SOLAR SPECTRAL IRRADIANCE OBSERVATIONS BETWEEN 200 AND 360 NM MADE DURING THE ATLAS 1 MISSION: COMPARISONS BETWEEN THE SOLSPEC, SUSIM, AND SSBUV MEASUREMENTS

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ABSTRACT

The SOLSPEC, SSBUV and SUSIM spectrometers observed the solar spectral irradiance simultaneously during the ATLAS-1 mission flown on board the Space Shuttle in March 1992. The three instruments use different methods and means of absolute calibration and were calibrated pre- and post-flight. The three data sets are reported from 200 to 360 nm at 1.1 nm resolution. The method of comparing the three independent data sets will be discussed. The importance of a common precise wavelength scale will be shown when comparing the data in the wavelength region of the strong Fraunhofer lines. The consistency of the three measurements is better than 5%.

The fact that the calibrations of the three instruments were based on three independent national standards ensures that the absolute solar spectral irradiance in the range 200-360 nm is now known with an accuracy better than 5%. The data taken from this mission are compared with solar observations from other space based missions.

INTRODUCTION

Solar spectral irradiance measurements are needed for modeling, photochemical studies, and understanding the thermal structure, dynamics, and energy budget of the earth's atmosphere. Observing the sun at any wavelength, but especially in the UV, is a difficult task due to the damaging effect of the solar photons and particles on the instruments. This effect, as well as the problem of achieving an accurate absolute calibration, were the main causes of the discrepancies observed when different data sets were compared previously. At the level of accuracy needed presently, the primary standards' absolute accuracies may still be questioned. Thus, a set of three solar spectrometers having different designs, calibrated with different methods, and using different absolute standards represents a way to verify if the measured absolute irradiance data are consistent. If so, then the absolute solar irradiance spectral irradiance can be determined with some confidence.

The ATLAS-1 payload flew on the Space Shuttle Atlantis (STS-45) from 24 March through 2 April 1992. The sun was simultaneous observed by the SOLSPEC, SSBUV, and SUSIM instruments during four periods. The data used in the comparison presented below were obtained primarily during the first observation period on 29 March 1992, where the thermal conditions were most stable.

SOLSPEC DESCRIPTION

SOLSPEC observes from 200 nm to 3000 nm using three similar double monochromator, holographic grating spectrometers. All six gratings are mounted on the same stepper motor-driven mechanical shaft. The accuracy of the rotation allows a positioning better than 0.01 nm. SOLSPEC incorporates diffusers in front of each of each entrance slit to reduce the effect of any pointing offset. The UV spectrometer (200-350 nm) uses a photomultiplier as detector. A wheel in front of each detector carriers second order filters and appropriate attenuaters in order to keep the signal level in an acceptable range, taking into account the great spectral variation of both UV solar irradiance and spectrometer responsivity. All wheels rotate as a function of the step number to place the filters at their appropriate positions. The electronics allow scanning by any increment of steps. During solar observations the scanning mode corresponds to about 0.4 nm for the UV spectrometer.

The instrument contains calibration lamps to monitor the responsivity and the spectral characteristics of the optics in space and on the ground. Two deuterium lamps are periodically activated to provide checks on the UV spectrometer's radiometric sensitivity. A He hollow cathode lamp provided 7 strong emission lines, allowing monitoring of the wavelength scale and the instrument slit function on the ground and in space.

SOLSPEC also flew on the Space Shuttle in 1983 on the Spacelab 1 mission.

SSBUV DESCRIPTION

SSBUV supports the long-term global stratospheric ozone and UV monitoring programs by providing repeated checks on the calibrations of UV ozone and solar monitoring instruments flying on US and international satellites. SSBUV has flown 7 times between October 1989 and November 1994; the ATLAS-1 mission was the fourth SSBUV flight. The SSBUV experiment consists of a double 1/4 m Ebert-Fastie spectrometer with a single bi-alkali PMT detector, an onboard calibration system, nadir and solar aspect sensors, and support electronics, all contained in two Get Away Special (GAS) canisters that were mounted on the starboard side of the Shuttle's cargo bay. The SSBUV wavelength range is 200 to 405 nm and the bandpass is 1.1 nm.

A 2-element quartz transmission diffuser is employed during solar observations to fully illuminate the spectrometer's field of view and reduce signal intensity to an acceptable level. SSBUV carries an onboard calibration system that employs a quartz halogen and a deuterium arc lamp to check radiometric stability and a Hg lamp to check wavelength stability.

SUSIM DESCRIPTION

The SUSIM instrument consists of two identical double-dispersion scanning spectrometers, with seven detectors, entrance and exit filters, and a microprocessor for instrument control, command, and data handling. The SUSIM covers the range 110-410 nm with 0.15 and 5.0 nm resolution. The SUSIM instrument has flown five times between March 1982 and November 1994. The SUSIM experiment has overcome the difficulty of making high absolute accuracy measurements in the ultraviolet by using contamination control techniques and sensitivity tracking with an onboard deuterium (D_2) lamp. The sensitivity changes are determined by using one of the spectrometers for only the calibration lamp to make characterization measurements of the filter and detectors. The second spectrometer is used for making solar measurements and for periodic measurements using rarely used filters and detectors. The solar spectrometer is compared to the calibration spectrometer to fully determine the sensitivity changes. The SUSIM ATLAS was the forerunner to the SUSIM UARS experiment, which is in its fourth year of making daily measurements.

SOLSPEC CALIBRATION

A German Heidelberg Observatory blackbody is used for the SOLSPEC radiometric calibration. Its graphite cavity can be heated up to 3100° K. The windowless cavity is flushed with argon to prevent oxygen contamination. The geometrical set-up allows the instrument to view the emitting cavity under the same solid angle as the sun. The temperature of the blackbody cavity is measured periodically using a pyrometer calibrated by the Physikalisch-Technische Bundesanstalt (PTB) of Berlin (Germany). Using the Planck's law, the blackbody irradiance is measured and the instrument responsivity determined from the instrument counts recorded when observing that source.

For each SOLSPEC spectrometer, a parabolic dispersion law giving the wavelength as a function of the step number is determined via a least squares regression of the observed position of lines from argon, krypton, and neon laboratory sources. The 2σ uncertainty in the SOLSPEC wavelength calibration is 0.1 nm.

SSBUV CALIBRATION

SSBUV is calibrated in a class 10,000 clean room at the NASA/Goddard Space Flight Center. Multiple 1000 watt quartz halogen (FEL) lamps, calibrated by the National Institute for Standards and Technology (NIST), are the primary standards used to calibrate SSBUV between 250 and 405 nm. NIST-calibrated deuterium (D_2) arc lamps also provide calibration data in the 250-350 nm region and are used to extend the SSBUV calibration to 200 nm. The D_2 measurements are normalized to the FEL data in the spectral overlap region. A field calibration fixture that mounts on the instrument GAS canister provides an additional check on the instrument's calibration and is used in conjunction with the absolute laboratory calibrations and calibration checks via the onboard system. Sensitivity changes during the ATLAS-1 mission ranged from roughly 1% near 400 nm to approximately 5% near 200 nm. The solar data reported here have been corrected for instrument sensitivity degradation. The 2σ uncertain in the absolute calibration ranges from approximately 2.6% at 400 nm to 6% at 200 nm.

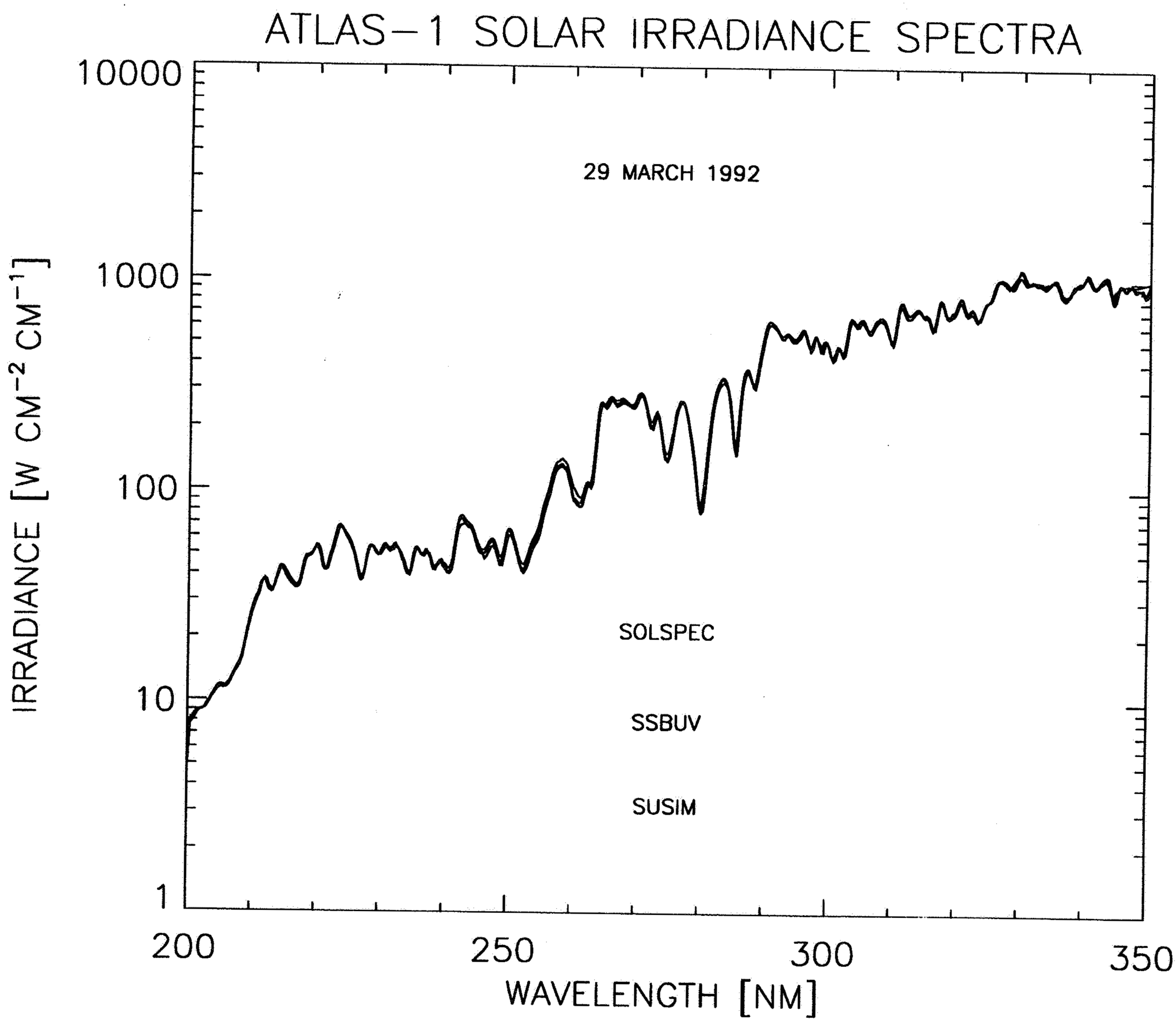
Similar to SOLSPEC, the absolute wavelength calibration of SSBUV as a function of the grating encoder step number is determined via a least squares regression of the observed position of lines from multiple laboratory sources. The estimated 2σ uncertainty of this calibration is 0.02 to 0.03 nm. Over its first 6 flights long-term changes in the SSBUV wavelength calibration were less than 0.02 nm and thermally driven intraflight changes were 0.05 nm or less.

SUSIM CALIBRATION

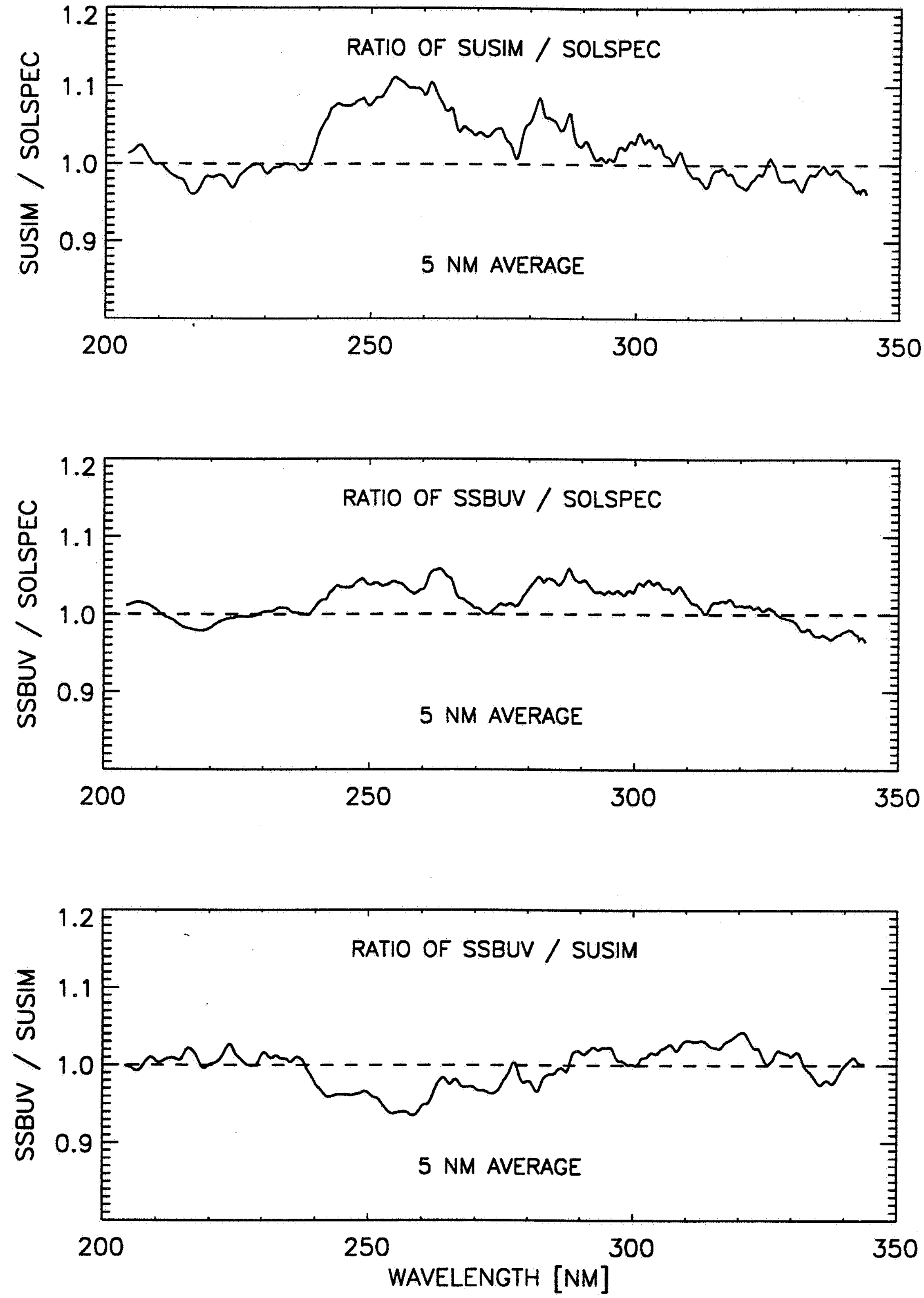
The calibration standard for the SUSIM is the NIST Synchrotron Ultraviolet Radiation Facility (SURF) which is a primary standard. During calibration SUSIM is oriented at 45° and 135° to the plane of the synchrotron; the average of the calibration factors for these two orientations removes almost all the effects of the polarization of the SURF beam. At the long wavelengths SUSIM is also calibrated using a NIST calibrated quartz tungsten-halogen FEL secondary standard lamp. The two independent calibrations, FEL and SURF, agree to within 2%.

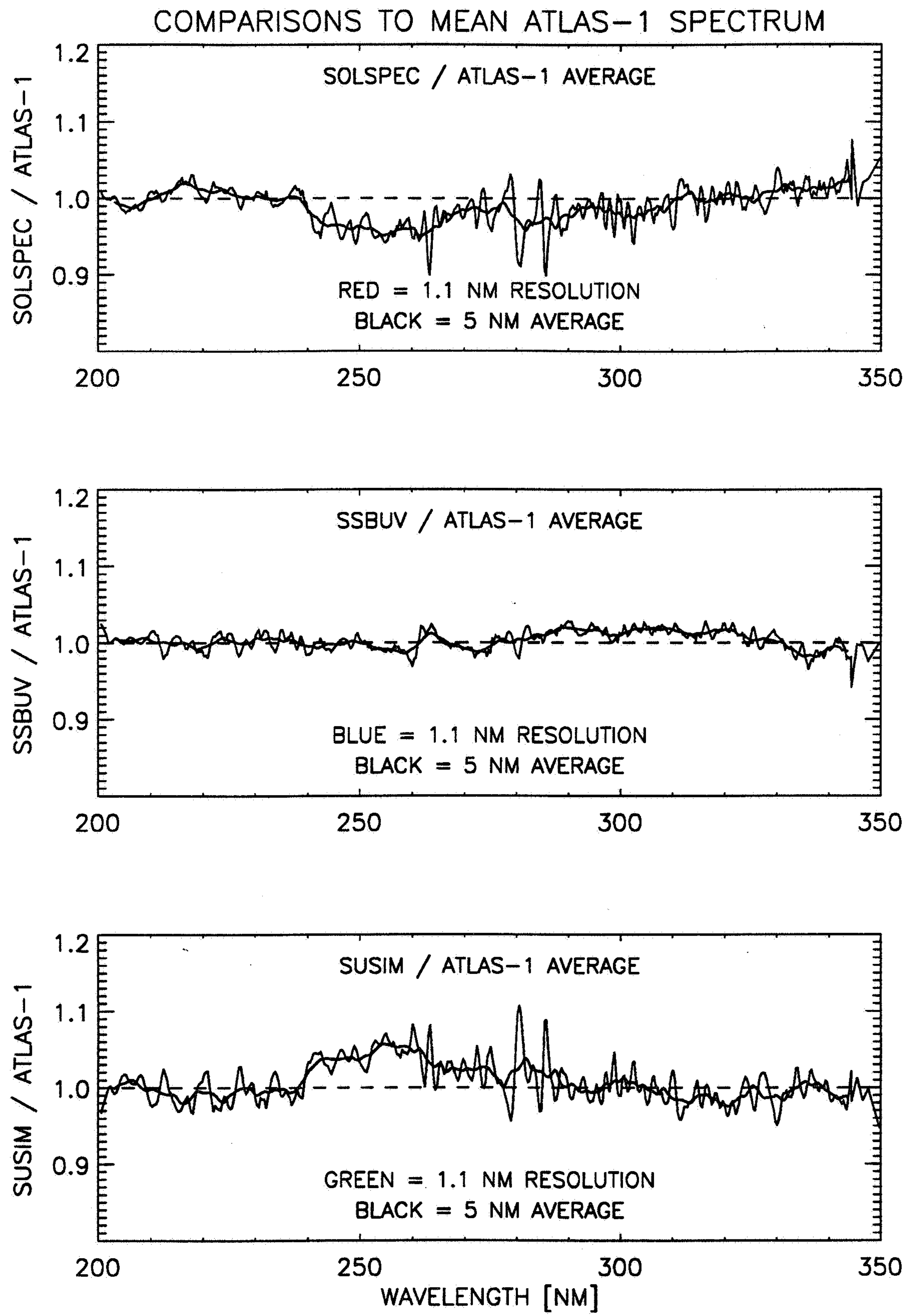
The aging correction to account for the UV degradation was based on a comparison of the NIST preflight and postflight calibrations. The onboard D_2 lamp was not stable during the ATLAS-1 mission and could only be used to give general validation to the corrections determined.

The wavelength scale for the high resolution SUSIM spectrum is derived by a second order polynomial fit to 11 well defined solar spectral lines across the range of the grating encoder positions. This calibration has an estimated 2σ uncertainty of 0.2 nm. The calibration of the low resolution spectrum is based on the high resolution spectrum.


ATLAS-1 SOLAR IRRADIANCE SPECTRA
29 MARCH 1992
SOLSPEC
SSBUV
SUSIM
IRRADIANCE [W CM^-2 CM^-1]
10000
1000
100
10
1
200
250
300
350
WAVELENGTH [NM]

COMPARISON OF ATLAS-1 SOLAR IRRADIANCE MEASUREMENTS





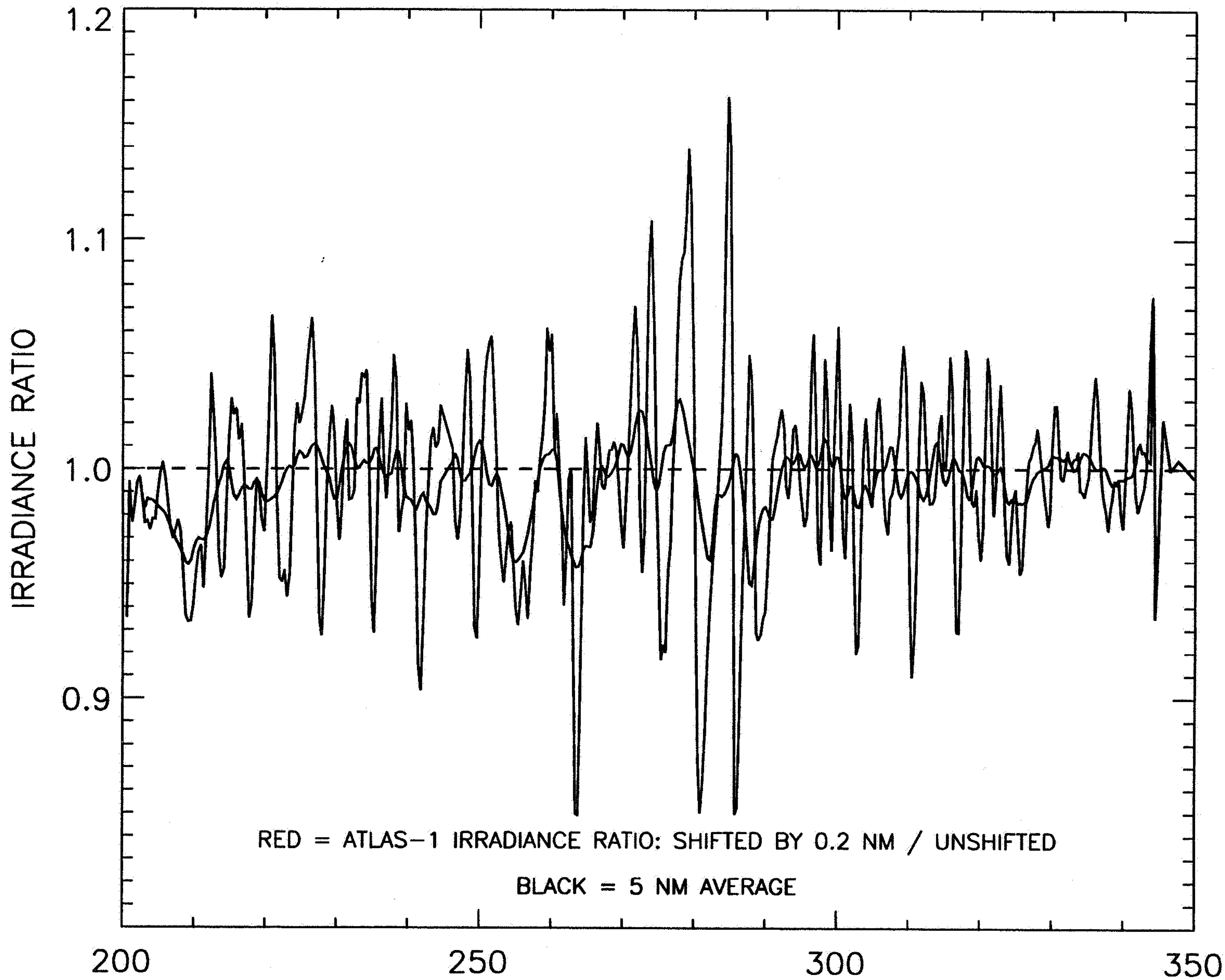
COMPARISONS TO MEAN ATLAS-1 SPECTRUM
SOLSPEC / ATLAS-1 AVERAGE
RED = 1.1 NM RESOLUTION
BLACK = 5 NM AVERAGE
SOLSPEC / ATLAS-1
1.2
1.1
1.0
0.9
200
250
300
350
SSBUV / ATLAS-1 AVERAGE
BLUE = 1.1 NM RESOLUTION
BLACK = 5 NM AVERAGE
SSBUV / ATLAS-1
1.2
1.1
1.0
0.9
200
250
300
350
SUSIM / ATLAS-1 AVERAGE
GREEN = 1.1 NM RESOLUTION
BLACK = 5 NM AVERAGE
SUSIM / ATLAS-1
1.2
1.1
1.0
0.9
200
250
300
350
WAVELENGTH [NM]

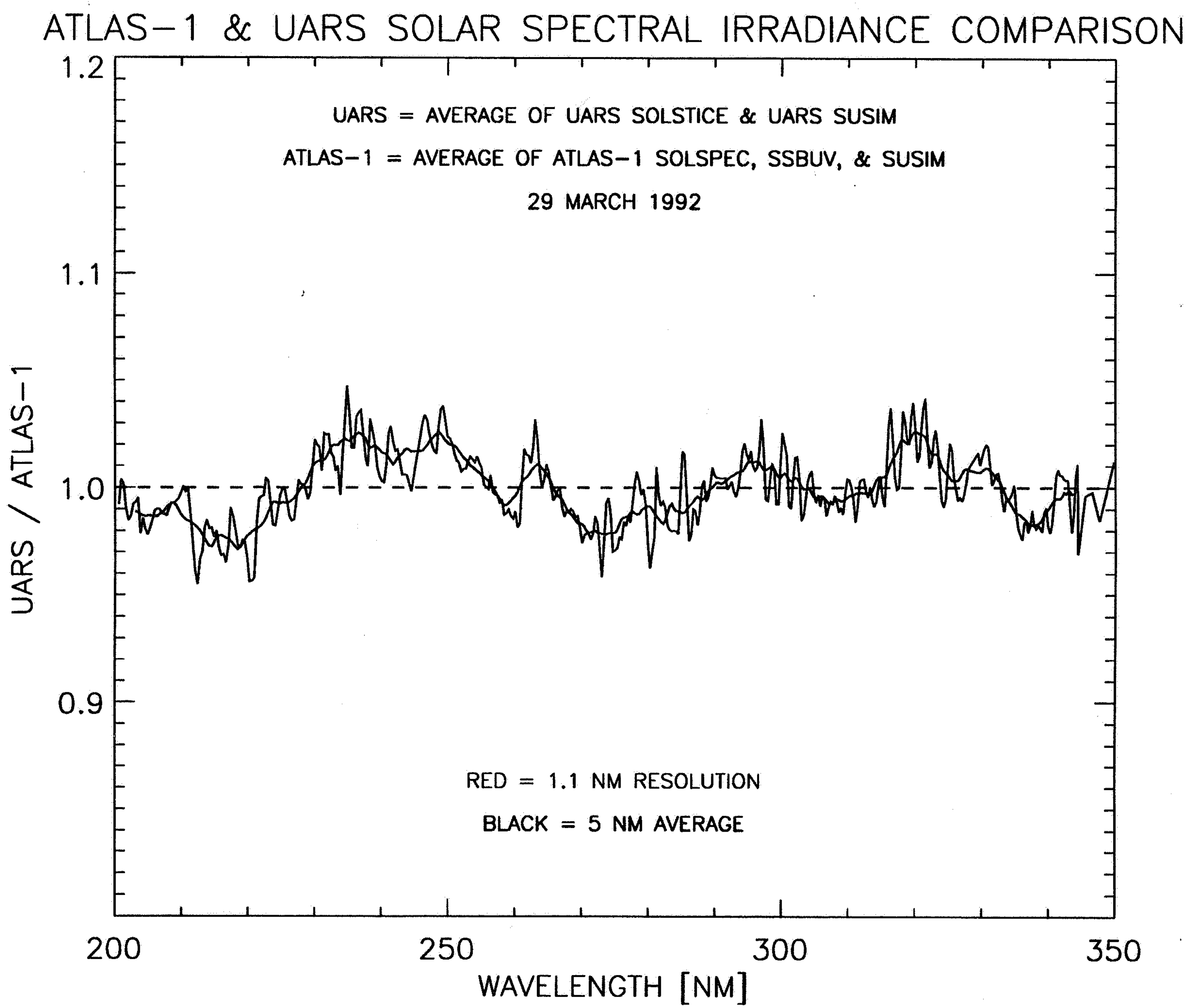
WAVELENGTH SCALE IMPACT

Each instrument team applies a detailed wavelength calibration to their data. However, small differences in the wavelength assigned to the UV solar irradiance spectrum can have a dramatic effect when spectra are compared. Especially problematic are the areas near solar emission and absorption lines, as well as regions where the spectrum makes large changes in magnitude. Each instrument has a slightly different bandpass width and shape, further amplifying sensitivity to wavelength error. Several techniques have been used by the experiment teams to establish accurate wavelength scales for their spectra. Among these are comparison to high resolution spectra, which can be determined with higher wavelength accuracy. Work is continuing by our ATLAS teams to achieve an accurate wavelength scale.

Comparison of the average ATLAS-1 spectrum with a second spectrum formed by shifting the initial spectrum by 0.2 nm is shown in order to demonstrate the sensitivity to wavelength determination error. The deviation of this shifted spectrum from the original spectrum approaches the size of the differences in the individual spectra and the differences to the UARS SUSIM and SOLSTICE mean spectrum for same day.

IMPACT OF A 0.2 NM SHIFT ON THE ATLAS−1 IRRADIANCE




ATLAS-1 & UARS SOLAR SPECTRAL IRRADIANCE COMPARISON
UARS = AVERAGE OF UARS SOLSTICE & UARS SUSIM
ATLAS-1 = AVERAGE OF ATLAS-1 SOLSPEC, SSBUV, & SUSIM
29 MARCH 1992
RED = 1.1 NM RESOLUTION
BLACK = 5 NM AVERAGE
1.2
1.1
1.0
0.9
UARS / ATLAS-1
200
250
300
350
WAVELENGTH [NM]

CONCLUSIONS

COMPARISONS BETWEEN INDIVIDUAL INSTRUMENTS AND A COMPARISON OF EACH INSTRUMENT'S SPECTRUM TO THE MEAN ATLAS-1 SPECTRUM SHOW:

- Generally good agreement within the instrument's calibration uncertainties
- Largest differences ($\sim$5%) from 250-300 nm

A COMPARISON BETWEEN THE AVERAGE ATLAS-1 SPECTRUM WITH THE AVERAGE COINCIDENT UARS SPECTRUM (WOODS ET AL., 1995) SHOWS AGREEMENT WITHIN ±2%.

- Small wavelength errors have little impact on the 5 nm comparison

THESE RESULTS SUGGEST THAT THE MIDDLE UV SOLAR SPECTRAL IRRADIANCE CAN NOW BE MEASURED BY INDEPENDENT INSTRUMENTS TO AN ABSOLUTE ACCURACY ON THE ORDER OF 5%