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

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KNMI

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Outline

- Merging level 2 data => multi-sensor reanalysis level 2
- Data assimilation => multi-sensor reanalysis level 4
- Results and quality analysis
- Approach for nadir ozone profiles

Total Ozone Record introduction

- Objective:
  - Constructing long-term consistent and complete ozone record of 30 years

- Difference with previous similar data sets:
  - 14 satellite data sets are used covering 30 years without a gap
  - retrievals are assimilated in a chemical-transport model to achieve complete global and temporal coverage. Resolution is 1x1.5 degree with 6 hour time steps.

- All satellite datasets are corrected for biases using the WOUDC ground observations on average as reference.

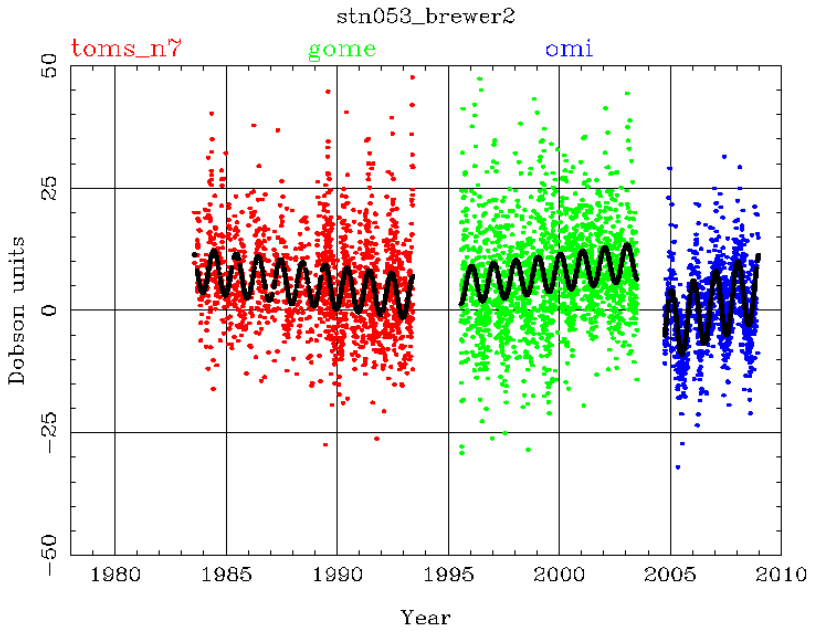
Available level 2 ozone data (UV-VIS)

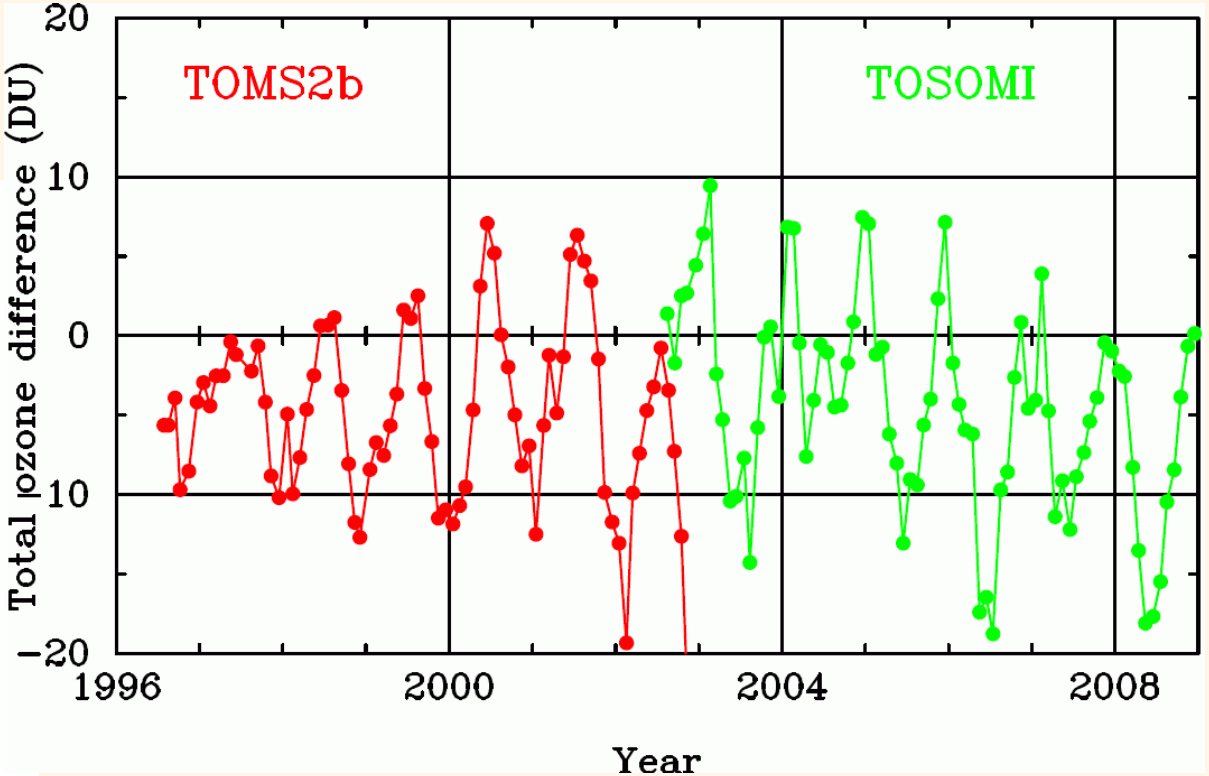
TOMS Nimbus 7:	**1978-1993**	**TOMS v.8**	**NASA**
TOMS EarthProbe:	**1996-2002**	**TOMS v.8**	**NASA**
SBUV 7, 9a, 9d, 11, 16:	**1978-2004**	**SBUV v.8**	**NOAA**
GOME :	**1995-2008**	**GDP v.4**	**ESA/DLR**
GOME :	**1995-2008**	**TOGOMI v1.2**	**KNMI**
SCIAMACHY :	**2002-2008**	**SGP v.3**	**ESA/DLR**
SCIAMACHY :	**2002-2008**	**TOSOMI v.0.43**	**KNMI**
OMI :	**2004-2008**	**TOMS v.3**	**NASA**
OMI :	**2004-2008**	**DOAS 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

Inconsistencies between satellite data sets

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

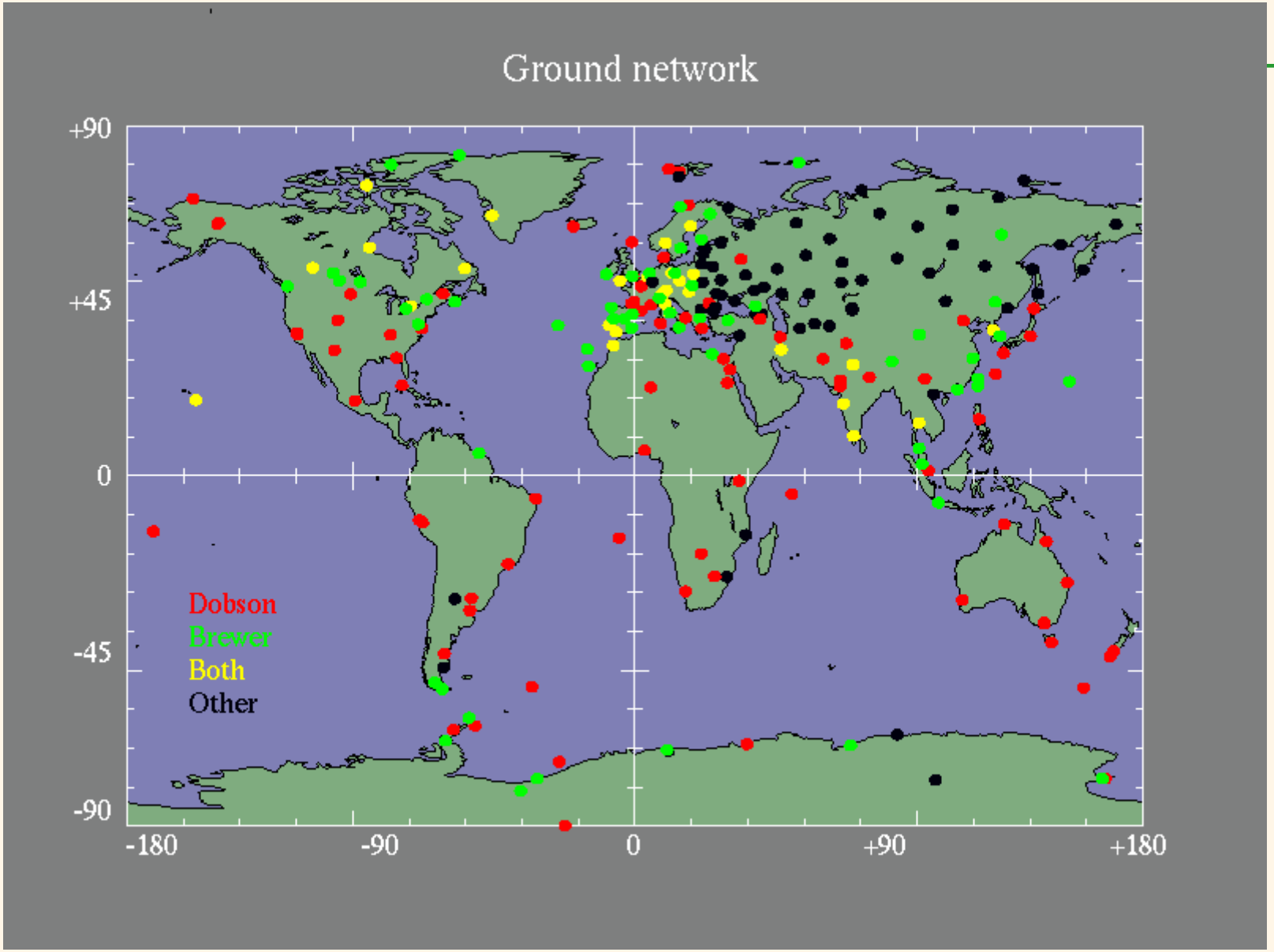




Corrections satellite data

Expected dependencies of satellite data

- Solar zenith angle (DOAS-AMF, O3 cross-section)
- Viewing zenith angle (scan mirror)
- Effective temperature (O3 cross-section)
- Time (instrument degradation)
- Offset (calibration)


Ground network
+90
+45
0
-45
-90
-180
-90
0
+90
+180
Dobson
Brewer
Both
Other

Constructing a multi-sensor level 2 data set

Multi-Sensor Reanalysis (MSR)

Reference data set :

- Data from 233 ground stations available in WOUDC
- 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)

Correction:

- Generating overpass data for all 14 satellite data sets for the selected 91 stations.
- Fitting all overpass data as function of viewing angle, solar zenith angle, effective temperature, time(trend) and an offset

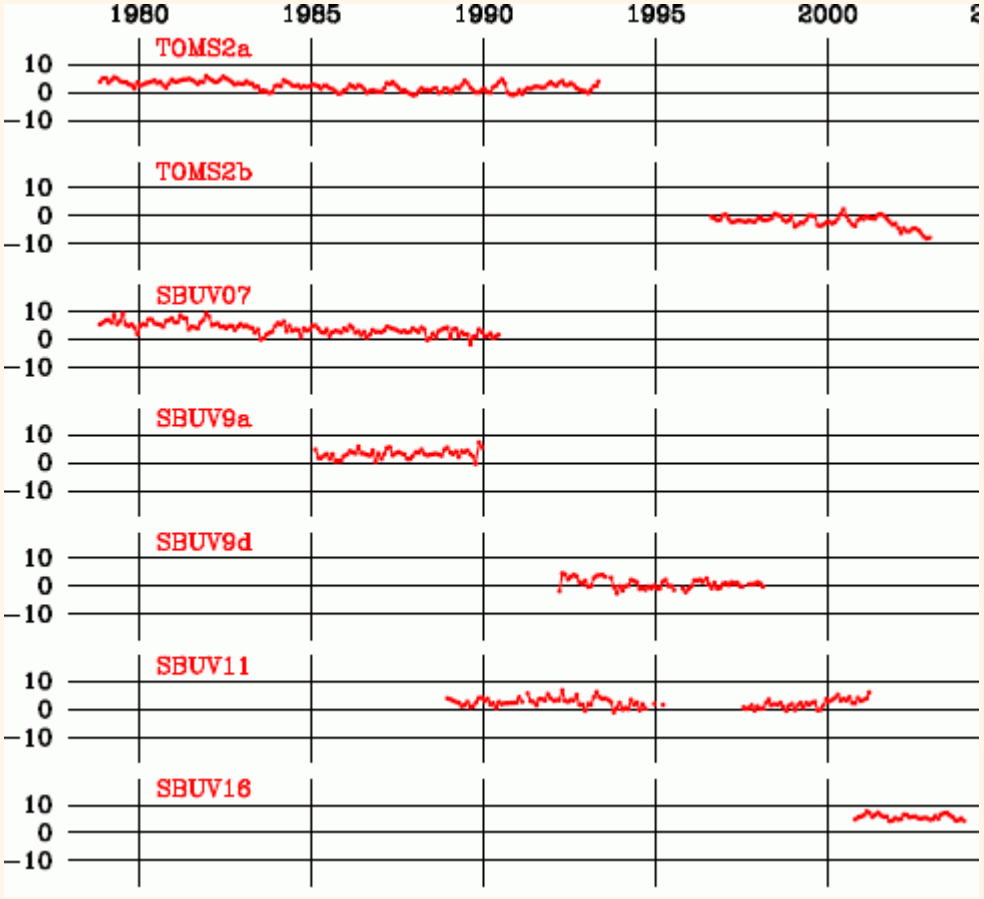
=> MSR level 2 data

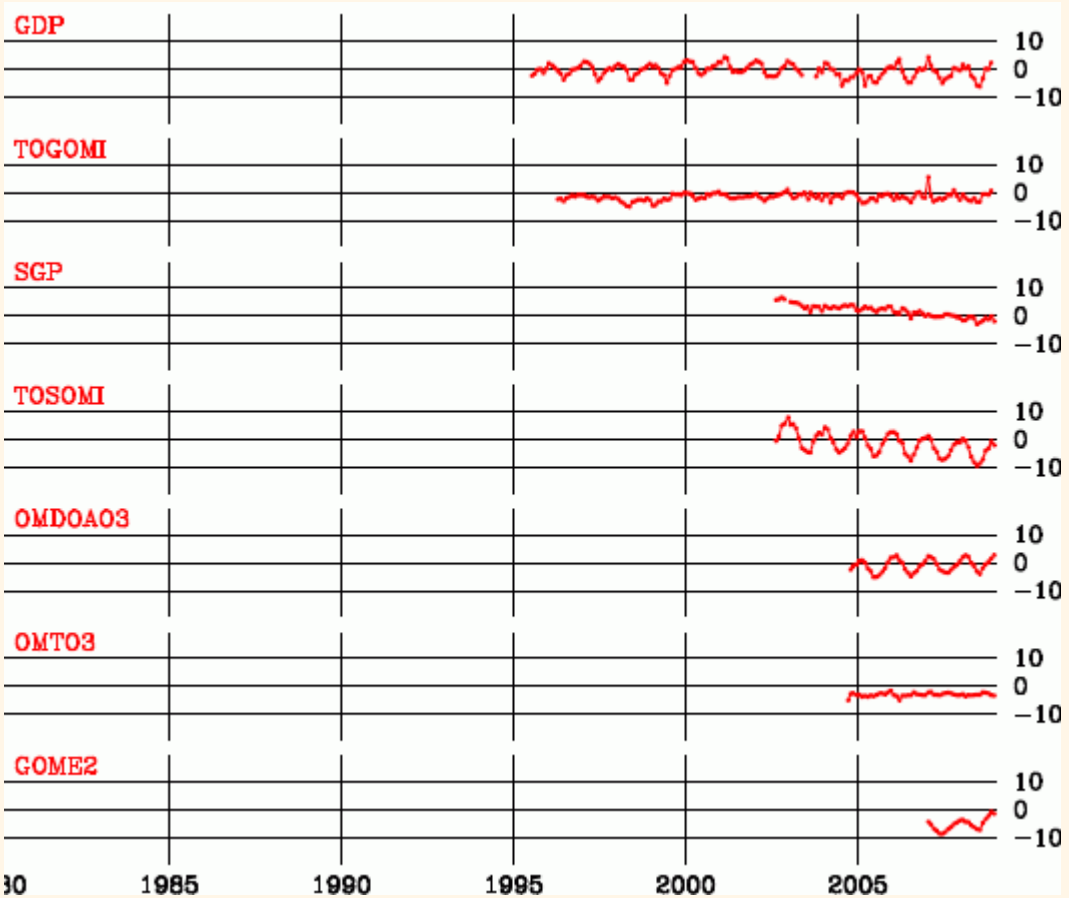
Applied corrections

Corrections applied per satellite data set :

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

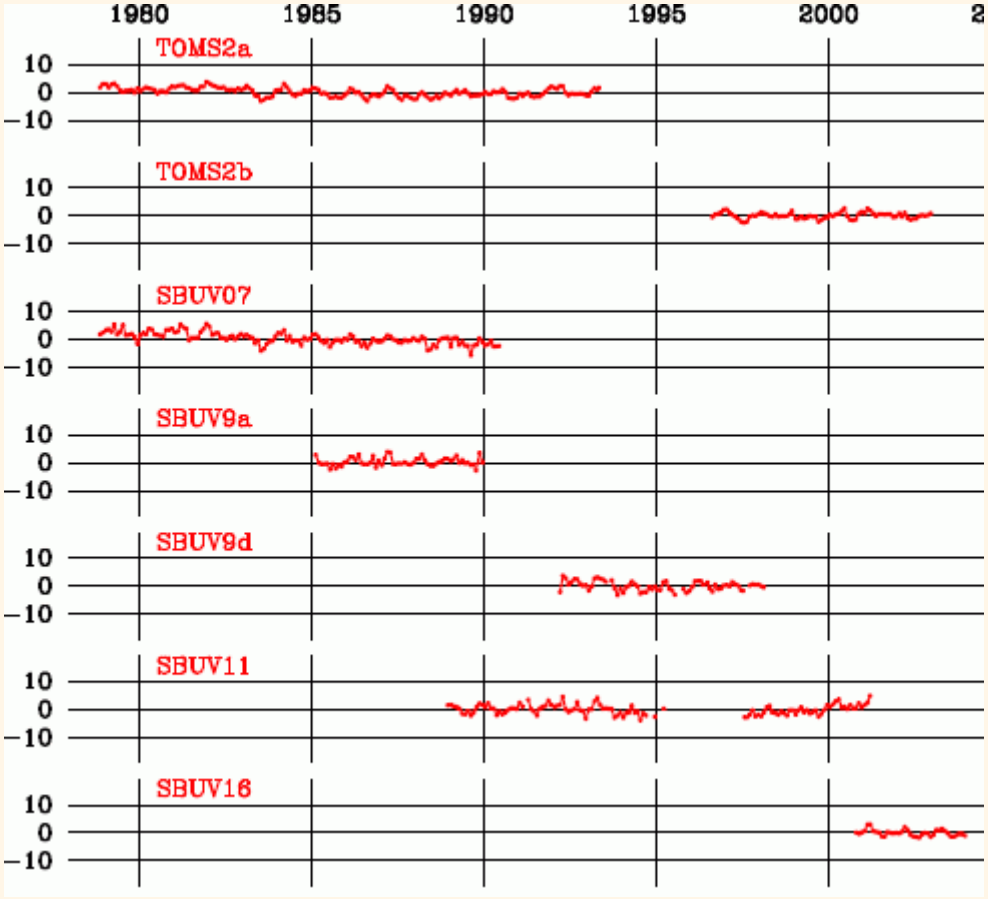
“Satellite minus Ground” with no corrections

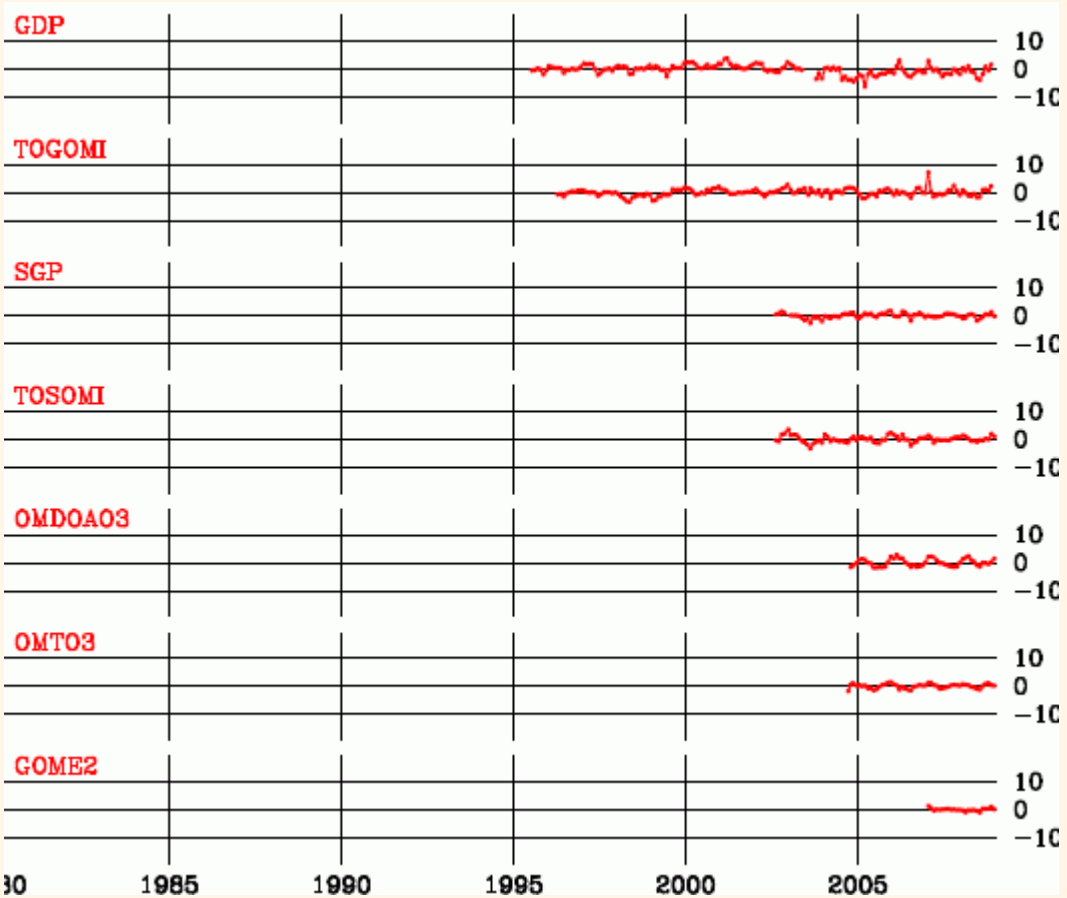




Monthly averaged data.

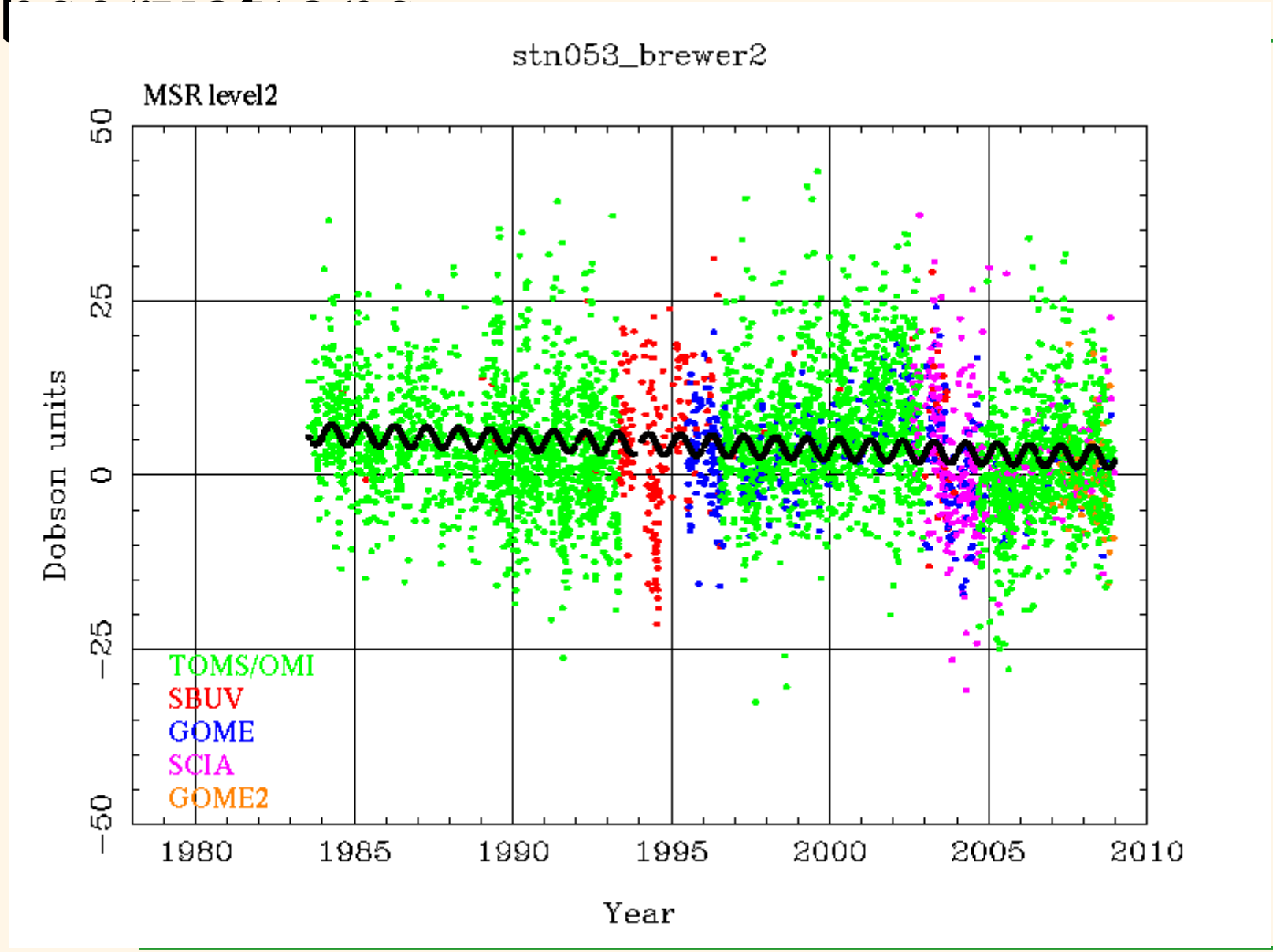
“Satellite minus Ground” after corrections





Monthly averaged data.

Corrected level 2 data vs. Ground observations



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

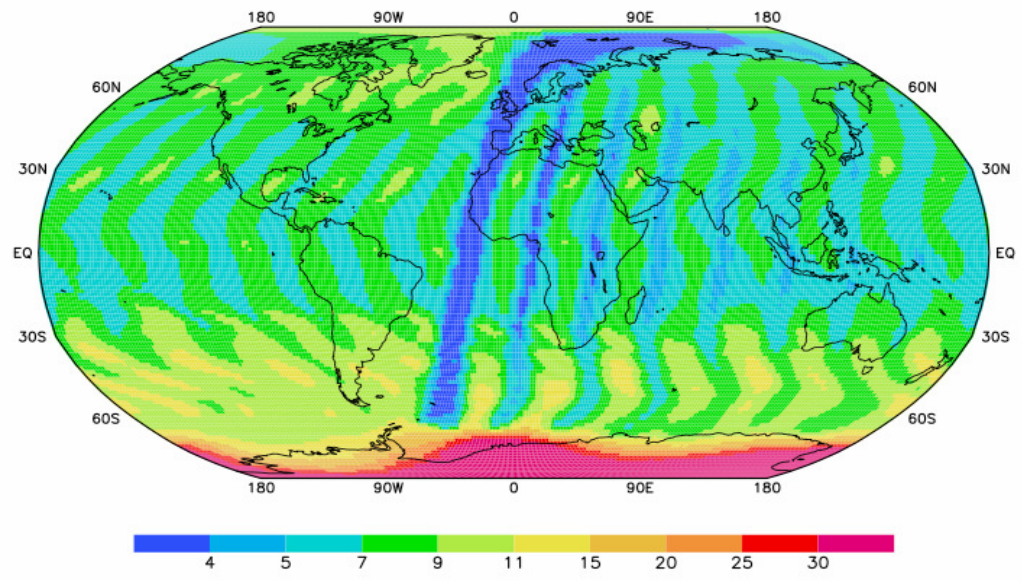
Correlation matrix:

function of the distance only

functional form determined from OmF statistics

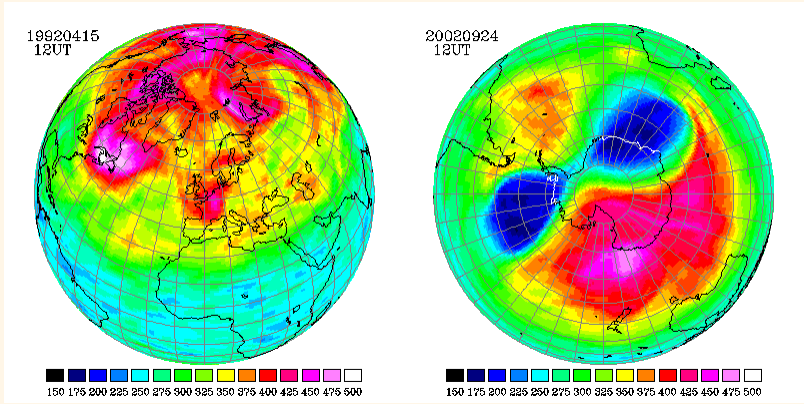
Variance:

- 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

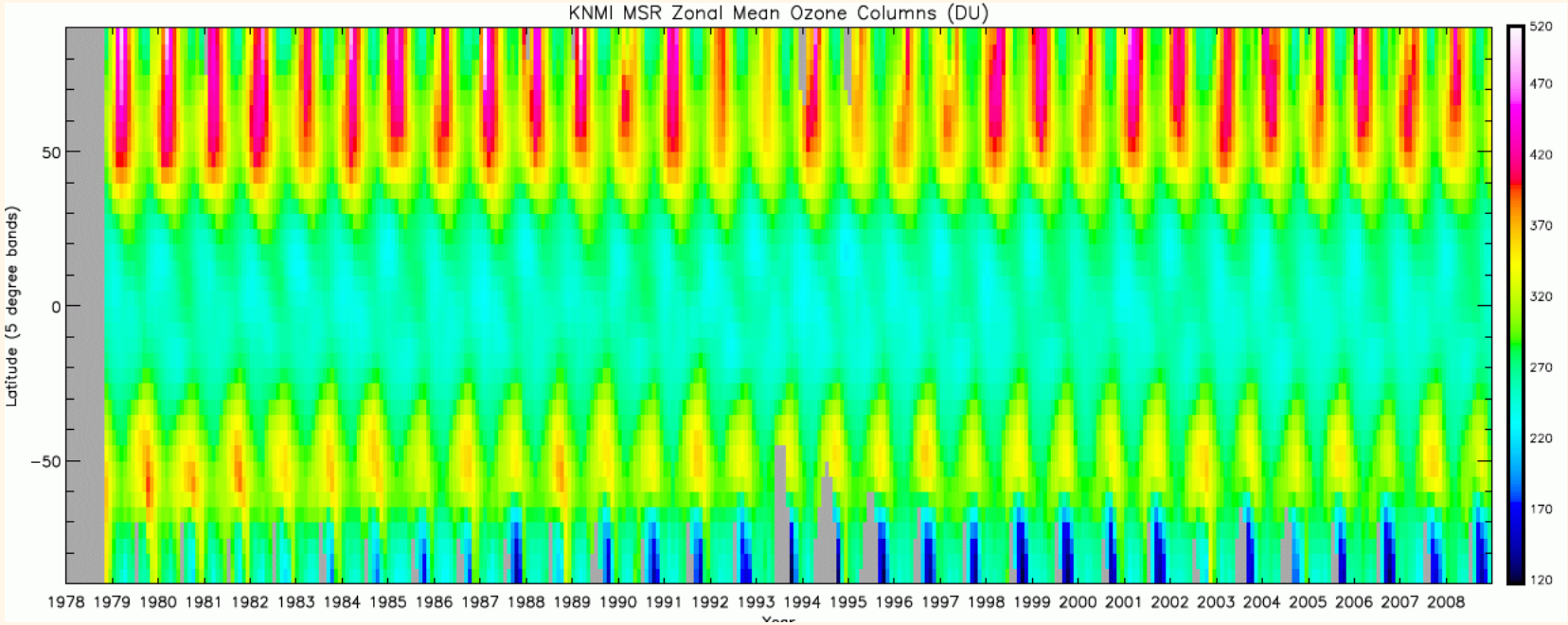
- Error estimates for each instrument
- Gridded input data (called super observations):
  - Averaged satellite observation weighted with the inverse of their variances
  - Correlations between observations taken into account
  - Similar approach for the observation errors



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
- Daily file of the modelled 3D ozone distribution



MSR level 4 averaged over zonal bands for 1978-2008

Typical forecast performance of MSR: OmF

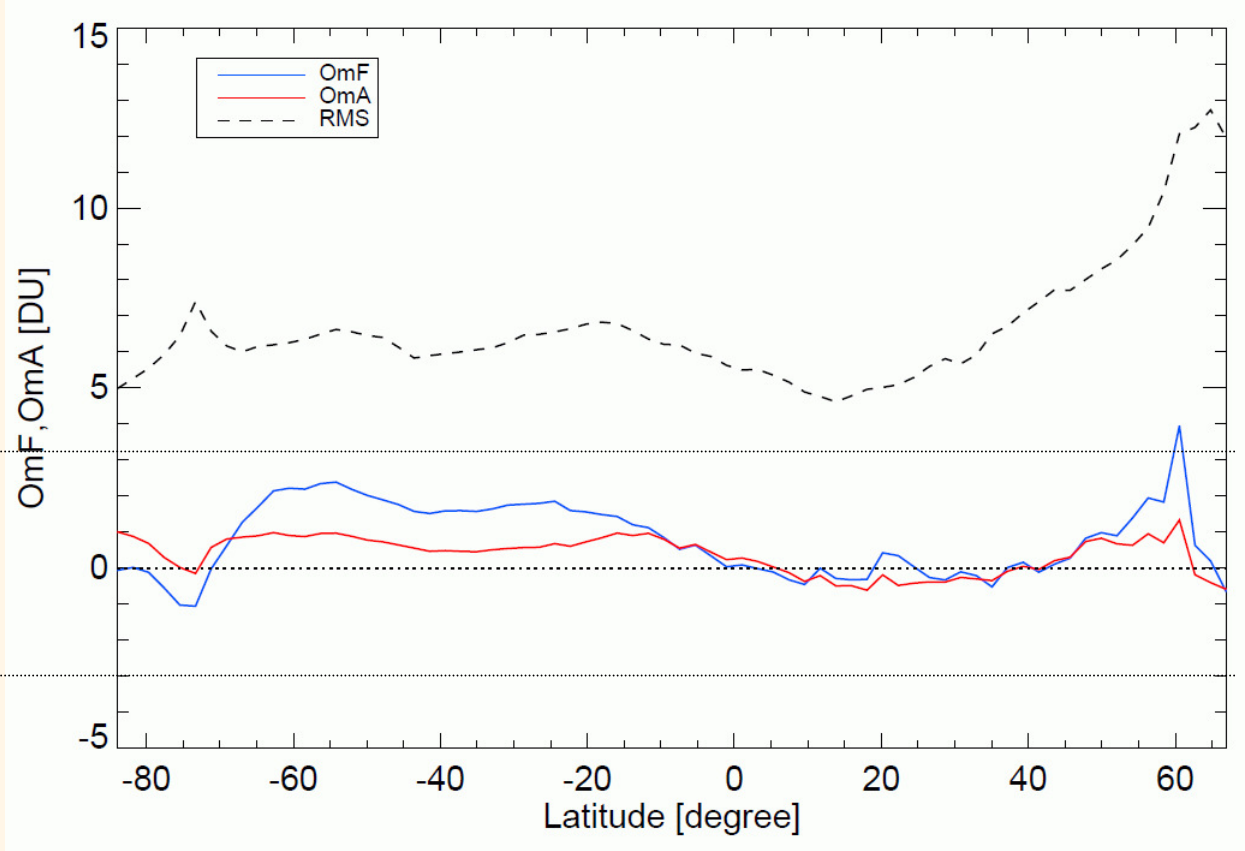
January 2008

Rms of the OmF (dotted) typically 2%

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

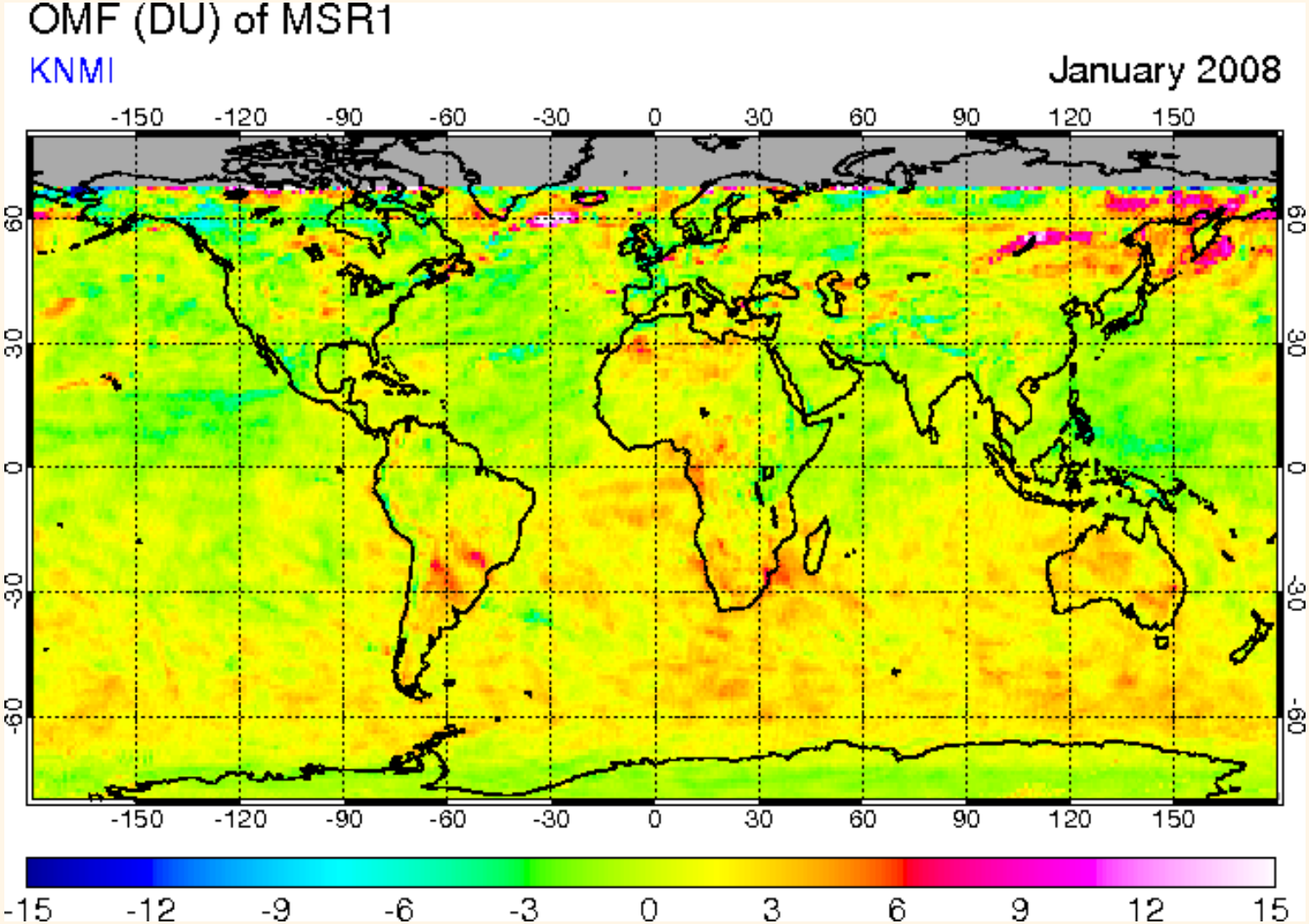
1% level

-1% level

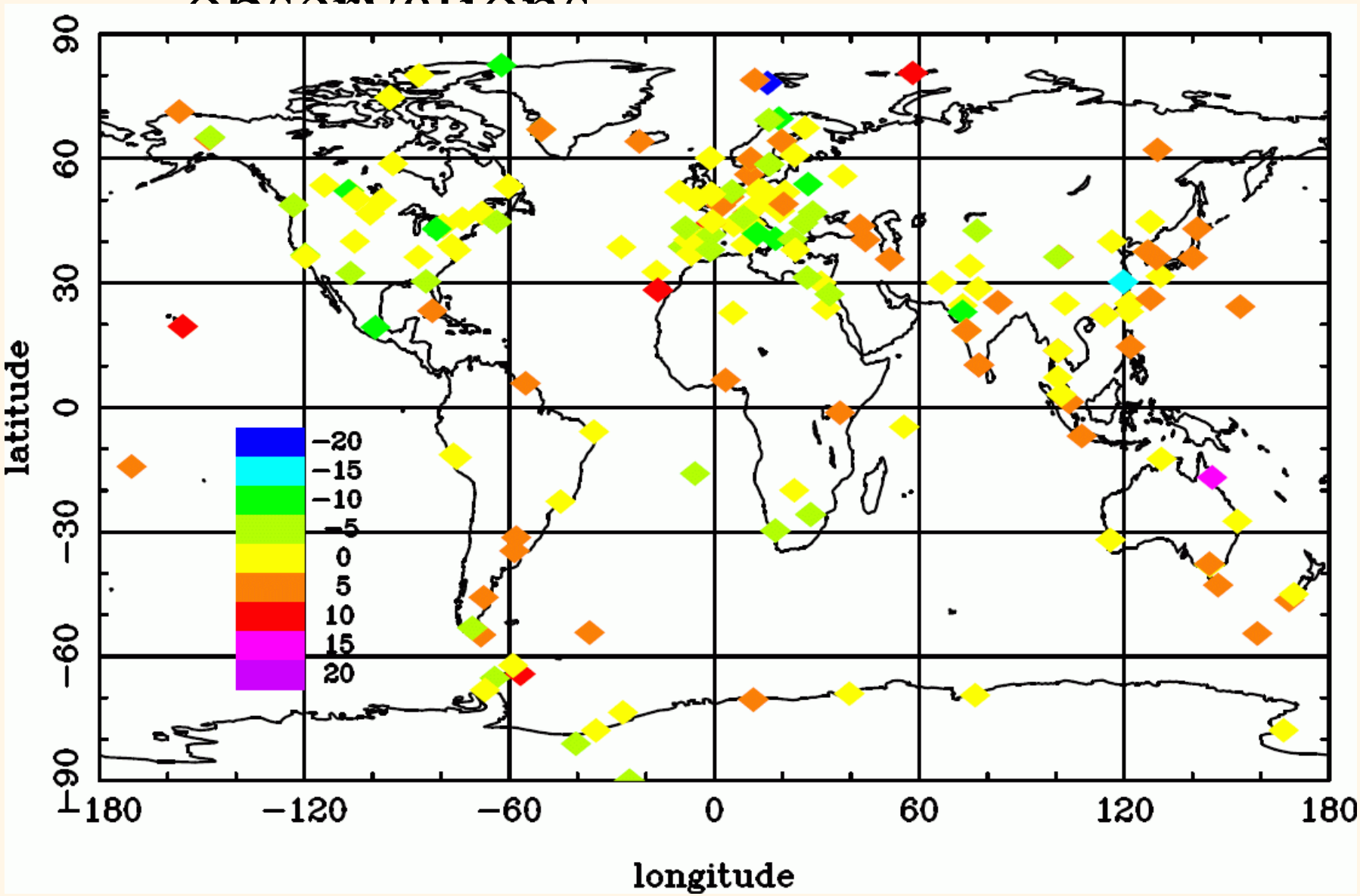


OmF of the Multi-Sensor Reanalysis (MSR)

Gridded for January 2008



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



Conclusions

Merged level 2 data set

- 14 datasets from TOMS, SBUV, GOME, SCIAMACHY and OMI
- Reference: WOUDC data of 91 stations (Brewer and Dobson)
- Correction 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 aand UV data available via www.temis.nl
- Published: *van der A et al., ACP, 2010*

Outlook:

- Reprocessing with new level 2 data.
- Approach can also be used for o3 profiles.

Outlook: Approach for nadir ozone profiles

Is this approach usable for nadir ozone profiles ?

- Satellite data:
  - 2002-2011: SCIAMACHY, GOME-2, OMI
  - 1995-2000: GOME (degradation after 2000)
  - 1978-1995: SBUV
- Ground observations:
  - Till 30 km : ozone sondes
  - Above 30 km: lidar, however data is sparse
- Same fit parameters, but per layer and use of averaging kernels
- Data assimilation of ozone profiles