Assimilated total ozone record from 30 year of UV-VIS satellite observations

Ronald van der A, Marc Allaart, Henk Eskes

KNMI

PROMOTE

TEMIS

macc Monitoring atmospheric composition & climate

Outline

- Introduction and background
- Merging level 2 data => multi-sensor reanalysis level 2
- Data assimilation => multi-sensor reanalysis level 4
- Results and quality analysis

Total Ozone Record
- approach -

- The objective is to constructing a long-term consistent and complete ozone record of 30 years
- All satellite data is used that is publicly available and complete.
- Step 1 : Correct satellite data to avoid biases. The reference data that is chosen are ground data observations from reliable WOUDC stations.
- Step 2 : Satellite data is assimilated in a chemical-transport model to achieve complete global and temporal coverage.

Available level 2 ozone data (UV-VIS)

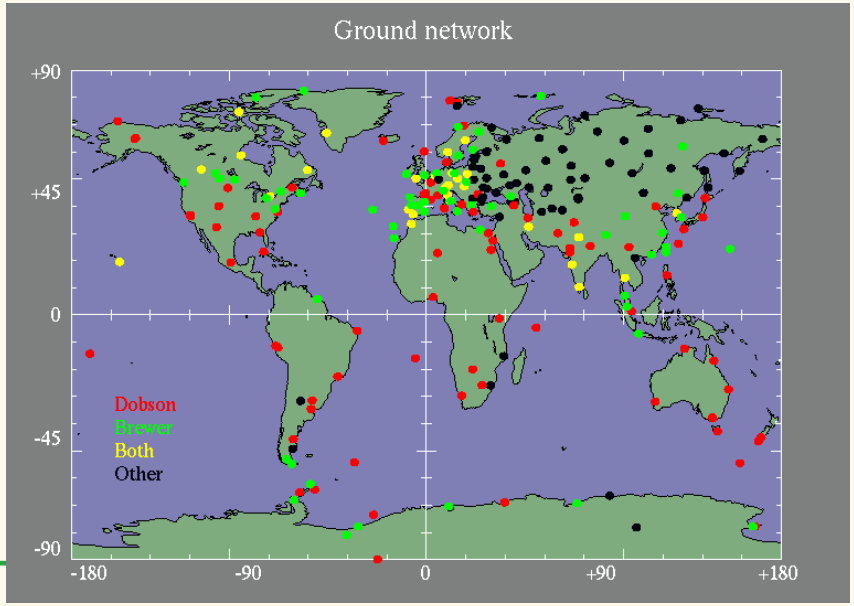
TOMS Nimbus 7:	**1978-1993**	**TOMS v.8**	**NASA**
TOMS EarthProbe:	**1996-2002**	**TOMS v.8**	**NASA**
SBUV 7, 9a, 9d, 11, 16:	**1978-2004**	**SBUV v.8**	**NOAA**
GOME :	**1995-2008**	**GDP v.4**	**ESA/DLR**
GOME :	**1995-2008**	**TOGOMI v1.2**	**KNMI**
SCIAMACHY :	**2002-2008**	**SGP v.3**	**ESA/DLR**
SCIAMACHY :	**2002-2008**	**TOSOMI v.0.43**	**ESA/KNMI**
OMI :	**2004-2008**	**TOMS v.3**	**NASA**
OMI :	**2004-2008**	**OMDOAO3 v.3**	**KNMI**
GOME-2 :	**2007-2008**	**GDP v.4.2**	**EUMETSAT/DLR**
WOUDC:	**1978-2008**	**Brewer(3,4), Dobson, Filter**	

Merging Level 2 data

Reference data

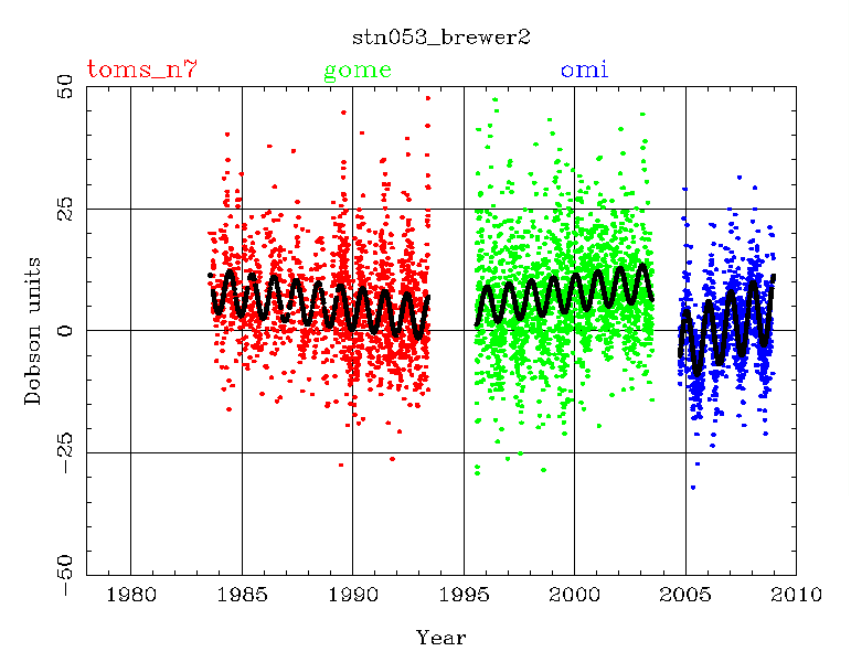
Reference data set:

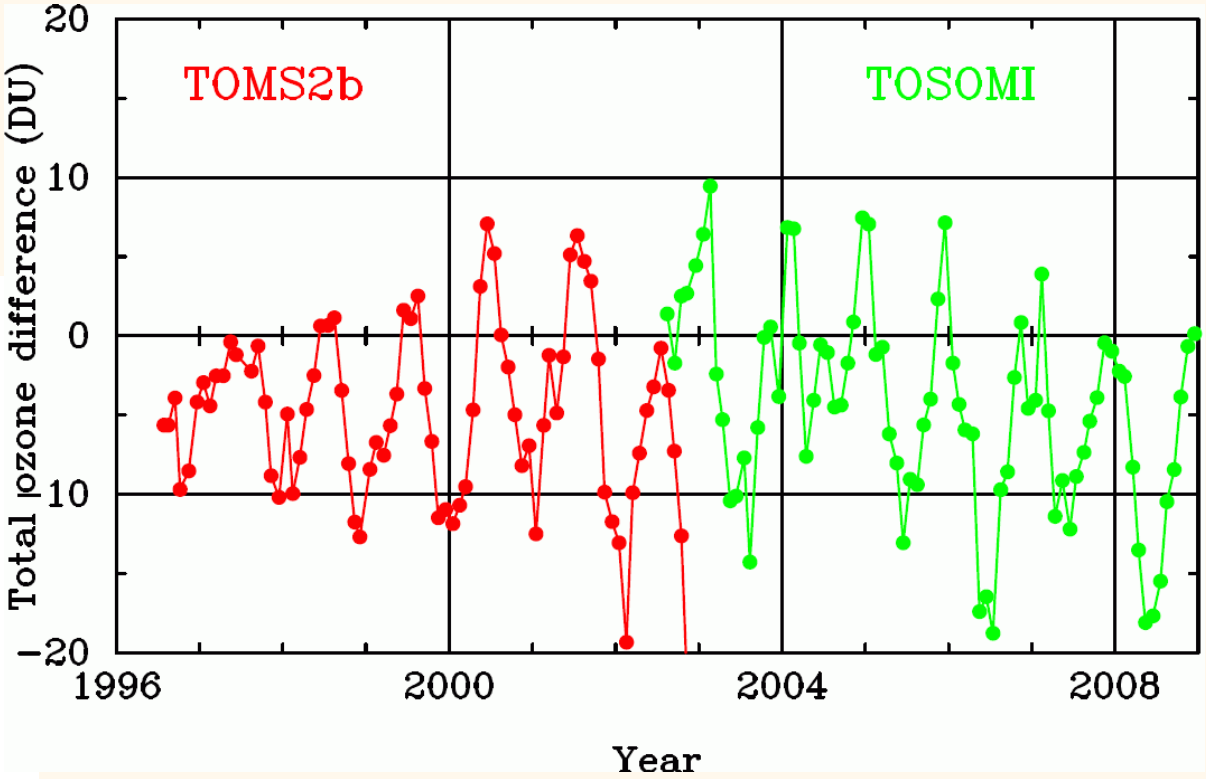
- Data from 233 ground stations available in WOUDC
- Only 91 stations selected with a long dataset (*Fioletov et al.*, JGR, 2008)
- Dobson, Brewer(3,4)–instruments (no filter-instruments used)
- Dobson corrected for temperature dependence (*Kerr et al.*, JGR, 2002)



Inconsistencies between satellite data sets

- "Satellite minus ground" observation reveals:
  - Out-of-phase seasonal dependencies
  - Trends
  - Offsets





Corrections satellite data

Expected dependencies of satellite data:

Parameter	**Physical mechanism**
Solar zenith angle	Light path
Viewing zenith angle	Scan mirror
Effective temperature	O3 cross-section
Time (trend)	Instrument degradation
Offset	Calibration

Constructing a multi-sensor level 2 data set

Multi-Sensor Reanalysis (MSR) level 2

Input:

- 14 satellite data sets from TOMS, SBUV, GOME, SCIAMACHY and OMI covering 30 years
- ECMWF 6h temperature fields (ERA+OD) and Fortuin-Kelder climatology

Correction:

- Generate time series of the 14 satellite data sets for the selected 91 stations.
- Fitting all time series as function of viewing angle, solar zenith angle, effective temperature, time(trend) and an offset.
- Corrections are applied as function of the fit parameters

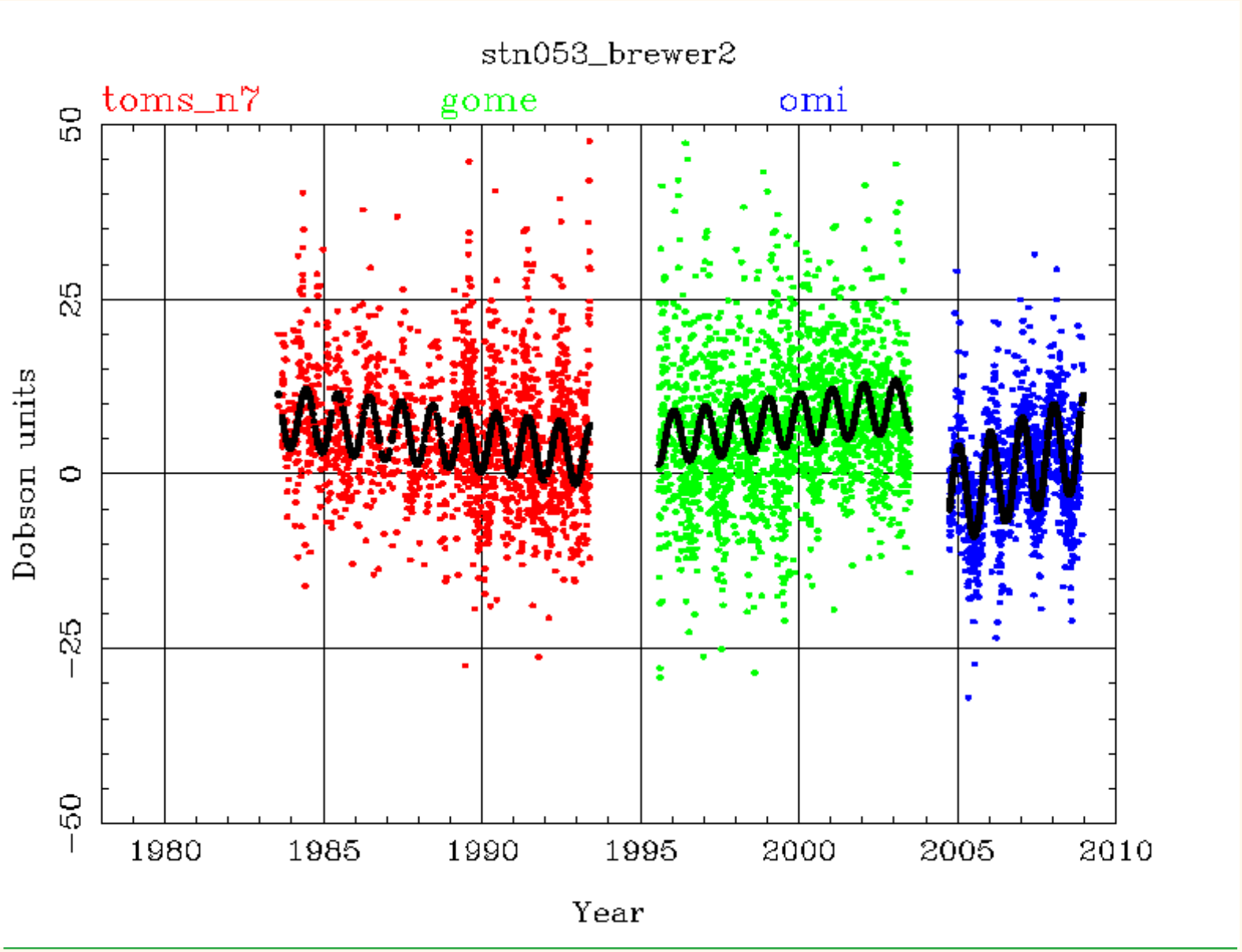
=> MSR level 2 data

Applied corrections

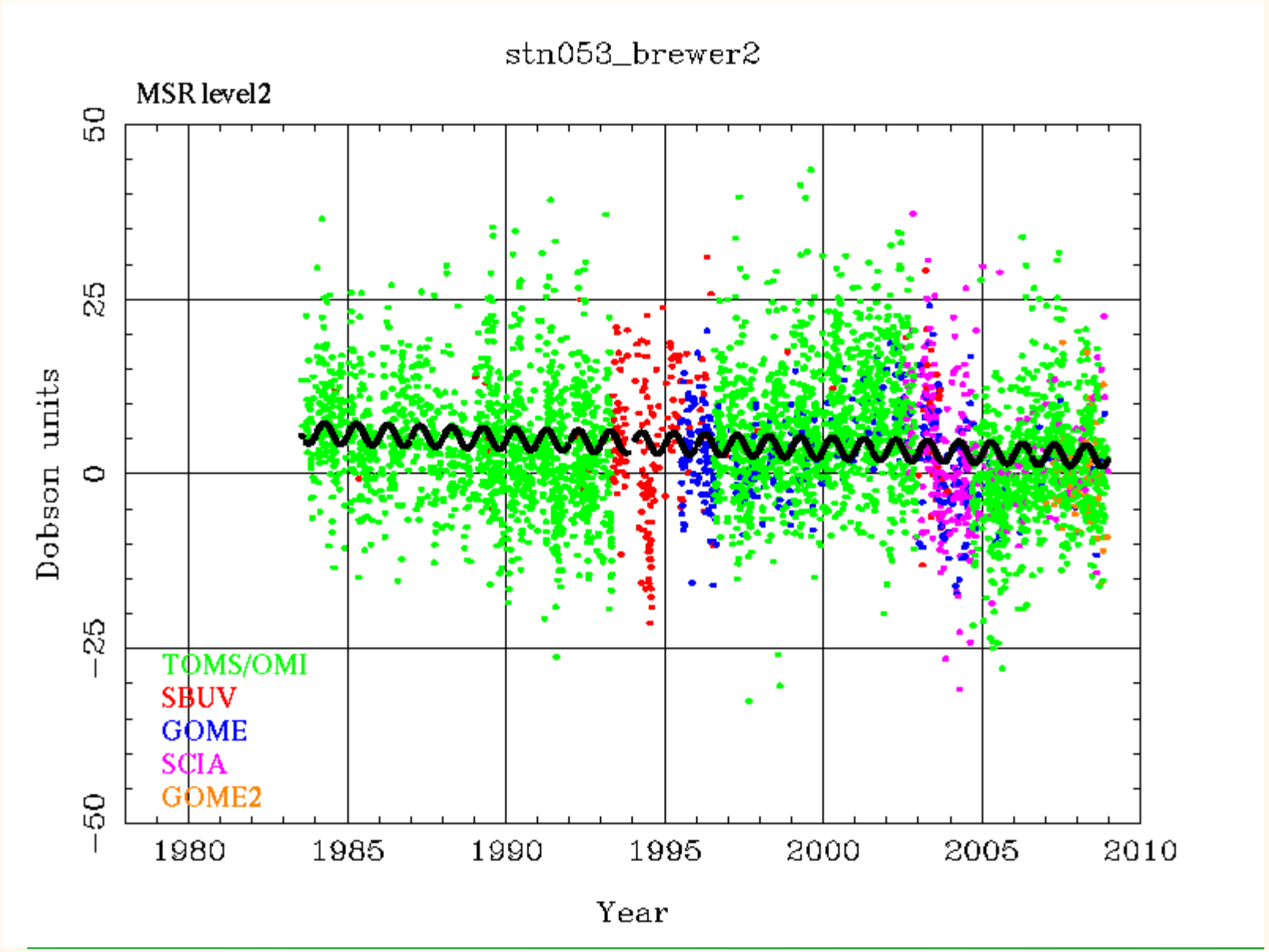
For each satellite data set only significant corrections are applied :

Name	RMS3 (DU)	Trend (y/n)	VZA (y/n)	SZA (y/n)	T_{eff} (DU/C°)	RMS4 (DU)
TOMS2a	10.16	no	no	no	-0.462	9.98
TOMS2b	9.84	partial	pixel	no	-0.447	9.33
SBUV07	11.12	no	no	no	-0.153	11.09
SBUV9a	11.87	no	no	no	-0.376	11.81
SBUV9d	10.66	no	no	no	-0.196	10.63
SBUV11	10.65	no	no	no	-0.258	10.60
SBUV16	10.43	no	no	no	-0.467	10.22
GDP	9.60	no	pixel	yes	no	9.39
TOGOMI	8.95	no	pixel	no	no	8.84
SGP	9.99	yes	yes	no	no	9.80
TOSOMI	9.80	yes	yes	yes	no	8.98
OMDOAO3	9.41	yes	no	nonlin	+0.300	9.01
OMTO3	7.60	no	no	no	-0.282	7.45
GOME2	8.30	yes	pixel	yes	no	7.71

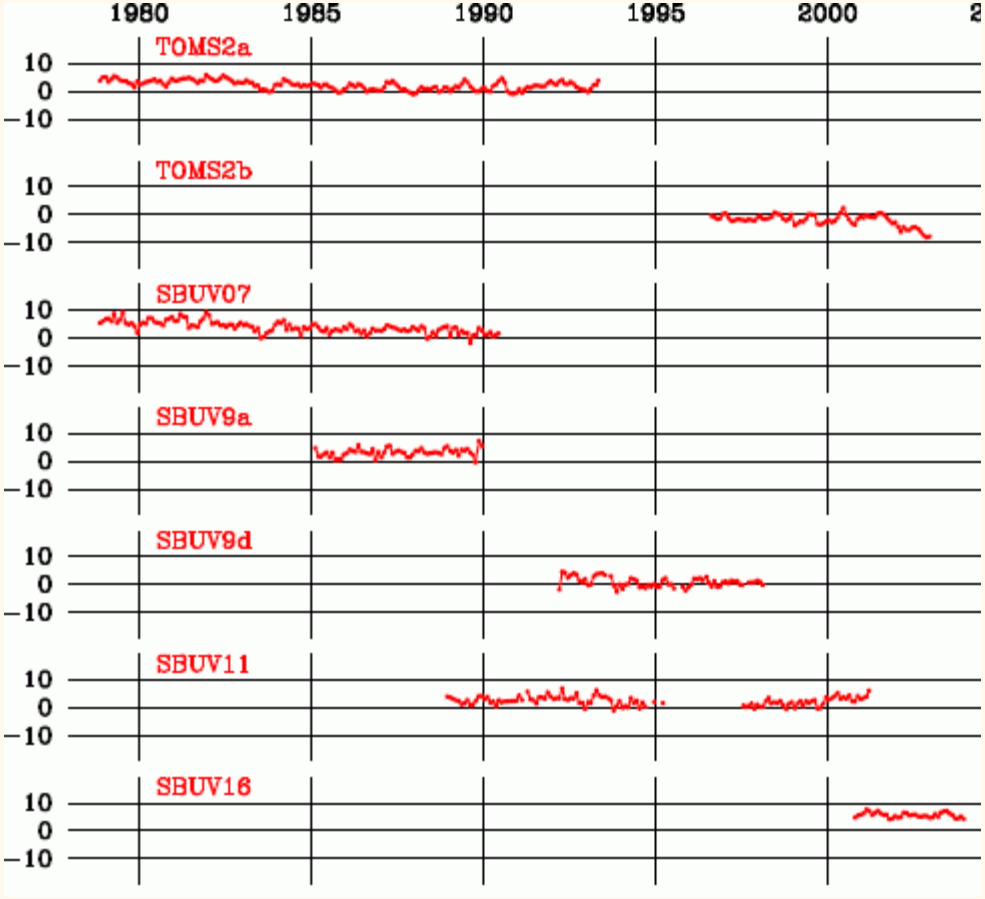
Level 2 data vs Uccle ground observations

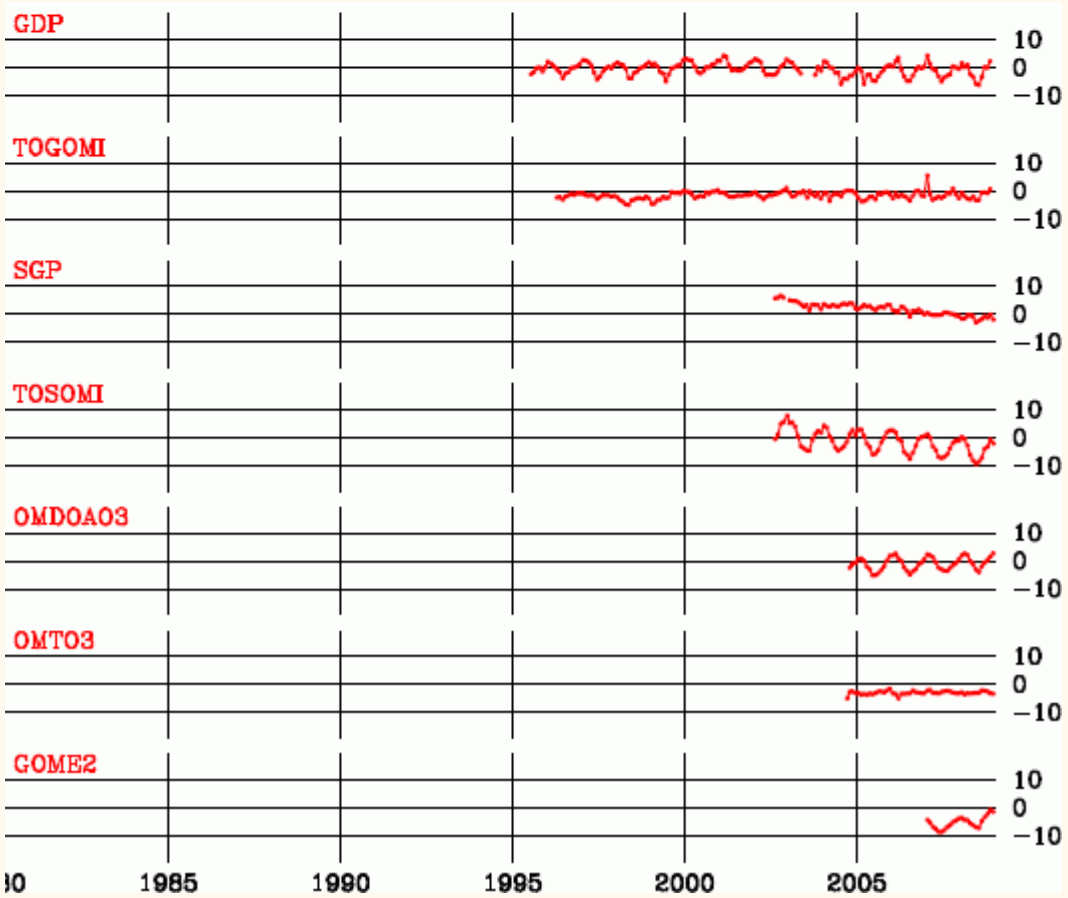


Corrected level 2 data vs Uccle ground observations



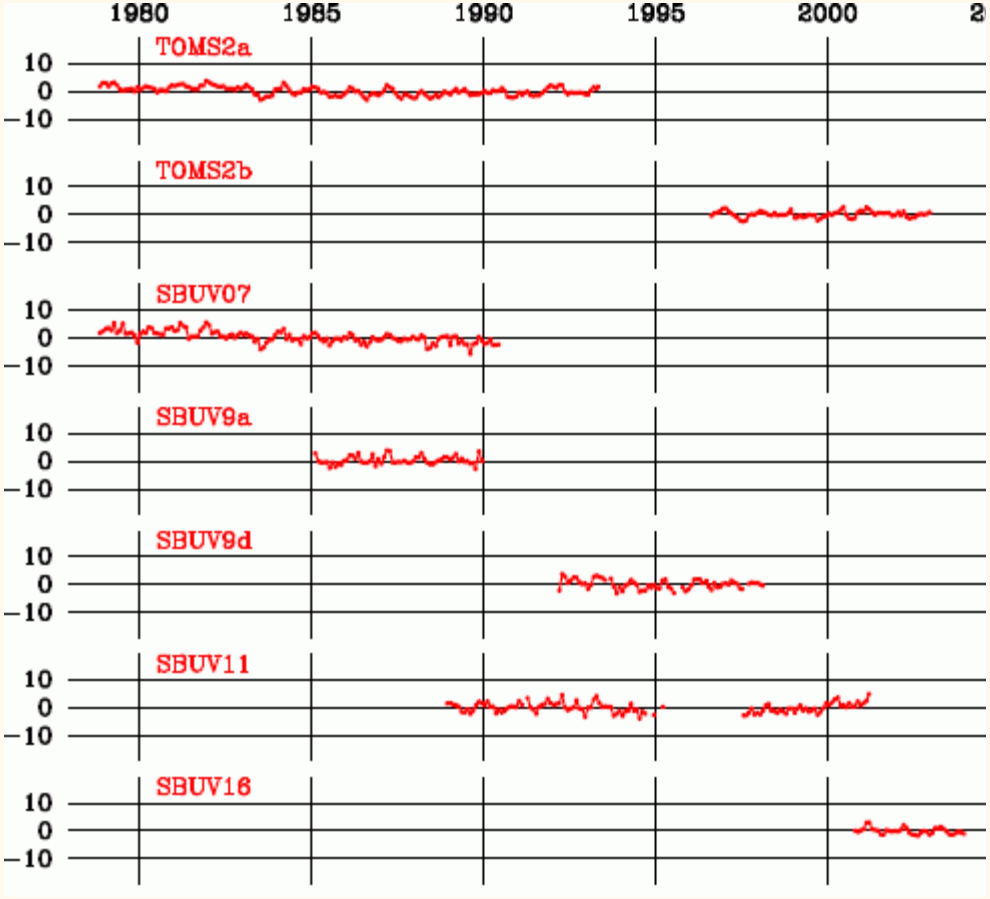
“Satellite minus Ground” with no corrections

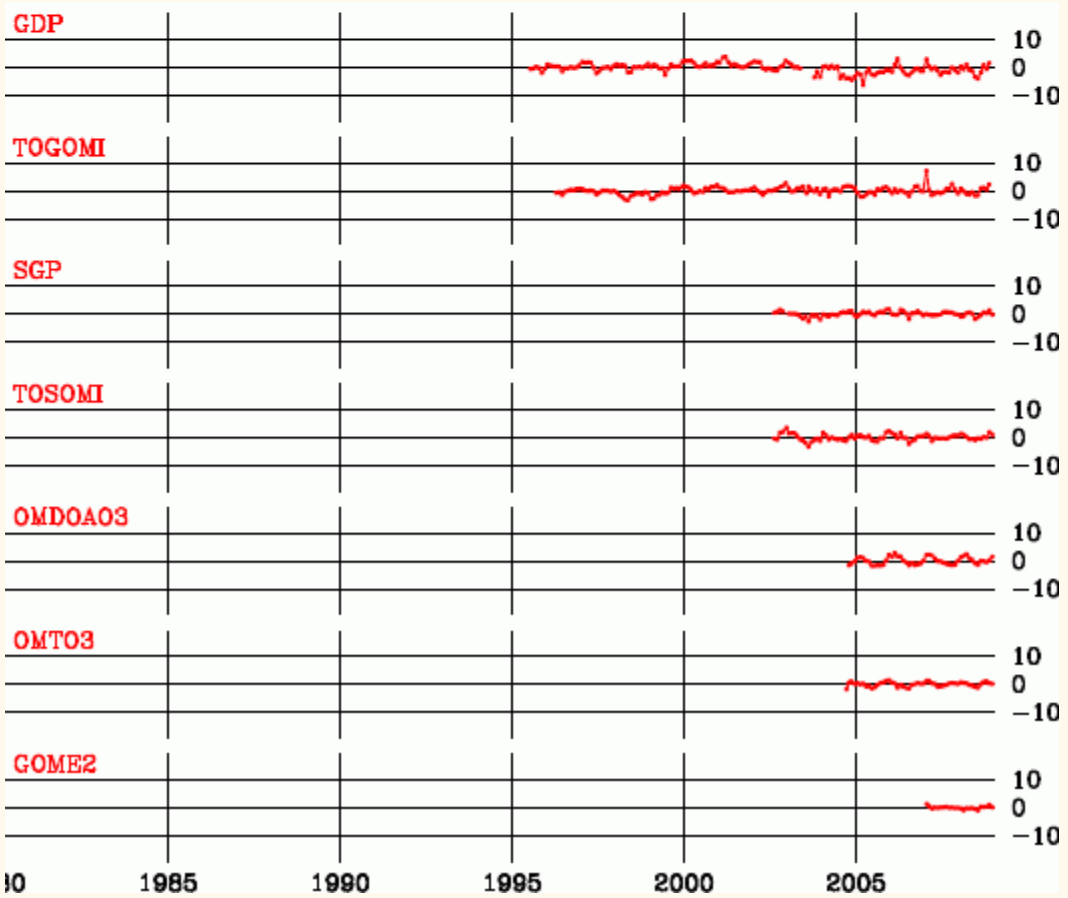




Monthly averaged data.

“Satellite minus Ground” after corrections





Monthly averaged data.

Data assimilation (level 4 data)

Ozone assimilation at KNMI

Chemistry-transport assimilation model TM3DAM:

- TM model with 44 layers
- ECMWF analyses of winds, temperatures
- Stratospheric chemistry parametrizations (Cariolle v.2.1)
- Kalman-type data assimilation scheme

- Near-real time and forecasts of SCIAMACHY, OMI, GOME-2
- Operational analyses and forecasts since 2000:

  http://www.temis.nl

More info: Eskes et al. Q. J. R. Meteorol. Soc., 2003

Forecast error modelling

Sub-optimal Kalman filter approach:

Forecast covariance = time-dependent variance * fixed correlations

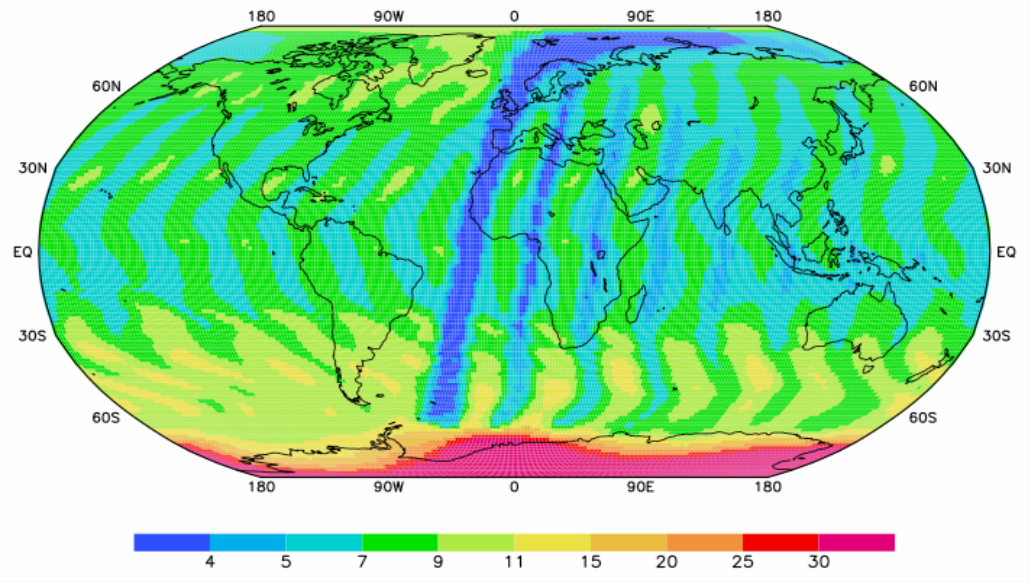
Correlation matrix:

function of the distance only

functional form determined from OmF statistics

Variance:

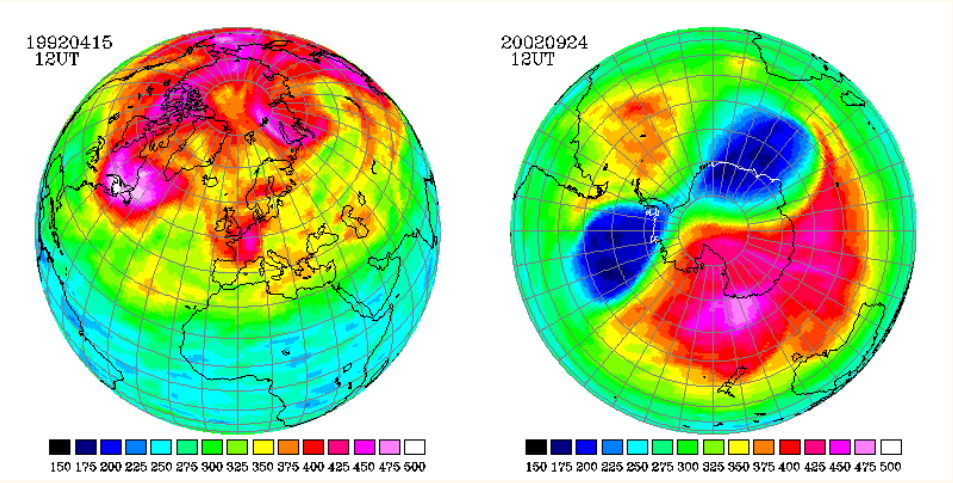
- Model error, growth of the forecast variance with time
- Advection of the forecast variance
- Analysis equation of forecast variance



Data assimilation of the MSR level 2 data

Input:

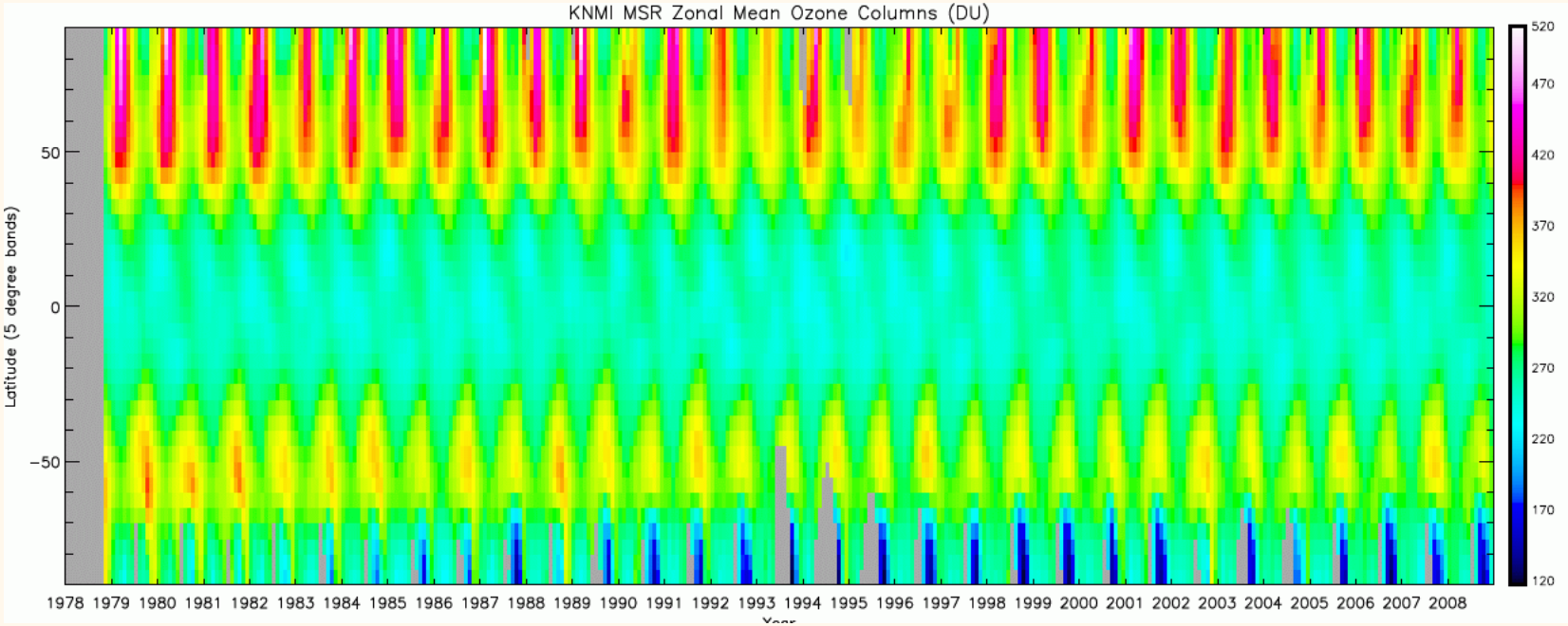
- ECMWF ERA-40 + OD
- Error estimates for each instrument
- Gridded input data:
  - Satellite observation weighted with the inverse of their variances
  - Correlations between observations taken into account
  - Similar approach for the observation errors
- Longest data gap in input data is 4 days.



MSR level 4 results

Output:

- Total ozone field every 6 hours including error
- Daily local time ozone field at noon (for UV index)
- Daily ObservationMinusForecast and ObservationMinusAnalysis files
- Resolution is 1x1.5 degree with 6 hour time steps



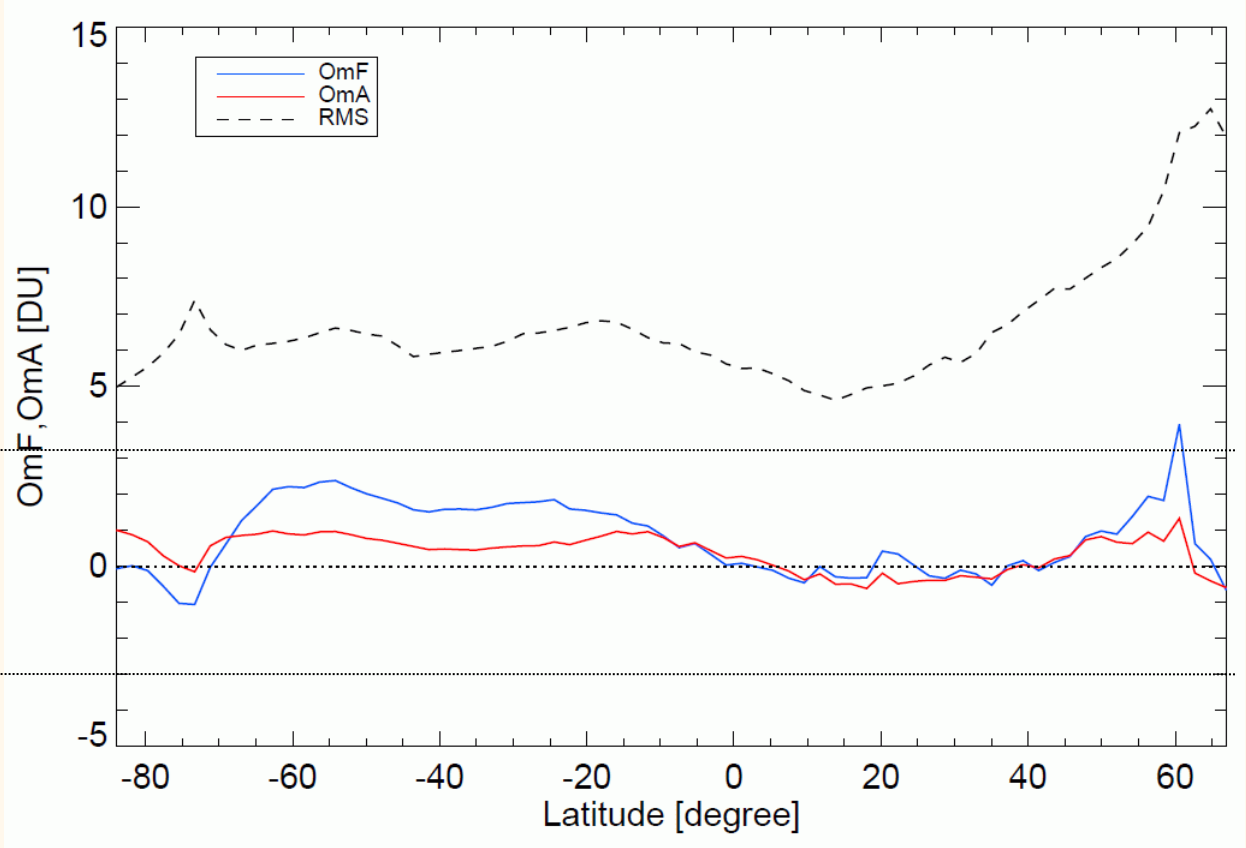
MSR level 4 averaged over zonal bands for 1978-2008

Typical forecast performance of MSR: OmF and OmA

Example for January 2008

Rms of the OmF (dotted) typically 2%

bias OmF (blue) and OmA (red) are less than 1%

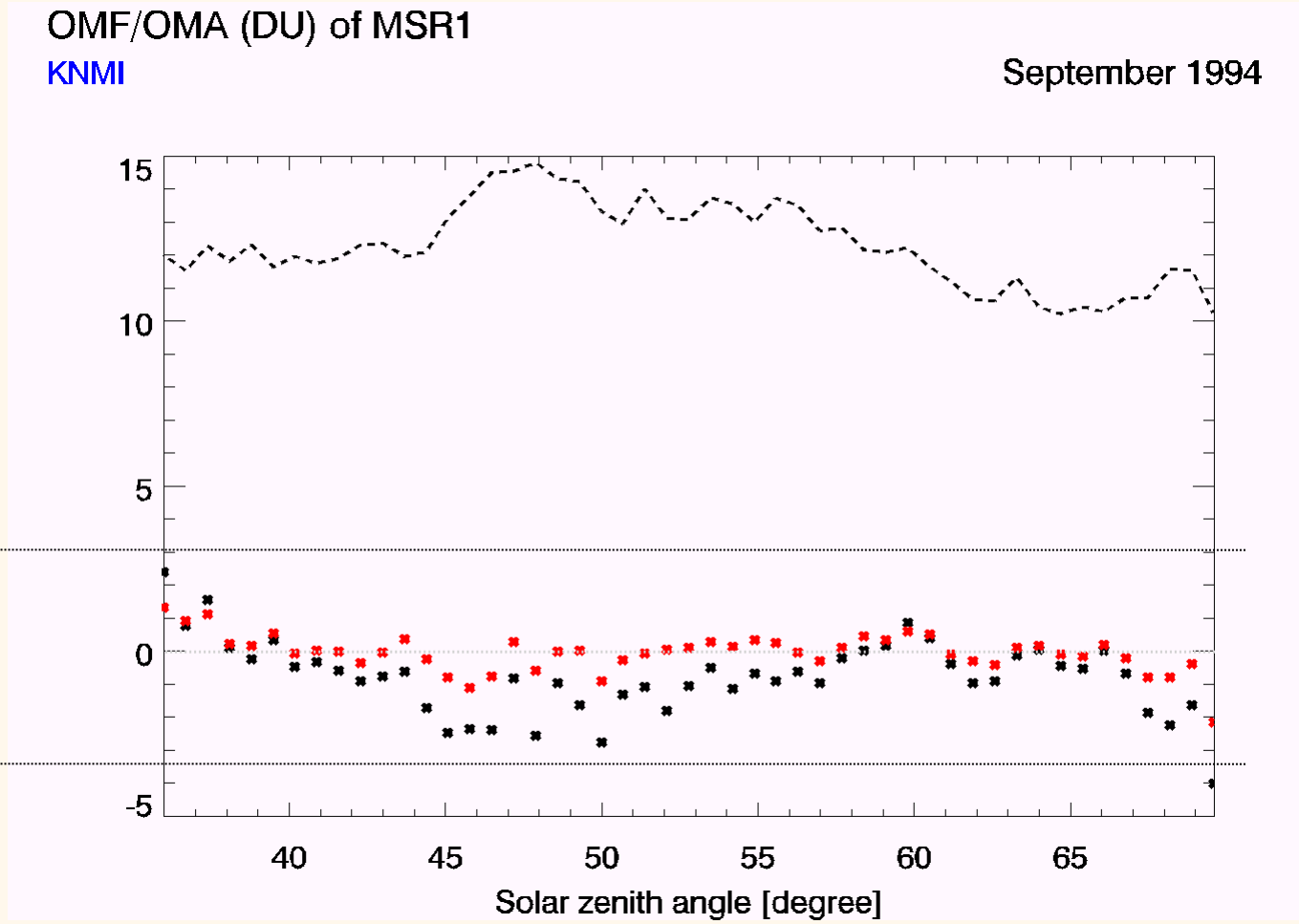


Typical forecast performance of MSR: OmF and OmA

Example for Sept 1994
SBUV only

Rms of the OmF (dotted) typically 4%

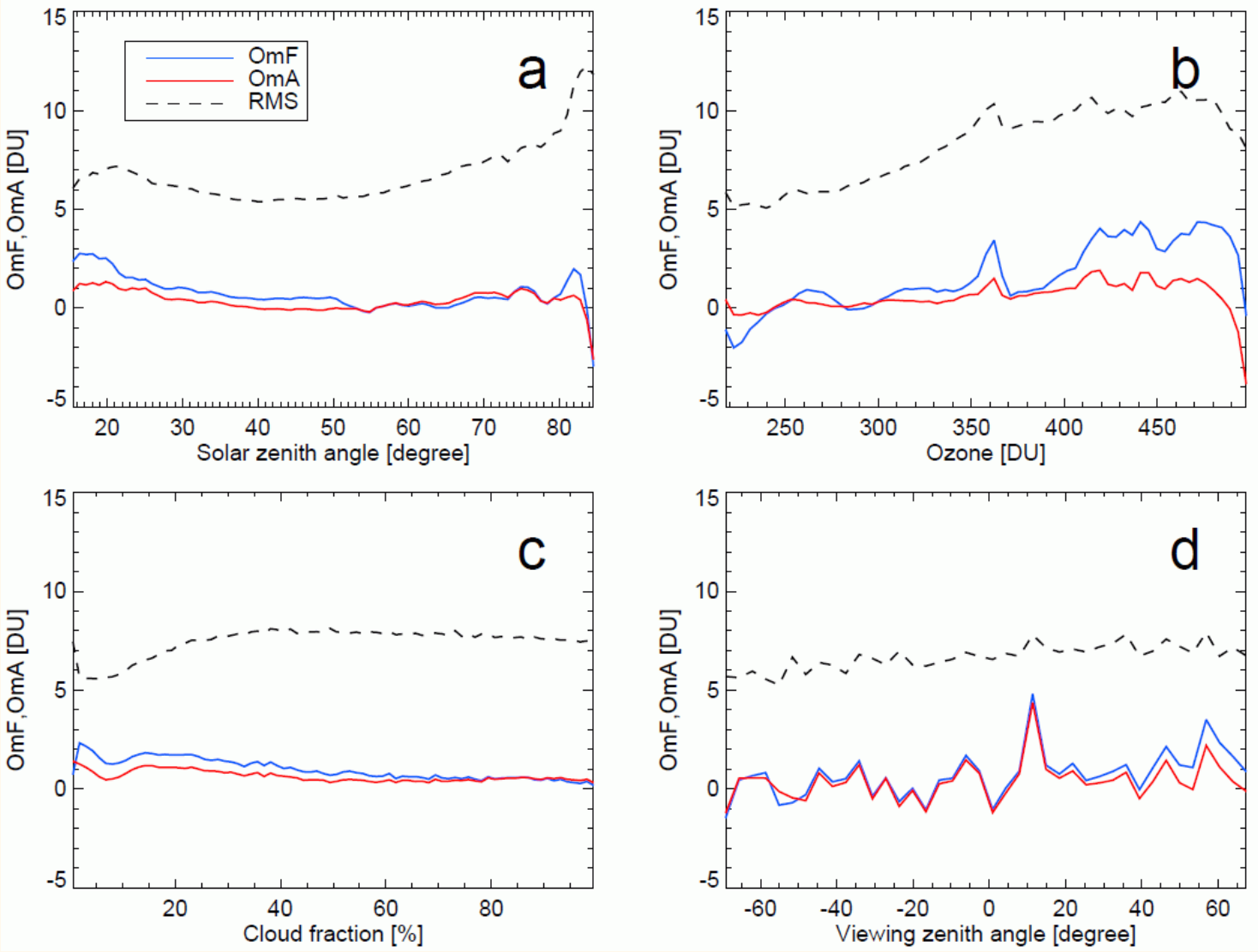
bias OmF (blue) and OmA (red) are less than 1%



OmF and OmA analysis

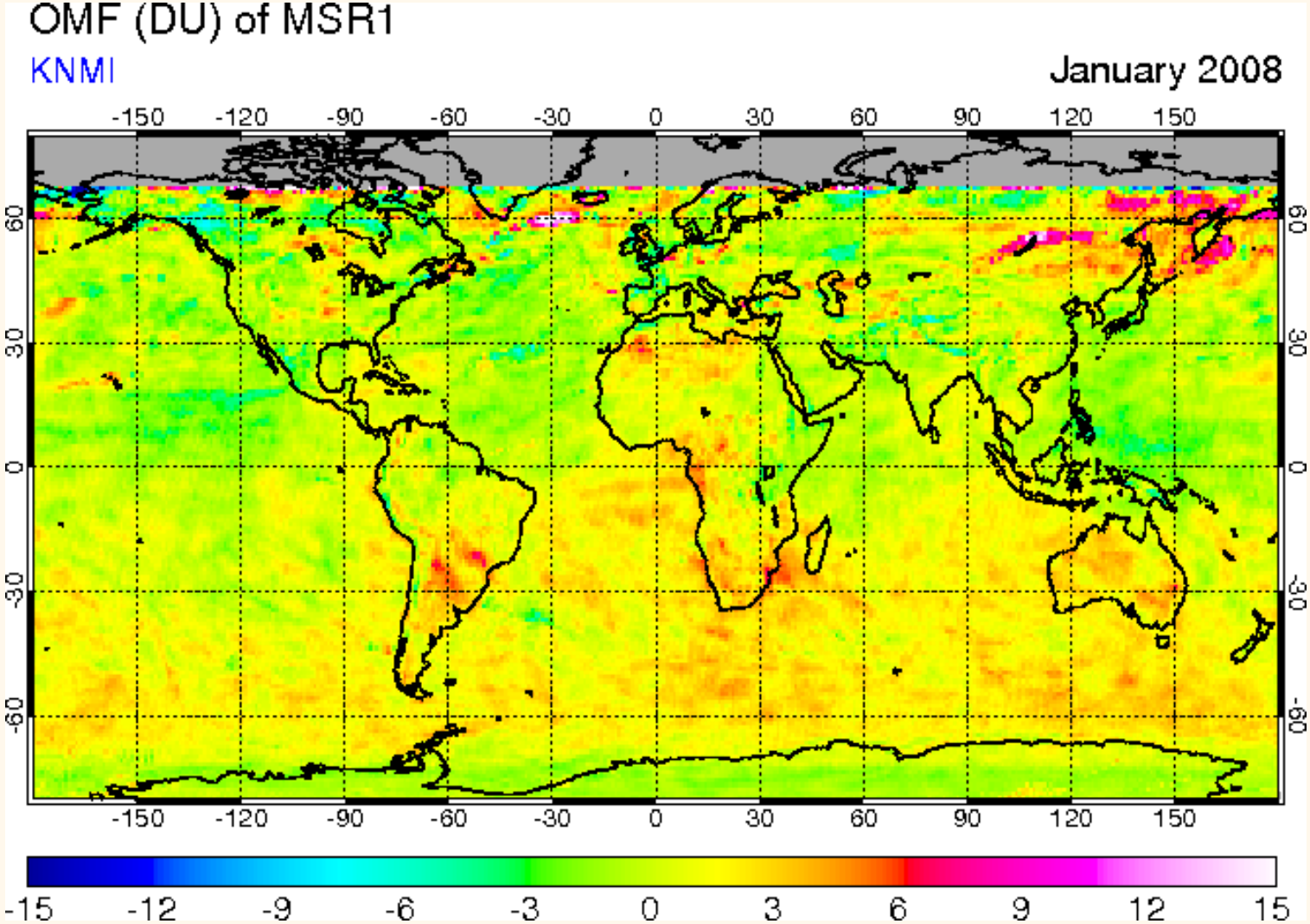
As function of

a. Solar angle
b. Ozone
c. Cloud fraction
d. Viewing angle

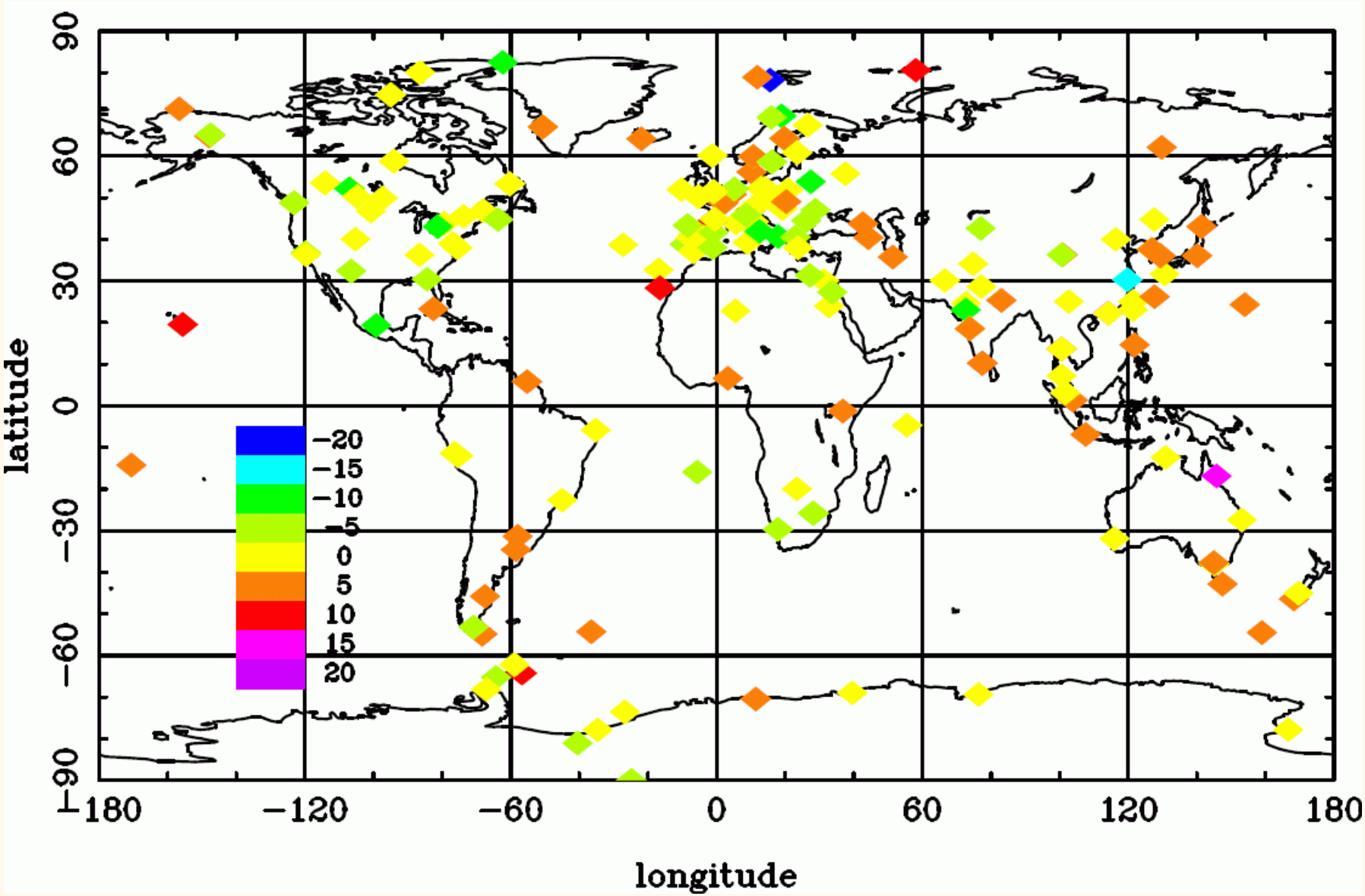


OmF of the Multi-Sensor Reanalysis (MSR)

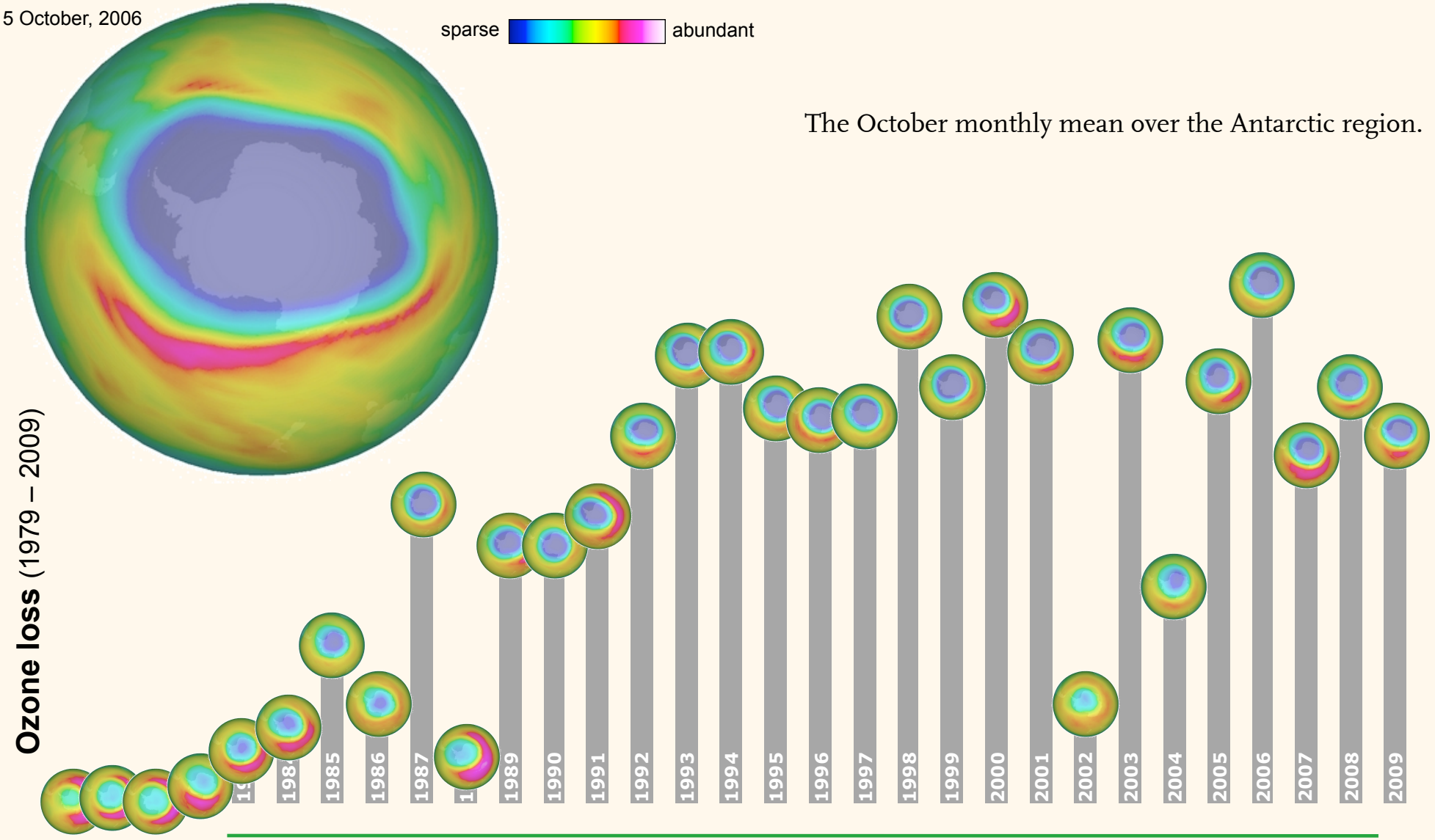
Gridded for January 2008



Fitted offset (DU) between MSR level 4 and ground observations

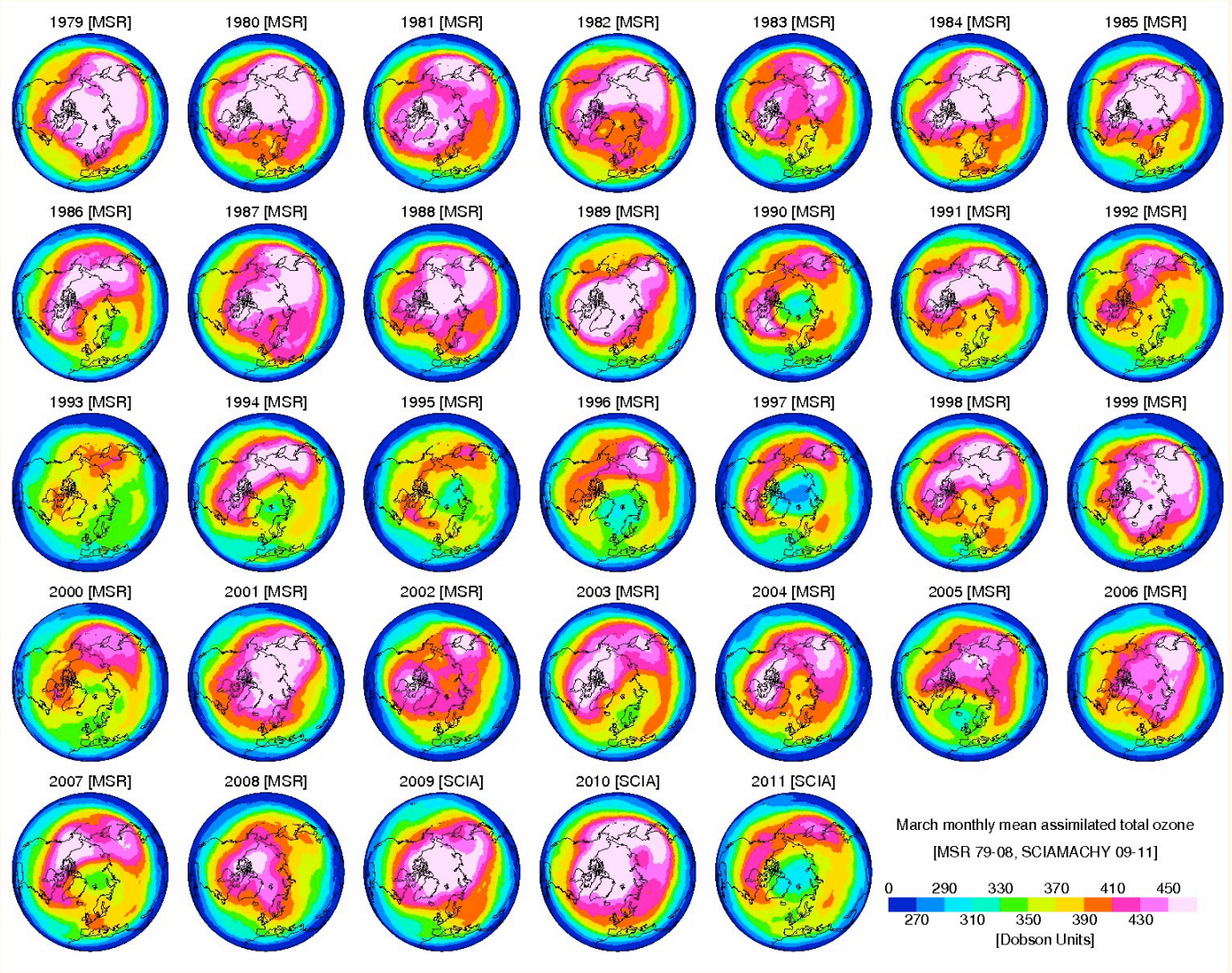


Evolution of the ozone loss (1979-2009)



Northern Hemisphere March - 2011

Monthly-mean total ozone for March in 1979-2011 in the Northern Hemisphere



Summary

Merged level 2 data set

- 14 data sets from TOMS, SBUV, GOME, SCIAMACHY and OMI
- Reference: Brewer and Dobson data (WOUDC) of 91 stations
- Corrections as function of viewing angle, solar zenith angle, temperature, time and an offset

Ozone column assimilation:

- Level 2 ozone assimilated with TM3DAM (sub-optimal Kalman filter)
- Long-term assimilated ozone reanalysis from 30 year satellite data
- Ozone and UV data available on MACC site and TEMIS.

Future work :

- Reprocessing (1978-2012) with new level 2 data sets within MACC-2.

Publication: van der A, Allaart, Eskes, ACP 10, 11277, 2010

Data access: www.temis.nl , www.gmes-atmosphere.eu/