Early Validation of Gomos Limb Products Altitude Registration by Backscatter Lidar using Temperature and Density Profiles

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ABSTRACT

One basic need for all limb data products is the correct registration of the altitude for each measurement level. The validation of profile products has to comprise beyond the comparison of absolute values also an inspection of the altitude registration assigned to the measurement values. Lidar instruments are particularly suitable to perform this kind of validation due to a very precise determination of altitude as well as an high altitude resolution. Several lidar instruments are included in the validation activities, however, at this early validation stage there are only two contributions to the validation of limb products altitude registration. One contribution is by the University of Bonn Lidar at the Esrange (Sweden) and the other by the York University Lidar at Toronto (Canada) presently run by the Meteorological Service of Canada (MSC). In a campaign lasting from mid July to the end of August validation measurements for Envisat atmospheric products were carried out with the University of Bonn backscatter lidar at the Esrange (68N, 21E) near Kiruna in northern Sweden. Temperature and density profiles of Gomos level 2 products processed with software version GOPR_LV2_5.3 were used for comparison with lidar relative density and absolute temperature profiles to obtain information on the altitude registration of Gomos data products. Calculating the cross correlation function of corresponding Gomos and lidar profiles yields altitude-shifts for the maximum cross correlation coefficient. This altitude-shift reveals information on the Gomos altitude-registration. Using the density data for comparison shows a perfect agreement in altitude-registration between Gomos and lidar whereas the comparison using temperature data results in slight altitude-shifts with a median value of -300 m. Larger altitude-shifts up to 1.7 km were observed in some individual cases. These altitude-shifts are not caused by an error in the Gomos altitude registration, but by different profile-shapes for the lidar and Gomos data; lidar data frequently show wave patterns, whereas Gomos data are rather smooth and do not show such patterns.

Comparison with the temperature data of the Toronto (44N, 80W) lidar are available for three Gomos occultations, two in July, one in October, processed also with software version GOPR_LV2_5.3. Although the Gomos data are very noisy the calculation of the cross correlation function was carried out. All comparisons show an altitude-shift of +3 km and even more between lidar and Gomos altitude registration.

1. INTRODUCTION

The Envisat atmosphere observation instrument Gomos delivers limb profiles of several atmospheric constituents as O_3 or NO_2 for example as well as vertical profiles of atmospheric number density and temperature. For processing Gomos limb-products a correct registration of the tangent point altitude is necessary. Several instruments like radio- and ozonesondes or other baloone-borne and airborne in situ and remote sensing instruments can be used for validation of each single product type as well as the corresponding altitude registration. Nevertheless these validation activities do not extend beyond 40 km altitude. Lidar measurements in contrast cover an altitude range from the troposphere up into the mesosphere or even up to the mesopause. A precise altitude registration as well as a high altitude resolution make them suitable to validate the altitude registration.

Altitude registration can be validated by identifying same patterns in both Gomos and lidar profiles, respectively. Possible patterns are high clouds in the troposphere as well as clouds in the strato- and mesosphere in polar winter and summer, respectively. Furthermore the density and temperature profiles have prominent structures like the stratopause for example. An altitude comparison of a given structure allows validation of Gomos altitude registration.

The backscatter lidar at the Esrange (68N, 21E) in northern Sweden [1] measures altitude profiles of relative density in an altitude range from 5–90 km with an altitude resolution of 150 m. Due to aerosols in the atmosphere the backscattered signal below 30 km altitude contains in addition to the pure atmospheric density also contribution of stratospheric and tropospheric aerosol load. Therefore the density profile can be used for validation only above 30 km altitude. Using the

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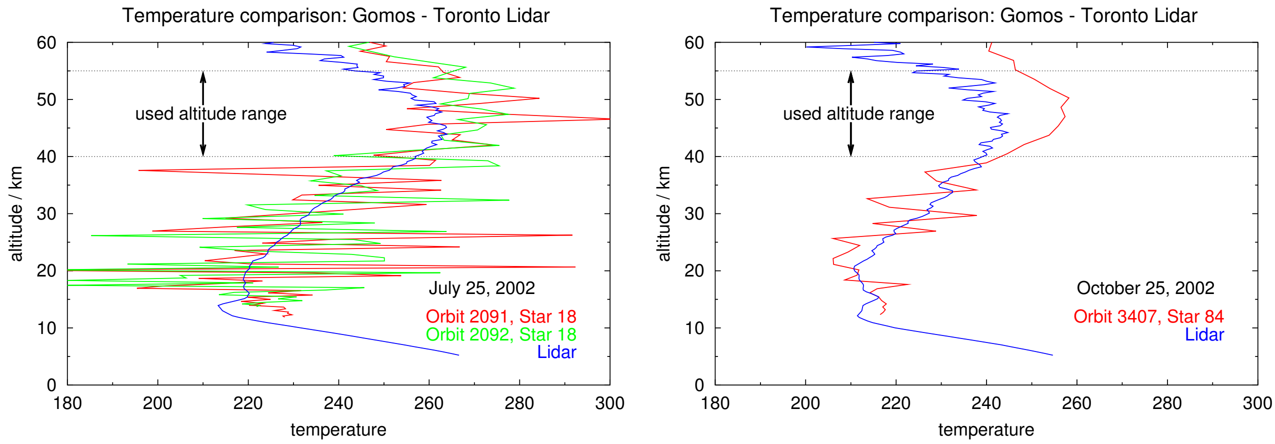

Figure 1: Correlated temperature profiles of Gomos and Toronto Lidar. Lidar data are plotted in blue. Left panel: Data of July 25, 2002; Orbits 2091 (red) and 2092 (green), star 18. The Lidar data comprise 5.2 hours integration time. Right panel: Data of October 25, 2002; Orbit 3407, star 84. The Lidar data comprise 5.0 hours integration time.

hydrostatic assumption and the ideal gas law allows calculation of absolute temperature profiles in this altitude range. The uppermost temperature value cannot be determined from the data but must be taken from an external reference temperature profile, which is in our case the campain mean temperature profile. A detailed overview of all validation activities within AOID 222 using the University of Bonn Lidar at the Esrange can be found in [2]. The reliability of lidar altitude registration has been established by several comparisons with measurements of other ground-based or rocket-borne measurements [3].

The MSC/York University Lidar at Toronto (43.7N, 79.5W) is a night-time only four channel (308 nm, 353 nm, 332 nm, 385 nm) Raman DIAL, working in the UV. The same system has been extensively used in the past under the NDSC measurement program. Under the ACVT its participation was under AOID 153 and was required to measure, report to ESA, and utilize for validation of geophysical parameters, ozone, aerosol, temperature and air density. The lidar covers an altitude range of 5–70 km. The temperature profiles can be measured with an altitude resolution of 300 m. Above 17 km altitude Rayleigh scattering, while below that altitude vibrational Raman scattering is used for temperature calculation. The advantage of this technique is, that it can provide temperature profiles also in an aerosol loaded atmosphere and thus at lower altitudes. A detailed description of the lidar system can be found in [4] and the detailed activities under AOID 153 related to ENVISAT Validation are contained in [5].

2. DATA BASE

The data base contains lidar data as well as Gomos data. While Gomos data were processed on request by ACRI, the available lidar data are in amount and temporal distribution different. Both lidar data sets as well as the corresponding Gomos data sets are described in the next paragraphs.

2.1 Gomos

The data base for validation of Gomos altitude registration is focused on data in July and August 2002 centered about Esrange within a radius of 1500 km. A total of 56 Gomos level-2 products were obtained from the ACRI-server. All data were produced with software version GOPR_LV2_5.3. Gomos density and temperature profiles cover an altitude range from 120 km partly down to 5 km with an altitude resolution better than 1.7 km depending on the occultation geometry. Several density and temperature profiles show ungeophysical jumps and in part excessive noise. Due to these ungeophysical shapes, not all retrieved data sets could be used for validation.

Further there are available three Gomos products centered about Toronto; two in July, one in October 2002. The temperature profiles of July are rather noisy with a scatter of ±40 K and more in the altitude range below 40 km. The bad data qualtity of the Gomos data makes the comparison of altitude registration difficult.

2.2 University of Bonn Lidar

In a campaign lasting from July 16 to August 31, 2002, 36 lidar measurements were carried out and relative density as well as absolute temperature pofiles could be obtained. Lidar data were used for validation only if the measurement error was below 5 %. Data sets with close time-coincidences were used for validation. Finally 33 Gomos data sets and 18 lidar data sets were usable for validation of altitude-registration covering a time range starting on July 18 and ending on August 23, 2002.

2.3 Toronto Lidar

Since July 2002 seven measurements were performed with the MSC/YorkU Lidar at Toronto, with durations of approximately 6 hours. For validation three Gomos occultations were available, two on July 25 and one on October 25, 2002. Both, Gomos and Lidar data are shown in Fig. 1. Whereas the Gomos data of July are rather noisy, the Gomos data of October show a good quality. However, due to the small amount of coincidences, also the data of July were used for comparison.

3. METHOD

To detect the relative altitude localization of patterns in temperature and density profiles, we compute the cross correlation coefficient (CCF) as a function of the relative altitude shift among the profiles. The CCF was calculated by the formula

$$CCF(j) = \frac{\sum_{i=1}^{N}(x(i)-\overline{x})(y(i+j)-\overline{y})}{\sqrt{\sum_{i=1}^{N}(x(i)-\overline{x})^2} * \sqrt{\sum_{i=1}^{N}(y(i+j)-\overline{y})^2}} \quad (1)$$

where N is the number of data points per profile and the shift index j is running from -N to +N.

In our case the lidar data were x and the Gomos data were y. We used lidar data from the altitude range 40–55 km for computation of the CCF. To reach a high altitude resolution, the Gomos profiles were interpolated to the lidar altitude grid. The CCF was only calculated if the overlap of the two profiles in the given altitude range was complete, which was possible for 33 profiles above Esrange and three profiles above Toronto. For each density and temperature profile the shift j was determined for which the CCF maximized. The j's were converted to altitudes.

An example for this method is shown in Fig. 2. Shown are example data of August 15, 2002. In red is plotted the UBonn Lidar temperature profile, green, blue and pink show the corresponding Gomos temperature profiles with no shift, –1.8 km and +1.8 km shift in altitude respectively. Obviously, the best correlation occurs for the Gomos profile without any shift, which can be seen from the calculated CCF values, which are 0.99, 0.94, and 0.74 respectively. The altitude range used for the CCF calculations is marked by two horizontal lines.

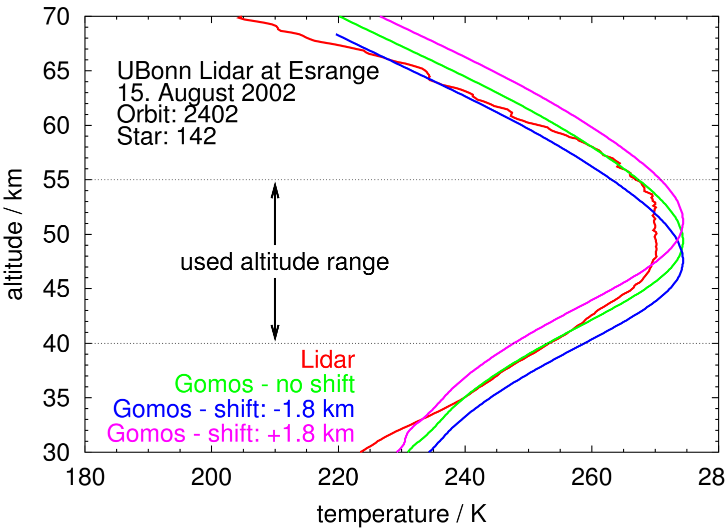

Figure 2: Calculation of cross correlation function. Example data of August 15, 2002. Shown are the UBonn Lidar temperature profile (red line) as well as the corresponding Gomos temperature profiles for different altitude shifts (green: no shift, blue: down shift of 1.8 km, pink: up shift of 1.8 km.)

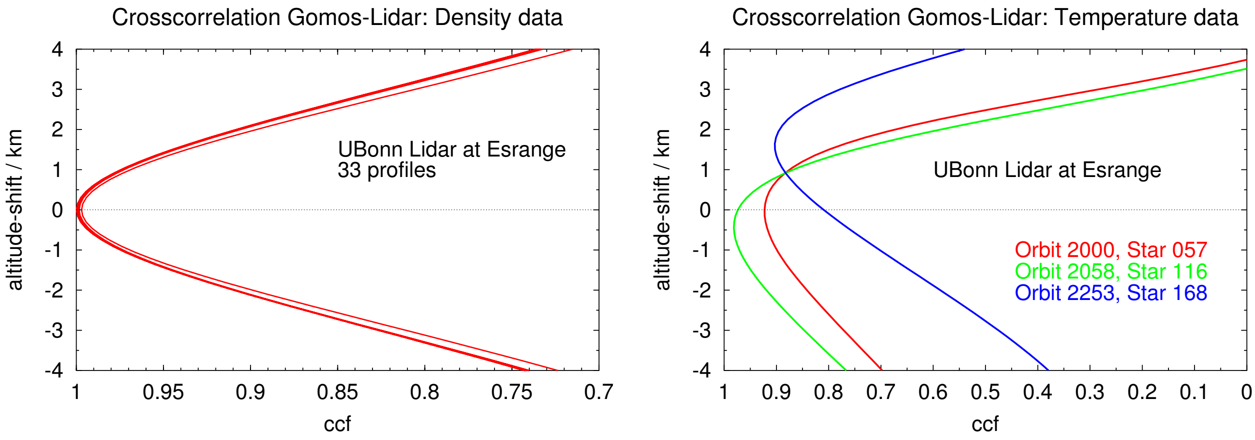

Figure 3: Left panel: Correlation coefficient for Gomos and UBonn Lidar for the logarithm of the density data in the altitude range of 40–55 km. There is no detectable altitude shift for all profiles. Note reversed abscissa. Right panel: Correlation coefficient for Gomos and UBonn Lidar for the temperature data in the altitude range of 40–55 km. Note reversed abscissa.

4. RESULTS

4.1 University of Bonn Lidar

Cross correlation calculations can be performed for density as well as for temperature profiles. The CCF for the densities was actually calculated for the logarithm of the density values. The resulting CCFs for all profiles are plotted in the left panel of Fig. 3. There is no detectable altitude-shift in the log-density profiles. The CCF for the Gomos and lidar temperature data are shown for a few profiles in the right panel of Fig. 3 as a function of the altitude-shift. Different from the density data, there is a spread in shift values, which are summarized in the left panel of Fig. 4. The mean shift is – 0.2 km, which compares well with the median value of – 0.3 km. Negative shift values imply that the Gomos data need to be shifted upward with respect to the lidar data for a better match. Reworded, this implies that the Gomos altitude registration for the same pattern is lower than the Lidar altitude registration. We have visually inspected the profiles for which the suggested altitude shifts are 1 km and higher for a good match. Affected are the Gomos occultations in the orbits 2244 (S057, S155), 2252 (S168), 2253 (S168), and 2458(S142). For all cases the Lidar profiles show considerably more structure than the rather smooth Gomos profiles as can be seen in the right panel of Fig. 4. This CCF-shift should not be interpreted as an altitude-shift. Rather it reveals a difference in profile shape caused by geophysical variability such as waves. On the one hand the Gomos altitude resolution is sufficiently high to detect these structures; on the other hand the distance from the Gomos measurement location to the Esrange was 850 to 1250 km and there is the possibility that we see spatial differences driven by geophysics.

4.2 Toronto Lidar

Cross correlation calculations were carried out for the temperature data of the Toronto Lidar. The results are shown in the left panel of Fig. 5. Due to the rather noisy Gomos data the results of the cross correlation calculation are not very suitable to determine an altitude-shift between Gomos and lidar data. As the small CCF-values of less than 0.6 and 0.8 for both comparisons of July 25 show, the agreement between Gomos and lidar data is rather bad. The altitude-shift of maximum CCF is not well determined. For orbit 2091 there is an altitude range from 4.5 km to 6.3 km with CCF-values larger than 0.5. The local maximum is at 5.1 km with an CCF of 0.55. For orbit 2092 the result is more ambigous. Between 3.3 km and 7.8 km altitude-shift the CCF values are larger than 0.7 with an maximum of 0.75 at 4.5 km altitude-shift. Better results can be achieved by the comparsion of the October data. A clear maximum can be found at 3.0 km altitude-shift with an CCF of 0.92, which implies a quite good agreement.

Although just three comparisons are not statistical significant and the Gomos data for July are rather noisy, it is remark-

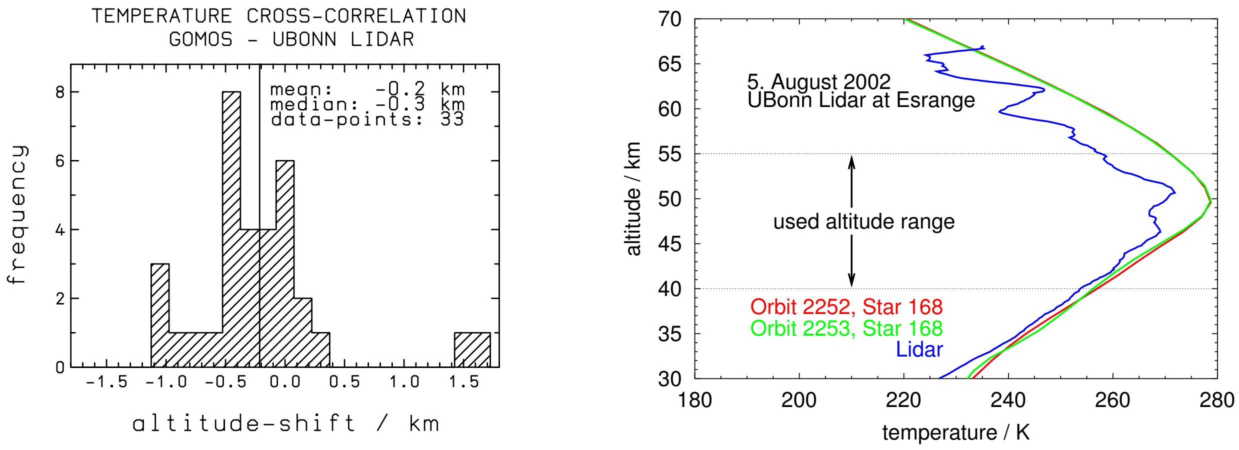

Figure 4: Left panel: Histogram of the altitude shifts for the cross correlation function for temperature data. Apparent shifts of 1 km and larger are caused by highly structured lidar profiles, while the associated Gomos profiles are rather smooth; these shifts should not be interpreted as a deviation in the altitude registrations. Rigth panel: Example data of August 5, 2002. Shown are the UBonn Lidar temperature profile (blue line) as well as two corresponding Gomos temperature profiles (red and green line). The lidar profile shows wave structure whereas the Gomos profiles have a rather smooth shape. The resulting shift for maximum CCF are +1.5 km and +1.6 km for the red and green profile respectively.

able, that the altitude-shift of maximum CCF for all three cases shows quite large deviations of 3 km and even more in the same direction.

The right panel of Fig. 5 shows the lower part of the temperature profile measured by Lidar on July 25 and October 25, 2002. It is obvious, that the tropopause altitude can be retrieved from this measurement. Thus it is possible to validate the altitude registration using the tropopause altitude, if the Gomos temperature profile covers also the troposphere.

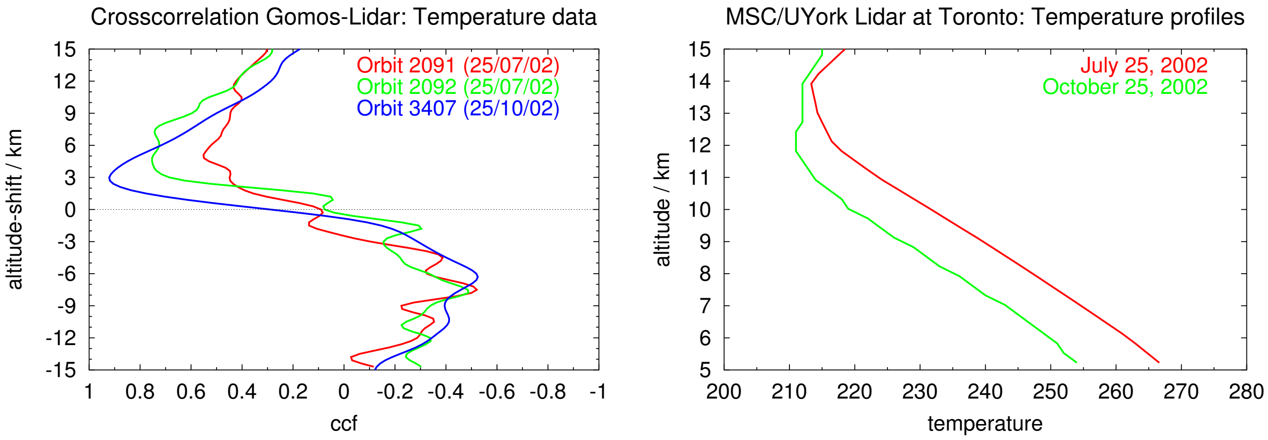

Figure 5: Data of Toronto Lidar for July 25 and October 25, 2002. The left panel shows the CCF for Gomos and Lidar temperature data. The altitude-shifts of the used Gomos profiles are 3.0 km and even more. The right panel shows the temperature profile measured by Lidar in the troposphere on July 25 and October 25, 2002.

5. SUMMARY

The altitude registration of Gomos limb products could be validated by backscatter lidar using temperature and density profiles. Comparsion with the Toronto Lidar was performed for three coincidences with two lidar profiles. Although the Gomos data of July were very noisy (especially below 40 km altitude) calculations of crosscorrelation were carried out. The altitude-shifts for the maximum CCF are 3.0 km and even more, however, the maximum CCF-values are rather low for the July data, which implies a bad correlation. Further the temperature data of the Lidar measurements can be used

to determine the tropopause altitude, which allows the validation of altitude registration, if Gomos data cover also the troposphere.
Lidar measurements at the Esrange on July and August 2002 allowed for a comparison with 33 Gomos profiles. Calculation of cross correlation coefficients showed for density data a perfect agreement of alitude registration between lidar and Gomos data, whereas the use of temperature profiles led to scatter in altitude-shifts of the maximum CCF with a median value of -300 m, which implies, that the Gomos altitude scale is to low with respect to the lidar data. However, both comparisons with UBonn Lidar data show an excellent agreement in the altitude registration.
Although the data base of comparison with Toronto Lidar is rather small there is a clear difference for the comparsions of Gomos data with lidar data of both stations. Whether these deviations are real or statistical artefacts needs further investigation. Therefore more measurements - also at other geographical locations - are necessary, to determine a probable geographical distribution of deviations in altitude registration.

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