UV-Indien Network

A network dedicated to the long-term monitoring of UV radiation in the Indian Ocean.

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Outline

1. Introduction
2. Calibration
3. Comparison between UV-OI Ground Based Measurements, Satellites Measurements and Modelling.
4. First characterisation of the UV in the Indian Ocean
5. Conclusion
6. Supplements.

Introduction: UV Indien Network

Network for the measurement of UV radiation and cloud cover in the south-western part of the Indian Ocean

- 9 stations in 5 countries of the Region and 8 scientific, institutional or meteorological partners:
  - LACy, Université de la Réunion, Réunion, France
  - IOGA, Institut de Géophysique d'Antananarivo, Madagascar
  - Institut Supérieur de Technologie de Diego Suarez, Madagascar
  - OPAR, Observatoire de Physique de l'Atmosphère de la Réunion, Réunion, France
  - Seychelles Meteorological Authority (SMA), Mahe, Seychelles
  - Agence Nationale de l'Aviation Civile et de la Météorologie, Moroni, Comores.
  - L'université des Comores, Moroni, Comores
  - Terre Australes et Antarctiques Françaises, St Pierre, Réunion, France

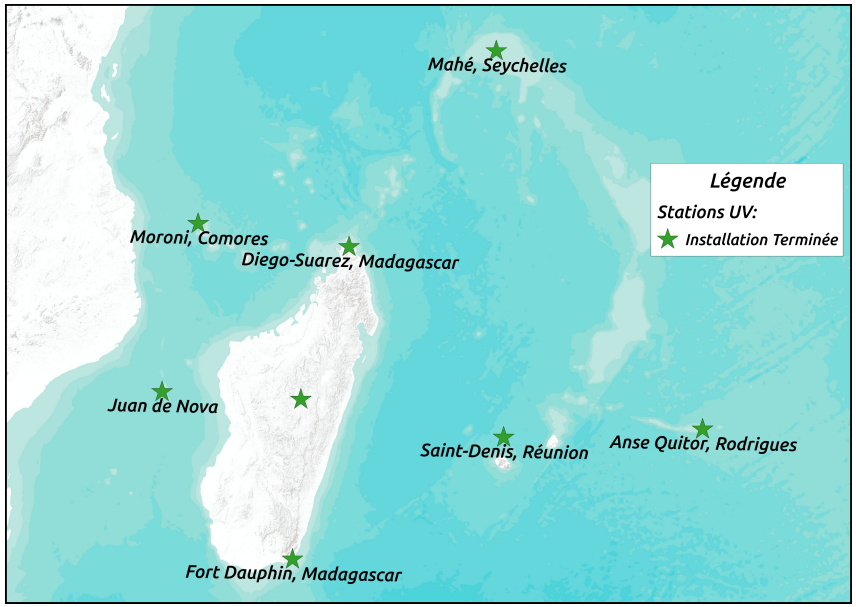


Figure: UV-Indien network map

Introduction (contd...)

Why monitor UV in the Indian Ocean ?

- CO2 is expected to accelerate the circulation of BDC (Butchart, 2014; WMO, 2018)
- An accelerated BDC circulation will induce a decrease of total ozone column in the tropics
- Decrease in mid-latitude UV and an increase in the tropics can be expected (Butler et al. 2016, Lamy et al. 2019)

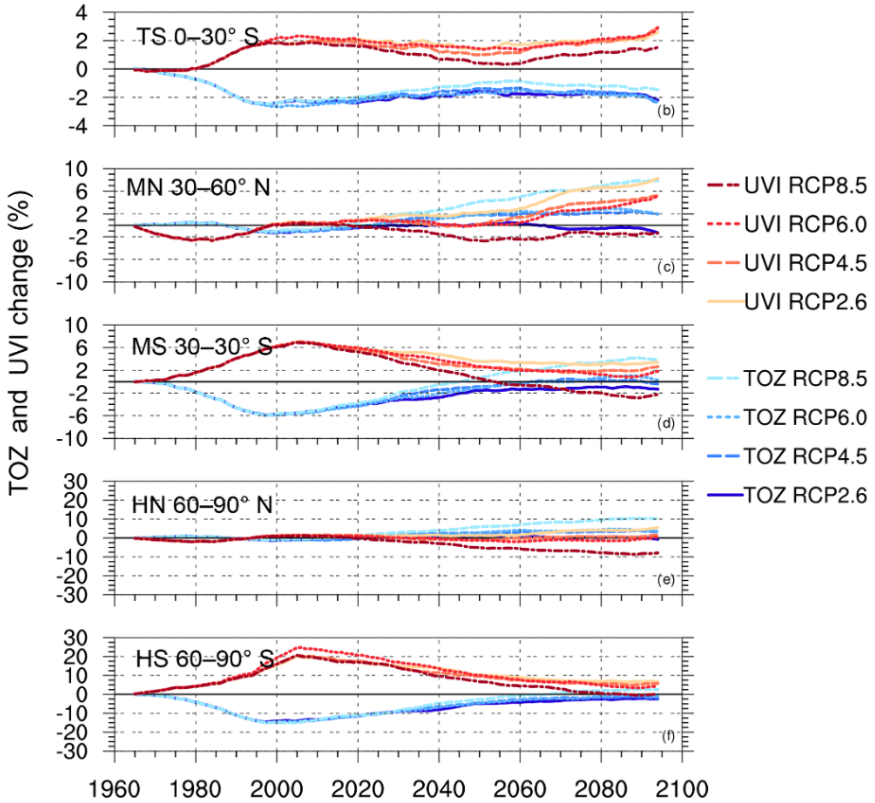


Figure: UV and Ozone Projection during the 21st Century. (Lamy et al., 2019)

Objectives

- The study of the annual and inter-annual variability of UVR over the whole Western Indian Ocean basin.
- Validation of the outputs of numerical models for UVR forecasting.
- Long-term monitoring of UV in the context of climate change and projected ozone depletion of 2 to 4% (Lamy et al., 2019).
- Satellite validation. The instruments of Juan, Seychelles and Antananarivo are involved in the validation of the TROPOMI satellite (Lakkala et al., 2020).

Stations of the UV-Indien Project

Station	Location	Coordinates	Altitude asl	Instrument	Data since	Frequency	UTC+
Saint-Denis	Reunion	20.902°S, 55.485°E	82m	BENTHAM DTMc 300	2009/12	15 min	+4
				Radiometer Kipp&Zonen UVS-E-T 15-0124	2016/12	5 min	
Maido	Reunion	21.079°S, 55.48°E	2200m	Radiometer Kipp&Zonen SUV-E 18-0020	2020/02	1 min	+4
Anse Quitor	Rodrigues	19.758°S, 63.368°E	32m	Radiometer Kipp&Zonen UVS-E-T 16-0158	2017/06	1 min	+4
				All Sky Camera	2019/09	1min	
Mahé	Seychelles	4,679 °S, 55.531 °E	15m	Radiometer Kipp&Zonen UVS-E-T 17-0207	2017/11	5 min	+4
Antananarivo	Madagascar	18.916°S, 47.565°E	1370m	Radiometer Kipp&Zonen UVS-E-T 16-0159	2016/12	5 min	+3
				All Sky Camera	2019/04	1 min	
Diego Suarez	Madagascar	12.28°S, 48.28°E	35m	Radiometer Kipp&Zonen SUV-E 18-0028	2019/11	1 min	+3
Fort Dauphin	Madagascar	25.028°S, 46.995°E	10m	Radiometer Kipp&Zonen SUV-E 18-0030	2020/01	1 min	+3
				All Sky Camera	2020/01	1 min	
Moroni	Comores	11.71°S 43.24°E	12m	Radiometer Kipp&Zonen SUV-E 18-0027	2019/12	1 min	+3
				All Sky Camera	2019/12	1 min	
Juan de Nova	France	17.054°S, 42.71°E	10m	Radiometer Kipp&Zonen SUV-E 18-0029	2019/04	1min	+3

Satellites and Model data used in this study.

Dataset	Platform	Type	Resolution	Field used for computation/calibration		References
				Ozone field used	Aerosol field used	
Bentham	Ground-Based	Spectrometer	dt = 15min	None	None	Brogniez et al., 2016
Radiometer K&Z	Ground-Based	Radiometer	dt = 1 or 5 min	OMI	None	Cadet et al., 2020
OMUVBd	Satellite (OMI)	Spectrometer (Measurement at 360nm then Table Look-Up)	Daily (Overpass/Solar Noon) 1.0 x 1.0 deg.	OMI	OMI (Krotkov et al., 1998) (Herman et al., 1999)	Tanskanen et al., 2006 Arola et al, 2009 Levelt et al., 200
TROPOMI	Satellite	Spectrometer (Measurement at 354nm then Table Look-Up)	Daily (Overpass/Solar Noon)	TROPOMI L2 total ozone column product (Garane et al., 2019).	Aerosol Climatology (Kinne et al., 2013)	Lindfors et al., 2018 Lakkala et al. 2020
METOP	Satellite (GOME-2)	Spectrometer	Daily (local solar noon) 0.5 x 0.5 deg.	GOME-2A TOZ	MODIS Level 3	Kujanpää and Kalakoski, 2015
CAMS	Model	Modelling	dt = 6 hours	Modelled	Modelled	Bozzo et al., 2015
TEMIS	Model	Modelling	Daily (local solar noon) 0.5 x 0.5 deg.	SCIAMACHY GOME-2A MSR	No direct correction	Zempila et al. , 2017

Calibration

UV-Indien Radiometers are recalibrated with a frequency of $\sim$ 2 year.

Calibration Procedure

- Radiometers repositionned on the Moufia super measurement site (University of Reunion Island - coordinates)
- Co-located with the BENTHAM spectrometer, during a period of 3 or 4 months
- Recalibration with the BENTHAM spectrometer as a reference
- Bentham UV spectrometer, itself is calibrated every 3 months (Brogniez et al., 2016)
- Repositionning of the calibrated radiometers on their original site.

Radiometers Location and Calibration

Radiometer	Current Calibration	Next Calibration Date	Current Location
UVS-E-T 15-0124	Davos	05/2020	Saint-Denis
UVS-E-T 16-0159	Manufacturer	06/2020	Antananarivo
UVS-E-T 16-0158	Manufacturer	06/2020	Anse Quitor
UVS-E-T 17-0207	Manufacturer	06/2020	Mahé
SUV-E 18-0020	Bentham	03/2022	Maido
SUV-E 18-0028	Bentham	03/2022	Diego Suarez
SUV-E 18-0030	Bentham	03/2022	Fort Dauphin
SUV-E 18-0027	Bentham	03/2022	Moroni
SUV-E 18-0029	Bentham	03/2022	Juan de Nova

SUV-E Radiometers Recent Calibration Results

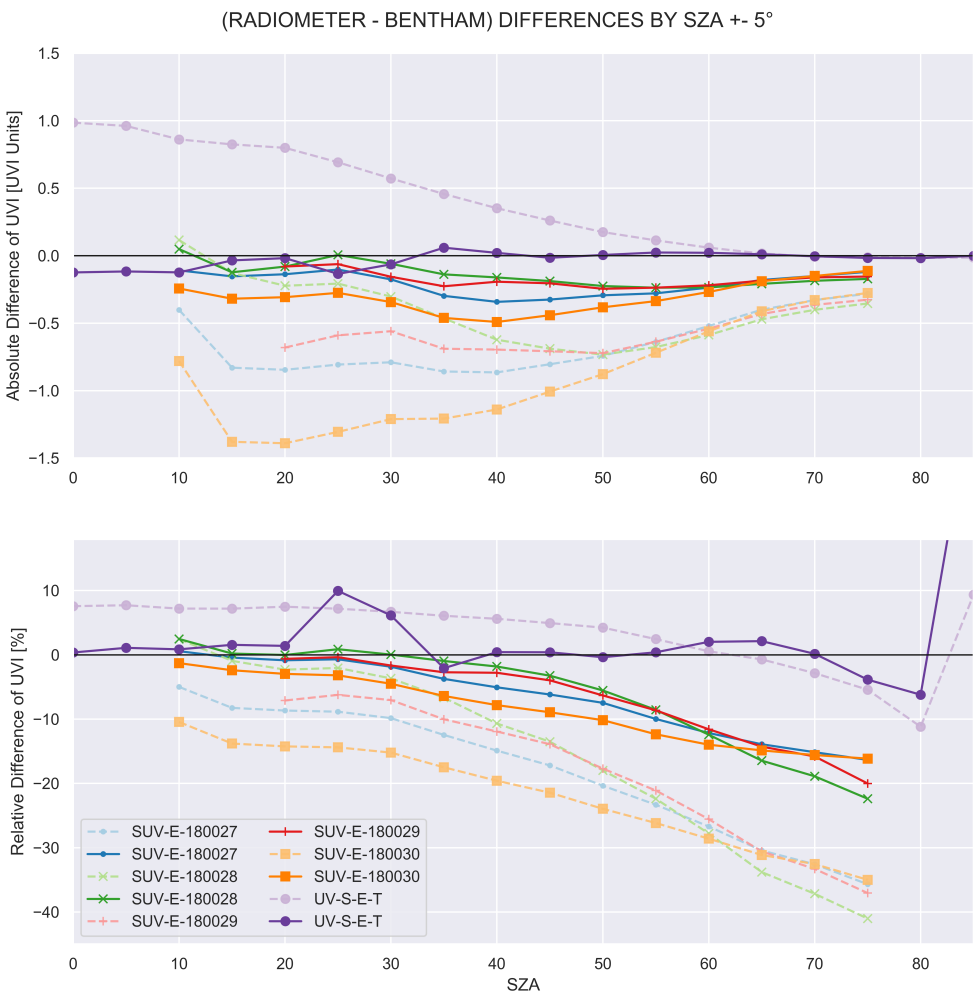


Figure: Absolute and Relative Difference Before (transparent dashed line) and After (plain line) Recalibration of the Radiometers

- Less than 10% Relative Difference at All SZA After Calibration
- Less than 0.5 UVI Units in Absolute Difference (AD)
- SZA depandancy is attenuated but remains for RD.

Correlation at ST-DENIS

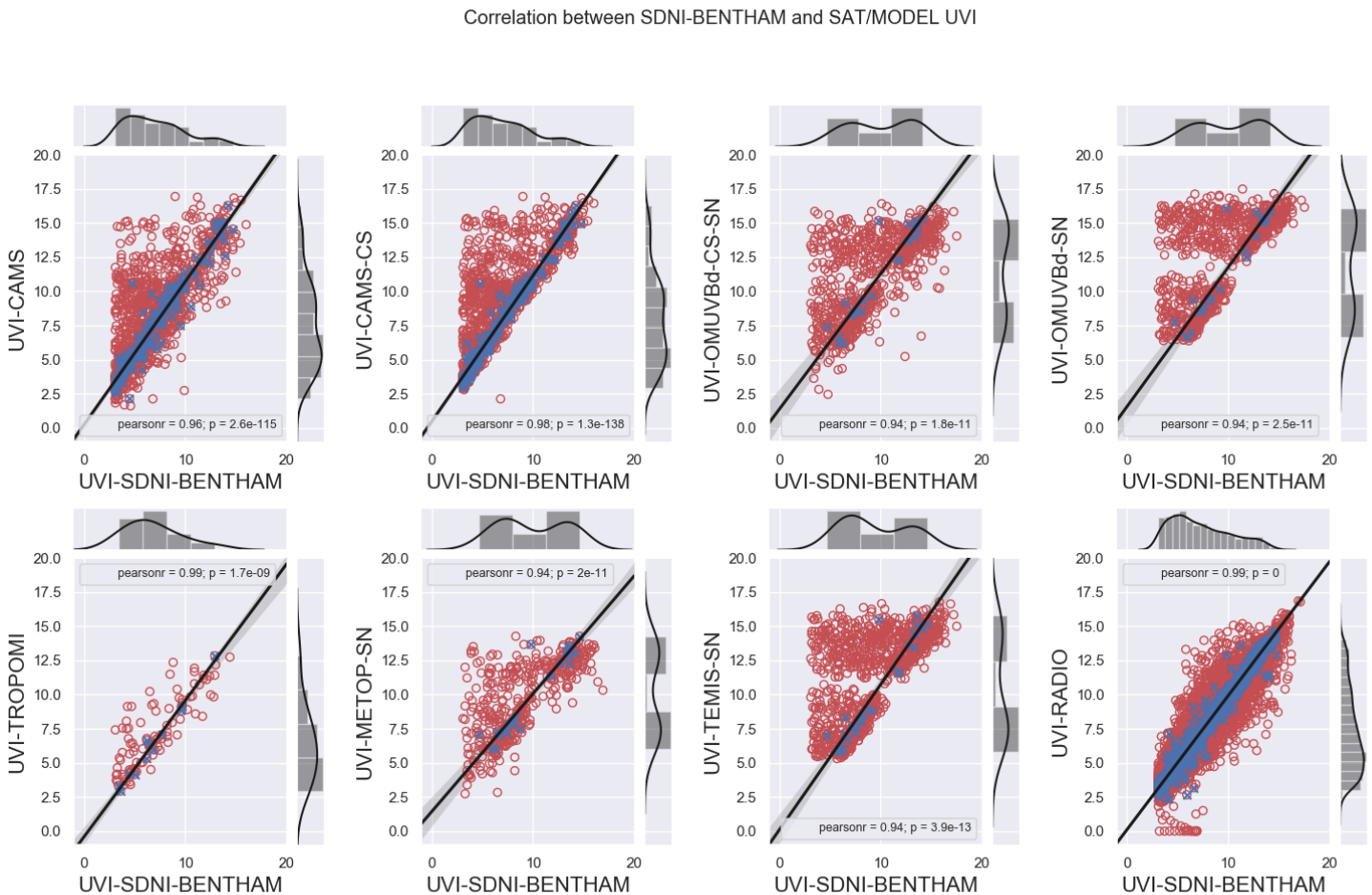
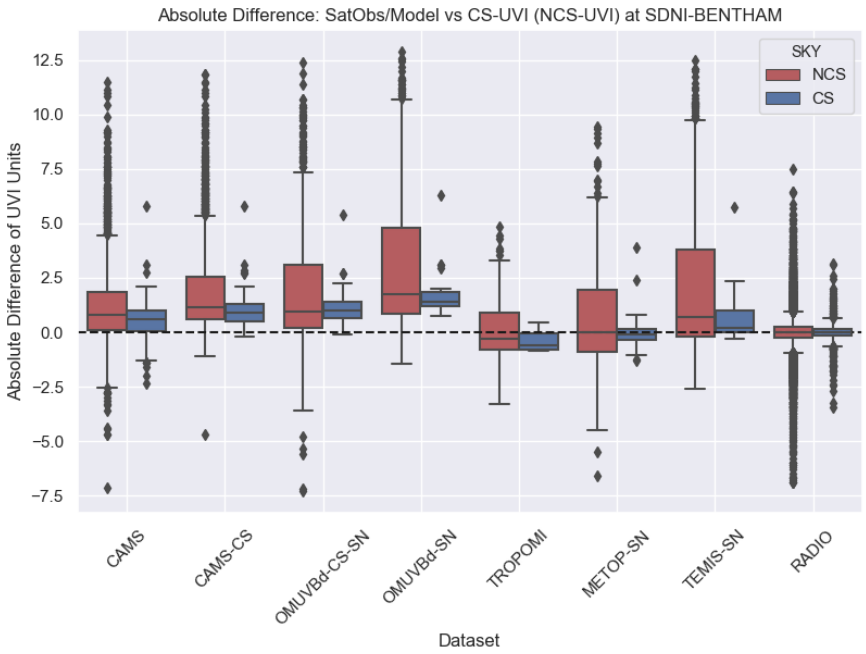


Figure: Correlation between UVI- BENTHAM and Sat/Model Measurements at ST-DENIS

Differences at ST-DENIS



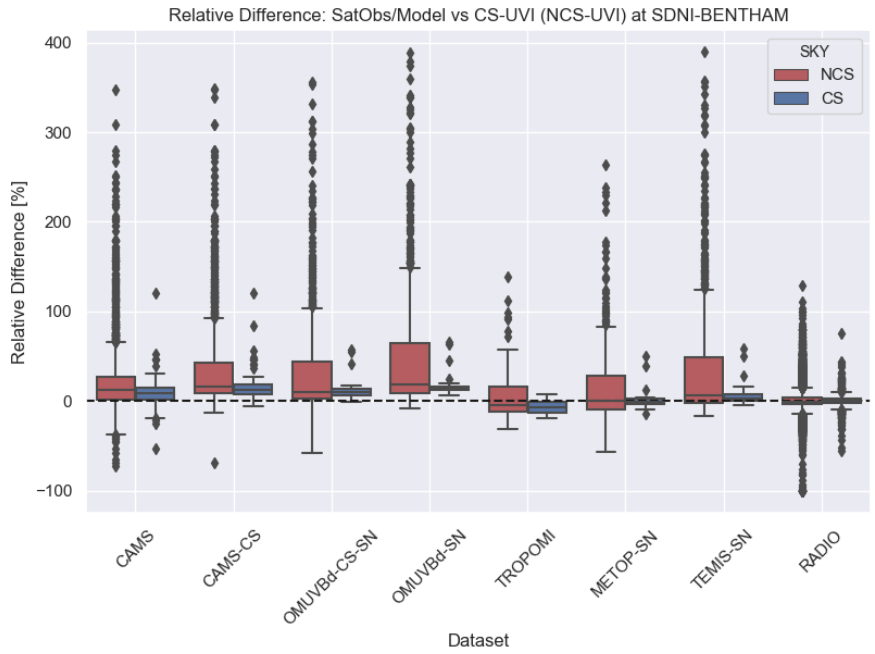


Figure: Boxplot of differences between UVI-BENTHAM and Sat/Model Measurements at ST-DENIS

Table

	SAT/MODEL Comparison Against CS-UVI (NCS-UVI) at SDNI-BENTHAM							
STATS	UVI-CAMS	UVI-CAMS-CS	UVI-OMUVBd-CS-SN	UVI-OMUVBd-SN	UVI-TROPOMI	UVI-METOP-SN	UVI-TEMIS-SN	UVI-RADIO
MEAN-AD	0.58 +- 0.87 (1.27 +- 2.15)	0.95 +- 0.68 (1.97 +- 2.18)	1.29 +- 1.11 (1.88 +- 2.77)	1.78 +- 1.16 (3.10 +- 3.04)	-0.43 +- 0.41 (0.15 +- 1.62)	0.07 +- 1.08 (0.61 +- 2.47)	0.70 +- 1.23 (2.05 +- 3.02)	-0.02 +- 0.39 (-0.01 +- 0.81)
MEAN-RD [%]	8.57 +- 14.81 (24.15 +- 46.17)	14.52 +- 13.08 (35.90 +- 49.71)	14.64 +- 15.07 (32.76 +- 56.30)	19.74 +- 15.67 (49.09 +- 66.42)	-7.02 +- 7.30 (7.64 +- 31.61)	2.55 +- 14.15 (16.39 +- 44.81)	7.78 +- 14.82 (35.53 +- 62.84)	0.02 +- 6.02 (0.59 +- 11.92)
MEDIAN-AD	0.62 (0.82)	0.91 (1.15)	1.02 (0.97)	1.42 (1.75)	-0.60 (-0.30)	-0.12 (-0.01)	0.21 (0.72)	-0.01 (-0.02)
MEDIAN-RD [%]	8.57 (12.44)	12.54 (16.58)	10.37 (10.51)	14.10 (18.10)	-7.03 (-4.95)	-0.98 (-0.06)	2.39 (6.89)	-0.08 (-0.41)
NDATA	198 (1490)	198 (1490)	23 (889)	23 (889)	12 (105)	23 (445)	27 (1084)	2096 (15472)

Figure: Boxplot of differences between UVI-BENTHAM and Sat/Model Measurements at ST-DENIS

- The differences shows UVI overestimation for CAMS, CAMS-CS, OMUVBd, OMUVBd-CS and TEMIS.
- For non-clear sky conditions, median overestimation ranges between 0.82 (CAMS) up and up to 1.85 UVI Units (OMUVBd).
- For clear-sky conditions, these differences decreases for CAMS, CAMS-CS, OMUVBd, and TEMIS. It does not change for OMUVBd-CS.

Differences between ST-DENIS BENTHAM and Sat/Model

- For non-clear sky conditions, TROPOMI, METOP and RADIO shows the closest median differences of UVI with values of -0.30, 0.01 and 0.02 respectively.
- For clear-sky conditions, TROPOMI and METOP show higher median values.
- It is expected for the RADIO to be aligned with the BENTHAM since it has been recalibrated with the BENTHAM measurements.
- Mean values follow the same pattern than median values for every dataset. We can note the presence of a significant number of outliers in non-clear conditions, most of theses outliers does not appear in clear-sky conditions. These outliers were also shown on the correlation figure.

UVI Climatology

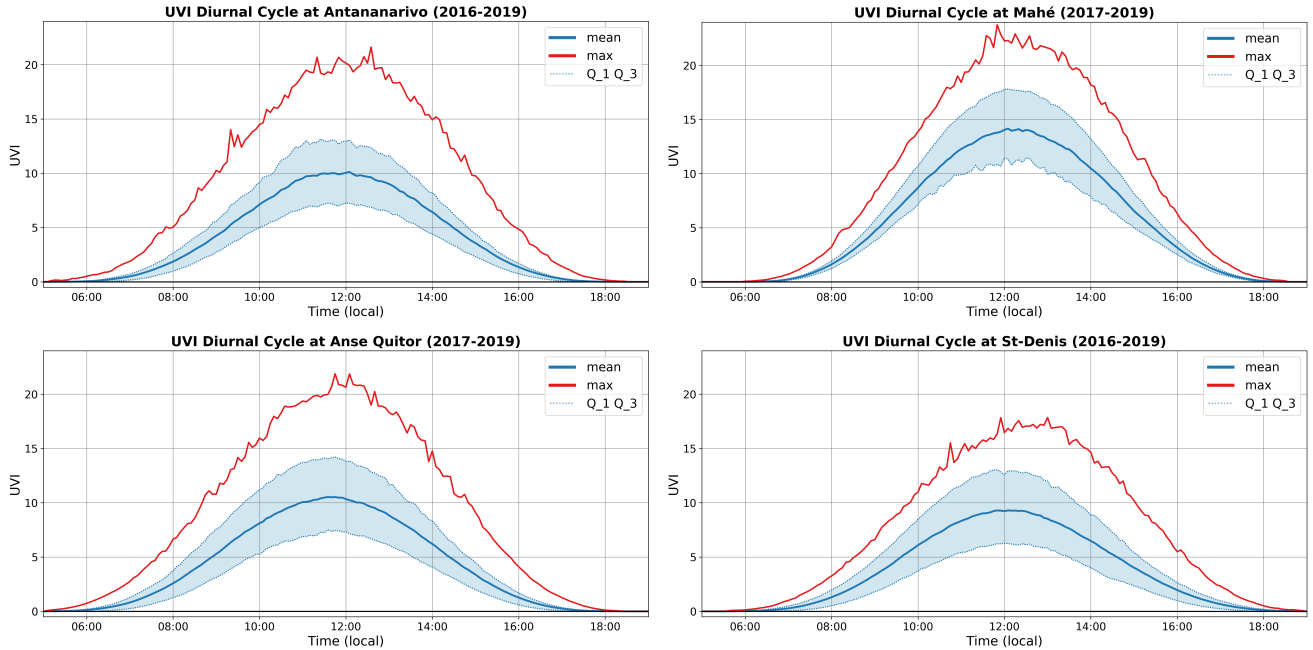


Figure: Diurnal Cycle of UVI at ST-DENIS. Mean UVI in blue, Max UVI in red, First and Third Quartile delimit the shade blue area.

UVI Climatology

- Mean UVI at local solar noon ranges between about 10 (Antananarivo, Plaine Corail, St-Denis) and up to about 14 UVI Units (Mahé, Seychelles)
- Difference is due to the latitude of theses stations, Antananarivo, Plaine Corail and St-Denis are at around 20° South, Mahé is at 4.6° South.
- At Mahé, SZA are always high during the year which induce higher Mean UVI.
- Max UVI can be as high as $\tilde{2}0$ UVI Units for all four stations.

Cloud measurements.

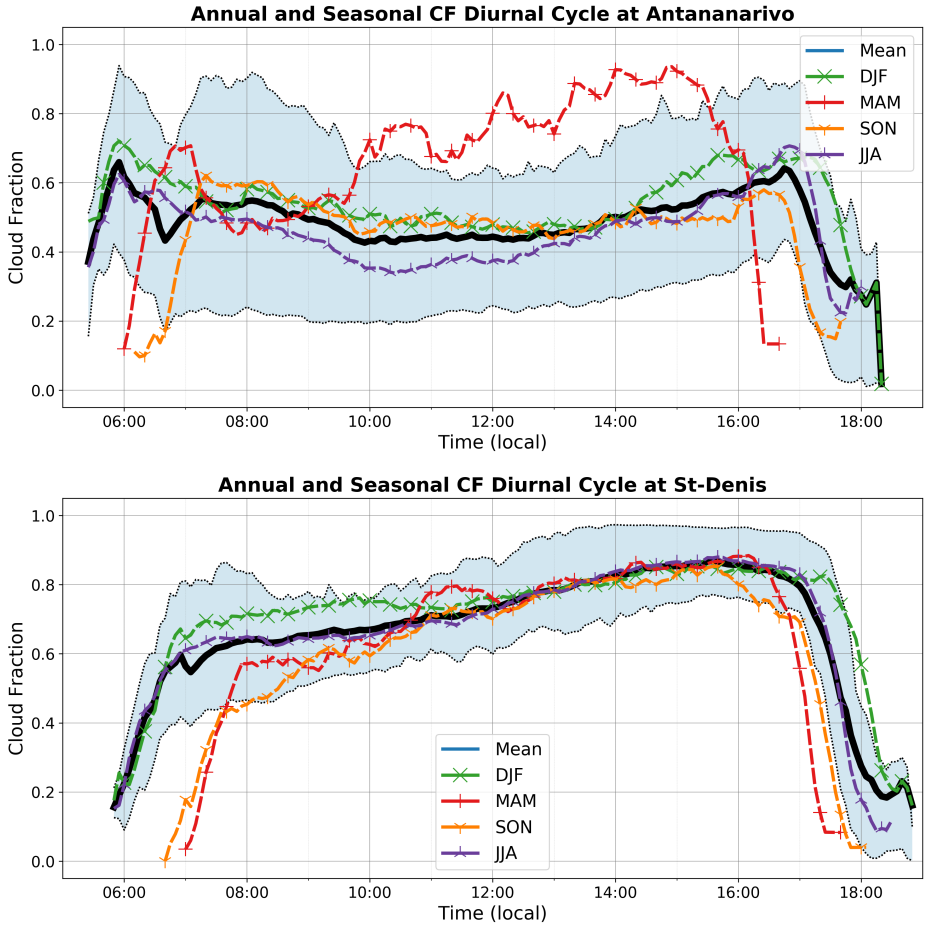


Figure: Diurnal Cycle of CF at ST-DENIS and ANTANANARIVO. Annual Mean CF in black, First and Third Quartile delimit the shade blue area. Seasonnal Mean in greed (DJF), red (MAM), orange(SON) and purple (JJA).

Cloud measurements.

- Over St-Denis the mean diurnal cycle presents low value of CF during the morning and a rising CF during the day
- St-Denis is located on the northern part of Reunion Island
- Reunion Island is a mountainous island under the influence of the southeast trade winds which induce clouds formation on the southern part of the island during the morning.
- During the day, the clouds tends to overflow over the rest of the island which induce a rising CF during the day.
- Over Antananarivo, CF tends to be high on the morning, decrease throught the day and increase again later in the day.
- Over Antananarivo, the MAM period is caracterized by high CF starting at 10AM.

Conclusion

- 2016: Deployment of the first measurement sites (Reunion Island, Madagascar, Seychelles, Rodrigues) in 2016.
- 2019: Extension of this network to 4 other sites (Juan de Nova, Diego Suarez, Fort Dauphin and Grande Comoros)
- The first intercomparison results between UV-Indien Ground-Based Instruments and Satellites or Modelled UVI shows absolute differences between -0.5 to 1.78 UVI Units and relative differences between -7.02 to 19.74 % in clear-sky conditions
- Non-clear-sky conditions presents significant discrepancy between ground-based instruments and satellites/model
- UVI along with Clouds measurements will allows us to understand UVI variability in this region (Notably Extreme Maximas of UVI due to fractionnal cloud cover) and the discrepancy between Satellites/Model and Ground-Based measurements

Supplements

- Correlation Figures for the remaining stations (Antananarivo, Plaine Corail, Mahé)
- Boxplot of AD and RD for the Remaining stations

This research and UV Indien Network are funded jointly by European cooperation programme PO InterregV, Regional Council of Reunion Island and University of Réunion Island.

Correlation at Antananarivo, Madagascar

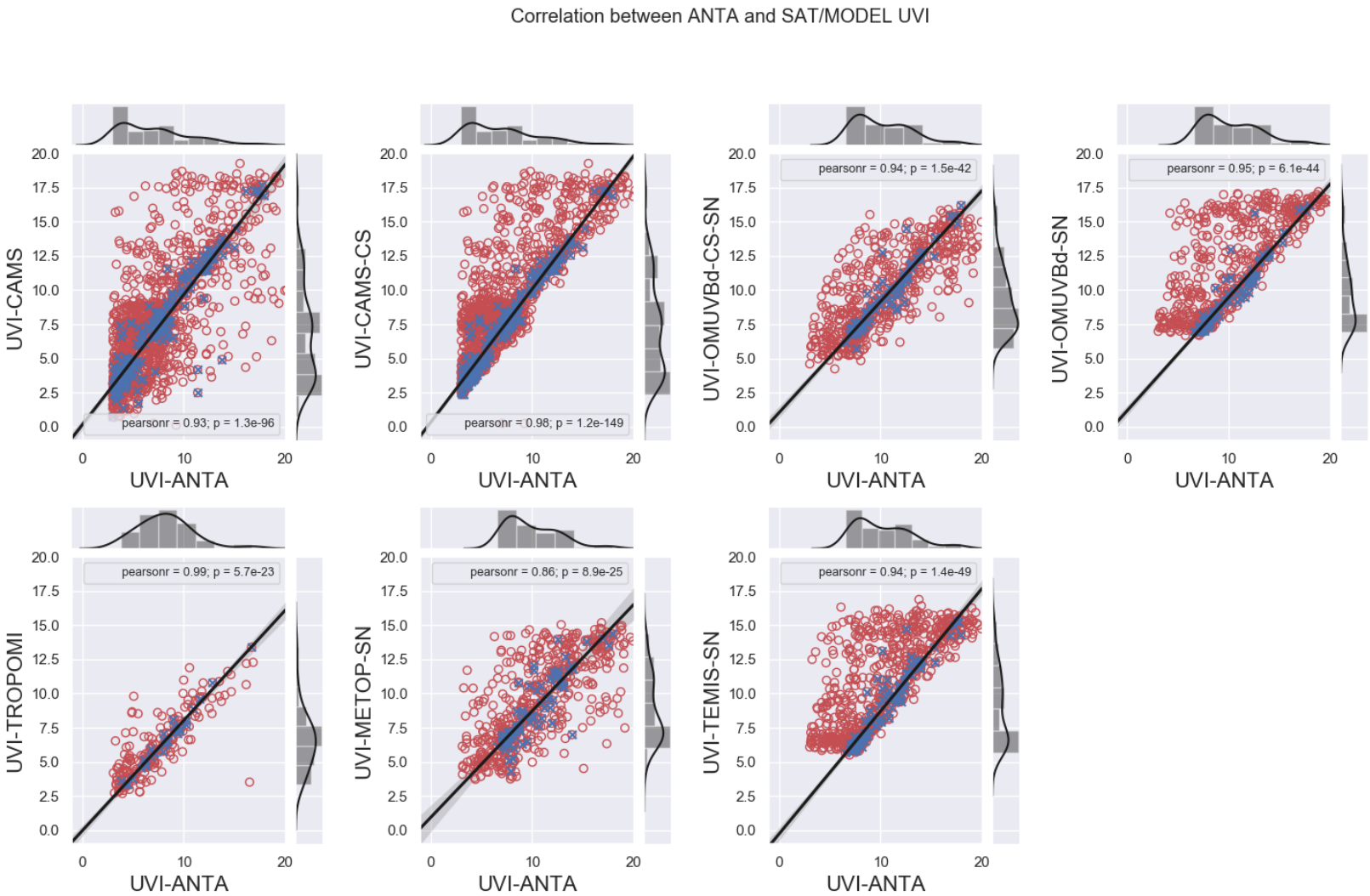


Figure: Correlation between ground-based UVI and Sat/Model Measurements Antananarivo, Madagascar

Correlation at Plaine Corail, Rodrigues

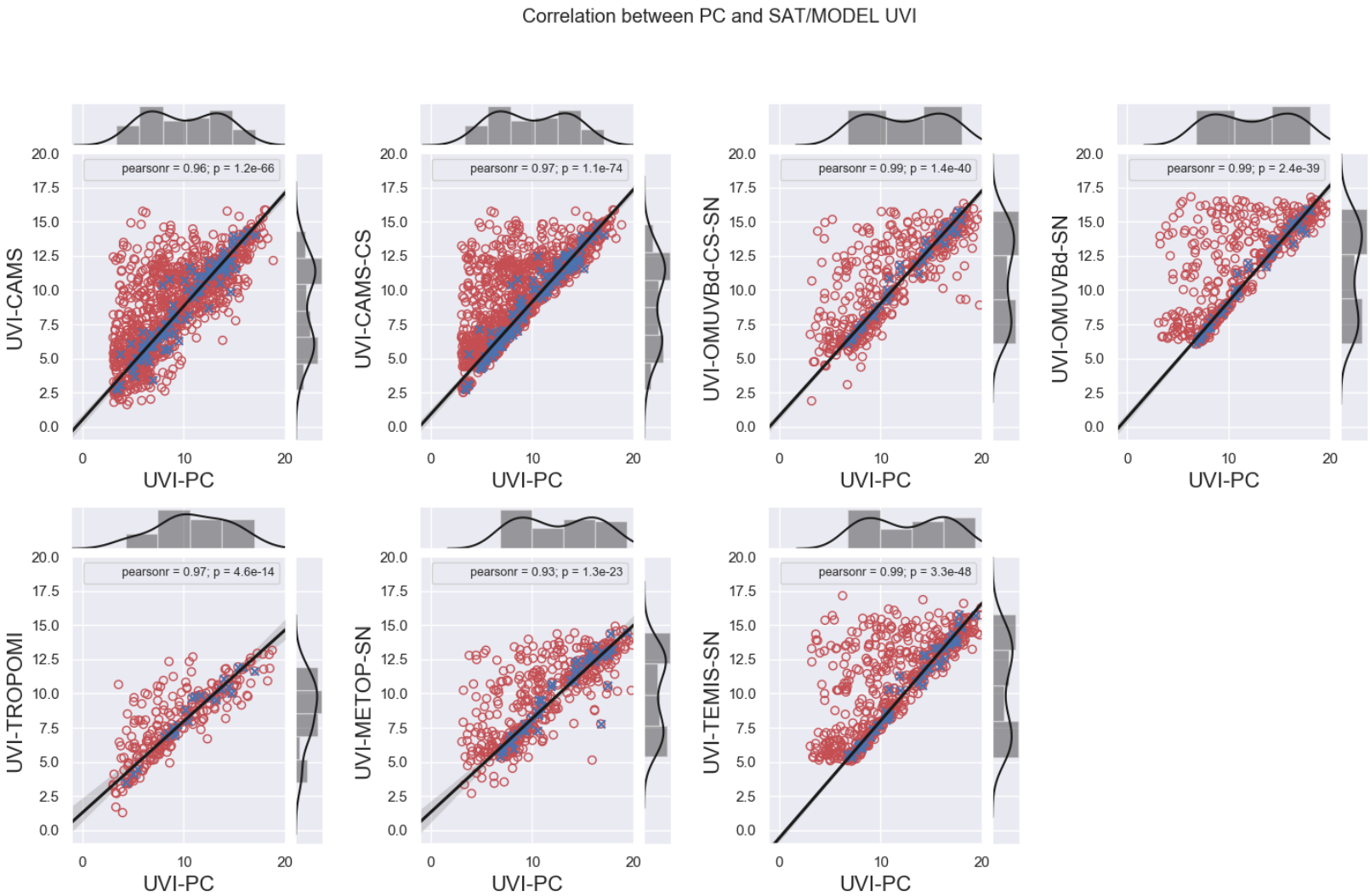


Figure: Correlation between ground-based UVI and Sat/Model Measurements Plaine Corail, Rodrigues

Correlation at Mahe, Seychelles

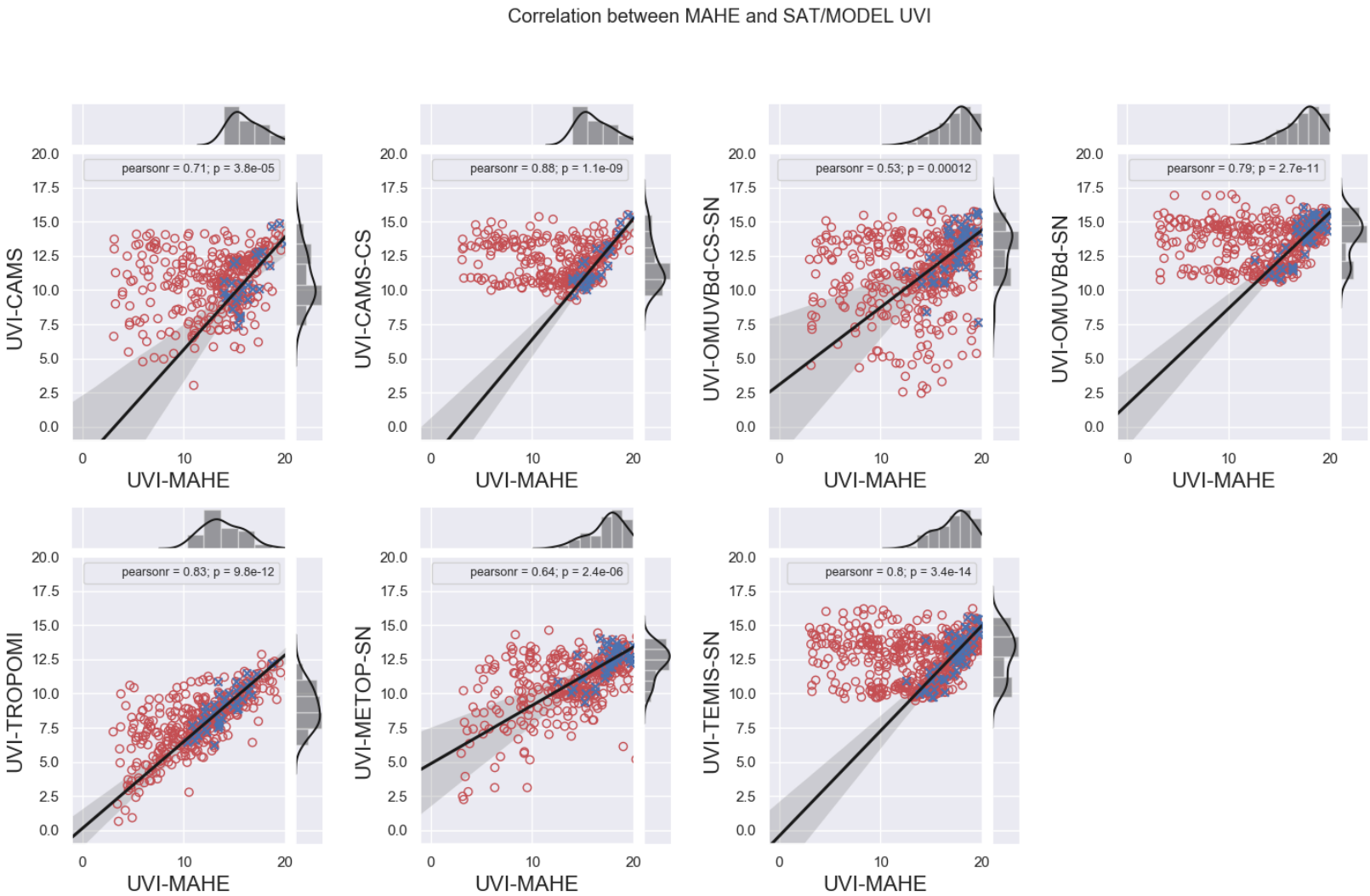
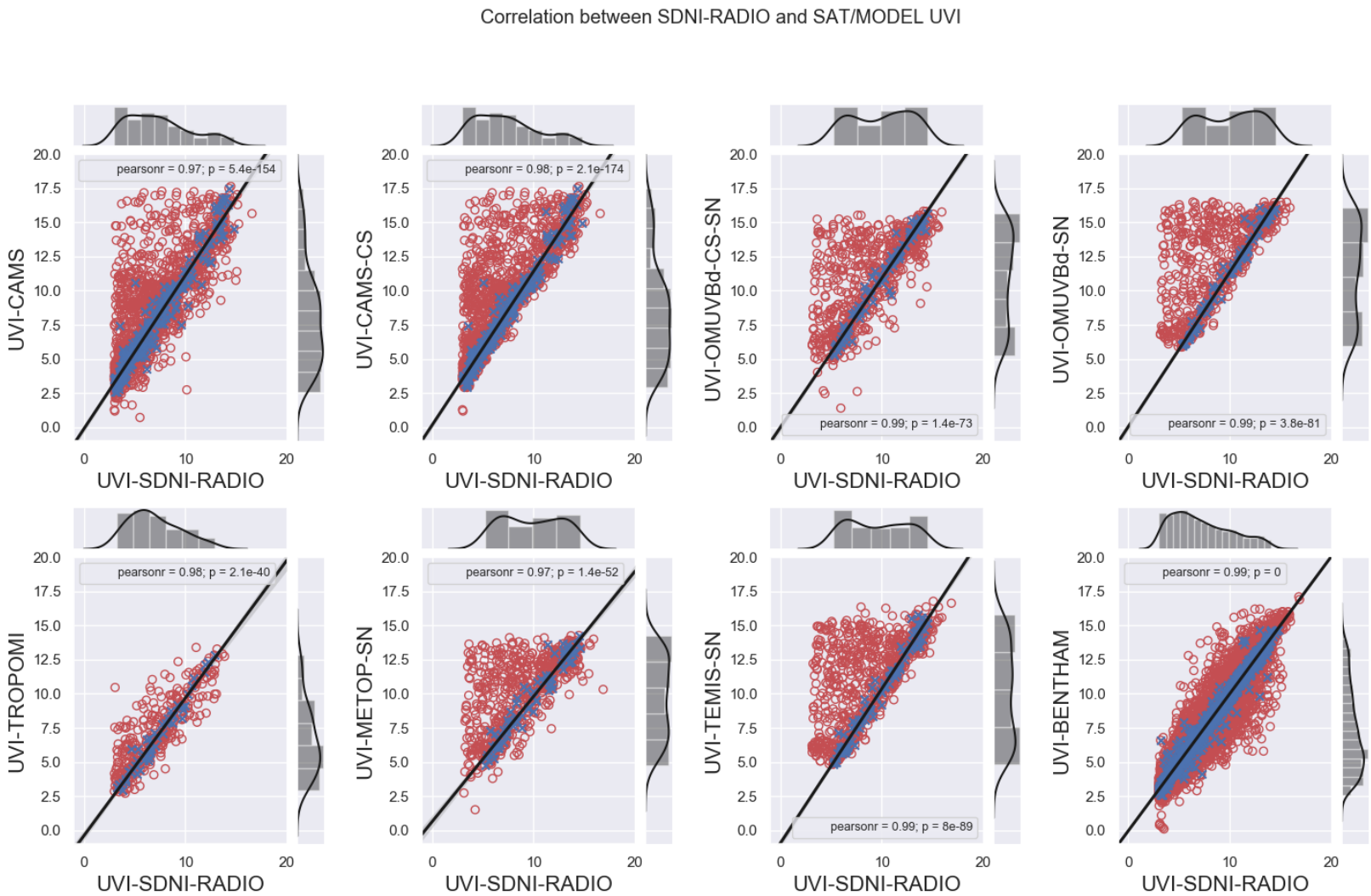
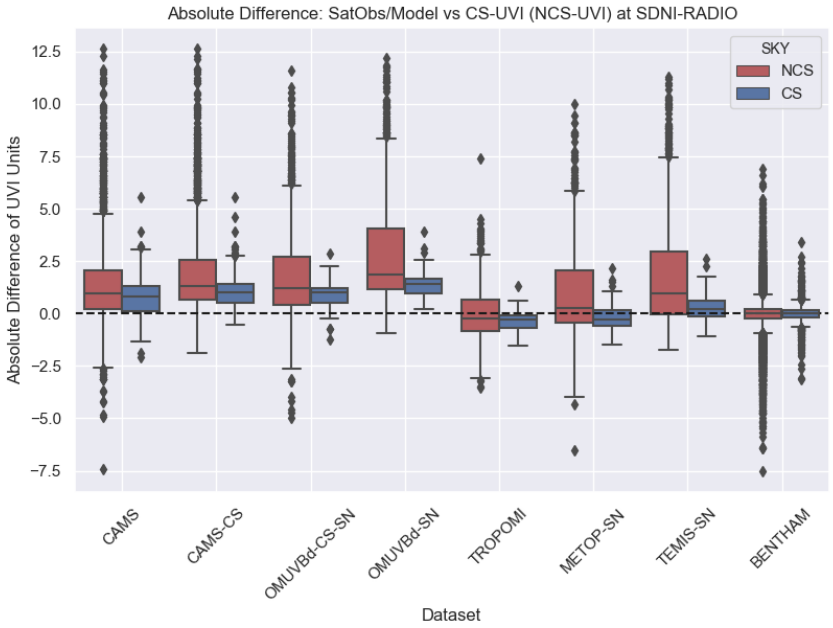


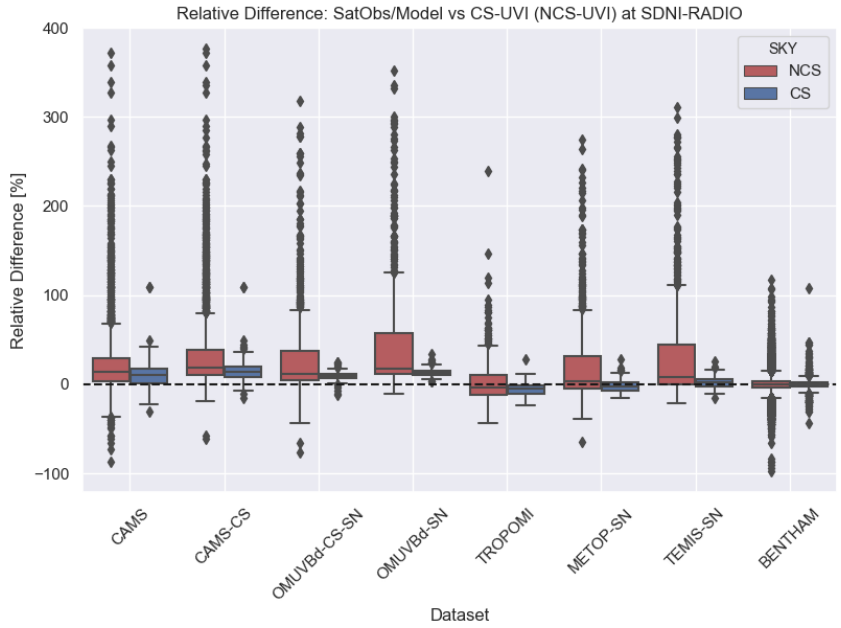
Figure: Correlation between ground-based UVI and Sat/Model Measurements at at Mahe, Seychelles

Correlation at Saint-Denis (RADIO), Reunion



AD and RD at Saint-Denis (RADIO), Reunion

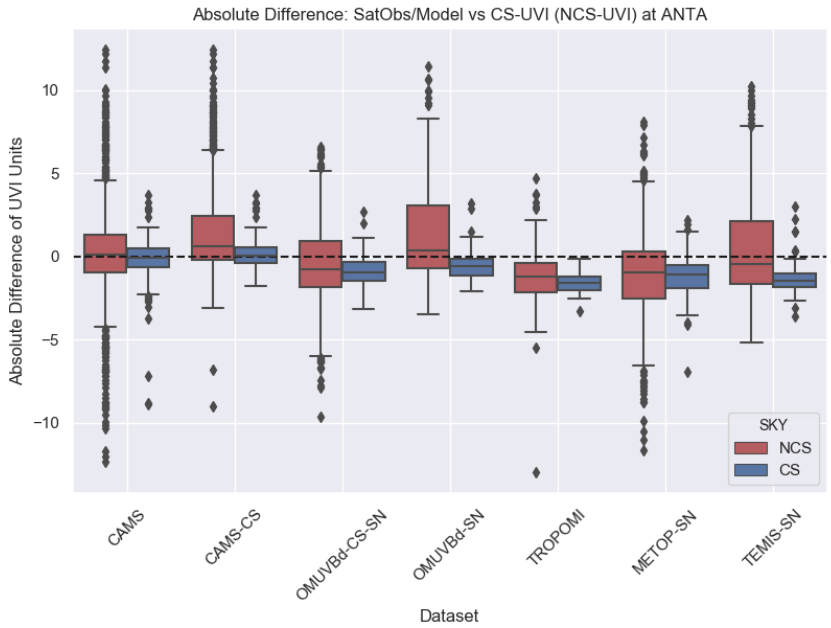


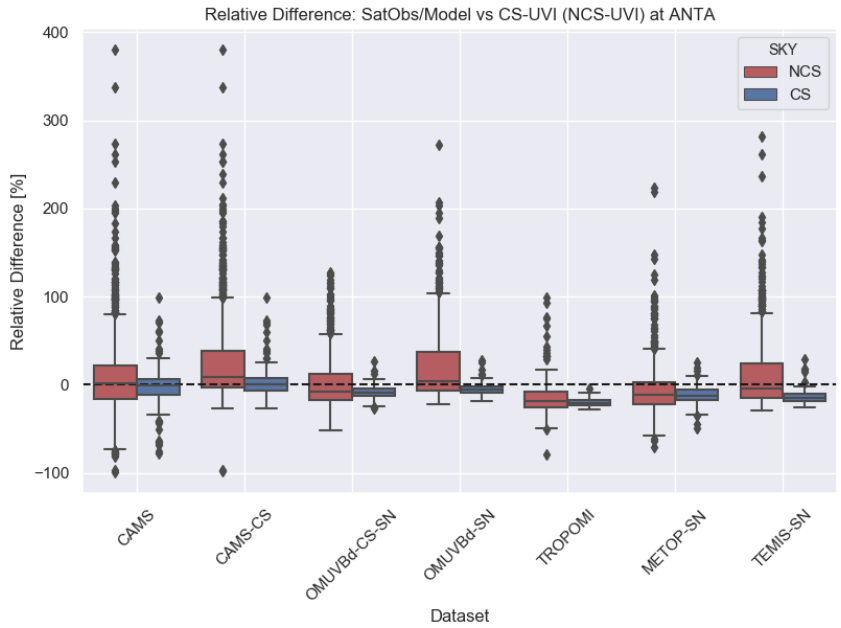


	SAT/MODEL Comparison Against CS-UVI (NCS-UVI) at SDNI-RADIO							
STATS	UVI-CAMS	UVI-CAMS-CS	UVI-OMUVBd-CS-SN	UVI-OMUVBd-SN	UVI-TROPOMI	UVI-METOP-SN	UVI-TEMIS-SN	UVI-BENTHAM
MEAN-AD	0.80 +- 0.98 (1.46 +- 2.24)	1.08 +- 0.84 (2.07 +- 2.22)	0.90 +- 0.62 (1.88 +- 2.50)	1.38 +- 0.61 (2.99 +- 2.69)	-0.34 +- 0.50 (0.01 +- 1.43)	-0.19 +- 0.71 (1.08 +- 2.47)	0.31 +- 0.67 (1.95 +- 2.71)	0.01 +- 0.38 (-0.02 +- 0.79)
MEAN-RD [%]	10.52 +- 14.88 (25.77 +- 46.60)	14.99 +- 12.68 (35.86 +- 48.86)	8.90 +- 6.10 (30.91 +- 51.57)	13.79 +- 4.92 (45.84 +- 59.79)	-5.44 +- 8.25 (3.89 +- 28.59)	-1.36 +- 7.62 (21.73 +- 47.31)	2.19 +- 7.07 (32.77 +- 56.13)	0.08 +- 6.08 (-0.15 +- 11.02)
MEDIAN-AD	0.80 (0.96)	1.01 (1.30)	1.01 (1.19)	1.41 (1.89)	-0.30 (-0.24)	-0.26 (0.29)	0.20 (0.94)	-0.00 (0.01)
MEDIAN-RD [%]	10.53 (13.93)	14.17 (19.00)	8.82 (11.53)	12.91 (18.03)	-4.86 (-3.69)	-2.48 (3.33)	2.16 (8.41)	-0.05 (0.12)
NDATA	253 (1856)	253 (1856)	96 (754)	96 (754)	57 (388)	85 (711)	112 (903)	2109 (15635)

Figure: Boxplot of differences between ground-based UVI-RADIO and Sat/Model Measurements at ST-DENIS

AD and RD at Antananarivo, Madagascar

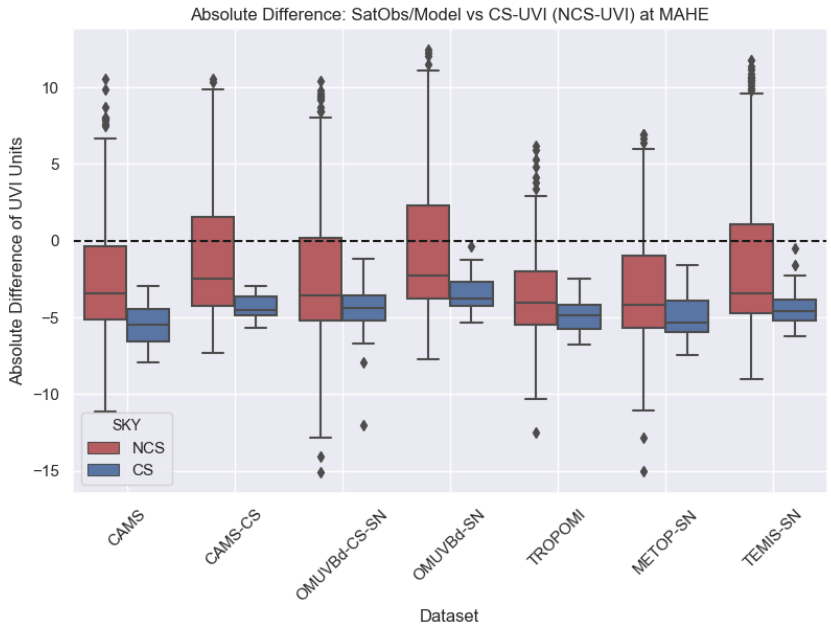


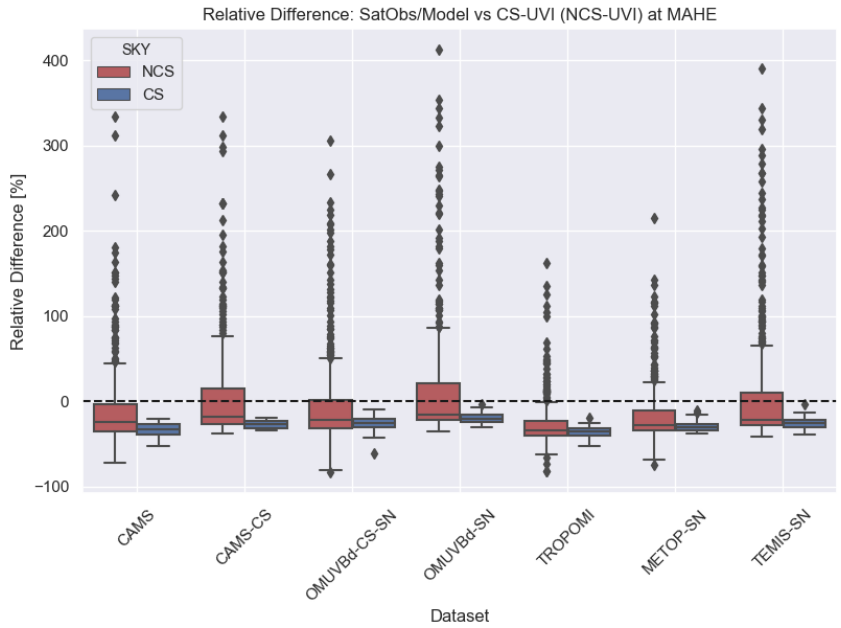


	SAT/MODEL Comparison Against CS-UVI (NCS-UVI) at ANTA						
STATS	UVI-CAMS	UVI-CAMS-CS	UVI-OMUVBd-CS-SN	UVI-OMUVBd-SN	UVI-TROPOMI	UVI-METOP-SN	UVI-TEMIS-SN
MEAN-AD	-0.20 +- 1.39 (0.19 +- 2.81)	0.14 +- 0.78 (1.35 +- 2.34)	-0.89 +- 0.95 (-0.56 +- 2.58)	-0.56 +- 0.91 (1.27 +- 2.78)	-1.63 +- 0.63 (-1.26 +- 1.78)	-1.28 +- 1.35 (-1.06 +- 2.78)	-1.32 +- 0.93 (0.41 +- 2.83)
MEAN-RD [%]	-2.60 +- 21.39 (7.27 +- 45.48)	2.75 +- 15.65 (24.86 +- 44.52)	-7.96 +- 8.13 (2.13 +- 31.69)	-4.59 +- 8.01 (22.52 +- 43.15)	-19.73 +- 5.19 (-12.88 +- 23.71)	-12.34 +- 12.04 (-4.29 +- 32.95)	-13.19 +- 8.73 (12.78 +- 42.21)
MEDIAN-AD	-0.07 (0.08)	0.05 (0.62)	-0.95 (-0.76)	-0.57 (0.36)	-1.59 (-1.23)	-1.10 (-0.99)	-1.45 (-0.49)
MEDIAN-RD [%]	-1.10 (1.32)	0.53 (9.18)	-9.07 (-7.87)	-5.95 (3.83)	-21.02 (-18.51)	-12.07 (-10.99)	-14.61 (-4.73)
NDATA	226 (1444)	226 (1444)	87 (600)	87 (600)	30 (200)	82 (542)	103 (721)

Figure: Boxplot of differences between ground-based UVI and Sat/Model Measurements at Antananarivo, Madagascar

AD and RD at Mahé, Seychelles





	SAT/MODEL Comparison Against CS-UVI (NCS-UVI) at MAHE						
STATS	UVI-CAMS	UVI-CAMS-CS	UVI-OMUVBd-CS-SN	UVI-OMUVBd-SN	UVI-TROPOMI	UVI-METOP-SN	UVI-TEMIS-SN
MEAN-AD	-5.43 +- 1.38 (-2.38 +- 4.12)	-4.32 +- 0.79 (-0.92 +- 4.16)	-4.46 +- 1.72 (-2.49 +- 4.60)	-3.49 +- 1.06 (-0.49 +- 4.43)	-4.92 +- 1.07 (-3.57 +- 2.78)	-5.06 +- 1.33 (-3.17 +- 3.63)	-4.38 +- 1.07 (-1.48 +- 4.42)
MEAN-RD [%]	-33.64 +- 8.61 (-6.01 +- 53.62)	-26.79 +- 4.96 (8.87 +- 62.27)	-25.52 +- 8.93 (-4.53 +- 55.88)	-20.04 +- 5.81 (14.49 +- 69.62)	-35.50 +- 6.07 (-25.86 +- 28.67)	-28.91 +- 6.21 (-14.38 +- 36.02)	-25.48 +- 6.18 (5.29 +- 63.94)
MEDIAN-AD	-5.50 (-3.41)	-4.50 (-2.46)	-4.37 (-3.54)	-3.74 (-2.28)	-4.86 (-4.05)	-5.34 (-4.19)	-4.57 (-3.42)
MEDIAN-RD [%]	-33.04 (-23.97)	-26.05 (-17.66)	-25.23 (-21.81)	-20.79 (-15.04)	-35.09 (-34.18)	-30.48 (-27.16)	-25.76 (-21.20)
NDATA	27 (321)	27 (321)	48 (427)	48 (427)	42 (378)	44 (377)	58 (548)

Figure: Boxplot of differences between ground-based UVI and Sat/Model Measurements at Mahé, Seychelles