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Real Time NIST Reference Radiometry using the International Space Station

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Abstract – The need for long term calibration reliability and assurance of accuracy is wide spread for optical data acquired by using remote sensing satellites. The International Space Station will be a unique asset for providing a platform for manned and maintained NIST/SI traceable standard sensors to augment the calibration of other remote sensing satellite sensors. As an example the uncertainty goals of the current total solar irradiance measurement programs will be analyzed and a possible approach to meet those requirements using the space station instrumentation will be presented.

INTRODUCTION

Provision for long-term calibration reliability and assurance of accuracy for space based sensor performance has been lacking in remote sensing programs. Many present and future remote-sensing satellites measure optical radiation from various sources. Examples of sources are geographical features on the Earth, the Sun, the Moon, stars and man-made reference objects or missiles. These satellites are expected to perform over many years with high accuracy, which presents a very challenging radiometric calibration problem that could be simply stated as follows. Any radiometric measurement involves both a source of optical radiation and a sensor. To measure changes in a source, the radiometric calibration of the sensor must be known. This radiometric calibration is determined by measuring a known source of optical radiation with the sensor. However, achieving a known source of optical radiation for a sensor on a satellite is very difficult. On-board sources can change, as can extraterrestrial sources such as the Moon or the Sun. Terrestrial sources can be measured using Earth-based systems, but the propagation of the optical radiation through the atmosphere to the satellite must be calculated. Therefore, instrumentation which improves the accuracy and long-term reliability of sensor calibration on remote-sensing satellites would correspondingly decrease the uncertainties associated with those measurements and improve the quality of the data obtained from the satellites launched in succession over long periods of time. The International Space Station (ISS) could serve as a platform from which manned and maintained real time radiometry using NIST reference standards can be carried out to augment the calibration of remote sensing satellite sensor platforms. In Section II, as an example, the current calibration requirements for the solar irradiance measurement sensors are reviewed and in Section III a possible approach to meet those requirements by utilizing the ISS as an asset will be presented. In Section IV successful verification of this approach in parallel cases are presented. The possible issues to be studied for successfully implementing the proposed approach are mentioned in Section V.

II. SOLAR IRRADIANCE CASE – AN EXAMPLE

Studies have shown that the Earth's global mean temperature increased by 0.5°C during the past century (Ref.1). Although, the concern is industrialization as a possible cause, there is considerable variance in the temperature increase between year to year and decade to decade that points to the need for more reliable data to understand this global climate change. The Sun plays a major role for the Earth's global climate. Any climate change could be either caused by the Sun or by man made green house gases and industrial aerosols or natural processes on the Earth such as volcanic eruptions and dynamics of ocean and atmosphere circulations. Therefore, monitoring the Sun's total irradiance is very important in this global climate study and it has become mandatory to have a platform above the Earth's atmosphere to gather accurate data by avoiding atmospheric transmission effects. Six U.S. remote sensing satellite missions (ERB, ACRIM I, ACRIM II, NOAA 9, 10, ERBS) have been flown at various times since 1978 to gather data on the Sun's total irradiance. The data are shown in figure 1. The instruments used in these missions are electrical substitution radiometers which are considered intrinsically absolute detectors, however corrections had to be made for extraneous effects. The data in figure 1 show considerable variability from mission to mission beyond the intrinsic uncertainty quoted for each instrument. Lean et al. have analyzed the accuracy and stability of the radiometers in these missions. They concluded that the systematic uncertainties could be up to 0.3 % and dominating, whereas random uncertainties are only of (Ref.3). The solar irradiance varies day to day by few tenth's of a percent as shown in Fig.2 due to rotation of the Sun on its axis every 27 days. This modulation is superimposed on the 11 year solar cycle variation with an amplitude of 0.1 % (Fig.2). The present database of 16 years is incomplete to reveal variations from one solar cycle to another. However, based on the current database one could infer there is 0.15% amplitude in the total solar irradiance variability within the recent 11-year

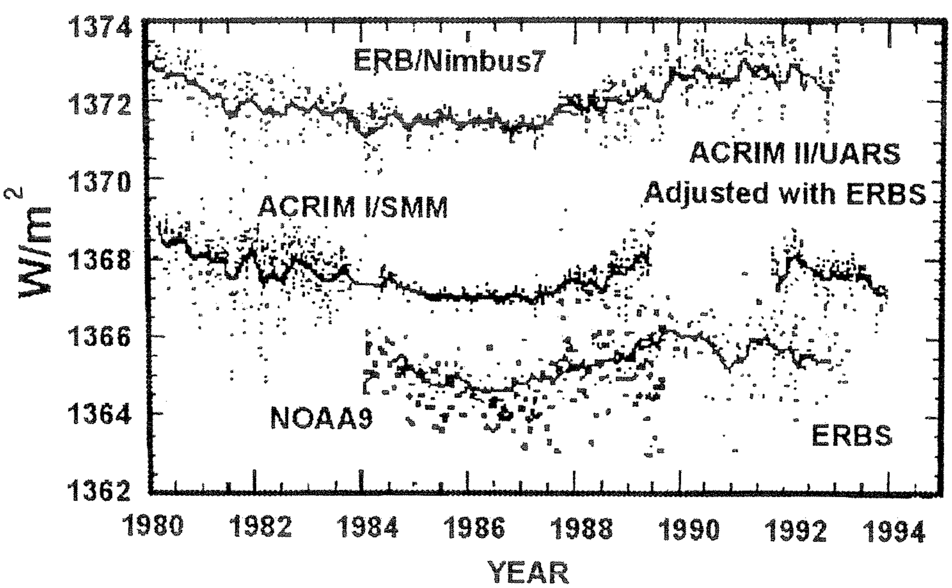

Figure 1. The data base of solar total irradiance observations from spacecraft since 1978. The ACRIM II data have been adjusted to the ACRIM I irradiance scale by using overlapping ERBS data.

the order of 0.1 to 0.2% (Ref.2). The quoted uncertainties of these instruments did not include all the possible systematic uncertainties which came to be known later and it explains the instrument to instrument variation shown in figure 1.

The data collected from these missions, although valuable, are found to be not of useful accuracy for the time scales needed for the climatological effects to show up. It is hard to predict the long term trends from just 16 years of data. However, Wilson concluded from this data that there is increase of 0.036% in total solar irradiance per decade resulting in a possible 0.4 K additional rise in global temperature to the predicted 1.5 K to 4.5 K rise due to greenhouse gases by the end of next century cycle (Ref.2). Historical circumstantial evidence based on ionized Ca emission from the Sun and the Sun like stars indicate there is roughly 0.25% increase in total solar irradiance from Maunder Minimum of 1700 AD to today as shown in Fig.2 (Ref.2). It means about 0.1% change in a century or 0.01% change in a decade. However, Wilson's conclusion mentioned earlier shows a predicted change of 0.25% by the end of the next century. The verification of these speculations on this long-term variability of total solar irradiance is in the forefront of research today because it is an important quantity that enters in global climate predictions. Also, it enters into the modeling algorithms that try to separate out components contributing to global warming which is of great concern to every nation in the world today.

The study team for the National Polar Orbiting Operational Environmental Satellite System (NPOES) after critically examining the issues mentioned earlier recommended for NPOES total solar irradiance measurements an absolute uncertainty goal of 0.03% with a threshold at 0.1% and relative uncertainty goal of 0.01% per decade with a threshold at 0.02% per decade (Ref. 2). With the long-term variability determination being the key factor, the relative uncertainty or stability requirements for the sensors became much more stringent. The 1997 joint EOS/NPOES Task Force draft report showed the requirement of relative uncertainty as 0.005% per decade. A recent report by Murdock and Pollock to the National Institute of Standards and Technology (NIST) recommended that the uncertainty goals for the instrumentation to measure the total solar irradiance in space environment should be within 0.01% (Ref.4).

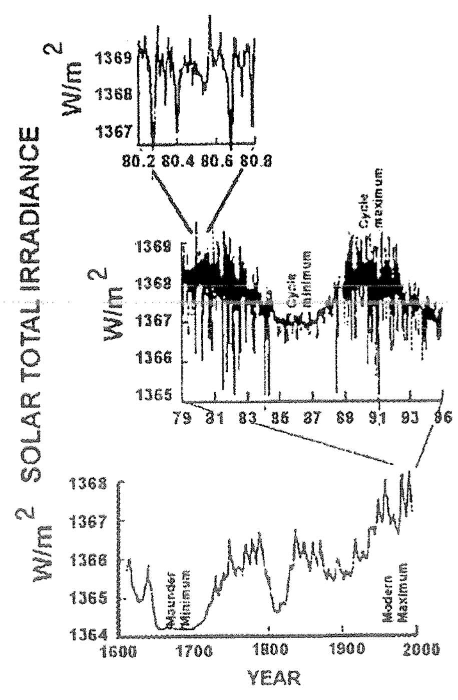

Figure 2. Time scales of observed solar total irradiance variability : Upper panel - The Sun's 27 -day rotation; Middle panel - The Solar cycle 21 (11 year duration); bottom panel - the larger amplitude variability speculated to have occured from the Maunder Minimum to the present.

A PRACTICAL APPROACH TO MEET THE REQUIREMENTS UTILIZING THE ISS

There has been recently great improvement in reducing the absolute and relative uncertainties in optical radiation measurements in the laboratories around the world with the introduction and perfection of cryogenic radiometers. These are also electrical substitution radiometers but operate at cryogenic temperatures preferably at 4 K or below. This low temperature operation brings many-fold reduction of the systematic effects that dominate the uncertainty budget of room temperature devices. As analyzed in Ref. 2 these devices have the potential to meet the above uncertainty requirements for the solar irradiance measurements. However, they can't be simply deployed in free flying spacecraft because sooner or later the cryogen runs out. Although one could envision futuristic cryocoolers that would operate for long periods, there are inherent difficulties of maintaining calibration on these devices unless there is periodic maintenance. Exposure to the Sun degrades parts and one has to contend with unwanted drifts in time resulting in reduced confidence in the data gathered. Ideally, one should retrieve the instrument periodically, recalibrate using the SI traceable standards in the laboratory on the ground and place it back in orbit for continuing the measurements with the required uncertainty limits. Also, the same instruments and the space craft platform should ideally be employed for continuous data gathering through the coming century to avoid variation of data from mission to mission as shown in Fig. 1. At present, only the ISS offers such a possibility. One could envision building two or more cryogenic radiometers for total solar irradiance measurements that meet the requirements especially of the relative uncertainty. These devices would be placed on a suitable platform in ISS for measurements of the solar irradiance. They would be manned and maintained by the astronauts. One or the other radiometer would be brought to a ground laboratory such as NIST periodically through the space shuttle flights for recalibration in reference to the SI traceable standards on the ground and redeployment on the ISS. This would ensure two-fold redundancy, and the measurements could be carried out through the next century and beyond as the space station is expected to operate for a long time to come. This possibility of periodic cross calibration and manned maintenance is a unique advantage offered by ISS for the measurement of the long-term variation of the total solar irradiance.

The analysis presented in Ref. 4 similar to that presented above for the solar irradiance case also shows the advantages for other radiometers on ISS to provide irradiance and radiance measurements on sources such as the Moon and certain terrestrial sites for cross calibration as these sources are used as calibration sources for satellite based sensors of EOS, NPOES and other programs.

SUCCESSFUL VERIFICATION OF THE SUGGESTED APPROACH IN PARALLEL CASES

The variability of data shown in Fig. 1 is not uncommon in the measurements of physical quantities carried out under controlled conditions with well-defined uncertainty limits even in the standard laboratories. The cross calibration with the use of a commonly accepted standard is the key to reduce the uncertainties. The international standard laboratories maintain such commonly accepted standards and even then they have to do periodic international intercomparisons to reduce uncertainties. Two examples are given below. One example is the intercomparison of laboratory scales derived from the commonly accepted primary standards which may be different from each other in each laboratory. The cryogenic radiometers where ever adopted as primary standards reduced uncertainties of optical radiation measurements. However, these are not yet adopted as primary standard detectors in all the national laboratories around the world. The scales for the measurement of irradiance from UV to near IR maintained at various laboratories were intercompared recently to check the derived scales (Ref.5). The results are shown in Fig. 3.
There is good overlap and agreement in the visible wavelengths because there have been many previous intercomparisons that resulted in improvement of scales in each laboratory at these wavelengths. The scales in the UV and near IR differed widely by many times the quoted uncertainties in each scale. Based on this intercomparison many systematic uncertainties have surfaced in each laboratory, and work is progressing to correct for them. This intercomparison has become possible because workers at each laboratory selected one set commonly agreed upon stable detectors and measured them in a round-robin experiment in each laboratory using their own procedures and compared the results. The parallel here is that the radiometers on ISS would be like those calibrated stable detectors to help in the intercomparison of various satellite sensors over time and reduce uncertainties in their optical measurements.

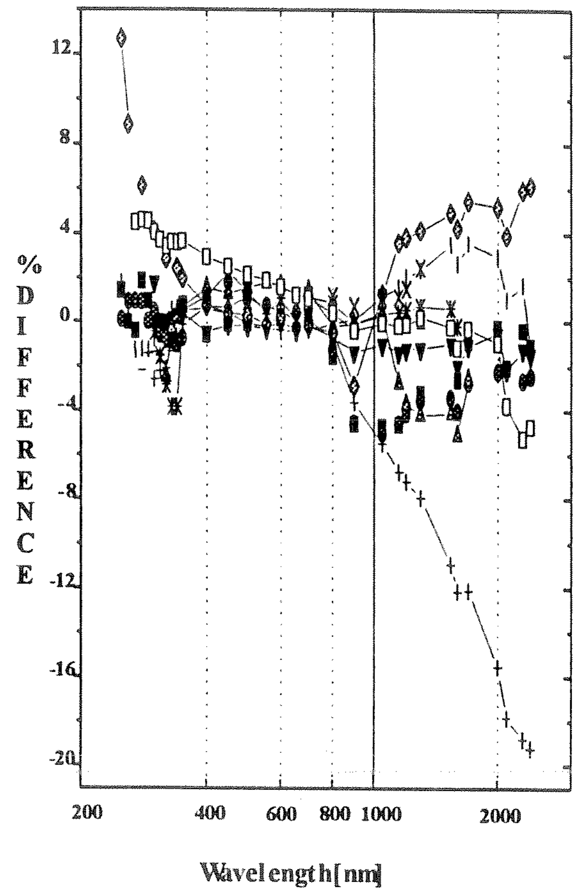

Figure 3. Recent irradiance scale intercomparison between various national laboratories

The second example is the use of an independent transfer standard that improved the working standard used for calibrating the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) instrumentation. An integrating sphere had been in use at NASA, Goddard for calibrating SeaWiFS instruments. However, the instruments were differing widely in their measurements and the integrating sphere was identified as a possible cause for the relative differences. If the integrating sphere is not a uniform source, each instrument will have a different calibration because different instruments have different fields of view. A transfer standard radiometer characterized at NIST was used to examine the integrating sphere and improvements were undertaken based on the results. Figure 4 shows the sphere uniformity problem and the improvement in the uniformity after it was recoated based on the results of characterization with a known transfer standard (Ref.6 and Ref.7). The SeaWiFS instruments showed better agreement with each other after their calibrations were carried out with the improved sphere. Again, the parallel here is maintenance of transfer standards such as the radiometers on ISS which establish sources for calibration such as the Sun, the Moon etc. will improve the calibrations of optical sensors on other remote sensing platforms.

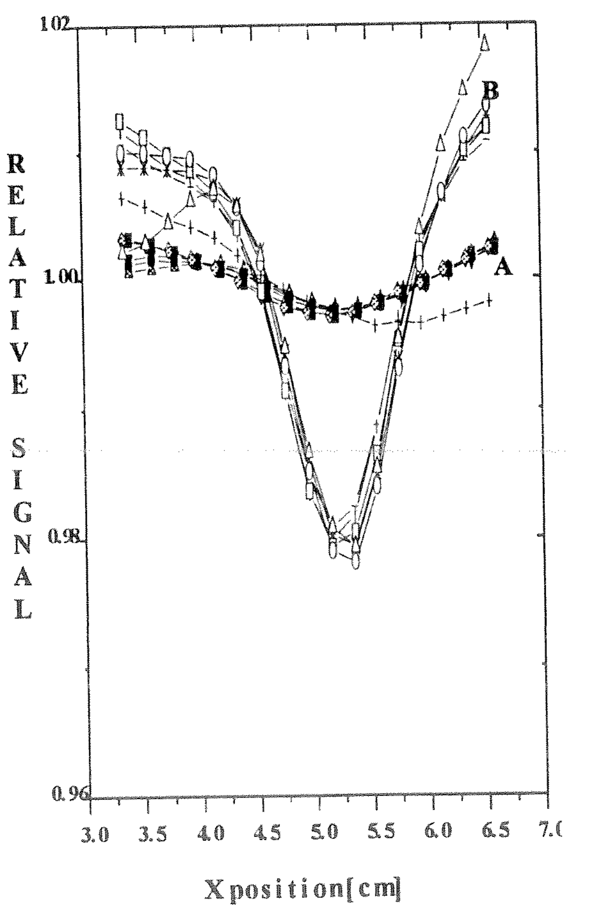

Figure 4. The uniformity of the integrating sphere source: B- before; A- after recoating

Therefore, the approach of maintaining an absolute standard on the ground, transfer standards in space and periodic cross calibration, works well for achieving the required measurement assurance for optical remote sensing programs.

The cryogenic vacuum chambers and the SI traceable cryogenic radiometers already exist at NIST to provide the basis for calibrations of space cryogenic radiometers. These are supported by the current Ballistic Missile Defense Organization (BMDO) and NASA EOS programs for various other calibrations. These chambers and facilities could also serve the calibration needs of the radiometers that could be deployed on the ISS. The present high accuracy absolute cryogenic radiometer (HACR) at NIST has a relative combined standard uncertainty of 0.02% and plans are in place to reduce the uncertainty by a factor of 5 (Ref.8).

POSSIBLE ISSUES FOR FURTHER STUDY

Various technical issues connected to the ISS have to be studied and resolved for successful implementation of the approach. Some of the issues Murdock and Pollock (Ref. 4) mentioned in their study were: 1. characterization of the contamination environment local to ISS, 2. the need to provide accurate pointing to view the Sun, the Moon or other sources, 3. geometrical constraints on the possible viewing angles, 4. schedules for possible deployment and maintenance of the instruments. These issues are not insurmountable, but a study has to be undertaken for their resolution.

CONCLUSION

The ISS offers a unique opportunity to strengthen the current and future remote sensing programs by providing a platform for manned and maintained absolute cryogenic radiometers. These radiometers would be able to provide calibration support to other satellite sensors and also provide data on the long-term variability of the Sun. The improved accuracy of remote sensing data would be of great help in resolving issues on global warming and long-term climatology.

REFERENCES

1. Intergovernmental panel on Climate Change - 1992, J.T Houghton, B.A. Callender, and S.K. Varney (eds.), (1992) Cambridge University Press.
2. Lean, J., Foukal, P., Lee III, R., Frohlich, C., and Jacobowitz, H. *Report of the study team for the National Polar Orbiting Operational Environmental Satellite System*, (1995).
3. Wilson, R., Total Solar Irradiance Trend during solar cycles 21 and 22, *Science*, Vol. 277, pp 1963-1964, (1997).
4. Murdock, T. and Pollock, D., *High Accuracy Space-Based Remote Sensing Calibration Requirements*, Report to Optical Technology Division, NIST under Grant No. 60NANB7D0073 (1998)
5. Walker, J. H., Saunders, R. D., Jackson, J. H., and Mielenz, K. D., *Results of a CCPR intercomparison of spectral irradiance measurements by national laboratories, J. of Res. Natl. Inst. Stand. Technol.*, Vol. 96, 647 (1991).
6. Mueller, J. H., Johnson, B. C., Cromer, C. L., Hooker, S. H., McLean, J. T., and Biggar, S. F., *The second SeaWiFS Intercalibration Round –Robin Experiment, SIRREX-2*, NASA Tech. Memo. 104566, Vol. 16 (1993).
7. Mueller, J. H., Johnson, B. C., Cromer, C. L., Hooker, S. H., McLean, J. T., and Biggar, S. F., *The second SeaWiFS Intercalibration Round –Robin Experiment, SIRREX-3*, NASA Tech. Memo. 104566, Vol. 34 (1994).
8. Gentile, T. R., Houston, J. M., Hardis, J. E., Cromer, C. L., and Parr, A. C., *National Institute of Standards and Technology High-Accuracy Cryogenic Radiometer, Applied Optics*, Vol. 35 (1996)