5.2 SSI time series

For comparisons with the re-calibrated SCIAMACHY SSI, we use the most recent data versions of SATIRE-S[34], SIM[35], and OMI[36]. SIM obtains daily solar spectra from 240 to 2400 nm at a variable spectral resolution of 1 to 34 nm with an absolute uncertainty of 2 %, and long-term repeatability of less than 0.1 % (Harder, 2019). Before any comparisons were performed, as shown in Figures 10 and 11, [..[37]]outliers are removed from SIM V25 time series. OMI provides daily solar spectra in the 265 – 500 nm range of mid resolution (0.4 – 0.6 nm) with an absolute accuracy of better than 4 % and high instrument stability. The optical degradation rate ranged from 0.2 to 0.5 % yr^{-1} (Marchenko et al., 2016, and references therein). The authors note that the current values underestimate the solar cycle variability by $\sim$ 0.1 % in the UV (< 350 nm) and < 0.05 % in the visible, which originates in the applied degradation correction approach.

Figure 10 shows SSI time series for several wavelength bands. Measurements from different instruments and model reconstructions are compared with SCIAMACHY SSI. The data are normalised to a reference date during solar minimum condition (October 5, 2008). The solar cycle minimum occurred by the end of 2008 / beginning of 2009. We choose this specific date as it lies within a period of stable SCIAMACHY measurements where uncertainties are smaller than in early 2009. The panels show the data starting with the reference date of SCIAMACHY degradation correction (February 27, 2003) until the end of 2009. As discussed in Section 4 and shown in Figs. 7 and 8 the degradation modelling had larger uncertainties after 2009 when instrument degradation became more prominent. For our comparisons between different data sets, we focus in the following on the descending phase of solar cycle 23 until the end of 2009.

Beginning with the lowest wavelength band centred at 330 nm, the SCIAMACHY SSI time series lies within the solar cycle variation of SATIRE-S and SIM V25 data sets. It shows the expected minimum at time of solar activity minimum in accordance with the other SSI data. Nevertheless large differences in comparison to SIM become obvious in the UV. This was previously reported by studies from e.g. Haberreiter et al. (2017); Mauceri et al. (2018); Coddington et al. (2019) that point to comparably large solar cycle variability results for recent SSI from SIM in the UV. [..[38]][..[39]]For higher wavelengths in the UV and visible spectral range (starting at 370 nm in Fig. 10) SCIAMACHY shows an increasing signal towards solar minimum and decrease afterwards. This would imply anti-correlation of the solar irradiances in the visible and the 11-year solar cycle. Similar results were published earlier for SIM (Harder et al., 2009; Haigh et al., 2010) but are inconsistent with other satellite measurements that show in-phase variations (Wehrli et al., 2013; Marchenko and DeLand, 2014)[..[40]]. Recent studies by Woods et al. (2018) and Mauceri et al. (2018) developed new methods to account for uncorrected degradation in SIM SSI. Both results, the MuSIL-corrected SIM and SIMc, show better agreement with independent SSI data such as SATIRE-S than the operational SIM product (Harder, 2019). The observed anti-correlation

[34] SATIRE-S: https://doi.org/10.17617/1.5U, Accessed: 17 Sep. 2018
[35] SIM V25 (Harder, 2019)
[36] OMI: https://gs614-sbuv-pz.gsfc.nasa.gov/solar/omi/lisird/readme_omi_irradiance.txt
[37] removed: outlier
[38] removed: In the UVband at 370
[39] removed: nm largest deviations with respect to SIM are evident. For higher wavelength
[40] removed: as well as for the most recent degradation correction approaches applied to SIM measurements (Woods et al., 2018; Mauceri et al., 2018).

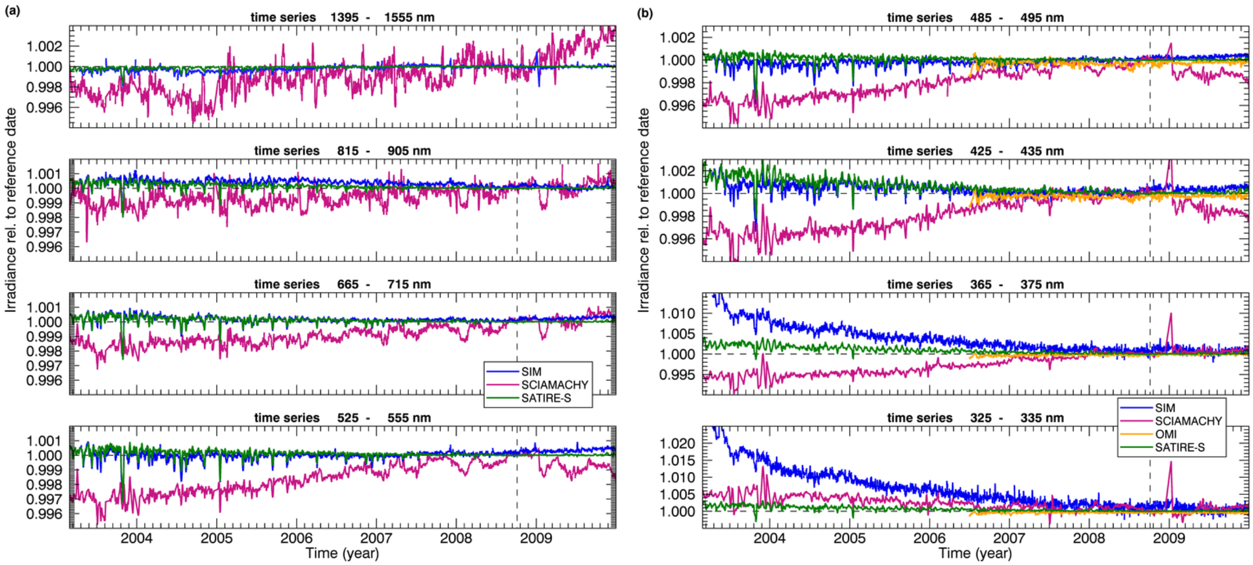

Figure 10. Time series of SSI, integrated in (b) 10 nm and (a) 30 – 160 nm wide wavelength bands from SCIAMACHY, SIM/SORCE V25, OMI/AURA satellite measurements and SATIRE-S. The time series are ratioed to values from October 5, 2008, which are representative for solar minimum conditions. Details see text. (Note the change in vertical scale for the different wavelength ranges.)

for the new SCIAMACHY results is therefore likely a remaining residual instrument artefact. For the time series in the NIR above 1000 nm (SCIAMACHY Channel 6) the overall increase agrees qualitatively with the SIM observations, but the rate of increase is higher than compared to SIM and SATIRE-S.

OMI generally shows good agreement with SATIRE-S [..[41]]and therefore, strengthen its role as reference for SSI comparisons. Unfortunately, the degradation corrected data set starts in July 2006 and is not available for the first part of the mission when solar activity was stronger.

It seems that for most parts of the visible and near IR spectral range a remaining positive drift, most likely instrumental in nature, is evident in the SCIAMACHY time series that is on the order of $+1\%$/decade. The SCIAMACHY mission was accompanied by a high number of instrument and platform anomalies as well as many regular maintenance activities as illustrated by blue lines in Figure 9. These anomalies and maintenances had mostly minimal impact on atmospheric trace gas retrievals, the primary purpose of SCIAMACHY, but has non-negligible impact on the degradation correction and radiometric stability. One of the most important maintenance activities were decontamination periods where the detectors were heated to remove ice contamination of the NIR detectors, but they also impacted the UV and visible spectral bands.

In 2004, larger short time variations are visible in the SCIAMACHY time series. At the beginning of the mission the contamination layers are still faint and the resulting degradation effect small. Therefore it is more difficult to determine the

[41] removed: ; unfortunately,

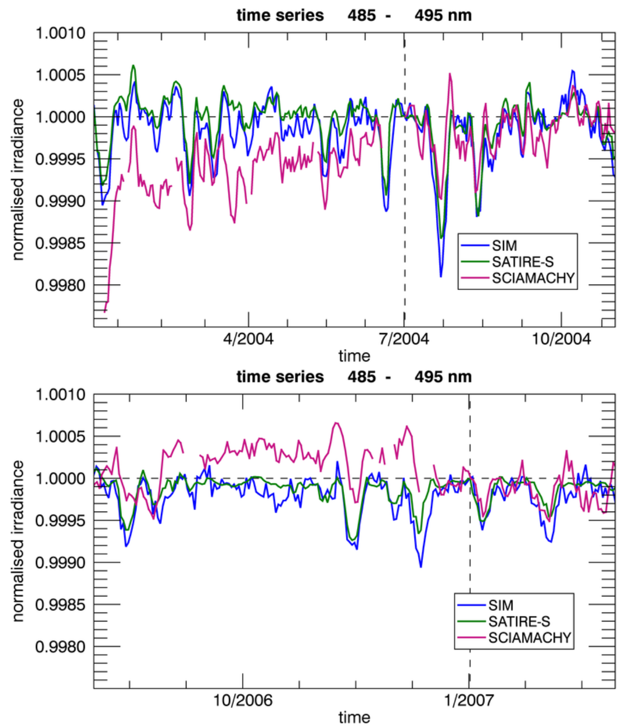

Figure 11. Time series of SSI, integrated in 10 nm wide wavelength band from SCIAMACHY, SIM/SORCE V25, and SATIRE-S. The Figure provide a detailed view of 10-months periods in 2004 (top) and 2006/2007 (bottom). The time series are ratioed to values from July 1, 2004, and January 1, 2007, respectively, to shift the data sets for better comparability.

degradation parameter in the degradation modelling. That is further hindered by ice decontamination periods that were included in the instrument operation more frequently at the beginning of the mission.

On smaller time scales (solar rotations), SCIAMACHY follows most of the prominent signatures in the time series, see Figure 11. Up to about 700 nm SCIAMACHY shows realistic decrease in the amplitude of variations from higher solar activity towards the minimum.

[..[42]]

Despite a clear improvement of the SCIAMACHY SSI in comparison with ESA V9.01, as discussed in Section 4, the current degradation correction is not yet sufficient to account for all instrumental effects, such as the remaining positive drift in the SSI [..[43]]time series. Further work is required to clarify the origins of differences between SCIAMACHY and other SSI data sets. Nevertheless, we were able to show that the white-light-source (WLS) in the new degradation correction scheme significantly contributes to improvements in the in-flight radiometric calibration.

[42]removed: Time series of SSI, integrated in 10 nm wide wavelength band from SCIAMACHY, SIM/SORCE V25, and SATIRE-S. The Figure provide a detailed view of 10-months periods in 2004 (left) and 2006/2007 (right). The time series are ratioed to values from July 1, 2004, and January 1, 2007, respectively, to shift the data sets for better comparability.

[43]removed: timeseries.