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Atmospheric Measurement Techniques Discussions

SCIAMACHY stratospheric aerosol extinction profile retrieval

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Abstract

The Ozone Mapper and Profiler Suite Limp Profiler (OMPS/LP) algorithm is used to retrieve ozone and aerosol profiles using a series of 120 SCIAMACHY limb measurements collocated with SAGE II solar occultation events. The primary goal of the study is to ascertain the capability of the OMPS/LP retrieval algorithm to accurately retrieve the vertical distribution of stratospheric aerosol extinction coefficient so as to better account for aerosol effects in the ozone profiling retrieval process. Using simulated radiances, we show that the aerosol extinction coefficient can be retrieved from limb scatter measurements within 5% and a standard deviation better than 15%, which is more than sufficient to improve the OMPS/LP ozone products to be used as Environmental Data Records. We also illustrate the ability of SCIAMACHY limb measurements to retrieve stratospheric aerosol profiles with accuracy comparable to other instruments. The retrieved aerosol profiles agree with collocated SAGE II measurements on average to within 25%, with a standard deviation of 35%.

1 Introduction

The Ozone Mapper and Profiler Suite (OMPS) mission will be launched on board the National Polar Orbiting Environment Satellite System (NPOESS) Preparatory Project (NPP) satellite in October 2011. The main goal of the mission is to produce Environmental Data Records (EDR) for total column ozone and ozone vertical distribution over the whole Earth atmosphere. The present paper is concerned with one of the OMPS suite of instruments, namely the Limb Profiler (LP), which will use the measurements of scattered solar radiation to infer information on the ozone vertical profile. More specifically, the paper is primarily focused on aerosol profile retrieval and its effect on the quality of the retrieved ozone profile. In order to test the OMPS retrieval algorithm, we use a simulated set of radiances and the limb scattering measurements of SCIAMACHY on board of Envisat. Another objective of this paper is to illustrate the capabilities of SCIAMACHY limb measurements to derive stratospheric aerosol profiles, since this work presents the first results of such a retrieval.

Stratospheric aerosols are an important parameter in the modelling of climate change and also play an important role in the chemical and dynamic processes related to ozone destruction in the stratosphere. Stratospheric aerosol has been measured with ground-based lidar (Poole and McCormick, 1988), balloon-borne Optical Particle Counters (OPC) (Hofmann and Deshler, 1991), and satellites such as the Stratospheric Aerosol Measurement (SAM II) (McCormick et al., 1982), the Stratospheric Aerosol and Gas Experiment (SAGE II) (Thomason, 1991), and SAGE III (Thomason and Taha, 2003). The capability to retrieve atmospheric aerosol properties globally from limb scatter (LS) measurements is particularly important at the present time, as no solar occultation sensors, which have been relied upon in the past 30 years, is currently active. At present, two LS sensors, namely the Optical Spectrograph and Infrared Imager System (OSIRIS) (Llewellyn et al., 2004), and the SCanning Imaging Absorption spectroMeter for Atmospheric ChartographHY (SCIAMACHY) (Bovensmann et al., 1999) are still in operation, while the OMPS is expected to launch next year. The capability of LS sensors has already been demonstrated with SAGE III LS (Rault and Loughman, 2007) and OSIRIS (Bourassa et al., 2007) measurements.

The paper reviews the main concepts of the OMPS/LP retrieval algorithm in Sect. 2. The performance of the OMPS/LP algorithm is illustrated in Sect. 3 where a set of synthetic LS radiance data is used to test the algorithm. It is shown that the OMPS/LP algorithm can accurately retrieve all the input parameters, namely surface reflectance, aerosol extinction, ozone density as well as tangent height registration (TH). The OMPS/LP algorithm is applied to SCIAMACHY data as shown in Sect. 4. A series of 120 SCIAMACHY LS events are selected which correspond to close coincidences with SAGE II solar occultation events in both space (less than 250 km) and time (less than one day) during 2004. The retrieved aerosol extinction profiles are presented, discussed and compared with SAGE II, first on a case by case basis and then on a global statistical level. The ozone retrieval results are presented and compared with both SAGE II and SCIAMACHY archived products. Finally, a summary and conclusions of this study are presented in Sect. 5.

2 Methodology

2.1 OMPS/LP retrieval algorithm

The retrieval of atmospheric constituents from limb radiance measurements involves comparing measured data with simulated data generated by a multiple scattering radiative transfer (RT) model. The RT model used for the LP was initially developed by Herman et al. (1994, 1995), and has been tuned and optimized for limb studies by Rault (2005). It is efficient in performing multi-wavelength computations, which allows one to perform convolution with the instrument slit function with sufficient accuracy and speed. The partial derivatives are computed semi-analytically for both ozone (single scattering) and aerosol (multiple scattering). The retrieval algorithm is based on the Rodgers nonlinear optimal estimation technique (Rodgers, 2000).

For ozone retrieval, the measurement vector is made of wavelength pairs and triplets, following the technique described by Flittner et al. (2000). The a priori data vector is evaluated for a given latitude and calendar month from the SAGE II climatology. For aerosol retrieval, the measurement vectors are normalized radiances at specific wavelengths corresponding to weak gaseous absorption. The a priori vector is a set of mean constant extinction vertical profiles corresponding to the present period of low stratospheric background aerosol. The a priori aerosol size distribution is assumed to be a single mode log normal distribution, with 0.06 µm effective radius and variance σ of 1.73, composed of spherical liquid sulphate particles with an index of refraction $m = 1.448 + 0\,i$. In the forward model, the atmospheric temperature and pressure profiles are generated from the NCEP dataset (Kalnay et al., 1996), and the NO_2 information is taken from climatology constructed using the PRATMO photochemical

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box model (McLinden et al., 2000). The retrieval uncertainties are evaluated from the diagonal of the covariance matrix, which itself is computed using the Signal-to-Noise-Ratio (SNR) specific to the sensor.

The OMPS/LP profile retrieval algorithm is composed of a series of sequential steps; first cloud height is determined using long wavelength channels with weak gaseous absorption, followed by a Tangent Height registration check, and adjustment if necessary (not adjusted in this study), using a scene-base method, such as the Rayleigh Scatter Altimeter Sensor (RSAS) technique (Janz et al., 1996). The following step consists of estimating the effective scene reflectivity (or albedo) by comparing the measured and modelled radiances in the TH range of 35–45 km. The aerosol extinction and size distribution are then retrieved, as described below, using spectral channels with weak gaseous absorption. TH registration is repeated using the retrieved aerosol profiles, since the TH registration is somewhat sensitive to aerosol loading. Finally, the ozone retrieval is performed using radiance data from both the UltraViolet and Visible wavelength channels, respectively for high altitudes (30–60 km) and low altitudes (Cloud top or 10–40 km).

2.2 Aerosol algorithm

The retrieval algorithm solves for the aerosol extinction at several wavelengths (524, 682, 750, 790, and 1028 nm) across the measured spectrum, and then uses that spectral information to infer information on the size distribution. Radiances are normalized to their value at 35.5 km, Rodgers' maximum likelihood technique is used to retrieve the extinction coefficients independently for each wavelength and the process is allowed to iterate up to convergence, similar to Rault and Loughman (2007). A median Angstrom coefficient is determined and used to interpolate the extinction coefficients at the wavelengths used by the ozone retrieval, thus ensuring that the aerosol extinction coefficients are smooth functions of wavelength and therefore do not introduce non-physical high frequency fluctuations into the ozone retrieval process. The aerosol profile is also updated at the RSAS channel, usually at ~350 nm, to improve the accuracy of the tangent height predictions. An alternative method to the Angstrom approach consists in using the retrieved multiple wavelength aerosol extinction to solve for a moment of the size distribution. In this work, we are only presenting results obtained using the first approach.

Figure 1 is a plot of the sensitivity of LS signal to aerosol [$d\log(I_\lambda)/d\log(\beta_\lambda)$], which shows clear aerosol sensitivity at wavelengths in the 500–1020 range. The optimal vertical altitude of the aerosol signal varies by wavelength, generally from 18–25 km at 520 nm to 12–30 km at 1020 nm. At shorter wavelengths, Rayleigh dominates the scattering signal. Aerosol sensitivity is used to determine upper and lower limits of the retrieved aerosol profile.

3 Results of synthetic data retrieval

The retrieval algorithm was first tested with a relatively large synthetic dataset, where we have full control on the problem parameters. This step allows one to quantify retrieval uncertainties and perform a statistical analysis of the retrieved products.

This dataset was generated by a forward model and is composed of 450 limb scattering events. Each event corresponds to a co-location of a SAGE II occultation measurement with a SCIAMACHY limb scattering measurement over a one-year period. These events encompass a wide range of geo-locations, seasons, and solar viewing angles. The input ozone, NO_2, and aerosol profiles for each event are those of SAGE II. The solar view angles are obtained from the SCIAMACHY measurements. The surface albedo is assumed to have a constant value of 0.15. The atmospheric temperature and pressure profiles are generated from NCEP reanalysis provided by the SAGE II data file. Figure 2 is the simulated events location map. The lower panel is a scatter plot of all events latitude vs. time.

The performance of the aerosol retrieval is illustrated in Fig. 3, which compares the retrieved aerosol profile to the assumed input profile or “truth”. The figure shows the mean bias and the standard deviation of the retrievals for the 525 and 994 nm wavelengths. For the longer wavelength at 994 nm, it can be seen that the aerosol can be retrieved within ∼5% over the altitude range of 15–30 km and a standard deviation of 10–15%. Similar bias and standard deviation can be seen for the shorter wavelength, 525 nm, but for a reduced altitude range of 17–25 km, and 25% outside that altitude range. The reduced altitude range for the 525 nm is correlated with reduced sensitivity to aerosol at large Single Scattering Angle (SSA). Figure 4 is an example of aerosol weighting function or Jacobian matrix, at 525 nm. The left panel is for a SSA of 132° while the right panel is for a SSA of 34°. For the large SSA, the weighting functions are positive and strongly peaked at an altitude range of 20–26 km. At lower altitudes, aerosols scatter more light out of the line of sight beam than they do into it, which causes the weighting functions to go negative, and reduces the sensitivity of the limb radiance to aerosols. When the SSA is small, the weighting functions are always positive. Aerosol weighting functions are generally positive for large wavelengths, as demonstrated in Fig. 5 for the 994 nm. To ensure maximum sensitivity towards aerosol, we use a very small aerosol a priori (Bourassa et al., 2009).

Results of the ozone retrieval exhibit a bias of 2%, and standard deviation less than 3%, with respect to the true values at altitude range 20–58 km, as depicted in Fig. 6. Aerosol modelling error in the forward model contributed up to 2% of the retrieval precision at altitude range 23–30 km, since there was no attempt made to constrain SAGE II aerosols profile spectral behaviour by an aerosol size model. Below 20 km, the large standard deviation ∼15% is mainly caused by very low ozone concentrations at certain geographical regions. Although the absolute bias is generally small for all altitudes, the percent difference is further enhanced when the ozone concentration is very low.

The effective albedo retrieval is within 11%, with standard deviation of 25%. The retrieved tangent height accuracy is within 75 m and standard deviation of 80 m.

It is clear that the accuracy of the retrieved aerosol is sufficiently ascertained and can accurately correct for the aerosol effect on the ozone retrieval, as well as the scene-based tangent height registration.

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4 Results of SCIAMACHY retrievals

4.1 SCIAMACHY dataset

The SCIAMACHY instrument on board Envisat (Environmental Satellite) has been in orbit since 2002, performing limb scatter radiance measurements from the near UV to the infrared region (For instrumental details we refer to Bovensmann et al., 1999). SCIAMACHY limb products include vertical profiles of ozone, NO_2, BrO, H_2O, and OClO, as well as polar stratospheric and Noctilucent clouds. A fairly good estimate of the aerosol extinction profile is critical to the retrieval accuracy of stratospheric minor constituent profiles, mainly in the Upper Troposphere-Lower Stratosphere (UT/LS) region, as shown by Loughman et al. (2005) and Rault and Taha (2007). For this study SCIAMACHY Level 1 version 6.03 data was used, that includes an improved tangent height registration compared to the lower Level 1 versions used in von Savigny et al. (2005). The accuracy of the tangent height registration is assumed to be better than 300–400 m.

In this paper, a subset of 120 SCIAMACHY events recorded in 2004 was selected. Each event corresponds to a geo-location in close proximity to a SAGE II solar occultation, within 250 km and within 24 h. SAGE II is widely recognized as benchmark for satellite ozone and aerosol measurements in the stratosphere (Wang et al., 2002; Borchi et al., 2004; Thomason and Peter, 2006). An OMPS proxy dataset was constructed from SCIAMACHY data by selecting radiance measurements at OMPS wavelengths, and convolving each radiance with the OMPS spectral instrument point spread function. The radiance data was then interpolated to a 1 km grid. A spatial Gaussian convolution with a Full Width Half Maximum (FWHM) of 2.7 km was also applied to the forward model to match the SCIAMACHY Field of View (FOV) function. As shown in Fig. 7, the proxy dataset is evenly distributed around the globe, and with time, in order to study the effect of seasonal/geographical variations on the ozone and aerosol retrieval. When comparing retrieval products, SAGE II aerosol and

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ozone profiles are convolved with a 2.5 km Gaussian filter to match the SCIAMACHY FOV function.

Figure 8 is a plot of the difference between SCIAMACHY normalized measured (y_{meas}) and modeled radiance (y_{clean}) for an aerosol free atmosphere, at 524, 692, 750, 793, and 1029 nm. Initial normalization level is 35.5 km. The signature of stratospheric aerosols is clearly evident from 12 to 30 km, with aerosol sensitivity increasing with wavelength. SCIAMACHY LS measurements show evidence of straylight in the spatial dimension, with the strongest contamination occurring at longer wavelengths (Gottwald et al., 2006). The straylight can be observed above 32 km for all wavelengths except for the 1029 nm, where it was above 29 km. At high altitudes, the difference between the measurements and the clean atmosphere should be negligible. To avoid straylight contamination effects, the high-altitude normalization is adjusted to the height level where this difference is at its minimum. Normalization altitudes are constantly calculated and updated for each wavelength. The high-altitude normalization is needed to reduce the effects of parameters such as surface/cloud reflectance, sensor absolute calibration and sensor residual polarization.

4.2 Aerosol retrieval results

Figure 9 shows the retrieved aerosol extinction at 793 nm (left) and 1028 nm (right) and the a priori profile for the same event shown in Fig. 8. Usually it takes 2–4 iterations for the aerosol retrieval to converge. The circles are positioned at the upper and lower limits of the retrieval for each iteration. The averaging kernel matrix for each selected wavelength is close to the identity matrix, which ensures that the retrieved aerosol profile is mostly independent of the a priori profile within the retrieval limits, as can be seen in Fig. 9.

Two separate retrievals of aerosol profiles from SCIAMACHY were performed using the following wavelengths: 750, 793, and 1028 nm, and 524, 682, 750, 793, and 1028 nm.

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For the second set of retrievals, the algorithm was modified to carry out the ozone retrieval first using aerosol climatology, and then perform the final aerosol and ozone retrievals, in order to minimize the ozone contamination at the shorter wavelengths. This change, alongside the use of very small aerosol a priori, was critical to successful retrievals of the shorter wavelengths, mainly the 524 and 682 nm. Unless stated otherwise, all presented results herein are using the first set retrieval.

4.3 Aerosol retrieval comparison with SAGE II

Figure 10 is an example of retrieved and interpolated aerosol extinction profiles for the same event depicted in Figs. 8 and 9. It reveals a typical stratospheric aerosol loading close to background levels on 24 January 2004, latitude 43.6°, and longitude 74.5°. The left panel shows the retrieved aerosol profiles for 750, 793, and 1028 nm (colour asterisk). The solid lines correspond to the 513–682 nm interpolated results. The black lines refer to SAGE II measurements at 525 and 1020 nm, whereas the dashed line refers to the interpolated SAGE II aerosol at 750 nm. The right panel is the percent difference between the retrieved aerosol and SAGE II profiles. SAGE II was interpolated at wavelengths 513, 750, and 793 nm. Differences are shown at 513 nm (which is interpolated), in order to illustrate the quality of the interpolated aerosol at the wavelength used in the ozone retrieval.

The retrieved SCIAMACHY aerosol profiles showed a good agreement with SAGE II with a flat bias within 25% at the altitude range of 12–28 km. The shape of the retrieved aerosol was in complete agreement with SAGE II. Both SCIAMACHY and SAGE II measurements at 12 km point to a cloud presence.

Figure 11 is similar to Fig. 10 but for 27 September 2004, latitude 13.2° and longitude 32.6°. The aerosol profile has a fairly unusual shape with multiple layers of aerosol particles at 12, 17, and 20–30 km. The origin of these multiple layers is not known, but it can be seen that SAGE and SCIAMACHY are in reasonable agreement in detecting the aerosol extinction profile shape, but not necessarily the absolute magnitude. Reasons for this may be the basic assumption made in the forward model

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regarding the aerosol size distribution uni-modal structure, shape, and composition (spherical sulphate particles) for the aerosol model in the retrieval algorithm. Obviously, a different aerosol model is required to account for the tropospheric aerosol seen at lower altitudes.

Figure 12 is another plot of the retrieved SCIAMACHY vs. SAGE II aerosol profiles, similar to Fig. 10 left panel, but for 13 September 2004, latitude -60.9° and longitude -81.2°, and 9 September 2004, latitude -61.2° and longitude -23.9°, respectively. The NCEP temperature was 192–194 K around the observed aerosol layers. The time, location, and temperature, indicates that this layer is most likely a Polar Stratospheric Cloud (PSC). For the second case, the retrieval manages to see through the cloud to detect a secondary aerosol layer that match SGE II aerosol profile shape. The origin of this aerosol layer is the sedimentation of PSC particles carrying with them the background aerosol, Thomason and Peter (2006). Although the agreement in profiles shape between SCIAMACHY and SAGE II is notable, the absolute agreement is not so. This example demonstrates the ability of the retrieval to detect multiple layers of enhanced aerosol, including thin PSCs.

4.4 Aerosol retrieval overall statistics

Figure 13 is a summary plot of the percent difference for all retrieved aerosol profiles used in this study with SAGE II, which includes 1028 nm (red), 750 nm (blue), as well as the interpolated 513 nm (cyan). The dashed lines are the standard deviations. In general, the SCIAMACHY retrieved aerosol shows a good agreement with SAGE II, within 25%. The 1028 nm channel shows a larger bias of ~30–35%, possibly because of the spatial straylight contamination. The standard deviation is flat and within 30–35%, which reflects on the larger variability of the differences for the compared profiles. It also reflects on real atmospheric variability between geo-locations of SAGE II and SCIAMACHY. There were several events similar to Figs. 11 and 12, where SCIAMACHY detected the aerosol shape, but not the absolute value, which can add to the large deviation seen here. The SCIAMACHY aerosol extinction at 513 nm, which

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is interpolated using the Angstrom coefficient of the retrieved profiles, is within 10–15% of SAGE II measurements, which reflects on the quality of the aerosol used in ozone retrieval. The second set of the aerosol retrievals, which included 5 wavelengths, yielded similar results to the first set, but with an increased bias of 3–4%. The retrieved 525 nm aerosol, in general, demonstrated similar behaviour as the longer wavelengths, but for a more restricted altitude range. For both sets of retrievals, the effect of aerosol on the retrieved ozone was similar, which indicates the Angstrom model used to predict the aerosol at shorter wavelengths is reasonably accurate for this purpose.

Sources of the observed bias with SAGE II can be partly explained by the use of the aerosol size distribution model for the phase function calculation. Straylight contamination can add to the bias, mainly at 1028 nm. Lowering the normalization height because of the straylight can lead to normalization at levels that might contain some aerosol, albeit very small values. Tangent height registration uncertainties can also add to the retrieval uncertainty. The effect of line-of-sight inhomogeneity, mainly at the UT/LS, is more complex and difficult to account for. Some of the observed differences were real, caused by instrument differences and atmospheric variability or mismatches.

Generally, aerosol measurements comparison is difficult in the stratosphere during a period of historically low background aerosol loading, more so in the UT/LS because of the highly variable atmospheric conditions in that region. Thomason and Peter (2006) carried out a comparison of various instruments that measure stratospheric aerosol, and found that the agreement between these instruments is within 20–60%. The accuracy and precision of the retrieved SCIAMACHY aerosol profiles is well within these limits and demonstrate the capabilities of the SCIAMACHY limb measurements, as well as the OMPS LP algorithm to retrieve a good stratospheric aerosol extinction profiles. These aerosol products should be suitable for scientific studies of various atmospheric events such as volcanic eruptions or high altitude biomass burning. Further tuning of the retrieval algorithm and the aerosol size distribution model, and a more extensive validation analysis using more instruments and a larger statistical sample would benefit the retrieval by further understanding and quantifying the retrieval uncertainties, and hence make use of SCIAMACHY and future OMPS aerosol measurements to extend the stratospheric aerosol records.

4.5 Ozone retrieval

Figure 14 is a summary plot of the SCIAMACHY retrieved ozone profile differences with SAGE II. The left panel shows the mean difference for Visible (red), Ultraviolet (blue), and University of Bremen (IUP) retrievals (yellow) for all events used in this study. The IUP ozone profile used here is (Stratozone 2.0), which is based on simultaneous retrieval in the UV (Hartley-Huggins) and visible Chappuis bands (Sonkaew et al., 2009). The IUP retrieval corrects for aerosol using a fixed climatology. The right panel shows the standard deviation (line) and the retrieval 1-σ uncertainty (dash). The retrieved ozone profile (vis.) show a good agreement with SAGE II, with ∼3% improvement over the IUP retrieval, which could be attributed to an improved aerosol profile solution. The standard deviation for both vis. and IUP retrieval is ∼10%. The 1-σ uncertainty is very small compared to the standard deviation, mainly because SCIAMACHY reported errors were small.

4.6 Tangent height registration

Figure 15 shows a tangent height registration histogram of all detected altitude offsets. The mean offset detected is –200 m, with a standard deviation of 430 m. The observed standard deviation is consistent with the assumed tangent height accuracy of SCIAMACHY level 1 radiances of 300–400 nm. A tangent height offset of –140 m and standard deviation of 200 m for SCIAMACHY measurements in the tropical region was noted by von Savigny et al. (2009), which are based on pointing retrievals using TRUE (Tangent height Retrieval by UV-B Exploitation) (Kaiser et al., 2004).

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5 Summary and conclusions

The OMPS/LP retrieval algorithm is being tested with a large set of synthetic and proxy radiance data in order to gauge its performance and identify sources of bias and systematic errors. The results of this performance analysis are being used to fine-tune the algorithm. Using the synthetic radiances, we showed that the aerosol extinction coefficient can be retrieved from limb scatter measurements within 5% and a standard deviation better than 15%, which is more than sufficient to improve the OMPS/LP ozone products to be used as Environmental Data Records. Using SCIAMACHY limb measurements as a proxy, the study presented in this paper has allowed a direct comparison of the OMPS/LP algorithm products with SAGE II retrievals, under a wide range of atmospheric conditions, geo-locations, scattering solar angles and seasons. Such comparison is obviously difficult since it does involve instrument artifacts and effects (which are different for each sensor) and atmospheric variability. The retrieved aerosol profiles agree with collocated SAGE II measurements on average to within 25%, with a standard deviation of 35%. A secondary outcome of this study shows that it is indeed possible to retrieve aerosol extinction profiles from SCIAMACHY LS data, which in turn, could lead to an improvement of the SCIAMACHY gaseous products in the UT/LS region.

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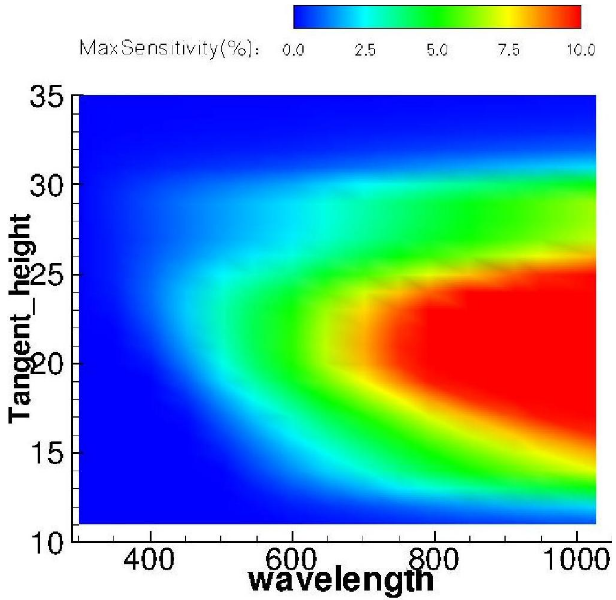

Fig. 1. Sensitivity of SCIAMACHY limb radiance to stratospheric aerosol. Sensitivity is defined as the maximum change [%] of limb radiance due to 1% change in aerosol extinction.

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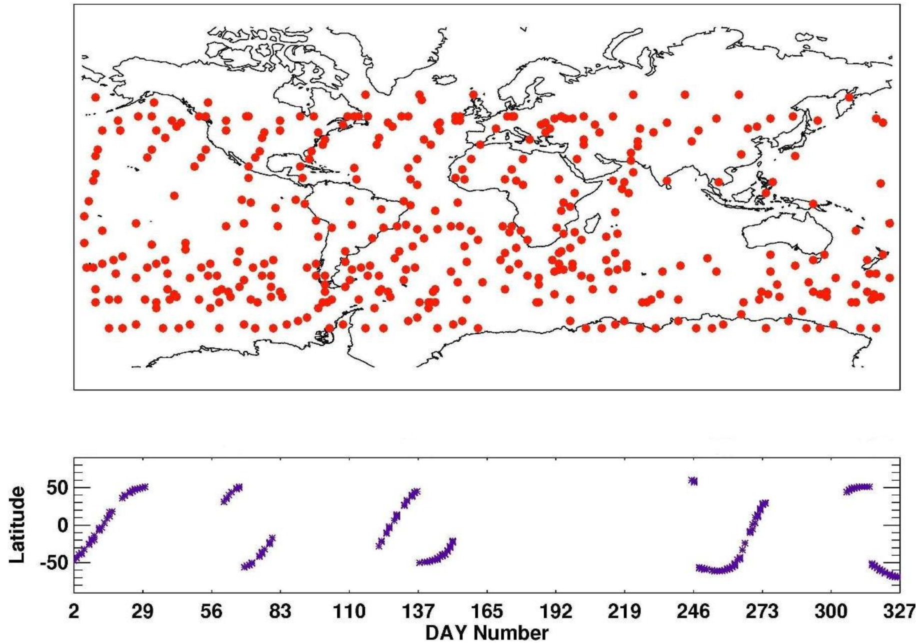

Fig. 2. Location of the simulated dataset (upper panel) and latitude vs. time (lower panel).

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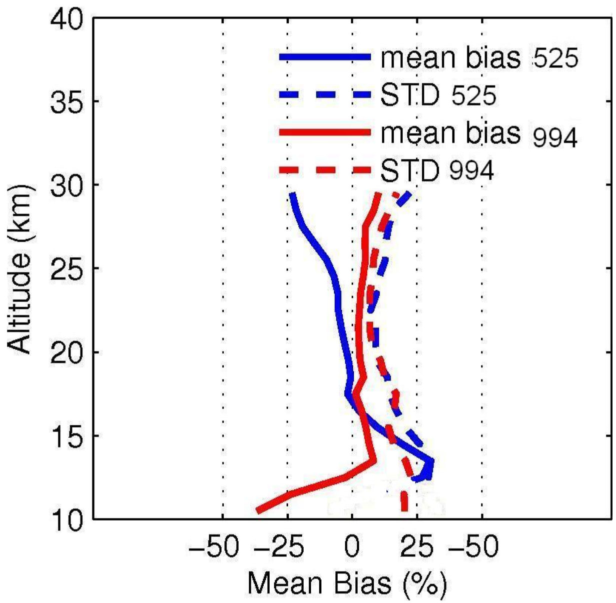

Fig. 3. Summary plot of the percent difference for all retrieved aerosol profiles for the 450 simulated radiances. Blue is 994 nm and red is 525 nm. The dashed lines are the standard deviations.

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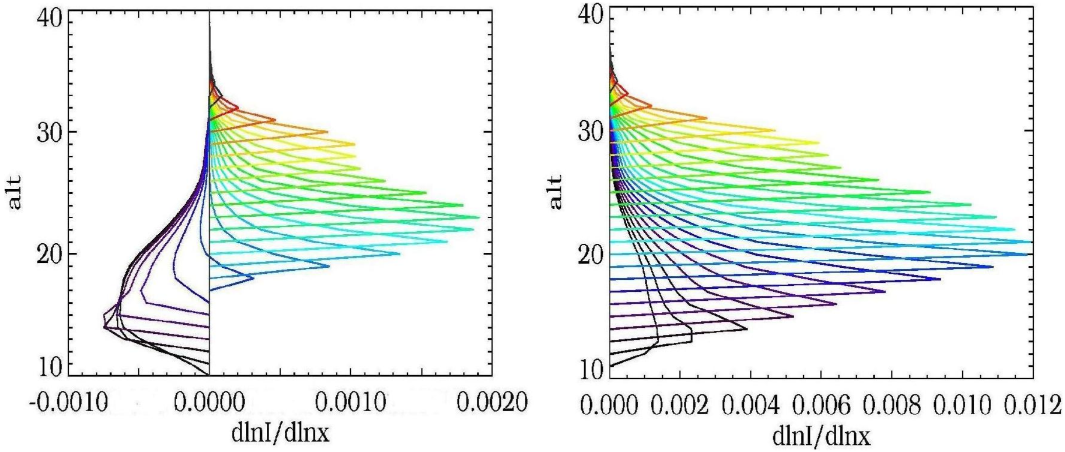

Fig. 4. Example of aerosol weighting functions at wavelength 525 nm. The left panel is for the SSA = 133°, right panel is for SSA = 43°, colored from black to red in ascending order.

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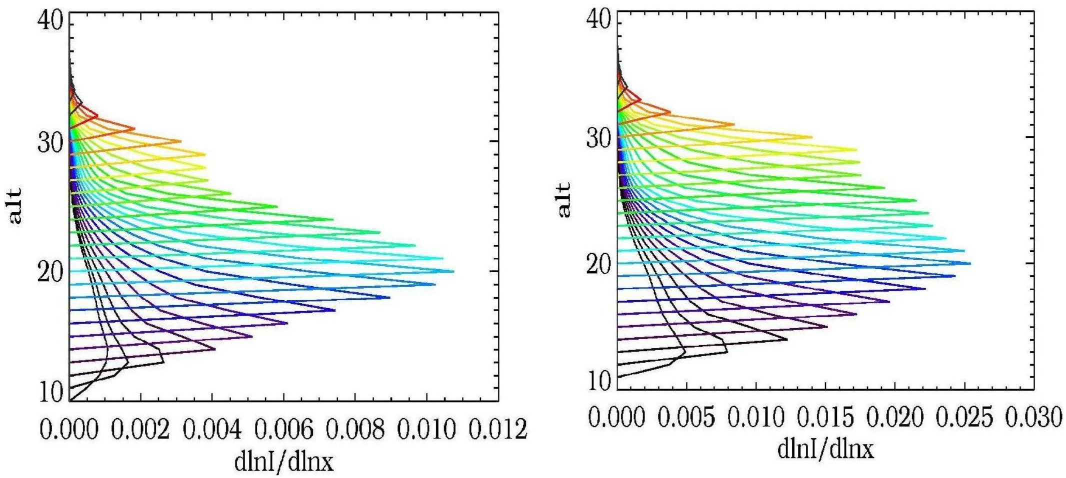

Fig. 5. Same as Fig. 4 but for wavelength 994 nm.

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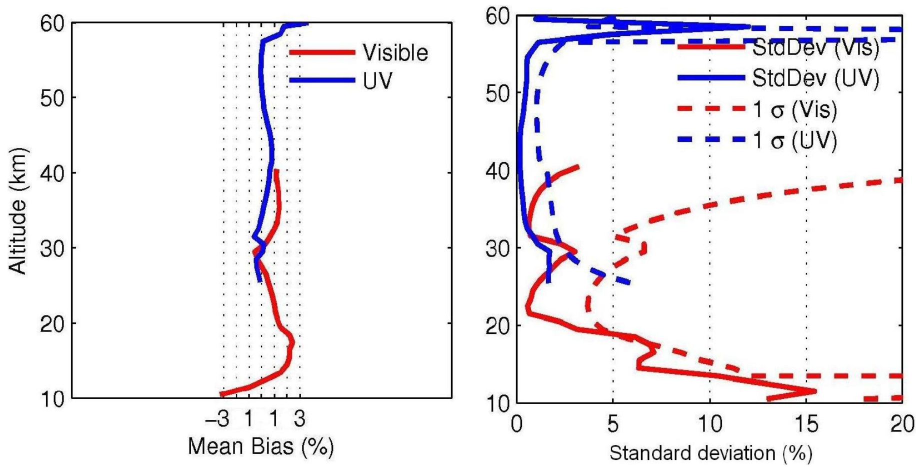

Fig. 6. Summary plot of the percent difference for all retrieved ozone profiles for the 450 simulated radiances, red is for visible, and blue is for UV retrievals. The right panel is the same but for standard deviation, dashed lines are the retrieval 1-σ uncertainty.

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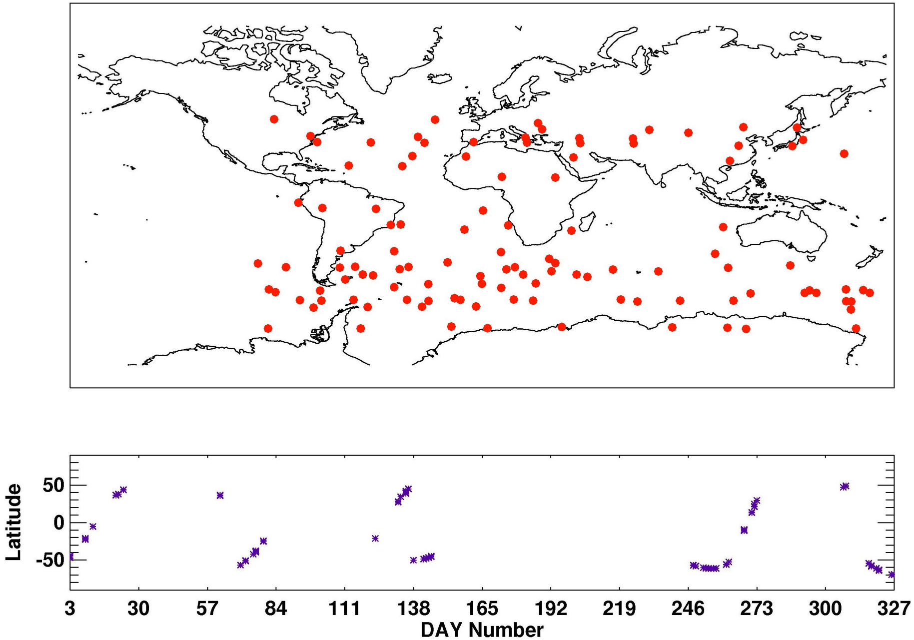

Fig. 7. Location of SCIAMACHY measurements subset, (upper panel) and latitude vs. time (day number) (lower panel).

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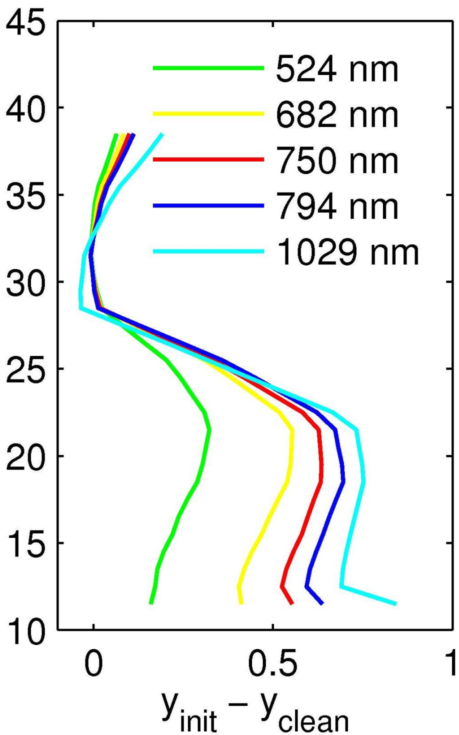

Fig. 8. Plot of the difference between SCIAMACHY normalized measured (y_{meas}) and modelled radiance (y_{clean}) with no aerosol, at 524, 692, 750, 794, and 1029 nm.

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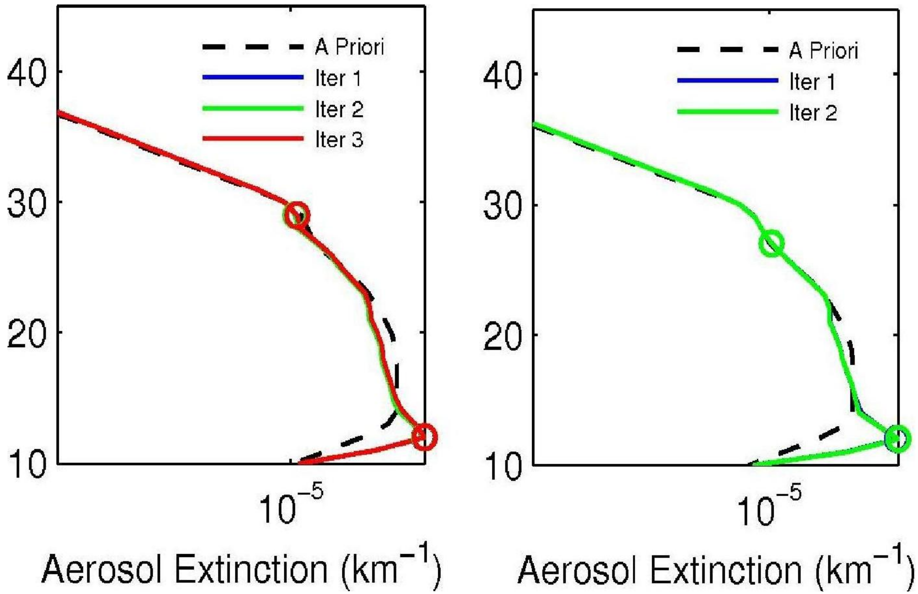

Fig. 9. Multiple iterations of retrieved aerosol extinction profiles at 793 nm (left) and 1028 nm (right) and the a priori profile.

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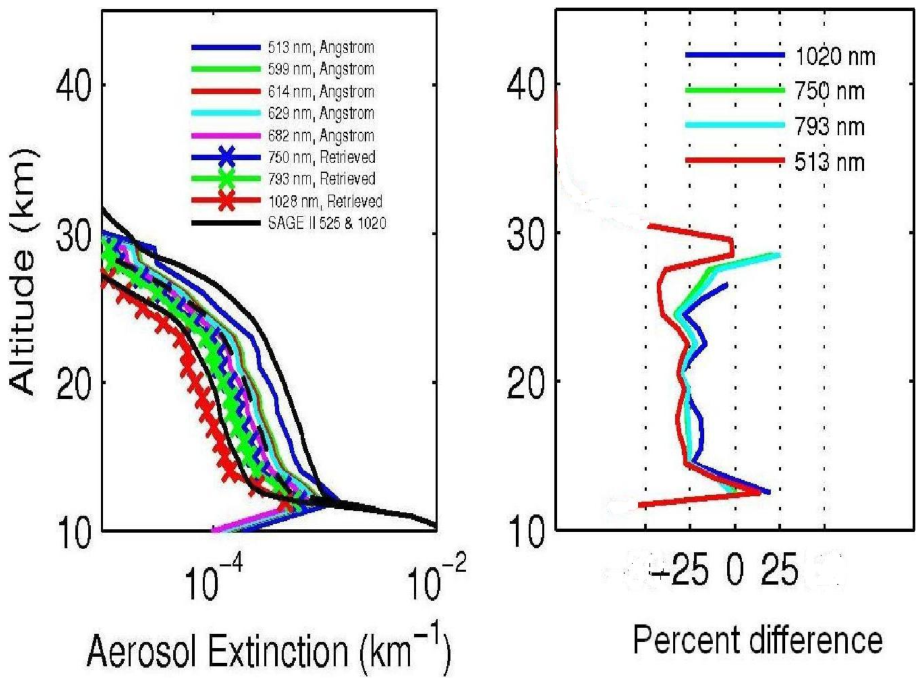

Fig. 10. The left panel is the retrieved aerosol profiles for 750, 793, and 1028 nm (color asterisk). The colored lines are for 513–682 nm interpolated aerosol. Black lines are SAGE II profile at 525 and 1020 nm. Dashed black line is the interpolated SAGE aerosol at 750 nm. The right panel is the percent difference between the retrieved aerosol profiles and SAGE II.

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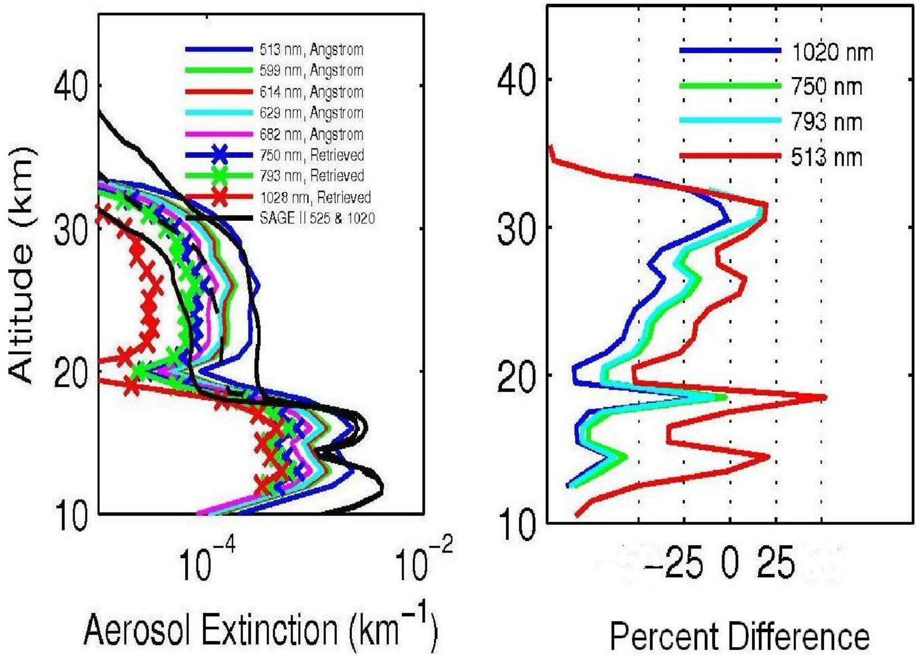

Fig. 11. Same as Fig. 10 but for 27 September 2004, latitude 13.2° and longitude 32.6°.

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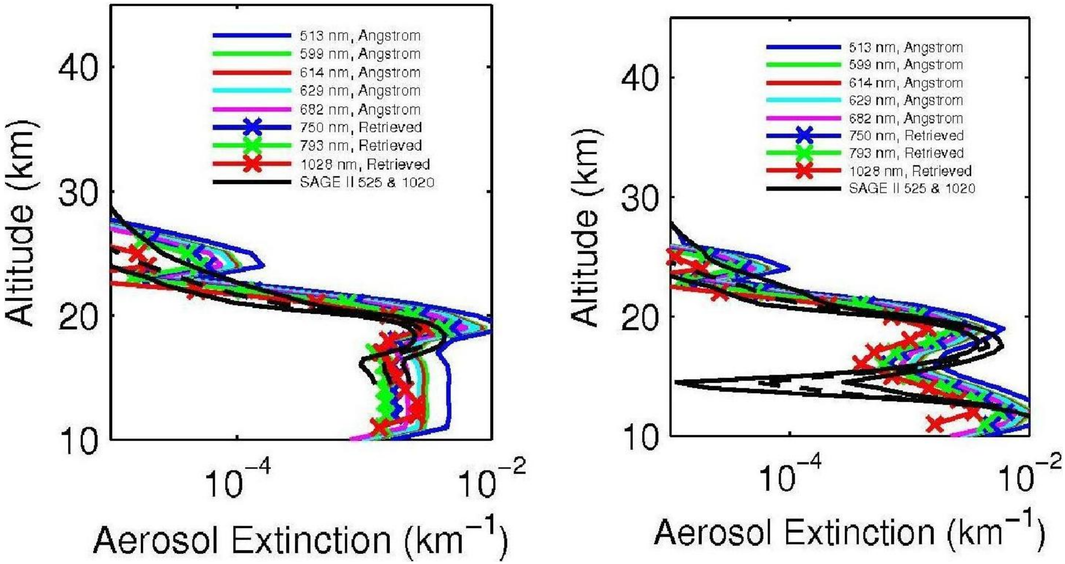

Fig. 12. Plot of the retrieved SCIAMACHY vs. SAGE II aerosol profiles, similar to Fig. 10 left panel, but for 13 September 2004, latitude −60.9° and longitude −81.2°, and 9 September 2004, latitude −61.2° and longitude −23.9°, respectively.

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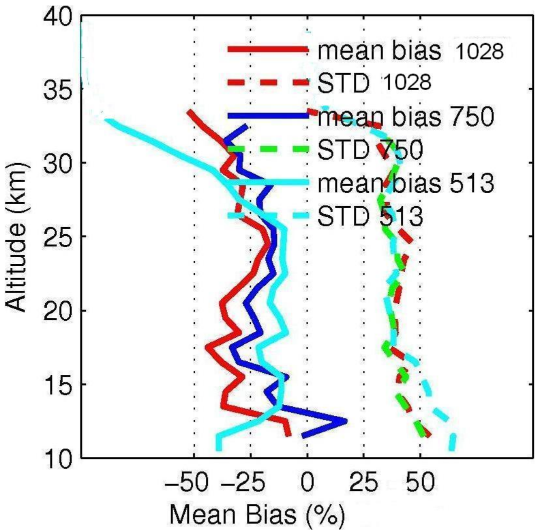

Fig. 13. Summary plot of the percent difference for all retrieved aerosol profiles used in this study with SAGE II, which includes 1028 nm (red), 750 nm (blue) and 513 nm (cyan). The dashed lines are the standard deviations.

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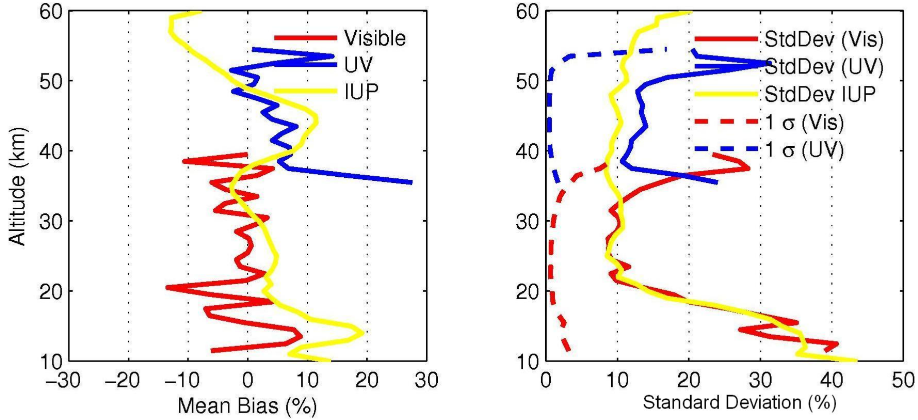

Fig. 14. Summary plot of the percent difference for all retrieved ozone profiles used in this study to SAGE II on the left. The right panel shows the standard deviations, and the retrieval 1-σ uncertainty.

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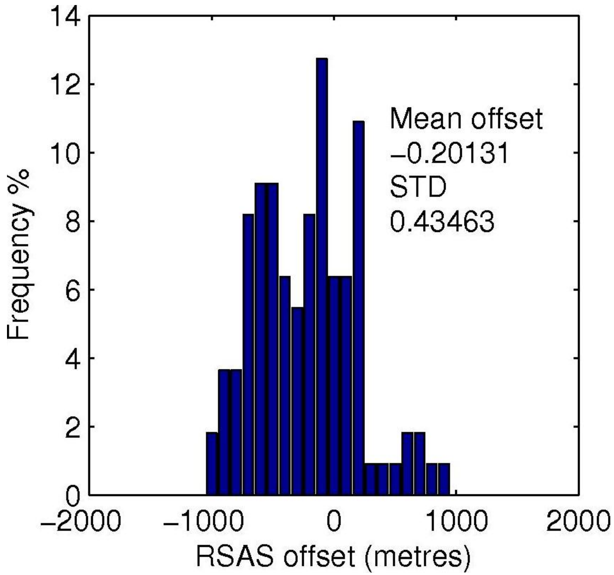

Fig. 15. Tangent height histogram of all detected offsets.

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