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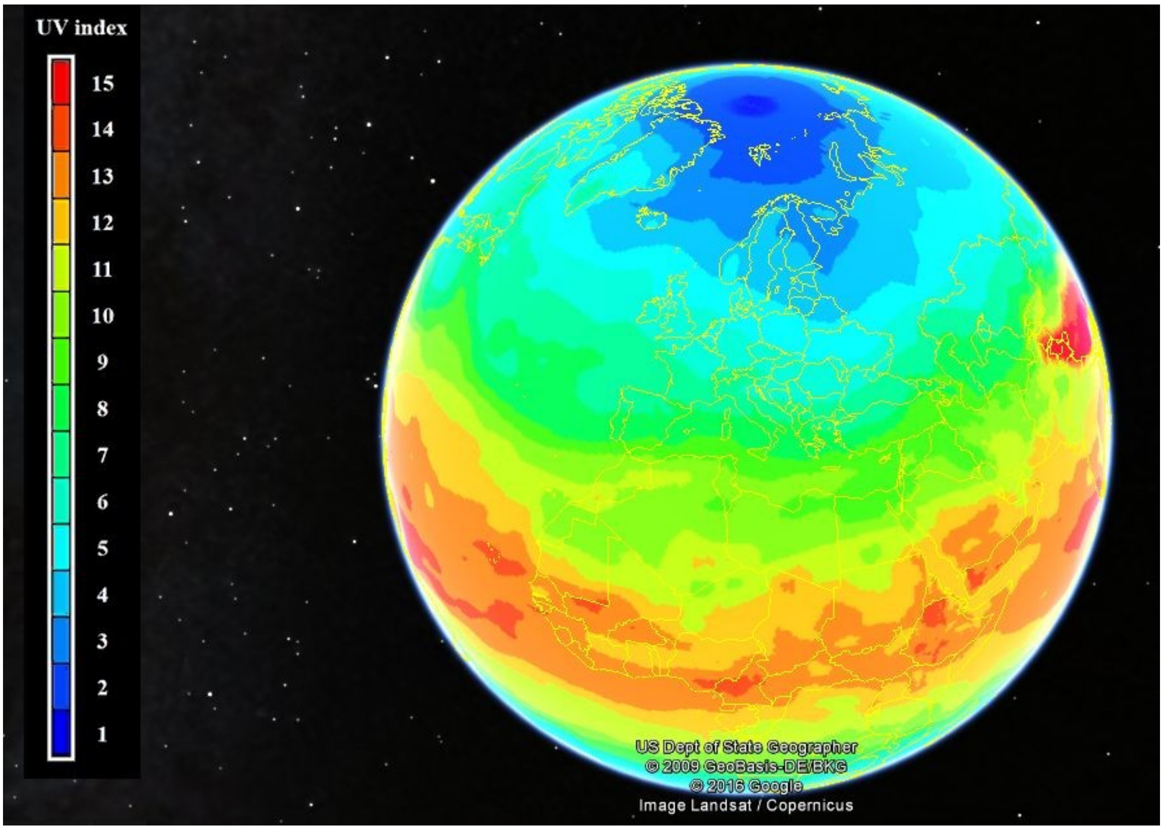
AC SAF VALIDATION REPORT

Validated products:

Name	Satellite(s)
Global UV index	Metop-B, and -C



Author:

Name	Institute
Helge Jønch-Sørensen	Danish Meteorological Institute

Reporting period: 2016-2019

Input data versions: Assimilated Total Ozone (ATO) version 4.2, since 03/10/2007

Data processor versions: NRTUVI version 3.5, since 01/01/2022

Introduction to EUMETSAT Satellite Application Facility on Atmospheric Composition monitoring (AC SAF)

Background

The monitoring of atmospheric chemistry is essential due to several human caused changes in the atmosphere, like global warming, loss of stratospheric ozone, increasing UV radiation, and pollution. Furthermore, the monitoring is used to react to the threats caused by the natural hazards as well as follow the effects of the international protocols.

Therefore, monitoring the chemical composition and radiation of the atmosphere is a very important duty for EUMETSAT and the target is to provide information for policy makers, scientists and general public.

Objectives

The main objectives of the AC SAF is to process, archive, validate and disseminate atmospheric composition products (O_3, NO_2, SO_2, BrO, HCHO, H_2O, OClO, CO, NH3), aerosol products and surface ultraviolet radiation products utilising the satellites of EUMETSAT. The majority of the AC SAF products are based on data from the GOME-2 and IASI instruments onboard Metop satellites.

Another important task besides the near real-time (NRT) and offline data dissemination is the provision of long-term, high-quality atmospheric composition products resulting from reprocessing activities.

Product categories, timeliness and dissemination

NRT products are available in less than three hours after measurement. These products are disseminated via EUMETCast, WMO GTS or internet.

- Near real-time trace gas columns (total and tropospheric O_3 and NO_2, total SO_2, total HCHO, CO) and high-resolution ozone profiles
- Near real-time absorbing aerosol height and absorbing aerosol index from polarization measurement detectors
- Near real-time UV indexes, clear-sky and cloud-corrected

Offline products are available within two weeks after measurement and disseminated via dedicated AC SAF web services.

- Offline trace gas columns (total and tropospheric O_3 and NO_2, total SO_2, total BrO, total HCHO, total H_2O) and high-resolution ozone profiles
- Offline absorbing aerosol height and absorbing aerosol index from polarization measurement detectors
- Offline surface UV, daily doses and daily maximum values with several weighting functions

Data records are available after reprocessing activities from the AC SAF archives.

- Data records generated in reprocessing
- Lambertian-equivalent reflectivity
- Total OClO

Users can access the AC SAF offline products and data records (free of charge) by registering at the AC SAF web site.

More information about the AC SAF project, products and services: https://acsaf.org/

AC SAF Helpdesk: helpdesk@acsaf.org

Twitter: https://twitter.com/Atmospheric_SAF

Contents

Applicable documents:

AC SAF Algorithm Theoretical Basis Document for NUV, SAF/ACSAF/DMI/ATBD/001, Issue 1.13 07.02.2025

AC SAF Product Requirements Document, *SAF/AC/FMI/RQ/PRD/001*, Issue 2.2, 20.12.2023

Reference documents:

Validation Report of the CAMS UV processor Issue #20, June-July-August (JJA) 2020, CAMS-72: Solar radiation products

Internal product ID's for project control

MxG-NUV	O3M-410.1

Issue	Date	Modified Items / Reason for change
1/2023	31.01.2023	Initial version
2/2023	22.8.2023	Modified to new requirements as per RR
3/2025	07.02.2025	Modified according to PCR+ORR RIDs

1. PURPOSE AND SCOPE

The purpose of this document is to present the validation of the NUV product version 3.5 against ground based measurements of UV index. Validation was performed on data from the time period 2016-2019

The NUV processor uses total ozone column data as input to calculate the clear sky UV index (NUV/CLEAR) at local noon (maximum solar elevation). Because of the requirement of Near Real Time the calculations are based upon lookup tables of UV index as function of ozone, sun zenith angle (SZA) and surface albedo, climatological values are used for all other atmospheric input data as well as surface albedo.

Three different ozone input sources may be ingested in the daily calculated global UV-field. The primary source is the ATO data delivered by AC SAF partner KNMI at 02:00UT. As a backup in case the ATO data does not arrive ECMWF total ozone forecast will be downloaded every night but only used in the before mentioned case of fail of delivery or corrupted ATO data. The third option in the unlikely case that neither ATO nor ECMWF data can be retrieved is to use a ozone climatology based on TOMS data that are available on the NUV processing computer. Validation of the NUV using ECMWF and ozone climatology was demonstrated in a previous validation report.

The correction for the effect of cloud cover is applied using fractional cloud cover forecast from ECMWF. The new approach involves the fractional cloud cover (ccf) of low (approximate altitude 0-2 km), medium (2-6 km) and high (above 6 km) clouds. Each layer having a damping coefficient, empirical derived from calibration against ground based measurements.

The 1h resolution product also validate here is a new product developed because of the request from users to not only have the noon (maximum) UV-index but also be able to follow the UV-index during the whole day. To that purpose ECMWF cloud cover forecast are retrieved on 1h resolution and an all-day, all-sky UV-index are produced as described in the ATBD.

1.1 Acronyms

ATO	Assimilated Total Ozone
DMI	Danish Meteorological Institute
NUV	Near Real Time UV index
SAVER-Net	South American Environment Risk Network

2. THE GROUND BASED MEASUREMENTS

Gound based measurement of pyranometer (YES) UV-index for the period 2016-2019 was collected from 7 locations, the DMI instrument in Copenhagen and 6 instruments in Argentina that is part of the SAVER-Net network.

The map below shows the position of the six measuring stations in Argentina (Tucuman not included in this study).

UV-index is measured at 1 minute intervals, for the comparison with NUV the data has been averaged in 10 minutes intervals. The results from each hour from 7 to 17 local time is then extracted and compared.

Site	Name	Longitude	Latitude	Altitude [m]	# Days
BAR	Bariloche	-71.164	-41.147	846	881
COM	Comodoro Rivadavia	-67.5	-45.78	43	1238
COR	Pilar-Cordova	-63.873	-31.676	330	720
CPH	Copenhagen	12.67	55.63	15	1440
NQN	Neuquen	-68.137	-38.952	270	1032
RG	Rio Gallegos	-69.32	-51.6	15	1256
VM	Villa Martelli	-58.48	-34.58	25	1368

In total measurements from 7952 days were available for the validation. The sample was limited in time to 7-17h local solar time and to UVI > 0. The clear sky identification routine described in Appendix A is also capable of identifying some instrumental failures, especially mismatch of clock and sudden drop of sensitivity and such measurements were removed. The number of hourly measurements for comparison with the NUV ended at 58050.

3. INTRODUCTION TO THE VALIDATION

The validation of the NUV product is performed in the following steps:

- Since there is not adequate data on the actual cloud conditions at the ground based stations, the only way to estimate the quality of the cloud cover forecast applied in the NUV processor is to identify obvious cases of clear sky conditions and compare with the forecast values. The routine for extracting clear sky conditions around noon from the observed daily UV-index 'profiles' is described in Appendix A.
- The NUV/CLEAR product is not part of this validation, however as the NUV/CLEAR is the basis of the allsky NUV product, the comparison between observed UV-index and NUV/CLEAR for the clear sky days is shown in sect. 4.2
- The NUV all sky product is then compared to ground based measurements for all days. The result is checked against the product requirements, for the individual locations and the total sample, and for all hours between 7h and 17h local solar time.
- The validation results for the NUV all sky product is also compared with the results of the CAMS UV processor.
- Of special interest for users of the NUV an overview of the improvements with respect to the previous version (3.3) of the NUV is addressed.

Throughout the validation a special focus will be on the requirements of the registered users of the NUV product who are mainly focused on health care/public awareness and may not be using e.g. mean- of standard deviations as a measure of the quality but more want answers to questions like "How often is the NUV UV-index too low" e.t.c.

The NUV product in the comparison is based on the ATO from the Metop-B satellite which was the primary operational satellite in time period of the comparison. Since then the Metop-C satellite has been declared operational and the primary input to NUV is now Metop-C ATO. In the Metop-C review it was shown that the NUV/Metop-B and NUV/Metop-C agree on a 1.7% level, so the results in this document will also apply for the now operational Metop-C NUV products.

To compare with the CAMS UV processor validation results the the parameters rBias (men relative bias) and rRMSE (relative root mean square difference) are computed for the results of the present comparison, they are defined as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(NUV(j) - UV_{obs}(j)\right)^2}$$

$$Bias = \frac{1}{n}\sum_{j=1}^{n}\left(NUV(j) - UV_{obs}(j)\right)$$

$$rBias = \frac{1}{\overline{UV}_{obs}} Bias$$

$$rRMSE = \frac{1}{\overline{UV}_{obs}} RMSE$$

4. VALIDATION RESULTS

4.1 The cloud cover forecast

From the observed UV of the whole sample of ground based measurements a total of 1267 days were found to fulfill the requirements for a clear sky at noon described in Appendix A. One test of the quality of the ECMWF forecast is then to see if the clear sky conditions are also present in the cloud cover forecast.

Below is the forecast CCF for low- , medium- and high altitude clouds shown for the 1267 clear sky days.

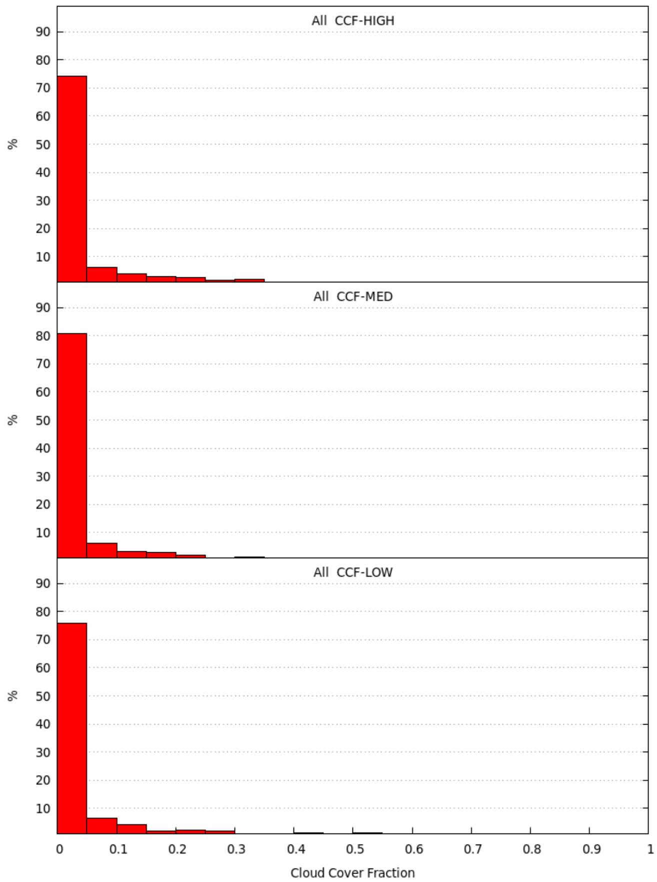


Figure 1. The forecast cloud cover fractions for low-, medium- and high clouds for 1267 days with clear sky conditions around noon.

As can be seen the majority, 70%-80%, of actual clear sky conditions have CCF forecast that implies the cloud cover is <5% of the sky. This is satisfactory but the results vary from site to site as can be seen in Fig. 2 below.

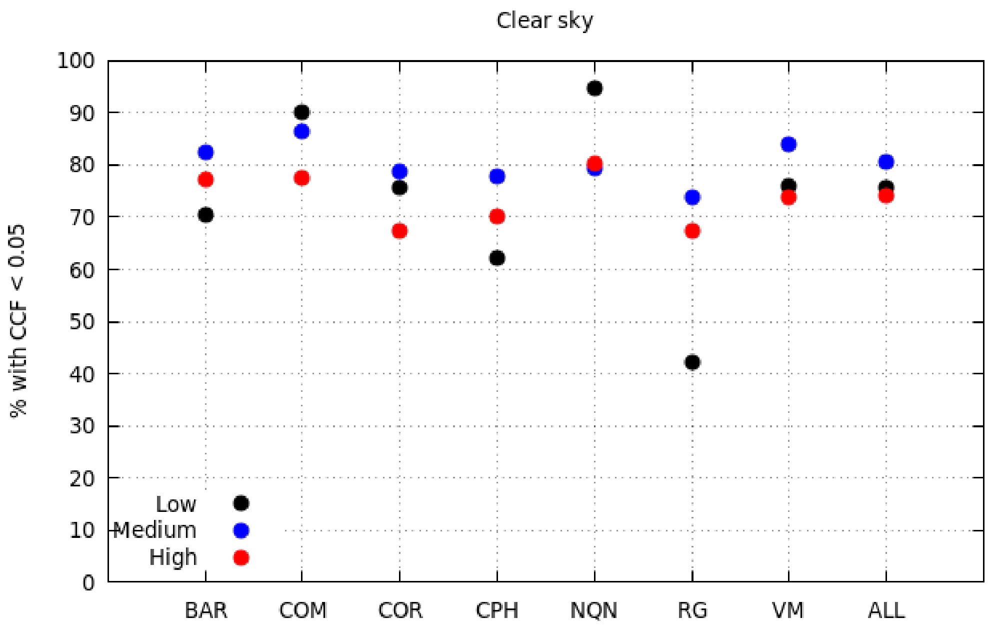


Figure 2. The relative number of clear sky days where the forecast CCF is below 0.05 for the three cloud categories for each site and the total result.

Most noticeable in Fig. 2 is the results for the low altitude cloud cover fraction for clear sky days at RG. Only 42% of these days were predicted to be free from low cloud cover.

4.2 NUV clear sky

The clear sky UV-index algorithm has not been changed from version 3.3, however as it is the starting point for the NUV/CLOUD product it is of interest to see how it performs for the six locations in Argentina who were not part of the previous validation of the NUV/CLEAR product. The algorithm for detecting clear sky conditions from the measurements (Appendix A) only works for the time around local noon, thus the comparison here is only based on the local noon values for a total of 1267 clear sky days.

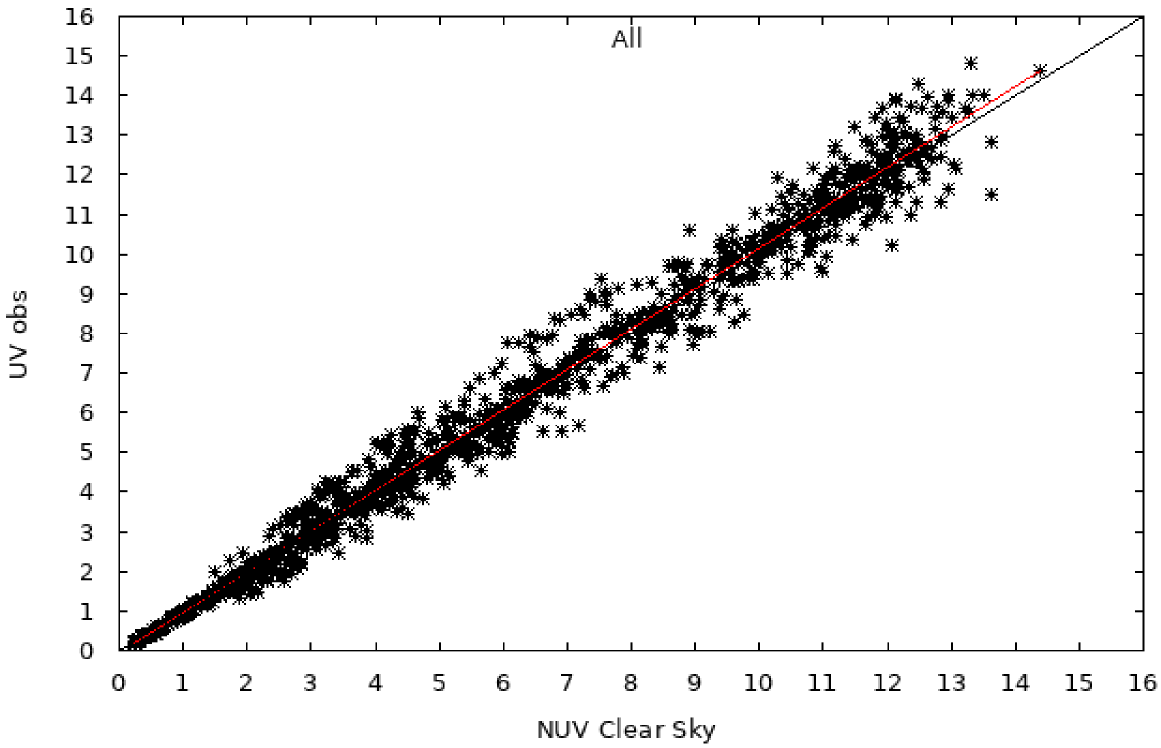


Figure 3. The observed versus estimated UV index for the total 1267 clear sky days. Black line is the 1 to 1 relation and the red line is the regression line with a slope of 1.019

The linear fit to all points in Fig. 3 has a slope of 1.019 with a correlation of 0.9917. Looking at the individual sites (Fig. 4) shows that all sites have slopes between 0.95 and 1.02 and correlations above 0.99. However, for COR there is a marked bias of 1.02 in the sense that NUV_{clear} is underestimating the observed UV (see Appendix B, Fig. B1). No reason for this could be found in the observed data or the NUV processing.

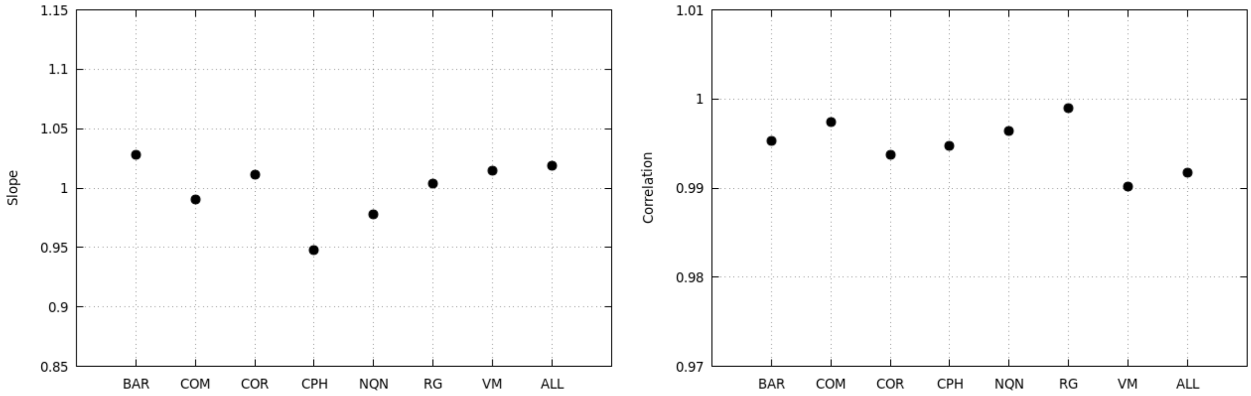


Figure 4. Results of fitting regression lines to the $UV_{measured}$ - NUV relation for clear sky days. Left the slopes for the individual locations and the total sample. Right the correlation of the fit.

4.3 The all sky NUV product

For the comparison of the total product the sample was limited to hours form 7 to 17 local solar time and to $UV_{measured}$ > 0.5. The data points are shown in Fig. 5 below.

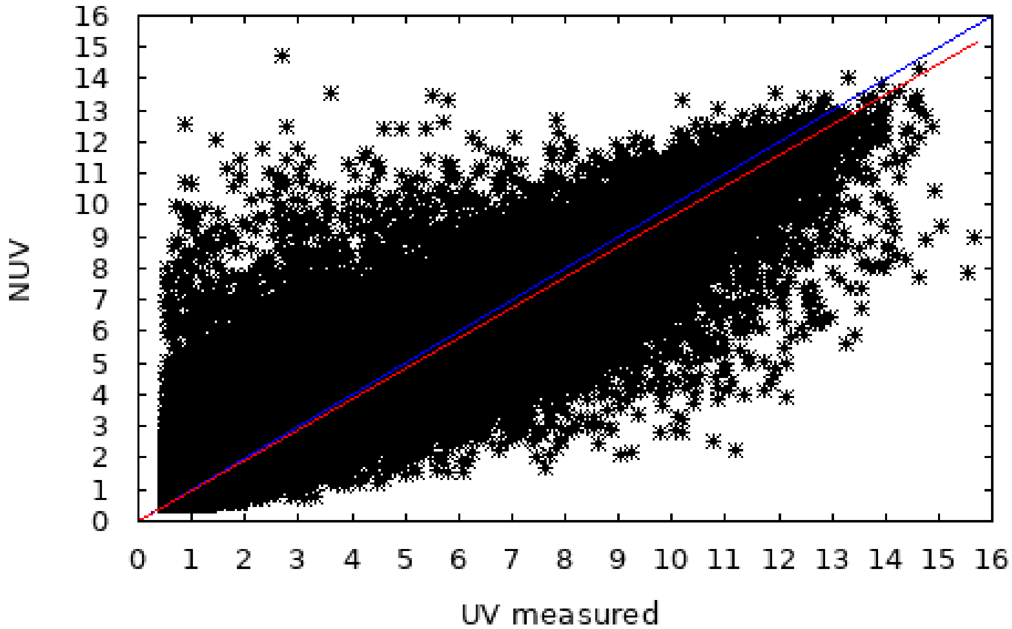


Figure 5: The total sample of 58050 hourly measurements from 7-17h local solar time with $UV_{measured}$ > 0.5. Blue line is the 1 to 1 line and red line the fitted line with a slope of 0.965 and correlation of 0.914

In Fig. 6 the slopes and correlation factors for the individual locations (see Appendix B, Fig. B2) and the total sample is shown.

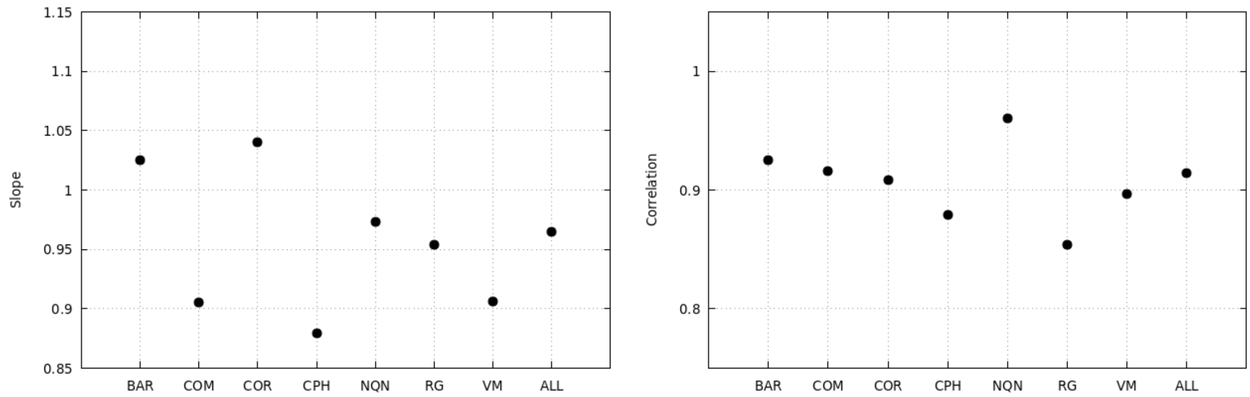


Figure 6: Results of fitting regression lines to the UVmeasured - NUV relations for the individual locations and the total sample. Left the slopes for the individual locations and the total sample. Right the correlation of the fit.

The relative difference between the observed and the NUV UV is shown in Fig. 7. The median value of the distribution is -3.31%. The lowest bin includes all levels below -150% and the majority of these are cases whit either instrumental problems, or unexpected thick clouds reducing the UV_{obs} far more than expected.

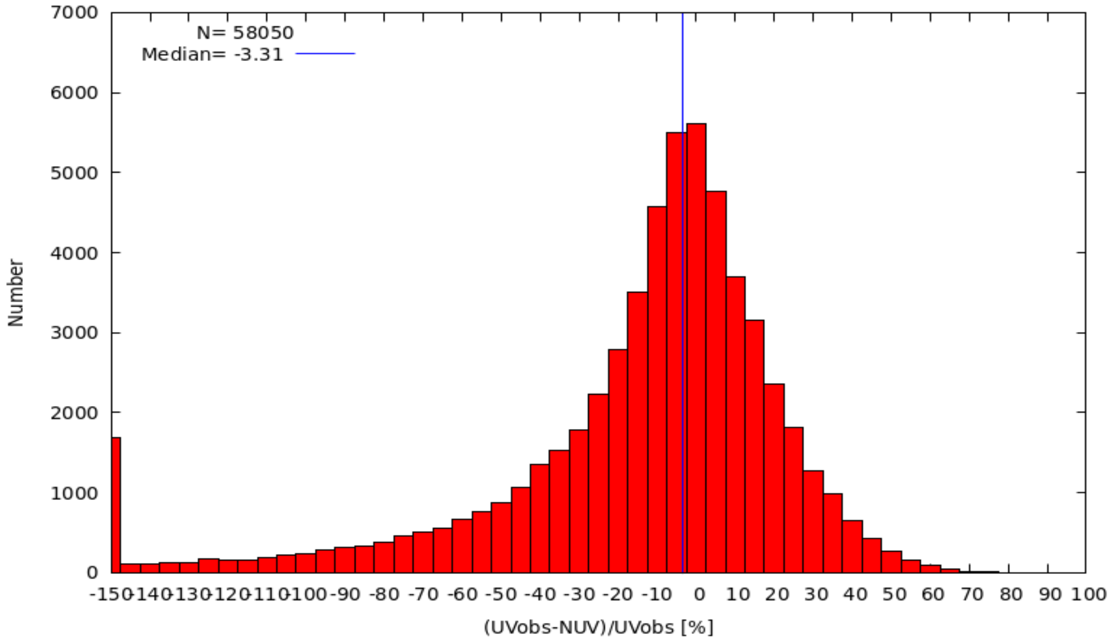


Figure 7: The relative difference between measured UV index and the NUV index for all 58050 observations.

4.3.1 The product requirements

The product requirements for the NUV is that the absolute deviations from the actual values should be 2.0, 1.0 and 0.5 respectively for the threshold-, target- and optimal levels. In Fig. 8 below this quantity is shown for the total sample for each location and for the grand total. In Fig. 9 the absolute deviation if shown as a function of time of day.

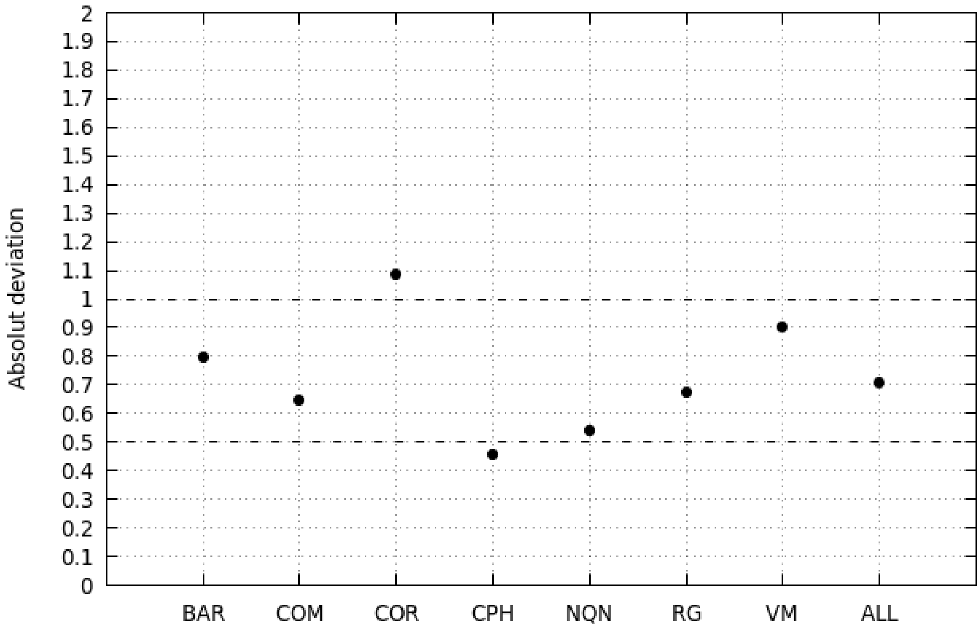


Figure 8: The absolute deviation between observed UV index and the NUV. For each location and for the total sample (ALL). Dashed lines show the optimal- and target requirements.

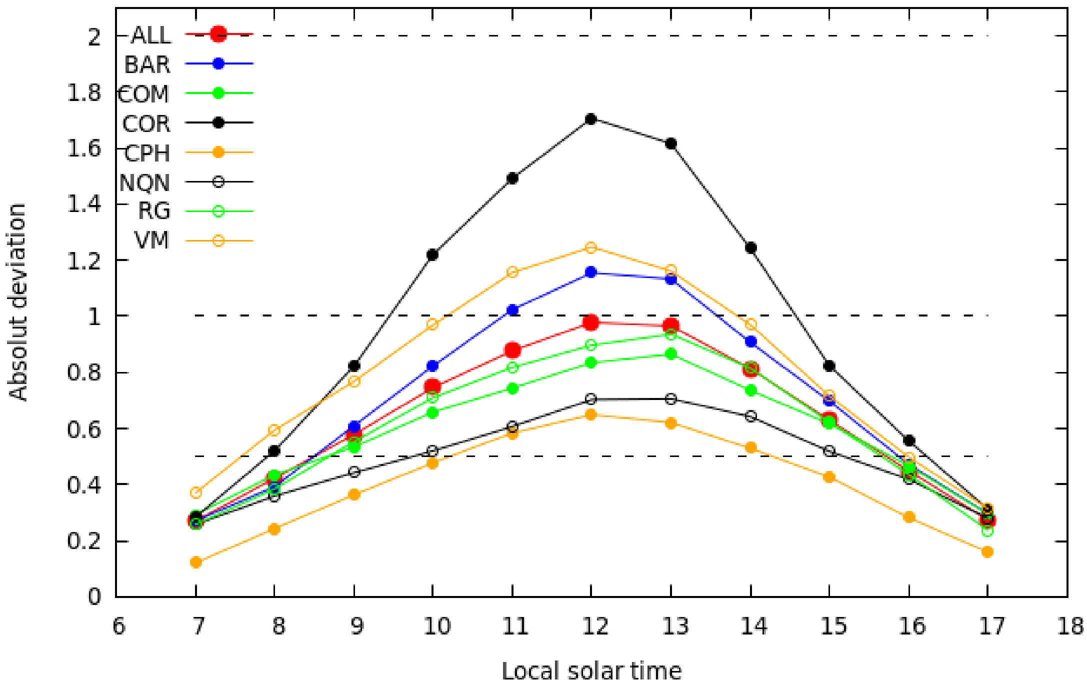


Figure 9: The absolute deviation of UVobs - NUV for each location and the total sample, for every hour from 7-17 local solar time. Dashed lines indicates the threshold, target and optimal requirements respectively.

As can be seen in Fig. 8 and 9 the results are well below the threshold accuracy limit for all locations and time of day. The COR station shows the largest deviation between observed UV and the NUV, which is an effect of the bias of the clear sky values mentioned in section 4.2.

4.3.2 Comparison with the CAMS UV processor

In the validation report of the CAMS UV processor it was validated against ground based measurements from 40 locations for the years 2016 to 2020. The reported accuracy of the UV index forecast was rRMSE of 0.33 and correlation 0.92, with the median relative bias of 0.01.

For the NUV results presented here the corresponding values are rRMSE equal to 0.34. the correlation is 0.91 and relative bias amounts to 0.03. In Fig. 10 the results for the individual locations and the total is shown.

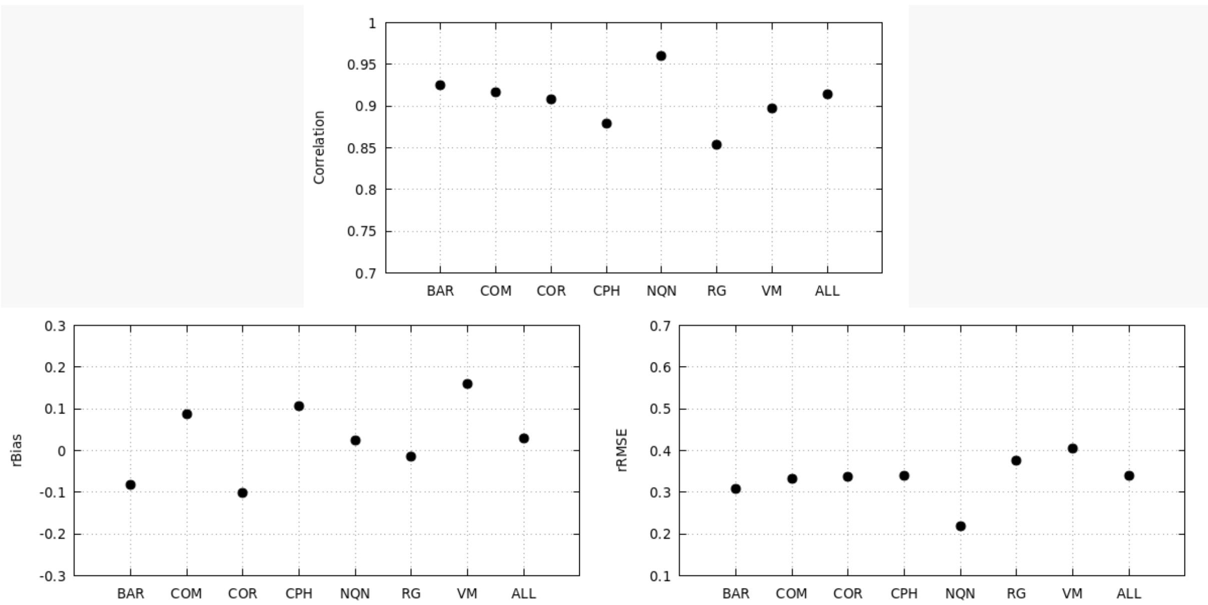


Figure 10: Top: Correlation of the NUV vs measured UVI relation for individual sites and the totel (ALL). Bottom left: rBIAS. Bottom right: rRMSE

Fig. 10 is produced on the same scale as the CAMS validation report (their Fig. 5). The comparison shows that the CAMS and the NUV processors produce UV index forecast of comparable accuracy.

In Fig. 11 the same parameters are show again for all sites and for each hour from 7 to 17 local solar time.

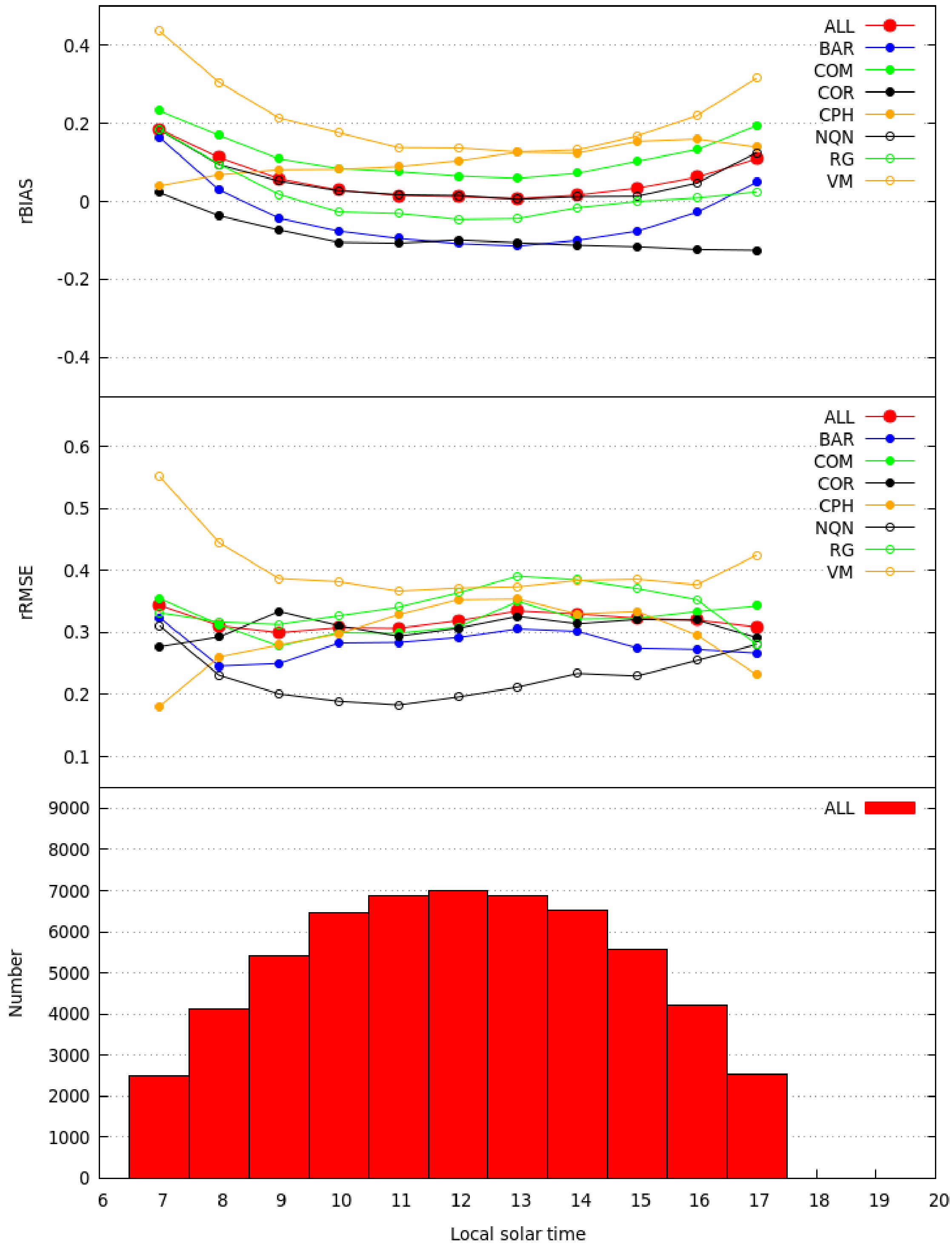


Figure 11: The same data as in Fig. 10 now shown for each hour of the day. Top: rBIAS, middle: rRMS and bottom panel shows the number of measurements in each hour interval for the total.

4.3.3 Improvements compared to version 3.3

In the NUV version 3.3 which has been operational since 2014 the algorithm for the cloud cover correction involved only the fractional total cloud cover and three damping coefficients for three intervals of total cloud cover fractions. Furthermore, the UV index was only calculated for local noon. That approach had the obvious weakness of the stepwise correction for clouds and furthermore, the fact that due to cloud cover the maximum UV index of a day may not be the UV index at local noon. It is therefor of importance to most users to know how the new approach with three layer cloud cover data and all day time resolution has improved the product

In Fig. 12 the comparison $(UV_{obs}$ $-NUV_{cloud})/UV_{obs}$ is shown for all 7890 measured UV-indices at noon for the new (version 3.5) and current (version 3.3) algorithm.

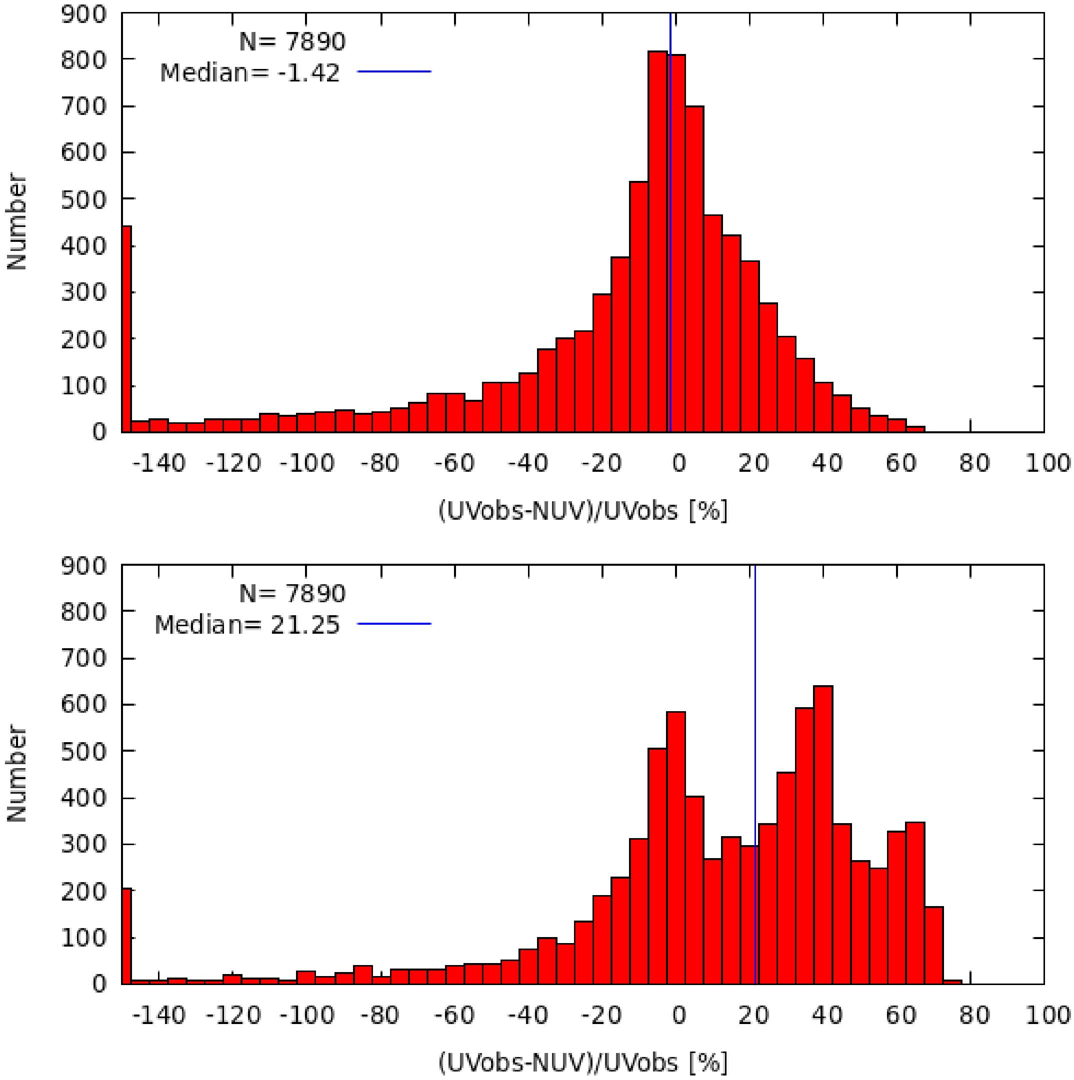


Figure 12: The distribution of (UVobs -NUVcloud)/UVobs for all noon measurements. Top: the new version (3.5). Bottom: the previous version (3.3).

The effect of the three-step approach in the version 3.3 is clear and the improvement in the new version is obvious.

An important parameter for the use of the UV-index is the expected maximum UV index of the day. For days with clouds this may not be at noon, in the current observed data this is the case for 35% of the days.

We therefore test if the 1h resolution UV_{cloud} product can provide reliable results on this. For all sites and all days we find the maximum UV index and at which hour it is found in the observed and calculated UV index respectively. We find (Fig. 13) that for 4395 days (61% of all days involved) the maximum UV_{obs} and maximum NUV are found at the same hour. The interval of ±1h includes 90% of the days.

The predicted NUV_{max} shows a median deviation from the measured of 2.7%.

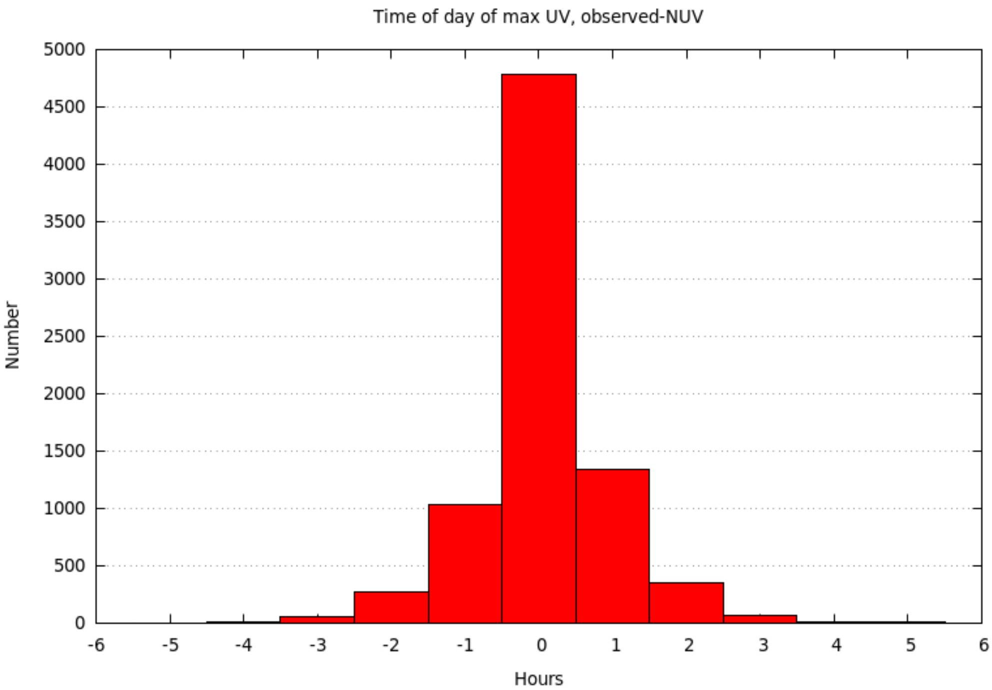


Figure 13: Histogram of the difference of the hour of the observed maximum UV index and the NUV maximum.

For the registered users of the NUV products the main focus is to prevent health damages caused by exposure to UV radiation from the sun. One main objective is to inform the public to take action when the UV index is so high that sunburns may be a risc. The general rule is that most people, depending on skin type, should apply sunscreen, seek shadow etc. in the midday sun, when the UV index is above 3.

Thus an important parameter for the NUV products is how accurate this is forecasted. Recognizing the problems with an accurate correction for cloud sky conditions, it has always been recommended to the NUV users not only to communicate the NUV/CLOUD value but also the NUV/CLEAR value.

To test the capability of the NUV/CLOUD to predict UV-noon values above 3 all measured UV values at noon has been compared with the corresponding NUV/CLOUD and NUV/CLEAR values in Fig. 14 below.

Green is where the NUV/CLOUD is also above 3, thus indicating a correctly issued "warning". Yellow is where the NUV/CLOUD is below 3 but the NUV/CLEAR is above, in which case the "warning" was issued if the NUV/CLEAR value was also considered. Red is the cases where both NUV values is below 3 and the "warning" was not issued. Left panel show the results for the new cloud cover algorithm and right panel the current version.

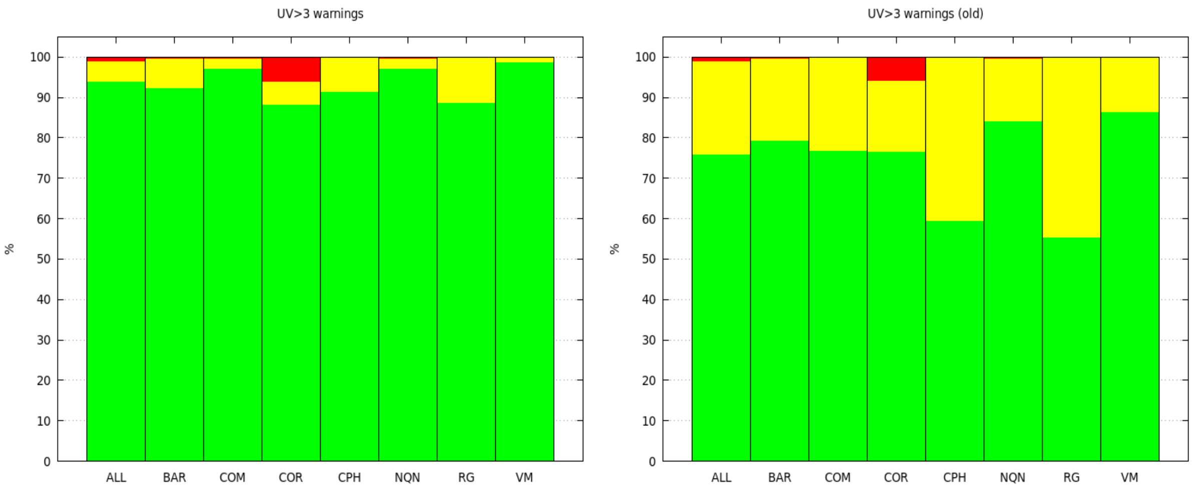


Figure 14: The capability to correctly issue a "UV-index > 3" warning. Green: The UVcloud is doing the job. Yellow: UVcloud fails but UVclear does not. Red: Both UVcloud and UVclear too low. Left: version 3.5 cloud correction algorithm. Left: version 3.3.

Variations from station to station is seen, the result for all 7890 measurements show that the NUV/CLOUD UV-index will correctly forecast the UV > 3 situation in 94% of the cases, and the worst case where none of the NUV products will forecast this is limited to 1.2%. For the current NUV/CLOUD product the corresponding numbers are 76% and 1.2% respectively. The above mentioned underestimation of the clear sky UV index for location COR is the reason why 6.4% of the UV>3 conditions is not detected even for NUV/CLEAR.

Considering the cases of "false alarms", i.e. when a NUV/CLOUD UV index above 3 is issued but the observed UV index is below. The results show that 11% of the UV_{cloud} values are too high.

4.3.4 Comparison with the AC SAF Off line UV product

The parameters for the correction for cloud was derived from a number of sites and as an early control of the global validity of the algorithm a comparison between the global NUV/CLOUD product with the AC SAF Offline UV product (OUV) was performed for January to September 2017. Only the local noon UV index fields were used here.

In Fig. 15 below an example of the two UV fields are shown.

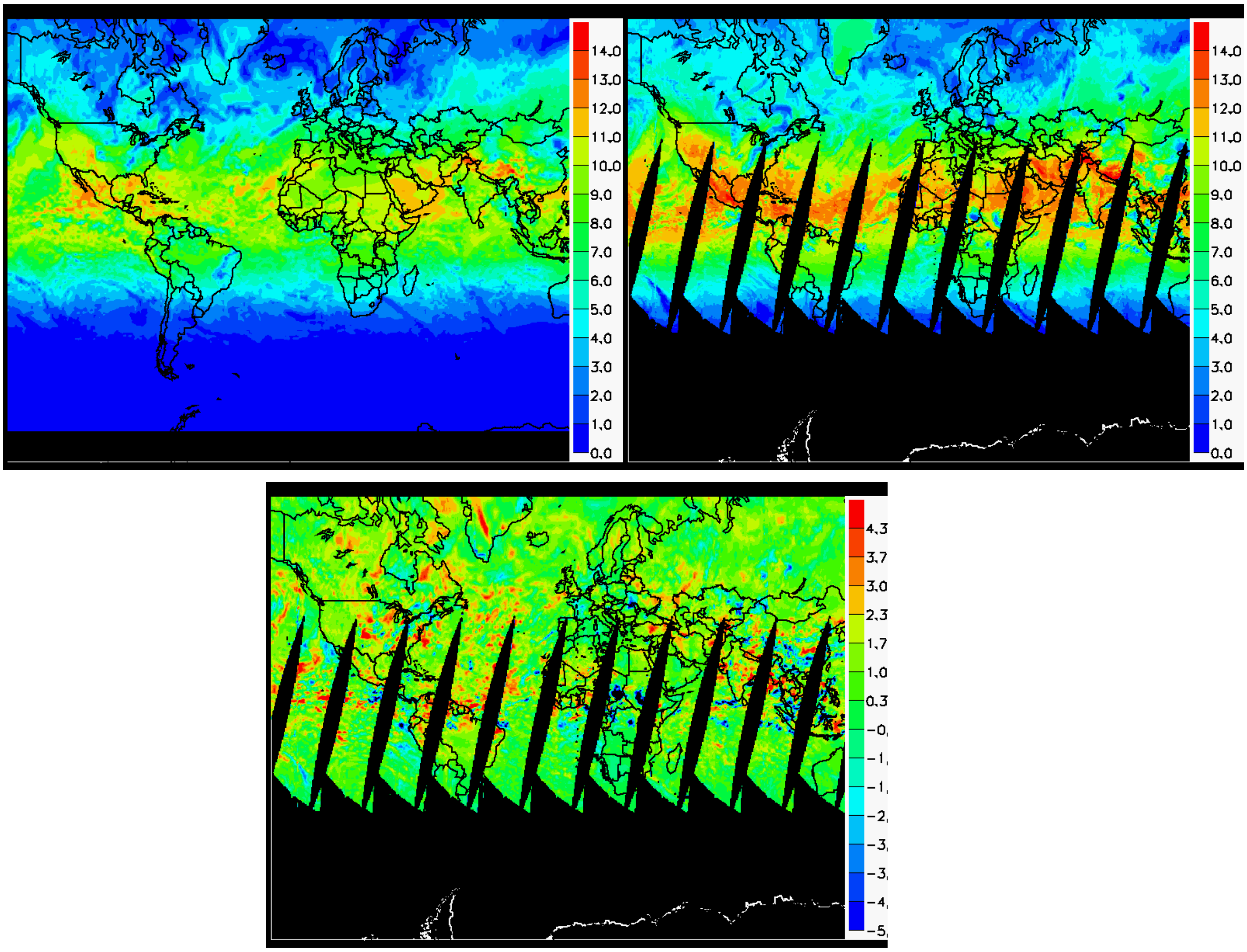


Figure 15: Top left NUV for June 23, 2017. Top right OUV for the same date and bottom is the difference OUV-NUV

The OUV is calculated from the observed GOME-2 near real time total ozone and the black areas in the top right image of Fig. 15 are areas with no measurements that day and are not included in the comparison with NUV.

The global comparison shows good agreement with an average offset of 0.6 UV index units for the whole time period. However, distinct difference are obvious in Fig. 15 (bottom), as deep-blue or red areas. This can be because either the cloud cover forecast applied in NUV did not match the observed cloud properties applied in OUV or because a difference in handling of the cloud attenuation, or both.

NUV and OUV was also compared for a number of sites, some examples shown in Fig. 16.

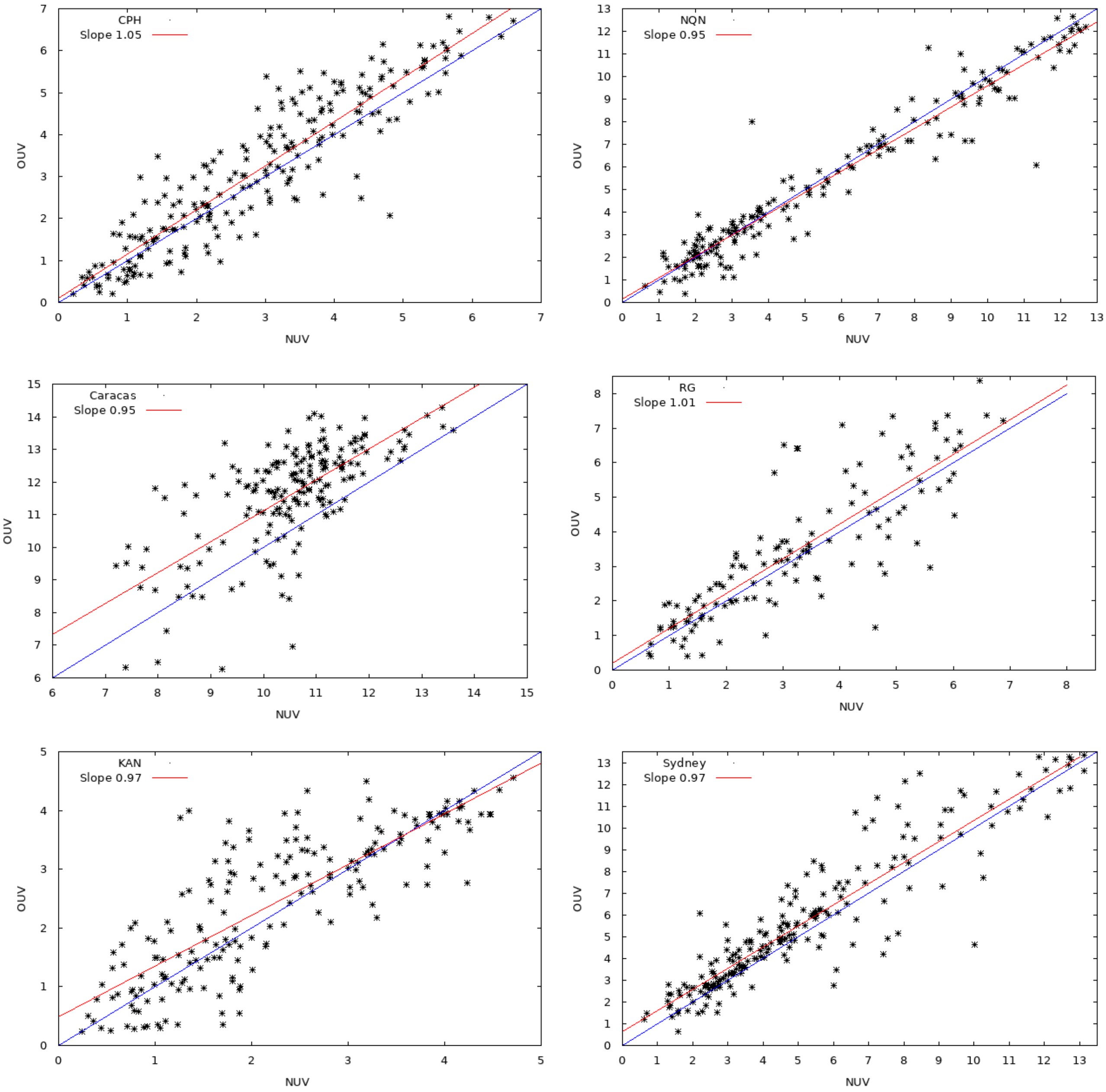


Figure 16. The OUV vs NUV for 2017 for three sites mentioned in the validation above (CPH, NQN and RG), Caracas in Venezuela, Sydney in Australia and Kangerlussuaq (KAN) in Greenland.

The examples shown in Fig. 16 demonstrated the general trend that there is an acceptable agreement between NUV and OUV. In equatorial areas (Caracas) there is however a bias of approx 1.5-2 index units and the polar regions (Kangerlussuaq) show a less significant linear relation between the two estimates of noon UV-index

5. CONCLUSION

- The comparison with the ground based measurements show that the NUV all sky product based on the new algorithm can reproduce observed UV-index with an accuracy well within the requirements on a time resolution of 1h from 7 to 17 local time.
- The quality of the NUV product is comparable to the CAMS UV processor output quality.
- Comparison with the AC SAF Offline UV product shows an agreement of 0.6 index units globaly
- It is demonstrated that the present version 3.5 is an improvement with regard to the previous operational version 3.3 on aspects of interest to the registered users.

APPENDIX A

Defining clear sky from measured UV

A procedure for estimating if clear sky conditions were applicable around local noon has been developed. The procedure works in several steps and involves a number of criteria that has been tuned by manually inspection a large number of daily profiles.

The daily variation of the measured UV is called a “profile” in this context.

Step 1:

For the given day, the procedure finds the maximum measured UV index (UV_{max}) and the UV index measure at local noon (UV_{noon}), defined as the time of minimum SZA. These two quantities have to pass the following subsequent criteria for the day to enter the next step.

- If any of these quantities are in error (less than zero, NaN, larger than 20) then the day is skipped.
- If any of these UV indices are measured at a time more than 1.5 hours from 12:00 LT the day is skipped.
- If the time difference between the two measurements are more than 30 minutes the day is also skipped.

The motivation for this first step is to be able to quickly exclude days where no good measurements are available around local noon (SZA_{min}), for example days where UV measurements are erroneous or days where measurements are only available in the afternoon and the SZA_{min} of the data set does not correspond to noon values.

Step 2:

In the following steps only measurements obtained in the interval 12LT +- 4 hours are included, and only if more than 5 such measurements are available otherwise the day is skipped. Next a Gaussian profile (with 5 terms) are fitted to the profile, and if these quantities are reasonable we proceed to next step.

Step3:

Next step is to compare the profile with the calculated NUV clear sky profile for that day and location, as descibed in the ATBD, this is done in the 12LT+-2hours interval assuming same ATO value for the time interval. The clear sky profile is scaled to the UV_{max} vaule and the deviation of the measured UV values to the corresponding clear sky values are calculated. The absolute mean deviation, the mean relative deviation and the standard deviations for the 4 hour profile are calculated and used below.

Inspecting a large number of profiles from various instruments and sites, NSF, NOAA, DMI instruments, a reasonable set of limits have been set to these quantities.

- At least more than 6 measurements in the 12+-1.5h interval
- Absolute mean deviation must be below 0.15
- Relative deviation must be below 0.05

- Standard deviation must be below 0.20

Step 4:

Allthough most non clear sky days are eliminated by steps 1-3 a small number of spurious profiles survives this far, and based on the inspection of those it was found that these were eliminated by demanding that the relative difference between the UV_{max} and the UV_{noon} should be no more that 1%.

The output is a file with one line per day giving: the day of year, time , sza , UV index and a flag describing wich criteria was passed by this day. The time and sza are the values corresponding to the UV_{max} . This file can be used for extra examination of specific days and further fine tuning of the parameters in the clear-sky routine.

APPENDIX B

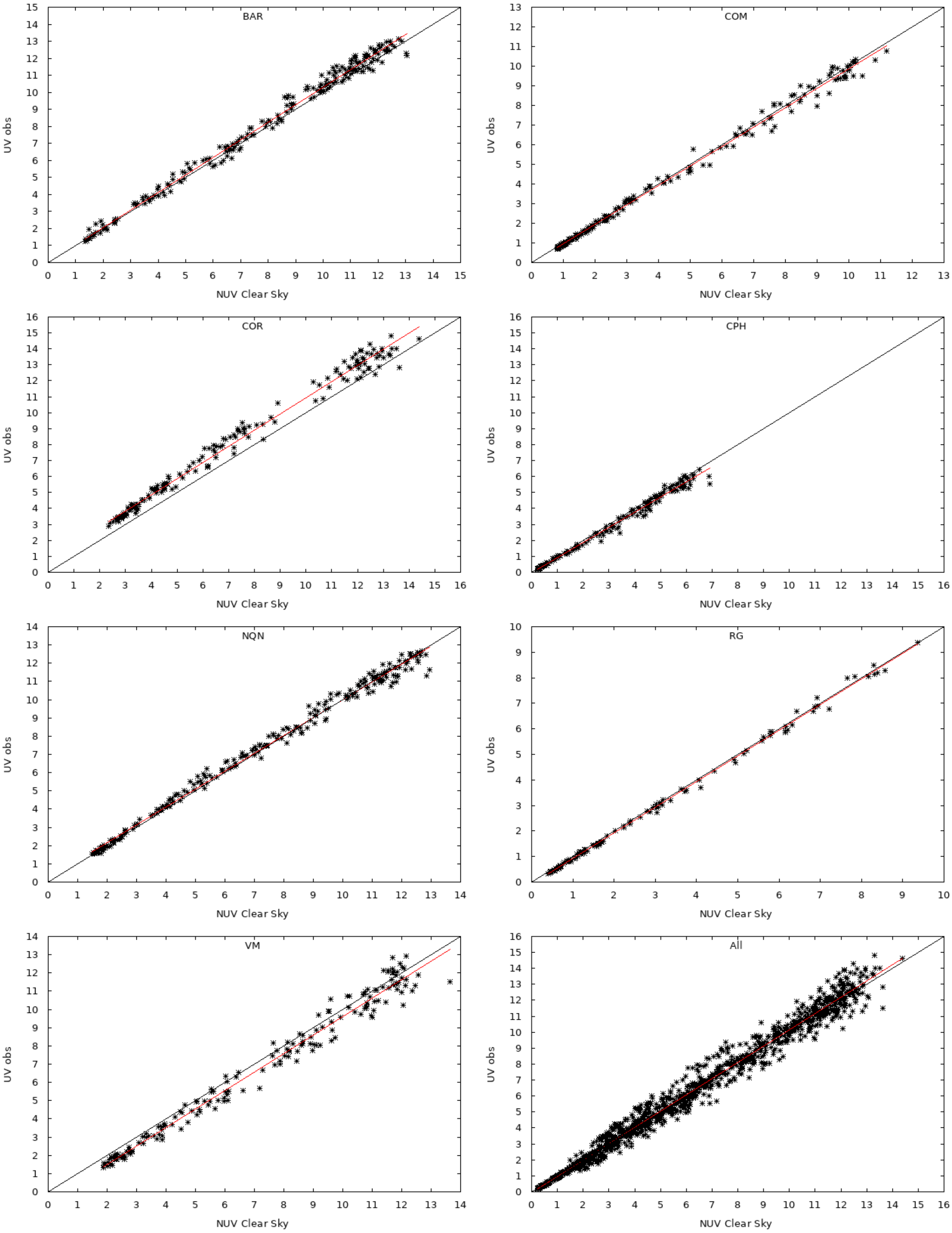


Figure B1: Observed vs estimated noon UV index for clear sky conditions for each site and the total sample.

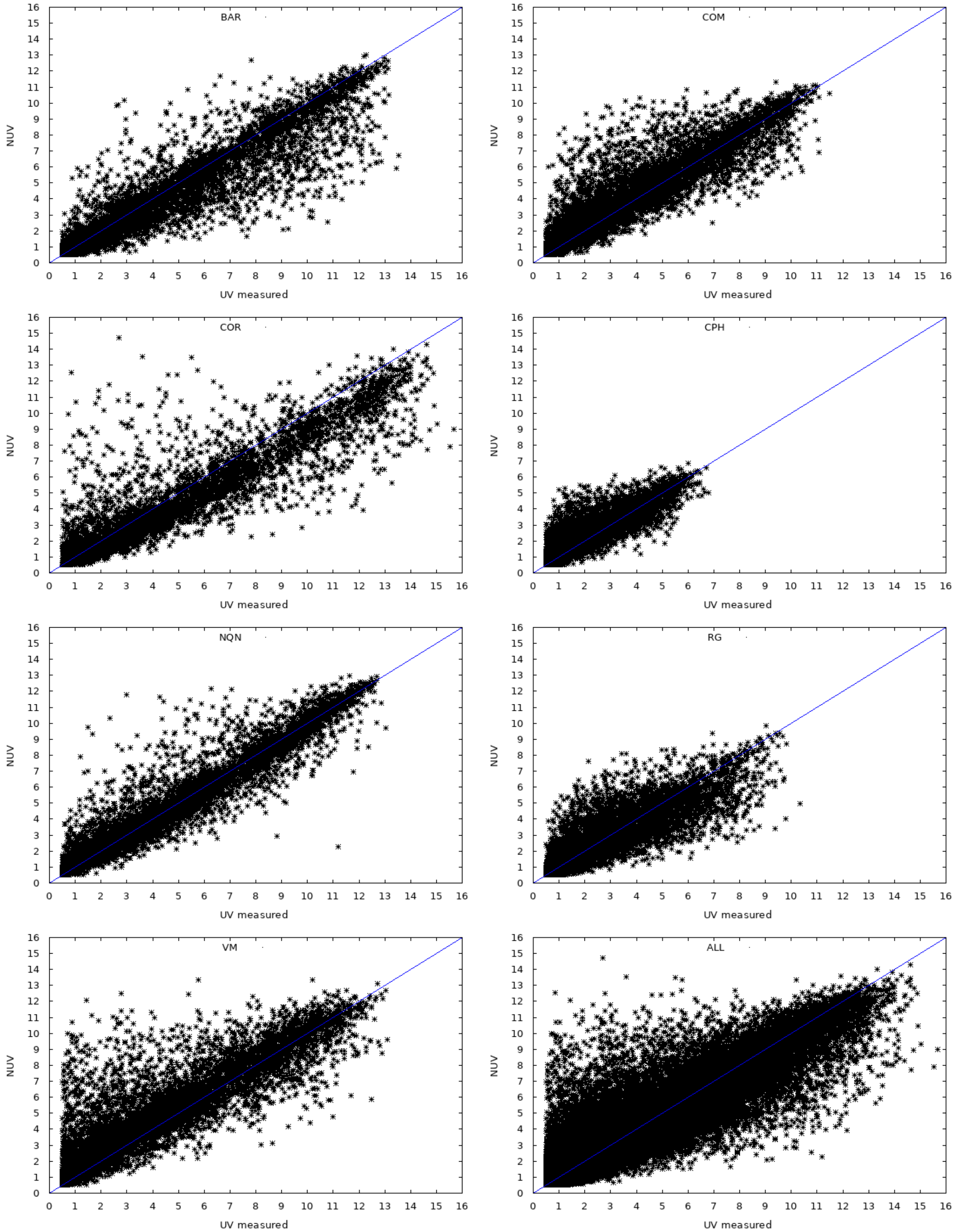


Figure B2: All sky UV index hourly measurements from 7-17h local solar time vs the calculated NUV. For each site and total sample.