A Field Spectrometer Designed to Interface with Dataloggers and Continuously Monitor Plant Canopy Reflectance

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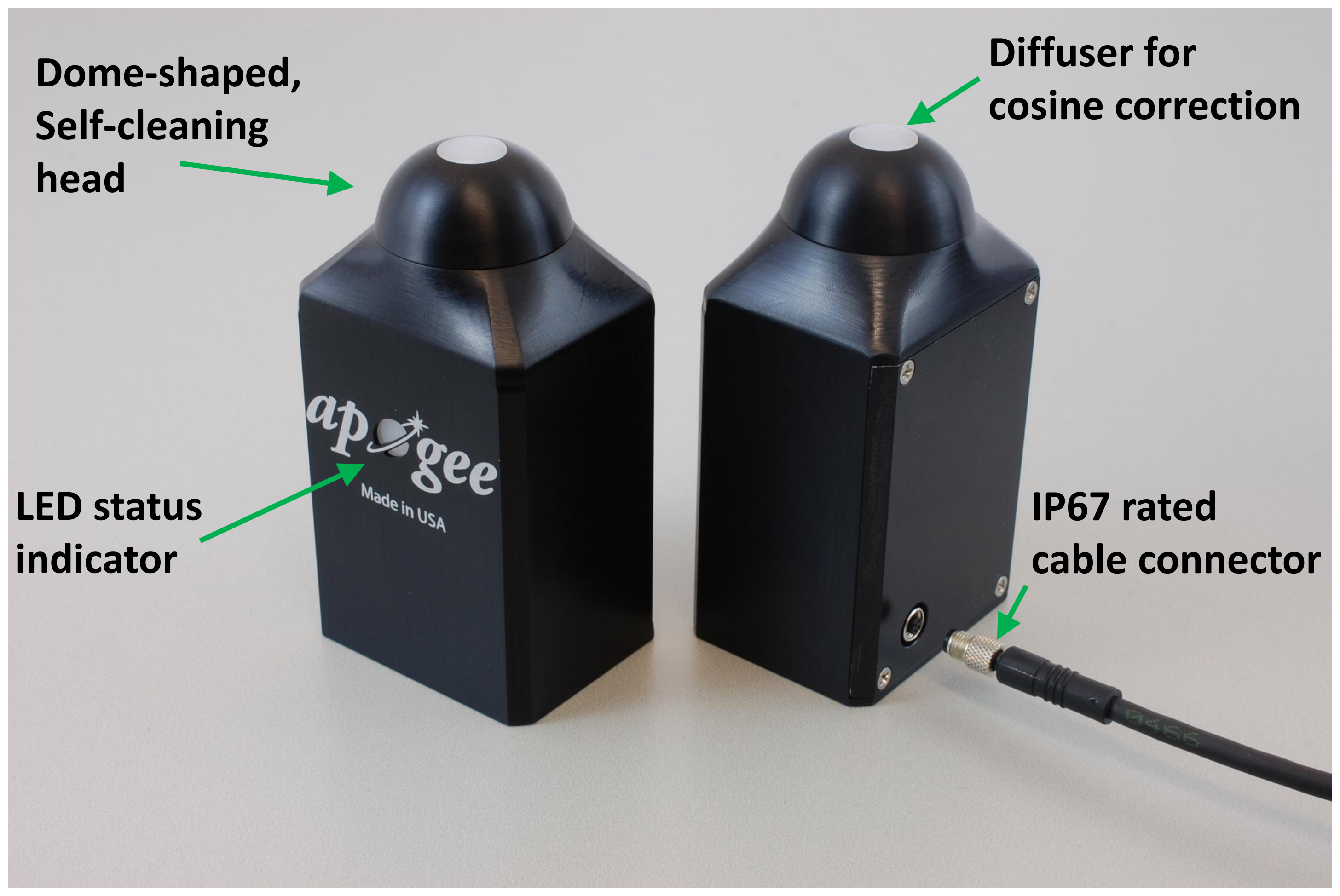
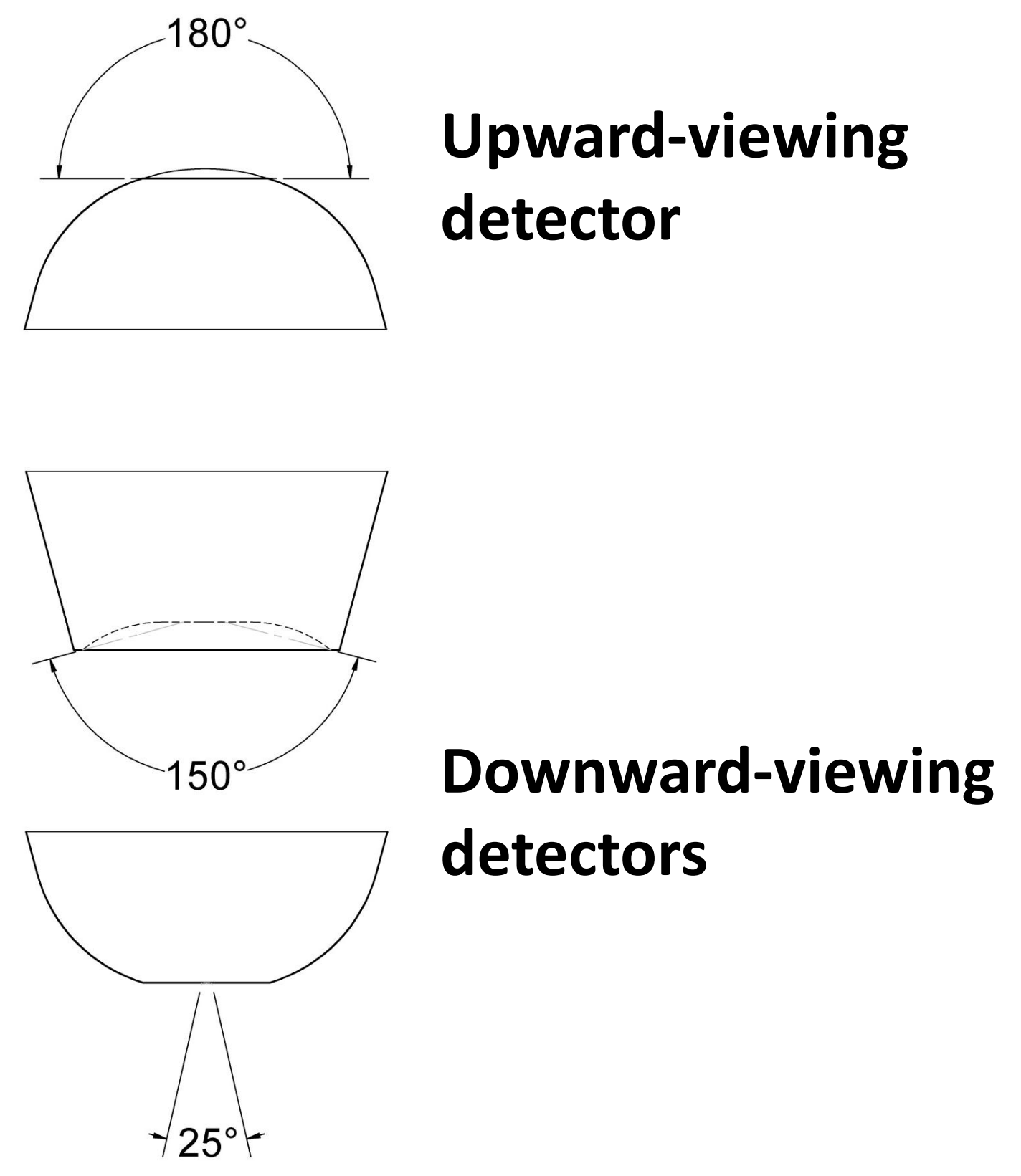
Abstract

Remote sensing is a valuable tool for measuring plant canopy characteristics across multiple spatial and temporal scales. Measurement of hyperspectral reflectance from plant canopies at the field scale is rapidly becoming a means of characterizing plant responses to the environment. Canopy reflectance at specific wavelengths can be used to monitor spectral indices related to plant canopy characteristics such as leaf area index, chlorophyll content, light use efficiency, and water status. Field-scale reflectance measurements of plant canopies can be linked with satellite and aircraft remote sensing to establish and validate reflectance indicators of canopy characteristics. There is also considerable interest in linking field-scale reflectance measurements with water and carbon flux data in an effort to determine relationships between reflectance and fluxes at the scale of a flux tower footprint. Portable spectrometers are widely available, but are typically large and heavy, expensive, and often require manual operation or a dedicated computer for automated data collection. Continuous measurement of hyperspectral reflectance at the canopy scale has thus been limited. Here we describe design, operation, and performance of a small, low-cost field spectrometer that interfaces with dataloggers (e.g., Campbell Scientific (CSI), Sutron; all measurements herein were made with Campbell Scientific model CR1000) to provide continuous measurements of surface spectral reflectance. Reflectance measurements were made with the spectrometer over multiple canopies and conditions and compared favorably to measurements from a reference spectrometer (Apogee Instruments model PS-100). Photosynthetic photon flux measurements were also made with the spectrometer over the course of two contrasting days, sunny and cloudy, and compared favorably to measurements from reference quantum sensors (LI-COR model LI-190).

Instrument Design



Three field of view options:

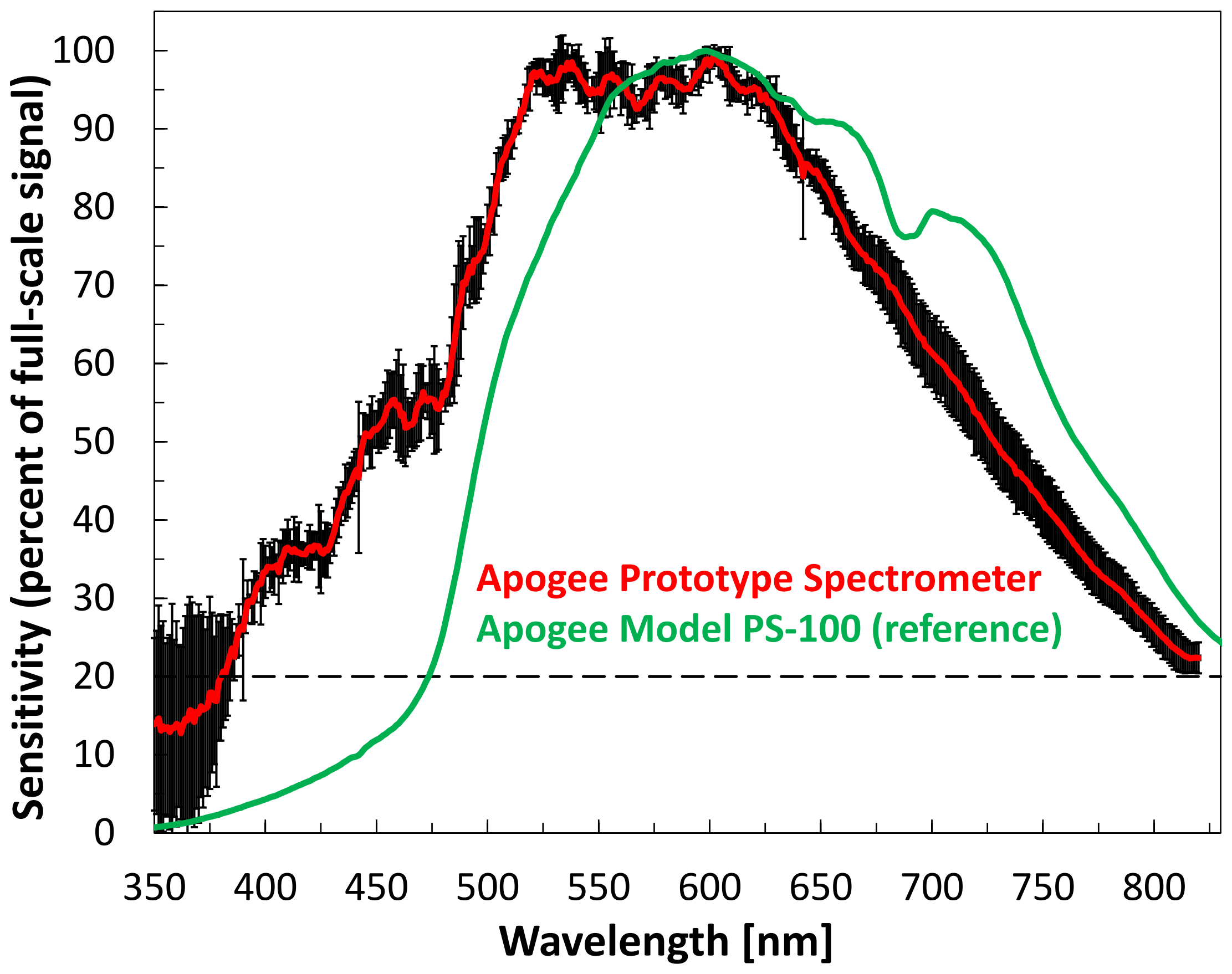


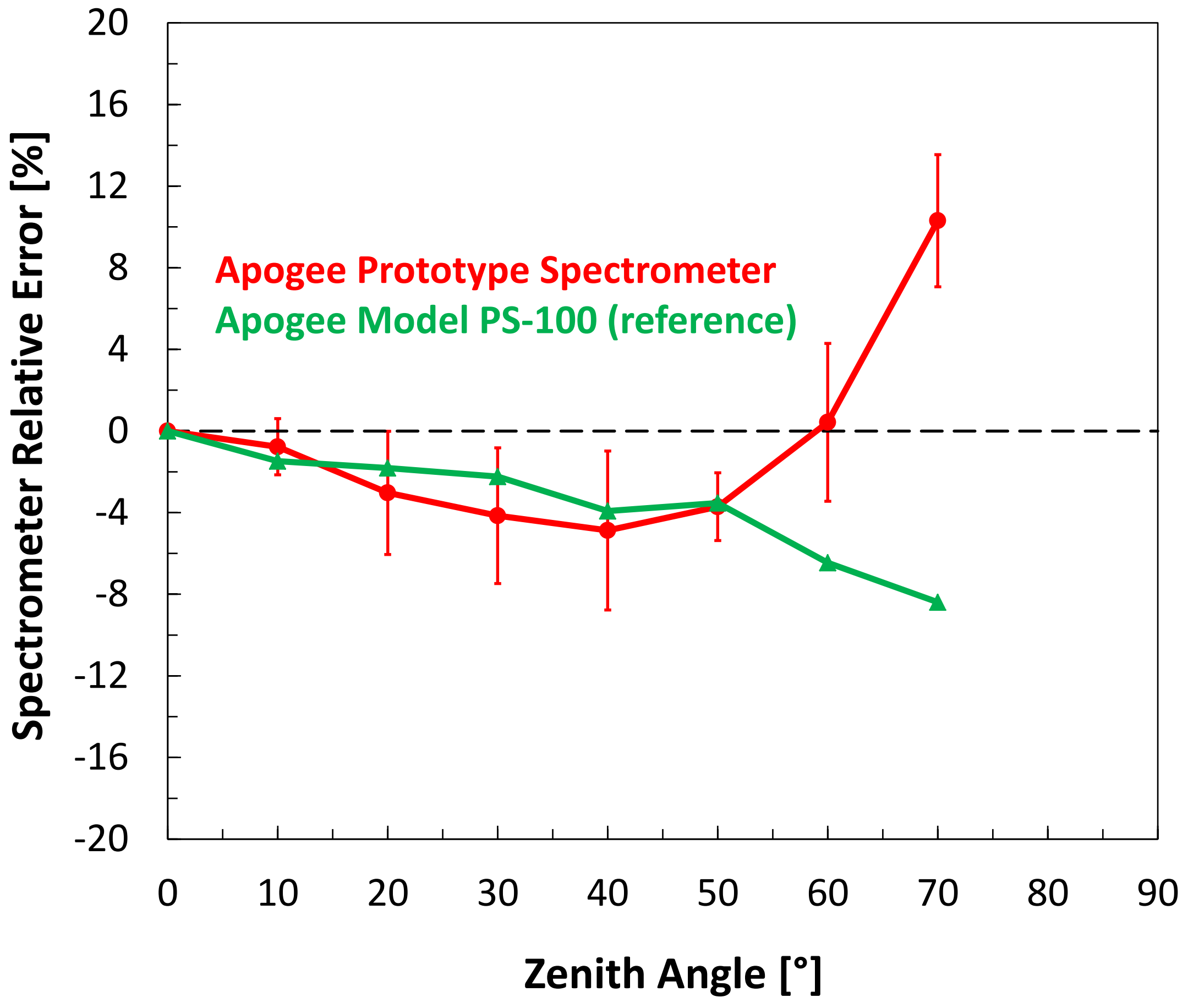
Spectrometer was designed to be small and lightweight to facilitate mounting on weather stations or in tight spaces. Spectrometer is weatherproof, allowing for continuous deployment in harsh conditions.

Specifications (Preliminary)

Wavelength Range:	350 to 820 nm
Measurement Resolution:	2 nm (full width, half maximum)
Signal to Noise Ratio:	1500 (at maximum signal)
Measurement Sensitivity:	> 15 % of full-scale signal (all wavelengths > 385 nm; see graph at right)
Measurement Repeatability:	< 1.0 % (at all wavelengths > 400 nm)
Non-linearity:	< 0.5 %
Stray Light:	< 0.25 % (at 450 nm)
Calibration Uncertainty:	± 5 % (for irradiance calibration)
Integration Time Range:	0.01 ms to 10 s
Field of View:	180° (upward-facing), 25° or 150° (downward-facing)
Directional (Cosine) Response:	± 5 % at 60° zenith angle (see graph at right)
Temperature Response:	-0.09 ± 0.10 % per C (see graph at right)
Operating Environment:	-20 to 70 C, 0 to 100 % RH
Power Requirement:	5 V (150 mW)
Current Drain:	115 mA (at fastest scan rate; can be reduced by slowing scan rate)
Communication Protocol:	ModBus
Dimensions:	90.7 mm (height), 48.3 x 38.1 mm (base)
Mass:	315 g (with 5 m of cable)
Estimated Cost:	$2000 per spectrometer

Spectrometer Sensitivity, Cosine Response, and Temperature Response

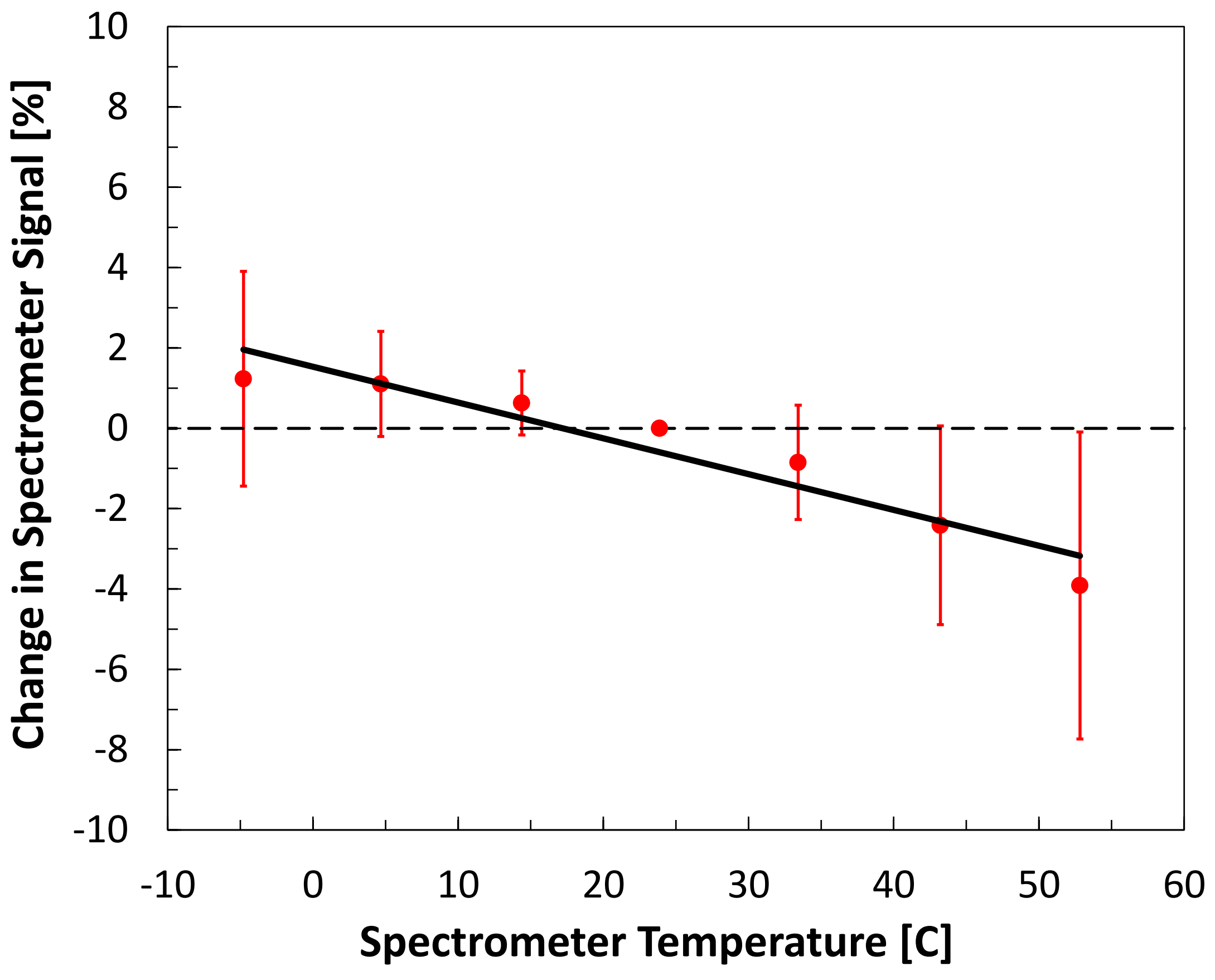




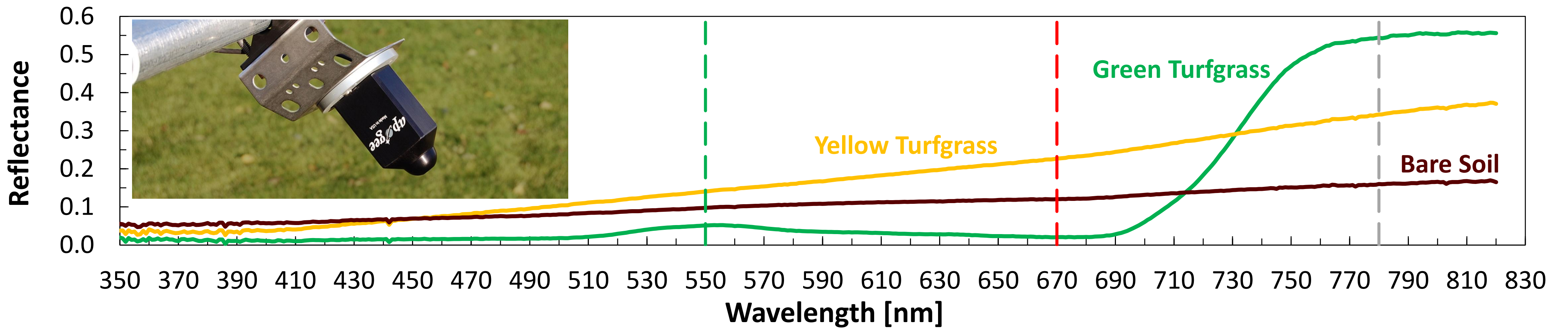
Spectral sensitivity was determined by calculating ratio of spectrometer signal to output from an NIST traceable lamp. Data shown is mean of four replicate spectrometers (error bars represent two standard deviations above and below mean).

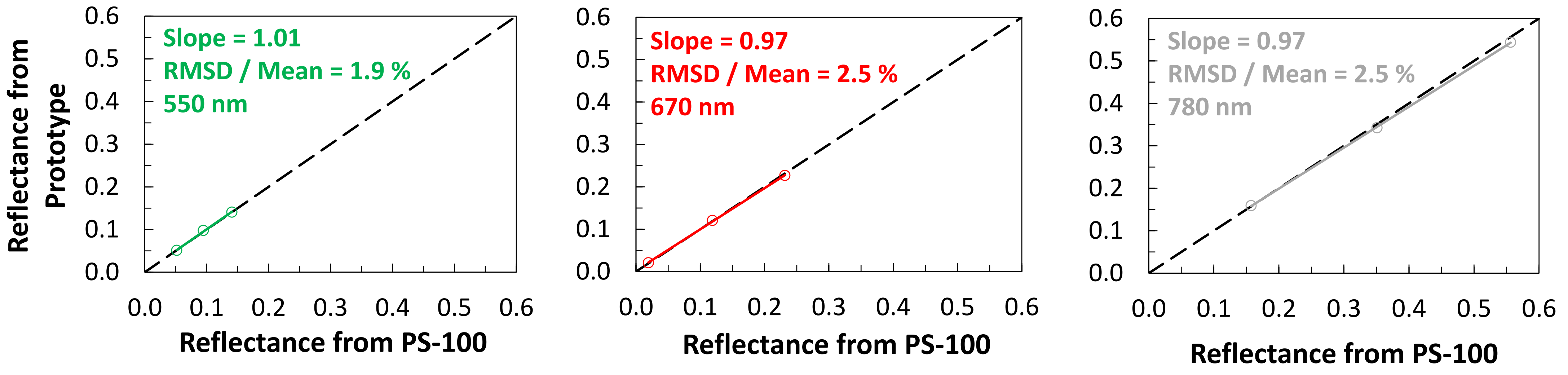
Cosine response was determined by calculating difference from ideal cosine response at different zenith angles. Data shown is mean of three replicate spectrometers (error bars represent two standard deviations above and below mean).

Temperature response was determined by comparing to a stable reference measurement across a range of approximately -10 to 50 C. Data shown is mean of four replicate spectrometers (error bars represent two standard deviations above and below mean).

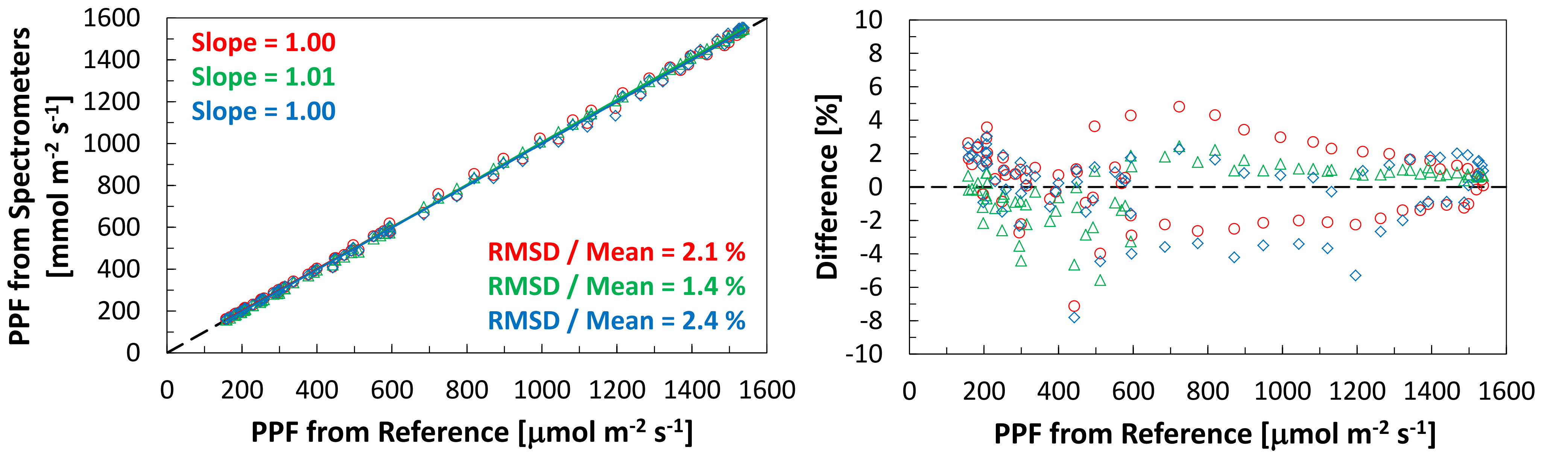


Spectral Reflectance and Photosynthetic Photon Flux Measurements





Spectral reflectance was measured for three different surfaces: green turfgrass, yellow turfgrass, and bare soil. Measurements from the prototype spectrometer were compared to measurements from a reference spectrometer (Apogee Instruments model PS-100) at three different wavelengths.



Photosynthetic photon flux (PPF) was measured on two consecutive, contrasting days: sunny and cloudy. Measurements from three replicate prototype spectrometers were compared to measurements from reference quantum sensors (mean of three LI-COR model LI-190 sensors).