Absolute Optical Power and Irradiance Comparisons with SORCE/TIM and Glory/TIM Instruments

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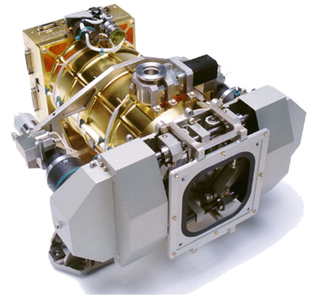


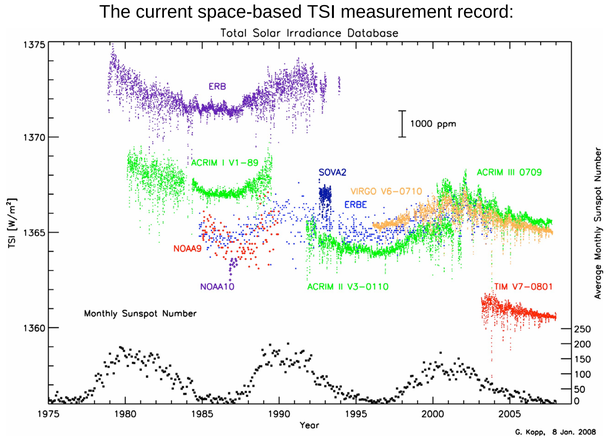
The total solar irradiance (TSI) climate data record began with spacecraft measurements nearly 30 years ago. While each instrument demonstrates the sensitivity to detect small changes in the Sun's radiant energy and many instruments can even track internal on-orbit degradation, the offsets between these instruments on an absolute scale generally exceed the stated instrument uncertainties. As a first step to address these offsets, optical power comparisons of ground-based TSI instruments representative of those on orbit against a NIST optical power standard were proposed. The ground-based Witness unit of the Total Irradiance Monitor (TIM) currently flying on the SOlar Radiation and Climate Experiment (SORCE) was the first TSI instrument to perform this comparison, completing it at NIST/Gaithersburg in 2006. We report on the findings of this comparison. One conclusion is that the TIM is not measuring optical power erroneously low by the net difference between it and the other TSI instruments, which have yet to perform this optical power comparison.

The next important step in addressing TSI instrument offsets is to perform comparisons in irradiance, rather than optical power, mode. The NASA Glory mission is funding the creation of the TSI Radiometer Facility (TRF) for such solar-power level irradiance calibrations. We describe here the details of the TRF, which is designed to achieve 0.01% absolute accuracy and operate the instruments in flight-like conditions, and preliminary results from a Glory/TIM to SORCE/TIM Witness unit comparison.

The Ultimate Goal

To reconcile offsets between TSI instruments and tie TSI to SI standards with a high degree of accuracy

The current space-based TSI measurement record:



As an initial step we are embarking on a series of ground-based intercomparison tests between representative TSI instruments and NIST traceable SI standards

Intercomparisons performed to date:

- Power mode intercomparison between SORCE TIM Witness instrument and a NIST trap diode transfer standard
- Irradiance mode intercomparison between Glory TIM and SORCE TIM Witness

Planned Intercomparisons:

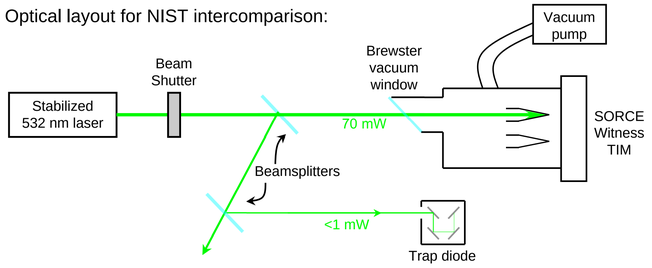
- Irradiance mode intercomparison between SORCE TIM Witness and a primary standard cryogenic radiometer
- Irradiance mode intercomparison between Glory TIM and a primary standard cryogenic radiometer
- Irradiance mode intercomparisons between ground-based versions of other TSI instruments representative of those on orbit and a primary standard cryogenic radiometer

NIST Power Mode Intercomparison

Fall 2006: NIST and LASP performed optical power comparisons between a trap diode transfer standard and a ground-based SORCE TIM Witness Instrument

- Applying solar power levels with the TIM in vacuum: ~68 mW @ 532 nm
- NPL has done similar power comparisons before, but in air
- Thanks to Allan Smith and Joe Rice at NIST for their work on this intercomparison

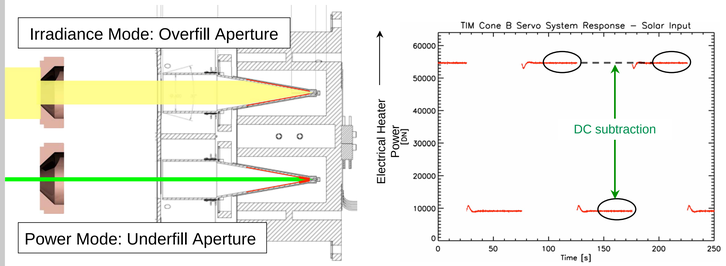
Optical layout for NIST intercomparison:



Results of power intercomparison:

Cone Comparisons Using DC Subtraction				
Date	Cone	NIST [mW]	TIM [mW]	Diff [ppm]
13 Nov. 2006	A	55.9525	55.8870	-1170
10 Nov. 2006	B	55.9063	55.8349	-1277
9 Nov. 2006	C	57.1211	57.0621	-1033
13 Nov. 2006	D	64.2561	64.1670	-1386
			Mean	-1217
			StDev	151
Cone C Diff from many meas.			Range	353

Under-filling the TIM cones in this lab test introduces significant nonequivalence between electrical and radiative heating. This precludes the use of phase sensitive detection, which relies on accurate knowledge of the nonequivalence. Instead, the intercomparison TIM data analysis used DC subtraction. On orbit tests have verified the agreement between phase sensitive detection and DC subtraction for the uniform illumination achieved on orbit.



Uncertainty budget for the NIST intercomparison:

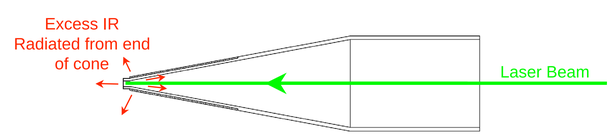
Uncertainty Budget for Laser Power Knowledge

Item	Value	Uncertainty	Units	Effect [ppm]
Trap Accuracy	200	200	ppm	200
Beam Splitter Ratio	0.00219621	0.00000052	unitless	238
Laser Stability	1500	50	ppm	50
Trap Spatial Uniformity	0.9999	0.0001	unitless	100
Trap Longitudinal Position		96	ppm	96
Brewster Window Transmission	0.999638	0.000100	unitless	100
			Total	359

Uncertainty Budget for TIM Measurement of Laser Power

Item	Value	Uncertainty	Units	Effect [ppm]
TIM Estimated Accuracy	350	350	ppm	350
Effect of Non-Equivalence	?	?	ppm	?
Positioning in Beam	213	0.5	mm	100
			Total	?

Time-dependent effects of the nonequivalence are dealt with though the use of DC subtraction. Steady state effects of nonequivalence, such as IR leakage of power, have not yet been addressed, but lab studies of such effects are planned with the new TRF.



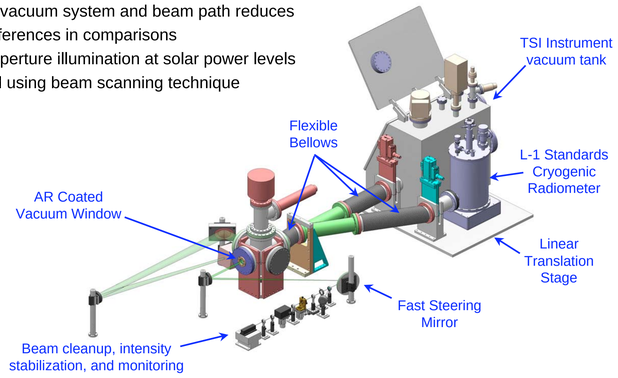
To test for this effect we plan on:

- Modeling the heat distribution of the cone with point illumination
- Performing a power intercomparison between the SORCE Witness and L-1 cryogenic radiometer for different beam sizes and beam illumination locations

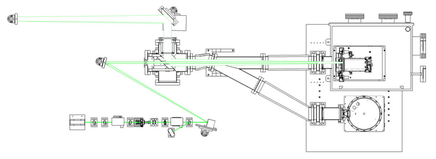
TSI Radiometer Facility (TRF)

This LASP facility was constructed to perform irradiance comparisons of TSI instruments to a reference cryogenic radiometer

- Custom built solar-power level cryogenic radiometer as an absolute reference
- Instrument tank designed to accommodate TIM and other TSI instruments to perform all tests in vacuum, simulating flight conditions
- Common vacuum system and beam path reduces optical differences in comparisons
- Uniform aperture illumination at solar power levels generated using beam scanning technique

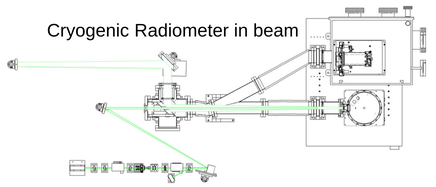


TSI Instrument in beam



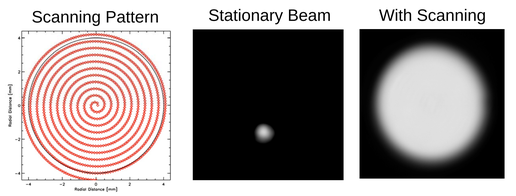
The design allows either the precision aperture of the cryogenic radiometer or a TSI instrument to be placed at the same spatial location in the stationary beam

Cryogenic Radiometer in beam



Uniform Beam Generation

A uniform beam is generated by scanning a smaller beam in a spiral pattern using a fast steering mirror. The instrument response time exceeds the scan period.



Glory TIM- SORCE TIM Witness Irradiance mode intercomparison

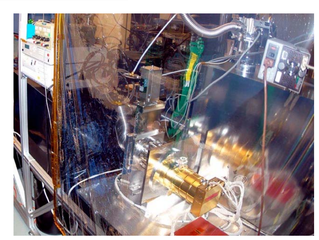
Fall 2007: We performed a preliminary intercomparison between Glory TIM and SORCE Witness TIM in the TRF facility

- SORCE Witness TIM placed in future position of cryogenic radiometer
- Compared Glory TIM channel A to SORCE Witness TIM channel A
- Solar irradiance levels using 532 nm laser (720-1340 W/m^2)

Glory TIM to SORCE Witness Irradiance Intercomparison				
Glory Cone	Witness Cone	Glory Average Irradiance [W/m^2]	Witness Average Irradiance [W/m^2]	Difference [ppm]
A	A	1032.36	1032.57	-292

Uncertainty budget for the intercomparison:

Item	σ [ppm]
Aperture Centering	382
Beam Centering	88
Aperture Sizes	18
Pointing Effects	6
Scattered Light	1
Beam Modulation	129
Statistical Uncertainty	153
Total	441



Future Work:

- Improve aperture centering: currently implementing a factor of ~10 improvement
- Integrate more stable 532 nm laser into TRF to reduce beam modulation effects
- Integrate cryogenic radiometer into TRF