

Application of a spectral sky in Radiance for daylighting calculations including non-image-forming light effects

Authors :

Parisa. Khademagha
M.B.C. Aries
A.L.P. Rosemann
E.J. van Loenen



TU/e

Technische Universiteit
Eindhoven
University of Technology

Where innovation starts

Presentation outline

- **Benefits of (day)light**
- **Application of spectral sky in Radiance**
 - Simulation
 - Measurement (small scale)
- **Conclusion**



A grayscale photograph of a sky scene. On the right side, a bright sun is partially obscured by a thin layer of clouds, creating a strong glow. To the left, there is a dense bank of darker, more textured clouds. The sky transitions from a dark gray at the top to a lighter gray near the horizon.

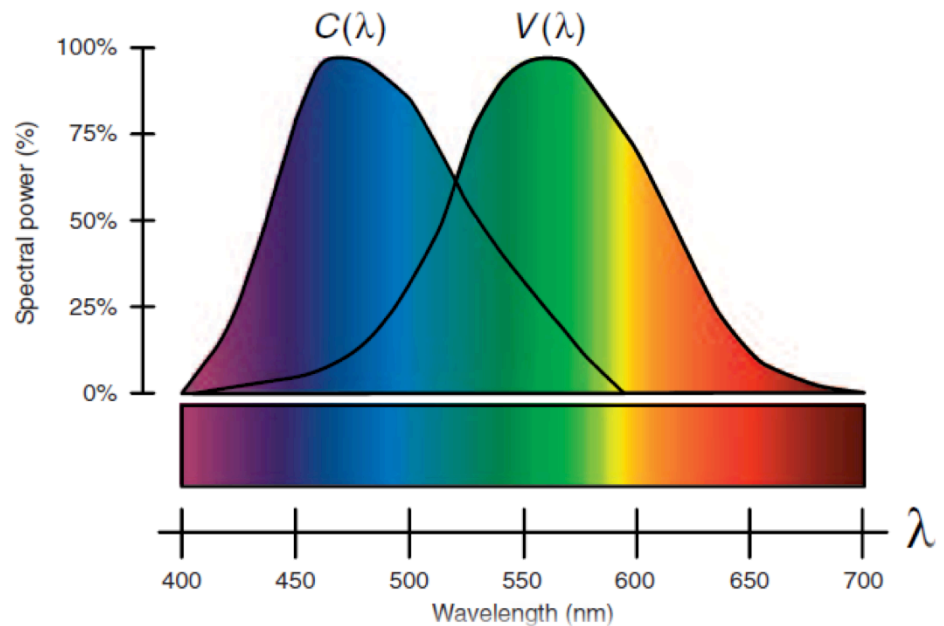
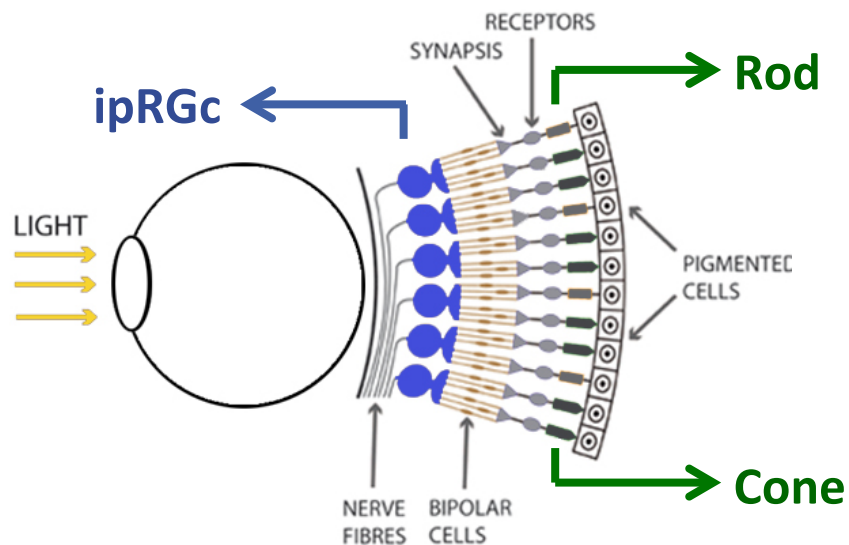
Why do we need **spectral** sky in simulations?

Benefits of (day)light

(day)light exposure

Image-forming
effects

*
Non-image-forming
effects



- [Khademagha P.](#) Aries MBC, Rosemann ALP, van Loenen EJ, Implementing non-image-forming effects of light in the built environment. Build. Environ. (2016), DOI: 10.1016/j.buildenv.2016.08.035.



Spectral sky models

Analytical models for daylight (e.g., Preetham, Shirley, and Smits, 1999; Hosek and Wilkie, 2012)

* Mark Stock code (Genutahsky.c), 2015





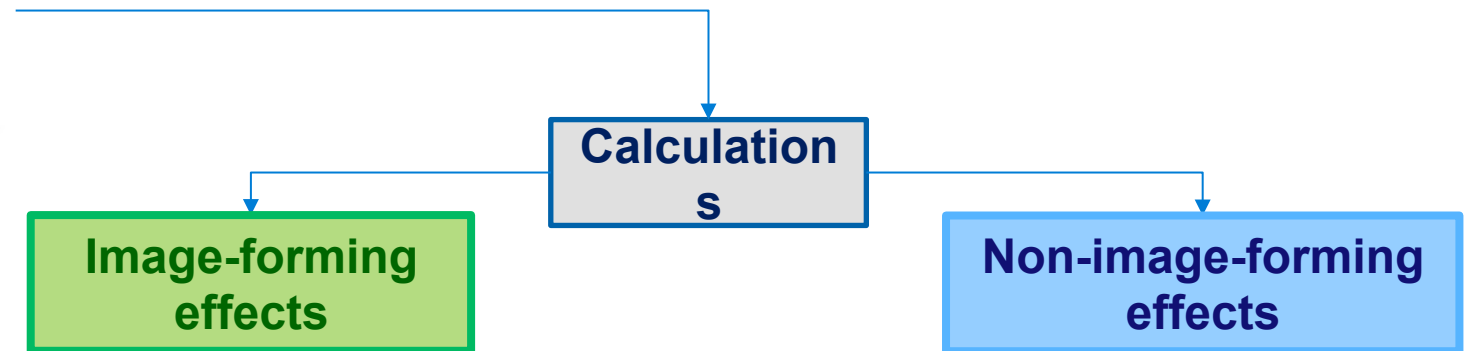
Simulation parameters

Gen(utah)sky		Eindhoven			Utah		
Sky parameters	Month	March June December			March June December		
	day	15 th			15 th		
	hour	8:00 to 17:00 (hourly)			8:00 to 17:00 (hourly)		
	Coordinates	-m (standard meridian)	-15		105		
		-a (latitude)	51.26		39.32		
		-o (longitude)	-5.28		111.09		
	-t (turbidity)						2.5
		Ambient parameters	-ab (ambient bounces)			7	
			-ad (ambient divisions)			2048	
			-as (ambient super-sample)			512	
			-ar (ambient resolution)			512	
			-aa (ambient accuracy)			0.08	
			-av (ambient value)			0.01 0.01 0.01	



Sky.rad

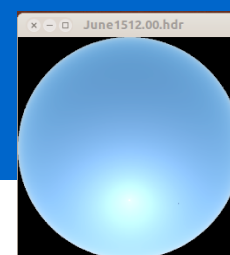
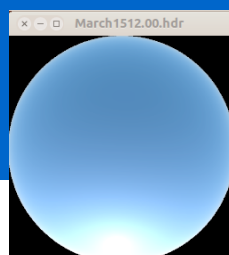
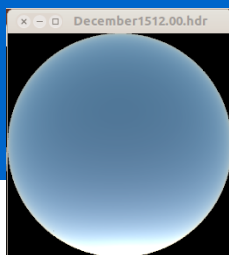
Daylight calculation



Quantity	$E = 179 \frac{lm}{W} \cdot (0.265 I_R + 0.670 I_G + 0.065 I_B)$	$E_{e,c} = -0.034 I_R + 0.323 I_G + 0.558 I_B$
Spectrum	$V(\lambda)$	$C(\lambda)$

* Geisler-Moroder and Dur, 2010

12:00

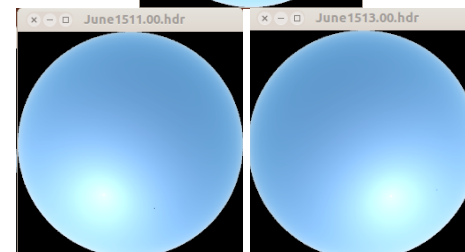
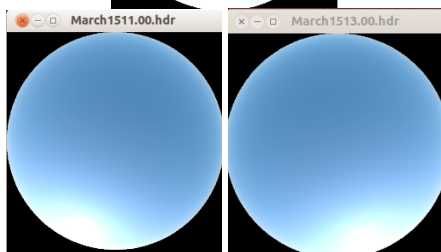


December
15

March 15

June 15

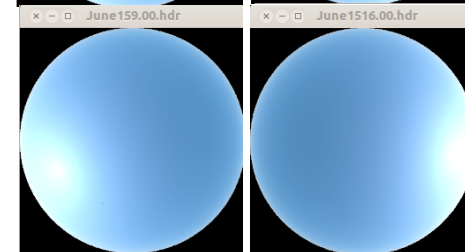
11:00



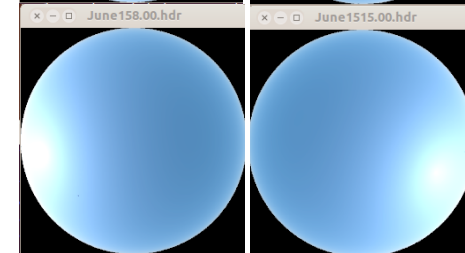
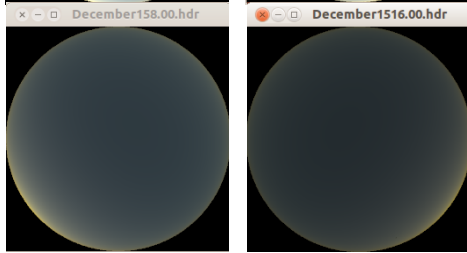
10:00



9:00



8:00



13:00

14:00

15:00

Location : Eindhoven

CIE clear sky vs. Spectral sky models - June 15th

8:00

9:00

10:00

11:00

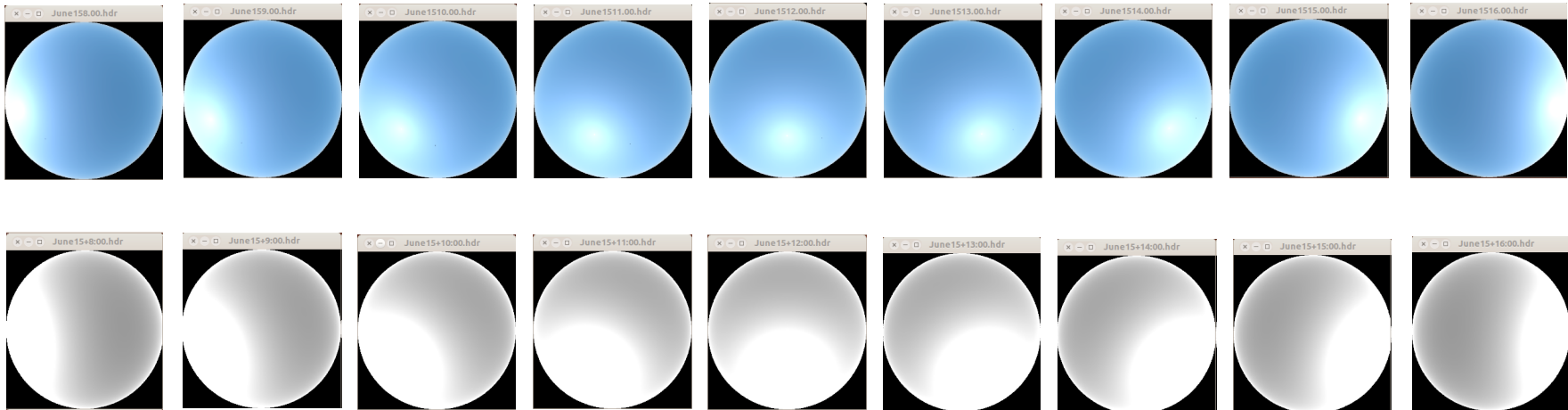
12:00

13:00

14:00

15:00

16:00



Comparing CIE clear sky vs. Spectral sky - simulations

Location : Eindhoven

December 15

Location : Utah December 15								
Solar time	CIE clearsky			Spectral sky				
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c
8:00	29.64	5303.72	22.39	24.69	28.77	30.85	4979.49	23.04
12:00	204.30	36562.26	154.33	206.13	217.13	231.26	38499.91	172.29
16:00	29.62	5301.52	22.38	20.41	23.81	24.93	4113.31	18.73
	0%	0%	0%	17%	17%	19%	17%	19%

Comparing CIE clear sky vs. Spectral sky - simulations

Location : Eindhoven March 15								
Solar time	CIE clearsky			Utahsky				
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c
8:00	102.10	18272.44	77.13	83.68	90.76	98.08	15992.08	72.89
12:00	271.90	48660.97	205.40	275.34	288.33	305.84	51187.50	228.03
16:00	102.09	18270.21	77.12	107.96	115.88	124.63	20464.28	92.69
	0%	0%	0%	-29%	-28%	-27%	-28%	-27%

Location : Utah March 15								
Solar time	CIE clearsky			Spectral sky				
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c
8:00	146.88	26285.64	110.95	128.40	137.00	146.94	24224.72	109.33
12:00	352.27	63043.15	266.10	364.75	379.23	398.88	67409.53	297.94
16:00	146.86	26282.16	110.94	57.56	167.15	178.82	29594.91	133.11
	0%	0%	0%	55%	-22%	-22%	-22%	-22%

Comparing CIE clear sky vs. Spectral sky - simulations

Location : Eindhoven June 15								
Solar time	CIE clearsky			Utahsky				
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c
8:00	276.34	49455.09	208.75	269.30	282.39	300.08	50122.12	223.64
12:00	424.24	75924.45	320.47	426.35	441.24	460.86	78486.97	344.77
16:00	276.33	49453.57	208.74	267.66	280.69	298.28	49819.11	222.30
	0%	0%	0%	1%	1%	1%	1%	1%

Location : Utah June 15								
Solar time	CIE clearsky			Spectral sky				
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c
8:00	281.61	50397.34	212.73	275.05	288.28	306.17	51171.16	228.2
12:00	469.57	84036.38	354.71	469.42	484.68	504.49	86245.95	377.7
16:00	281.59	50395.32	212.72	273.20	286.39	304.23	50834.61	226.7
	0%	0%	0%	1%	1%	1%	1%	1%

Comparing CIE clear sky vs. Spectral sky - simulations

Location : Eindhoven
December 15th

Solar tim	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
8:00	11.63	2081.08	8.78	2.77	3.62	3.67	607.52	2.79	-71%	-68%
9:00	28.60	5117.40	21.60	23.22	27.08	28.79	4682.68	21.54	-8%	0%
10:00	55.26	9889.22	41.74	52.19	57.91	62.70	10148.58	46.62	3%	12%
11:00	87.24	15612.19	65.90	83.47	90.50	97.72	15946.23	72.63	2%	10%
12:00	98.14	17563.55	74.14	92.52	99.84	107.57	17609.79	79.98	0%	8%
13:00	87.25	15615.42	65.91	78.58	85.44	92.21	15043.66	68.56	-4%	4%
14:00	55.26	9889.22	41.74	42.58	47.89	52.10	8367.66	38.71	-15%	-7%
15:00	28.63	5123.40	21.63	20.29	23.68	24.79	4089.58	18.62	-20%	-14%
16:00	11.46	2084.14	8.80	1.49	1.90	1.84	320.20	1.42	-85%	-84%
17:00	3.73	666.99	2.82	0.06	0.07	0.05	12.08	0.04	-98%	-99%

Location : Utah
December 15th

Solar time	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
8:00	29.64	5303.72	22.39	24.69	28.77	30.85	4979.49	23.04	-6%	3%
9:00	90.05	16115.70	68.02	92.05	99.34	107.03	17521.33	79.58	9%	17%
10:00	152.31	27257.23	115.05	156.06	165.50	176.91	29302.89	131.71	8%	14%
11:00	191.11	34202.60	144.37	194.89	205.54	219.09	36436.59	163.19	7%	13%
12:00	204.30	36562.26	154.33	206.13	217.13	231.26	38499.91	172.29	5%	12%
13:00	191.18	34213.82	144.42	189.13	199.60	212.81	35377.60	158.51	3%	10%
14:00	152.34	27263.12	115.08	144.43	153.48	164.20	27161.81	122.23	0%	6%
15:00	90.07	16119.93	68.04	75.67	82.45	89.07	14510.16	66.21	-10%	-3%
16:00	29.62	5301.52	22.38	20.41	23.81	24.93	4113.31	18.73	-22%	-16%
17:00	8.98	1606.44	6.78	0.49	0.59	0.52	100.06	0.41	-94%	-94%

Location : Eindhoven
March 15th

Solar tim	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
8:00	102.10	18272.44	77.13	83.68	90.76	98.08	15992.08	72.89	-12%	-5%
9:00	173.46	31042.31	131.03	160.63	170.31	182.13	30157.53	135.58	-3%	3%
10:00	227.37	40690.39	171.75	220.37	231.93	247.02	41133.40	184.02	1%	7%
11:00	260.59	46635.39	196.85	259.44	272.07	288.98	48287.92	215.39	4%	9%
12:00	271.90	48660.97	205.40	275.34	288.33	305.84	51187.50	228.03	5%	11%
13:00	260.64	46646.02	196.89	266.60	279.38	296.54	49591.64	221.06	6%	12%
14:00	227.35	40688.30	171.74	234.16	246.12	261.91	43662.37	195.14	7%	14%
15:00	173.45	31042.02	131.03	180.22	190.57	203.55	33764.81	151.56	9%	16%
16:00	102.09	18270.21	77.12	107.96	115.88	124.63	20464.28	92.69	12%	20%
17:00	32.60	5834.43	24.63	27.54	32.22	35.38	5581.06	26.27	-4%	7%

Location : Utah
March 15th

Solar tim	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
8:00	146.88	26285.64	110.95	128.40	137.00	146.94	24224.72	109.33	-8%	-1%
9:00	233.90	41859.15	176.69	222.95	234.57	249.78	41605.07	186.08	-1%	5%
10:00	298.67	53451.06	225.62	296.95	310.38	328.62	55121.76	245.11	3%	9%
11:00	338.69	60613.69	255.85	345.22	359.46	378.85	63880.48	282.85	5%	11%
12:00	352.27	63043.15	266.10	364.75	379.23	398.88	67409.53	297.94	7%	12%
13:00	338.67	60609.09	255.83	353.82	368.19	387.72	65437.78	289.53	8%	13%
14:00	298.63	53444.58	225.59	313.45	327.22	345.96	58125.06	258.12	9%	14%
15:00	233.88	41856.74	176.68	246.55	258.84	275.18	45929.36	205.07	10%	16%
16:00	146.86	26282.16	110.94	57.56	167.15	178.82	29594.91	133.11	13%	20%
17:00	43.45	7775.60	32.82	52.14	57.88	62.72	10142.48	46.62	30%	42%

Location : Eindhoven
June 15th

Solar tim	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
8:00	276.34	49455.09	208.75	269.30	282.39	300.08	50122.12	223.64	1%	7%
9:00	338.52	60582.82	255.72	334.51	348.79	368.23	61968.97	274.82	2%	7%
10:00	385.14	68926.43	290.94	384.70	399.45	419.26	71017.15	313.31	3%	8%
11:00	413.87	74067.65	312.64	415.64	430.51	450.21	76569.50	336.71	3%	8%
12:00	424.24	75924.45	320.47	426.35	441.24	460.86	78486.97	344.77	3%	8%
13:00	413.89	74071.05	312.65	415.24	430.11	449.81	76496.67	336.41	3%	8%
14:00	385.12	68923.30	290.92	383.36	398.12	417.96	70778.86	312.32	3%	7%
15:00	338.52	60583.18	255.72	333.39	347.67	367.11	61768.54	273.97	2%	7%
16:00	276.33	49453.57	208.74	267.66	280.69	298.28	49819.11	222.30	1%	6%
17:00	202.28	36200.68	152.80	191.00	201.89	215.83	35775.53	160.66	-1%	5%

Location : Utah
June 15th

Solar tim	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
8:00	281.61	50397.34	212.73	275.05	288.28	306.17	51171.16	228.21	2%	7%
9:00	357.89	64049.30	270.35	355.92	370.46	390.17	65837.51	291.35	3%	8%
10:00	415.61	74378.40	313.95	417.64	432.52	452.21	76927.76	338.23	3%	8%
11:00	453.50	81160.61	342.58	456.22	471.25	490.80	83851.26	367.41	3%	7%
12:00	469.57	84036.38	354.71	469.42	484.68	504.49	86245.95	377.71	3%	6%
13:00	453.56	81170.68	342.62	455.74	470.78	490.32	83765.94	367.05	3%	7%
14:00	415.58	74374.00	313.93	416.70	431.59	451.31	76762.05	337.54	3%	8%
15:00	357.88	64048.42	270.35	354.15	368.69	388.41	65521.77	290.02	2%	7%
16:00	281.59	50395.32	212.72	273.20	286.39	304.23	50834.61	226.75	1%	7%
17:00	189.90	33985.84	143.45	178.55	189.05	202.31	33489.61	150.57	-1%	5%

Daylight spectral measurement



July 19-21



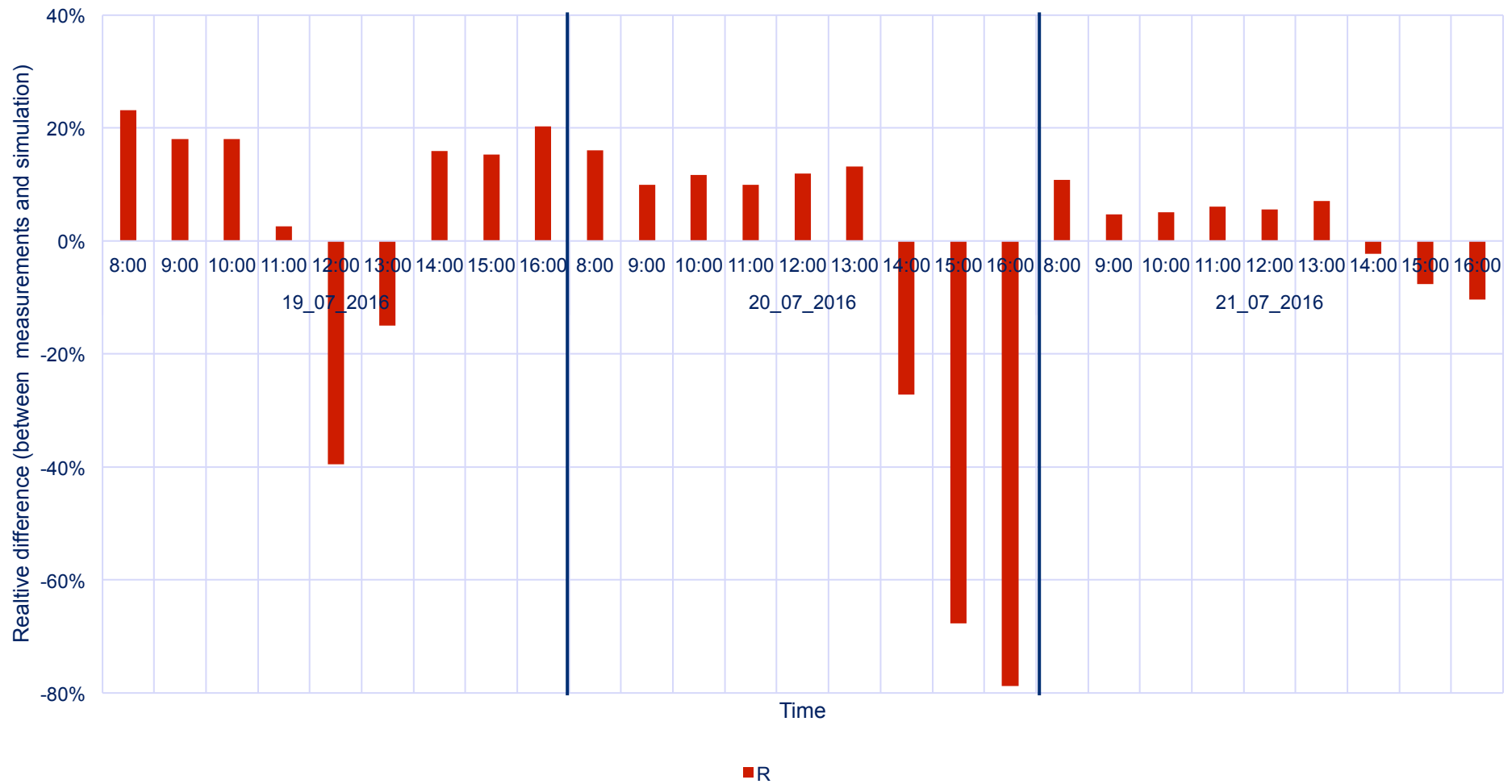
XYZ value



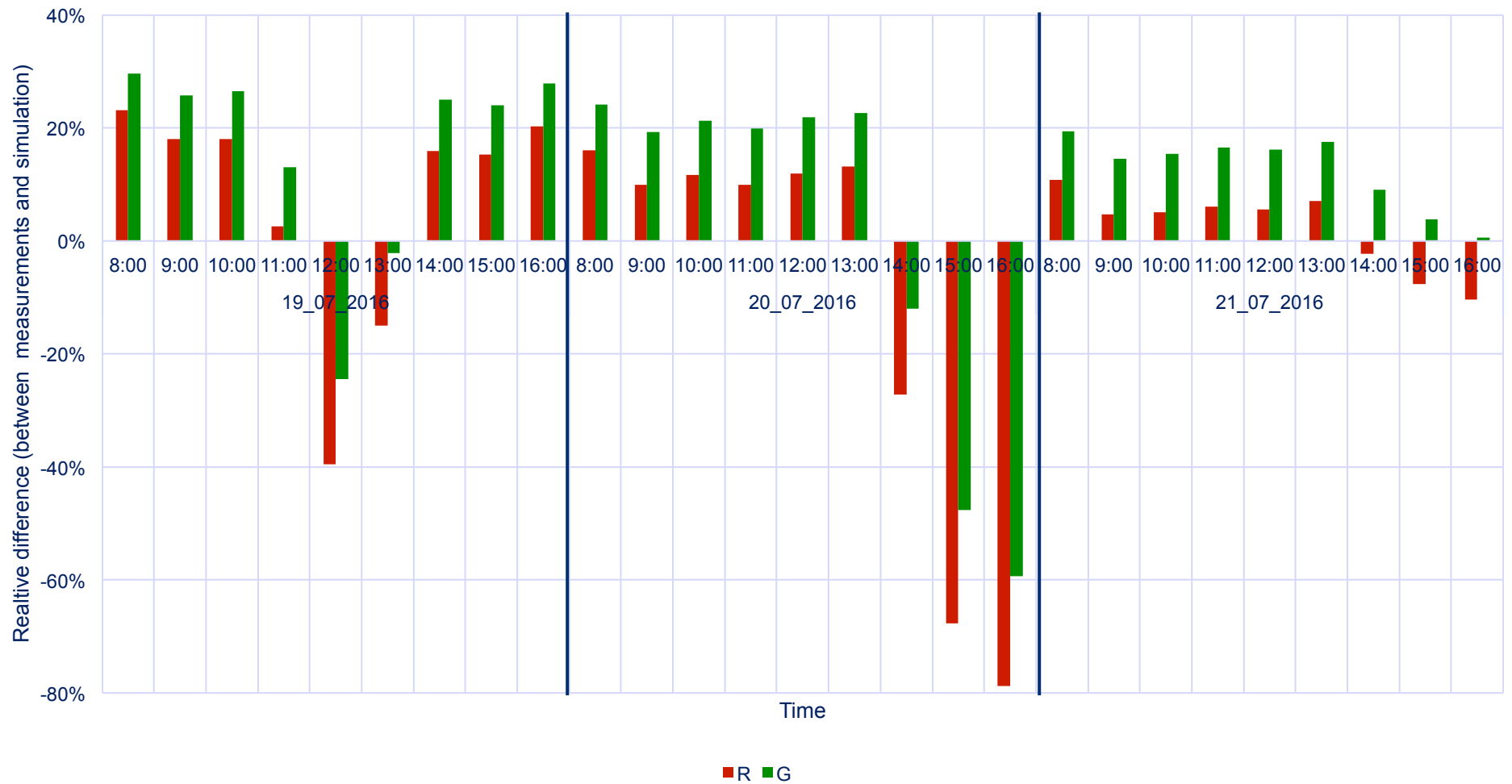
xyz_rgb.cal

RGB value

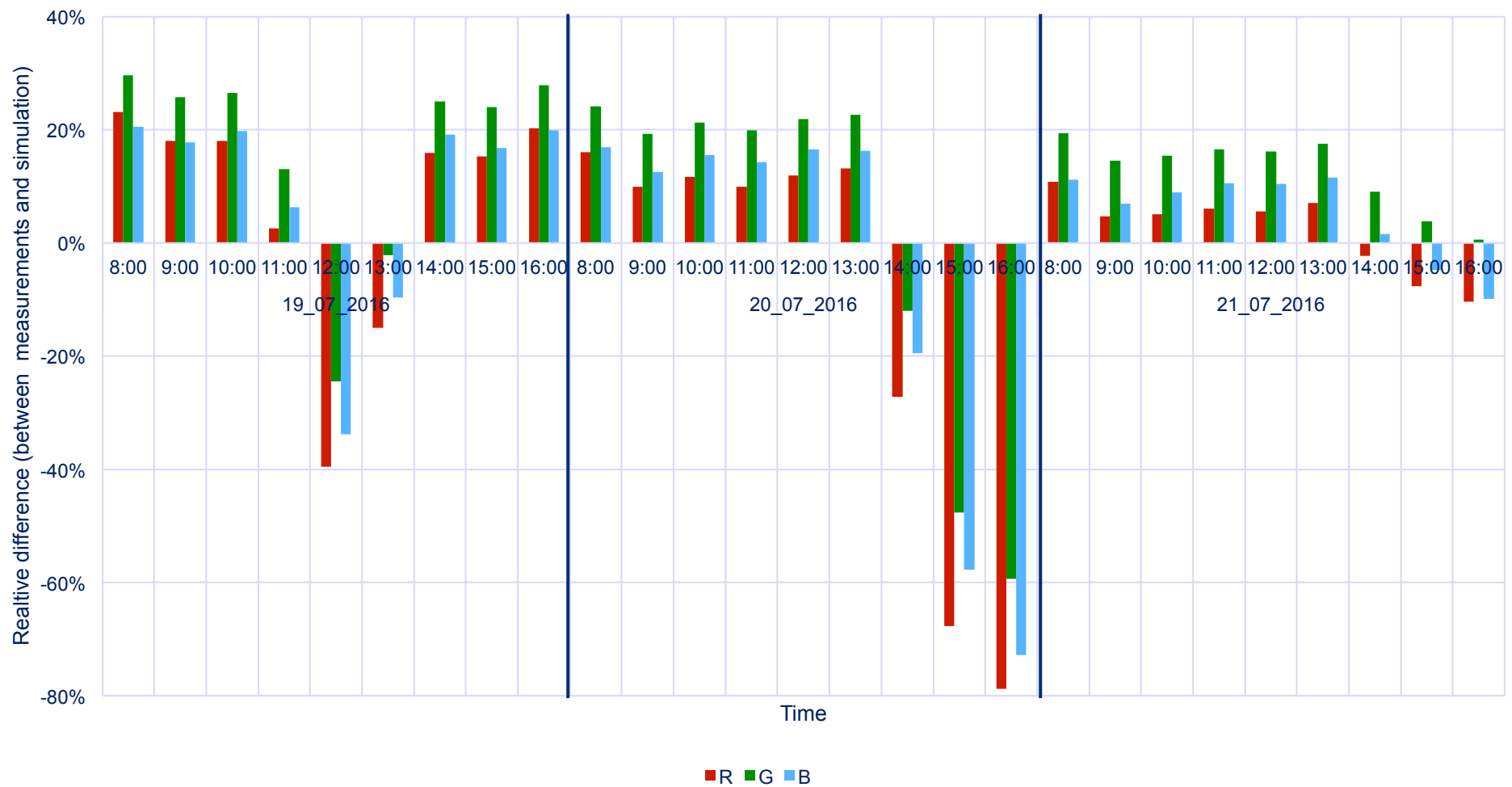
Comparing CIE clear sky vs. Spectral sky - measurements



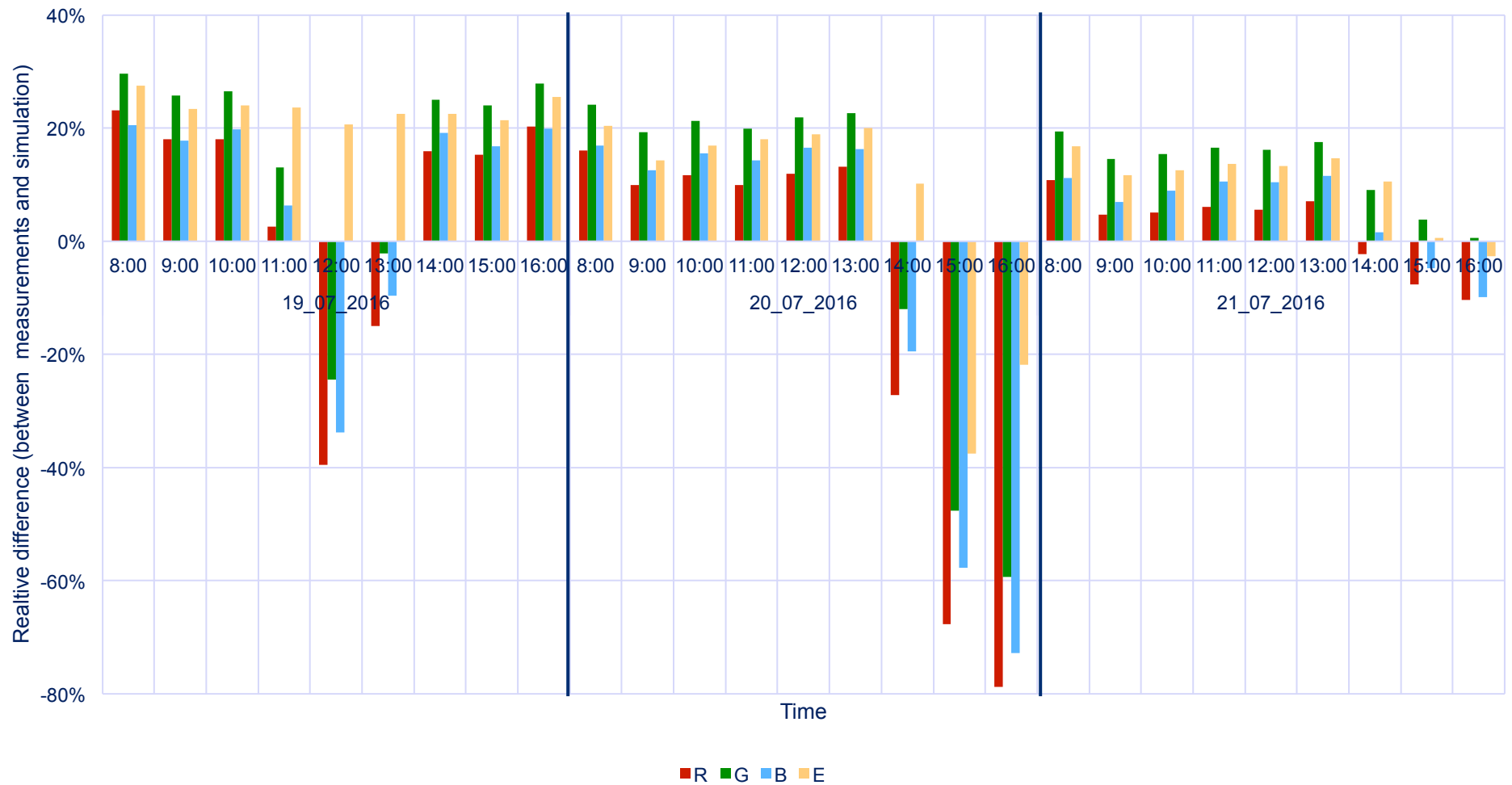
Comparing CIE clear sky vs. Spectral sky - measurements



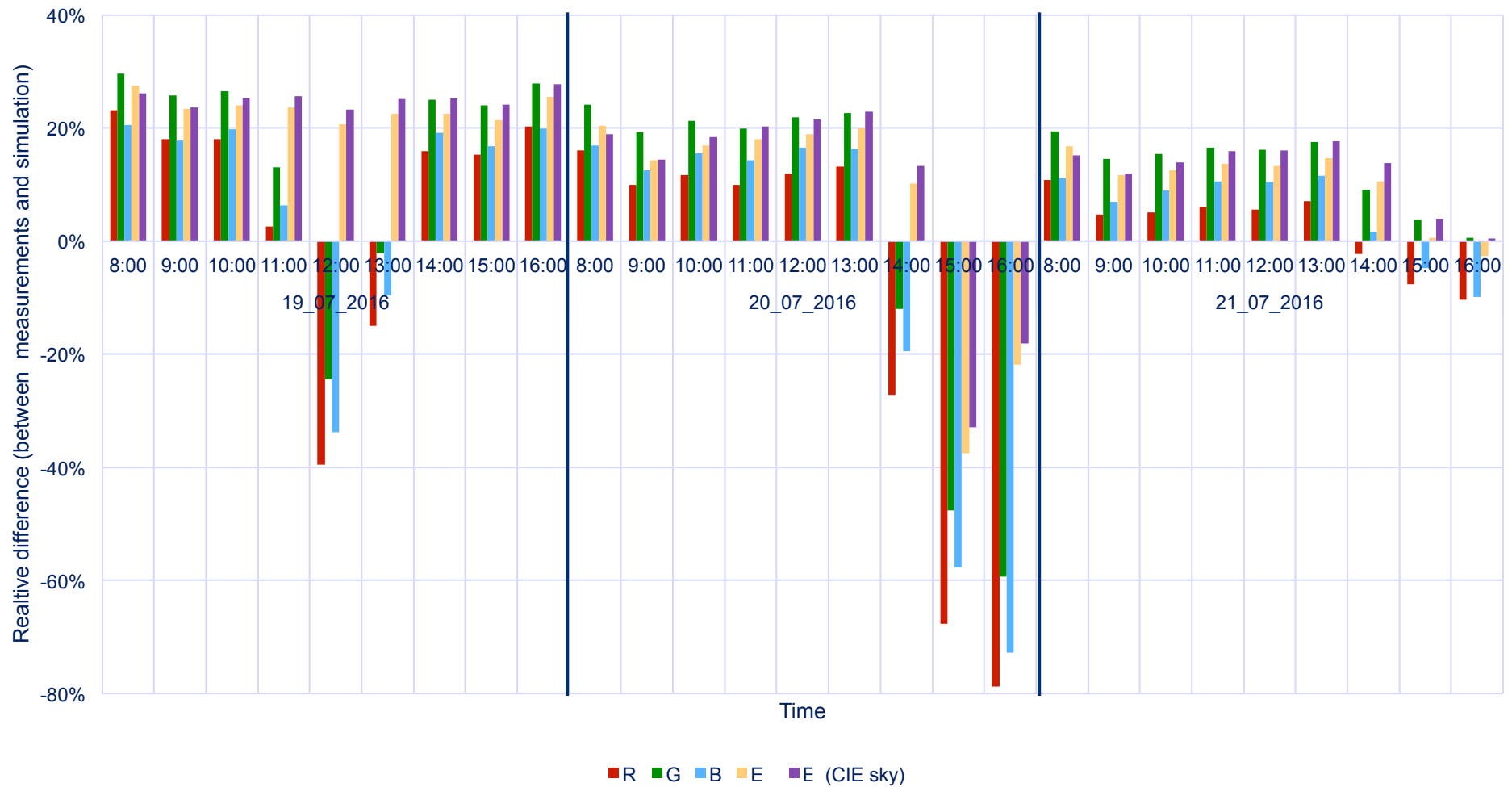
Comparing CIE clear sky vs. Spectral sky - measurements



Comparing CIE clear sky vs. Spectral sky - measurements



Comparing CIE clear sky vs. Spectral sky - measurements



Influence of turbidity on simulation results

15th December 8:00

Eindhoven_location	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
Turbidity_1.5	12.59	2252.55	9.51	-0.89	-0.81	-0.24	-142.00	-0.29	-106%	-103%
Turbidity_2	12.13	2169.88	9.16	3.85	5.02	5.01	843.08	3.83	-61%	-58%
Turbidity_2.5	11.63	2081.08	8.78	2.77	3.62	3.67	607.52	2.79	-71%	-68%
Turbidity_3.5	10.70	1915.39	8.09	1.94	2.47	2.49	416.65	1.90	-78%	-77%
Turbidity_5	9.31	1666.92	7.04	1.37	1.66	1.62	282.33	1.24	-83%	-82%

Utah_location	CIE clearsky			Spectral sky					% Relative difference	
	RGB	E(lux)	E e,c	R	G	B	E(lux)	E e,c	E(lux)	Ee,c
Turbidity_1.5	24.56	4394.59	18.55	11.26	11.33	12.70	2040.50	9.33	-54%	-50%
Turbidity_2	27.12	4854.23	20.49	27.04	32.91	36.80	5656.36	27.23	17%	33%
Turbidity_2.5	29.64	5303.72	22.39	24.69	28.77	30.85	4979.49	23.04	-6%	3%
Turbidity_3.5	34.68	6205.79	26.19	23.90	26.53	26.80	4626.72	20.28	-25%	-23%
Turbidity_5	42.34	7578.05	31.99	24.36	25.65	24.30	4514.06	18.67	-40%	-42%

Conclusions

- When the two sky models are compared, results are comparable for the higher sun angles, but significantly different for low sun angles.
- Simulation errors increase when turbidity increases and decreases from the default 2.5 value.
- When simulation and measurement data are compared, errors are:
 - higher than 20% for E (both skies) and G wave-band
 - Lower than 20% for R and B wave-bands



Thank You!

p.khademagha@tue.nl
p.khademagha@gmail.com

TU/e

Technische Universiteit
Eindhoven
University of Technology

Where innovation starts