# CIE, VITAMIN D AND DNA DAMAGE
# A SYNERGETIC STUDY IN THESSALONIKI, GREECE

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## ABSTRACT

The present study aims to **validate different approaches for the estimation of three photobiological effective doses: the erythemal UV, the Vitamin-D and that for the DNA damage**, through surface-based measurements of solar UV since 2005. Data from a UV spectrophotometer, a multi-filter radiometer, and a UV radiation pyranometer that are located **in Thessaloniki, Greece (40.63ºE, 22.96ºN)**, are used together with appropriate algorithms and models in order to calculate the desired quantities. In addition to the surface-based doses retrievals, **OMI/Aura and the combined SCIAMACHY/Envisat and GOME/MetopA** satellite products are also used in order to assess the accuracy of each of the presented methods.

## GROUND-BASED MEASUREMENTS

The calculation of the three photobiological doses over Thessaloniki, Greece, are based on measurements of three different types of instruments.

**A Brewer MKIII spectrophotometer** with serial number #086 (B086) measures the UV solar spectrum (286.5 - 363 nm). The more simple, single monochromator Brewer with serial number #005 (B005) has been providing total ozone column measurements since 1982. The B086 spectra have been extended to 400 nm using the SHICrivm algorithm and weighted with the action spectra for the erythemal doses, the formation of vitamin D in the human skin, and the DNA damage.

**A NILU-UV multi-filter radiometer** has been fully operational since 2005. The NILU-UV with serial number #04103 (NILU103) provides one-minute measurements in 5 UV channels with nominal central wavelength at 302, 312, 320, 340 and 380; while its sixth channel that measures the Photosynthetically Active Radiation (PAR) is used to determine cloud free cases. A feed-forward function-approximating neural network (NN) model was trained to calculate the biological UV products resulting from B086 response weighted spectra as outputs from the NILU103 irradiance measurements, using as inputs the solar zenith angle (SZA) and temporal variables such as the day of the year, DOY, and its sinusoidal components Cos(DOY) and Sin(DOY), plus the day of the week.

**A YES UVB-1 pyranometer**, (YES), provides one minute erythemal dose measurements while its spectral response is very similar to the official erythemal action spectrum. Using the effective doses derived from the B086, we evaluated the empirical relationship suggested by Fioletov et al. (2009) to convert erythemal irradiance to effective dose for the formation of vitamin D. A complex empirical relationship that consists of three different functions (one of TOC and UVI, one of cosθ and one of the ratio between the UVI and the climatological value of UVI for the specific day and SZA was developed and used to derive the DNA damage effective spectrum.

## SATELLITE MEASUREMENTS

Satellite estimates of erythemal UV, Vitamin-D and DNA damage effective dose time series from the **OMI/Aura, SCIAMACHY/Envisat and_GOME2/ MetopA** instruments are also used to provide a comparison for the surface-based estimates. The OMI/Aura surface UV irradiance data from 2005 to 2015 include the erythemally-weighted daily dose and erythemal dose rate both at the overpass time and also at local solar noon. The SCIAMACHY/Envisat and GOME2/MetopA joint UV product, that includes the same sub-products as the OMI/Aura dataset.

Data have been downloaded from NASA's **Aura Data Validation Center**, http://avdc.gsfc.nasa.gov/, and from ESA's **Tropospheric Emission Monitoring Internet Service**, http://www.temis.nl.

## RESULTS I : NILU-UV & OMI/AURA

The OMI/Aura algorithm provides erythemal doses and dose rates at the overpass time as well as at local noon. Both cases were investigated while the discrimination of the cloud free cases was performed by two different ways: the cloud screening algorithm based on NILU-PAR measurements was used to define the NILU103 clear sky cases, while the limitation of cloud optical depth less than 20% was set to the satellite data estimations in order to derive the satellite cloudless cases.

**Table 1.** Statistical analysis of the comparisons between erythemal dose rates provided by NILU103 and OMI for the overpass and noon local time.

| | Overpass | | | Local Noon | | |
|---|---|---|---|---|---|---|
| | All Skies | OMI Clear | NILU Clear | All Skies | OMI Clear | NILU Clear |
| N counts | 2152 | 1361 | 610 | 2426 | 2208 | 663 |
| **$R^2$** | **0.92** | **0.91** | **0.93** | **0.89** | **0.88** | **0.91** |
| Mean (%) | 14.07 | 9.97 | 13.28 | 18.47 | 14.38 | 17.68 |
| STD (%) | 49.22 | 42.77 | 49.63 | 68.03 | 58.87 | 62.85 |

The OMI dataset also includes the daily erythemal doses, i.e. daily integrals were calculated for days that did not have more than 15 minute gaps in their record. The NILU103 daily values were characterized as clear when more than 70% of the measurements were identified as cloud free by the PAR cloud screening algorithm. Scatter plot of the NILU-UV and OMI daily CIE doses are presented in **Fig. 1.**

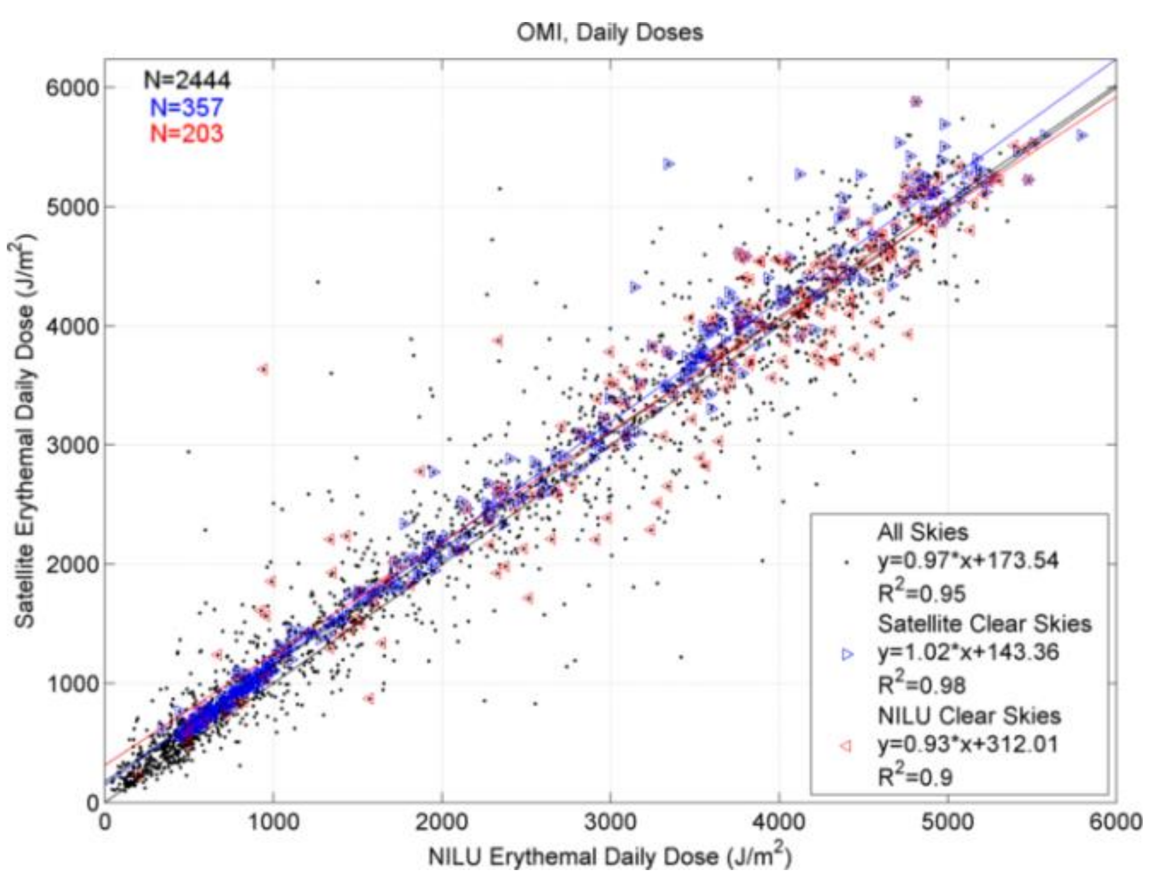


**Figure 1.** Scatter plot of daily erythemal values provided by OMI (y axis) and NILU103 (x axis) in J/m$^2$.Colour scale is used to denote the all skies from cloud free cases based on the satellite and ground-based criteria. NILU103 and OMI clear days are provided in blue and red triangles respectively.

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## RESULTS II : NILU-UV & SCIAMACHY/GOME2A

The daily all skies erythemal doses agree within 15% while a seasonal pattern is detected. Although all daily datasets achieve **high correlations of 0.92, 091 and 0.92 for CIE, vitamin D and DNA damage respectively**, the observed differences for the latter two are not consistent.

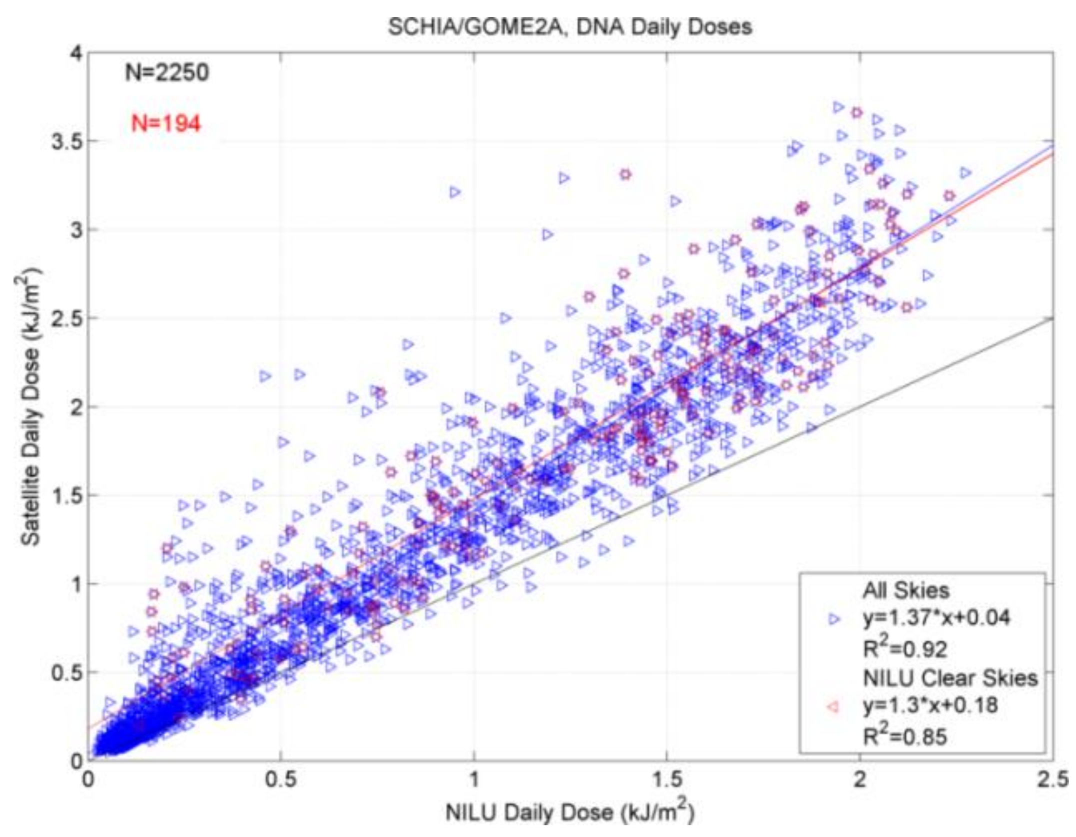


**Figure 2.** Scatter plot of daily erythemal values provided by the joint SCIA/GOME2A UV products (y-axis) and NILU103 (x-axis) in kJ/m2.Colour scale is used to separate the all skies from cloud free cases based on the ground-based criteria used in **Fig. 1.**

**For vitamin D**, the action spectrum used in satellite retrievals is shifted 3nm towards shorter wavelengths than that used in the NILU103 retrievals. This discrepancy leads to a significant **underestimation of the satellite vitamin D doses by almost 50%** for both all and clear sky cases. **For DNA damage** even though the applied action spectra are identical, **the satellite overestimates by 48.84% for all skies** and 55.4% for clear skies. These inconsistencies can be attributed to high uncertainty levels on B086 spectra at wavelengths lower than 305 nm. In addition, the aerosol climatology used in the satellite retrieval algorithm and the uncertainties introduced in the algorithm retrieval at low UV-B wavelengths (e.g. ozone retrieval errors) can affect the accuracy of its performance.

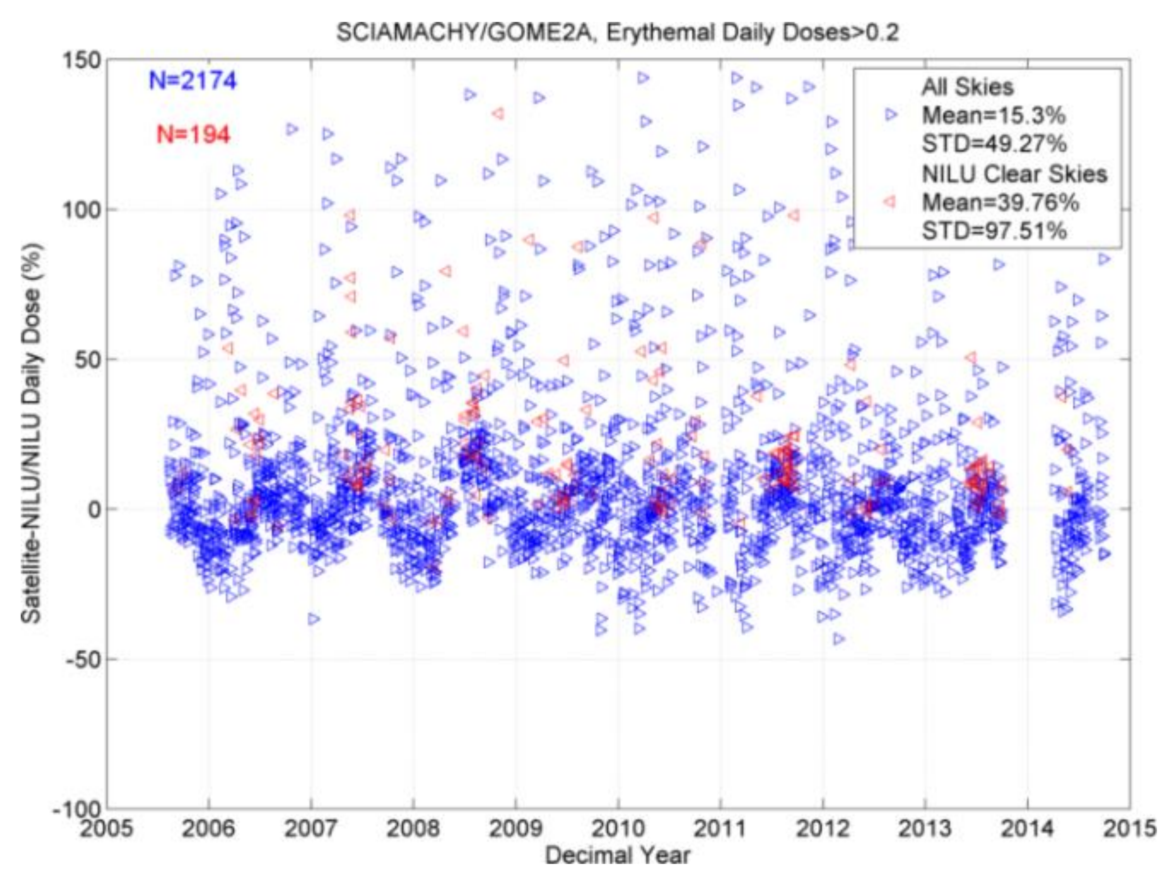


**Figure 3.** Time series of the relative percentage differences between the SCIA/GOME2A and NILU erythemal daily doses. Blue triangles depict the all skies daily data while red ones provide the comparisons for the characterized clear days.

## RESULTS III : NILU-UV & YES

The agreement between the two ground-based datasets is very good with close to zero mean differences and low standard deviation (< 11%). Similarly, it was found that NILU-UV calculated vitamin D hourly means also have a low (1.28%) overestimation in comparison with the YES data. DNA damage presents higher scatter than that of the CIE and vitamin D dose rates due to higher sensitivity at lower UV-B wavelengths. **The mean differences are of the order of ~5% ± 50%** with the YES dataset providing lower values under all sky conditions than those from NILU103. On the contrary, under cloud free skies, **YES data overestimates this dose by only 2.23%.** In both cases the correlation of the two datasets is close to unity (**$R^2$ ≈ 0.99)** suggesting close agreement over the full range.

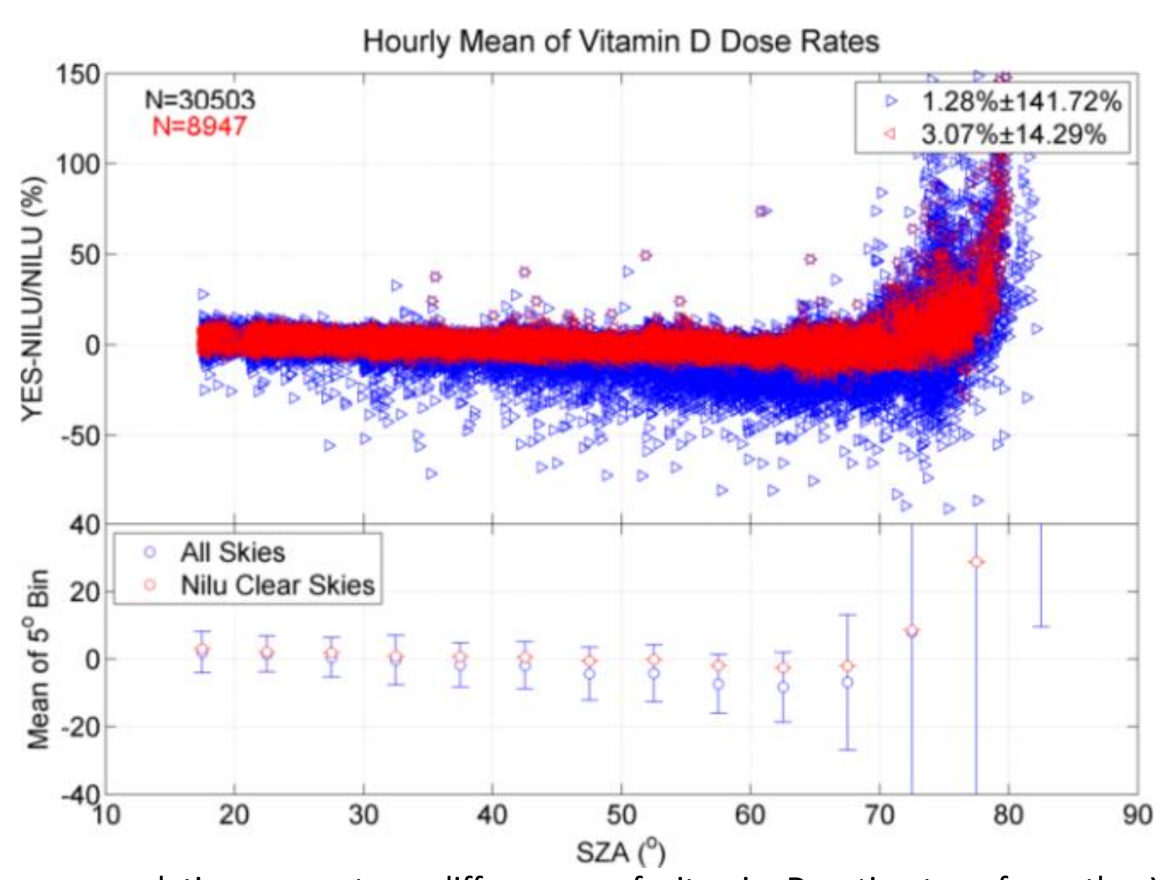


**Figure 4.** Hourly mean relative percentage differences of vitamin D estimatess form the YES and NILU103 radiometers against SZA (upper panel) and the same datasets averaged on 5º SZA bins (lower panel).

## CONCLUSIONS

In this work ground-based measurements, model estimates, and satellite-retrievals of the important photobiological UV products - CIE, vitamin D and DNA damage effective dose have been produced, compiled and compared so as to thoroughly discuss their accuracy and limitations at the mid-latitude UV and Ozone monitoring station in the Laboratory of Atmospheric Physics of the Aristotle University of Thessaloniki, Greece.

We show how a NN can be trained on NILU-UV multi-filter radiometer irradiances at 5 different wavelengths together with weighted action-spectra from a Brewer MKIII spectrophotometer to produce 1-minute time series of erythemal CIE, vitamin D and DNA damage dose rates. Furthermore, while the NN estimated erythemal UV dose rates can be directly compared with YES calibrated measurements, we show how appropriate methodologies can be applied to the original YES data to also produce vitamin D and DNA damage dose rates at the same temporal resolution as the NILU-UV instrument to enable a ground-based verification and evaluation of NN model estimates resulting from NILU103 measurements. The comparisons with the full YES dataset revealed very good agreement.