GSICS Global Space-based Inter-Calibration System

Quarterly

Special Issue on Space Weather

Newsletter Summer 2024 Issue

doi: 10.25923/myah-9189
Vol. 18 No 2, 2024
Guest Editor: Tsutomu Nagatsuma (NICT)

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New GRWG sub-group on space weather established within GSICS

By Tsutomu Nagatsuma, National Institute of Information and Communications Technology(NICT)

In 2022, the GRWG space weather sub-group was newly established within GSICS. Space weather is a relatively new matter in WMO, and there are needs to implement space-based space weather observation systems and space weather forecasting services and applications using globally-sourced data in an operational framework. Therefore, the space weather subgroup plays an important role in GSICS. One of the major differences between inter-calibration of conventional space-based terrestrial weather observations and that of space-based space weather observations is that many space weather observations are performed using *in situ* measurements. This means that the method of inter-calibration of space weather *in situ* sensors is a new challenge for GSICS. This effort will proceed in collaboration and cooperation with the space weather research community.

Space weather is a term that refers to the state and variations in the space environment that are mainly driven by solar activity. Variations in the space environment not only affect spacecraft and manned space activities, but also various societal infrastructures such as ground power grids, GNSS positioning, aircraft operations, and short-wave communications. Monitoring and forecasting of space weather are necessary to mitigate the risks to societal systems affected by space weather disturbances.

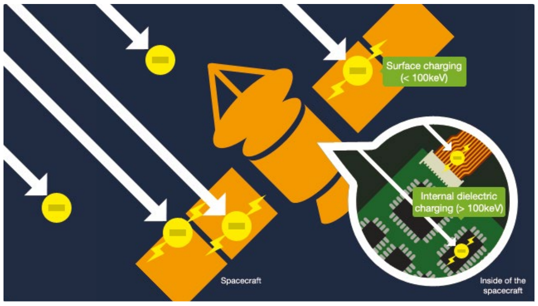

Image Above: Shows influences of high energy particles on spacecraft

WMO has increased its involvement in space weather since a technical document describing its potential role in space weather was published in 2009 [1].

Matters of operational space-based space weather observations have been coordinated by CGMS/SWCG since 2018. To utilize space-based space weather observations operated by CGMS member organizations in space weather forecast services and applications, inter-calibration of high energy electron sensors in geostationary orbit (GEO) has been discussed in the task group within CGMS/SWCG since February 2019. The task group submitted a white paper about the inter-calibration of high energy electron sensors to GSICS-EP in 2021. GSICS-EP endorsed the establishment of the GRWG space weather sub-group in 2022.

The scope of GRWG space weather sub-group is as follows.
As experts in space environment measurements, their applications, and understanding user requirements, members of the SW sub-group carry out the following activities.

- Discussion and coordination of research, development and implementation of inter-calibration of space environment sensors

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- Analysis of the characterization (sensitivity, secular variation, etc.) of individual sensors and publication of the outcomes (product), and consideration of its implementation in the framework of GSICS
- Examination and documentation of standardization (data format, data exchange, inter-calibration, etc.)
- Examination of developing standard products (based on near-real time and archival data) that integrate multiple satellite data

High energy particle observations need to measure the same space environment for inter-calibration. Since they are *in situ* measurements, the best inter-calibration is possible when sensors are in the same location (i.e., within of order one charged particle gyroradius) and looking in the same direction. However, it is unrealistic to expect all satellites for space weather observations to be in the same location for inter-calibration. We need to consider other ways for inter-calibration. Charged particles bounce along a magnetic field line (K) and drift along a shell of magnetic field lines (L^*). The adiabatic invariants K and L^* depend on instrument orientation, geographic longitude and latitude, universal time, day, season, and geomagnetic activity. If the K and L^* coordinates of two satellites are the same (a magnetic conjunction), it is expected that both satellites measure the same space environment. However, it is not easy to satisfy this condition. Further discussion is necessary toward standardization of the inter-calibration of high energy particle sensors.

The special issue on inter-calibration of space weather sensors consists of five articles. *Jin-Tian Lv et al.* introduce an on-orbit inter-comparison of high energy electron flux from FY-4B, GOES-16, and Himawari-8. They confirm that the variations of high energy electron flux from these three GEO satellites show similar trends during the development of geomagnetic activity. *Ingmar Sandberg et al.* present inter-calibrations of ESA radiation monitors using science-class particle detectors on the Japanese research satellite Arase (ERG). *Daehyeon Oh & Jiyoung Kim* introduce a comparison of electron flux over two years from particle detectors on GK2A KSEM PD and GOES-16 MPS-HI. The electron flux observations from the two satellites are strongly correlated. *Brian T. Kress et al.* present an overview of inter-calibration between GOES energetic particle sensors. They point out that careful analysis using state-of-the-art geomagnetic field models will be needed to determine the viability of inter-calibrations among GEO radiation belt particle detectors using L^*-K conjunctions. *Inchun Park & Tsutomu Nagatsuma* introduce calibration methods for Arase HEP that use a Geant4 simulation. The detector response is consistently calibrated by this simulation. They also discuss the potential for inter-calibration with observations from GEO satellites.

The space weather sub-group will first establish standard inter-calibration procedures of high energy particles and aim to ensure the quality and traceability of operational space weather data obtained from satellites operated by CGMS member organizations. To consider the standard inter-calibration procedures, we will work in collaboration and cooperation with the space weather research community, represented by COSPAR (Committee on Space Research) and other international organizations. Our activities will support the realization of services and applications for nowcast and forecast of high-energy particle environment in geospace based on data from multiple satellites. Although the sub-group initially focused on inter-calibration of high-energy particle sensor, we will consider standardization of inter-calibration procedures for other space weather sensors, such as magnetometers, solar X-ray flux monitors, solar EUV imagers, etc. in near future.

Reference

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On-orbit cross-comparison results of electron flux from Fengyun-4B, GOES-16, and Himawari-8

By Jing-Tian LV[1,2], Cong Huang[1,2], An-Qin Chen[1,2] , Chun-Qin Wang[3], Wei-Guo Zong[1,2], and Xiao-Xin Zhang[1,2]

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doi: 10.25923/myah-9189

1 Introduction

Fengyun-4 is CMA's second-generation three-axis stabilized, geostationary meteorological satellite series (Yang et al., 2016). The Space Environment Monitoring Instrument package is one of the main payloads of the Fengyun-4B. Compared with Fengyun-4A, Fengyun-4B space environment detection subsystem has the characteristics of finer detection energy spectrum and more detection elements and higher time resolution. It conducts surveys of the space environment and its effects in geostationary orbit, including solar activity, space charged particle radiation, geomagnetic activity, ionospheric activity and environmental effects, and provides space weather products for the public and professional users (Zhang et al. 2022).

In terms of high-energy particle detection capabilities, Fengyun-4B is equipped with three high-energy particle detectors, each of which includes multiple telescope systems to achieve full spectrum detection of electrons and protons. The observation of medium energy electrons is very important for space weather forecast and aerospace engineering support. The high energy electron burst can be predicted by the change of medium energy electron flux, which becomes a new forecasting method.

Table 1: The energy channel of three satellites.

Channel	FY 4B (keV)	Himawari 8 (keV)	GOES 16 (keV)
1	275	300	289
2	450	450	413
3	700	650	600
4	900	1000	900

Fengyun-4B's medium energy electron observation fills the gap of medium energy electron measurement of space particle radiation in China, and can provide basic data for satellite platform design, satellite fault analysis and establishment of dynamic radiation belt model (Zhang et al., 2023).

On GEO orbit, GOES-16 and Himawari-8 are excellent satellites in space weather observation. In this paper, in order to conduct a more comprehensive on-orbit cross-comparison result, we compared the observation data of Fengyun Satellite with GOES-16 and Himawari-8 during the same time period. The comparison mainly includes: The timing diagram of electron flux of three satellites and the comparison of flux spectrum between the three satellites.

2 The timing diagram of electron flux of satellites

Figure 1(a) shows the electron time series of three satellites in different energy bands during a geomagnetic event.

The time interval is from May 15, 2023 to May 30, 2023. Among them, the solid line represents Fengyun satellite data, the dashed line represents Himawari-8 satellite data, and the dotted line represents GOES-16 satellite data. The energy of Fengyun-4B is 275, 450, 700 and 900 keV, respectively, which is slightly different from the electron energy of the other two satellites. Blue, cyan, yellow, and red respectively represent the four energy channels. The GOES-16 and Fengyun-4B's data adopts an averaged differential fluxes method, which averages the fluxes measured in all observation directions.

In order to reflect the changes of three satellites under the same geomagnetic activity conditions, we selected a geomagnetic event and compared this data.

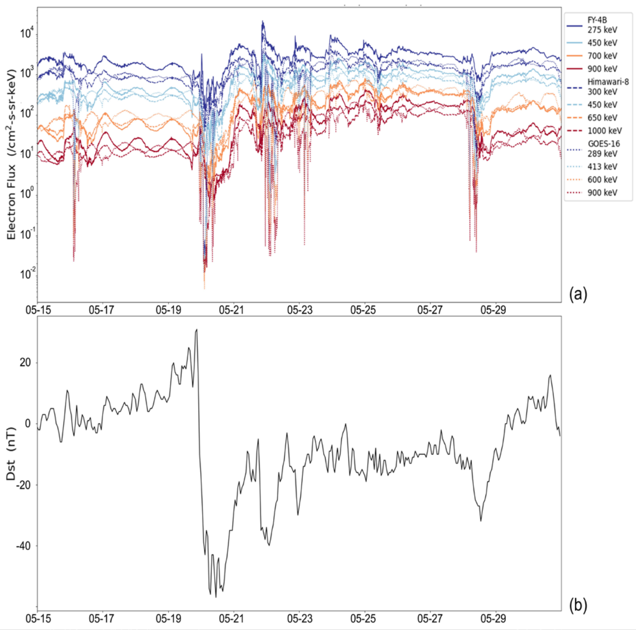

Figure 1. The electron flux of 3 satellites and *Dst* index in 2023/05/15 - 2023/05/30.

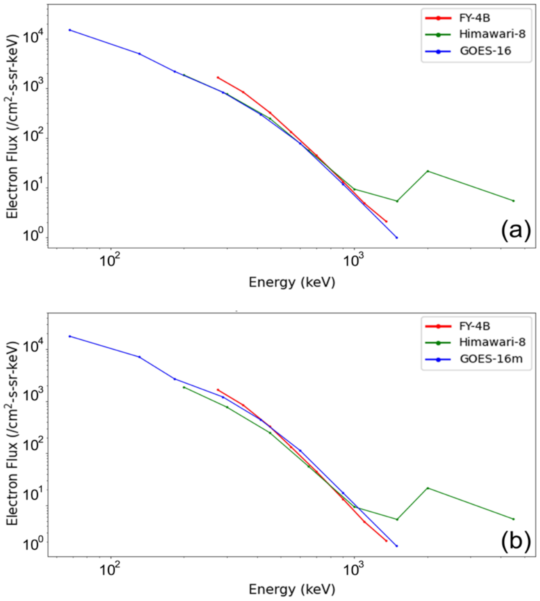

Figure 2. The comparison of flux spectrum between the 3 satellites, 2023/05/18 0:00.

doi: 10.25923/myah-9189

The Figure 1(b) shows the temporal variation of the *Dst* index during this time period. The peak of this event is close to -60 nT, appearing around 14:00 on May 19th. Starting from May 15th, a significant change of *Dst* can be observed. After the main phase, the recovery phase lasted for about four days. On May 28th, another small geomagnetic storm occurred. This seamless connection between two geomagnetic storms often occurs in space weather.

Through qualitative analysis, it can be concluded that during the entire event, the electron fluxes of the three satellites in different channels showed responses to geomagnetic activity, and the electron fluxes and changes in different phases were positively correlated with the *Dst* index. When the main phase of the geomagnetic storm appeared, the electron flux of different energy channels of the three satellites decreased. Fengyun satellites can effectively reflect changes in electron flux during periods of quiet and disturbance in geomagnetic activity.

3 The comparison of flux spectra between the three satellites

The comparison results for flux spectra among the three satellites are shown in Figure 2.

In the Figure 2(a), the data of GOES-16 was selected from average data. The red, green, and blue lines represent Fengyun-4B, Himawari-8, and GOES-16 observations, respectively. As the energy increases, the electron flux decreases. The results of energy bands with similar energy are highly consistent. The results of Himawari-8 and GOES-16 are more consistent.

In the Figure 2(b), the maximum values of the data for GOES-16 were selected – taking the maximum flux measured in all observation directions. Compared to the results using average data, the electron flux curve of “max-selected” data showed a significant increase. In terms of trend, the observation results of the channel are consistent with those of the other two satellites. Compared with the average data, the comparison results of this group of data have undergone certain changes. In terms of energy spectrum distribution, the energy spectrum distribution trends of the three satellites at different time points are consistent. As the energy increases, the electron flux decreases. In terms of correlation, the data of Fengyun-4B and GOES-16 are closer and have better correlation than other pairwise comparisons.

4. Summary

In this paper, we introduce some basic information about Fengyun-4B and its particle observations. We selected an event and compared the electron flux observation data of Fengyun-4B with GOES-16 and Himawari-8. We will summarize the comparison results as follows:

1. During the development of geomagnetic activity, the electron flux observed by the Fengyun-4B has the same trend as the other two satellites.
2. Compared with the trend of geomagnetic activity, the observed data of electron flux from Fengyun-4B can well reflect the various phases of geomagnetic activity, especially the main phase of geomagnetic storms.
3. Compared with the GOES-16 average data, the observed electron data of Fengyun-4B is closer to the GOES-16 "max" data.

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Cross-calibrations of ESA radiation monitors

By Ingmar Sandberg[1], Hugh Evans[2], Melanie Heil[3], Piers Jiggens[2] and Petteri Nieminen[2].
[1]SPARC, [2]ESA/ESTEC, [3]ESA/ESOC.

Introduction

Meteorological satellites are exposed to several particle radiation sources over their lifetime. These include solar energetic particles (SEPs), trapped energetic particles in the radiation belts (RBs), and galactic cosmic rays. Spacecraft anomalies on polar-orbiting weather satellites are predominantly associated with single-event effects attributed to the intense trapped proton radiation in the South Atlantic Anomaly (the lowest extent of the inner RB), while anomalies at weather satellites placed in geosynchronous orbit (GEO) are mostly associated with the enhancement of trapped electron fluxes, as the latter can cause charging of the surfaces of cables and circuits. ESA has a variety of radiation monitors deployed on different orbits. In-flight calibration is essential to obtain precise measurements. This work describes ongoing efforts to enhance the accuracy and consistency of the radiation environment measurements through calibration and validation (Cal/Val) activities, which ultimately contribute to advancements in space weather modeling and to the update of space radiation environment specification models.

Radiation Environment Data Processing and Results

ESA's Standard Radiation Environment Monitor (SREM) units have delivered measurements over the last two decades along Low Earth Orbit (LEO), GNSS, Highly Eccentric Orbits (HEO) and interplanetary orbits. Two units of the Environmental Monitoring Unit (EMU) on board EU Galileo satellites track the harsh environment of GNSS orbit since 2016. More recently, units of ESA's Next Generation Radiation Monitor (NGRM) are hosted in several payload flights; the first unit was placed onboard the GEO European Data Relay System C (EDRS-C) telecommunication satellite, a second onboard the LEO Sentinel-6 Michael Freilich (S6-MF) Copernicus satellite operating at 1336 km altitude, and a third unit onboard Meteosat Third Generation – Imager 1 (MTG-I1) EUMETSAT satellite in GEO.

Space radiation monitors have typically wide field-of-view window, and their un-calibrated raw data are typically provided as time-series of channel outputs, C_i, as the result of the unit's measurement process, which can be mathematically described by

$$C_i = \sum_{q=p,e} \int_0^{+\infty} f_q(E) RF_{i,q}(E) dE. \quad (1)$$

Here q is the particle species (protons, p, or electrons, e), and $f_q(E)$ and $RF_{i,q}(E)$ denote the differential flux spectra and the corresponding energy response functions under the assumption that incident fluxes are omni-directional. $RF_{i,q}(E)$ is typically broad and is usually determined by numerical calibrations conducted using radiation transport codes supplemented by limited ground experimental calibrations. The derivation of $f_q(E)$ is an inverse problem which is conducted using different optimization techniques.

In-flight comparisons of raw and derived flux measurements, using third party measurements, are necessary for the evaluation of the radiation monitor performance providing insights on the unit's response in flight conditions and on the accuracy of the subsequently derived fluxes. Measurements from science-class particle detectors are selected as reference as they present superior characteristics, compared to monitors, in terms of energy resolution. Once a sufficiently large volume of radiation environment measurements, spanning different states of solar and magnetospheric activity, are available, cross-calibrations can lead to the production of improved (higher-level) flux datasets that can be applied for the development, improvement, validation of space weather forecasting models. The creation of cross-calibrated higher-level flux datasets accounting different orbits with overall time durations that approach or exceed the solar cycle period supports the development of state-of-the-art specification models accounting the near-Earth space radiation environment.

SEPs provide an excellent opportunity for the in-flight calibration of proton measurements since the incident radiation environment can be considered identical along any orbital segment outside the Earths' magnetic shielding. Such studies, using NASA IMP-8/GME dataset as reference [1], led to the creation of the ESA SEPEM dataset consisting of NOAA Geostationary Operational Environmental Satellites (GOES) solar proton flux measurements with re-calibrated values of the protons' energy bins.

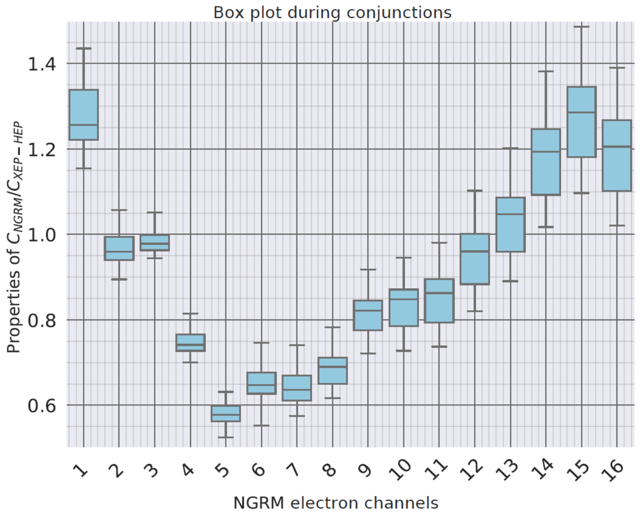

Figure 1. Box-and-whisker plots of the ratios between actual and expected EDRS-C/NGRM electron measurements during the ERG conjunctions.

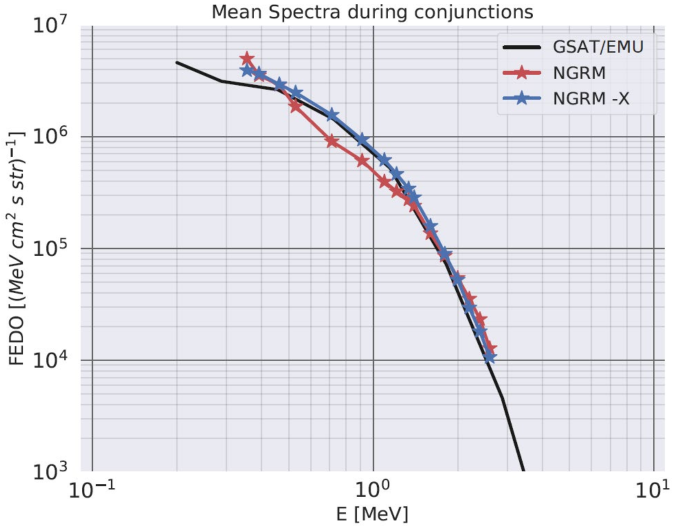

Figure 2. Galileo/EMU data (black) compared to EDRS-C/NGRM data (red) and cross-calibrated - with ERG - NGRM fluxes (blue).

The calibration and validation of trapped electron flux measurements require the definition of a reference dataset from a third-party detector that crosses the outer RB and of a sufficient number of suitable conjunctions between the different satellite orbits – where the detectors are expected to encounter the same trapped electron population. Such conjunctions are determined – in the spirit of the recommendations of the COSPAR Panel on Radiation Belt Environment Modelling – by a set of permissible differences between magnetic (e.g. the L-shell value, the equatorial pitch angle α_{Eq}) and temporal (e.g. Universal Time and Magnetic Local Time) coordinate parameters during suitable magnetospheric conditions, as defined by the *Kp* index. The energetic electron RB measurements from the science-class electron detectors of the active JAXA Exploration of energization and Radiation in Geospace (ERG) scientific mission (2017-ongoing) provide a suitable reference for Cal/Val studies, given also their successful evaluation against the measurements of NASA Van Allen Probes (VAP) (2012-2019) mission [2].

The initial evaluation and analysis of ESA NGRM electron measurements utilized the geostationary transfer orbit of the EDRS-C satellite, whose eccentricity resulted in multiple conjunctions with the ERG spacecraft. To evaluate and calibrate the measurements, comparisons were made against the theoretically expected values for an electron radiation environment defined by the reference measurements of ERG HEP and XEP electron detectors during the conjunctions. The expected count-rate measurements were obtained by convolving the reference ERG/HEP-XEP flux spectra with NGRM electron response function (see Equation 1). Figure 1 presents a quantitative overview of these comparisons, illustrating the median, lower and upper quartiles, and the minimum and maximum values of the ratios between the actual and the expected EDRS-C/NGRM electron measurements during the ERG conjunction events.

The ratios of the median values, ranging here within 0.6-1.3, can be considered as suitable set for re-scaling the measurements of NGRM electron channels and optimizing the agreement with the reference dataset.

A broader set of electron cross-calibration studies were recently completed in the framework of ESA activities aiming to the development of International and European space radiation environment models. These studies considered non-ESA instruments as well, including those from VAP, the Japanese meteorological "Himawari" satellites and the NOAA GOES, along with ERG. For the rapid determination of conjunctions, equivalent datasets with identical timestamps were constructed by resampling the measurements. The calibration scaling factors – estimated either as the median values of the flux ratios or as the factors that minimize their mean squared error – demonstrated an overall agreement within less than a factor of two for most of the monitor channels.

An example of comparisons of Galileo207/EMU with EDRS-C/NGRM electron flux is shown in Figure 2. The EDRS-C/NGRM electron flux energy spectrum is plotted here before (in red) and after (in blue) the application of the cross-calibration using the reference dataset ERG/HEP-XEP, demonstrating indirectly an excellent agreement of EMU with the reference dataset.

Conclusion

Once the Cal/Val studies get finalized, an overall consistency between RB electron measurements will be established, ensuring a consistent baseline across different epochs and orbits. The impact on space environment and space weather models of including/excluding different datasets will be ascertained and cross-calibrated datasets will be used for ongoing space weather forecasting activities and updating radiation specification models.

Acknowledgements

The work presented has been supported by ESA under Contract numbers 4000127954/19/D/CT and 4000127282/19/NL/IB/gg between ESA and SPARC and under Contract number 4000137689/22/NL/CRS between ESA and ONERA.

The authors acknowledge Y. Miyoshi, T. Mitani, T. Takashima, T. Hori, N. Higashio, and I. Shinohara for the use of XEP and HEP ERG data.

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doi: 10.25923/myah-9189

Comparison of Electron Fluxes Over 2021 from Particle Detectors on Geostationary Satellites: GK2A KSEM PD and GOES-16 MPS-HI

By Daehyeon Oh and Jiyoung Kim (NMSC/KMA)

Introduction

The increasing social reliance on artificial satellites in various fields, including communications, navigation, and climate monitoring, underscores the importance of accurate and timely space weather observations. These observations help in mitigating the potential disruptions caused by strong space weather events, such as solar energetic particles which can penetrate satellite electronics and have significant impacts on satellite operations. The Korean Space Weather Monitor (KSEM) on the GEO-KOMPSAT-2A (GK2A) satellite, which has been operational since July 2019 in geostationary orbit at 128.2°E longitude. This article provides the recent results from a comparative study between the KSEM Particle Detector (PD) aboard GK2A satellite and the Magnetosphere Particle Sensor-High (MPS-HI) on the GOES-16 satellite.

Instruments and Data

The KSEM Particle Detector is designed to measure energetic electron flux within the energy range of 100 keV to 3.8 MeV. While the PD is also capable of detecting protons, this report will focus exclusively on electrons. The primary mission of the PD is to monitor the near-Earth space environment, particularly in geostationary orbit, where numerous satellites, including those for weather, communication, and navigation, operate. The PD consists of six particle telescopes, each oriented in a different direction. These telescopes are designed to detect electrons across a wide range of energies, providing critical data for understanding the behavior of energetic particles in the magnetosphere. By contrast, the MPS-HI is on the GOES-16 satellite, operates in GEO at a longitude of 75.2°W, a position that is 156.6° away from GK2A, positioning of the satellites allows for simultaneous observations of the same space weather phenomena from different locations, thereby providing a more comprehensive coverage of the space environment. The electron channel energies of KSEM PD and MPS-HI are shown in Table 1.

Responses to Quiet Magnetospheric Conditions

The study compares electron flux data of KSEM PD and MPS-HI in 2021. This comparison focused on omnidirectional fluxes, which are averages across all directional flux intensities, providing a comprehensive view of the particle environment. The analysis covers a year of data and considers geomagnetic activity during this period, leading to generally weak geomagnetic conditions. To minimize the influence of magnetic disturbances, the comparison was conducted on quiet magnetospheric conditions, defined as those with a daily average Kp index of 2 or less. Scatter plots of daily average electron flux on quiet magnetospheric conditions (Figure 1) reveal a clear correlation between the two detectors, with Pearson's R values generally around 0.85 or higher. In Channels 8 and 9, the two detectors showed a constant background offset, with KSEM PD measuring higher fluxes than MPS-HI. The algorithm applied to the GOES-16 MPS-HI electron telescope includes a step to eliminate background noise caused by proton contamination. A similar procedure is currently lacking for the KSEM PD. This may explain the differences observed in channels 8 and 9.

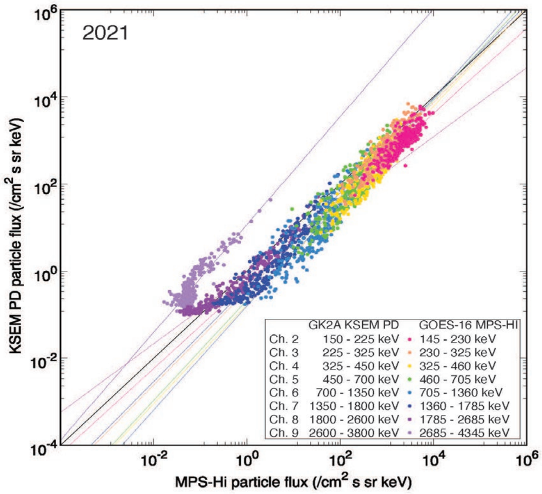


Figure 1. Scatter plot of daily-averaged electron particle flux from KSEM PD and MPS-HI. The conjunction condition of $dL^* < 0.1$ was used. The correlation between the data from the two detectors was high, except for Channel 9. The fitting lines were derived using the equation $\log(\text{Flux[KSEM PD]}) = \alpha \log(\text{Flux[MPS-HI]}) + \beta$, where α represents the slope and β the intercept.

Responses to Enhanced Energetic Particle Conditions

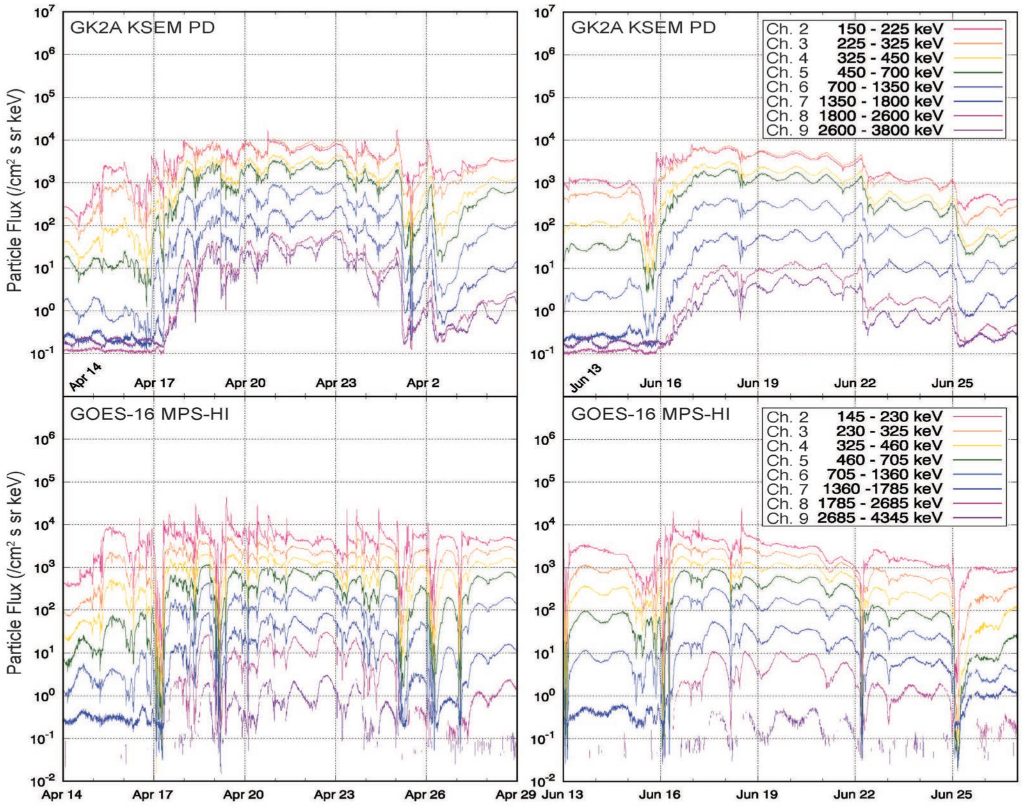
Two enhanced energetic electron environments from 2021 were analyzed to assess the instruments' responses:

1. Case 1: April 14–28, 2021 (Figure 2(a)) In April 2021, high-speed solar wind streams (HSSs) impacted the Earth's magnetosphere from April 16th. Both KSEM PD and MPS-HI observed electron flux enhancements, with MPS-HI showing significant fluctuations during substorms. Before the HSS arrival, KSEM PD's higher energy channels (including

Channel 9) displayed daily peaks around 18:00 UT, while lower energy channels peaked near local noon. After the HSS and a weak magnetic storm, electron flux variations in Channel 9 aligned with other channels.

2. Case 2: June 13–26, 2021 (Figure 2(b)) On June 15, 2021, HSSs arrived at Earth at the end of the day. KSEM PD and MPS-HI observed similar trends during the HSSs, with dropouts observed immediately after arrival. Prior to the HSS, Channel 9 of the KSEM PD showed different phase daily flux variations, similar to the April event. After the HSS, the flux levels of Channels 8–9 from the KSEM PD were reversed, compared with the pre-HSS levels.

During the enhanced particle events, while MPS-HI exhibited higher fluctuations and more robust responses, the measurements from both detectors showed similar trends with slight differences in timing. The amplitude differences might be attributed to variations in the instruments' response functions, calibration methods, or the natural dynamics of energetic electrons. Further analysis of the detailed differences between the two instruments, as well as an in-depth examination of electron dynamics, will be necessary for clarification.



(a) Apr 14 - Apr 28, 2021 (b) Jun 13 - Jun 26, 2021

Figure 2. KSEM PD and MPS-HI electron flux measurements. Two events of particle flux enhancements were selected: (a) April 14-28 and (b) June 13-26.

Summary and Conclusion

The electron flux data from both instruments showed a strong correlation, with some exceptions, such as in Channel 9. Although MPS-HI exhibited stronger responses during specific flux enhancement events, the overall trends and key features were similar between the two detectors, with some timing differences due to their different locations. In future study, combining magnetic field data from each satellite will help clarify the electron flux characteristics. This study highlights the value of GK2A KSEM PD data for monitoring the energetic electron environment in the eastern hemisphere and its potential for enhancing space weather monitoring when combined with GOES-R MPS-HI data in the western hemisphere. The similarities and differences between these detectors, separated by near-half a day in local time, underscore the importance of multi-point measurements for understanding locational characteristics in energetic flux during active conditions of space weather. The study emphasizes the need for reliable, multi-satellite *in situ* data to improve the accuracy of space weather forecasting and to better understand the dynamic nature of the space weather environment, especially at geostationary orbit.

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doi: 10.25923/myah-9189

Overview of inter-calibration between GOES energetic particle sensors

By B. T. Kress, A. Boudouridis, and J. V. Rodriguez CIRES at CU Boulder and NOAA - National Centers for Environmental Information

Space weather instruments on NOAA's Geostationary Operational Environmental Satellites (GOES) provide real-time data to the Space Weather Prediction Center (SWPC) for monitoring and forecasting hazards to spacecraft systems and humans in space. With the launch of NOAA's new GOES-R series (GOES 16-19) beginning in 2017, NOAA's legacy Energetic Particle Sensors (EPS) were replaced with the new Space Environment In-Situ Suite (SEISS), including the high energy Magnetospheric Particle Sensor (MPS-HI) and the Solar and Galactic Proton Sensor (SGPS). Quantification of measurement differences among GOES particle sensors is critical for continuity of radiation belt alerts and Solar Energetic Particle (SEP) storm scales at SWPC, and for establishing long-term self-consistent data sets. Recent efforts within the GSICS Space Weather subgroup to facilitate inter-calibrations among NOAA's international partners will aid in identifying and understanding measurement discrepancies, potentially correcting errors and ultimately improving space-based particle detector systems.

Absolute calibration of space particle detectors is not possible on orbit. Ground calibrations are performed to verify performance requirements, and on orbit comparisons with similar detectors are used for an additional accuracy check and to uncover anomalies. The GOES-R SEISS inter-calibrations exploit periods when similar flux measurements are expected in both detectors to identify and correct instrument and/or calibration anomalies.

The focus of this article is the methodology used for inter-calibration of GOES-R particle detectors. Full inter-calibration results are presented in instrument performance reviews available at https://www.noaasis.noaa.gov/GOES/product_quality.html by sequentially selecting menu items: GOES-16, -17 or -18 PS-PVRs, SEISS tab, "Magnetospheric e-/p+: High Energy" or "Solar & Galactic Protons", then Provisional or Full "Science Presentation".

MPS-HI Inter-Calibrations

MPS HI is comprised of 5 electron and 5 proton telescopes arranged in a north to south fan in the meridional plane looking away from the Earth. Each electron telescope measures 0.05-4 MeV electrons in 10 differential channels and >2 and > 4 MeV electrons in 2 integral channels. Each proton telescope measures 0.08-12 MeV protons in 11 differential channels. For additional information see Boudouridis et al. [2020].

One approach to inter-calibrations between radiation belt particle detectors is comparison of fluxes at second and third adiabatic invariant L^*-K ($K = I/\sqrt{B_m}$) conjunctions determined in a geomagnetic field model, assuming uniformity of flux over drift shells. Discrepancies between measurements made at L^*-K conjunctions are partly due to geomagnetic field model error, which is usually greater at higher L-shells. In addition, under moderately disturbed conditions L^* is not defined at geosynchronous due to incomplete drift shells and dayside drift orbit bifurcation.

NOAA's inter-calibrations between MPS-HI units are not performed using L^*-K conjunctions. Instead, flux distributions are compared during periods when GOES spacecraft are in close proximity during the commissioning phase. Percentiles of 1-minute averaged flux distributions from each channel-telescope pair are accumulated over several months and compared [Boudouridis et al., 2020]. Figure 1 shows an example of the GOES-17 and -18 electron percentile spectra comparison for telescope 4 (equatorially viewing). The inter-calibration was conducted during 2022-09-07 – 2022-12-06 when the two spacecraft were

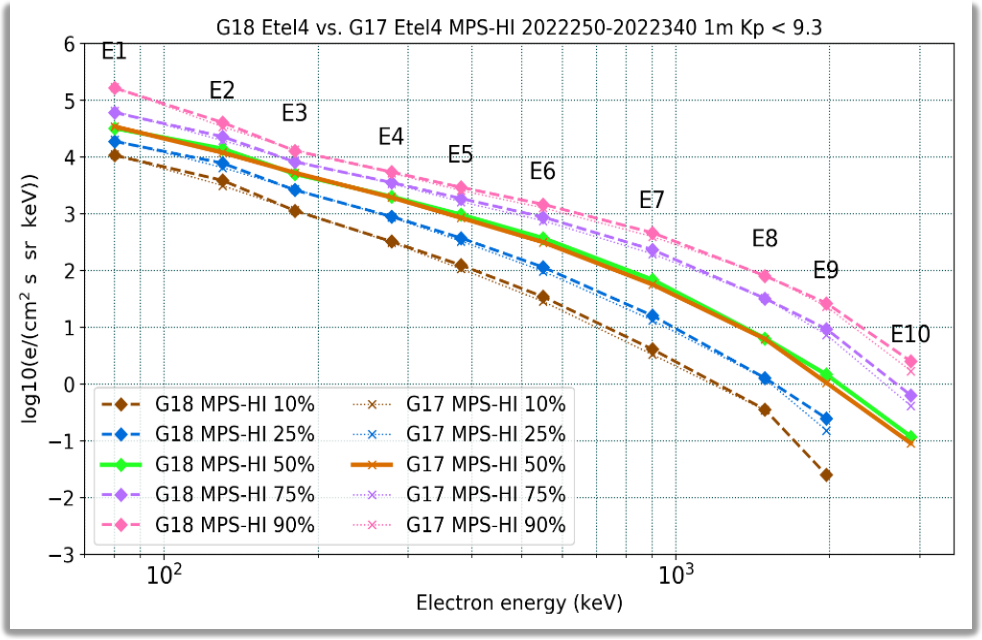

Figure 1. Example of GOES-17 and -18 MPS-HI inter-calibrations during 2022-09-07 – 2022-12-06 showing percentile spectra comparison. Five percentile spectra from each MPS-HI unit are shown, each including the ten differential electron channels.

doi: 10.25923/myah-9189

separated by 0.4° longitude.

SGPS Inter-Calibrations

There are two SGPS units on each GOES-R series spacecraft looking in the west and east directions. SGPS measures 1–500 MeV proton fluxes in 13 logarithmically spaced differential channels and >500 MeV proton flux in a single integral channel. For additional information see Kress et al. [2021].

At the onset of a SEP event, solar protons arrive at 1AU with an anisotropic distribution. During the event peak and declining phase, the interplanetary distribution usually becomes more isotropic making it possible to perform valid inter-calibration between geosynchronous proton measurements in the 100s of MeV at all local times and in all look directions. Care must be taken when comparing solar proton measurements in the low 10s of MeV, which are partially shielded by the magnetosphere at geosynchronous. During geomagnetically disturbed periods, magnetospheric shielding of solar protons is suppressed, and it's possible to perform valid inter-calibration of proton channels measuring energies in the low 10s of MeV [Kress et al., 2021, and references therein].

In 2017, GOES-13 and -15 EPS and GOES-16 SGPS inter-calibrations characterized systematic differences between EPS and SGPS measurements. An example scatter plot is shown in Figure 2. In channels measuring energies in the 100s of MeV the SGPS fluxes exceed the EPS measurements by approximately a factor of two [Kress et al. 2021]. The complete set of scatter plots showing all SGPS-EPS comparisons is available at https://www.ngdc.noaa.gov/stp/space-weather/satellite-data/satellite-systems/goesr/solar_proton_events/sgps_sep2017_event_data/

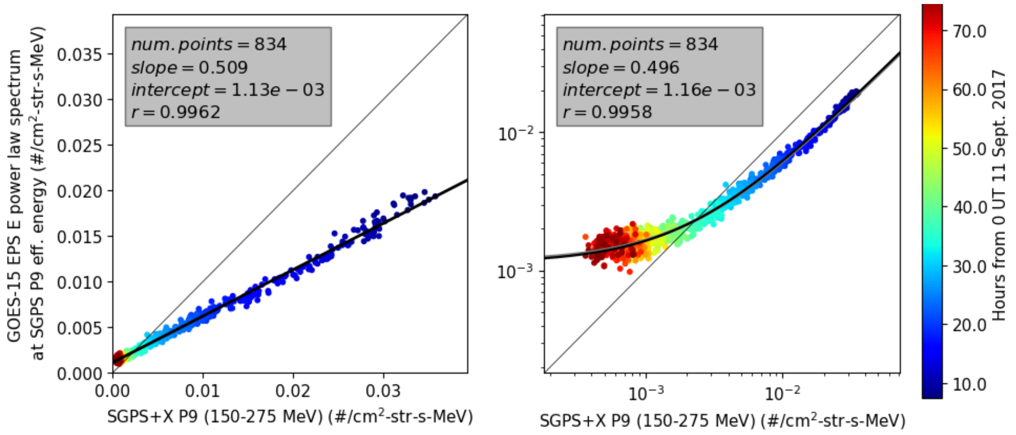

Figure 2. Example of GOES-15 and -16 SGPS inter-calibrations during the September 2017 SEP events showing GOES-15 East FOV versus GOES-16 SGPS+X P9 scatter plots of simultaneous 5-minute averages using linear and log scales. A power law is fit to the EPS fluxes, and comparisons with the EPS spectrum are made at SGPS channel effective energies. The same data and OLS fit are shown in both panels.

Summary and Discussion

Inter-calibration of solar proton sensors at geosynchronous are facilitated by an isotropic interplanetary SEP distribution occurring during a geomagnetically disturbed period, so that geomagnetic shielding of solar protons is suppressed. In contrast, inter-calibration of trapped particle measurements at different locations in the magnetosphere require quiet geomagnetic periods, when the assumption of approximately uniform flux over a particle drift shell is valid, and geomagnetic field models used for mapping are more reliable. Since the geographic equatorial plane is inclined with respect to the geomagnetic equator, detectors stationed at different longitudes along geostationary orbit are usually at different L^*. Two possible approaches for inter-calibration between geosynchronous trapped particle detectors are

1. Analysis including magnetic mapping to identify magnetic conjunctions and interpolation or extrapolation using fits to L-shell and pitch angle distributions
2. Planned spacecraft maneuvers during commissioning period that bring detectors into near proximity .

If the first approach is taken, the contribution to measurement differences from errors in magnetic field model mapping and interpolations must be quantified and shown to be less than systematic measurement errors. Careful analysis using state of the art geomagnetic field models will be needed to determine the viability of inter-calibrations among geostationary radiation belt particle detectors using L^*-K conjunctions.

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doi: 10.25923/myah-9189

Calibration of High-Energy Electron Data Using Geant4 and Cross-Calibration Potential for GEO Satellites

By Inchun Park and Tsutomu Nagatsuma, National Institute of Information and Communications Technology

Since its launch in 2016, Arase, JAXA's scientific research satellite, has been conducting observations of the radiation belts using various instruments. The primary objective of the mission is to reveal the interactions between waves and particles in the Earth's space environment. The key findings of this research are based on high precision measurements, particularly of electrons with energies ranging from tens of keV to MeV. These observations are crucial not only for understanding space science but also for assessing space weather. High precision measurements require the development of high-quality instruments and careful calibration based on their characteristics. In this article, the calibration methods for the high-energy electron experiments (HEP) instrument onboard the Arase satellite, which measures electrons in the keV to MeV energy range are introduced. We will also discuss the potential for cross-calibration with observations from GEO satellites.

The Arase satellite is equipped with several instruments to observe high-energy particles in the radiation belts. HEP detects electrons with energies ranging from 70 keV to 2 MeV, using two detectors depending on the energy level. These instruments use a stack of silicon strip detectors with collimators and shields to determine the precise energy and direction of incident particles (Figure 1). Particle energies and trajectories observed by the detector are not the same as those incidents, because the energy and trajectory of the incident particles are modulated due to scattering by the collimator and/or shield structures. For calibration, we have adopted Monte Carlo simulations using Geant4 (Geometry and tracking) to estimate the modulations caused by electron scattering. In the simulation, the detailed configuration of HEP is reconstructed, and the pencil beam was irradiated perpendicular to the detector. The simulation was conducted with 10^5 electrons with energies ranging from 1 to 2,500 keV with intervals of 1 keV. Arase has other particle detectors that cover both lower and higher energy ranges with some overlap of HEP. The Medium-energy particle experiments-electron analyzer (MEP-e), which covers the lower energy range and overlaps with 85 to 95 keV of HEP, electrons. MEP-e can measure electron energy more precisely than HEP due to its detection method. For this reason, we will use the MEP-e's overlapping energy channel to verify the calibration results of HEP.

Figure 2a shows the results of the simulation. The observed energies are distributed the same as incident energy or below due to electron scattering. The response matrix composed of observation energy bins are created from the results. The original incident energy of the electrons is derived from the observed energy using the inverse of this matrix. We applied this inverse matrix to actual HEP observations and compared them to MEP-e observations. Figures 2b and 2c show the results of the calibration. These results provide a smooth spectrum connection between calibrated HEP and MEP-e, and the quantitative correspondence between differential fluxes of 95 keV electrons obtained from calibrated HEP and those obtained from MEP-e. From these results, we conclude that the calibration using Geant4 simulation is reliable, and the calibration method can be applied to HEP observations.

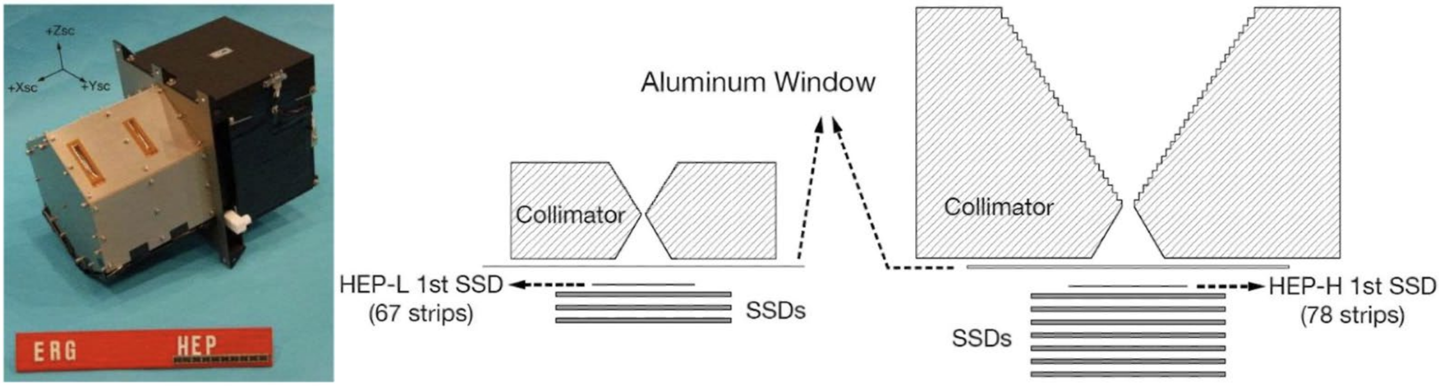

Figure 1. Configuration of Arase HEP instruments. The electrons are shielded and scattered by collimators and Aluminum windows.

doi: 10.25923/myah-9189

Similarly, high-energy particle detectors onboard GEO satellites have been evaluated to determine the response between incident energy and observed energy through simulations and/or ground experiments for calibration of the detectors. More accurate calibration seems possible if the characteristics of the high-energy particle detectors are incorporated into the simulation. To achieve this, it is necessary to thoroughly understand the physical characteristics, geometry, and specifics of the detectors. Although GEO satellites from different countries provide information about their detectors, the lack of a unified format and differences among manufacturers and operators complicate the process. Unfortunately, standardization of evaluation methods and information sharing regarding the response of high-energy particle detectors has not yet progressed. Discussions will need to take place within the GSICS GRWG Space Weather Sub-group.

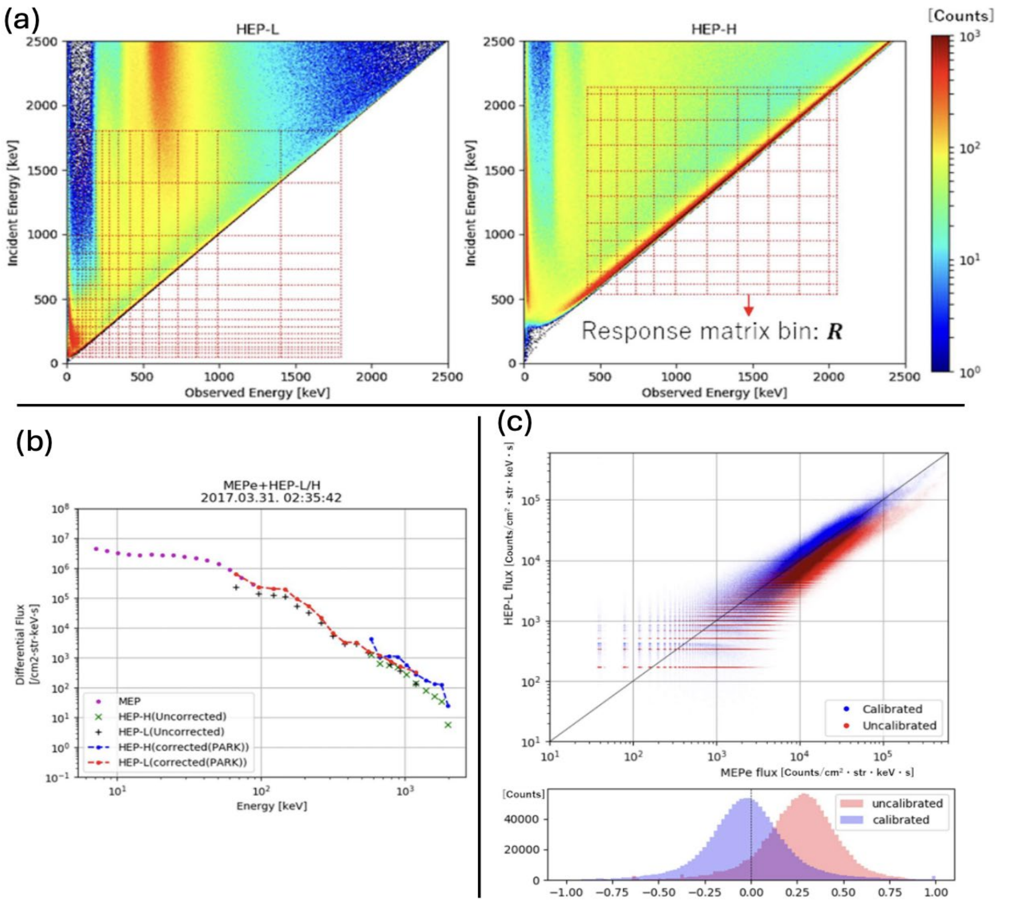

Figure 2. (a) Result of the electron beam simulation. The vertical axis and the horizontal axis show the incident energy and the observed energy, respectively. The color scale shows count. The red lines are the boundaries of the response matrix. (b) Energy spectrum obtained by MEP-e(Purple dots), HEP-L(Calibrated: Red dashed line, Uncalibrated: Black crosses) and HEP-H. (c) Comparison of differential flux from MEP and HEP at 95 keV channel (upper) and distributions of each observation ratio (lower). The red and blue colors indicate uncalibrated and calibrated data, respectively

Since particle observations are *in-situ* measurements, integrating multiple satellite observation points is necessary to understand spatial-temporal variations within the magnetosphere. Therefore, performing cross-calibration between instruments and unifying data quality is important. To perform cross-calibration of high-energy particle detectors between satellites in different locations, it is necessary to find the period during which the conditions for magnetic conjunction are met and analyze the data during that period. However, finding such periods among GEO satellites may be challenging. Since Arase has an elliptical orbit that overlaps with the L^* shell of GEO, there are many opportunities for magnetic conjunction with individual GEO satellites. High quality of high-energy particle observation from Arase can be used for cross-calibration of GEO satellite observations. It is apparent that applying routine observations of the scientific quality of the satellite which has an elliptical orbit that overlaps with the L^* shell of GEO has significant potential for cross-calibration of GEO satellite observations.

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NEWS IN THIS QUARTER

First Data from GOES-19 SEISS Instrument

By Athanasios Boudouridis and Juan V. Rodriguez (CIRES and NOAA/NCEI)

The Space Environment In-Situ Suite (SEISS) instrument onboard NOAA's GOES-19 satellite is now sending radiation data back to Earth. GOES-19 launched on June 25, 2024, and the SEISS https://www.goes-r.gov/spacesegment/seiss.html sensors have been collecting data continuously since August 22, 2024. SEISS is a suite of sensors that monitors proton, electron, and heavy ion fluxes in the magnetosphere, which are observations used to support space weather monitoring and prediction. After GOES-19 is assigned the operational role as NOAA's GOES East satellite in early 2025, NOAA's Space Weather Prediction Center will use GOES-19's SEISS data to issue solar radiation storm and radiation belt alerts, and improve energetic particle forecasts. For the first data from GOES-19 SEISS Magnetospheric Particle Sensor – High Energy (MPS-HI), please see https://www.nesdis.noaa.gov/news/noaa-shares-first-data-goes-19-seiss-instrument

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Communications between COSPAR/PRBEM and GSICS Space Weather Sub-group

By Tsutomu Nagatsuma (NICT)

To establish a standard procedure on cross-calibration of high energy particle sensors, GSICS/Space Weather Sub-group have been considering applying the document, Data Analysis Procedure v1.2 (https://prbem.github.io/documents/Standard_Data_Analysis.pdf), compiled by Panel on Radiation Belt Environment Modeling (PRBEM) under Committee on Space Research (COSPAR) since Dec. 2023. After the document review by the sub-group members, we have realized that several regulations of magnetic conjunction for cross-calibration described in the document has several problems, especially for GEO-GEO cross-calibration. So, we asked chair/vice-chairs of COSPAR/PRBEM to arrange an opportunity to discuss about this issue in the COSPAR Scientific Assembly. COSPAR 45th Scientific Assembly (COSPAR 2024) was held in July 13-21, 2024 at Busan, Korea. They proposed us to submit an abstract about the review on PRBEM data analysis procedure to the session, "Standards and Tools for Radiation Measurements and Supporting Data (PRBEM.1)". We submitted an abstract and ask them to coordinate additional time slot for discussion on the future collaboration between GSICS/Space Weather Sub-group and COSPAR/PRBEM. As a result, we had the following two time slots for our discussion on PRBEM data analysis procedure in PRBEM.1.

- July 17, 2024, 15:50-16:10 Review on PRBEM Data Analysis Procedure
- July 17, 2024, 16:10-16:30 Discussion – GSICS International collaborative effort

After our presentation and subsequent discussion, our issues with the PRBEM document on data analysis procedure were positively received. PRBEM chairs/co-chairs agreed to discuss whether to include this matter in the resolution at the business meeting during the COSPAR 2024. Finally, PRBEM decided that the issue on updating the document of data analysis procedure with establishing communication/discussion with GSICS is included in the PRBEM resolution. This matter is being discussed by COSPAR Bureau. We will take the first step in promoting the standardization of cross calibration of high energy particle sensor through collaboration between the research domain and the operational one.

doi: 10.25923/myah-9189

Announcements

WGCV-54 & WGISS-58 Joint meeting to be held October 15th - 18th, 2024 in USGS EROS, Sioux Falls, South Dakota, USA

By Manik Bali (NOAA/UMD)

This year the Working Group on Calibration and Validation (WGCV-54) and Working Group on Information Systems and Services (WGISS-58) would be held at USGS EROS in Sioux Falls, South Dakota, USA.
A short breakout session on SI Traceable Satellites (SITSats) is planned for 18 Oct 2024.

The meeting page is at https://ceos.org/meetings/wgcv-54-wgiss-58/

The final agenda is being worked out at :

- WGCV-54: https://docs.google.com/document/d/1CeZTXu2nluN1_wCT-L1XhTAzBjJOhWaJ1F7fR52DTh8
- WGISS/WGCV: https://docs.google.com/document/d/1CUMC4BQGxLO3PlZ5bv4PhMhOS6l-_Q1rfexj5TlU0hs

Workshop on Pre-flight Calibration and Characterization of Optical Satellite Instruments for Earth Observation to be held 19-22 November 2024 at ESTEC, Noordwijk, Netherlands

By Nigel Fox (NPL) and Xiaoxiong (Jack) Xiong (NASA)

The workshop seeks to bring together, experts from industrial and academic developers of instruments, those specifying, designing and performing calibration and characterisation as well as scientists, engineers, New Space actors, agencies and funding organisations interested in: what is and/or might be possible for a next generation instrument or future application. The workshop will be organised to encourage discussion and debate on what is 'fit for purpose' for particular types of application.

UV to SWIR and TIR:

- Future Calibration / Characterisation Requirements
- Principles of Calibration / Characterisation / Traceability / Uncertainty and its Documentation / Reporting
- Spectral Response Function / Bandwidth / Wavelength / Smile (Discrete bands & Spectrometers)
- Stray Light (Out-of-Field, Out-of-Band), Point Spread Function, Ghosts, Scattered
- Radiometric Gain / Non-Linearity / Polarisation Sensitivity

Workshop Website: https://atpi.eventsair.com/pre-flight-calibration-workshop/

GSICS-Related Publications

Lee, Y., M.-H. Ahn, M. Kang, M. Eo, D. Kim, and K.-J. Moon. 2024. '**Advantages of Inter-Calibration for Geostationary Satellite Sensors Onboard Twin Satellites**'. *Geophysical Research Letters* 51 (14). https://doi.org/10.1029/2024GL109364.

Vos, Natasha, Tristan S. L'Ecuyer, and Tim Michaels. 2024. '**Enabling Process Science with CubeSat Intersections: An Orbit Resampling Study Inspired by PREFIRE**'. Copernicus GmbH. https://doi.org/10.5194/egusphere-2024-2040.

Xie, Y, D Feng, W Shao, J Han, and YD Chen. 2024. '**Radiometric Cross Calibration of HY-1C/COCTS Based on Sentinel-3/OLCI**'. *IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING* 17:10422–31. https://doi.org/10.1109/JSTARS.2024.3403107.

doi: 10.25923/myah-9189

Submitting Articles to the GSICS Quarterly Newsletter

The GSICS Quarterly Press Crew is looking for short articles (800 to 900 words with one or two key illustrations), especially related to calibration / validation capabilities and how they have been used to positively impact weather and climate products. Unsolicited articles may be submitted for consideration anytime, and if accepted, will be published in the next available newsletter issue after approval / editing. Please send articles to manik.bali@noaa.gov.

With Help from our friends:

The GSICS Quarterly Editor would like to thank Tsutomu Nagatsuma (NICT), Juan V. Rodriguez(CIRES/NOAA/NCEI), Jing-tian LV(CMA), Ingmar Sandberg(SPARC), Daehyeon Oh(KMA), Brian T. Kress(CIRES/NOAA/NCEI), Inchun Park(NICT), and Lawrence Flynn (NOAA) for reviewing articles in this issue.

Thanks are due to Jan Thomas (NOAA) for helping with 508 compliance.

Published By
GSICS Coordination Center
NOAA/NESDIS/STAR NOAA
Center for Weather and Climate Prediction,
5830 University Research Court
College Park, MD 20740, USA

CISESS
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