Simultaneous retrieval of total ozone column amounts and cloud/aerosol optical depths *from multi-channel, moderate bandwidth filter instruments*

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Outline

- Motivation
- Goals of Study
- The NILU-UV **Multi-Channel** moderate bandwidth filter **Instrument** (MCI)
- Methodology
  - Lookup Table (LUT) method
  - Neural Network (NN) method
  - Radiative Transfer Model – **AccuRT**
- Results
- Summary – Future Outlook

Motivation

Retrieval of total ozone column (TOC) and cloud optical depth (COD) values from ground-based MCI data

- can be significantly improved by using a Neural Network (NN) method instead of a traditional look-up table (LUT) method:
  - the NN method was found to yield better agreement with TOC values obtained from the Ozone Monitoring Instrument (OMI) with a significant increase in the correlation between NN-derived and OMI-derived TOC values.

Under cloud-free conditions, the aerosol optical depth (AOD) can also be retrieved:

- The TOC, COD, and AOD information obtained from MCI data can be used to estimate ***trends*** in radiative forcing and hence the impact of ozone, clouds and aerosols on the radiative energy balance:
- Deployment of MCIs with additional channels at AERONET (and other) sites and analysis of such data in conjunction with AERONET and satellite remote sensing data
- can provide crucial information needed to assess ***trends*** in the climate impact of ozone, clouds, aerosols, and water vapor.

Goal of this work

Use data obtained by 3 MCIs over a 3-year period in the New York area to

- demonstrate that the 3 instruments provide the same information;
- **present a new NN-based method for simultaneous retrieval of TOC and COD values, and present retrieval results**;
- demonstrate that this **NN-method results in a larger number of valid retrievals** (daily average values within a meaningful range of 200-500 DU) than the LUT method.
- extend the NN methodology to retrieve **aerosol optical depth (AOD)** under cloud-free conditions from existing MCI data.

Focus of this presentation:

- discuss results obtained over a 3-year period in the New York area, and
- **discuss the potential for using MCIs with additional channels to retrieve climate related information such as water vapor amount.**

The NILU-UV MCI (1)

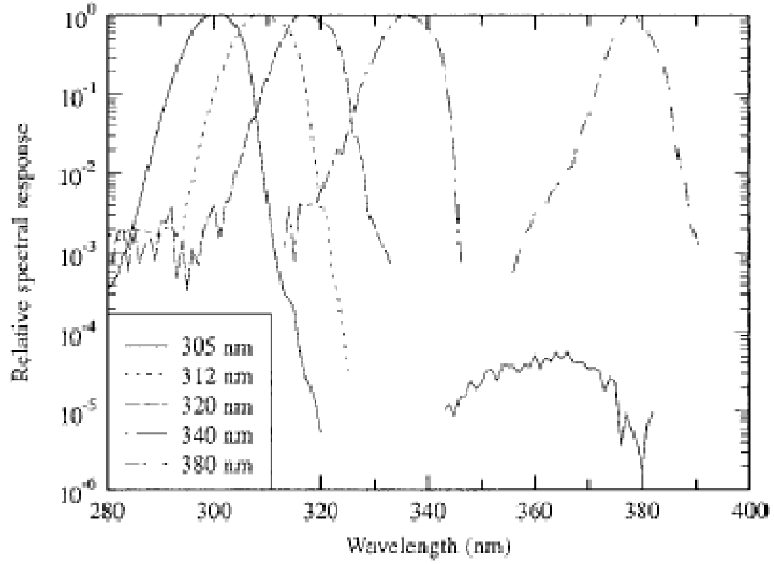
Description

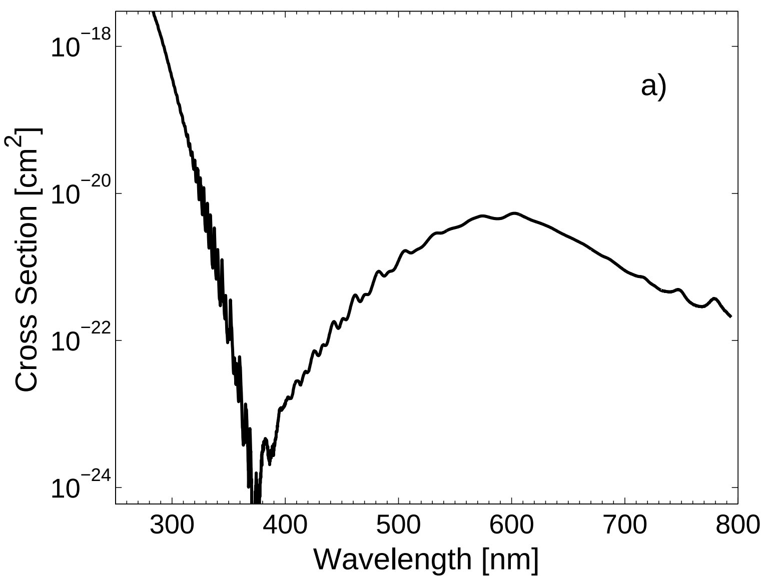
- Six channels:
  - **305 nm (UV-B) sensitive to Ozone** (10 nm bandwidth)
  - 312 nm (UV-B) sensitive to Ozone (10 nm bandwidth)
  - **320 nm (UV-A) much less sensitive to Ozone** (10 nm bandwidth)
  - 340 nm (UV-A) much less sensitive to Ozone (10 nm bandwidth)
  - **380 nm (UV-A) much less sensitive to Ozone** (10 nm bandwidth)
  - PAR channel (400–700 nm).
- Teflon diffuser;
- Interference filters (and blocking filters) to obtain desired spectral response;
- Silicium detector;
- Built-in temperature controller and data-logger.

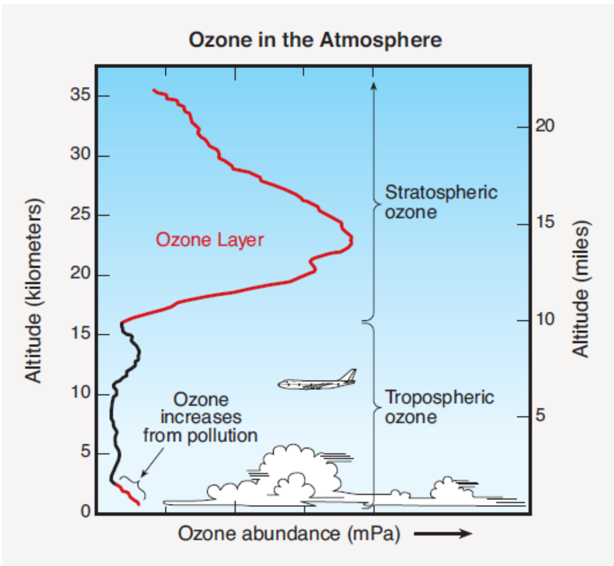
Maintenance

- Do relative calibration routinely (every other week);
- Clean dust off the instrument.

The NILU-UV MCI (2)







The NILU-UV MCI (3)

Absolute calibration

The voltage V_i across the detector in channel i is:

$$V_i = \int_0^\infty R_i(\lambda) F(\lambda) d\lambda \tag{1}$$

where $F(\lambda)$ is the irradiance measured simultaneously with an accurate spectroradiometer. The absolute response function: $R_i(\lambda) = k_i R_i'(\lambda)$. Hence:

$$k_i = \frac{V_i}{\int_0^\infty R_i'(\lambda) F(\lambda) d\lambda}. \tag{2}$$

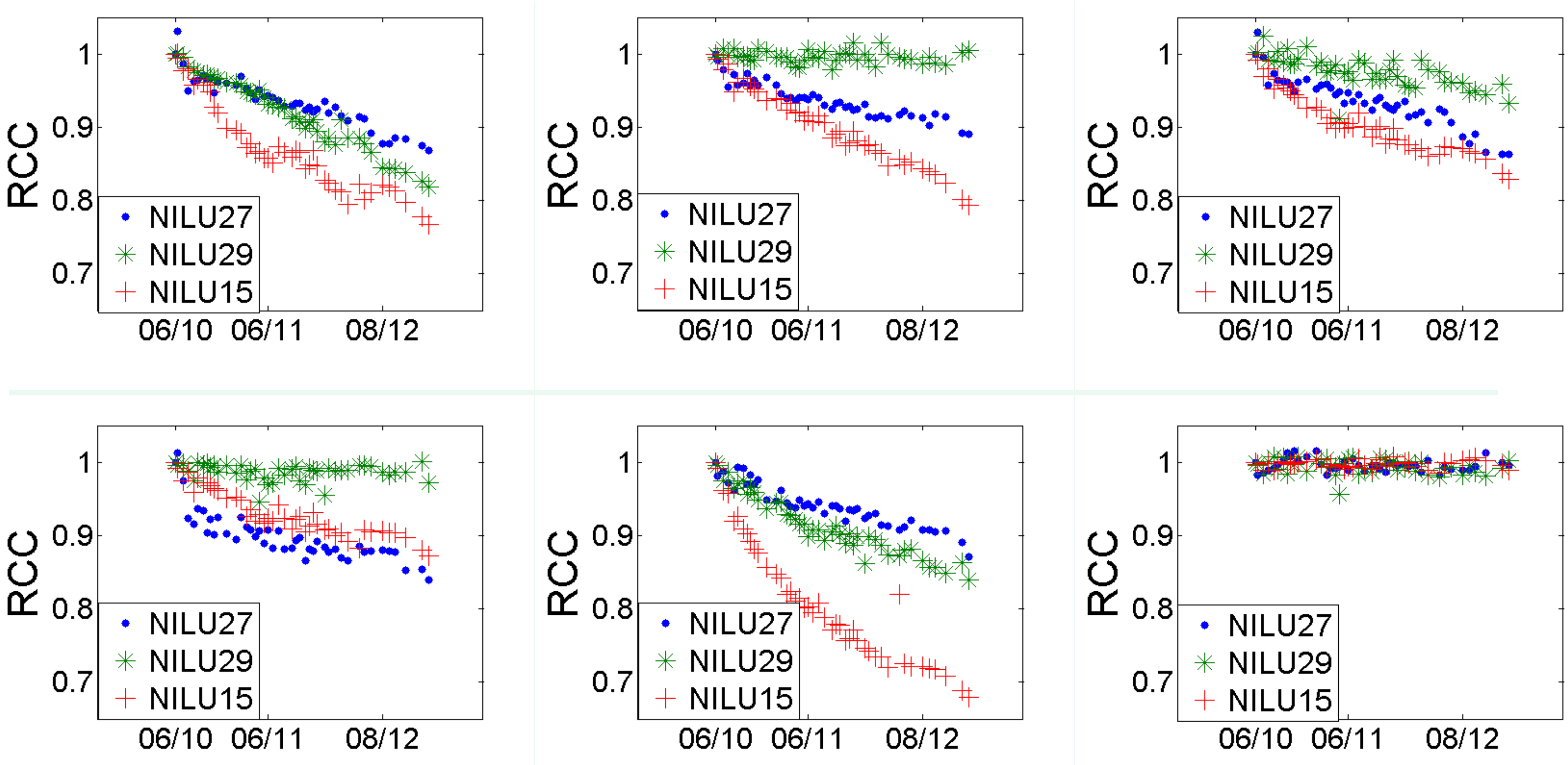
Relative calibration

- Relative calibration device: a hood and three standard lamps.
- Measure the voltage in each channel with the three lamps one by one.
- Calculate the average ratio between the measured voltage and the corresponding voltage measured in the initial calibration:

$$\mathrm{RCC} = \frac{1}{3}\left(\frac{V_{\mathrm{meas1}}}{V_{\mathrm{init1}}} + \frac{V_{\mathrm{meas2}}}{V_{\mathrm{init2}}} + \frac{V_{\mathrm{meas3}}}{V_{\mathrm{init3}}}\right) \tag{3}$$

where $V_{\mathrm{meas}i}$, $V_{\mathrm{init}i}$ $(i = 1, \ldots, 3)$, are the measured voltages for the three lamps.

The NILU-UV MCI (4)



Relative calibrations are essential in order to get accurate results.

Retrieval of TOC, Cloud effects, and UV index (1)

- Retrieve TOC value and Radiation Modification Factor (RMF) value using LUT method (based on a radiative transfer model, RTM)*
- Retrieve COD and TOC values simultaneously by applying NN-method (trained using a RTM)†
- Retrieve UV index (UVI) based on UV dose rate obtained by applying CIE action spectrum‡

LUT method

- TOC value

$$N(\theta_0, \mathrm{TOC}) = \frac{\sum_{\lambda=0}^{\infty} R_i(\lambda) F(\lambda, \theta_0, \mathrm{TOC})}{\sum_{\lambda=0}^{\infty} R_j(\lambda) F(\lambda, \theta_0, \mathrm{TOC})}$$

$F(\lambda, \theta_0, \mathrm{TOC})$ is the irradiance, and i, j refer to two different channels, one being **sensitive to ozone (e.g. 305 nm)**, the other being **much less sensitive (e.g. 320 nm)**.

- RMF value ($\lambda_1 =$ **380 nm**)

$$\mathrm{RMF} = \frac{F^m(\lambda_1, \theta_0)}{F^c(\lambda_1, \theta_0)} \times 100$$

ratio of measured to computed clear-sky irradiance.

*Fan, L., W. Li, A. Dahlback, J. J. Stamnes, S. Englehardt, S. Stamnes, and K. Stamnes, Comparisons of three NILU-UV instruments deployed in the New York area, Applied Optics, 53, 3598-3606, 2014.

†Fan, L., W. Li, A. Dahlback, J. J. Stamnes, S. Stamnes, and K. Stamnes, New neural-network-based method to infer total ozone column amounts and cloud effects from multi-channel, moderate bandwidth filter instruments, Opt. Expr., 22, 19595-19609, 2014. DOI:10.1364/OE.22.019595.

‡Fan, L., W. Li, A. Dahlback, J. J. Stamnes, and K. Stamnes, Long-term comparisons of UV index values derived from a NIL-UV instrument, NWS and OMI in the New York area, Applied Optics, 54, 1945-1951, 2015. http://dx.doi.org/10.1364/AO.54.001945.

Retrieval of TOC, Cloud effects, and UV index (2)

Limitations of the LUT approach:

- TOC and RMF (cloud effects) values are **retrieved separately**, which leads to reduced accuracy under cloudy conditions.

How can we improve upon the LUT approach? Answer: Use

NN-method

Simultaneous retrieval of TOC and COD values. HOW?

Step 1: Use an accurate RTM§ to create a large synthetic dataset of

- the ratio $F(\lambda = 320)/F(\lambda = 305)$ (sensitive to TOC, insensitive to COD)
- the irradiance at 380 nm (sensitive to COD, insensitive to TOC)

for all possible combinations of

- solar zenith angles between $\theta_0 = 30°$ and $\theta_0 = 70°$ (depending on location)
- TOC values between 250 and 500 (depending on location)
- COD values between 0 and 100.

§B. Hamre, S. Stamnes, K. Stamnes, and J.J. Stamnes, Ocean Optics XXII, Portland, ME, 2014. http://www.geminor.com/media/Hamre_OO2014_A0_portrait_v3.pdf

Retrieval of TOC, Cloud effects, and UV index (3)

Step 2: Use the synthetic dataset to train a NN to provide a link between

Input parameters:

- solar zenith angle
- ratio between irradiances: $F(\lambda = 320)/F(\lambda = 305)$ $\longleftarrow$ **TOC**
- irradiance at 380 nm $\longleftarrow$ **COD**

and

Output parameters:

- Total ozone column (TOC) amount
- Cloud optical depth (COD).

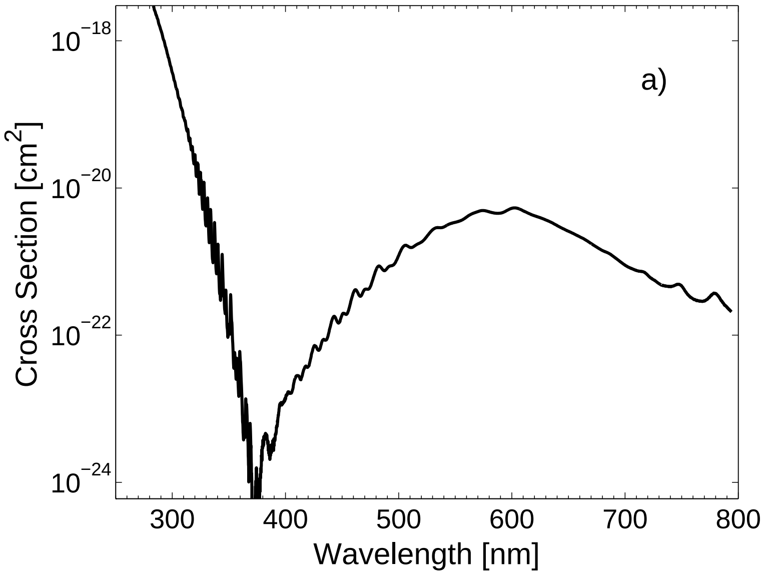
Advantages of NN method:

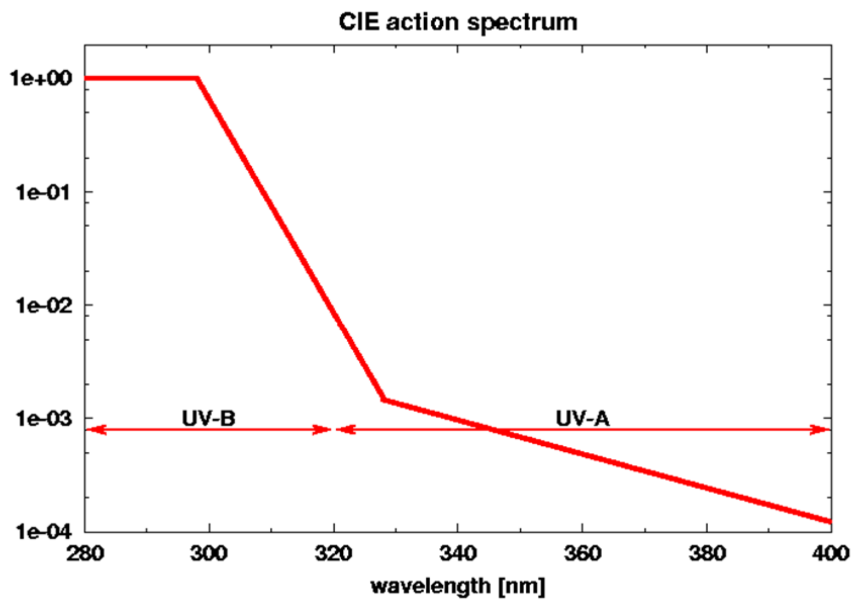
Compared to the LUT method, the NN method was found to yield

- better agreement with TOC values derived from OMI data
- more valid retrievals (daily average values within a meaningful range).

Simultaneous retrieval provides more reliable estimation of cloud effects – more accurate TOC and COD values.

Retrieval of TOC, Cloud effects, and UV index (4)



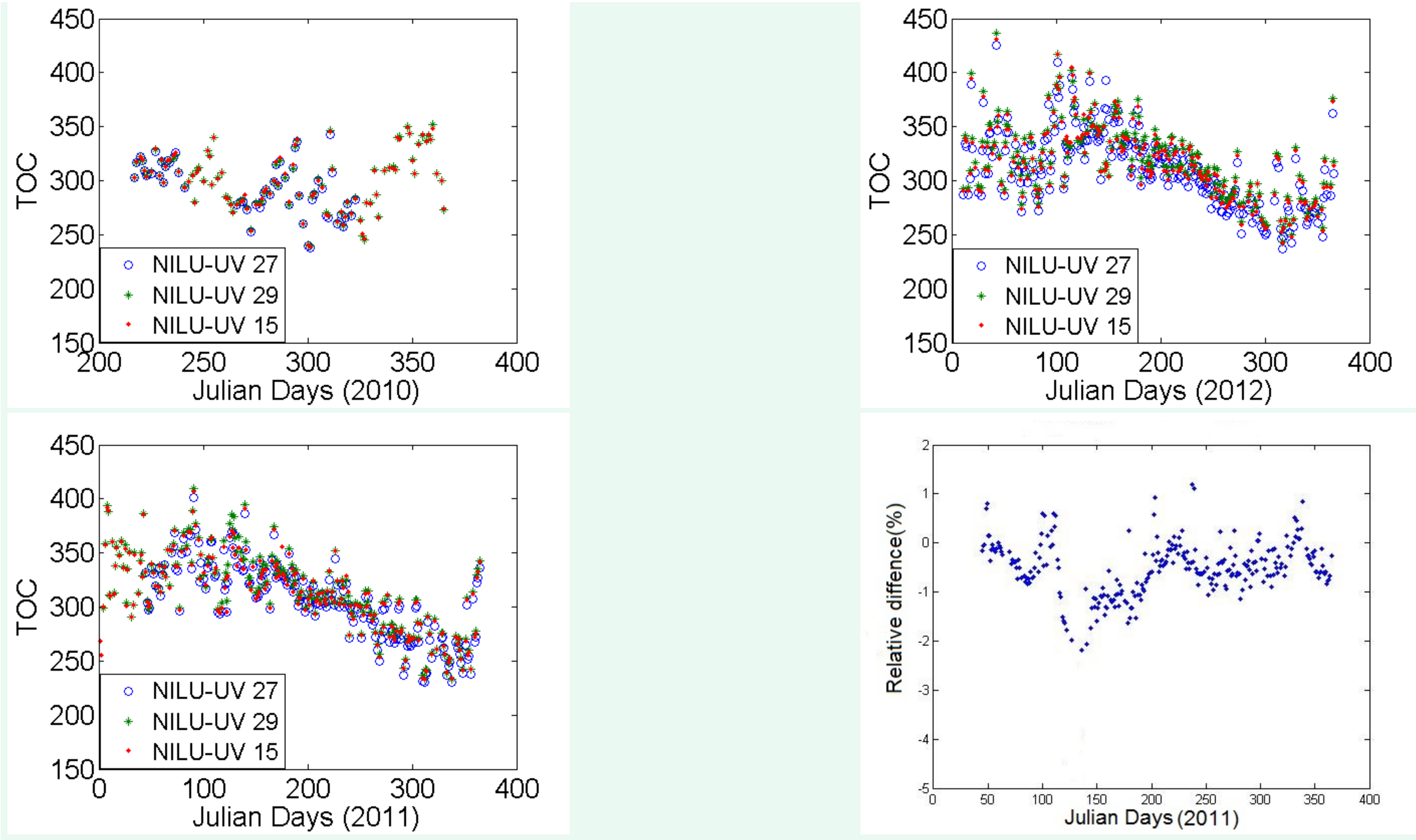


$$\frac{dD}{dt} = \int_0^\infty A(\lambda)F(\lambda)d\lambda \approx \sum_{i=1}^{5} a_i V_i \quad \longleftarrow$$ **CIE weigthed UV dose rate**

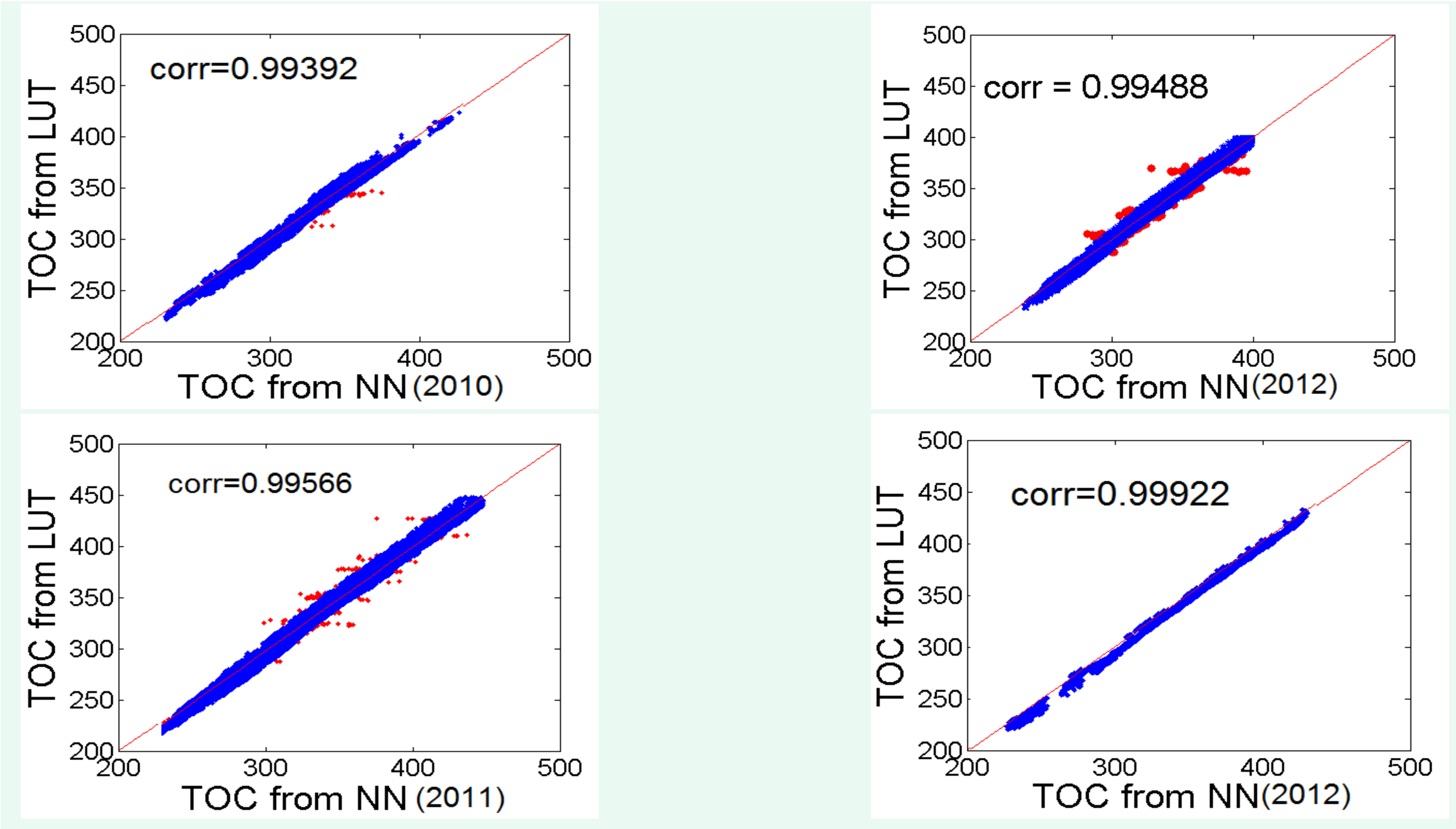
where the CIE Action Spectrum $A(\lambda)$ is a model of the sensitivity of skin to sunburn proposed by McKinlay & Diffey (1987), and the UVI is defined as

$$\text{UVI} \equiv 40 \times \textbf{CIE weighted UV dose rate.}$$

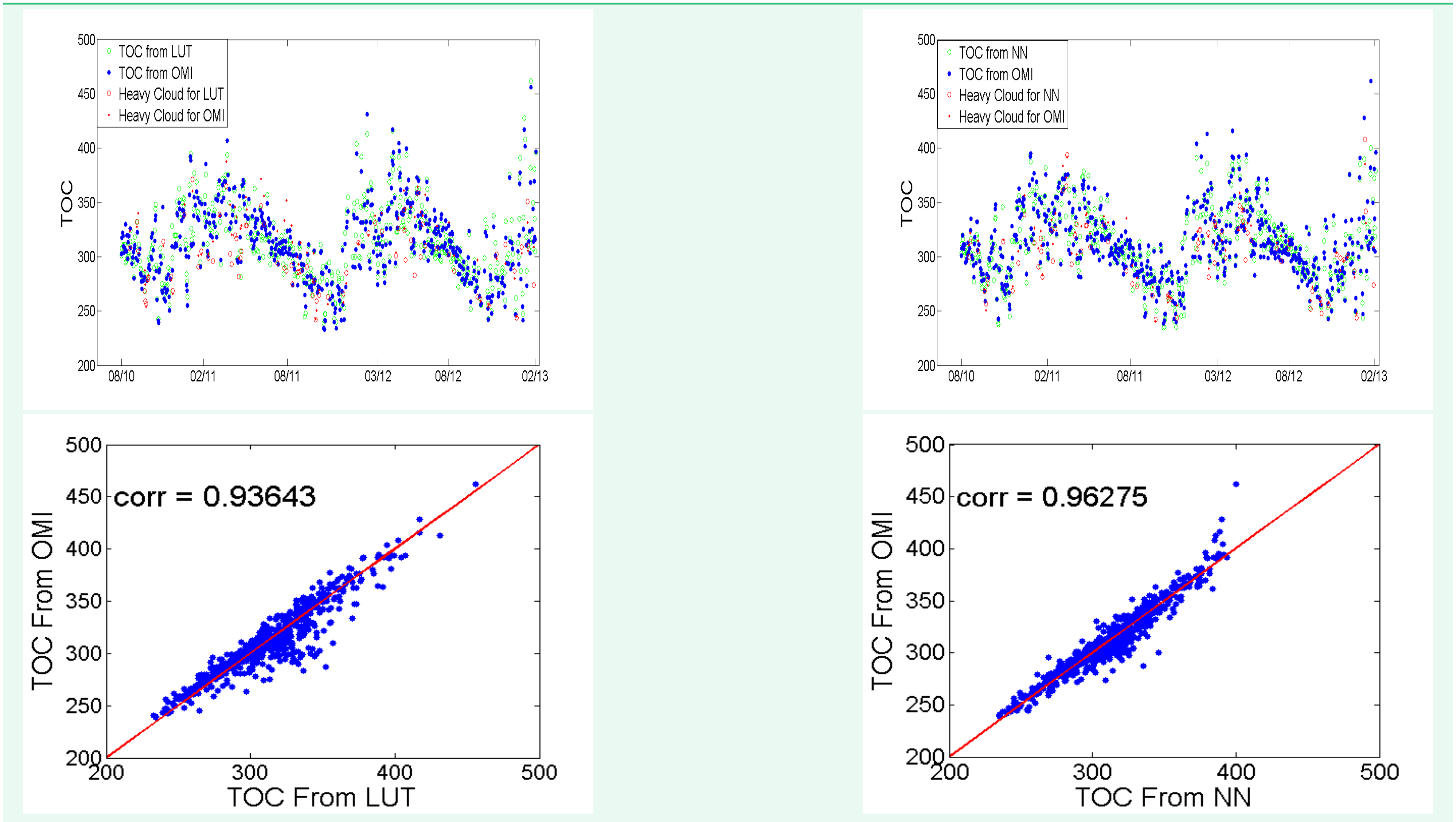
Comparison of TOC values derived from 3 NILU-UV instruments



Comparison of TOC values derived by LUT and NN methods



Comparisons of TOC values derived from NILU-UV MCIs and OMI (1)



Left: TOC from LUT method. Right: TOC from NN method.

Comparisons of TOC values derived from NILU-UV MCIs and OMI (2)

Correlations between TOC values derived from OMI and NILU-UV data using the NN and LUT methods:

Year	Correlations	
	OMI vs NN	OMI vs LUT
2010	0.9509	0.9153
2011	0.9673	0.9313
2012	0.9674	0.9313
2013	0.9801	0.9712

Correlations between TOC values derived from OMI and NILU-UV data using the NN method for different cloud conditions (COD values):

Cloud Optical Depth	Correlations
	OMI vs NN
$\mathrm{COD} < 5$	0.9812
$5 < \mathrm{COD} < 10$	0.9688
$10 < \mathrm{COD} < 20$	0.9570
$20 < \mathrm{COD}$	0.9469

UVI (1)

Recall definition of UVI:

$$\text{UVI} \equiv \mathbf{40 \times CIE\ weighted\ UV\ dose\ rate.}$$

UVI Exposure Categories:

UVI	Description	Exposure Category
0-2	Low Danger	Low
3-5	Moderate risk of harm	Moderate
6-7	High risk of harm	High
8-10	Very high risk of harm	Very high
11+	Extreme risk of harm	Extreme

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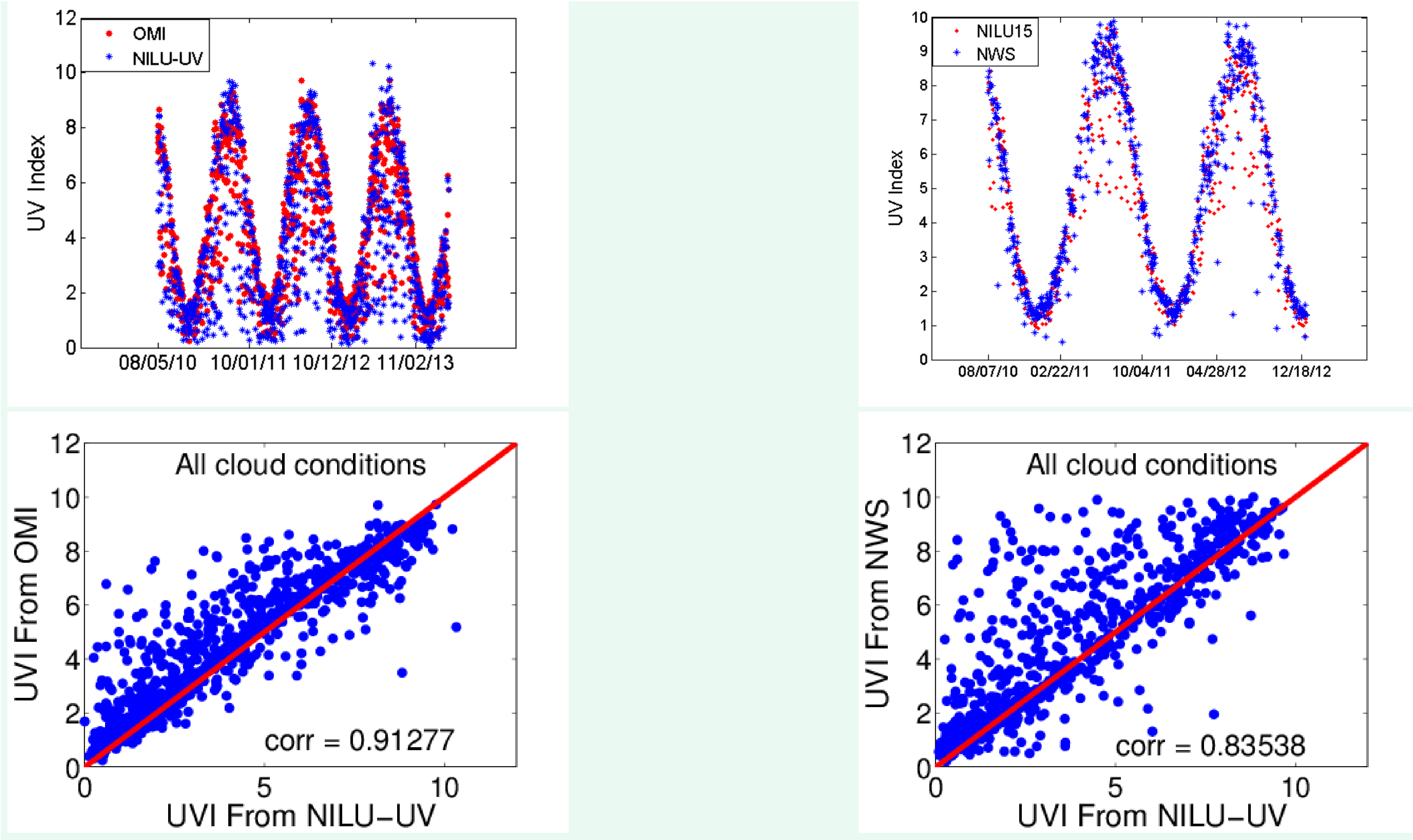
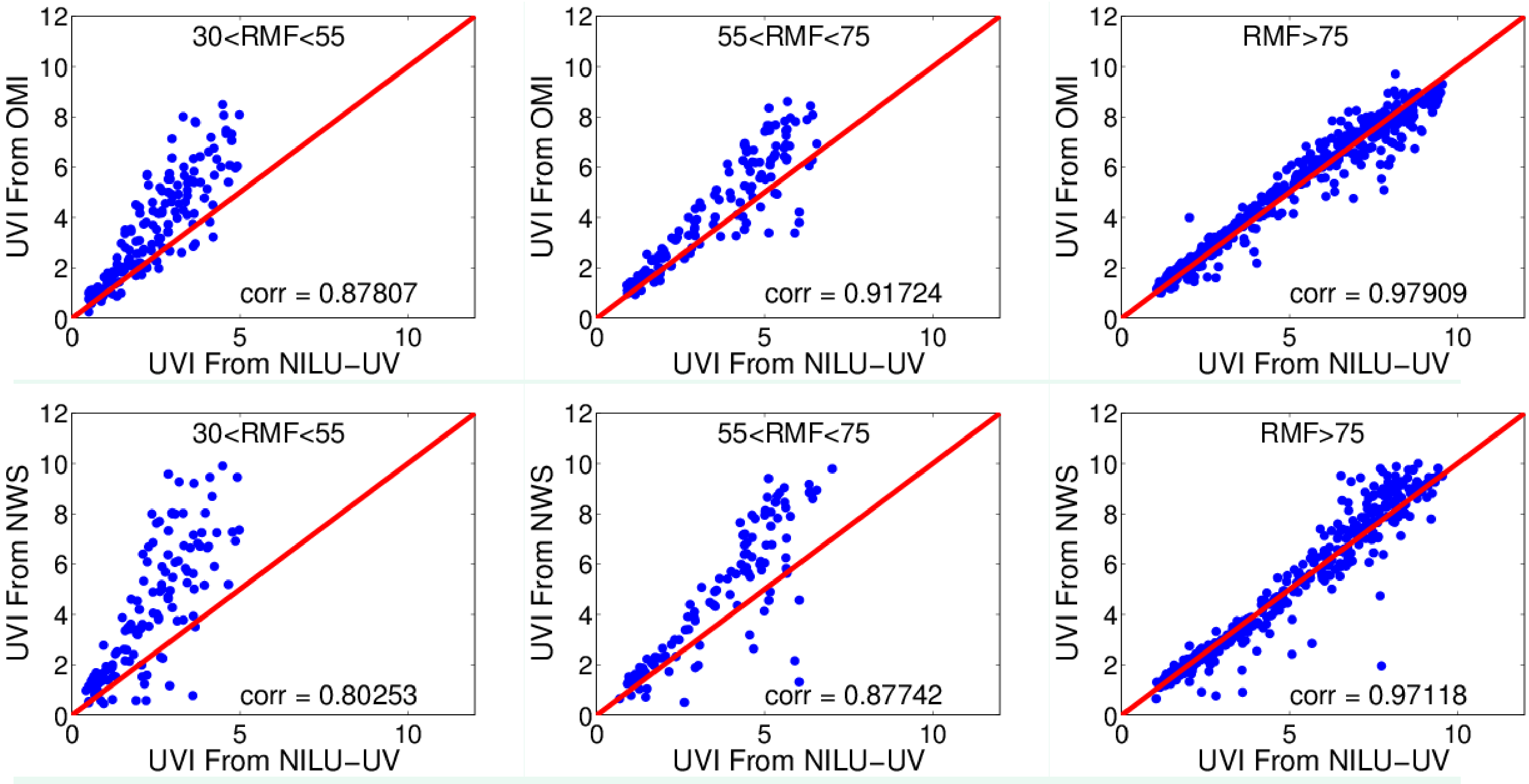
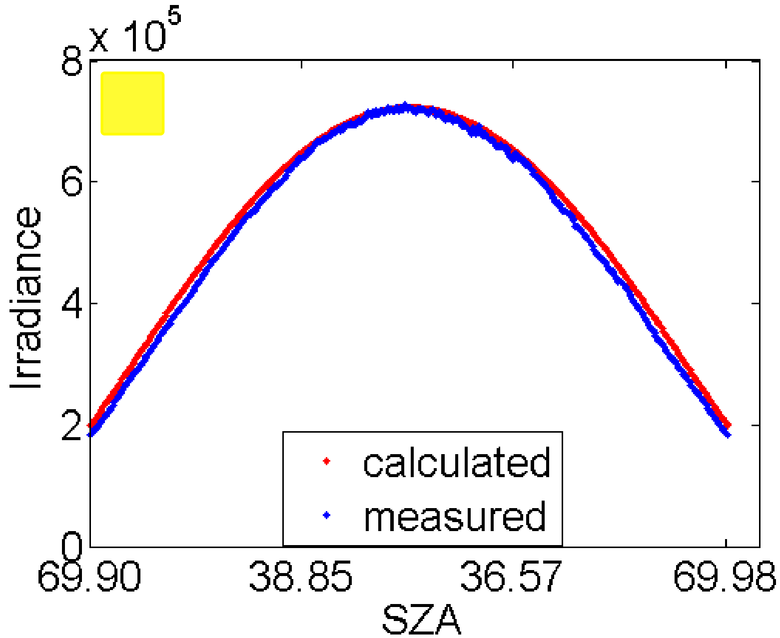
UVI (2)


OMI
NILU-UV
UV Index
08/05/10 10/01/11 10/12/12 11/02/13
NILU15
NWS
UV Index
08/07/10 02/22/11 10/04/11 04/28/12 12/18/12
All cloud conditions
UVI From OMI
UVI From NILU−UV
corr = 0.91277
All cloud conditions
UVI From NWS
UVI From NILU−UV
corr = 0.83538

UVI (3)


30<RMF<55
corr = 0.87807
UVI From OMI
UVI From NILU–UV
55<RMF<75
corr = 0.91724
UVI From OMI
UVI From NILU–UV
RMF>75
corr = 0.97909
UVI From OMI
UVI From NILU–UV
30<RMF<55
corr = 0.80253
UVI From NWS
UVI From NILU–UV
55<RMF<75
corr = 0.87742
UVI From NWS
UVI From NILU–UV
RMF>75
corr = 0.97118
UVI From NWS
UVI From NILU–UV

Retrieval of AOD (1)



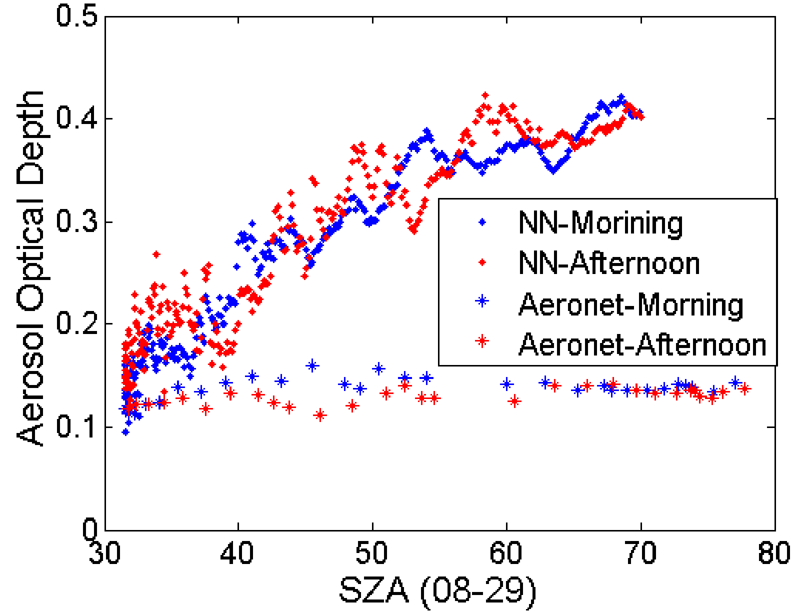


Figure 1: Left panel: a comparison of measured (blue) and computed (red) irradiances in the 340 nm channel on a cloud-free day. Right panel: a comparison of AODs derived from the NILU-UV data shown in the left panel and from AERONET data.

The discrepancies between the AODs derived from NILU-UV and AERONET data (Fig. 1, right) could be due to the imperfect cosine response of the sensor.

Retrieval of AOD (2)

- To correct for the imperfect cosine response the RTM was used to compute the irradiance versus solar zenith angle using the AOD value derived at noon.
- These computed irradiances were divided by the measured irradiances to obtain "cosine-corrected" irradiances.

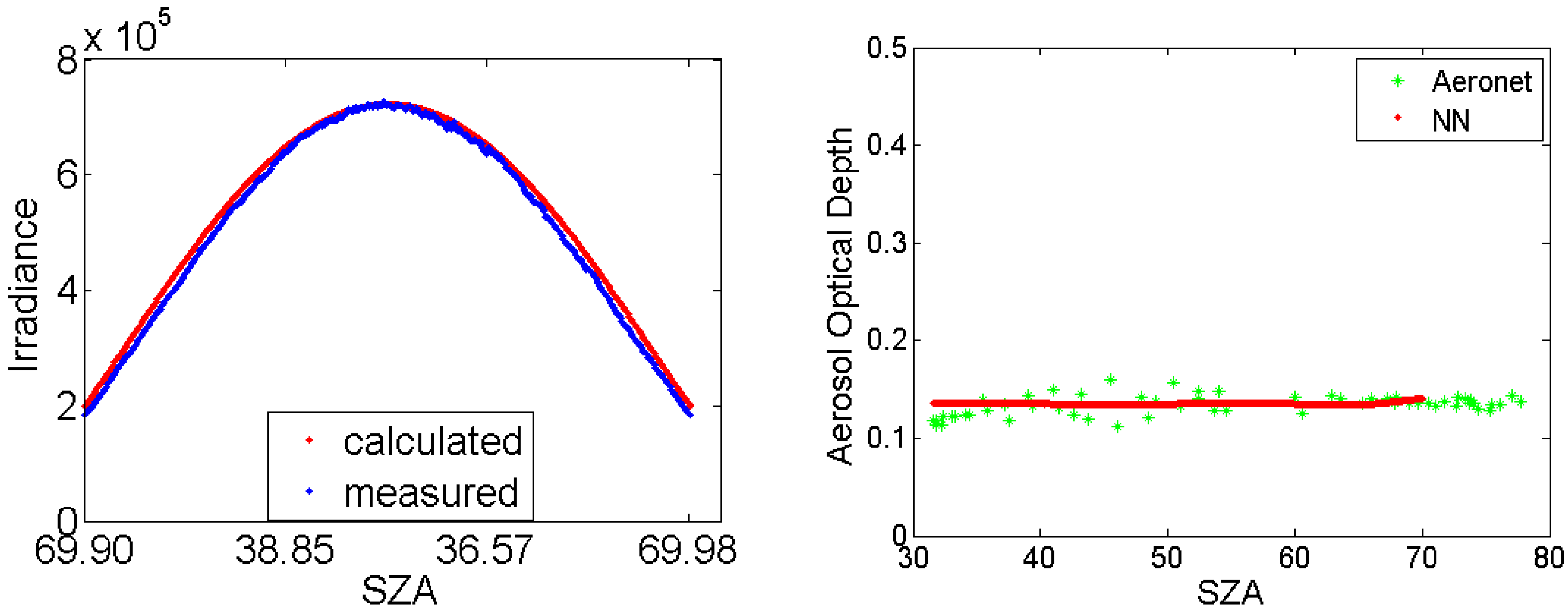


Figure 2: Left: Measured and modeled irradiances in the 340 nm channel on 08/29/2010. Right: AOD comparison on 08/29/2010 using "cosine-corrected" NILU-UV data.

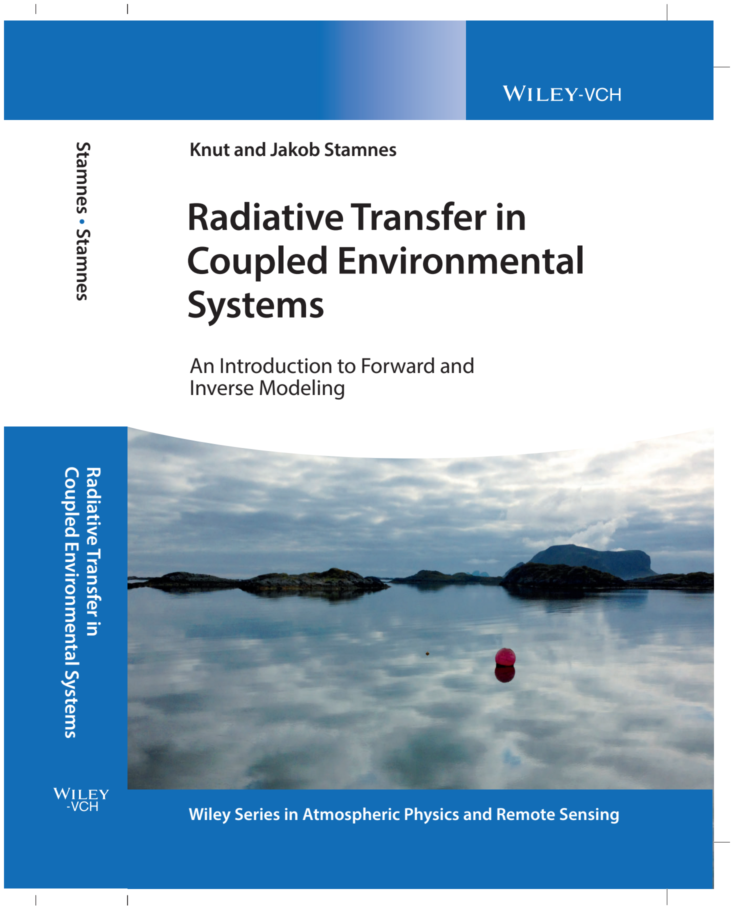
The red trace in the right part of Fig. 2 shows the AODs retrieved from the NILU-UV data using the "cosine-corrected" irradiances.

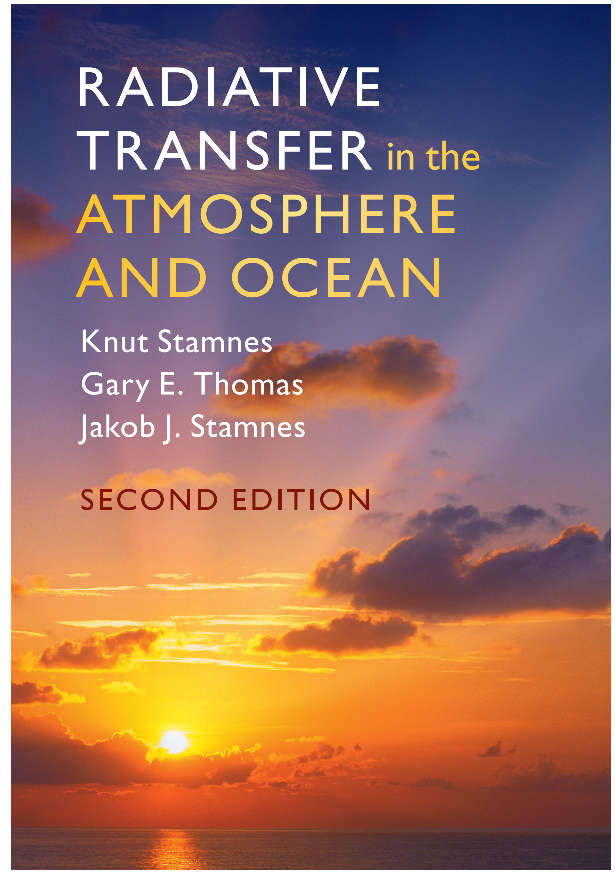
Summary and Outlook

The results may be summarized as follows:

- Both absolute and relative calibrations are essential prerequisites for high quality determinations of TOC, COD, and UVI values from MCI measurements.
- UVI values obtained from NILU-UV measurements and inferred from OMI data and NWS generally agree well in good weather (cloud-free) conditions.
- Simultaneous NN-retrieval of TOC and COD values leads to more accurate TOC values than those obtained by the LUT method.
- The TOC, COD, and AOD (cloud-free conditions) information obtained by MCIs can be used to estimate radiative forcing and hence the **impact of ozone, clouds, and aerosols** on the radiative energy balance:
- Future deployment of MCIs with **additional channels** at AERONET (and other) sites and analysis of such data in conjunction with AERONET and satellite remote sensing data can provide crucial information needed to **assess *trends* as well as the climate impact** of ozone, clouds, aerosols, and water vapor.

Questions – Comments – Suggestions – Further reading?





THANK YOU FOR YOUR ATTENTION!

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