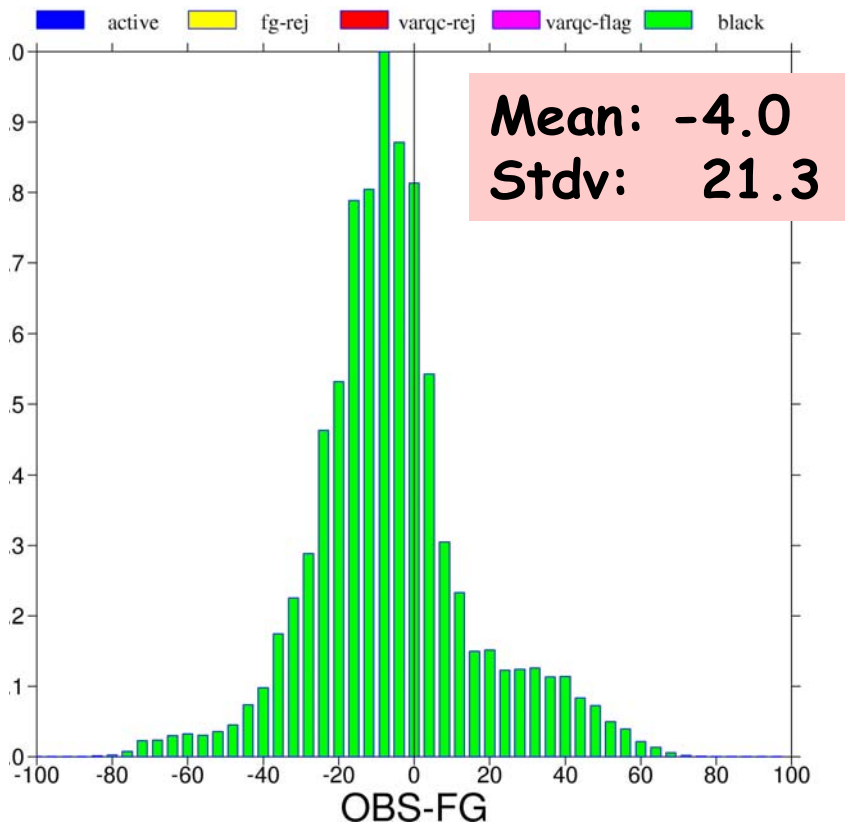
Relative difference between GOME and Brewer obs. (1999)

Developing a bias correction for ozone

GOME

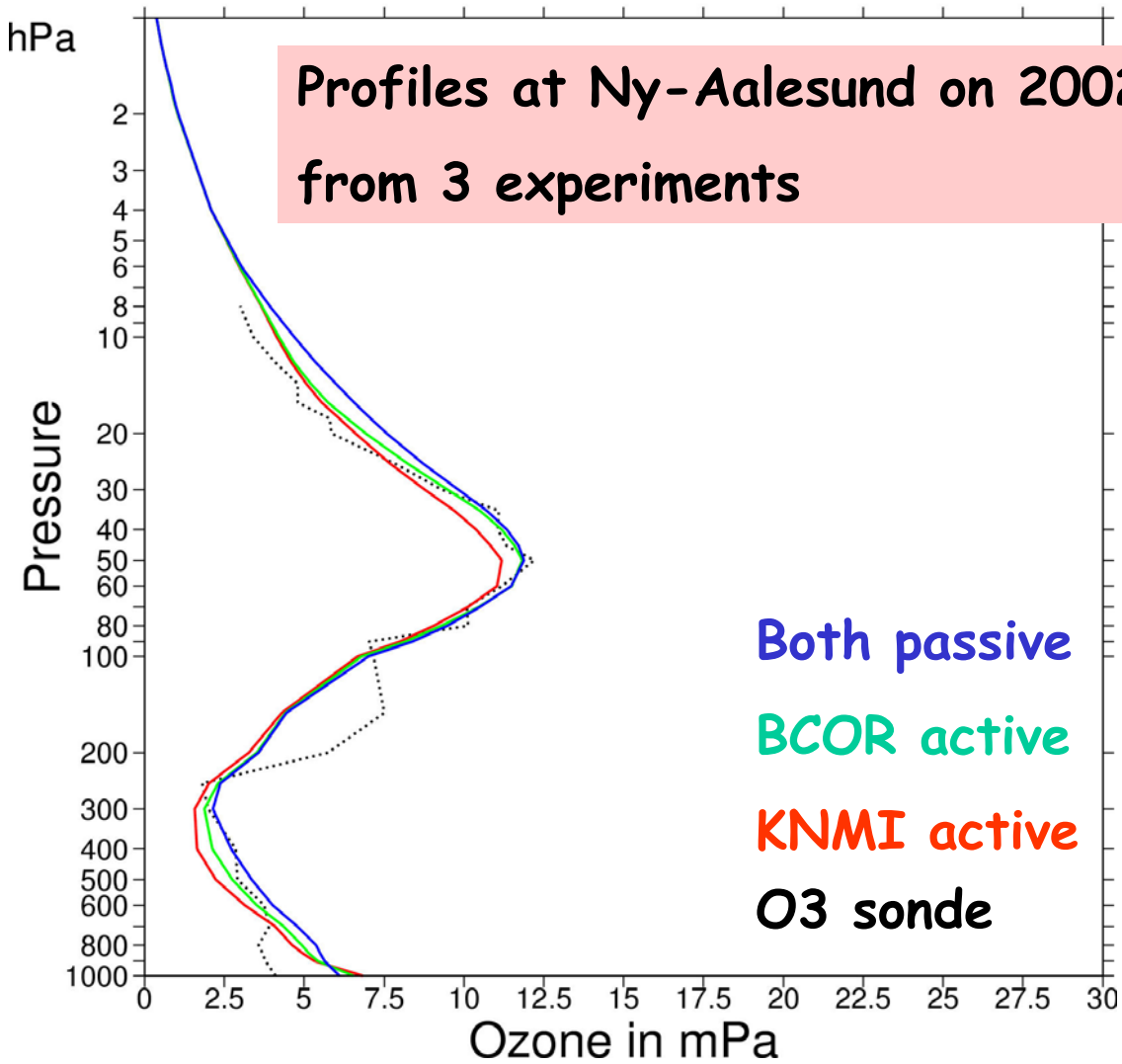


Bias corrected GOME



First-guess departures in DU (Period: 20021010 – 20021015)

Developing a bias correction for ozone



Improvement when bias corrected data are assimilated

4) Monitoring of new data

- **Use assimilation system to evaluate**
  - Data quality
  - Biases
  - Instrument and algorithm stability

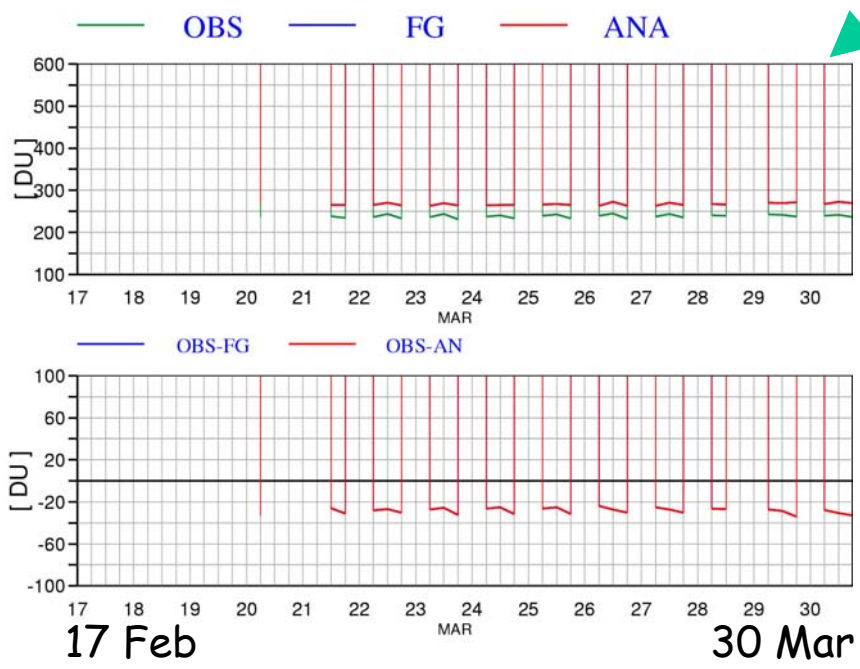
- **ENVISAT retrievals are currently monitored passively**
  - **SCIAMACHY** total ozone
  - **MIPAS** ozone, temperature, water vapour profiles
  - (**GOMOS** ozone, temperature, water vapour profiles)

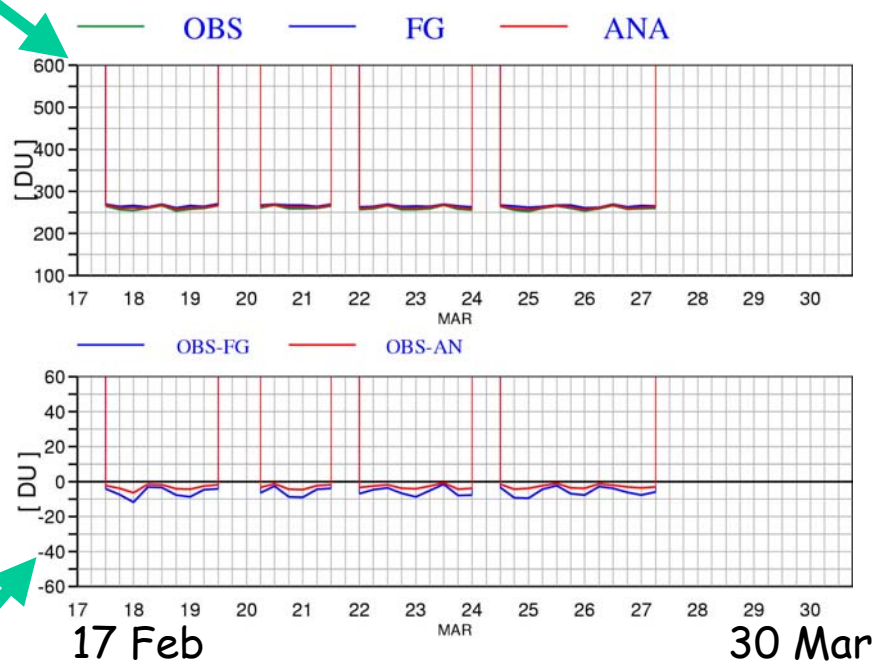
SCIAMACHY total ozone

SCIAMACHY

Total fields (30N-30S)

GOME





-30

17 Feb

30 Mar

17 Feb

30 Mar

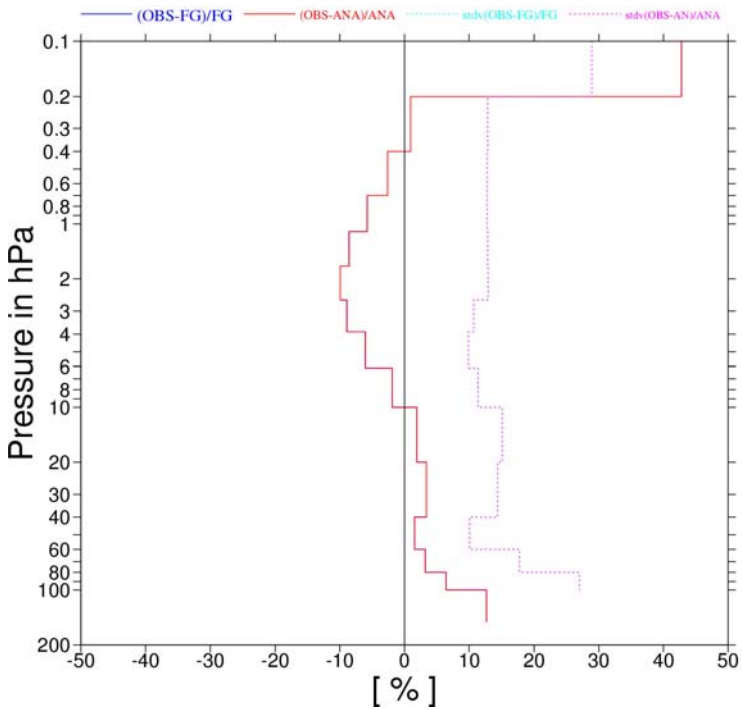
Departures

SCIAMACHY about 25 DU lower than GOME

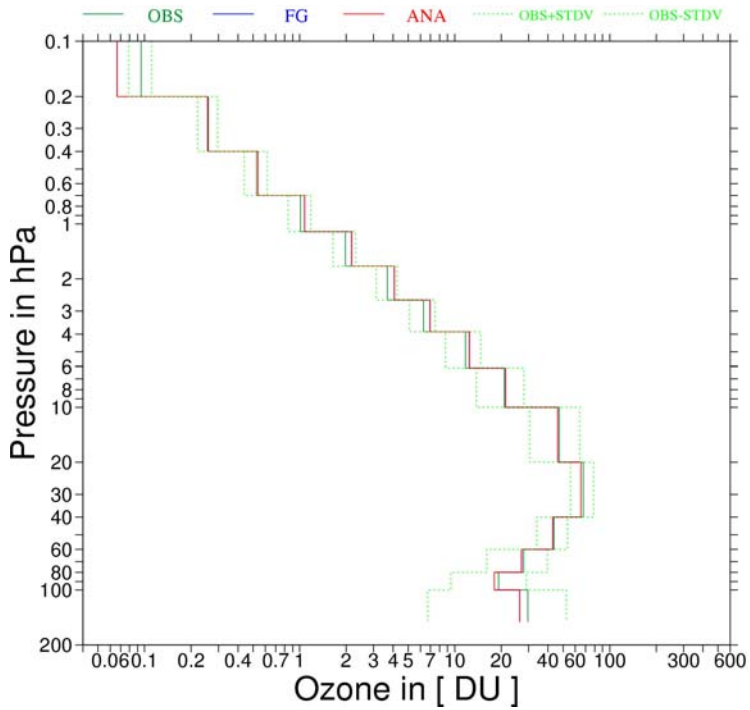
MIPAS ozone data

Global means: 1.5.-15.5.2003

Departures



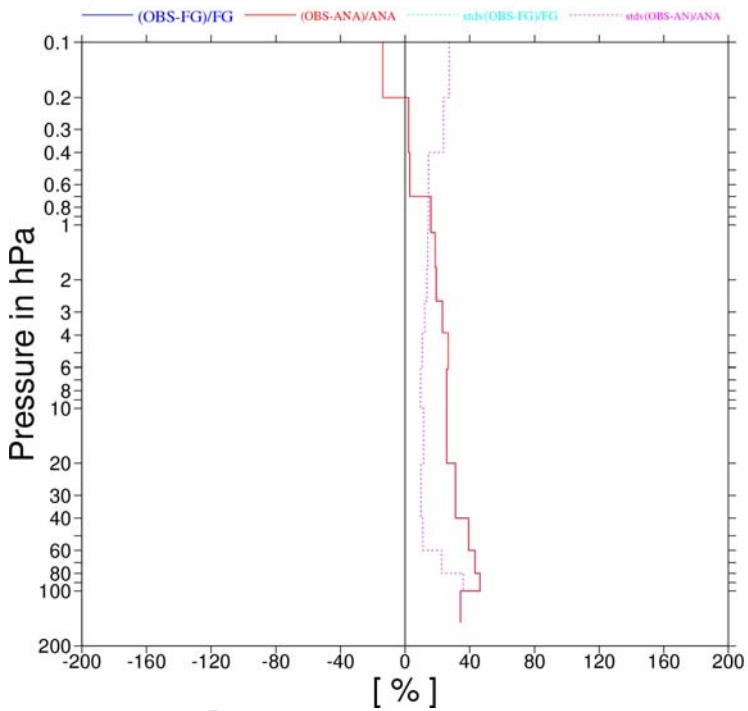
Obs and Ana



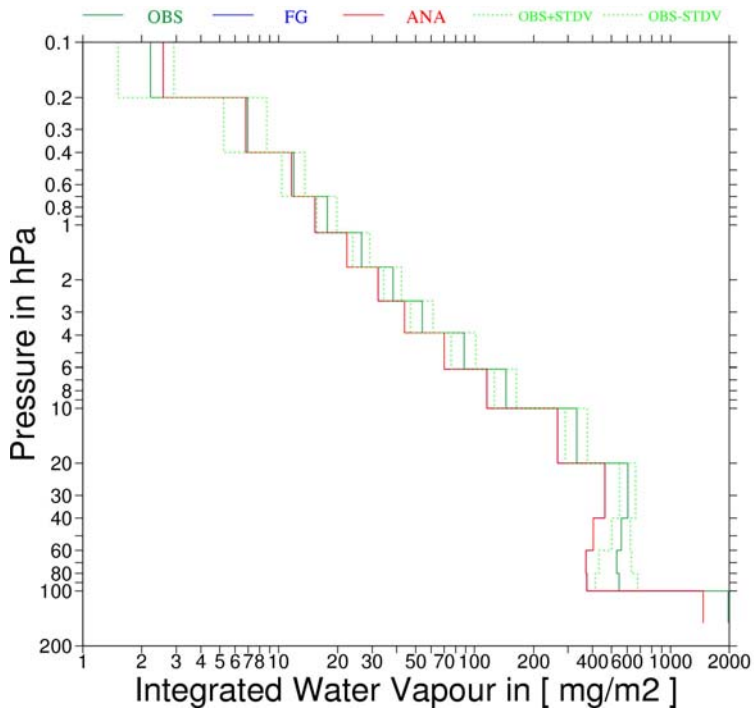
MIPAS water vapour data

Global means: 1.5.-15.5.2003

Departures



Obs and Ana



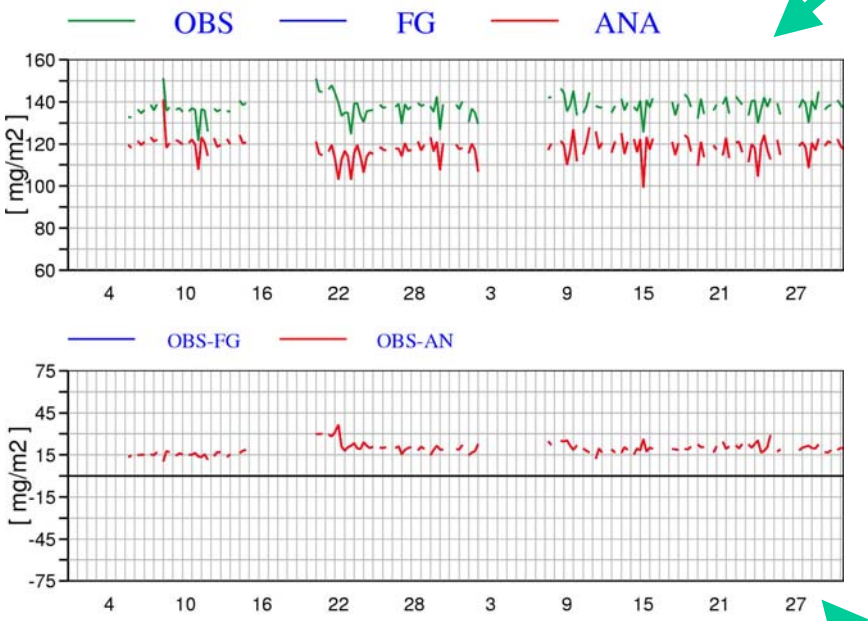
MIPAS moister than ECMWF analysis

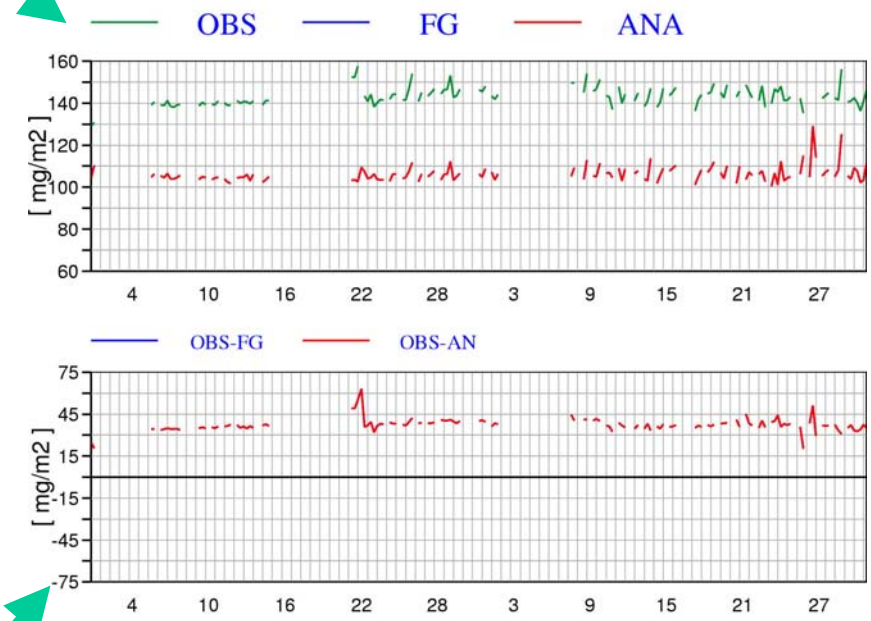
MIPAS water vapour data: 1.3.-30.4.2003

Obs and Ana (6-10 hPa)

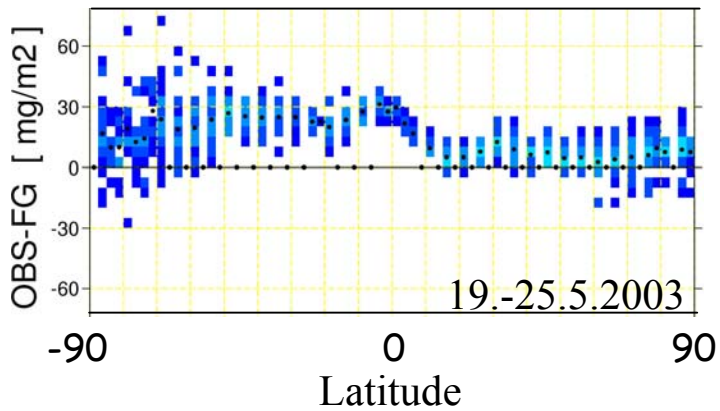
20-65S

65-20N





Departures



Departures larger in SH than in NH

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

Summary cont.

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

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

Monitoring

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