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Deployment and Early Results from the CanSIM (Canadian Solar Spectral Irradiance Meter) Network

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Abstract. Three of seven stations have been deployed as part of the Canadian Solar Spectral Irradiance (CanSIM) network situated in Ottawa, Varennes and Egbert to measure long term spectral variation of the direct normal (DNI) and global horizontal irradiances (GHI) across the country. Every station is equipped with a solar tracker, SolarSIM-D2+, SolarSIM-G+, and SR20 pyranometer, reporting the spectral DNI, GHI, diffuse horizontal irradiance (DHI) and aerosol optical depth in the 280–4000 nm range, broadband DNI, GHI, and DHI, atmospheric total column ozone and water vapour amounts. The spectral GHI as measured by the SolarSIM-G+ was within 5% as compared to EKO MS-700 spectroradiometer in 350–1050 nm range on 17 March 2017. The difference in the GHI as reported by SolarSIM-G+ and SR20 pyranometer from all stations was within 2% on 14 April 2017. Furthermore, on this day, the daily GHI sum for the Ottawa, Varennes, and Egbert stations was 7.01, 6.95, and 7.11 kWh/m^2, respectively, while the daily DNI sum was 10.65, 10.86, 10.04 kWh/m^2, respectively.

INTRODUCTION

The solar irradiance reaching the ground level is a dynamic resource fluctuating temporally in spectrum and intensity mainly due to air mass, aerosols, and atmospheric gases. Every photovoltaic (PV) device is affected by spectral changes in sunlight, but a concentrating photovoltaic system (CPV) is impacted the most due to the fundamental structure of its multi-junction solar cells (MJSC). MJSCs consist of several series-connected subcells, so the lowest performing one dictates the overall operation of the device [1]–[3]. Typically, MJSCs are designed to be current matched for the AM1.5D from the ASTM G173 standard. Under field conditions, spectral variations cause MJSCs and consequently the CPV system to deviate from the desired operating point. Thus the knowledge of local solar spectrum is paramount to comprehensively characterize the performance of any PV or CPV system.

Historically, spectral field measurements were challenging to perform due to high instrumentation costs, involved setup and data acquisition protocols. As a result, there are only a few well funded institutions in the world today that continuously measure the solar spectrum, such as the Solar Radiation Research Facility at the National Renewable Energy Laboratory in Golden, Colorado, USA [4] and King Abdullah City for Atomic and Renewable Energy in Saudi Arabia [5]. Recently, the development of a Solar Spectral Irradiance Meter (SolarSIM) models D2+ and G+ by Spectrafy have led to a breakthrough in accuracy, ease of use, and affordability in acquiring direct normal and global horizontal spectral irradiances in the 280–4000 nm range, respectively. The SolarSIM-D2+ uses ground-based measurements to inform software algorithms for real-time resolution of the direct normal solar spectrum, total irradiance and various atmospheric constituents. The SolarSIM-D2+ works by measuring the solar spectral irradiance in

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FIGURE 1. The location of seven stations belonging to the Canadian Solar Spectral Irradiance Meter network

six narrow wavelength bands, using silicon photodiodes with hard coated bandpass filters. These measurements are then used in spectral reconstruction through parametrization of the major atmospheric processes, including aerosol extinction, ozone and water vapour absorptions [6]. Overall, the SolarSIM-D2+ allows the user to infer the total direct normal irradiance (DNI), spectral DNI and the aerosol optical depth (AOD) in the 280–4000 nm range, in addition to the atmospheric total column ozone amount and the precipitable water vapour content. Much like the D2+, the SolarSIM-G+ uses low-cost silicon photodiodes and hard coated bandpass filters to make the accurate measurements of the solar spectrum in several narrow wavelength bands. However, it utilizes an innovative optical design to detect the global sunlight in a 180° field of view, coupled with a software algorithm optimized to spectrally resolve the global horizontal irradiance (GHI) in the 280–4000 nm range and the total GHI. In addition to the aforementioned measurement capabilities, the deployment of both the SolarSIM-D2+ and SolarSIM-G+ allows one to also infer the spectral and broadband diffuse horizontal irradiance (DHI).

In 2016 the Canadian government through the Build in Canada Innovation Program awarded Spectrafy the contract to commission the Canadian Solar Spectral Irradiance Meter (CanSIM) network. This network will help to quantify the long term spectral variation of the DNI and GHI across the country, which is useful for both the PV and CPV applications. The CanSIM network consists of seven stations across Canada, as shown in Fig. 1, equipped with a solar tracker, a SolarSIM-D2+, a SolarSIM-G+, and a pyranometer. In this paper, we describe the CanSIM network and present the early results from three deployed stations thus far. We compare the daily GHI profiles between the SolarSIM-G+ and the SR20 pyranometer from Huksenflux at the Ottawa, Varennes, and Egbert stations. Furthermore, we examine the measurements of the spectral GHI from the EKO MS-700 spectroradiometer and the SolarSIM-G+ at the Ottawa station.

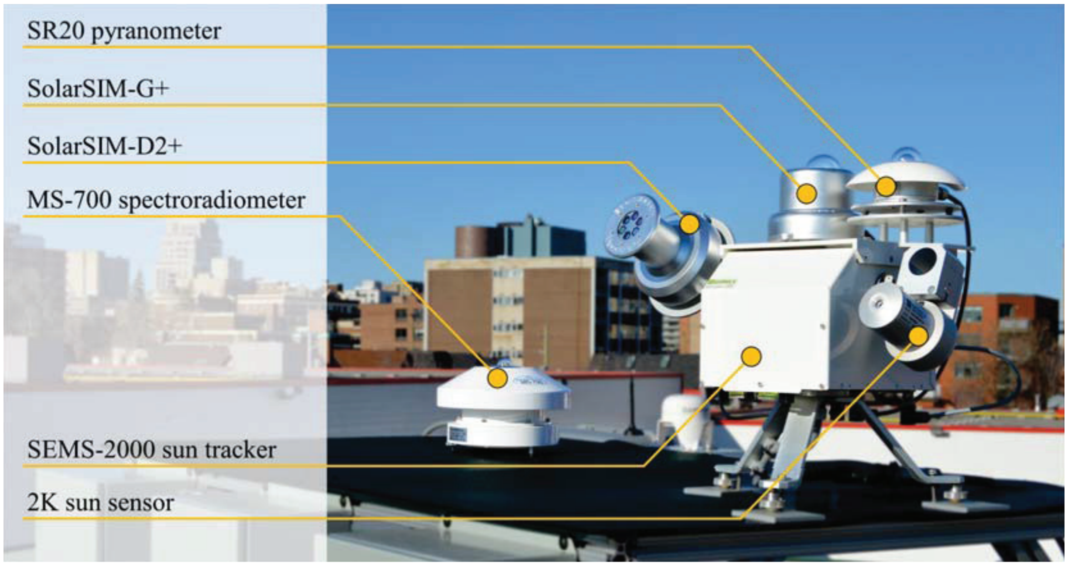

FIGURE 2. CanSIM station 3242 in Ottawa consisting of a SEMS-2000 sun tracker with a 2K sun sensor, a SolarSIM-D2+, a SolarSIM-G+, SR20 pyranometer, and a MS-700 spectroradiometer.

CANSIM NETWORK

The Canadian Solar Spectral Irradiance Meter (CanSIM) network consists of seven stations across six provinces situated in Ottawa and Egbert in Ontario (ON), Varennes in Quebec (QC), Charlottetown in Prince Edward Island (PE), Devon in Alberta (AB), Saturna Island in British Columbia (BC) and Cambridge Bay in Nunavut (NU), as illustrated by Fig. 1. The geographical coordinates of each station are presented in Table 1. The typical CanSIM station consists of a SEMS-2000 solar tracker with a 2K sun sensor (for close loop tracking) from Geonica, a SolarSIM-D2+ and a SolarSIM-G+ from Spectrafy, and a SR20 pyranometer from Huksenflux. The data are acquired in one minute intervals. In addition, the Ottawa station has a MS-700 spectroradiometer from EKO, as shown in Fig. 2. The data from each instrument is collected by Geonica's Meteodata 3000C datalogger every minute and is remotely transmitted to a central server for storage and analysis. The CanSIM station provides a vast amount of atmospheric and solar data, including the ambient temperature, pressure and humidity, the DNI and GHI, the spectral DNI, GHI and AOD in the 280–4000 nm range, the atmospheric total column ozone, and the precipitable water vapour content, as summarized in Table 2. Furthermore, the spectral diffuse horizontal irradiance (DHI) and the total DHI can be readily computed from the spectral DNI and GHI, as derived by the SolarSIM-D2+ and the SolarSIM-G+, respectively.

The first CanSIM station was deployed in Ottawa on 12 December 2016, with subsequent deployments at Varennes and Egbert on 15 December 2016 and 21 February 2017, respectively. The rest of stations are scheduled to be deployed during the summer of 2017.

TABLE 1. CanSIM stations' geographical coordinates.

Station ID	Location	Coordinates	Deployment
3242	Ottawa, ON	75.7° W, 45.4° N	12 Dec. 2016
3240	Varennes, QC	73.4° W, 45.6° N	15 Dec. 2016
3246	Egbert, ON	79.8° W, 44.2° N	21 Feb. 2017
3248	Devon, AB	113.7° W, 53.4° N	1 Jun. 2017*
3250	Saturna Island, BC	123.2° W, 48.8° N	20 Jun. 2017*
3252	Charlottetown, PE	63.1° W, 46.3° N	15 Jul. 2017*
3254	Cambridge Bay, NU	105.1° W, 69.1° N	15 Aug. 2017*

* scheduled to be deployed

TABLE 2. CanSIM station measurement capabilities

Measured parameter	Instrument			
	SolarSIM-D2+	SolarSIM-G+	SR20	MS-700*
DNI	✓			
Spectral DNI	✓[1]			
Spectral AOD	✓[1]			
Ozone content	✓			
Water vapour content	✓			
GHI		✓	✓	
Spectral GHI		✓[1]		✓[2]
Ambient temperature	✓	✓		
Ambient pressure	✓	✓		
Ambient humidity		✓		

∗ installed only at the Ottawa station
[1] 280–4000 nm spectral range
[2] 350–1050 nm spectral range

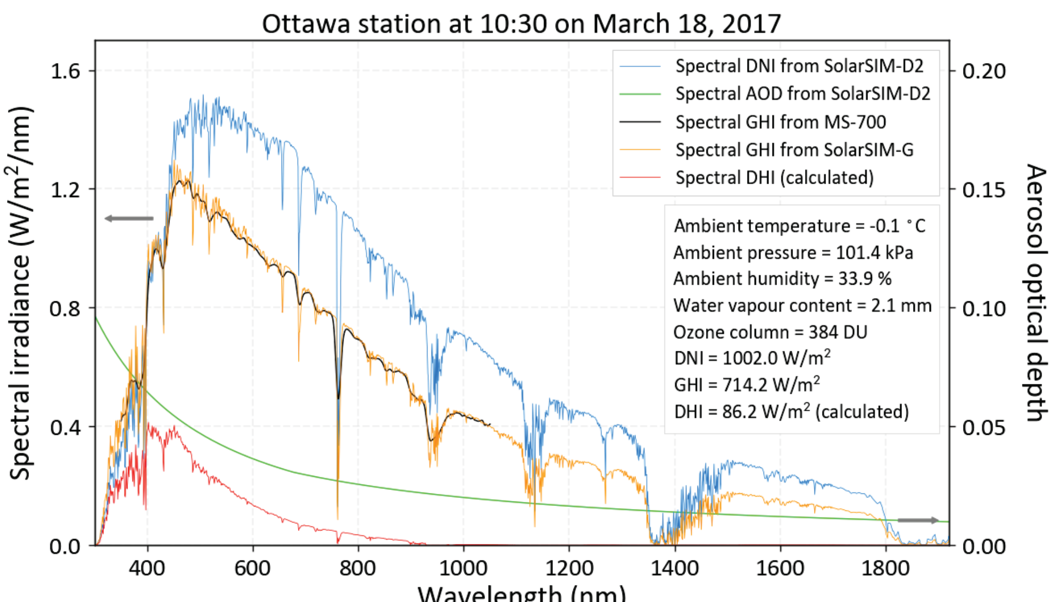

FIGURE 3. A complete parameter data set as produced by the Ottawa CanSIM station at 10:30 am on March 18, 2017.

EARLY RESULTS

The CanSIM network is first of its kind in Canada, providing an unparalleled quality and quantity of solar and atmospheric data. Fig. 3 shows a complete, instantaneous parameter data set gathered at the Ottawa CanSIM station on 18 March 2017 at 10:30 am, including the spectral DNI, GHI, DHI and AOD, broadband DNI, GHI, and DHI, ambient temperature, pressure and humidity, the total column ozone and water vapour amounts. A high DNI of over 1000 W/m^2 was observed on this day, which was mainly due to low AOD (less than 0.05 at 500 nm) and low water vapour column of 2.1 mm. For reference, the ASTM G173 standard DNI spectrum has the AOD at 500 nm of 0.084 and water vapour column of 14.2 mm. Fig. 3 also shows the spectral GHI comparison between the SolarSIM-G+ and EKO MS-700 spectroradiometer in the latter's 350–1050 nm measured range. A good agreement is observed between both instruments, whose spectral GHI is within of 5% of each other.

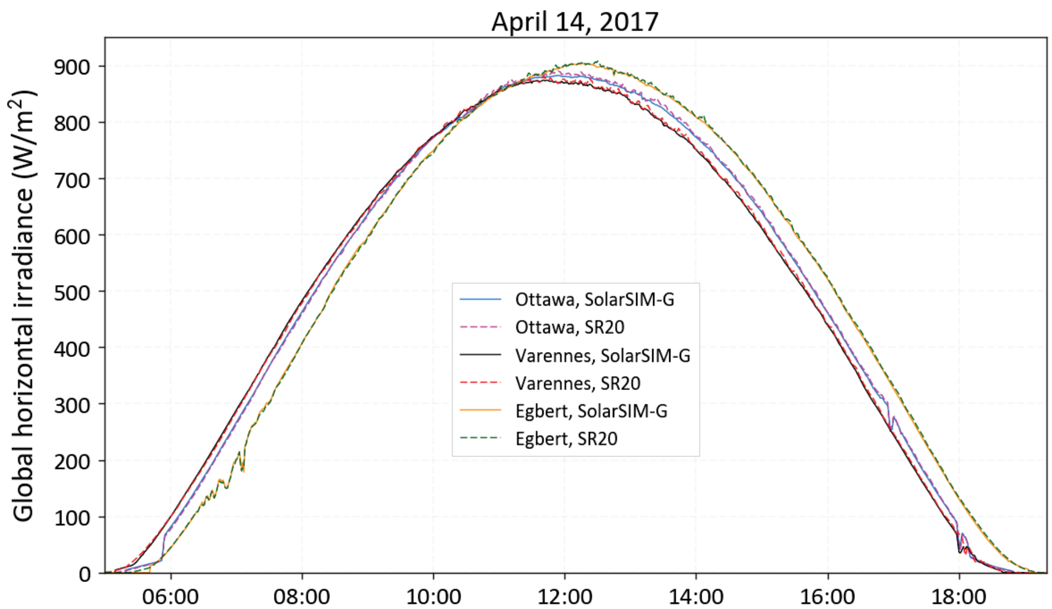

FIGURE 4. The daily GHI comparison between the CanSIM stations in Ottawa, Varennes, and Egbert as measured by the SolarSIM-G+ and SR20 pyranometer on April 14, 2017.

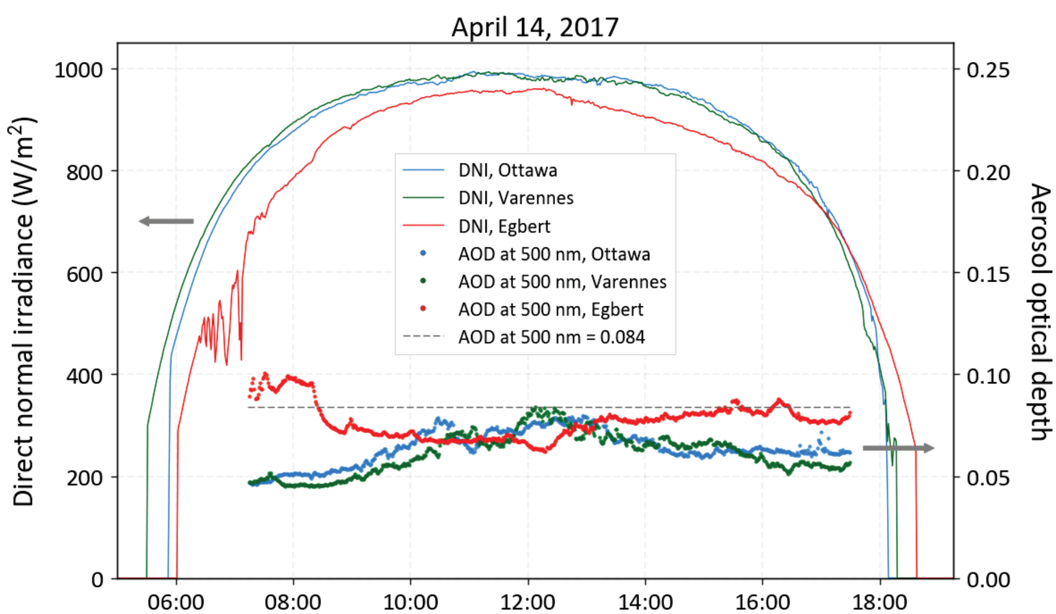

FIGURE 5. The daily DNI and the AOD at 500 nm from the CanSIM stations in Ottawa, Varennes, and Egbert as measured by the SolarSIM-D2+ on April 14, 2017.

The solar spectra from both the SolarSIM-D2+ and SolarSIM-G+ can be integrated for each timestamp throughout the day to obtain the broadband DNI and GHI profiles. Fig. 4 shows the daily GHI comparison from the Ottawa, Varennes, and Egbert stations between the SolarSIM-G+ and SR20 pyranometer on 14 April 2017. For all stations, the difference in the GHI between the SolarSIM-G+ and SR20 pyranometer was within 2% throughout the day. As expected, the GHI profiles are shifted in time – with the east-most, Varennes, and west-most stations, Egbert, having the earliest sunrise and the latest sunset, respectively. The daily GHI sum for the Ottawa, Varennes, and Egbert stations was 7.01, 6.95 and 7.11 kWh/m^2, respectively, with the minimum and maximum daily GHI sum differing by 2.3%. Fig. 5 shows the daily DNI profiles from the aforementioned stations on 14 April 2017. As it can be seen, there is more variability in the DNI between the stations, as compared to the GHI. The daily DNI sum for the Ottawa, Varennes, and Egbert stations was 10.65, 10.86, and 10.04 kWh/m^2, respectively, with the minimum and maximum daily DNI sums differing by 7.5%. All stations are located at near equal latitudes, hence, one expects near identical daily DNI sums if the atmospheric conditions were similar at all locations. However, the Egbert station had the lowest DNI sum due to a few clouds in the morning, higher aerosol optical depth and total water vapour column amount throughout the day. On the other hand, the Ottawa and Varennes stations had near identical DNI profiles due to similar atmospheric conditions. The current data set suggest that the temporal variations of the atmosphere have a more profound impact on the DNI more as opposed to the GHI.

CONCLUSION

The CanSIM network is a bold step forward in measuring the spectral variations of the DNI and GHI across Canada, which is paramount for solar applications. Once completed, this network will provide an unprecedented quality and quantity of solar and atmospheric data, including the spectral DNI, GHI, DHI, and AOD in the 280–4000 nm range, broadband DNI, GHI, and DHI, total column ozone and water vapour atmospheric amounts. Three stations have been deployed so far in Ottawa, Varennes and Egbert. Early results show the SolarSIM-G+ spectral irradiance is within 5% as compared to the EKO spectroradiometer in its 350–1050 nm range as measured at the Ottawa station on 18 March 2017. Furthermore, the difference in the broadband GHI as measured from all stations by the SolarSIM-G+ and SR20 pyranometer was within 2% throughout the day on 14 April 2017.

The data gathered on 14 April 2017 was a rare case when all three stations had a near perfectly clear conditions throughout the day. On this day, the daily GHI sum for the Ottawa, Varennes, and Egbert stations was 7.01, 6.95, and 7.11 kWh/m^2, respectively, while the daily DNI sum was 10.65, 10.86, 10.04 kWh/m^2, respectively. As expected, the GHI was less sensitive to variations in the atmospheric conditions, as compared to the DNI. Further deployments and data analysis will aid in quantifying the spectral GHI and DNI fluctuations across the country, and how they will impact prospective PV or CPV installations.

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