

$$p = \frac{\rho RT}{m}$$

$$S(\lambda) = S_0(\lambda) e^{-m \cdot \delta(\lambda)}$$

# TOTAL SOLAR PYRANOMETER MODEL TSP-400

BULLETIN TSP-400

## General Description

The Model TSP-400 Total Solar Pyranometer is a precision meteorological instrument that measures global (direct and diffuse) total solar radiation. It is ruggedly designed for long-term field use and available in either non-ventilated or ventilated configurations (Model TSP-400V). When properly characterized the Model TSP-400V meets or exceeds the World Meteorological Organization's requirements for *high quality* pyranometers (formerly called a *secondary standard*).

The TSP-400's innovative design preserves the basic principle of total solar radiation measurement, that is, relating the incident irradiance to the temperature difference between a radiation receiver and a shielded thermal reference. However, the TSP-400 uses a rugged metal solar radiation-receiving surface, thermally bonded to a modern bismuth telluride thermopile, to make the temperature measurement. The special design of the radiation-receiving surface results in an instrument with these features:

- Medium level, low-impedance (<300Ω) output signal
- Superior linearity and long-term calibration stability
- Excellent cosine response completely free from axial asymmetry errors
- Freedom from the effects of changes in ambient temperature (no thermal correction is required by the user as with some older pyranometers)

The radiation receiving surface is protected by two domes, which block long-wave radiation and prevent conductive cooling of the radiation sensing element. The double-domed configuration also keeps the instrument weather-tight.

## Instrument Development

The TSP-400 represents a major advancement in the field of total solar radiation measurement. Historically, total solar pyranometers have relied on thermopiles (bundles of copper-constantan thermocouples) to measure the temperature difference between a radiation-receiving surface and a shielded thermal mass. The output voltage of a single thermocouple used in a conventional pyranometer is approximately 22 μV/°C, so many junctions connected in series are required to produce a usable output voltage.



**Model TSP-400 Total Solar Pyranometer**

The Seebeck coefficient of a bismuth telluride thermocouple is an order of magnitude greater than that of the conventional thermocouple; the TSP-400 typically produces ≈40 mVdc for a solar irradiance of 1250 W/m<sup>2</sup> (max. 60 mVdc FS).

## Applications

The TSP-400 is sensitive to radiation with wavelengths between 0.3 and 3 μm, making it an ideal instrument for the measurement of incident solar radiation. Typical applications include:

- Meteorological and climatological measurements
- Global warming and surface albedo studies
- Evaluation of solar energy systems
- Control of HVAC systems
- Remote-sensing ground truth experiments

## Calibration

Every TSP-400 is calibrated against a co-located reference pyranometer on an outdoor test stand under the sun. Our reference pyranometer is traceable to an absolute cavity radiometer, which in turn is referenced to the WRR (World Radiometric Reference), following ASTM E 824-81, *Standard Method for Transfer of Calibration From Reference to Field Pyranometers*, similar to ISO 9847, *Solar Energy — Calibration of field pyranometers by comparison to a reference pyranometer*.



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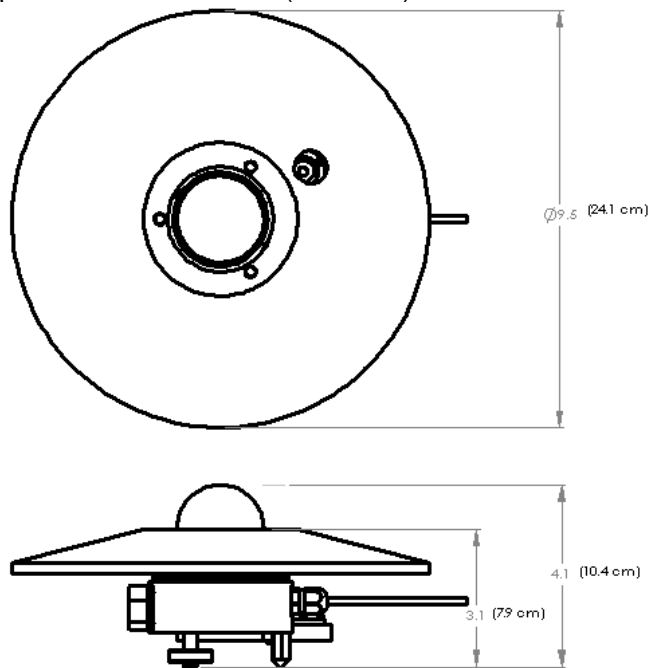
Calibration to "High Quality/Secondary Standard" is optionally available. Although not all High Quality characteristics are characterized for individual units, extensive testing has been conducted to characterize its cosine response, spectral response, and time response to prove that these parameters are uniform from unit-to-unit. Each system includes a calibration certificate, manual, and cables.

### Cosine Response

Much of the TSP-400 design effort focused on producing an instrument with a superior cosine response, achieved by special attention to the radiation-receiving surface. A typical normalized cosine response is shown; the horizontal line at 1.00 would indicate a "perfect" response.

### Mechanical Configuration

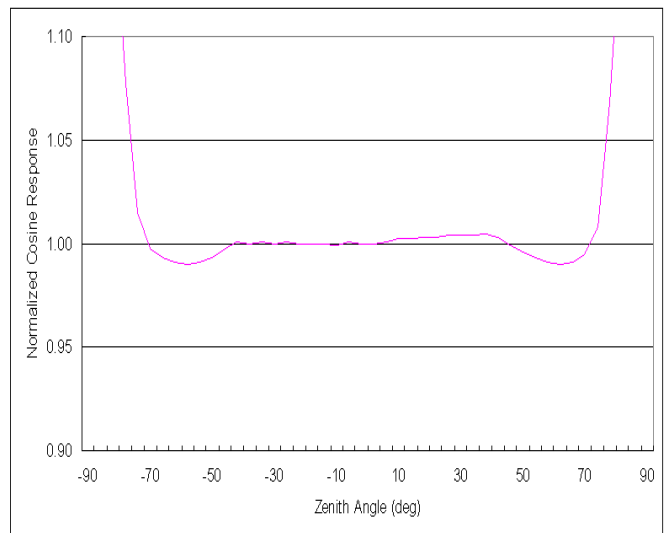
Unlike other plastic pyranometers, a TSP-400 is made from solid aluminum with a outer powder-coated aluminum radiation shield. This radiation shield minimizes ground return and helps to isolate the instrument from solar warming. Its baked-on finish has shown to give superior performance in outdoor environments. Internal components are O-ring sealed. A high quality bubble level is provided and a visible humidity indicator is backed up with a separate internal desiccant pack. Stainless steel leveling screws and two hold-down screw holes are provided on a 2.75 inch (6.985 cm) diameter



bolt circle. Each TSP-400 package includes a calibration certificate and 3 meter cable.

### Specifications

Spectral Response:	0.3 to 3 $\mu\text{m}$
Resolution:	1 $\text{W}/\text{m}^2$
Sensitivity:	Approx. $48\mu\text{V}/(\text{W}/\text{m}^2)$ , output impedance $<300\ \Omega$ , $\approx 40\ \text{mVdc}$ nominal (60 $\text{mVdc}$ max FS)
Cosine Response:	Better than $\pm 1\%$ for a $\pm 75^\circ$ SZA; better than $\pm 2\%$ for a $\pm 85^\circ$ SZA
Temperature Dependence:	$< 1\%$ of F.S. over $\pm 50^\circ\text{C}$ ambient temperature range
Response Time:	$\approx 12\ \text{sec}$ (1/e response to a step change in incident irradiance)
Linearity:	0.5% (0-1400 $\text{W}/\text{m}^2$ )
Axial Asymmetry:	$< 0.1\%$
Weight:	3.2 kg (7 lb.)



TSP-400 Mechanical Interface (left) and typical normalized cosine response (right)



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