ENVISAT DATA VALIDATION BY NIWA: 2006 UPDATE


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ABSTRACT

Ground based measurements of atmospheric composition using certified NDACC instruments have been made by NIWA at Lauder, New Zealand (45S, 170E) and a number of other sites around the world for a number of years. These measurements have been used in the validation of GOMOS, MIPAS and SCIAMACHY data. In particular, this paper presents highlights of a comparison of SCIAMACHY products with ground based Dobson and UV/Visible observations of O_3 and NO_2, at several sites, with emphasis on Lauder and Arrival Heights.

2. INTRODUCTION

Continuous ground-based measurements were started at Lauder, New Zealand, using the twilight-zenith technique to measure stratospheric NO_2, in December 1980. This NO_2 data series is now the longest in the world of its type. These measurements were followed in the mid eighties by ozone column (Dobson) and ozone profile (sonde) measurements. In 1991 Lauder became the Southern Hemisphere mid-latitude primary station for the Network for the Detection of Stratospheric Change (NDSC), since renamed Network for the Detection of Atmospheric Composition Change (NDACC) because of the increasing role of network stations in measuring total atmospheric composition. Lauder’s NDSC role led to the establishment of a full suite of network instruments at Lauder and a subset at Arrival Heights, Lidar (ozone and aerosol) at Lauder, FTIR (HNO_3, HCl, CINO_2, HF, CH_4, N_2O, O_3) at Lauder and Arrival Heights, Microwave emission Radiometry (O_3 and H_2O at Lauder, and CIO at Arrival Heights), UV/Visible spectroscopy (NO_2 and BrO at Lauder, and NO_2, OCIO and BrO at Arrival Heights), Dobson ozone columns and ozone profile sondes flights (both at Lauder and Dobson only at Arrival Heights), and UV Spectroradiometry at Lauder. Additionally, Lauder experiments are used at other NDACC sites; Kiruna (UV/Visible NO_2), Mauna Loa Observatory (UV/Visible NO_2 and BrO, and UV Spectroradiometry), and Macquarie Island (UV/Visible NO_2). Lauder’s role in the NDACC provides a suite of sondes and ground based atmospheric measurements well suited for satellite validation purposes. Tab. 1 shows the data currently submitted to the ENVISAT validation data base. The remainder of this paper focuses on comparing selected ground based measurements with those of ENVISAT.

Table 1. Summary of all NIWA data sets submitted for Envisat Validation

<table>
<thead>
<tr>
<th>Site</th>
<th>Measurement</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lauder 45.04°S, 169.68°E</td>
<td>Dobson Total Column Ozone</td>
<td>Jan 2000</td>
<td>Sept 2006</td>
</tr>
<tr>
<td>Lauder 45.04°S, 169.68°E</td>
<td>Ozone Sonde Profiles (0.37 – approx 32 km)</td>
<td>Sept 2006</td>
<td></td>
</tr>
<tr>
<td>Lauder 45.04°S, 169.68°E</td>
<td>Fourier Transform Infra-Red Spectroscopy: O_3 total column, N_2O total column, NO_2 12-100km partial column, CH_4 total column, CH_4 12-100km partial column, HNO_3 total column, CO total column, HCl total column</td>
<td>Jan 2002</td>
<td>June 2006</td>
</tr>
<tr>
<td>Arrival Heights (77.83°S, 166.65°E)</td>
<td>Dobson Total Column Ozone</td>
<td>Jan 2000</td>
<td>Oct 2006</td>
</tr>
<tr>
<td>Lauder 45.04°S, 169.68°E</td>
<td>NO_2 slant column amounts (90° SZA)</td>
<td>Oct 2006</td>
<td></td>
</tr>
<tr>
<td>Kiruna (67.8°N, 20.4°E)</td>
<td>NO_2 slant column amounts (90° SZA)</td>
<td>Oct 2006</td>
<td></td>
</tr>
<tr>
<td>Macquarie Island (54.5°S, 159°E)</td>
<td>NO_2 slant column amounts (90° SZA)</td>
<td>Aug 2006</td>
<td></td>
</tr>
<tr>
<td>Mauna-Loa Obs. (19.5°N, 156°E)</td>
<td>NO_2 slant column amounts (90° SZA)</td>
<td>April 2004</td>
<td></td>
</tr>
</tbody>
</table>
3. SCIAMACHY VALIDATION

3.1. Dobson measurements of total column ozone at Lauder.

Total column ozone measurements have been made at Lauder (45.04°S, 169.68°E) with Dobson spectrophotometer #72 since 29 January 1987. The Lauder instrument has been calibrated regularly against the world standard Dobson (#83), most recently in February 2006. All available direct sun observations (A–D wavelength pairs) closest to local noon between January 2000 and September 2006 have been submitted to the ENVISAT validation data base. This data set has been compared with SCIAMACHY total column ozone (TOSOMI version 0.4 overpass) provided at http://www.temis.nl/protocols/o3col/overpass_scia.htm.

The comparison between both data sets is shown in Fig. 1 for mid-2002 to late 2006. Ground-based and SCIAMACHY data are plotted only for days when both are available with the Dobson observations made typically between 1200 ± 0300 NZST while SCIAMACHY observations are made between 1000 ± 0030 NZST (top panel). The absolute and percentage differences are shown in the middle and bottom panels respectively.

The percentage and absolute difference between both data sets shows no dependence on the distance of the SCIAMACHY observations to the Lauder site.

Statistical analysis on the 5 years of absolute difference (Dobson – SCIAMACHY) values shows a slope of 1.2 DU/year (zero within confidence limits) with a mean of 1.2 ± 1.2 DU (1 sigma). Number of data points = 233.
3.2. Dobson Measurements of total column ozone at Arrival Heights.

The Arrival Heights (77.83°S, 166.65°E) total column ozone data set measured with Dobson #17 has been submitted to the ENVISAT validation data base for the period January 2000 to October 2006. As for the Lauder Dobson data, only direct sun measurements closest to local noon have been included. SCIAMACHY total column ozone (TOSOMI version 0.4 overpass) provided at the above web page for McMurdo (77.83°S, 166.67°E) has been compared with the Dobson data in Fig. 2. Ground-based and SCIAMACHY data are plotted only for days when both are available with the Dobson observations made typically between 1200 ± 0300 NZST while SCIAMACHY observations are made between 2030 ± 0100 NZST (top panel). The absolute and percentage differences are shown in the middle and bottom panels with the SCIAMACHY data being consistently higher than the Dobson.

As for Lauder, the percentage and absolute difference between both data sets shows no dependence on the distance of the SCIAMACHY observations to the Arrival Heights site.

Statistical analysis on the 4 years of absolute difference (Dobson – SCIAMACHY) values shows a slope of -0.32 DU/year (zero within confidence limits) with a mean of -9.2 ± 1.3 DU (1 sigma). Number of data points = 252. The bias appears to have a seasonal variation with a probable increase in Spring and maybe late Autumn. The large swings in ozone values in Spring are due to the edge of the vortex moving back and forth over Arrival Heights resulting in alternating sampling of air inside and outside the ozone poor vortex.

Figure 2. Comparison of all daily ground-based Dobson (#17) measurements at Arrival Heights submitted to the ENVISAT data base available as, groundbased_uvvis.dobson_niwa017_arrival.heights_d2_20000103t230000z_001.hdf (direct sun observations closest to local noon) with all available coincident SCIAMACHY data.
3.3. UV-Visible DOAS Measurements of NO\textsubscript{2} at Arrival Heights.

The twilight zenith technique is used to measure stratospheric NO\textsubscript{2} at Arrival Heights during the spring and autumn periods when the solar zenith angle (SZA) is suitable. No winter measurements are possible because of low light levels. At high SZAs (>80°) the stratospheric air mass for NO\textsubscript{2} is high enough to produce low measurement errors, whereas at small SZAs (<70°) the NO\textsubscript{2} absorption signal to (photon) noise becomes too small to be useful. The range of SZAs at Arrival Heights covers 65-95°, with the spring and autumn periods having the better absorption signal to noise ratios. In Fig. 3 the slant column amounts of NO\textsubscript{2} measured by SCIAMACHY and NIWA ground-based DOAS are compared from Southern Hemisphere spring 2002 to early spring 2006. The absolute differences are also shown.

A seasonal and/or SZA dependence can be seen in the absolute difference (DOAS – SCIAMACHY) on top of a probable constant offset in summer and present throughout all seasons. However, the amplitude of this offset is not large, at about (2-3)x10\textsuperscript{16} cm\textsuperscript{-2} slant column amount, given the sources of systematic error in the measurement techniques. For example, this is typically less than one fifth of the NO\textsubscript{2} amount estimated to be present in the reference spectrum used to analyse all the Arrival Heights data, and is within the uncertainty of this estimate. (The twilight zenith technique uses the log of the ratio of the observation spectra with a midday spectrum as the function fitted with the known absorbers such as NO\textsubscript{2}, O\textsubscript{3}, etc., and so the NO\textsubscript{2} amount in the reference spectrum is missing in the NO\textsubscript{2} result amount.)

During the early spring and late autumn periods the difference changes sign and grows with SZA, suggesting a dependence on airmass due to slant path geometry differences between the two techniques. The slightly higher differences in early spring may also be a consequence of the vortex movements over Arrivals Heights at this time.

![Figure 3. Slant column amounts of NO\textsubscript{2} measured by SCIAMACHY and NIWA ground-based DOAS are compared from Southern Hemisphere spring 2002 to early spring 2006. The absolute differences and SZA of the SCIAMACHY observations are also shown in the lower panels. SCIAMACHY Data: IUP-Bremen V2.0 NO\textsubscript{2} data product.](image-url)
To see the effect of the Antarctic polar vortex, Fig. 4 shows the variations during the extremely unusual spring of 2002. Expanded in time, the large changes in NO\textsubscript{2} amount on opposite sides of the edge of the rotating elliptical vortex during early spring can be seen as wave like features in the NO\textsubscript{2} slant column amount. Low NO\textsubscript{2} is a necessary condition for chlorine driven ozone loss to occur inside the vortex. The difference also varies with amount, with higher positive differences generally related to the lower NO\textsubscript{2} amounts seen when Arrival Heights is inside the vortex edge. The accuracy of the DOAS technique is high at these SZAs, so we don’t consider it likely that DOAS measurement error contributes to this feature. It seems possible that the airmass calculations inside the vortex are not accurate enough in this extreme environment.

**Figure 4.** Slant column amounts of NO\textsubscript{2} measured by SCIAMACHY and NIWA ground-based DOAS are compared during southern hemisphere spring 2002. The absolute difference is shown in the upper plot which includes a spline fit (tension 10) black line. SCIAMACHY Data: IUP-Bremen V2.0 NO\textsubscript{2} data product.

### 3.4. UV-Visible DOAS Measurements of NO\textsubscript{2} at Kiruna.

NIWA has made stratospheric NO\textsubscript{2} measurements using the twilight zenith technique at Kiruna since 1990 as part of its NDACC work. Comparison with SCIAMACHY has been carried out on 2002 to 2006 data. However, it does suffer from the direct comparison method we have used because the ground based DOAS measurements SZA during the SCIAMACHY overpasses fall between 45° and 90°, with the good signal to noise ratio, i.e. SZA >80°, passes occurring in winter when the stratospheric NO\textsubscript{2} amounts are naturally low (see Fig 5 top panel and the absolute difference and SZA panels). However, the agreement is still reasonable with the absolute difference (DOAS – SCIAMACHY) slant column amount generally less than 4x10\textsuperscript{15} cm\textsuperscript{-2}. Clearly this difference has a SZA dependence. The high DOAS peaks in winter seem most likely due to tropospheric NO\textsubscript{2} pollution from the Kiruna power station a few km west of the IRF observatory.

These results show us that we need to use a comparison technique that compares vertical column NO\textsubscript{2} amounts when overpass SZAs are large, or use a chemical model to infer DOAS NO\textsubscript{2} slant column amounts at the time of the overpass when overpass SZAs are small. This model would use DOAS NO\textsubscript{2} amounts at SZAs > 80° morning and evening to derive the variation over the day.
Figure 5. Comparison of slant column amounts of NO\textsubscript{2} measured by SCIAMACHY and NIWA ground-based DOAS at Kiruna, Sweden. DOAS measurements courtesy of Institutet for rymdfysik (IRF), Kiruna. SCIAMACHY Data: IUP-Bremen V2.0 NO2 data product

4. TOTAL COLUMN CO\textsubscript{2} OBSERVATIONS AT LAUDER.

New work at Lauder in collaboration with the Total Column Carbon Observing Network (TCCON), may be of interest to the wider satellite community. OCO validation work is planned. Fig. 6 shows measured daily averages against a model prediction. The rms difference between the two is 0.7 ppmv, or ~0.2% showing the high precision of the FTIR column measurement. The scatter includes both measurement precision and atmospheric variability.

Figure 6. Daily average values of column-weighted CO\textsubscript{2} vmr compared to MATCH model.
5. USE OF NIWA DATA FOR ILAS AND GOMOS VALIDATION.

For the ACVE-3 workshop we focused on SCIAMACHY product validation as described above. However, NIWA data has been used in a number of ILAS and GOMOS validation papers in these proceedings as well as in many publications.

Examples of presentations at this ACVE-3 include:

- T Blumenstock, Validation of O₃, HNO₃, CH₄, N₂O profiles from MIPAS-ENVISAT with ground-based measurements at Kiruna.
- Y Meier, Pole to pole validation of MIPAS ozone profiles by the Envisat Quality Assessment with Lidar (EQUAL) project.
- M Hoepfner, Validation of the IMK MIPAS CLONO₂ data product.
- U Cortesi, Geophysical validation of MIPAS-ENVISAT ozone data: final results form the co-ordinated analysis of ESA level 2 operational products.

Examples of publications and proceedings include:


Lauder data has also been incorporated into validation projects at various stages of completion, for example:


Lauder data has also been used in a profile comparison of HNO₃ and N₂O in which the use of a data assimilation scheme, to address the problems of limited coincidence of ground-based with satellite data, was used and evaluated:

6. CONCLUSIONS

Ozone validations at Lauder show good agreement between the Dobson and SCIAMACHY results. While the standard deviation in the 5 years of absolute (Dobson – SCIAMACHY) difference values is about 20 DU, the mean is $1.2 \pm 1.2$ DU (1 sigma), demonstrating no bias.

Ozone validation at Arrival Heights shows some bias between the Dobson and SCIAMACHY results with a mean of $-9.2 \pm 1.3$ DU (1 sigma) in the (Dobson – SCIAMACHY) difference values. The bias appears to have a seasonal variation with a probable increase in Spring and maybe late Autumn.

NO\textsubscript{2} validation at Arrival Heights is promising, but significant seasonal and/or SZA biases are present on top of a probable offset. During the early spring and late autumn periods the difference changes sign and grows with SZA, suggesting a dependence on airmass due to slant path geometry differences between the two techniques. This difference also varies with NO\textsubscript{2} amount in early spring, with higher positive differences generally related to the lower NO\textsubscript{2} amounts seen when Arrival Heights is inside the vortex edge. It also seems possible that the airmass calculations for inside the vortex are not adequately correcting for the very cold air there, or maybe the strong scattering in the polar stratospheric clouds present produces errors in these calculations.

NO\textsubscript{2} validation at Kiruna demonstrates significant limitations in the way we are comparing SCIAMACHY with our ground-based DOAS measurements. Use of a chemical model to infer DOAS NO\textsubscript{2} slant column amounts at the time of the overpass when overpass SZAs are small should improve the precision of the comparison.

New total column carbon measurements at Lauder in collaboration with the Total Column Network may be of interest to the wider satellite community. OCO validation work is planned in the future.

7. THANKS

Jean-Christopher Lambert, BIRA, for vital and continuing support for data collection and validation work at Lauder.

8. ACKNOWLEDGEMENTS

Antarctica NZ for logistical support of all Antarctic observations.

Andreas Richter for providing the SCIAMACHY NO\textsubscript{2} data as well as invaluable advice on its use.

SCIAMACHY Data: IUP-Bremen V2.0 NO2 data product.

Kiruna DOAS measurements were made courtesy of Institutet for rymdfysik (IRF), Kiruna.