



# Tales from Sky Spectra: Measurement, Analysis, and Simulations





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# Outline

#### 1 Measuring skies in Seattle (and around the world)

- Spectrophotometric measurements
- Three-stimulus measurements with High Dynamic Range Photography
- CIE Technical Committee 3-60: Spectral Daylight Characteristics

#### <sup>2</sup> Analysis: What did we learn?

- Global horizontal spectra and CCT
- Spectra of the sun
- Spectral variation across the sky dome
- Spectral variation in the field of view
- Challenges and solutions: calibration procedures required for obtaining high-quality measurements

### 3 The impact of spectral input in simulations

# Spectral Measurement Setup



- Ocean Insight Flame VIS-NIR Spectrometer installed on the roof of Gould Hall at UW
- The data collection started in June 2021 at 1-minute intervals
- Measures global horizontal spectra (W/m<sup>2</sup>) between 338-823 nm at 1nm intervals



- A weather station is available on the roof of the UW Atmospheric Sciences Department
- Measures global horizontal radiation (W/m<sup>2</sup>), along with Temperature, Relative Humidity, Wind, Rain, and Pressure.



# CIE Technical Committee 3-60 Spectral Daylight Characteristics

Paraguay

United State

The spectral variation of skies is an active research area, but the data that demonstrates its variability based on atmospheric conditions, time and date of the year, and location are still emerging. <u>https://cie.co.at/technicalcommittees/spectral-daylight-characteristics</u>

South Afri

Algérie #XX:510

Kalaalli Nunaat Росси United States Algérie NXX:5FO Républiqu du Cor Bolivia Paraguay Paragua South Africa "The objectives are to 1) to trace the evolution of the CIE reconstruction method (D Illuminants); 2) to emphasise the necessity for a localised reconstruction procedure; and

3) to elaborate on the methodology of data collection and analysis established to develop a localised reconstruction procedure that considers geographical, seasonal and diurnal variations."

## CIE 3-60: Round Robin



- Newly calibrated JETI specbos 1211-2 spectrophotometer traveled around the world between participated members.
- We also measured with a
- JETI spectraval 1511
- Konica Minolta CL-70F
- along with the Ocean Insight Flame VIS-NIR Spectrometer





# High Dynamic Range Photography 180° Field of view Sky 180° of view Field (A vertical orientations



Spectrophotometer



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## Global Hor. Correlated Color Temperature: Seattle





CCT (K) Intervals

#### Golden, CO (2014)<sup>2,3</sup>

18000 16000

14000

12000

10000

8000

6000

4000

2000

Count

Measurement

59% of the data between 5.5K-6K 82% of the data between 5.5-6.5K 3% of the data >10K



45% of the data between 5.5K-6K 62% of the data between 5.5-6.5K

<sup>1</sup> Inanici M and ZGF LLC, 2024.

<sup>2</sup> Andreas A, Stoffel T. NREL Solar Radiation Research Laboratory (SRRL): Baseline Measurement System (BMS); Golden, Colorado (Data); 1981, NREL Report No. DA-5500-56488.

CCT (K) Intervals

<sup>3</sup> https://www.nrel.gov/grid/solar-resource/spectral-solar.html

<sup>4</sup> Hernández-Andrés J, Romero J, Nieves JL, Lee, Jr. RL. Color and spectral analysis of daylight in southern Europe. Journal of the Optical Society of America A 2001, 18(6): 1325-1335

<sup>5</sup> University of Granada, Color Imaging Laboratory, Granada Daylight Spectral database, http://colorimaginglab.ugr.es/pages/Data# doku granada daylight spectral database







## Challenges: Condensation on the sensor



## Challenges: Maintaining (Re)calibration

0.70









## **Direct Solar Radiation Spectra**



ASTM G173-03(2020) Standard Tables for Reference Solar Spectral Irradiances: Direct Normal Radiation Publicly available **Direct Solar Radiation Spectral Data** 



Eugene, OR



Perez sky, June 20, 15:55 91550 Lux Cd/m<sup>2</sup>

30000

18597.7

11681.8

7337.67

4609.02

3093.91

1943.38

1000



HDRI sky, June 20, 15:55 91648 Lux





Global horizontal CCT: 5807 K



Inanici M. "Tri-stimulus Color Accuracy in Image-based Sky Models: Simulating the Impact of Color Distributions throughout the Sky Dome on Daylit Interiors with Different Orientations", *IBPSA Conference*, Rome, Italy, September 2-4, 2019.

Image Based Sky	Orientation1	Orientation2	Orientation3	Orientation4
Nov 9 13:48	100		100,000 cd/m <sup>2</sup>	
CCT = 6,452 K	CCT = 6,166 K	CCT = 6,095 K	CCT = 6,302 K	CCT = 6,485
8,711 Lx	3,939 Lx	3,610 Lx	2,574 Lx	2,044 Lx
8,745 EML	3,824 EML	3,475 EML	2,543 EML	2,056 EML

Inanici <u>M</u>, Abboushi B, and Safranek S. "Evaluation of Sky Spectra and Sky Models in Daylighting Simulations," *Journal of Lighting Research and Technology*, 55(6), 2023, 502-529. Inanici M. "Tri-stimulus Color Accuracy in Image-based Sky Models: Simulating the Impact of Color Distributions throughout the Sky Dome on Daylit Interiors with Different Orientations", *IBPSA Conference*, Rome, Italy, September 2-4, 2019.

Image Based Sky	Orientation1	Orientation2	Orientation3	Orientation4
Nov 7, 12:02	100		100,000 cd/m <sup>2</sup>	
CCT = 5,797 K	CCT = 5,140 K	CCT = 10,264 K	CCT = 6,859 K	CCT = 7,936 K
27,481 Lx	96,323 Lx	5,993 Lx	4,617 Lx	3,746 Lx
25,603 EML	86,896 EML	7,557 EML	5,955 EML	4,263 EML

Inanici <u>M</u>, Abboushi B, and Safranek S. "Evaluation of Sky Spectra and Sky Models in Daylighting Simulations," *Journal of Lighting Research and Technology*, 55(6), 2023, 502-529. Inanici M. "Tri-stimulus Color Accuracy in Image-based Sky Models: Simulating the Impact of Color Distributions throughout the Sky Dome on Daylit Interiors with Different Orientations", *IBPSA Conference*, Rome, Italy, September 2-4, 2019.

Image Based Sky	Orientation1	Orientation2	Orientation3	Orientation4
Dec 4, 14:20	100		100,000 cd/m <sup>2</sup>	
CCT = 22,686 K	CCT = 4,623 K	CCT = 4,618 K	CCT = 7,172 K	CCT = 7,192 K
3,725 Lx	72,481 Lx	62,183 Lx	3,100 Lx	2,806 Lx
5,727 EML	54,862 EML	46,945 EML	3,359 EML	3,028 EML

Inanici <u>M</u>, Abboushi B, and Safranek S. "Evaluation of Sky Spectra and Sky Models in Daylighting Simulations," *Journal of Lighting Research and Technology*, 55(6), 2023, 502-529. Inanici M. "Tri-stimulus Color Accuracy in Image-based Sky Models: Simulating the Impact of Color Distributions throughout the Sky Dome on Daylit Interiors with Different Orientations", *IBPSA Conference*, Rome, Italy, September 2-4, 2019.



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Jung B, Cheng Z, Brennan M, Inanici M. "Multispectral Lighting Simulation Approaches for Predicting Opsin-driven Metrics and their Application in a Neonatal Intensive Care Unit," IBPSA 2023 Conference, Shanghai, China, September 4-6, 2023. NICU Single Family Patient Room modeled after Cincinnati Children's Hospital Drawings: ZGF LLP Photographs: Ryan Kurtz









## Conclusions

- Spectral variability and intensity across date, time, and across the sky dome have impacts on visual and non-visual light-induced responses.
- Long-term measurements provide information about the dominant CCT and the range in a location. D65 as the **global horizontal CCT** does not represent dominant conditions for many locations. The dominant CCT range for Seattle is 5500-5750K.
- Global horizontal CCT values are higher during sunrise and sunset.
- CCT variation across the sky dome has a much wider range than global horizontal values. It is highest at 180° from the sun horizontally and 90° from the sun across the zenith.
- Variation across the sky dome significantly impacts spectra based on view direction and orientation.

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- Bo Jung, University of Washington
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