Preliminary Proposal of the World Meteorological Organization (WMO)
for the joint initiative of the
International Space Station (ISS) Program Science Forum (PSF)
and the United Nations Human Space Technology Initiative (UN-HSTI)

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Scope

The present proposal is a contribution to the overarching goal of extending, and communicating, the benefits of the ISS to humanity, with particular regard to Earth Observation and Disaster Risk Reduction which are among the target areas of activities identified by the ISS PSF and for which WMO has a mandate from the UN and is a major player at the global level.

It is proposed to fly an absolutely calibrated calibration reference payload on ISS, which will be used to provide the traceability to international standards that is currently missing. Absolute calibration of satellite instruments is critical to improve the accuracy and consistency over time of meteorological and climate measurements from space and the detection and quantification of changes in the Earth's environment.

Such improved accuracy will improve the reliability of satellite imagery for hazard mapping and post-disaster damage assessment, as part of Disaster Risk Reduction (DRR) strategies. Absolute calibration will provide a major improvement in the accuracy of climate change monitoring. It will provide the basis for an improved representation of physical processes in the Numerical Weather Prediction (NWP) and climate models and in the modeling of climate change impact in support of climate change mitigation or adaptation strategies. In enabling an assessment of systematic errors in NWP models used worldwide in operational weather forecasting, it will benefit a number of services that rely on weather modeling, including extreme weather event preparedness.

Benefits

Adaptation to climate variability and change poses a major challenge for the sustainable development of society. This has both short-term and long-term consequences, as a growing population is exposed and vulnerable to extreme weather events that tend to be more frequent as a result of climate change. Effective climate adaptation requires understanding of risks and development of knowledge and predictive capacities of the evolution of climatic conditions, as well as of the changing patterns of extreme weather events, to empower risk management, planning and decision-making in various socio-economic sectors. Since climate signals over a decade, however, are of similar or smaller magnitude than the measurement uncertainties of many existing space-based observations, new high accuracy rigorous calibration protocols are required to detect these signals. Accurate calibration of climate sensors is a key for assessing climate change and improving the reliability of climate prediction.

In addition, it is recalled that Space-based Earth Observation is the dominant source of input data of NWP models used in operational forecasting. This applies in particular to the forecasting of hydro-meteorological hazards (hurricanes, high winds, floods, snow storms, extreme temperatures, etc) which represent 90% of the disasters caused by natural hazards and have caused worldwide damage above 1300 Million US Dollars and more than one million casualties between 1980 and 2007, i.e. in less than three decades (Source: *"EM-DAT: The OFDA/CRED International Disaster*

Database, www.emdat.be - Université catholique de Louvain - Brussels - Belgium"). On a global scale, as revealed by statistics for the past five decades, the economic losses attributable to hydro-meteorological hazards have increased nearly 50 times. However, the reported loss of life has decreased dramatically during the same period by a factor of about 10 as a consequence of the development of early warning systems (EWS) in a number of high-risk countries, owing to advances in hydro-metrological hazard monitoring and forecasting, linked to risk mapping and emergency preparedness on the ground. The provision of observations with absolute SI traceable accuracy provides the basis to better assess systematic errors in weather forecasting models which would directly impact on the ability to provide warnings with longer lead-time and save human lives. A consequential benefit is a better understanding of physical processes in the weather/climate system which in turn leads to better modeling capabilities.

Furthermore, hazard mapping and estimation of disaster losses are fundamental for risk assessment to quantify and understand the risks associated with natural hazards, their changing characteristics in context of climate variability and change and their socio-economic impacts, which constitutes the basis of disaster risk reduction. The radiometric, geometric, and spectral characteristics of sensors should be well understood to generate consistent and reliable geophysical and biophysical products based on remote sensing imagery for disaster-related mapping activities. For generating accurate maps, mitigation of disasters, quantitative assessment of the impacts, etc. absolute data calibration is pivotal to allow the merging of different data sources into consistent data sets and their comparison over time.

The benefits of the project would thus be three-fold:

(i) Providing high-accuracy observations supporting the meteorological and climate applications above;

(ii) Serving as a calibration transfer standard for current and planned constellations of visible and infrared imager/sounder radiometers used for meteorology, climate and land surface observations worldwide, and therefore leveraging their accuracy and usefulness to a wealth of services;

(iii) Early demonstration, with potential for evolution, of concepts and technology paving the way for a future operational series of calibration transfer standard that would ultimately fly on dedicated spacecraft.

State of the art

Space-based measurements need to be accurate, consistent and traceable to allow comparison with each other, with ground-based observations and enable the detection of long term trends. Several international initiatives have been taken to optimize the calibration of space-borne radiometric measurements with the goal to provide optimal accuracy and consistency of observations. Strategies are being developed to establish or improve traceability to absolute references, and the current proposal would represent a major step in that direction.

A brief summary of the current international efforts in this area includes:

- The Global Space-based Inter-Calibration System (GSICS) initiated by WMO and the Coordination Group for Meteorological Satellites (CGMS) involves 13 space agencies. GSICS has developed and is implementing operational inter-calibration procedures whereby virtually all operational infra-red sensors are compared with a high-precision hyperspectral instrument taken as reference. Additional procedures are being developed for the calibration of solar channels (Ultraviolet, Visible and Near-infrared). While this approach is very successful in providing consistent datasets across the constellation of instruments, it does not provide absolute traceability.

- The Working Group on Calibration and Validation (WGCV) of the Committee on Earth Observation satellites (CEOS) has also been working to ensure long-term confidence in the accuracy and quality of Earth Observation (EO) data and products for many years. The WGCV provides an international forum for the exchange and coordination of calibration and validation technical information and documentation, for coordinating and fostering scientific collaboration towards defining best practices, for establishing cooperative activities and experiments, and for sharing of facilities, expertise, and resource. WGCV has provided letters of support for both CLARREO and TRUTHS missions in the past and continues to strongly support any effort to improve calibration and instrument interoperability in support of climate, weather, and earth observation requirements.

- The CEOS, has led the development of a Quality Assurance Framework for Earth Observation (QA4EO) based on a set of key guidelines derived from “best practices” under the auspices of the Group on Earth Observation (GEO). Their use by the community will facilitate the assignment of an unequivocal Quality Indicator to all sensor-derived data products.

- The Metrology for Earth Observation and Climate (MetEOC) project of the European Metrology Research Programme (EMRP) has the goal to develop new standards/methods to calibrate and validate the measurements of satellite sensors pre- and post- launch in a sustainable manner through the creation of a virtual European metrology centre for Earth observation and climate (EMCEOC).

- WMO is cooperating with the Bureau International des Poids et Mesures (BIPM). A joint WMO-BIPM workshop was organized on “Measurements challenges for Global Observation Systems for Climate Change Monitoring: Traceability, Stability and Uncertainty”. In the report of this workshop (published as IOM Report N°.105, WMO/TD-N°.1557, Rapport BIPM-2012/08) on-orbit traceabilit y is highlighted as a priority for climate missions.

- The Institute of Applied Physics "Nello Carrara" and the National Research Council of Italy (IFAC-CNR) have developed a Radiation Explorer in the Far Infrared - Prototype for Applications and Development (REFIR-PAD) instrumentation package which was deployed with success both on stratospheric balloons and from ground-based measurements (e.g. in Antarctica).

- Dedicated satellite missions have been proposed to fly absolutely calibrated instruments: the Climate Absolute Radiance and Refractivity Observatory (CLARREO) was identified by the US National Research Council as a top priority for this decade; the Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) was similarly proposed by the United Kingdom National Physical Laboratory. Extensive scientific research has been performed to prepare and support these missions, which are complementary to each other. While such missions are highly needed and should remain an objective, there is currently no confirmed plan to fly them.

The proposed mission concept would build on the scientific research completed so far within these initiatives and on the high degree of collaboration of the international Earth Observation community in this area.

Many climate indicators require the detection of subtle changes over decades. In the “solar reflective” domain this can be less than 0.5 % per decade. Because no existing EO optical sensor comes close to achieving this level of absolute accuracy, most current climate change observational strategies rely on instrument stability normalised by intercalibration of simultaneous measurements and by overlapping times-series of measurements in order to remove instrumental biases. However, such strategies are high risk because besides the fact that every transition from one instrument to the following one increases uncertainty, this approach is vulnerable to gaps in instrument continuity from either early instrument failures or delayed launches of replacements. Provision of an absolute reference in space would allow a new ability to mitigate the risk of gaps in the record without losing the ability to rigorously detect climate change signals.

Key features of the proposed mission concept

The proposed mission concept would take advantage of the space station *orbit*, which allows monthly intercalibration observations matched in time, space, and angle of view with all infrared and reflected solar instruments in both low earth orbit as well as geostationary orbits. The proposed mission could also take advantage of *serviceability*, which is a unique feature of the ISS, and *long-term availability*, since the ISS is planned to be operated for more than a decade. The mission would include a very high absolute accuracy sensor package maintaining a continuous record of radiometric measurements. The serviceability would be used primarily to replace the instruments at regular (3-year) intervals with a view to monitor and maintain the performance of the payload at the required levels throughout the duration of the project, or to replace a sub-system in case of noticeable degradation. Furthermore, if such capability became available in the ISS operations plan, serviceability would be used for bringing back instruments or calibration subsystems of the payload for post-flight comparison with the pre-flight laboratory tests, and thereby verifying the consistency of pre-launch and post-launch absolute calibration. While the latter aspect of serviceability is not a pre-requisite for this mission, it would augment the ability to independently verify the accuracy levels achieved in orbit.

If an early deployment of a free-flyer based sensor (in an alternative orbit) could also be achieved this would further enhance the concept allowing the establishment of a “climate and calibration” constellation”. The combination would provide full global and diurnal sampling and the ability to truly “cross compare” independent high-accuracy systems in-orbit, ensuring a seamless transition to a long-term “operational service”.

The ISS and UN-HSTI framework is particularly well suited to support such a project which, by definition, serves the *international community* since it will provide a common reference to the radiometric measurements of a worldwide diversity of satellites and instruments. It will involve a broad scientific and operational community who has an excellent record of international collaboration under the auspices of WMO, GSICS, CGMS and CEOS.

Finally it would serve *public benefit* as explained above, in supporting disaster-related mapping activities and in improving weather and climate observations, as weather and climate events affect every citizen of this planet, have high impact on safety of life and property, and are the origin of 90% of disasters caused by natural hazards.

High-level mission concept

The mission would have two primary Earth viewing instruments flying on the ISS as attached payloads.

1) Top of Atmosphere reflected solar radiation spectrometer

- Hyperspectral pushbroom imaging spectrometer,
- UV through Near-infrared contiguous spectral coverage (>95% of Earth reflected solar energy),
- 4 nm spectral sampling to allow intercalibration of narrow band imagers,
- 0.3% (k=2) absolute accuracy in spectral reflectance,
- < 1km nadir field of view,
- 100 - 200 km viewing swath,
- < 0.2% polarization sensitivity,
- two-axis gimbal pointing to enable continuous nadir spectral monitoring as well as intercalibration pointing alignment during orbit crossings with Low Earth Orbit (LEO) satellites such as METOP, Suomi-NPP, FY-3, JPSS, and all geostationary satellite visible imagers.

Calibration of this instrument can be accomplished by pointing toward and scanning the sun using a combination of attenuators including precision apertures, varying detector dwell times, and neutral density filters. Pointing toward and scanning the moon with no attenuators can be used to verify the stability of the instrument, and to improve the characterization and traceability of the spectral reflectance of the lunar surface. Alternatively there is also a design for independent calibration using a cryogenically cooled active cavity radiometer as a primary reference absolute detector.

2) Top of Atmosphere thermal infrared upward radiation spectrometer

- Four-port interferometer
- Mid through Far Infrared contiguous spectral coverage (>95% of Earth emitted infrared energy),
- ~ 0.5 cm^{-1} spectral resolution for intercalibration of high spectral resolution sounders,
- 0.07K (k=2) absolute accuracy in spectral radiance,
- 25-km to 100-km nadir field of view,
- very high emissivity blackbodies (>0.999 emissivity) with temperature control from 200 to 320 K,
- multiple phase change cells for high accuracy blackbody thermometry,
- blackbody emissivity monitoring,
- spectral lineshape monitoring,
- ports for polarization sensitivity monitoring,
- two-axis gimbal capable of maintaining pointing at nadir for continuous spectral monitoring, as well as alignment pointing during orbit crossings with LEO satellites such as METOP, Suomi-NPP, JPSS, and with all geostationary satellite infrared imagers.

The accuracy of the proposed instruments is driven by the requirement that the uncertainty be less than natural variability in order to avoid delay or corruption in observations of critical climate change signals. The accuracy specification is highly challenging but now achievable based on the last decade of advances at international metrology centers in absolute calibration of radiometers at infrared and solar wavelengths. Both instruments and calibration systems are based on Technology Readiness Level (TRL) 6 or higher. Demonstration versions of instruments with these capabilities have been constructed at NASA Langley, University of Wisconsin, University of Colorado-LASP, and NASA Goddard Space Flight Center. The National Institute of Standards and Technology (NIST) and National Physical Laboratory (NPL) metrology laboratories have been actively engaged in the instrument and calibration system design.

Mission scenario

Instruments would be flown to the ISS using existing launch services and robotically attached to either the ELC or JEM modules. Instrument lifetime design would be 3 years. Instrument replacement would be every 3 years, with a 3-month overlap period on the ISS to verify consistency of both instruments. Should there be a capability to carry some payload back to Earth, the instruments being replaced would be returned to Earth for laboratory recertification of absolute calibration. At that time, instruments could be refurbished and recalibrated for later re-flight. A continuous cycle of instruments would be used as long as the ISS remains in operation.

During this time there would be a transition to free-flight versions to carry on the climate observation mission and provision of reference calibration traceability for much of the weather and climate observing systems on a long-term, sustained basis.

Utilization scenario

The above two Earth viewing instruments would serve the international community as the reference transfer radiometers for key weather, climate and other Earth observing instruments including but not limited to ABI, AGRI, AHI, ASI, AVHRR, CERES, CrIS, ETM+, FCI, GIIRS, GOME-2, HIRS, IASI, IRAS, IRS, MERSI-2, MODIS, OLCI, SEVIRI, SGLI, SLSTR, VIIRS, and VIRR (See instrument acronym table below). The GSICS project together with CEOS will incorporate these references in its operational procedures for the derivation of calibration corrections provided to the global user community. The results of the proposed mission will be made openly available to the science community and all space agencies for research and operational applications.

Synergy with other ISS missions

In addition to the primary Earth viewing measurements mentioned above there is significant value in maintaining the current solar observation programme of the ISS with instruments of upgraded performance. Whilst the ISS cannot replace the need for platforms able to provide continuous or near continuous observations of Total and spectrally resolved Solar Irradiance, it can provide a means to anchor the long-term record and bridge the gap caused by recent launch failures. Existing instrumentation, either flight-ready or at high TRL, can facilitate an upgrade and extension to the existing observation programme.

The detailed characteristics of the proposed mission, including both its space-based and ground-based elements, will be defined in consultation with ISS PSF and UN-HSTI by the project Steering Committee.

Management

A project Steering Committee will be established with stakeholders and experts from the various initiatives mentioned above. This committee will decide the final mission concept, establish a project team, validate the project plan, oversee the developments, validate the deliverables, organize the communication to ensure visibility to the project. This committee or its designated representatives will be the high-level interface with the ISS PSF and UN-HSTI.

Scientific and technical support of the proposal

This proposal is elaborated under the coordination of WMO by a broad international community of scientific and technical experts with particular input or support from the following persons and organizations:

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- N. Fox, National Physical Laboratory, London, UK
- J. Harries, H. Brindley and R.J. Bantges, Imperial College, London, UK
- J. G. Anderson, S. Leroy, and J. A. Dykema, Harvard Univ., Cambridge, MA, USA
- H. Latvakoski, Utah State Univ. Space Dynamics Lab, North Logan, UT, USA
- J. Rice, S. Mekhontsev, and L. Hanssen, National Institute of Standards and Technology, Gaithersburg, MD, USA
- L. Palchetti and B. Carli, Instituto di Fisica Applicata "Nello Carrara" – Consiglio Nazionale delle Ricerche (IFAC-CNR), Sesto Fiorentino, Italy
- J. Schmetz, T. Hewison, European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Germany
- T. Igarashi, K. Umezawa, Japan Aerospace Exploration Agency (JAXA), Tokyo, Japan
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INSTRUMENT ACRONYMS

ABI	Advanced Baseline Imager	GOES-R, GOES-S, GOES-T, GOES-U
AGRI	Advanced Geostationary Radiation Imager	FY-4 A to G
AHI	Advanced Himawari Imager	Himawari -8 and -9
ASI	Atmospheric Sounding Interferometer	FY-3 D to G
AVHRR	Advanced Very High Resolution Radiometer	NOAA and MetOp
CERES	Clouds and the Earth's Radiant Energy System	Terra, Aqua, TRMM, Suomi-NPP, JPSS
CrIS	Cross-track Infrared Sounder	NPP, JPSS-1, JPSS-2
ETM+	Enhanced Thematic Mapper +	Landsat-7
FCI	Flexible Combined Imager	MTG-I1, MTG-I2, MTG-I3, MTG-I4
GIIRS	Geostationary Interferometric Infrared Sounder	FY-4 A to G
GOME-2	Global Ozone Monitoring Experiment - 2	MetOp A to C
HIRS	High-resolution Infra Red Sounder	NOAA 18 & 19, MetOp A,B
IASI	Infrared Atmospheric Sounding Interferometer	MetOp A to C
IRAS	Infra Red Atmospheric Sounder	FY-3 A to C
IRS	Infra Red Sounder	MTG-S1, MTG-S2
MERSI-2	Medium Resolution Spectral Imager -2	FY-3 C to G
MODIS	Moderate-resolution Imaging Spectro-radiometer	EOS Terra/Aqua
OLCI	Ocean and Land Colour Imager	Sentinel-3 A and B
SEVIRI	Spinning Enhanced Visible Infra-Red Imager	Meteosat 8 to 11 (MSG)
SGLI	Second-generation Global Imager	GCOM-C 1/2/3
SLSTR	Sea and Land Surface Temperature Radiometer	Sentinel-3 A and B
VIIRS	Visible/Infrared Imager Radiometer Suite	NPP, JPSS-1, JPSS-2
VIRR	Visible and Infra Red Radiometer	FY-3 A to C