The HyperSpectral Imager for Climate Science (HySICS) on the CLARREO Pathfinder Mission

Greg Kopp[1], Gary Fleming[2], Peter Pilewskie[1], Paul Smith[1], Greg Ucker[1], Bruce Wielicki[2]

[1]Laboratory for Atmospheric and Space Physics, Univ. of Colorado, Boulder, CO, U.S.A., [2]NASA Langley Research Center, Hampton, VA, U.S.A.

Greg.Kopp@LASP.Colorado.edu

The HyperSpectral Imager for Climate Science (HySICS), to be flown as the CLARREO Pathfinder payload in 2023, is a spatial/spectral pushbroom imager achieving 6 nm of spectral resolution with 0.5-km spatial resolution for Earth scenes viewed from its platform on the International Space Station. Covering 350 to 2300 nm and having a 70-km swath, the HySICS will acquire images of the Earth's ground and atmosphere with unprecedented radiometric accuracies of <0.3% (*k*=1) achieved via on-orbit calibrations using the spectral solar irradiance. These high radiometric accuracies enable benchmarking of Earth radiances for climate studies and provide reference calibrations for other on-orbit Earth-viewing sensors.

CLARREO RADIOMETRY

The 2007 U.S. Academy of Sciences Decadal Survey for Earth Science recommended the Tier 1 mission CLARREO (Climate Absolute Radiance and Refractivity Observatory) [2] to acquire high-accuracy, climate-benchmarking spatial/spectral radiances of the Earth's surface and to provide reference calibrations for other on-orbit sensors. The more recent 2018 Decadal Survey similarly prioritized reference radiance inter-calibrations as one of its "Most Important Targeted Observables," providing on-orbit SI traceability for other programs such as the Global Space Based Inter-Calibration System. To achieve these climate-benchmarking and inter-calibration capabilities, the space-borne imaging spectrometer for the CLARREO requires radiometric-accuracy improvements that are 4 to 8x better than any currently-flying spectrometer provides, necessitating innovative new on-orbit measurement techniques.

The HyperSpectral Imager for Climate Science (HySICS) is currently in development for the NASA CLARREO Pathfinder (CPF), a low-cost, Class-D mission planned for launch to the International Space Station (ISS) in 2023 for a 1-year mission to demonstrate both the CLARREO-needed on-orbit radiometric accuracies and reference calibrations of other space-based assets. The two primary goals of this mission are to demonstrate 1) on-orbit, high-accuracy, SI-traceable calibrations for measurements of Earth-reflected radiances in the solar-spectral region, and 2) the ability to transfer calibrations to other on-orbit sensors, in particular the VIIRS and CERES as proof-of-concept. The instrument will also acquire lunar radiances at various phase and libration angles to improve the knowledge of the Moon as an on-orbit calibration source. A two-axis HySICS pointing system enables target selection (Earth-nadir, Sun, Moon, and off-nadir for reference-calibration coincidence pointing with other instruments).

The CLARREO Pathfinder is currently in Phase C with intended installation in the ISS ExPRESS Logistics Carrier #1 Site #3.

HYSICS CALIBRATION APPROACH

The radiometric uncertainty goal for the Pathfinder HySICS is 0.3% (*k*=1), which is much better than any current spaceflight reference detector or calibration light source is capable of providing. Instead of either of these traditional detector- or source-based calibration approaches, the HySICS relies on on-orbit calibrations provided by direct views of the spectral solar irradiance (SSI), which is known on an absolute SI-traceable scale to ~0.2% from other space-based instruments such as the TSIS-1 Spectral Irradiance Monitor [2].

Two signal-attenuation approaches enable the HySICS's direct views of the Sun for these SSI cross-calibrations: 1) knife-edged apertures of different sizes prior to the telescope entrance limit the amount of entering light by precisely-known amounts, giving ~10^{-3} attenuation due to geometric area between a 2-cm diameter Earth-viewing aperture and a 500-µm diameter Sun-viewing aperture; and 2) changes in focal-plane-array (FPA) integration times coupled with well-characterized detector linearity provide similar levels of attenuation. In conjunction, these two attenuation methods enable viewing both the Earth and the Sun with the same optical system despite the 10^6 difference in radiances. A prototype HySICS demonstrated these attenuation approaches and the desired radiometric accuracy improvements during two high-altitude balloon flights under a NASA Earth Science Technology Office program [1].

Estimated CPF HySICS uncertainties across the spectral range are shown in **Figure 1**.

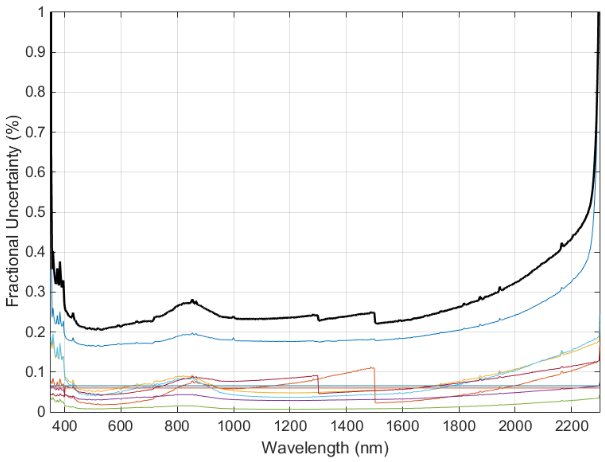

Figure 1. Estimated HySICS uncertainties with dominant contributors (colored curves) are summed in quadrature (black curve) to give a mean radiometric uncertainty of 0.27% across the spectrum.

HYSICS OPTICAL DESIGN

The HySICS is an Offner-based imaging spectrometer that contiguously covers 350 to 2300 nm with 6-nm spectral resolution (3.1-nm sampling). The nadir-looking instantaneous field-of-view is 130 m (instrument-intrinsic 67 arcsec) sampling a cross-track swath width of 71 km with a 10.1° field of view from the ISS's orbit altitude. An orthogonal arrangement of the optical planes of the four-mirror anastigmat telescope (4MA), providing imaging for the spectrometer, and the Offner reduces instrument-induced polarization to <0.1% from 350 to 1800 nm and <0.2% above 1800 nm. These low polarization sensitivities are needed for maintaining radiometric accuracy from scenes of unknown polarization. An aperture wheel prior to the imager's 4MA allows selection of Earth- and solar-viewing apertures.

Cross-track observations of Earth scenes acquire spatial/spectral information of the ground and atmosphere. Cross-slit scans of the Sun give composite measurements of the SSI, to which the HySICS is radiometrically referenced to SI. Along-slit solar scans enable flat fielding in the instrument's solar-viewing configuration, while a transmissive diffuser in the aperture wheel enables Earth-viewing-geometry flat fielding. A Hg/Ar pen-ray lamp provides on-orbit wavelength calibrations across the spectral range.

This full spectral range is spanned by a single HgCdTe FPA with 100% fill-factor pixels in a 640x480 format to acquire spatial/spectral images. The high-speed CMOS design includes an electronic global shutter allowing precise control of integration timing needed for known attenuation control. With nominal 15-Hz sampling, ground images have an along-track smear-limited 500-m spatial resolution; cross-track pixels are binned to the same resolution in Level-1 data products. Read-out noise is <100 e^-. Dark current and thermal backgrounds are reduced with the FPA's 150 K operating temperature, reducing uncertainties.

SUMMARY

The Sun is the most accurately-known and most stable radiometric light source in space. Using direct views of the spectral solar irradiance to provide on-orbit radiometric calibrations, the HySICS transfers this SI-traceable source to Earth reflectances with 0.3% uncertainties. This methodology is intended to provide needed radiometric accuracies for long-term climate studies and to improve, via inter-calibrations, measurements from other on-orbit sensors. The CLARREO Pathfinder is implementing the HySICS and this SI-traceable on-orbit calibration approach from the ISS starting in 2023. This mission is intended to demonstrate: current state-of-the-art in establishing traceability in orbit; new observations and climate-sensitivity detection capabilities and concepts; needed measurements, timescales, and accuracies for long-term climate studies; and reference calibrations to other on-orbit assets using identical viewing-geometries of targets.

REFERENCES

1. G. Kopp, P. Smith, C. Belting, Z. Castleman, G. Drake, J. Espejo, K. Heuerman, J. Lanzi, and D. Stuchlik, "Radiometric flight results from the HyperSpectral Imager for Climate Science (HySICS)," *Geoscientific Instrumentation Method. Data Syst.*, 6, pp. 169-191, 2017, doi:10.5194/gi-6-169-2017
2. http://lasp.colorado.edu/home/tsis/instruments/sim-spectral-irradiance-monitor/
3. B. Wielicki et al., "Achieving Climate Change Absolute Accuracy in Orbit," BAMS, Oct. 2013, doi:10.1175/BAMS-D-12-00149.1