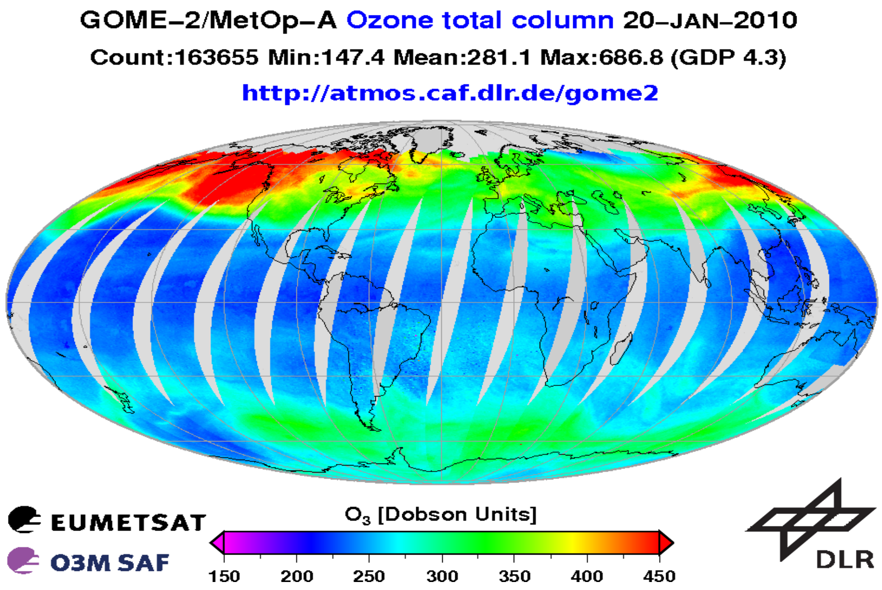
# O3M SAF VALIDATION REPORT

## Validated products:

| Identifier | Name | Acronym |
|---|---|---|
| O3M-40 | Reprocessed Offline Total Ozone | OTO/O3RP |




## Authors:



| Name | Institute |
|---|---|
| **Dimitris Balis** | **Aristotle University of Thessaloniki** |
| **Mariliza Koukouli** | **Aristotle University of Thessaloniki** |
| **Diego Loyola** | **German Aerospace Center** |
| **Pieter Valks** | **German Aerospace Center** |
| **Nan Hao** | **German Aerospace Center** |



| | |
|---|---|
| Reporting period: | **January 2007 – June 2009** |
| Input data versions: | **GOME-2 L1b version 4.x, since 1 January 2007** |
| Data processor versions: | **GDP 4.4, UPAS version 1.4.0** |

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AUTH | Aristotle University of Thessaloniki |
| BUFR | Binary Universal Form for the Representation of meteorological data |
| CDOP | Continues Development and Operations Proposal |
| DLR | German Aerospace Center |
| DOAS | Differential Optical Absorption Spectroscopy |
| GDP | GOME Data Processor |
| GOME | Global Ozone Monitoring Experiment |
| HDF | Hierarchical Data Format |
| MetOp | Meteorological Operational satellite |
| NRT | Near-real-time |
| NTO/O3 | Near-real-time Total Ozone Product |
| O3MSAF | Ozone Monitoring Satellite Application Facility |
| OMI | Ozone Monitoring Instrument |
| OTO/O3 | Offline Total Ozone Product |
| SCIAMACHY | Scanning Imaging Absorption SpectroMeter for Atmospheric Chartography |
| SZA | Solar Zenith Angle |
| TOMS | Total Ozone Mapping Spectrometer |
| WOUDC | World Ozone and UV Data Center |

# Applicable O3MSAF Documents

[ATBD] Algorithm Theoretical Basis Document for GOME-2 Total Column Products of Ozone, $NO_2$, $SO_2$, BrO, $H_2O$, HCHO, OClO, tropospheric NO2 and Cloud Properties, DLR/GOME-2/ATBD/01 Iss./Rev. 2C, Valks, P., Loyola D., Hao N., Rix M., Slijkhuis S., 2010.

[PUM] Product User Manual for GOME Total Column Products of Ozone, $NO_2$, $SO_2$, BrO, $H_2O$, HCHO, OClO, tropospheric NO2 and Cloud Properties, DLR/GOME/PUM/01, Iss./Rev. 2/C, Loyola D., Zimmer W., Kiemle S., Valks P., Emmadi S., 2010.

[PRD] Product Requirements Document, SAF/O3M/FMI/RQ/PRD/001/Rev. 1.0, D. Hovila, S. Hassinen, D. Loyola, P. Valks, J., S. Kiemle, O. Tuinder, H. Joench-Soerensen, F. Karcher, 2009.

# Technical information

*GOME-2 product name* total ozone column (OTO/O3, NTO/O3)

*Validation reporting period* January 2007 - June 2009

*Level-2 processor version* GDP 4.4, UPAS version 1.4.0

*Input GOME-2 Level-1B data version table*

| Start Date | Start Orbit | Level 1B Version |
|---|---|---|
| Jan.4, 2007 | 1093 | 4.0.0 |
| Jan. 07, 2009 | 11521 | 4.1.0 |
| Apr. 7, 2009 | 12796 | 4.2.0 |
| Aug. 18, 2009 | 14687 | 4.3.0 |

# 1. Introduction

The structure of the report is as follows: first we present summary global and latitudinal averages of the statistics from the comparisons between reprocessed GOME-2 total ozone product (reprocessed OTO/O3) and ground based instruments, separately performed for Dobson and Brewer spectrophotometers.

The latitude statistics are grouped in $10^o$ latitude belts, separately for Brewer and Dobson instruments. For each $10^o$ belt we show:

a. Time series of the monthly mean differences between ground based and reprocessed GOME-2 OTO/O3RP
b. Mean differences per $5^o$ SZA between ground based and reprocessed GOME-2 OTO/O3RP separately for each season.

The global summary statistics include:

a. Mean difference per latitude band ($10^o$) between ground-based and reprocessed GOME-2
b. Time series of the mean differences between ground-based and reprocessed GOME-2 instruments for the Northern Hemisphere
c. Time series of the monthly mean differences between ground-based and reprocessed GOME-2 instruments for the Southern Hemisphere (only for Dobson comparisons)
d. Month-latitude cross section of the differences.
e. Total Ozone – Solar Zenith Angle cross section of the differences.

In all plots that also contain an error bar it represents the 1-σ, i.e. the standard error on the mean percentage differences. The mean values are always extracted from the averaging of all individual daily measurements that fall within the bin in question.

Next we present direct comparisons of reprocessed GOME-2 OTO/O3RP with overpass data from operational GOME-2 OTO/O3, GOME-1, OMITOMS, OMIDOAS and SCIAMACHY for the same locations where also ground-based data are available.

In all the plots we use GOME2 for GOME-2/MetOp-A and GOME1 for GOME/ERS-2

In section 6 we present the DOAS fit analysis and scan angle dependence for the reprocessed GOME-2 OTO/O3. The comparison results are summarized in tables in section 7 and finally the conclusions of the current report are presented in section 8.

# 2. Data sources

1. Reprocessed GOME-2

DLR has reprocessed the OTO/O3 product for the period between January 2007 until December 2009 to generate the OTO/O3RP reprocessed data set. The reprocessed OTO/O3RP products have been processed with GDP4.4. A soft correction for the scan angle dependency has been introduced in the algorithm [ATBD]. All products have been stored locally and have been separately compared with ground-based data. The reprocessed satellite measurements are based on version 4.x of level 1b data. A description for the reprocessed level 1b data is available in EUMETSAT's validation report GOME-2 Level 1b Product Validation Report No. 4 EPS GOME-2 Reprocessing L1B-R1 data-set (http://www.eumetsat.int/Home/Main/Documentation/Technical_and_Scientific_Documentation/ProductValidationReports/index.htm?l=en)

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2. Ground-based observations

Archived Brewer and Dobson total ozone data have been downloaded from the World Ozone and UV Data Centre (WOUDC) at Toronto. These data are of archived quality and are usually quality controlled by each station and WOUDC. Most stations upload their data to the database two to four months after observation. In this report we use for the comparisons only archived data for the period January 2007 to June 2009 depending on the availability of data for each individual station. The WOUDC stations considered for the comparisons are listed in table 2.1 along with number of observations of archived data used. In all comparison plots and statistics presented in this report, the direct sun observations provided by the Brewers and Dobsons are utilized.

3. GOME-1

In order to check the consistency of the two GOME instruments GOME-1 total ozone data processed with GDP4.1 [Van Roozendael, 2006] for the months of January 2007 till June 2009 were also compared with ground-based data.

4. OMI

In this report we also present comparisons of GOME-2 data with OMI total ozone data using both OMITOMS and OMIDOAS overpass data extracted from Aura Validation Data Centre. OMITOMS and OMIDOAS level-2 total ozone data are based on collection 3 level 1b data and have been processed with TOMS v8.5 and OMDOAO3 v1.0.1 algorithms respectively (see ATBD documents at http://toms.gsfc.nasa.gov and http://www.temis.nl).

5. SCIAMACHY

We also present comparisons of GOME-2 versus ground based data together with comparisons of SCIAMACHY total ozone versus ground based data, for common dates only. SCIAMACHY total ozone columns are retrieved with SDOAS (BIRA/IASB), i.e. using the GDP 4.0 algorithm.

**Table 2.1: List of Brewer ground-based stations used for the comparisons**

| ID | Name | LAT | LON | ELEV( m) | Nobs |
|---|---|---|---|---|---|
| 314 | BELGRANO | -77.87 | -34.63 | 255 | 276 |
| 454 | SAN-MARTIN | -68.13 | -67.1 | 30 | 341 |
| 351 | KING-GEORGE-ISLAND | -62.18 | -58.9 | 10 | 235 |
| 322 | PETALING-JAYA | 3.1 | 101.65 | 46 | 571 |
| 306 | CHENGKUNG | 23.1 | 121.37 | 0 | 166 |
| 30 | MARCUS-ISLAND | 24.28 | 153.97 | 17 | 192 |
| 349 | LASHA | 29.4 | 91.03 | 3633 | 271 |
| 325 | LINAN | 30.3 | 119.73 | 0 | 44 |
| 376 | MRSA-MTROUH | 31.33 | 27.22 | 35 | 673 |
| 336 | ESFAHAN | 32.47 | 51.12 | 1550 | 277 |
| 332 | POHANG | 36.03 | 129.38 | 0 | 818 |
| 295 | MT.WALIGUAN | 36.17 | 100.53 | 3816 | 569 |
| 213 | EL-ARENOSILLO | 37.1 | -6.73 | 41 | 567 |
| 252 | SEOUL | 37.57 | 126.95 | 84 | 240 |
| 346 | MURCIA | 38 | -1.17 | 69 | 762 |
| 447 | GODDARD | 38.99 | -76.83 | 100 | 580 |
| 308 | MADRID | 40.45 | -3.55 | 0 | 771 |
| 261 | THESSALONIKI | 40.52 | 22.97 | 4 | 35 |
| 65 | TORONTO | 43.78 | -79.47 | 198 | 97 |
| 326 | LONGFENSHAN | 44.75 | 127.6 | 0 | 592 |
| 35 | AROSA | 46.77 | 9.67 | 1860 | 644 |
| 100 | BUDAPEST | 47.43 | 19.18 | 140 | 461 |
| 99 | HOHENPEISSENBERG | 47.8 | 11.02 | 975 | 635 |
| 290 | SATURNA | 48.78 | -123.13 | 0 | 110 |
| 331 | POPRAD-GANOVCE | 49.03 | 20.32 | 0 | 771 |
| 96 | HRADEC-KRALOVE | 50.18 | 15.83 | 285 | 1273 |
| 53 | UCCLE | 50.8 | 4.35 | 100 | 1499 |
| 318 | VALENTIA | 51.93 | -10.25 | 0 | 646 |
| 316 | DEBILT | 52 | 5.18 | 0 | 724 |
| 174 | LINDENBERG | 52.22 | 14.12 | 98 | 674 |
| 76 | GOOSE | 53.32 | -60.38 | 44 | 120 |
| 21 | EDMONTON | 53.57 | -113.52 | 668 | 120 |
| 279 | NORKOPING | 58.58 | 16.12 | 0 | 734 |
| 77 | CHURCHILL | 58.75 | -94.07 | 35 | 107 |

| | | | | | |
|---|---|---|---|---|---|
| 284 | VINDELN | 64.25 | 19.77 | 0 | 502 |
| 267 | SONDRESTROM | 67 | -50.98 | 150 | 127 |
| 262 | SODANKYLA | 67.37 | 26.65 | 179 | 394 |
| 24 | RESOLUTE | 74.72 | -94.98 | 64 | 130 |
| 315 | EUREKA | 79.89 | -85.93 | 10 | 128 |
| 18 | ALERT | 82.5 | -62.33 | 62 | 128 |

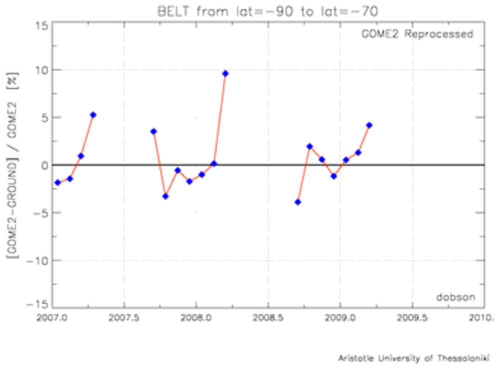
**Table 2.2: List of Dobson ground-based stations used for the comparisons**

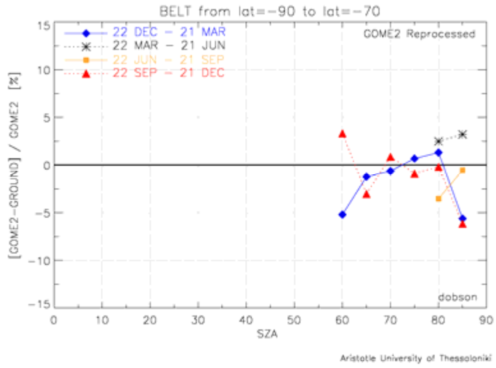
| ID | Name | LAT | LON | ELEV( m) | Nobs |
|---|---|---|---|---|---|
| 111 | AMUNDSEN-SCOTT | -89.98 | -24.8 | 2835 | 177 |
| 268 | ARRIVAL-HEIGHTS | -77.83 | 166.4 | 250 | 175 |
| 57 | HALLEY-BAY | -75.52 | -26.73 | 31 | 6 |
| 101 | SYOWA | -69 | 39.58 | 21 | 414 |
| 232 | VERNADSKY-FARADAY | -65.25 | -64.27 | 7 | 16 |
| 233 | MARAMBIO | -64 | -57 | 198 | 296 |
| 339 | USHUAIA | -54.85 | -68.31 | 7 | 450 |
| 29 | MACQUARIE-ISLAND | -54.48 | 158.97 | 6 | 629 |
| 342 | COMODORO-RIVADAVIA | -45.78 | -67.5 | 43 | 544 |
| 256 | LAUDER | -45.03 | 169.68 | 3701 | 376 |
| 253 | MELBOURNE | -37.48 | 144.58 | 125 | 599 |
| 91 | BUENOS-AIRES | -34.58 | -58.48 | 25 | 556 |
| 159 | PERTH | -31.95 | 115.85 | 2 | 385 |
| 343 | SALTO | -31.58 | -57.95 | 31 | 492 |
| 27 | BRISBANE | -27.47 | 153.03 | 5 | 572 |
| 191 | SAMOA | -14.25 | -170.57 | 82 | 211 |
| 84 | DARWIN | -12.47 | 130.83 | 0 | 504 |
| 429 | MARCAPOMACOCHA | -11.4 | -76.32 | 4479 | 224 |
| 214 | SINGAPORE | 1.33 | 103.88 | 14 | 383 |
| 317 | LAGOS | 6.45 | 3.5 | 0 | 309 |
| 216 | BANGKOK | 13.73 | 100.57 | 2 | 512 |
| 218 | MANILA | 14.63 | 121.08 | 61 | 462 |
| 187 | POONA | 18.53 | 73.85 | 559 | 385 |
| 31 | MAUNA-LOA | 19.53 | -155.58 | 3397 | 263 |
| 2 | TAMANRASSET | 22.8 | 5.52 | 1395 | 563 |
| 245 | ASWAN | 23.97 | 32.45 | 193 | 606 |

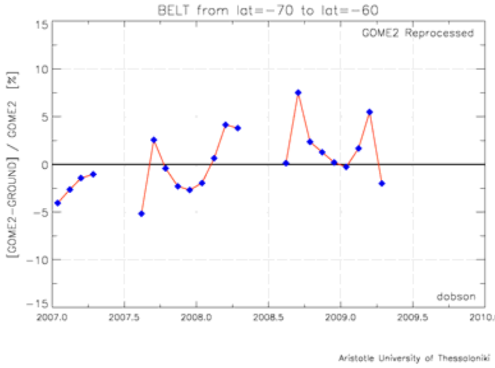
| | | | | | |
|---|---|---|---|---|---|
| 209 | KUNMING | 25.02 | 102.68 | 1917 | 332 |
| 74 | VARANASI | 25.45 | 82.87 | 76 | 415 |
| 190 | NAHA | 26.2 | 127.67 | 29 | 566 |
| 10 | NEW-DELHI | 28.63 | 77.22 | 216 | 787 |
| 152 | CAIRO | 30.08 | 31.28 | 35 | 647 |
| 11 | QUETTA | 30.18 | 66.95 | 1799 | 178 |
| 14 | TATENO | 36.05 | 140.13 | 31 | 615 |
| 106 | NASHVILLE | 36.25 | -86.57 | 182 | 450 |
| 341 | HANFORD | 36.32 | -119.63 | 73 | 359 |
| 213 | EL-ARENOSILLO | 37.1 | -6.73 | 41 | 216 |
| 252 | SEOUL | 37.57 | 126.95 | 84 | 318 |
| 107 | WALLOPS-ISLAND | 37.87 | -75.52 | 4 | 118 |
| 293 | ATHENS | 38 | 23.7 | 15 | 437 |
| 208 | SHIANGHER | 39.77 | 117 | 13 | 513 |
| 67 | BOULDER | 40.02 | -105.25 | 1634 | 360 |
| 410 | AMBERD | 40.38 | 44.25 | 2070 | 458 |
| 12 | SAPPORO | 43.05 | 141.33 | 19 | 657 |
| 40 | HAUTE-PROVINCE | 43.92 | 5.75 | 580 | 175 |
| 19 | BISMARCK | 46.77 | -100.75 | 511 | 466 |
| 35 | AROSA | 46.77 | 9.67 | 1860 | 561 |
| 20 | CARIBOU | 46.87 | -68.02 | 192 | 280 |
| 99 | HOHENPEISSENBERG | 47.8 | 11.02 | 975 | 357 |
| 96 | HRADEC-KRALOVE | 50.18 | 15.83 | 285 | 329 |
| 53 | UCCLE | 50.8 | 4.35 | 100 | 360 |
| 68 | BELSK | 51.83 | 20.78 | 180 | 208 |
| 43 | LERWICK | 60.15 | -1.15 | 90 | 627 |
| 284 | VINDELN | 64.25 | 19.77 | 0 | 165 |
| 105 | FAIRBANKS | 64.8 | -147.89 | 138 | 124 |
| 199 | BARROW | 71.32 | -156.6 | 11 | 126 |

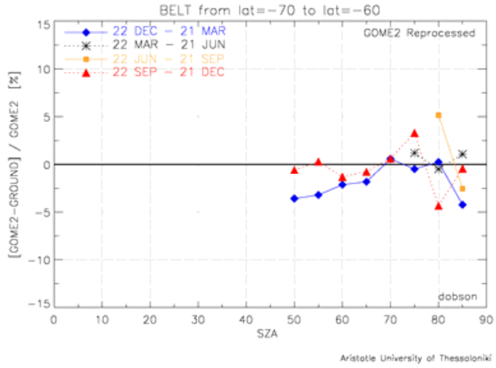
# 3. Latitudinal and global comparisons between reprocessed GOME-2 OTO/O3 and archived ground-based data from WOUDC

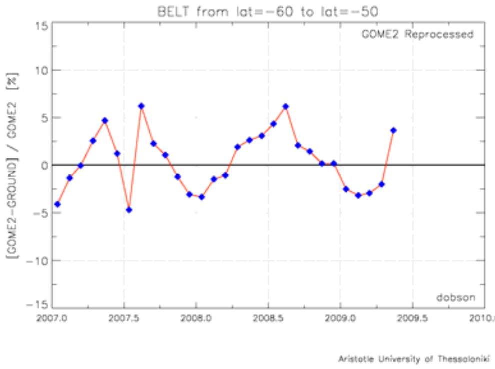
## 3a. Reprocessed GOME-2 comparisons with Dobson instruments for 10° latitude belts Southern Hemisphere

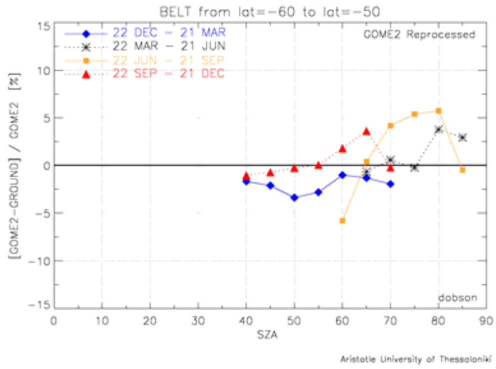


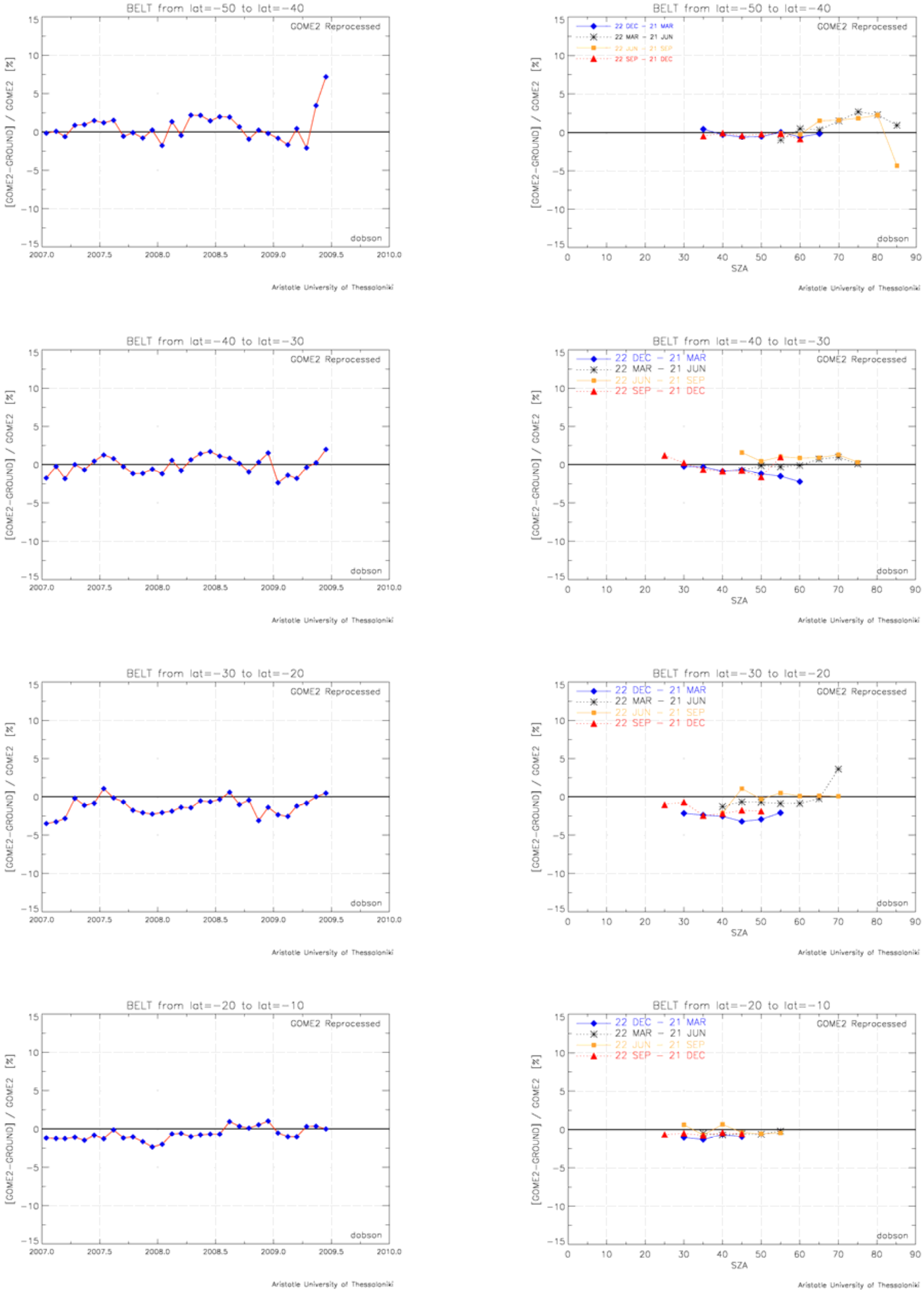



**Figure 3.1.** Comparisons between the reprocessed GOME2 total ozone estimates and the Dobson instruments per latitude belt for the Southern Hemisphere depicted as a time series [left column] and as a seasonal solar zenith angle

dependence [right column]. From top to bottom: belt between -90° to -70°, -70° to -60°; -60° to -50°;-50° to -40°;-40° to -30°, -30° to 20° and -20° to -10°.

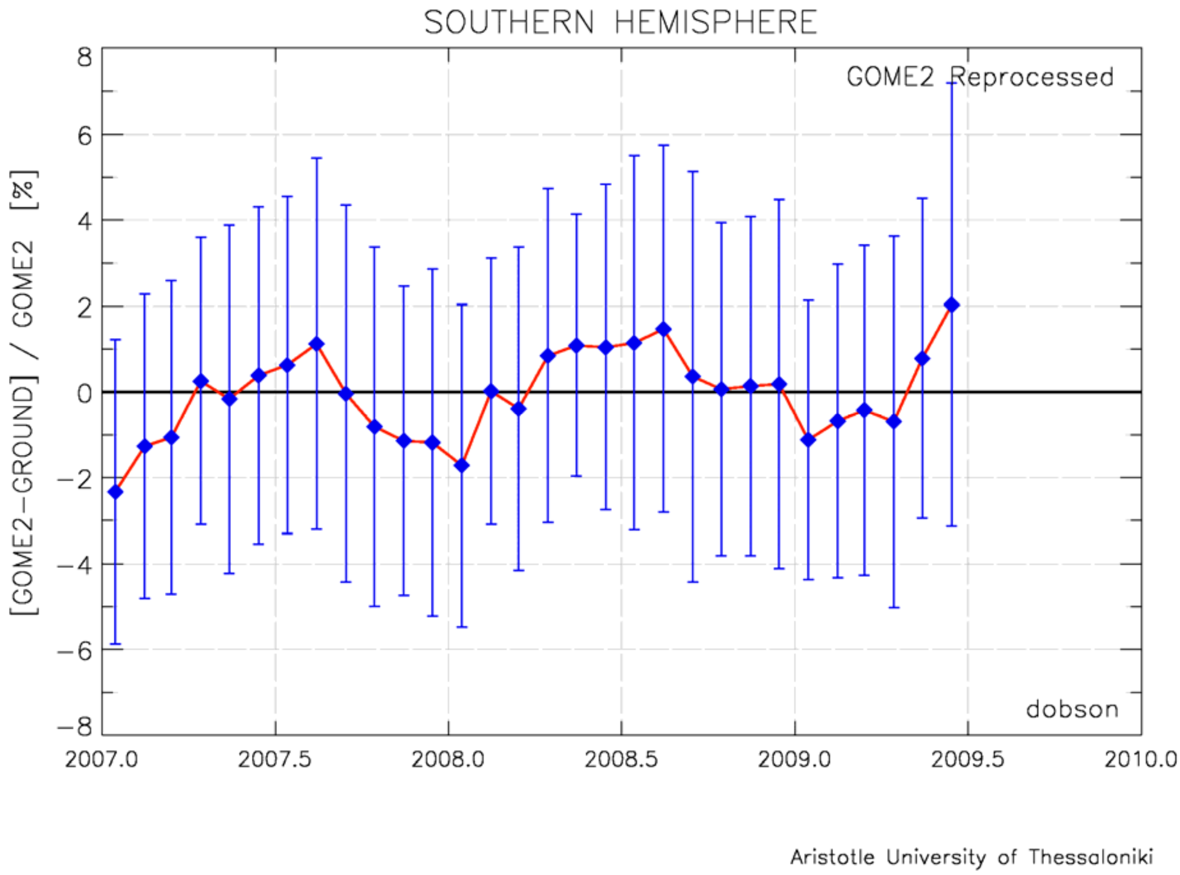
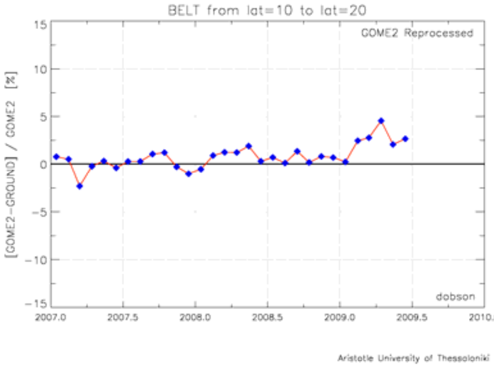
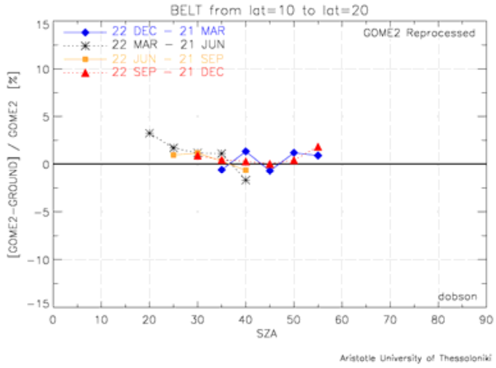
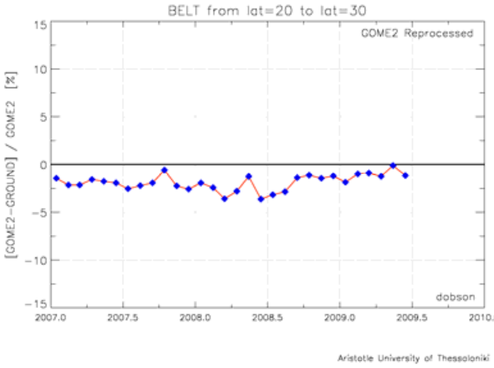


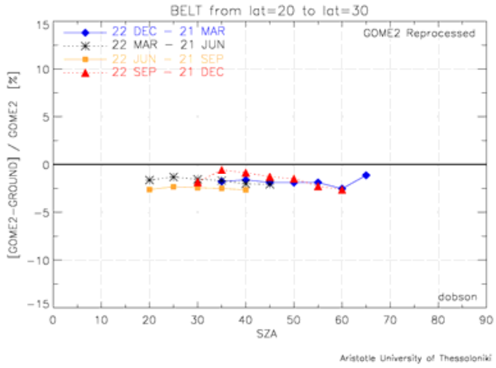

**Figure 3.2** The time series of the difference between reprocessed GOME 2 and Dobson instruments for the entire Southern Hemisphere depicted as monthly mean values.

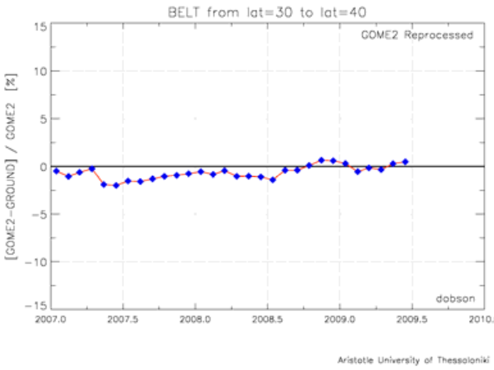
## Northern Hemisphere

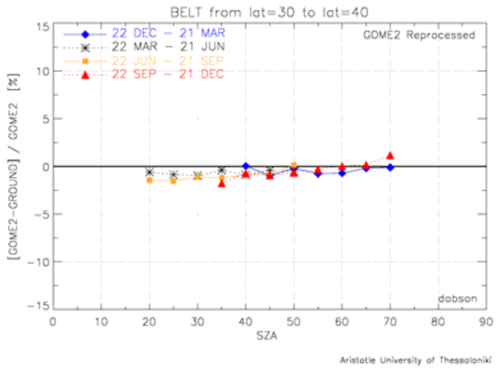


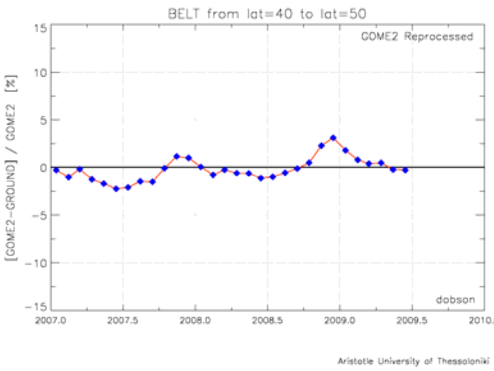



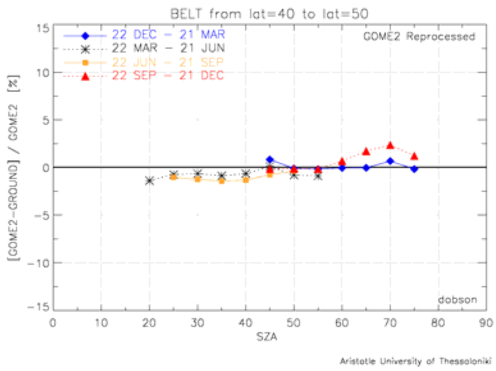



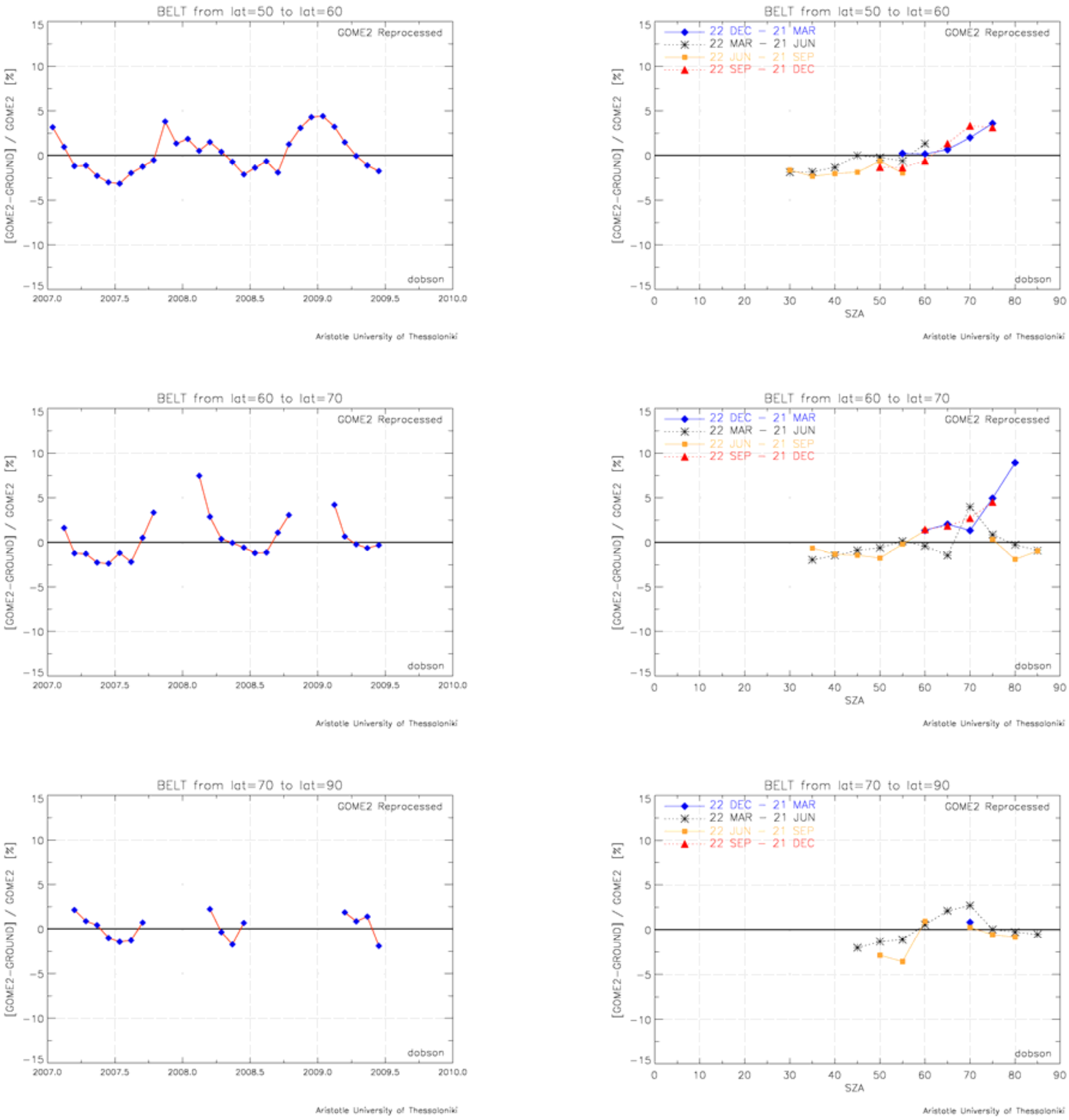



**Figure 3.3** Comparisons between the reprocessed GOME2 total ozone estimates and the Dobson instruments per latitude belt for the Northern Hemisphere depicted as a time series [left column] and as a seasonal solar zenith angle dependence [right column]. From top to bottom: belt between 10° and 20°; 20° to 30°;30° to 40°, 40° to 50°, 50° to 60°, 60° to 70° and 70° to 90°.

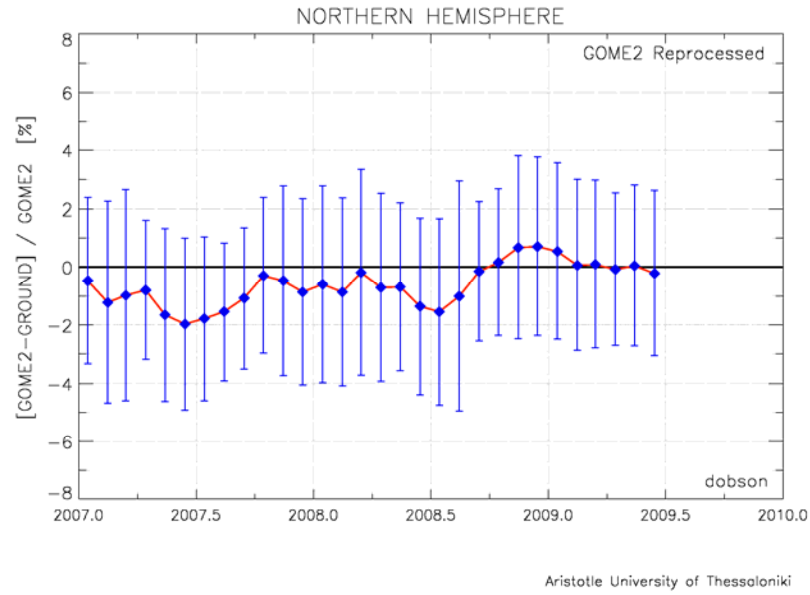



**Figure 3.4** The time series of the difference between reprocessed GOME 2 and Dobson instruments for the entire Northern Hemisphere depicted as monthly mean values.

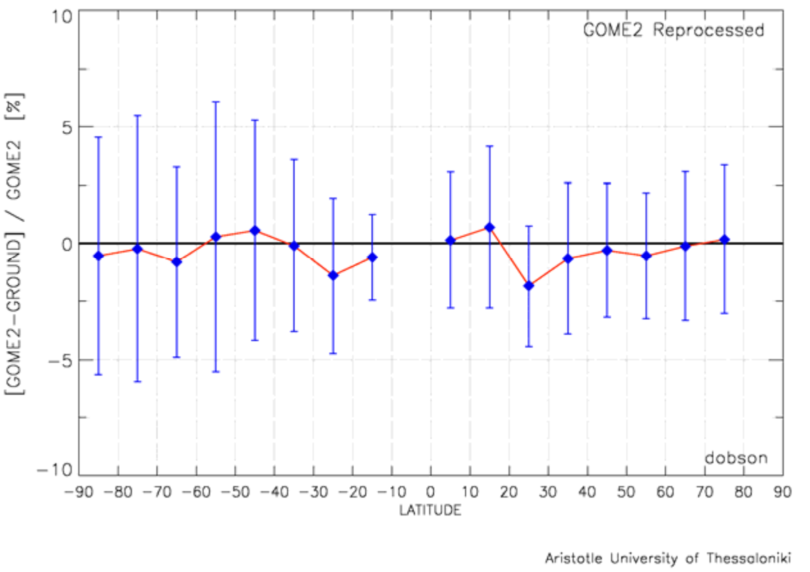



**Figure 3.5** Latitudinal average differences between reprocessed GOME 2 and Dobson instruments based on the period March 2007-June 2009

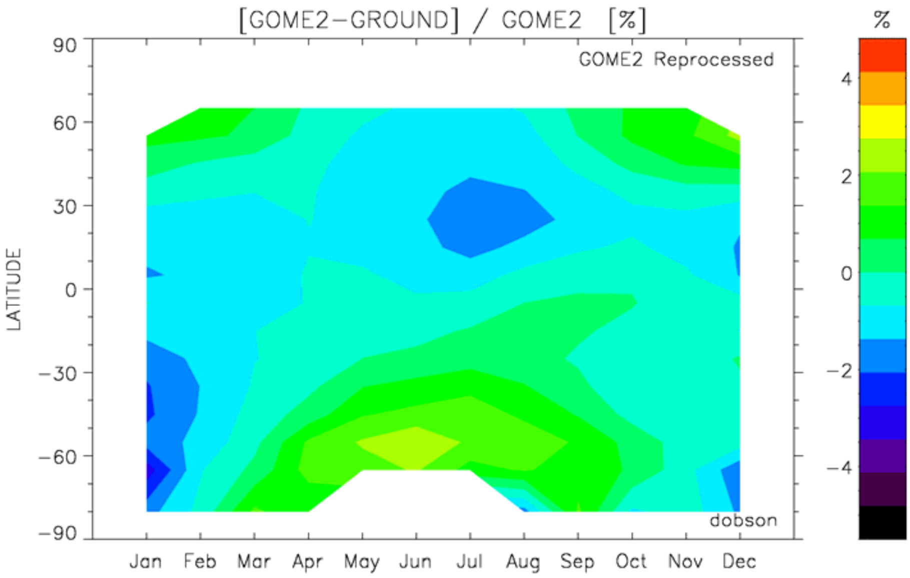



**Figure 3.6.** The mean seasonal and latitudinal variability of the differences in total ozone between reprocessed GOME2 and Dobson instruments

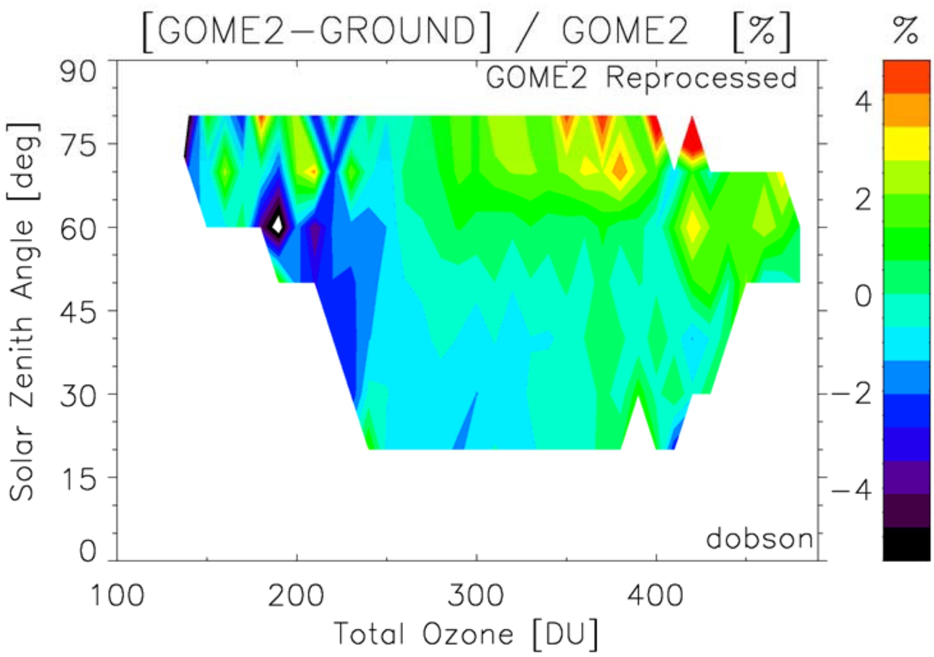



**Figure 3.7.** The differences in total ozone between reprocessed GOME2 and Dobson instruments as function of the columnar ozone value and the solar zenith angle. The merit of this contour plot is to show if a total ozone column dependence exists in the differences, for e.g for ozone hole conditions relating to the climatological ozone profile used, or under extreme measurements geometries. As shown, a high overestimation is observed for high total ozone conditions and high SZA conditions in this comparison, and not for high total ozone and low SZA conditions where the opposite applies.

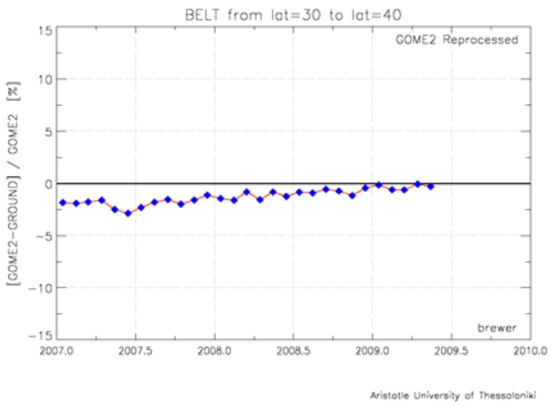
**Summary of the reprocessed GOME-2 – Dobson comparisons**

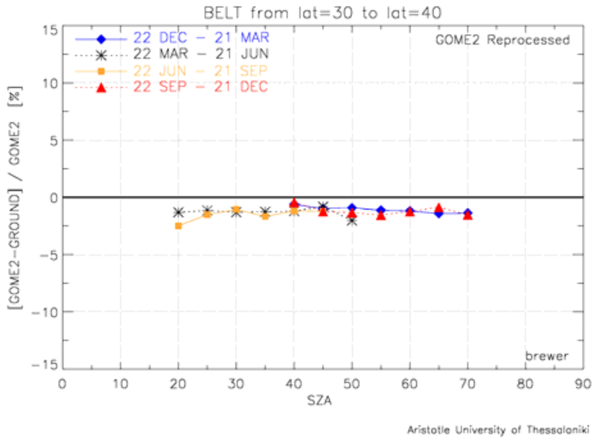
a. Reprocessed GOME-2 underestimates ozone by about 0.5% over the middle latitudes of the Northern Hemisphere and slightly overestimates (again around 0.5%) over the middle latitudes of the Southern Hemisphere. Over the high latitudes of the Northern Hemisphere GOME-2 has almost no offset relative to Dobson readings while over the high latitudes of the Southern Hemisphere underestimates ozone by less than 1%. Over the tropical latitudes GOME-2 estimates on the average less ozone by 0 to 2% compared to Dobson measurements.
b. Reprocessed GOME-2 data when compared to Dobson measurements show a small dependence on solar zenith angle. GOME-2 underestimates ozone for small SZAs. (2-3%) and slightly overestimates ozone (1%) for) SZAs greater than 70°. However using the current ground-based data set it is not easy to separate the SZA dependence from the seasonal dependence due to the variability in stratospheric temperatures since both are related to the seasonal cycle.
c. There is a seasonal dependence of the differences between reprocessed GOME-2 and Dobson data over the Northern Hemisphere, consistent and with the same amplitude with the one observed in GOME-2 OTO/O3 and GOME-1 data comparisons but with less offset when compared to the Dobson measurements. Reprocessed GOME-2 data underestimate total ozone during the warm period compared to the Dobson measurements. This seasonal dependence of the differences is a known feature from previous validation studies of GDP4.0 and to large extend is associated with the variability of the stratospheric temperatures which affects the Dobson measurements due the fact that the ozone absorption cross sections used routinely have a moderate temperature dependence which is not taken into account in the operational Dobson algorithm (Staehelin et al, 2003).
d. The underestimation and overestimation from the reprocessed GOME-2 ozone are considerable reduced compared with the currently operational product.
e. There is an indication of a small drift in the reprocessed GOME-2 ozone data over the Northern Hemisphere after early/mid 2008. The reprocessed GOME-2 data since mid 2008 are closer to the ground-based observations. This drift is eventually associated with instrumental issues such as changes in the GOME-2 PMD settings since March 2008 and

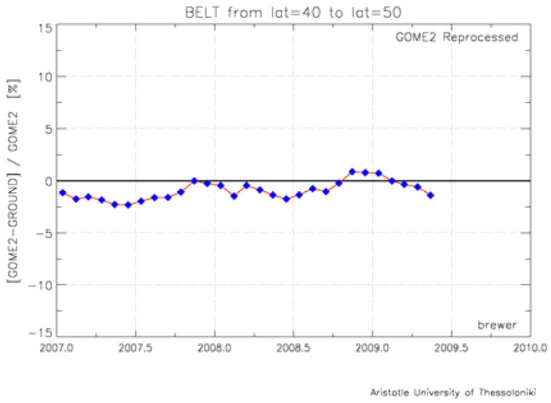
changes in the version of level 1b data used afterwards, but there also indications that the observed drift could be also related to year-to-year changes of stratospheric temperature. This investigation is still on going.

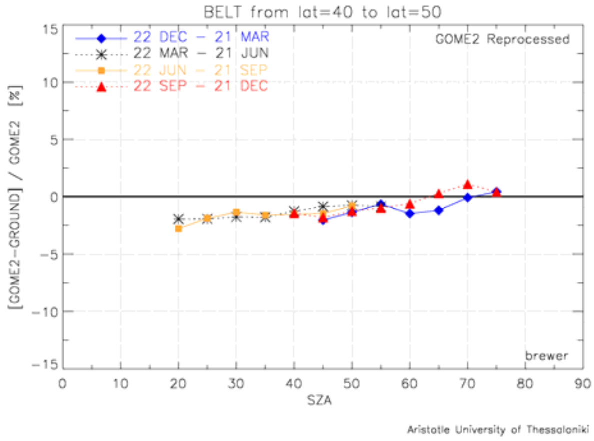
## 3b. Reprocessed GOME-2 comparisons with Brewer instruments for 10$^{o}$ latitude belts

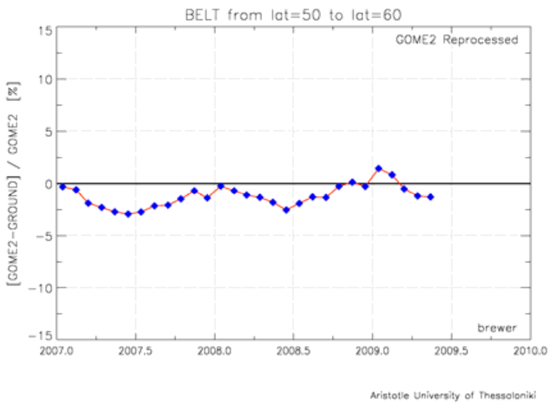
### I. Northern Hemisphere

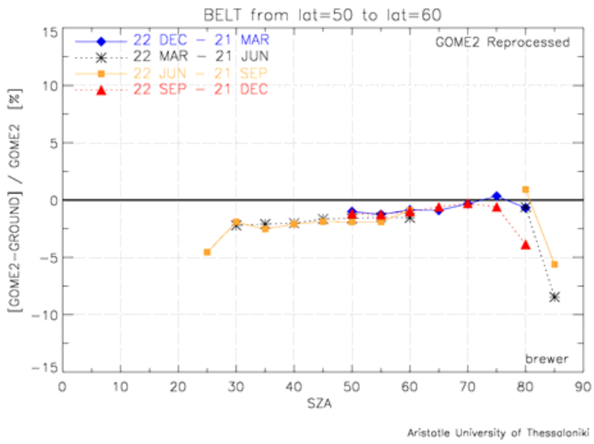


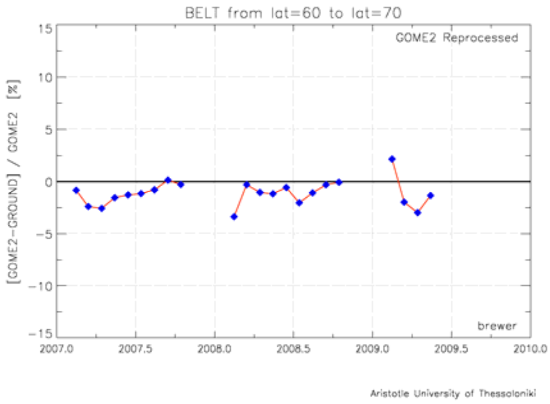





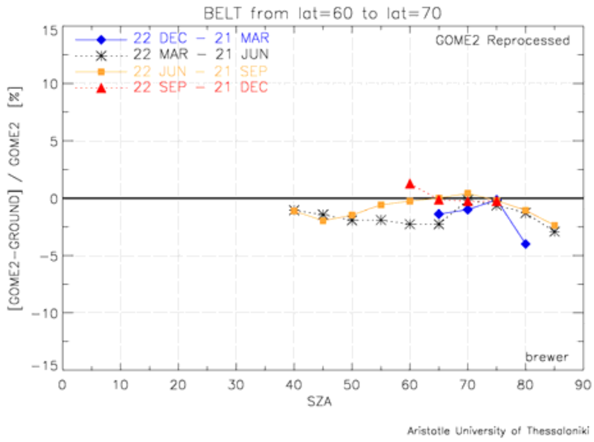




**Figure 3.8** Comparisons between the reprocessed GOME2 total ozone estimates and the Brewer instruments per latitude belt for the Northern Hemisphere depicted as a time series [left column] and as a seasonal solar zenith angle dependence [right column]. From top to bottom: belt between 30° and 40°; 40° to 50°;50° to 60°, 60° to 70°.

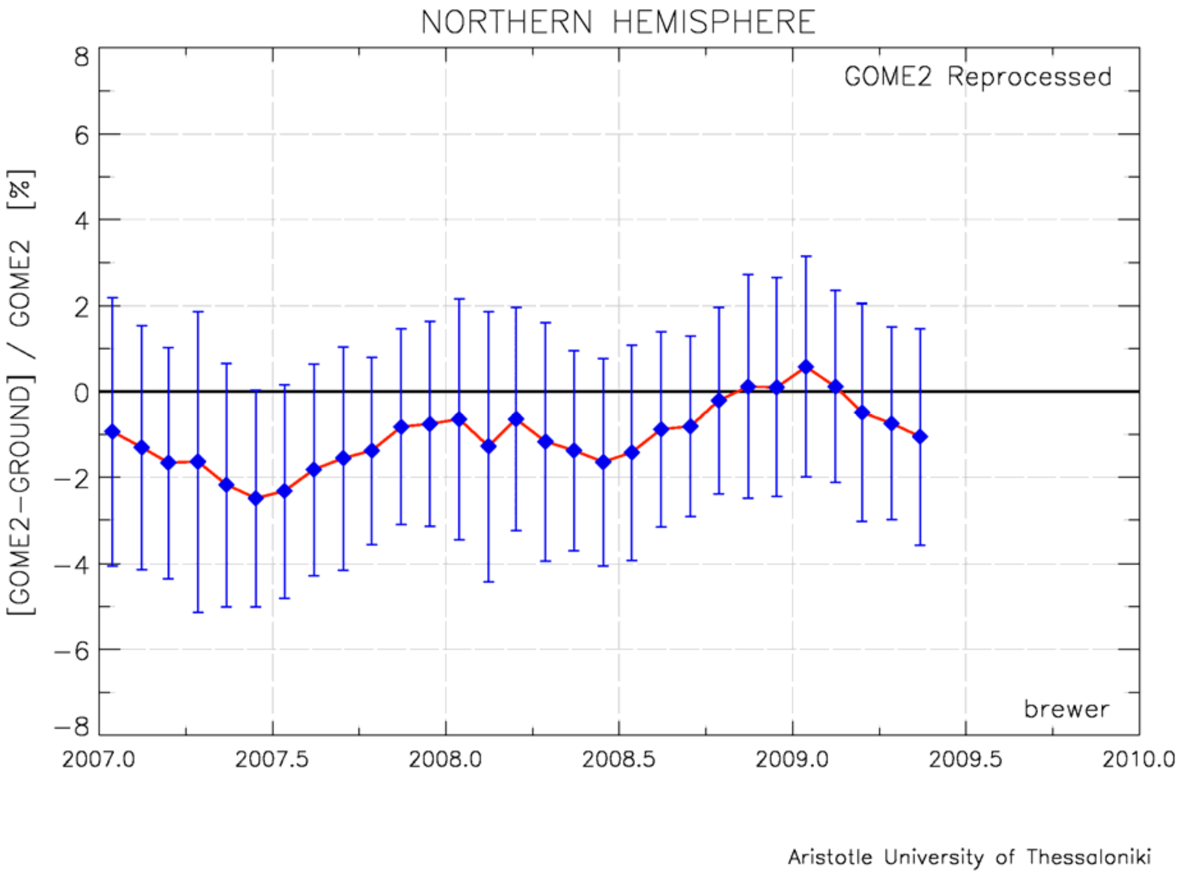



**Figure 3.9** The time series of the difference between reprocessed GOME 2 and Brewer instruments for the entire Northern Hemisphere depicted as monthly mean values.

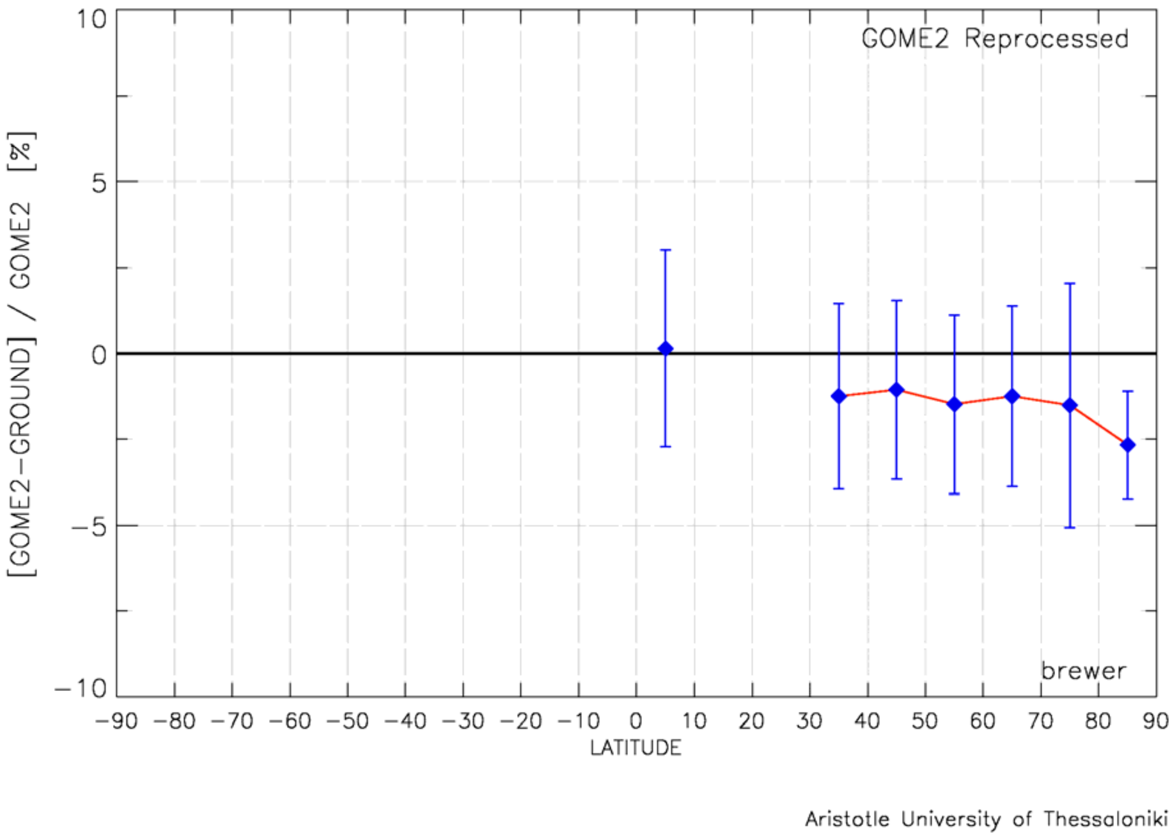



**Figure 3.10** Latitudinal average differences between reprocessed GOME 2 and Brewer instruments based on the period March 2007-May 2008

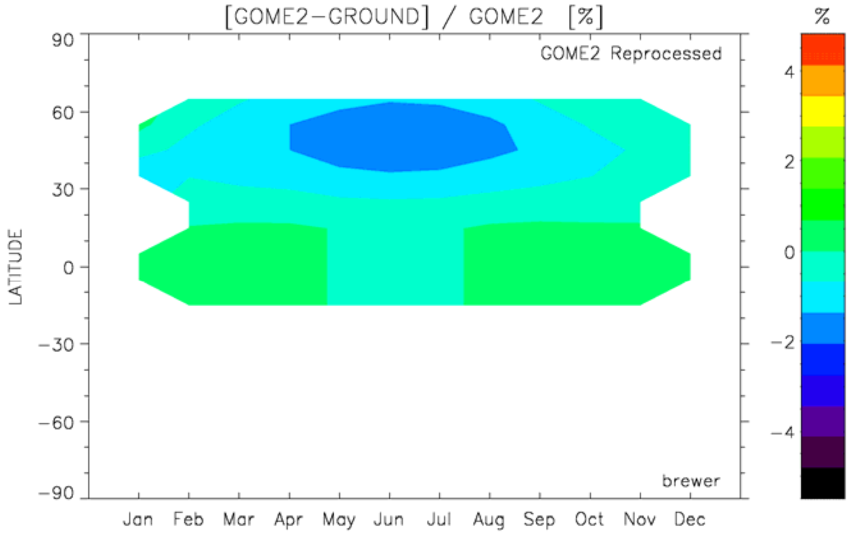



**Figure 3.11** The seasonal and latitudinal variability of the differences in total ozone between GOME2 and Brewer instruments [bottom.]

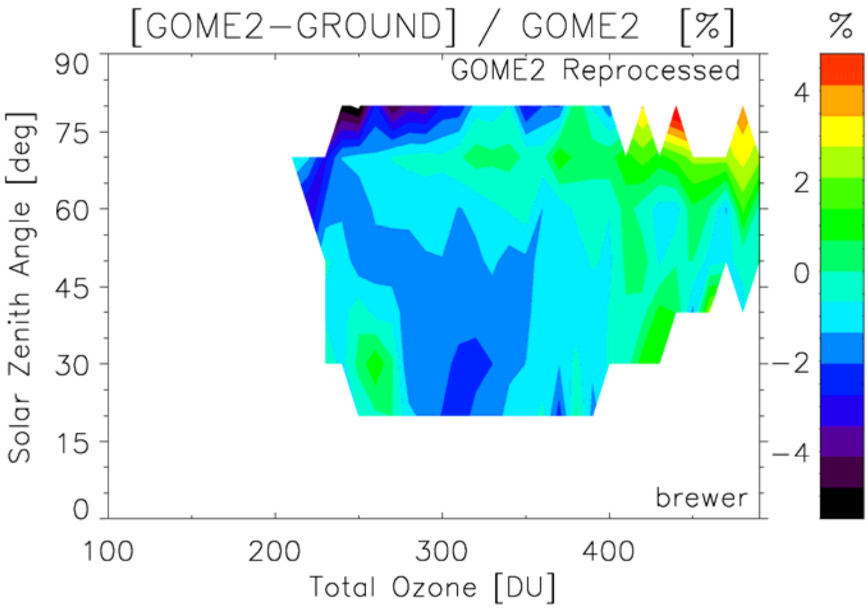



**Figure 3.12.** The differences in total ozone between reprocessed GOME2 and Brewer instruments depending on the actual total ozone value and the solar zenith angle variability. The merit of this contour plot is to show if a total ozone column dependence exists in the differences, for e.g for ozone hole conditions relating to the climatological ozone profile used, or under extreme measurements geometries. As shown, a high overestimation is observed only for extremely high total ozone conditions [> 400 D.U.] and high SZA conditions in this comparison.

**Summary of the reprocessed GOME-2 – Brewer comparisons**

a. Reprocessed GOME-2 comparisons with Brewer ozone data over the Northern Hemisphere are consistent with the GOME-2 – Dobson comparisons and show an underestimation of 1%, which tends to be slightly higher (1-2%) over the Arctic.
b. Reprocessed GOME-2 data when compared to Brewer measurements show a small dependence on solar zenith angle, similar to the one found in the Dobson comparisons.
c. As mentioned earlier there is a seasonal dependence of the differences between reprocessed GOME-2 and Brewer measurements. Its amplitude is slightly smaller in the Brewer comparisons over the middle to high latitudes with respect to the Dobson comparisons, mainly due to the fact that the temperature dependence of the Brewer measurements is smaller than the of the Dobson ones (Staehelin et al. 2003).
d. There is an indication of small drift in GOME-2 ozone data over the Northern Hemisphere after early/mid 2008. The GOME-2 data since mid 2008 are closer to the ground-based observations. This drift is eventually associated with changes in the GOME-2 PMD settings since March 2008 and/or changes in the version of level 1b data used afterwards.

The summary comparisons for the reprocessed GOME-2 both for Dobson and Brewer instruments will be available at http://lap.physics.auth.gr/o3safval and will cover the period presented in the current report, as soon as this report has been accepted and the reprocessed data will be declared as the official GOME-2 OTO/O3.

# 4. Example comparisons between reprocessed GOME-2 OTO/O3RP and representative high quality Brewer and Dobson ground-based data

## 4a. Individual station comparisons

In this section we present detailed comparisons between reprocessed GOME-2 OTO/O3 data and two characteristic examples of a well maintained Dobson and Brewer instrument. We show comparison results for the station of Arosa (Dobson) and Hohenpeissenberg (Brewer) using archived data from WOUDC. These stations perform only direct sun measurements, so the comparison results using all available types of ground based observations and the ones which correspond to direct sun observations are identical. This is the case for most of the Brewer instruments but it is not the case for most of the Dobson instruments. Similar comparisons have been performed for all Dobson and Brewer instruments considered in the report and are available on request. Once the reprocessed GOME-2 OTO/O3 data will be declared official, all individual station comparisons will be uploaded to the GOME-2 validation site for ozone of O3MSAF at http://lap.physics.auth.gr/o3safval. All latitudinal and summary plots are based on the individual station comparisons of the stations listed in table 2.1. The individual station comparisons along with comparisons with other satellites are also used to monitor the quality of each individual station, before this station is considered in the summary statistics.

## Station 35: Arosa (46.8°N – 9.67°E) - Dobson

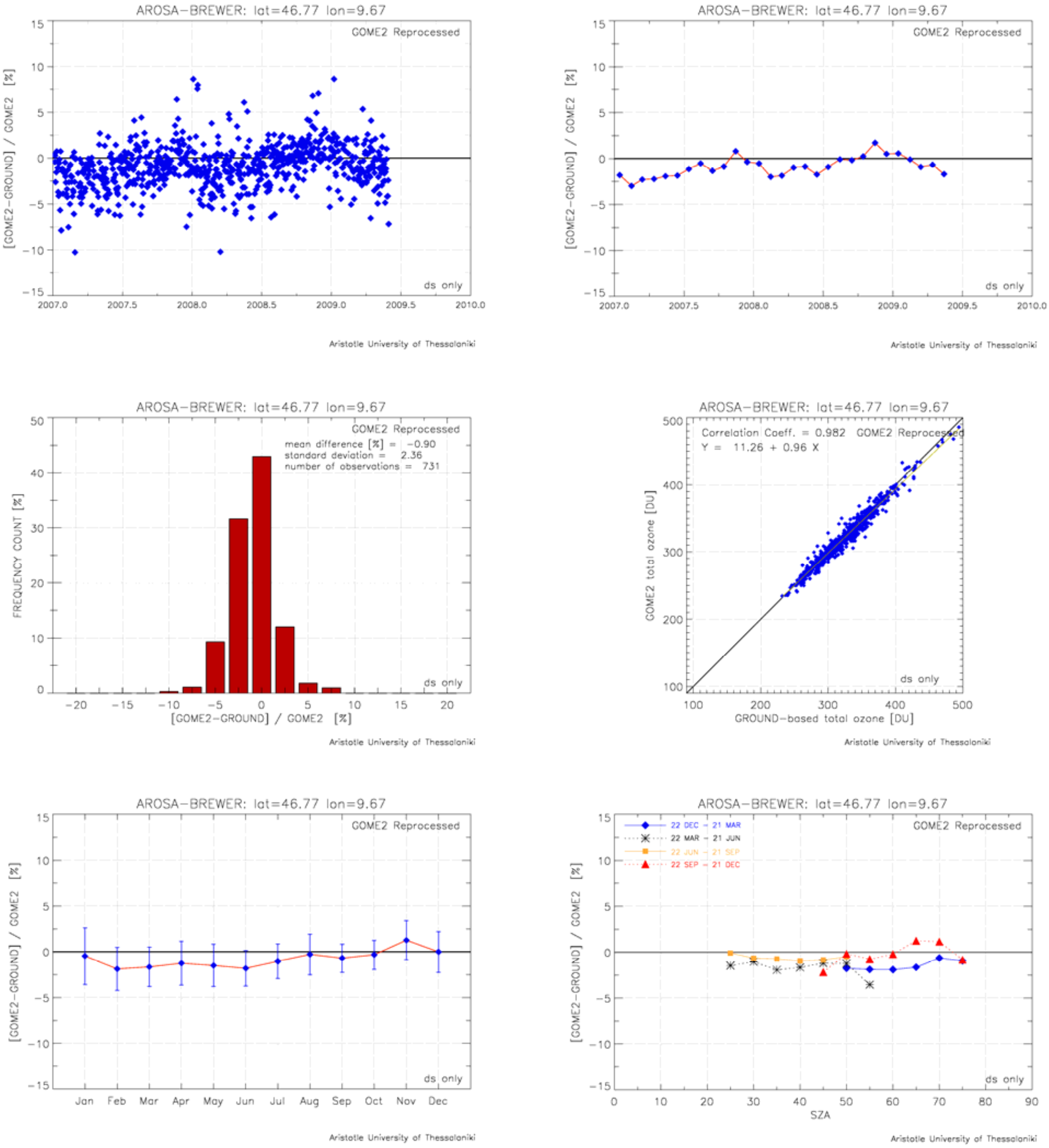



**Figure 4.1** The comparison between the reprocessed GOME2 and the ground-based stations estimates by the Arosa Dobson is shown in various formats: (from top to bottom and from left to right) ; the time evolution of the differences with no averaging performed; the time evolution of the monthly averaged differences; histogram representation of the differences with a mean difference of 0.90 and standard deviation of 2.36 for the 751 measurements used in this comparison; the scatter plot of the total ozone values found with a correlation coefficient of 0.98; the average seasonal variability of the differences which shows a small seasonal pattern; the solar zenith angle dependence of the differences for each of the four seasons of the year, blue for winter, black for spring, yellow for summer and red for autumn.

**Station 99: Hohenpeissenberg [47.80°N – 11.02°E] - Brewer**

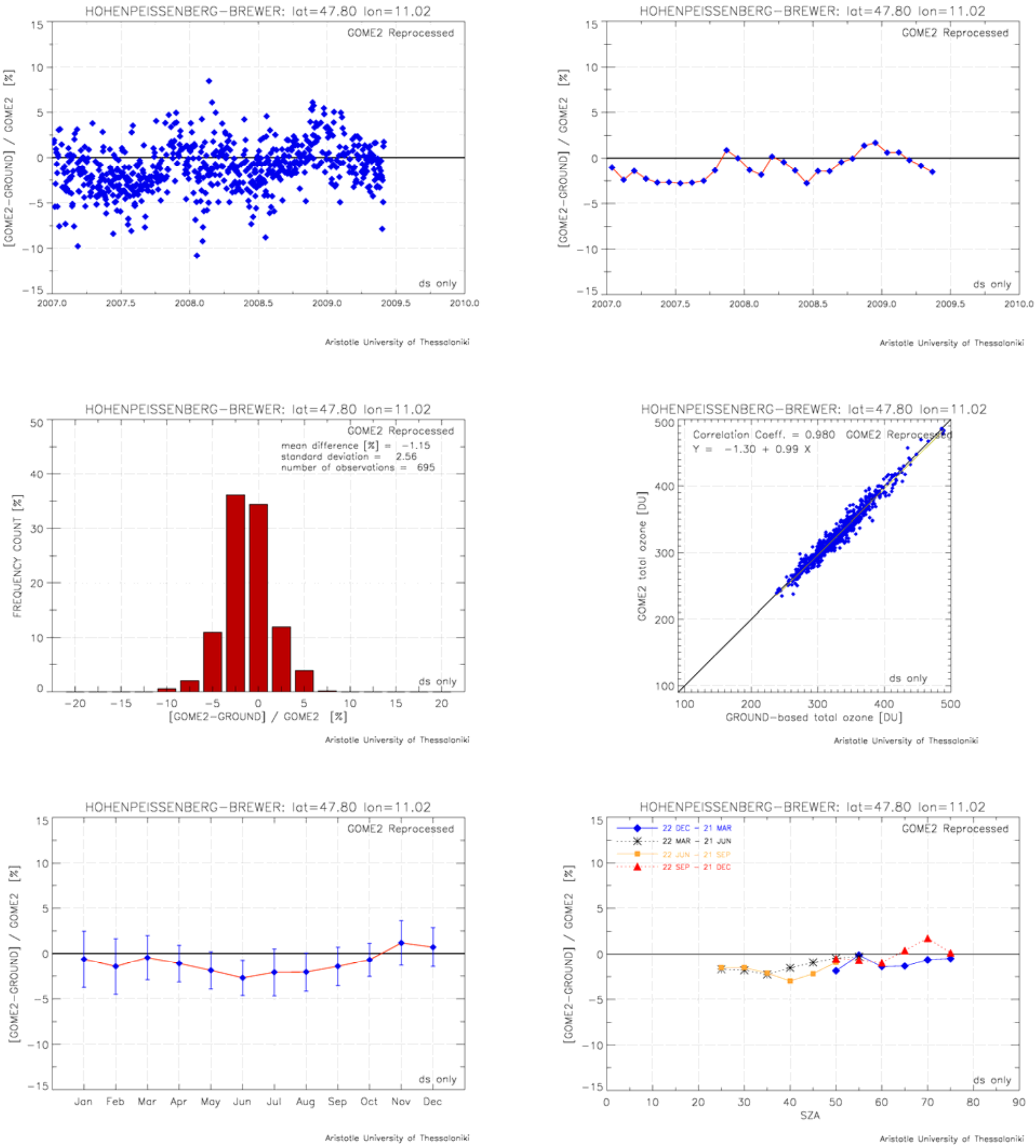



**Figure 4.2** The comparison between the reprocessed GOME2 and the ground-based stations estimates by the Hohenpeissenberg Brewer is shown in various formats: from top to bottom; the time evolution of the differences with no averaging performed; the time evolution of the monthly averaged differences; histogram representation of the differences with a mean difference of -1.18 and standard deviation of 2.57 for the 723 measurements used in this comparison; the scatter plot of the total ozone values found with a correlation coefficient of 0.979; the average seasonal variability of the differences; the solar zenith angle dependence of the differences for each of the four seasons of the year, blue for winter, black for spring, yellow for summer and red for autumn.

# 5. Comparisons of reprocessed GOME-2 with GOME-1, SCIAMACHY, OMI and the operational GOME-2 OTO/O3 for common days against selected ground-based locations

### Instrument characteristics

First we present in table 5.1 the instrument characteristics of each satellite instrument considered in the direct comparisons. Apart from algorithm issues, differences in the estimated total ozone can be also a result of differences in the level-1 products, in the instruments and satellites themselves and therefore such differences should be taken into account when comparing two satellite datasets.

**Table 5.1** Main characteristics of the GOME-2/MetOp GOME/ERS-2, SCIAMACHY and OMI instruments affecting the total ozone column products.

| | **GOME-2/MetOp** | **GOME/ERS-2** | **SCIAMACHY** | **OMI** |
|---|---|---|---|---|
| **Principle** | UV/VIS grating spectrometer | UV/VIS grating spectrometer | UV/VIS/NIR grating spectrometer | UV/VIS grating spectrometer |
| **Detectors** | Reticon linear diode array | Reticon linear diode array | Reticon linear diode array | 2-dimensional CCD |
| **Spectral resolution** | 0.26 nm | 0.20 nm | 0.26 nm | 0.45 nm |
| **Spatial resolution (default)** | 80 x 40 km2 | 320 x 40 km2 | 60 x 30 km2 | Up to 13 x 24 km2 |
| **Swath width** | 1920 km | 960 km | 960 km | 2600 km |
| **Eq. crossing time** | 09:30 LT | 10:30 LT | 10:00 LT | 13:38 LT |
| **Level-0-to-1b alg.** | GOME2 PPF 4.x | GDP L01 4.0 | IPF 6.03 | OML1BRUG (v003) |
| **Level-1-to-2 alg.** | GDP 4.4 | GDP 4.1 | SDOAS (GDP 4.0) | OMDOAO3 v1.0.5<br>OMTO3 v1.1.0 |

* In addition to the parameters listed here, the differential signal-to-noise characteristics of the instruments can have an impact on the total ozone column retrieval as well.

## Reprocessed GOME-2 OTO/O3RP comparisons with GOME-1

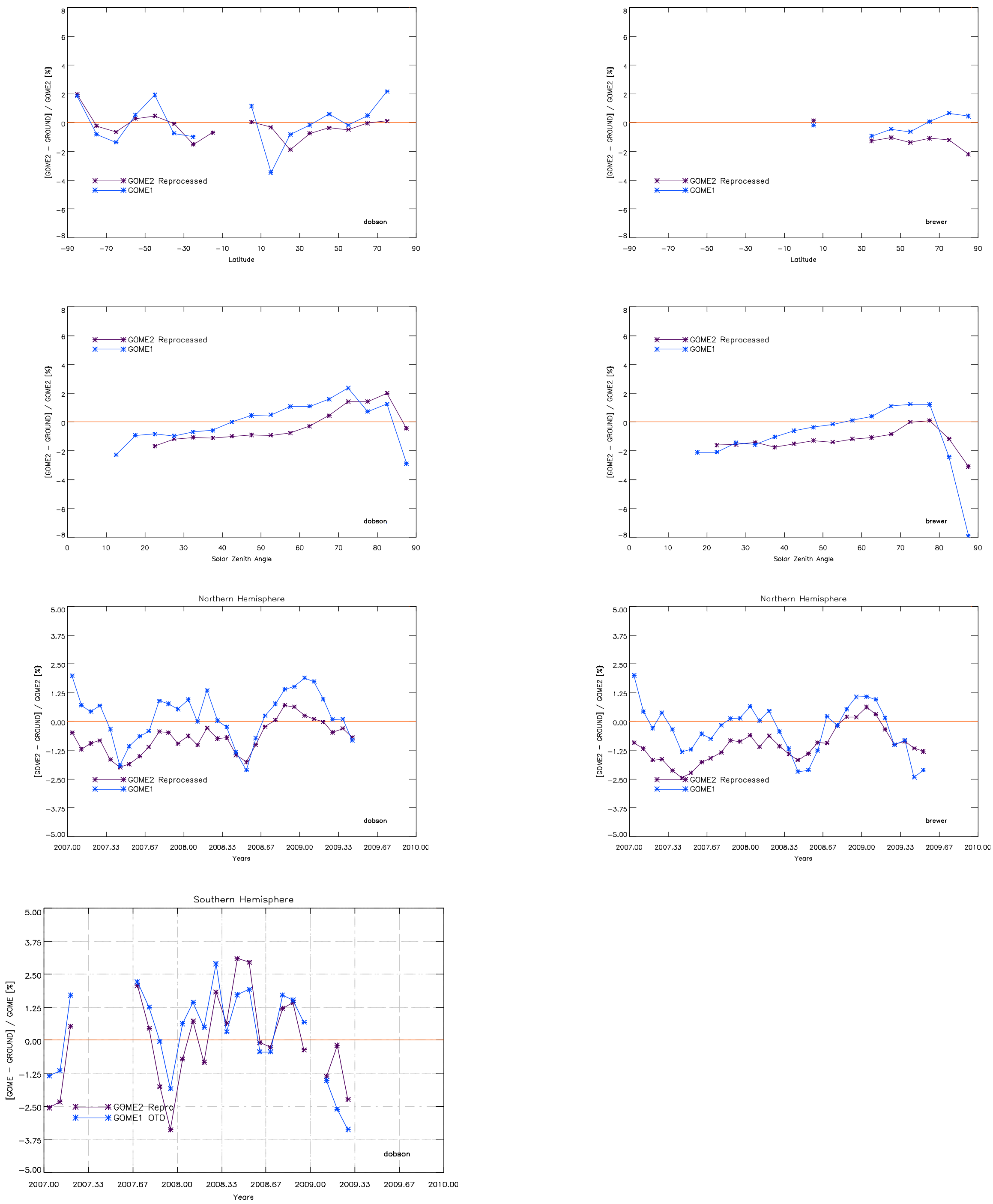



**Figure 5.1** Comparisons of common dates of GOME/ERS-2 and GOME-2 data with ground-based data, for the same Dobson (left column) and Brewer geolocations (right column). These include (from top to bottom) latitudinal dependence of the differences, the SZA dependence of the differences and time series of the differences averaged over the Northern and the Southern hemisphere.

## Reprocessed GOME-2 OTO/O3RP comparisons with OMI-DOAS

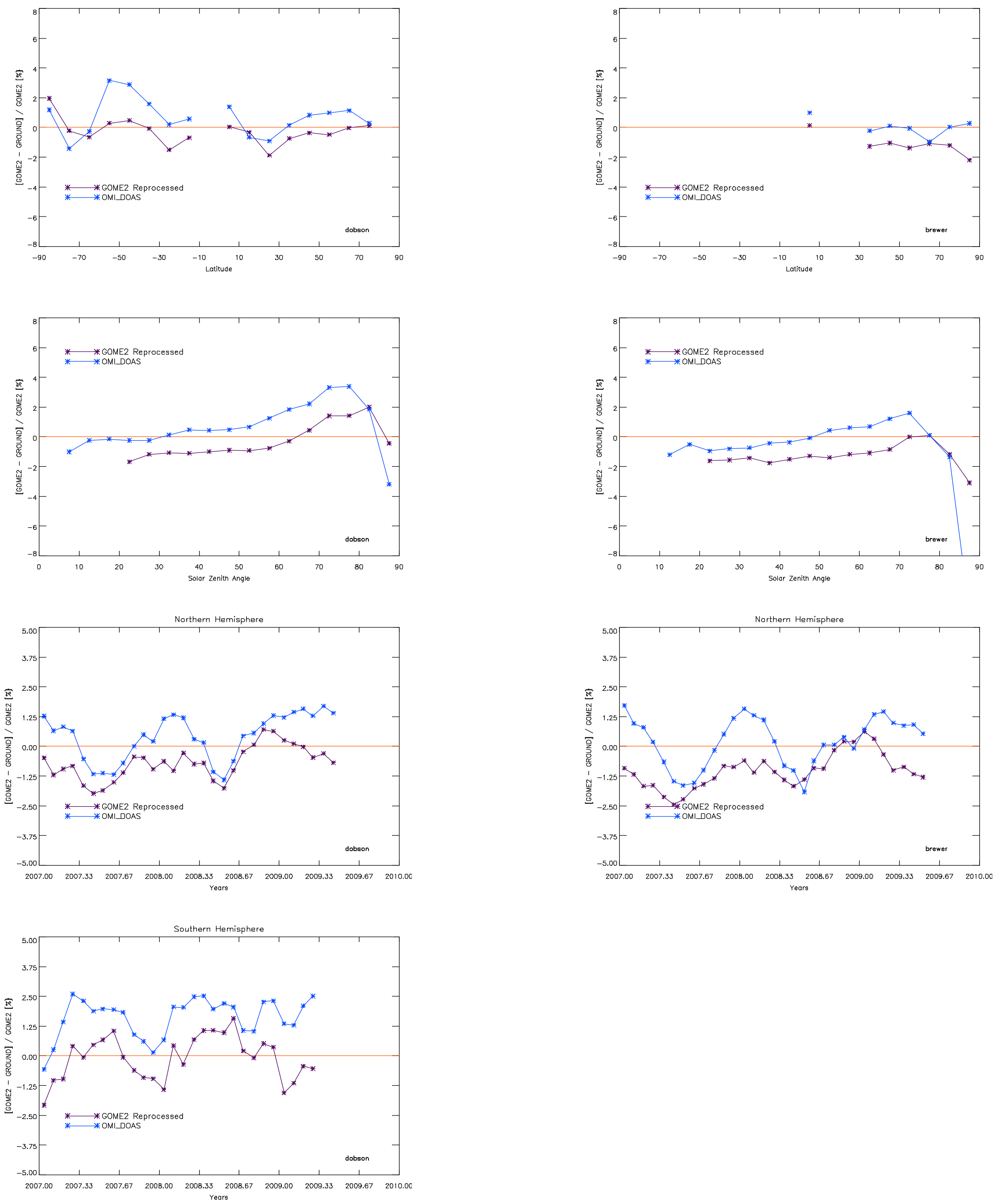



**Figure 5.2** Comparisons of common dates of OMI-DOAS and reprocessed GOME-2 data with ground-based data, for the same Dobson (left column) and Brewer geolocations (right column). These include (from top to bottom) latitudinal dependence of the differences, the SZA dependence of the differences and time series of the differences averaged over the Northern and the Southern hemisphere.

## Reprocessed GOME-2 OTO/O3RP comparisons with SCIAMACHY

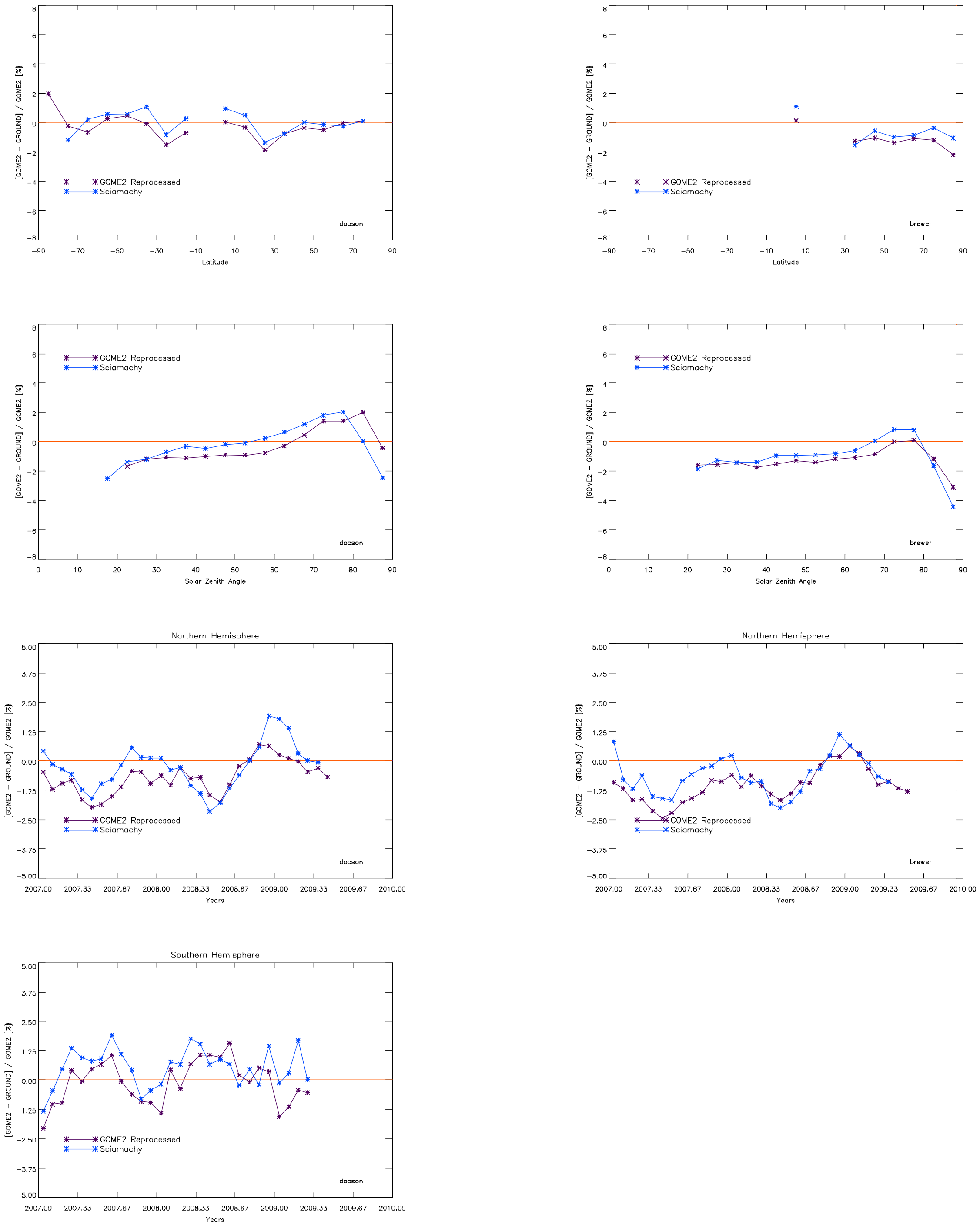



**Figure 5.3.** Comparisons of common dates of SCIAMACHY and reprocessed GOME-2 data with ground-based data, for the same Dobson (left column) and Brewer geolocations (right column). These include (from top to bottom) latitudinal dependence of the differences, the SZA dependence of the differences and time series of the differences averaged over the Northern and the Southern hemisphere.

## Reprocessed GOME-2 OTO/O3RP comparisons with OMI-TOMS

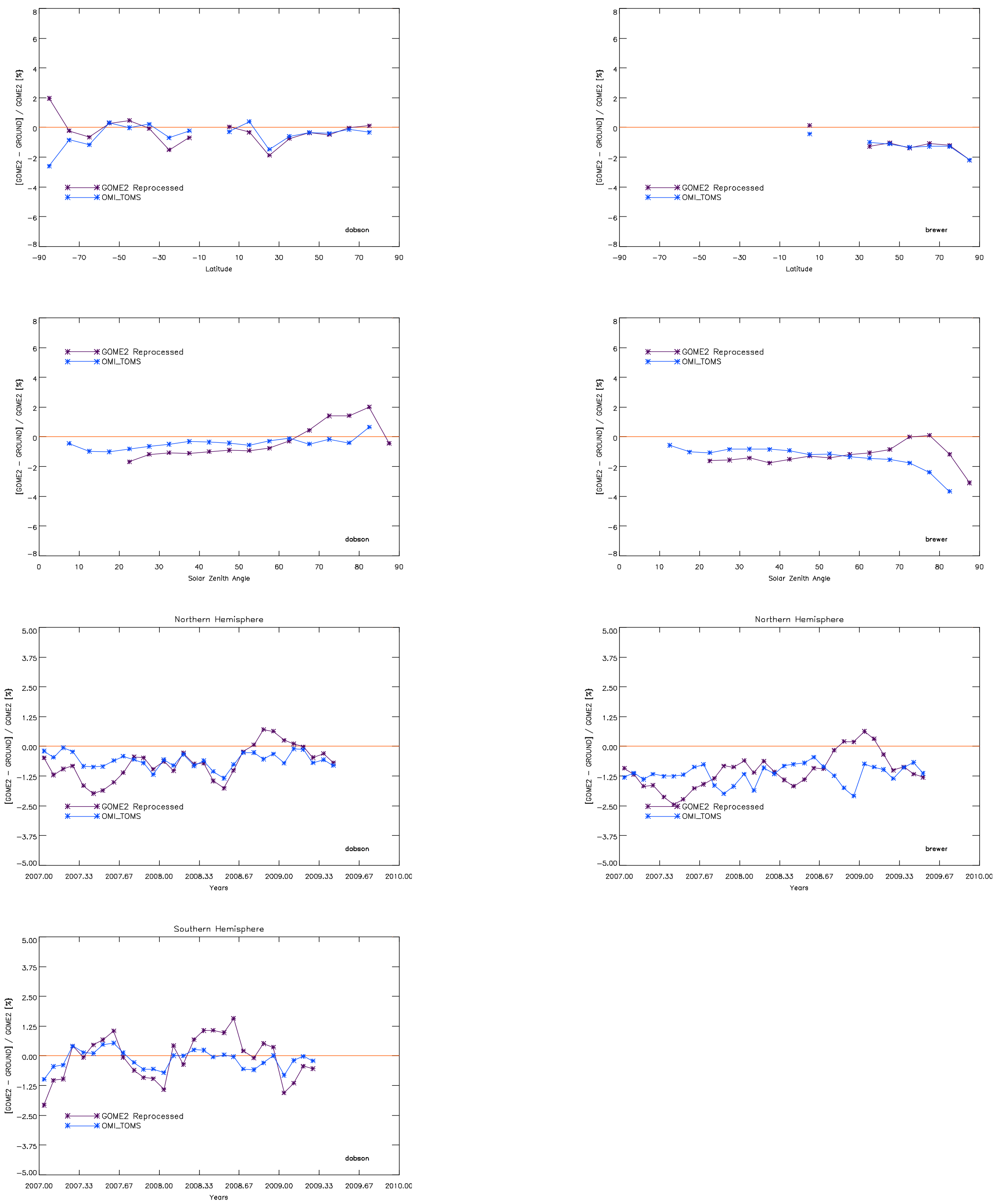



**Figure 5.4.** Comparisons of common dates of OMI-TOMS and reprocessed GOME-2 data with ground-based data, for the same Dobson (left column) and Brewer geolocations (right column). These include (from top to bottom) latitudinal dependence of the differences, the SZA dependence of the differences and time series of the differences averaged over the Northern and the Southern hemisphere.

## Reprocessed GOME-2 OTO/O3RP comparisons with operational GOME-2 OTO/O3

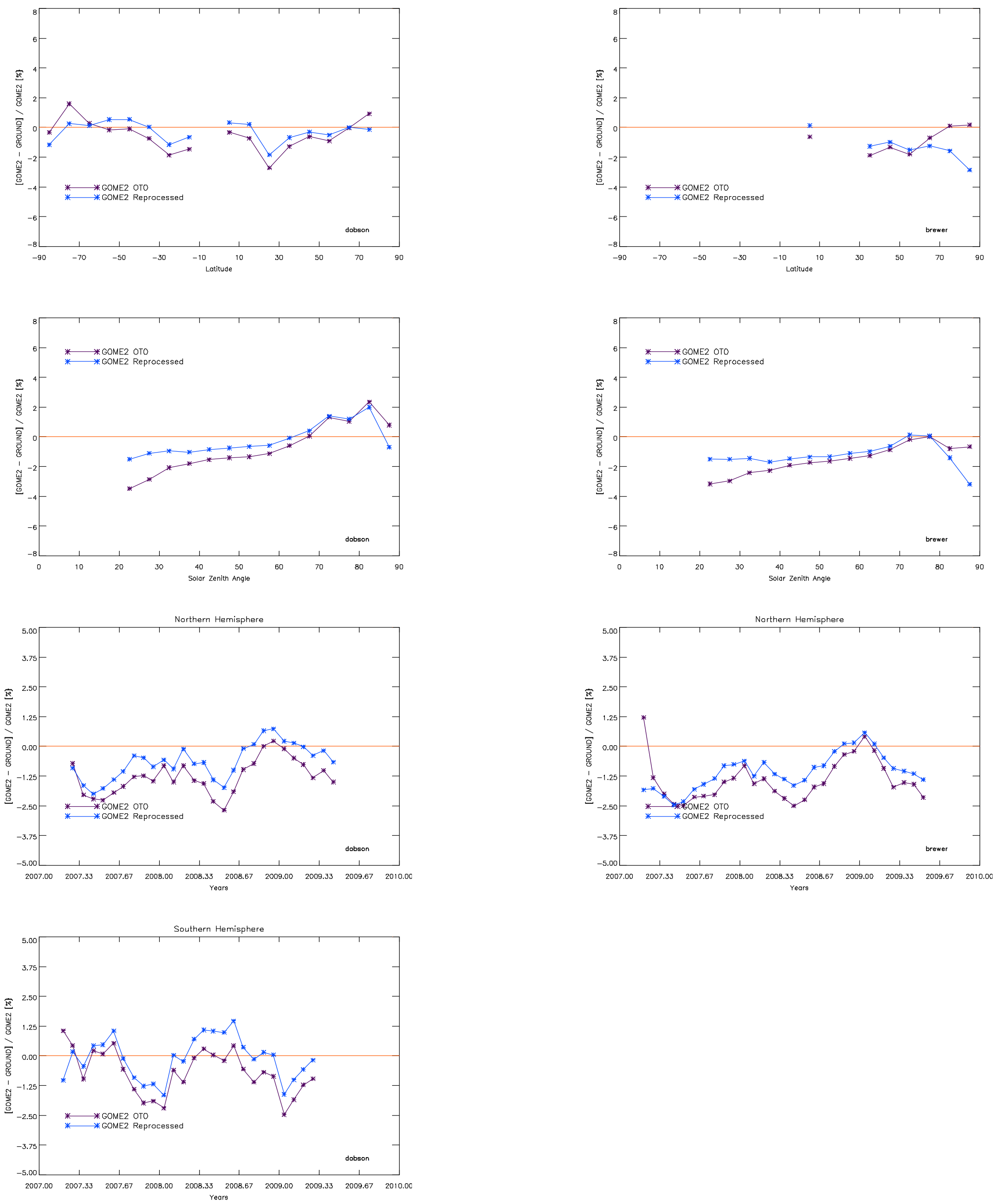



**Figure 5.5.** Comparisons of common dates of operational GOME-2 OTO/O3 and reprocessed GOME-2 data with ground-based data, for the same Dobson (left column) and Brewer geolocations (right column). These include (from top to bottom) latitudinal dependence of the differences, the SZA dependence of the differences and time series of the differences averaged over the Northern and the Southern hemisphere.

**Summary of reprocessed GOME-2 OTO/O3RP comparisons with other satellite instruments**

**Summary of reprocessed GOME-2 comparisons with other satellite instruments**

a. On the average the mean differences of the reprocessed GOME-2 relative to GOME/ERS-2 data is about **-0.80%**, and relative to SCIAMACHY data is -**0.37%.** There is no seasonal dependence of the differences between GOME-2, GOME-1 and SCIAMACHY. The latter is expected since the three data sets are based on similar algorithms (GDP4.x). This negative difference of GOME-2 is within the uncertainty of reference data used in the comparisons.
b. On the average the mean difference of the reprocessed GOME-2 data relative to OMIDOAS (collection 3) data is **-1.28%**, without any significant seasonal dependence of the differences between them. The lack of seasonality might be expected since both GDP4.4 and OMIDOAS are DOAS-type algorithms and both consider the variability of the stratospheric temperatures in their retrievals.
c. On the average GOME-2 data and OMITOMS (collection 3) data **have almost no bias** (GOME-2 **smaller by 0.09%**).
d. The reprocessed GOME-2 relative to the operational GOME-2 OTO/O3 have **less SZA dependency** especially for small SZAs and estimate about 0.5% more ozone and thus have an overall better agreement with ground-based data**.**

# 6. DOAS fit analyses and GOME-2 scan angle dependencies

### 6a. Increase of DOAS fit residual

The long term increase of DOAS fitting residuals for ozone is progressing at a faster pace for GOME-2(Fig 6.1) than has been observed for GOME-1 (Fig 6.2). The monthly averaged residuals shown in these figures have been calculated for the equator pacific region. A similar trend in the residuals is found for the other regions as well. GOME-2 fitting residuals for ozone have increased to the level of the GOME-1 fitting residuals which were consistent in first five years. Most likely, this increase in the fitting residuals is related to the continuous throughput degradation of the GOME-2 instrument.

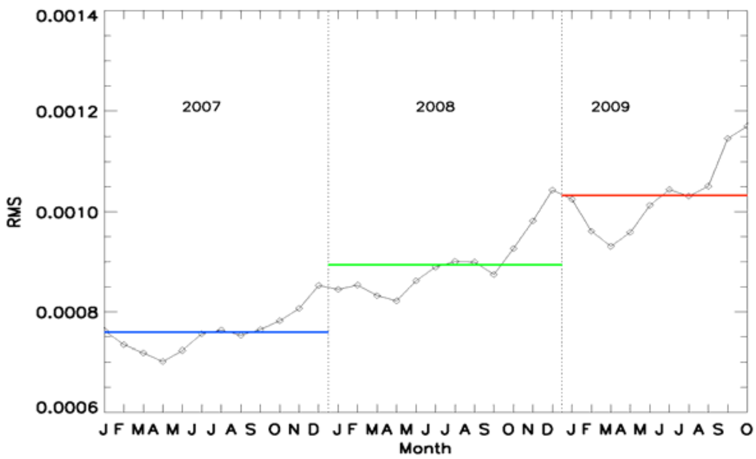



**Figure 6.1** Long-term DOAS fitting residuals for the 325-335 nm ozone fitting-window for GOME-2. The monthly averaged residual values have been calculated for the Equator Pacific region (10S-10N, 160E-160W)

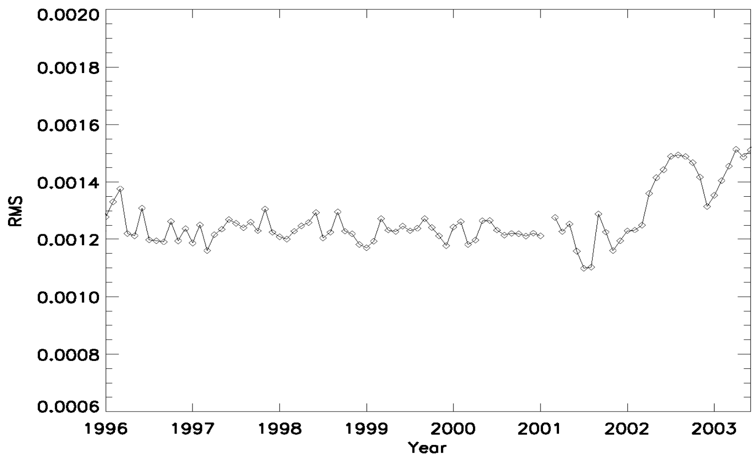



**Figure 6.2** Long-term DOAS fitting residuals for the 325-335 nm ozone fitting-window over Equator Pacific region for GOME-1. The monthly averaged residual values have been calculated for the Equator Pacific region (10S-10N, 160E-160W)

## 6b. GOME-2 scan angle dependencies

The operational GOME-2 OTO/O3 vertical ozone columns show a significant scan angle dependency [9] with a bias of about 1.5% - 2% between the ozone columns for the west and east ground-pixels (west higher than east). This bias depends on the latitude and solar zenith angle, and varies also from month to month [7]. Note that, in contrast to GOME-2, no significant scan angle bias in the vertical ozone column or fitting residuals is found for GOME-1. The use of reprocessed GOME-2 level1B-R1 data (version 4.0) for the total ozone retrieval did not have a significant impact on the scan angle dependencies [8]. The scan angle dependence in the operational GOME-2 ozone columns is also visible in comparisons with Dobson ground-based data [8].

Possible causes for the GOME-2 scan angle dependency are the use of a scalar radiation transfer model for the AMF calculations and mainly remaining calibration issues in the GOME-2 level-1 spectra. The use of a vector radiative transfer model for the AMF calculations has been considered. Calculations with the vector radiative transfer model VLIDORT indicate that the scan angle dependency in the vertical ozone columns can be reduced up to ~50% for low- and mid-latitudes. However, for high latitudes no clear improvement in the scan angle dependency is found. The real cause of this dependency is under investigation; the current assumption is that it can be mainly attributed to possible remaining calibration issues in the GOME-2 level-1 data.

The GDP 4.4 used for reprocessing the GOME-2 data introduces a soft correction for the scan angle dependency which removed almost completely this dependency in the forward scans. This is shown in Figure 6.3 where the reprocessed GOME-2 data are compared with ground-based data as function of the subpixel scan.

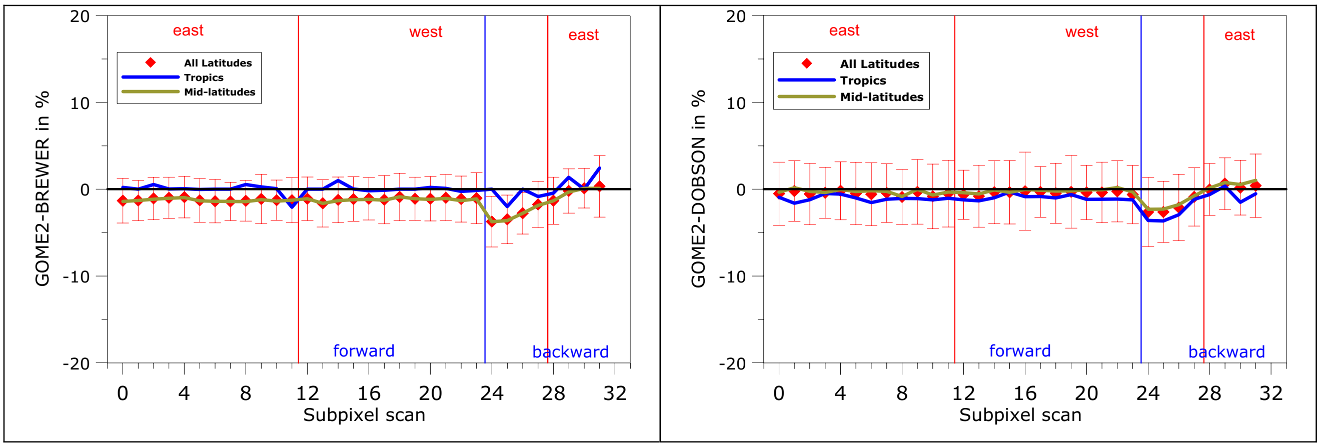



**Figure 6.3** The scan angle dependency of the difference between the Dobson estimates [left] and the Brewer estimates [right] and the reprocessed GOME2 total ozone is shown in these plots. In the upper graphs: the blue curve depicts the mean per one degree scan angle of the stations in the tropics only, the green line the mid-latitude average and the red dots and associated standard deviation bars for the entire dataset.

# 7. Summary tables

The comparison results of the reprocessed GOME-2 OTO/O3 product are summarized in the following tables. According to the PRD the target accuracy for O3M-06 (and O3M-40) is 3% for SZA<80o and 6% for SZA 80o, while the optimal accuracy of O3M-06 (and O3M-40) should be 1.5%.

**Table 7.1** Mean global differences between the various instruments examined for coincident measurements only. The standard deviation represents only the latitudinal variability of the differences.

| | *mean diff [%]* | *std [%]* | correlation |
|---|---|---|---|
| GOME2 OTO/$O_3$ vs Dobson | −0.44 | 4.97 | 0.91 |
| GOME2 OTO/$O_3$ vs Brewer | −1.07 | 3.78 | 0.95 |
| GOME1 vs Dobson | −0.04 | 4.48 | 0.91 |
| GOME1 vs Brewer | −0.05 | 4.09 | 0.95 |
| | | | |
| GOME2 OTO/$O_3$ vs GOME1 [Dobsons] | −0.80 | 2.80 | 0.97 |
| GOME2 OTO/$O_3$ vs OMITOMS [Dobsons] | −0.09 | 3.42 | 0.95 |
| GOME2 OTO/$O_3$ vs OMIDOAS [Dobsons] | −1.28 | 4.14 | 0.93 |
| GOME2 OTO/$O_3$ vs SCIAMACHY [Dobsons] | −0.37 | 2.92 | 0.97 |

**Table 7.2:** Mean differences between ground-based and satellite data for individual Brewer stations

| LAT | INSTR. | GOME2 REPRO | | GOME1 | | OMI | | OMI DOAS | | SCIAMACHY | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | σ | Mean | σ | Mean | σ | Mean | σ | Mean | σ |
| 53.57 | 21 | -1.93 | 2.99 | 0.16 | 3.92 | -0.91 | 2.05 | -0.3 | 2.92 | -0.82 | 2.93 |
| 74.72 | 24 | -0.63 | 4.03 | 0.94 | 3.51 | -0.7 | 2.49 | 0.3 | 3.75 | 0.24 | 3.71 |
| 46.77 | 35 | -0.89 | 2.36 | 0.46 | 2.79 | -1.05 | 1.95 | 0.23 | 3.25 | 0.31 | 2.46 |
| 50.8 | 53 | -0.97 | 2.47 | -0.62 | 2.69 | -0.67 | 2.19 | 0.33 | 3.48 | -0.2 | 2.3 |
| 43.78 | 65 | -2.08 | 2.55 | -0.66 | 2.75 | -1.41 | 2.1 | -1.38 | 2.53 | -1.18 | 2.59 |
| 53.32 | 76 | -3.06 | 2.67 | -1.98 | 2.76 | -2.46 | 2.32 | -1.05 | 2.85 | -2.29 | 2.92 |
| 58.75 | 77 | -1.62 | 3.15 | 1.69 | 2.49 | -1.24 | 2.9 | -0.02 | 2.92 | -0.94 | 3.05 |
| 50.18 | 96 | -1.25 | 2.47 | -0.8 | 2.49 | -1.39 | 2.03 | 0.14 | 3.49 | -0.71 | 2.48 |
| 47.8 | 99 | -1.17 | 2.58 | -0.58 | 2.61 | -1.2 | 1.92 | 0.52 | 3.57 | -0.94 | 2.42 |
| 47.43 | 100 | -1.81 | 2.15 | -0.99 | 2.73 | -1.87 | 2.06 | -0.5 | 2.67 | -1.27 | 2.42 |
| 52.22 | 174 | 0.21 | 2.64 | 0.59 | 2.52 | -0.19 | 2.36 | 2.27 | 3.43 | 0.82 | 2.75 |
| 37.1 | 213 | -1.77 | 2.25 | -1.19 | 2.44 | -1.61 | 1.83 | -0.74 | 2.62 | -1.5 | 2.52 |
| 40.52 | 261 | -2.84 | 2.3 | -2.12 | 2.5 | -2.52 | 2.16 | -1.08 | 2.67 | -2.32 | 2.55 |
| 67.37 | 262 | -1.24 | 2.4 | -0.41 | 3.03 | -1.29 | 2.05 | -1.64 | 14.91 | -0.87 | 2.63 |
| 67 | 267 | -1.05 | 2.54 | 1.26 | 2.91 | -2.36 | 2.49 | -0.2 | 3.52 | -0.66 | 2.91 |
| 58.58 | 279 | -1.64 | 2.37 | -0.25 | 2.4 | -1.57 | 1.91 | 0.09 | 3.31 | -1.69 | 2.71 |
| 64.25 | 284 | -0.97 | 2.88 | 0.12 | 3.73 | -0.87 | 2.53 | -0.69 | 21.43 | -0.9 | 3.27 |
| 48.78 | 290 | -0.74 | 2.23 | -0.16 | 3.06 | -0.58 | 2.62 | 0.05 | 2.64 | -0.47 | 2.85 |
| 36.17 | 295 | 0.53 | 2.14 | 1.32 | 2.45 | 0.74 | 2.01 | 1.13 | 3.92 | -0.16 | 2.62 |
| 40.45 | 308 | -2.18 | 2.05 | -2.2 | 2.65 | -2.2 | 1.68 | -1.02 | 2.79 | -2.58 | 2.28 |
| 79.89 | 315 | -1.84 | 2.81 | 0.28 | 2.38 | -2.2 | 1.46 | -0.25 | 2.68 | -1.09 | 2.13 |
| 52 | 316 | -2.44 | 2.64 | -1.45 | 2.85 | -2.24 | 2.27 | -1.11 | 4.75 | -2.07 | 2.54 |
| 51.93 | 318 | -1.37 | 2.54 | -0.25 | 2.76 | -1.44 | 2.32 | -0.25 | 4.87 | -0.82 | 2.7 |
| 3.1 | 322 | 0.14 | 2.88 | -0.19 | 2.5 | -0.43 | 2.91 | 0.99 | 4.41 | 1.1 | 2.02 |
| 44.75 | 326 | -0.53 | 2.51 | -0.5 | 2.67 | -0.28 | 2.3 | 0.25 | 4.39 | -0.65 | 2.74 |
| 49.03 | 331 | 0.55 | 2.87 | 0.93 | 3.31 | 0.09 | 2.46 | 1.65 | 3.66 | 1.53 | 2.96 |
| 36.03 | 332 | -0.93 | 2.82 | -0.37 | 3.4 | -0.7 | 2.52 | -0.22 | 3.55 | -1.1 | 3.56 |
| 38 | 346 | -2.71 | 2.04 | -1.33 | 2.59 | -2.17 | 1.67 | -0.9 | 2.76 | -2.78 | 2.79 |

**Table 7.3:** Mean differences between ground-based and satellite data for individual Dobson stations

| *LAT* | *INS TR.* | *GOME2 REPRO* | | *GOME1* | | *OMI* | | *OMI DOAS* | | *SCIAMACHY* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Mean* | *σ* | *Mean* | *σ* | *Mean* | *σ* | *Mean* | *σ* | *Mean* | *σ* |
| 22.8 | 2 | -0.25 | 1.79 | 1.12 | 2.05 | 0.11 | 1.64 | 0.72 | 3.11 | 0.74 | 2.17 |
| 30.18 | 11 | -2.08 | 3.62 | | | -1.3 | 3.61 | -1.64 | 3.9 | -2.1 | 2.99 |
| 43.05 | 12 | -0.69 | 2.86 | | | -0.49 | 2.28 | 0.07 | 3.3 | -1.7 | 3.07 |
| 36.05 | 14 | -1.52 | 2.8 | | | -1.03 | 1.94 | -0.09 | 2.86 | -0.73 | 2.69 |
| 46.77 | 19 | -1.75 | 2.45 | 0.66 | 2.57 | -1.53 | 1.72 | -0.37 | 3.1 | -1.23 | 2.36 |
| 46.87 | 20 | -0.62 | 4.42 | 1.03 | 4.16 | -0.67 | 3.56 | -0.09 | 4.28 | -0.63 | 3.69 |
| -27.47 | 27 | -1.23 | 3.35 | 0.98 | 2.5 | -0.46 | 1.71 | 0.41 | 2.89 | -0.6 | 3.51 |
| -54.48 | 29 | -2.47 | 6.71 | 0.98 | 8.35 | -0.35 | 2.69 | 0.44 | 3.43 | -2.02 | 6.65 |
| 19.53 | 31 | 2.38 | 1.84 | | | 3.32 | 2.51 | 1 | 4.01 | 2.91 | 1.9 |
| 46.77 | 35 | 0.62 | 2.29 | 2.03 | 2.79 | 0.47 | 1.75 | 1.77 | 3.25 | 1.86 | 2.4 |
| 43.92 | 40 | -0.29 | 2.28 | 0.06 | 3.14 | -0.65 | 2.74 | 0.86 | 3.38 | -0.99 | 3.03 |
| 60.15 | 43 | -0.35 | 2.85 | 0.72 | 3.18 | -0.59 | 2.09 | 0.85 | 3.76 | -0.53 | 2.96 |
| 50.8 | 53 | -0.61 | 1.8 | 0.49 | 2.34 | -0.66 | 1.91 | 1.01 | 2.65 | 0.49 | 2.76 |
| -75.52 | 57 | -0.63 | 4.72 | -0.75 | 3.96 | -2.04 | 4.65 | -2.36 | 6.39 | -1.53 | 4.17 |
| 40.02 | 67 | 0.15 | 3.28 | 0.4 | 3.06 | 0.22 | 3.19 | 1.14 | 4.67 | -0.11 | 2.93 |
| 51.83 | 68 | -1.5 | 3.46 | -0.71 | 3.67 | -0.7 | 2.3 | 0.19 | 4.1 | -1.12 | 3.41 |
| -12.47 | 84 | -0.74 | 1.96 | | | -0.12 | 1.66 | 0.55 | 3.09 | 0.07 | 2.19 |
| -34.58 | 91 | 0.68 | 3.07 | | | 1.09 | 1.63 | 2.27 | 3.07 | 1.65 | 3.62 |
| 50.18 | 96 | -0.12 | 2.52 | -0.03 | 2.93 | -0.23 | 1.92 | 1.22 | 3.58 | 0.42 | 2.67 |
| 47.8 | 99 | -0.79 | 2.85 | -0.2 | 2.8 | -0.66 | 2.02 | 1.11 | 3.74 | -0.42 | 2.8 |
| -69 | 101 | 0.45 | 4.15 | -1.93 | 4.02 | -0.61 | 2.71 | 0.46 | 5.19 | 1.13 | 4.19 |
| 64.8 | 105 | 1.45 | 4.4 | -0.8 | 5.67 | 1.54 | 4.38 | 1.94 | 8.87 | 0.74 | 5.06 |
| 36.25 | 106 | -1.32 | 2.3 | -1.48 | 2.39 | -1.34 | 1.97 | -0.79 | 3.21 | -0.4 | 2.58 |
| 37.87 | 107 | 0.37 | 3.16 | 1.23 | 2.41 | 0.52 | 2.52 | 1.24 | 3.18 | 0.92 | 3.27 |
| -89.98 | 111 | 1.96 | 5.35 | 1.87 | 4.98 | -2.59 | 4.31 | 1.19 | 4.31 | -1.97 | 3.75 |
| 30.08 | 152 | -1.67 | 2.81 | -1.39 | 3.11 | -1.02 | 2.74 | -0.45 | 3.45 | -0.47 | 2.42 |
| -31.95 | 159 | -1.29 | 2.36 | -1.03 | 1.98 | -0.92 | 1.97 | 0.14 | 2.77 | -0.13 | 2 |
| 26.2 | 190 | -1.36 | 1.69 | -1.02 | 1.92 | -1.16 | 1.52 | -0.56 | 3.11 | 0.75 | 2.26 |
| -14.25 | 191 | -0.58 | 1.67 | | | -0.44 | 2.23 | 0.61 | 3.41 | 0.11 | 2.82 |
| 71.32 | 199 | 0.12 | 2.94 | 2.17 | 5.25 | -0.33 | 2.52 | 0.29 | 4.35 | -2.07 | 2.74 |
| 39.77 | 208 | -1.45 | 2.63 | -0.73 | 3.27 | -1.58 | 2.78 | -0.56 | 3.99 | -0.91 | 1.98 |
| 25.02 | 209 | -2.06 | 2.15 | -2.51 | 2.39 | -2.08 | 1.74 | -1.45 | 3.15 | -1.19 | 3.25 |
| 37.1 | 213 | -1.3 | 2.92 | -1.33 | 3.24 | -1.22 | 2.85 | -0.18 | 3.58 | 0.95 | 3.14 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.33 | 214 | 0.04 | 2.83 | 1.15 | 2.97 | -0.29 | 2.81 | 1.39 | 4.48 | -2.6 | 3.04 |
| 13.73 | 216 | -3.34 | 2.35 | -3.46 | 3.22 | -2.86 | 2.17 | -2.53 | 3.03 | -1.78 | 2.91 |
| -65.25 | 232 | -2.97 | 3.09 | -1.5 | 2.17 | -2.31 | 2.4 | -1.73 | 4.1 | -5.59 | 3.34 |
| 23.97 | 245 | -4.33 | 2.5 | -2.83 | 2.71 | -3.4 | 2.23 | -2.95 | 3.35 | -0.89 | 2.7 |
| 37.57 | 252 | -1.02 | 2.81 | -0.85 | 2.57 | -0.8 | 2.26 | -0.44 | 3.01 | -0.57 | 4.28 |
| -37.48 | 253 | -1.33 | 4.8 | -0.71 | 2.27 | -0.9 | 1.99 | 0.66 | 3.25 | -1.09 | 5.79 |
| -45.03 | 256 | -1.33 | 5.62 | 1.4 | 7.56 | -2.19 | 2.44 | 0.68 | 2.74 | -0.32 | 1.44 |
| -25.25 | 265 | -3.09 | 1.05 | | | -1.47 | 0.76 | -1.23 | 2.2 | -0.71 | 6.65 |
| -77.83 | 268 | 0.2 | 6.72 | -0.66 | 6.7 | 0.48 | 3.54 | -0.45 | 4.71 | -0.31 | 3.28 |
| 64.25 | 284 | -0.49 | 2.64 | 0.49 | 3.14 | -0.4 | 1.91 | 1.28 | 3.22 | 0.44 | 4.8 |
| 38 | 293 | 1.48 | 5 | 1.85 | 5.01 | 1.54 | 4.71 | 2.42 | 5.01 | 2.17 | 3.33 |
| -54.85 | 339 | 2.07 | 4.06 | 2.56 | 3.53 | 0.75 | 5 | 4.87 | 5.57 | -4 | 1.9 |
| -29.67 | 340 | -4.46 | 1.61 | | | -3.01 | 1.2 | -1.81 | 2.15 | -1.23 | 3.42 |
| 36.32 | 341 | -0.68 | 2.9 | -0.34 | 3.58 | -0.73 | 2.27 | 0.53 | 2.81 | 1.76 | 2.46 |
| -45.78 | 342 | 1.75 | 2.8 | 2.12 | 2.11 | 1.55 | 2.29 | 4.47 | 3.08 | 3.01 | 5.47 |
| -31.58 | 343 | 1.5 | 2.66 | | | 1.41 | 2.08 | 2.84 | 4.25 | 0.74 | 2.17 |

# 8. Conclusions

The comparisons between reprocessed GOME-2 and archived ground-based ozone data can be summarized as follows:

a.) Reprocessed GOME-2 **underestimates** ground-based ozone by about **0.5%** over the middle latitudes of the Northern Hemisphere and slightly **overestimates** (again around **0.5%**) over the middle latitudes of the Southern Hemisphere. Over the high latitudes of the Northern Hemisphere GOME-2 has almost **no offset** relative to Dobson readings while over the high latitudes of the Southern Hemisphere **underestimates ozone by less than 1%**. Over the tropical latitudes GOME-2 estimates on the average less ozone by 0 to 2% compared to Dobson measurements.

b.) Reprocessed GOME-2 comparisons with Brewer ozone data over the Northern Hemisphere are consistent with the GOME-2 – Dobson comparisons and show an **underestimation of 1%**, which tends to be slightly higher (1-2%) over the Arctic.

c.) Reprocessed GOME-2 data when compared to Dobson and Brewer measurements show a small dependence on solar zenith angle. GOME-2 underestimates ozone for small SZAs. (2-3%) and slightly overestimates ozone (1%) for SZAs greater than 70°. However using the current ground-based data set it is not easy to separate the SZA dependence from the seasonal dependence due to the variability in stratospheric temperatures since both are related to the seasonal cycle.

d.) As mentioned earlier there is an indication for a seasonal dependence of the differences between GOME-2 and ground-based (both Dobson and Brewer). The amplitude tends to increase with increasing latitude. The amplitude and the phase consistent with corresponding GOME-1 comparisons.

e.) There is an indication of a small drift in the reprocessed GOME-2 ozone data over the Northern Hemisphere after early/mid 2008. The reprocessed GOME-2 data since mid 2008 are closer to the ground-based observations. This drift is eventually associated with changes in the GOME-2 PMD settings since March 2008 and/or changes in the version of level 1b data used afterwards.

f.) On the average the mean differences of the reprocessed GOME-2 relative to GOME/ERS-2 data is about **-0.80%**, and relative to SCIAMACHY data is **-0.37%.** There is no seasonal dependence of the differences between GOME-2, GOME-1 and SCIAMACHY. The latter is expected since the three data sets are based on similar algorithms (GDP4.x). This negative difference of GOME-2 is within the uncertainty of reference data used in the comparisons.

g.) On the average the mean difference of the reprocessed GOME-2 data relative to OMIDOAS (collection 3) data is **-1.28%**, without any significant seasonal dependence of the differences between them. The lack of seasonality might be expected since both GDP4.4 and OMIDOAS are DOAS-type algorithms and both consider the variability of the stratospheric temperatures in their retrievals.

h.) On the average GOME-2 data and OMITOMS (collection 3) data **have almost no bias** (GOME-2 **smaller by 0.09%**).

i.) The reprocessed GOME-2 relative to the operational GOME-2 OTO/O3 have **less SZA dependency** especially for small SZAs and estimate about 0.5% more ozone and thus have an overall better agreement with ground-based data**.**

j.) The soft correction introduced in GDP 4.4 removes the scan angle dependency on the GOME-2 reprocessed data (the operational OTO/O3 data have a bias of more than +1.5% between the ozone columns for the west and east ground-pixels).

This validation of the reprocessed GOME-2 total ozone data using more than two full years of ground-based measurements and the direct comparison with GOME-1, OMI and SCIAMACHY shows that the reprocessed GOME-2 total ozone products are a further improvement to the operational GOME-2 OTO/O3 products that already have an excellent quality. The reprocessed GOME-2 total ozone products are well within the targeted (3%) and optimal (1.5%) accuracy values determined in the PRD document and the observed differences are also within the uncertainty of reference data used in the comparisons. According to Weatherhead et al, (1998) the crucial factors in a data set that affect the detection of long term trends is the autocorrelation and standard deviation of the noise (expressed as percent variability of the month-to-month data) and in addition sudden level shifts (due to instrumental or natural causes) can strongly impact the number of years necessary to detect significant trends of certain magnitude. Therefore the observed drift in GOME-2 will be further investigated in order to characterize the GOME-2 potential contribution for the detection of long-term trends. Note however that for trend detection the time period cover by GOME-2 is very short and hence GOME-2 data must be merged with older and validated satellite data such GOME and SCIAMACHY total ozone columns.

References

1. EUMETSAT, GOME-2 Level 1b Product Validation Report No. 4 EPS GOME-2 Reprocessing L1B-R1 data-set. 2008
2. Balis D, Koukouli ME, Brinksma EJ, Kroon M, Veefkind JP, Labow G, McPeters RD, Validation of Ozone Monitoring Instrument total ozone column measurements using Brewer and Dobson spectrophotometer ground-based observations, Journal of Geophysical Research, 112 (D24): Art. No. D24S46 DEC 8 2007
3. Balis D., J-C. Lambert , Van Roozendael M., D. Loyola, R. Spurr, Y. Livschitz, P. Valks, T. Ruppert, P. Gerard, J Granville and V. Amiridis, Reprocessing the 10-year GOME/ERS-2 total ozone record for trend analysis: the new GOME Data Processor Version 4.0, Validation, *J. Geophys. Res.*, vol. 112, D07307, doi:10.1029/2005JD006376, 2007+
4. Balis D., M. Koukouli, D. Loyola, P. Valks, and N. Hao, Validation of GOME-2 total ozone products (OTO/O3, NTO/O3) processed with GDP4.2, SAF/O3M/AUTH/GOME-2VAL/RP/01, July 2007
5. Balis D., M. Koukouli, D. Loyola, P. Valks, and N. Hao, Validation of one year of GOME-2 total ozone measurements, in Abstratcts of the XXI Quadrennial Ozone Symposium, 30 June-July 2008, Tromsoe, Norway, 2008.
6. McPeters, R., M. Kroon, G. Labow, E. Brinksma, D. Balis, I. Petropavlovskikh, J.P. Veefkind, P.K. Bhartia and P.F. Levely, Validation of the Aura Ozone Monitoring Instrument Total Ozone Product, *J. Geophys. Res.*, 2008
7. Staehelin J., J. Kerr, R. Evans and K. Vanicek (2003), Comparison of total ozone measurements of Dobson and Brewer spectrophotometers and recommended transfer functions, WMO TD N. 1147, No 149.
8. Van Roozendael M., D. Loyola, R. Spurr, D. Balis, J-C. Lambert, Y. Livschitz, P. Valks, T. Ruppert, P. Kenter and C. Fayt, Reprocessing the 10-year GOME/ERS-2 total ozone record for trend analysis: the new GOME Data Processor Version 4.0, Algorithm Description, *J. Geophys. Res.*, 111 (D14): art. no. D14311 JUL 26 2006
9. Balis D., M. Koukouli, D. Loyola, P. Valks, and N. Hao, Validation of GOME-2 total ozone products (OTO/O3, NTO/O3) processed with GDP4.2, SAF/O3M/AUTH/GOME-2VAL/RP/02, November 2008
10. Balis D., M. Koukouli, D. Loyola, P. Valks, and N. Hao, O3MSAF Validation Report, SAF/O3M/AUTH/GOME-2VAL/RP/03, November 2009
11. Weatherhead, E. C., G. C. Reinsel, G. C. Tiao, X. Meng, D. Choi, W. Cheang, T. Keller, J. DeLuisi, D. J. Wuebbles, J. B. Kerr, A. J. Miller, S. J. Oltmans, and J. E. Frederick, 1998: Factors affecting the detection of trends: Statistical considerations and applications to environmental data. Journal of Geophysical Research, 103, 17149-17161.