HIGH FREQUENCY RETRIEVAL OF TOTAL OZONE FROM A GROUND-BASED NILU-UV RADIOMETER USING A NEURAL NETWORK MODEL: VALIDATION OF THE MODEL AND EVALUATION OF SATELLITE OBSERVATIONS

M.M. Zempila[1,2], M. Taylor[2], M.E. Koukouli[2], A. Bais[2], C. Lerot[3], K. Fragkos[2], I. Fountoulakis[2], T. Drosoglou[2], F. Gkertsi[2], S. Kazadzis[4], D. Balis[2], and M. van Roozendael[3]

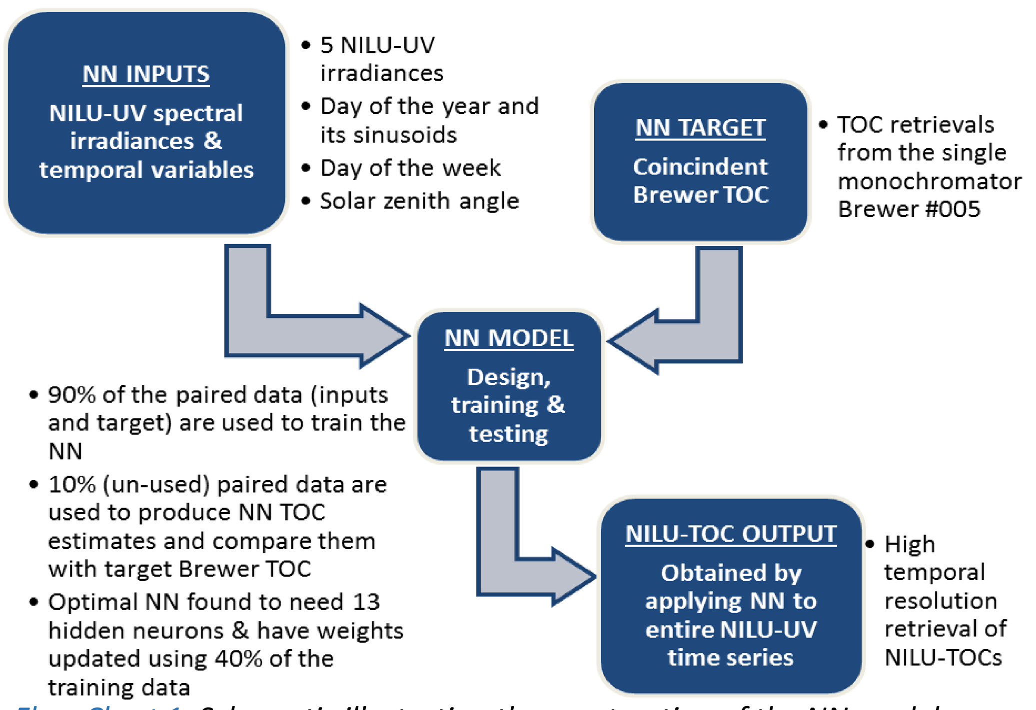
(1) *Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado, U.S.A.*
Email: melina.zempila@colostate.edu
(2) *Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece.*
(3) *Belgian Institute for Space Aeronomy, BIRA IASB, Brussels, Belgium.*
(4) *Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Switzerland.*

Abstract

The present study presents a new approach to retrieve total ozone at high temporal frequency from surface irradiance measurements performed with a NILU-UV multi-filter radiometer. Time series of 1-minute NILU-UV irradiances at central wavelengths of 302, 312, 320, 340 and 380 nm are used as inputs to a neural network model together with collocated solar zenith angles calculated at Thessaloniki, Greece (40.63E, 22.96N), and the day of the year and as well its sinusoidal components as temporal variables. A decade of coincident Brewer total ozone measurements (TOCs) are used as the target (output) values. A key feature of this Neural Network Model is the use of Singular Spectrum Analysis to denoise all time-series variables. The model is then fed with unseen real (noisy) inputs to estimate TOCs for the decade 2005-2014. Satellite total ozone from the GOME/ERS-2, SCIAMACHY/Envisat, OMI/Aura, and GOME2/MetopA GODFIT_v3 Ozone-CCI ESA algorithm at each overpass time are used to provide a comparison for instantaneous TOC estimates produced by the neural network model from NILU-UV irradiances. Furthermore, a collocated CCD spectrometer system provides TOCs values since late 2013 by applying the DOAS technique to the direct sun measurements performed in the UV spectral region of 315-337 nm. Time series analysis and correlation statistics identify the agreement limitations as well as atmospheric, algorithm-related and technical factors responsible for sources of discrepancy among the TOC retrievals.

Ground-Based Measurements

The calculation of the total ozone column over Thessaloniki, Greece, are based on measurements of three different types of instruments.
A single monochromator Brewer with serial number #005 (B005) has been providing total ozone column measurements since 1982. B005 has been calibrated in the past a number of times against the travel reference Brewer (Brewer#017). Its latest calibration showed an agreement with the reference Brewer#185 better than ±0.5%. A collocated Brewer MKIII spectrophotometer with serial number #086 (B086) measures the UV solar spectrum (286.5 - 363 nm) with 1-sigma uncertainty in the final product is lower than ~5%, for wavelengths higher than 305 nm and solar zenith angles, smaller than 80°.
A NILU-UV multi-filter radiometer 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. The NILU dataset was subjected to intercomparisons with the Brewer#086 UV irradiance data for the whole period under investigation and its measurements uncertainty was found to be 6.4% for the 305 nm channel and less than 5.4% for the remaining UV channels.
A feed-forward function-approximating neural network (NN) model was trained to calculate the TOCs resulting from B005 retrieved TOCs as outputs from the denoised 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). The denoised NILU103 irradiance data resulted from the application of singular spectrum analysis. 95% of the differences between the NN estimates and the coincident target Brewer data fall within ≈13 D.U.



Flow Chart 1. Schematic illustrating the construction of the NN model.

A collocated CCD spectrometer system has been providing TOC values since late 2013 by applying the DOAS technique to the direct-sun measurements in the UV spectral region of 315-337 nm by means of the QDOAS software v.2.108 developed by BIRA-IASB and S[&]T [Danckaert et al., 2014]. The Phaethon retrieval error is below 3 DU (~1%) for 80% of the TOC data. The average agreement between the Phaethon-derived TOCs and Brewer #005 measurements is about 0.75±1.5%. The Phaethon system has participated in the COST ACTION ES1207 European Brewer Network (EUBREWNET) campaign / X Regional Brewer Calibration Center for Europe (RBCC-E) intercomparison held at El Arenosillo Atmospheric Sounding Station of the National Institute for Aerospace Technology (INTA), Huelva, Spain during May 27 - June 5 2015. The comparison of Phaethon total ozone data with the reference Brewer #185 TOCs during the campaign revealed an average agreement of ~0.2±0.5% (see also poster P230).

Satellite Measurements

Total ozone column records from GOME/ERS-2, SCIAMACHY/Envisat, OMI/Aura and GOME-2/MetopA have been reprocessed with the European Space Agency's Climate Change Initiative GODFIT (GOME-type Direct FITting) version 3 algorithm. Inter-sensor comparisons and ground-based validation of this dataset indicate that these ozone data sets are of unprecedented quality with stability better than 1% per decade, a precision of 1.7%, and systematic uncertainties less than 3.6% over a wide range of atmospheric states.

Results I: NILU-UV & SATELLITE GODFIT_v3 Ozone-CCI ESA

Scatter plots of all 4 satellite sensor TOC retrievals against the NILU-UV estimated TOCs are presented in the left panel of Figure 1, while the percentage relative differences are provided in the right panel of the same figure. For the comparisons mean values of the ground retrieved TOCs of ±30 min around overpass time of each satellite platform were used. No filter was applied to limit these comparisons.

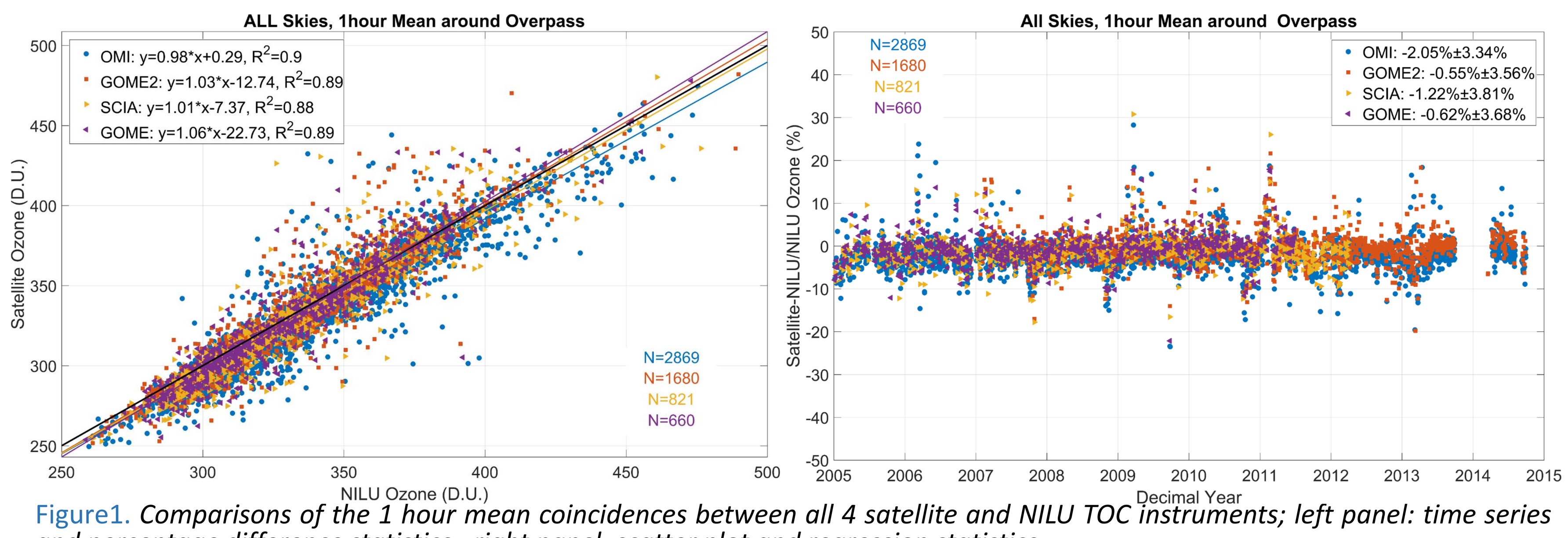


Figure1. *Comparisons of the 1 hour mean coincidences between all 4 satellite and NILU TOC instruments; left panel: time series and percentage difference statistics ; right panel: scatter plot and regression statistics.*

All 4 satellite instruments provide a unique agreement with the NILU-UV ground-based TOCs, with the satellite estimations found to overestimate by less than 2%, while the standard deviation of the comparisons doesn't exceed 4%. The slopes of the scatter plots are close to unity while the y-intersects are less than the accuracy of the NN model retrievals, less than 13 D.U., for most of the cases. The high R^2 values reveal the good agreement between satellite and NILU-UV TOC estimates.

Results II: NILU-UV & CCD

The scatter plot between the CCD TOC retrievals and the NILU-UV estimated TOCs are presented in the upper panel of Figure 2, while the histogram of the relative differences is provided in the lower panel of the same figure. The coincidences of the two datasets were found within a time window of 5 minutes.

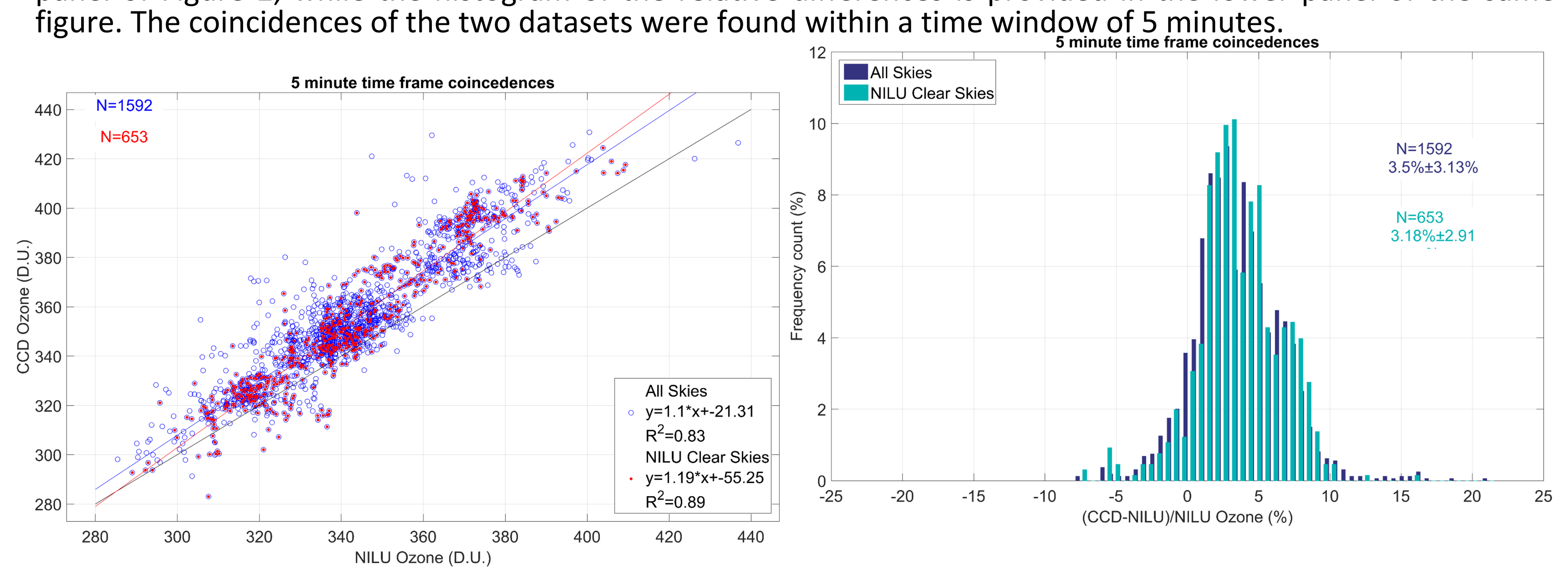


Figure 2. *Comparisons of the 5 minute time frame coincidences between CCD and NILU TOC retrievals; left panel: scatter plot and regression statistics; right panel: histogram of the distribution of percentage differences.*

As seen in Figure 2 the 2 ground-based retrieved TOC datasets agree within 3.5% for all skies cases, while this percentage is reduced to 3.18% when the NILU-UV cloud screening algorithm based on its sixth measurements, detected cloud free. The standard deviation of the relative percentage differences is of the order of 3% for both the cloudiness cases. According to the scatter plots, retrievals under cloudless conditions, end to higher overestimation, though the R^2 value is higher than that of the all skies circumstances.

Conclusions

In this work ground-based measurements, model estimates, and satellite-retrievals of the total ozone column (TOC) 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 TOCs from a Brewer spectrophotometer to produce 1-minute time series of TOC values. While the accuracy of the NILU-UV NN estimated TOCs are assessed by internal processes, retrievals of TOC from 4 different satellite sensors are evaluated through the NILU-UV TOC data. Furthermore, an additional source of ozone data stemming from DOAS technique applied to CCD measured spectra is also evaluated revealing promising results.

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