ECOSTRESS End-to-End Radiometric Validation

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Abstract— **The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) will measure the brightness temperature (BT) of plants from the space station. This information will be used to generate products such as evapotranspiration (ET) over an effective diurnal cycle to better understand how much water plants need and how they respond to stresses (i.e. lack of water, sun, nutrients). The imaging radiometer on board the ECOSTRESS payload provides five thermal infrared (TIR) spectral bands with approximately 70m pixels and a nearly 400km swath. It incorporates many new technologies such as a high-speed Mercury Cadmium Telluride (MCT) focal plane array (FPA), black silicon calibration targets, and a thermal suppression filter allowing shortwave infrared (SWIR) bandpass. This radiometer has two on-board blackbodies to maintain calibration every sweep of the scan mirror (1.29s).**

The system has undergone an end-to-end test in a thermal-vacuum (TVAC) chamber showing excellent pre-flight radiometric results. This performance is in part enabled by newly developed, high-speed, low noise, readout electronics. The readout electronics converts all 32-analog channels to digital for downstream on board processing and downlink. Noise equivalent delta temperature (NEΔT) measurements and BT retrievals are well within requirements. The optical modulation transfer function (OMTF) is also within specification.

The instrument was launched on SpaceX CRS-15 along with the Latching End Effector for Canadaarm2 as well as three Biarri-Squad cubesats. ECOSTRESS passed In-Orbit Checkout (IOC). This is where all systems as well as science/calibration data are checked and verified to be operational. The payload is currently in Phase E operations. ECOSTRESS uses a local WiFi that sends data from the payload to the ISS. Data packets are then downlinked to the Huntsville Operations Support Center (HOSC) and subsequently archived in the science data system (SDS) servers. A series of calibration targets (Lake Tahoe and the Salton Sea) have been utilized to verify the top of atmosphere radiometric integrity of the science data. Other geometrical targets such as the crop fields of California and a few large bridges around CONUS have been used to verify the geolocation accuracy when compared with previous data from (Visible Infrared Imaging Radiometer Suite) VIIRS and ASTER.

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1. INTRODUCTION

The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) [1] measures the thermal infrared brightness temperatures (BT) of plants from space. It uses this information to allow a better understanding of how much water plants need and how they respond to stress. ECOSTRESS will address three overarching science questions:

- How is the terrestrial biosphere responding to changes in water availability?
- How do changes in diurnal vegetation water stress impact the global carbon cycle?
- Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?

Three science objectives have been identified to address these questions:

- Identify critical thresholds of water use and water stress in key biomes (e.g., tropical/dry transition forests, boreal forests);
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle;
- Measure agricultural water consumptive use over CONUS at spatiotemporal scales applicable to improving drought estimation accuracy.

These questions require an absolute accuracy in temperature retrievals at a smaller spatial scale than any other orbiting platform to date. Plants regulate their temperature by releasing water through tiny pores on their leaves called stomata. If they have sufficient water, they can maintain their temperature, but if there is insufficient water, their temperatures will rise, and thus this temperature rise can be measured with a sensor in space. In addition to this, the measurements need to sample the same ground targets at different times of day. This type of sampling, when averaged over a year, will allow a better understanding of the diurnal cycle of plant function. The ECOSTRESS payload will reside on the International Space Station (ISS). The ISS orbit is inclined relative to the poles, providing more observation time of forests and vegetation over temperate land masses than possible from the polar orbits commonly used for other types of Earth observations.

ECOSTRESS uses a multi spectral thermal infrared imaging radiometer to measure BT. This can be processed to higher level products such as land surface temperature (LST) and emissivity (ϵ). The Jet Propulsion Laboratory (JPL) devel-

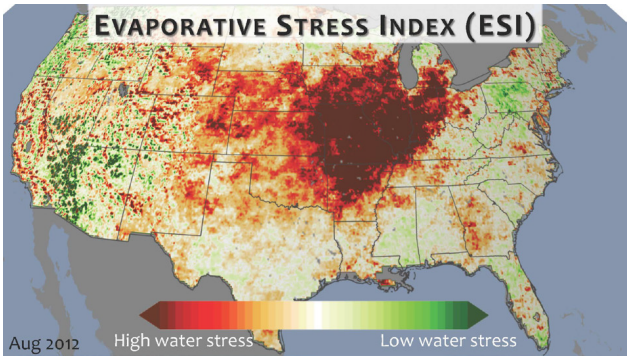

Figure 1. The Evaporative Stress Index (ESI), derived from thermal infrared-based ET measurements, is able to detect the US Midwest drought of 2012

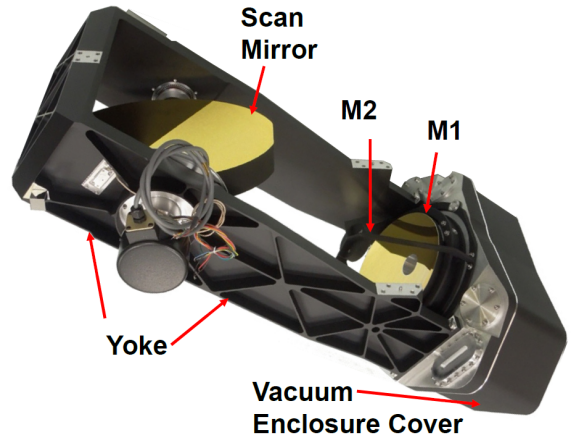

Figure 2. The PHyTIR scan instrument engineering model with build in vacuum enclosure used for ground testing

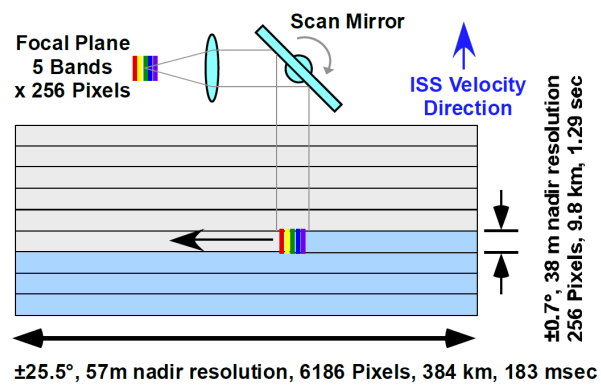

Figure 3. The ECOSTRESS scan method provides 5 spectral channels covering a 53°-wide ground swath.

oped radiometer was installed in its payload, calibrated, and delivered to Kennedy Space Center (KSC) in Florida for installation in the Dragon trunk on the Falcon 9 Space-X fifteenth Commercial Resupply Services (CRS-15) mission. Launch occurred on 29 June 2018 at 09:42 UTC at Cape Canaveral Air Force Station Launch Complex 40. The spacecraft rendezvoused with the ISS on 2 July 2018. It was captured by the Canadarm2 at 10:54 UTC and was berthed to the Harmony node at 13:50 UTC. In the proceeding days, one remote controlled mechanical arm was used to remove it from the Dragon trunk. It was handed off from the first arm to a second mechanical arm. This second arm moved the ECOSTRESS payload into its final installation position on the Japanese Experiment Module - Exposed Facility (JEM-EF) site position 10. The radiometer will acquire the most detailed temperature images of the surface ever acquired from space and will be able to measure the temperature of an individual farmers field.

One of the core products that will be produced by the ECOSTRESS team is the Evaporative Stress Index (ESI). ESI is a leading drought indicator - it can indicate that plants are stressed and that a drought is likely to occur providing the option for decision makers to take action. Figure 1 illustrates the ESI for the United States during the 2012 drought. The red areas indicate regions of high water stress.

2. RADIOMETER DESCRIPTION

ECOSTRESS was implemented by utilizing a few key parts of the existing space-ready Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR) on the ISS [6]. Parts included the focal plane, encoder, and optics design. PHyTIR, shown in Figure 2, was developed under the Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP). From the ISS, PHyTIR provides data with 38-m in-track by 69-m cross-track spatial sampling (science requirement is 100 m) and predicted temperature sensitivity of 0.15 K (science requirement is 0.3 K). The ISS orbit allows excellent coverage of the selected targets including diurnal coverage.

The existing hardware was developed to reduce the cost and risk for the thermal infrared radiometer on the future Hyperspectral Infrared Imager (HyspIRI) mission [2]. A double-sided scan mirror, rotating at a constant 25.4 rpm, allows the telescope to view a 53°-wide nadir cross-track swath as well as two internal blackbody calibration targets every 1.29 seconds (Note that the two-sided mirror rotating at 25.4 rpm provides 46.6 sweeps per minute). The blackbody targets use a new black silicon [3] surface treatment allowing emissivity beyond what's required for accurate temperature retrievals. The optical signal is focused by a telescope onto a focal plane held at 65K. It consists of a custom 13.2-μm-cutoff mercury-cadmium-telluride (MCT) infrared detector array. Spectral filters on the focal plane define five spectral bands in the 8-12.5 μm range and an additional band at 1.6μm for hot target and cloud detection (six bands total, five used for science). The focal plane is cooled by two commercial Thales cryocoolers [5]. Electronics consist of six build-to-print and four commercial boards. Heat rejection for the ECOSTRESS cryocoolers, electronics, and cold blackbody is provided by the cooling fluid loop on the ISS JEM-EF. Figure 3 illustrates the ECOSTRESS scan method which enables a wide swath and high spatial resolution. As the ISS moves forward, the scan mirror sweeps the focal plane ground projection in the cross-track direction. Each sweep is 256-pixels wide. The different spectral bands are swept across a given point on the ground sequentially. From the 400$\pm$25-km ISS altitude, the resulting swath is 384 km wide. A wide continuous swath is produced even with an ISS yaw of up to ± 18.5 °.

The ECOSTRESS optics consist of an electroplated gold double sided scan mirror plus two separate optical modules. The first module is a narrow field (1.4°) two mirror off-axis

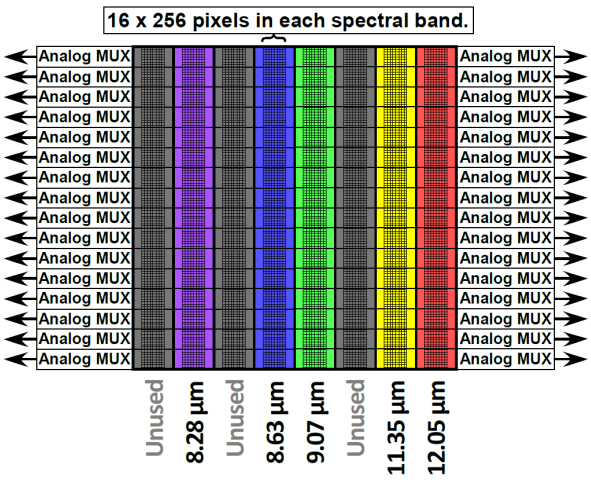

Figure 4. 32 analog multiplexer output lines allow the ROIC to achieve a 29.4-s frame-time. 16 columns of pixels within each spectral band allow selection of the 4 optimal columns in each band.

telescope (M1 and M2), which forms an image of the ground through the vacuum window and relay assembly. The second module (fold mirror and M3) is an all-reflective relay used to control stray radiation and aberrations. The design is a Korsch-variant design [4] optimized for thermal infrared. A cold Lyot-stop baffle minimizes radiation from the warm fore optics. The two-module design allows placement of field and aperture stops before the spectral filters on the focal plane, providing shielding of stray radiation from the ambient temperature telescope.

Unlike the conventional frame camera in which the focal plane closely defines the size of the output image, the ECOSTRESS rotating scan mirror illuminates a relatively small focal plane and combines multiple FPAs to produce a composite image. The ECOSTRESS focal plane uses a custom readout integrated circuit (ROIC). It has 16 columns of 256 40μm detectors in each of eight spectral channels. A subset of these columns can be selected for high-rate readout via 32 output multiplexer channels operating at frame times as low as 29.4μs. The redundant columns and selectable readout mitigates the imperfect yield typical of long-wavelength MCT detectors. The ROIC was designed for the eight HyspIRI TIR bands, but ECOSTRESS uses only five. A fast clock rate and associated settling times require that the immediately following 4-pixel column be skipped such that each one of the four illuminated pixel columns actually consumes a set of two columns. This means that (4x2=) 8 of the 16 pixel columns in each FPA band are used for imaging and the remaining eight pixel columns are available as backup. This 50% reserve combined with the two unused band/columns provides an exceptional FPA contingency. A single-band image delivered to the ground is 5400 pixels (lines; Y; across-track) by 11264 pixels (samples; X; along-track) and is a mosaic of 237,600 focal planes (where each FPA is 1x256 pixels). The total data delivered to the ground (approximately every minute) is five TIR bands and one Reflectance (SWIR) band, plus associated Blackbody calibration and related metadata. Additional high-speed readout electronics were developed using a total of four 8-channel multiplex analog-to-digital (A/D) converters held off chip.

3. Ground Testing

After final assembly of the payload, an extensive set of ground tests was performed to verify the performance of the imaging radiometer. These tests were broken up into before and after vibration testing as well as during thermal vacuum full functional testing. As mentioned earlier, the imaging radiometer has a built in vacuum chamber around the cold parts of the instrument (i.e FPA, cold stop, shielding). This allowed testing to be performed after each step of the process without having to take the payload into the large and costly thermal vacuum chamber. Most of the basic radiometric and optical tests could be performed this way. The stray light, expanded range linearity, and motion modulation transfer function tests needed a full vacuum chamber due to the need for the full payload signal manipulation.

Preliminary Discussion

The planned science products include Earth surface radiance, temperature, emissivity, evapotranspiration, water use efficiency, and an evaporative stress index. To measure radiance, the instrument uses a continuously rotating scan mirror in a push-whisk configuration to direct light from the telescope through five narrowband interference filters to the FPA. The focal plane consists of 8x16x256 arrays of MCT detectors hybridized on a CMOS (complementary metal oxide semiconductor) manufacturing process. The ECOSTRESS FPA was originally developed at JPL as the PHyTIR instrument and has been tested in the Laboratory and documented previously [7].

Calibration is the process of removing (correcting) non-uniform light measurement between individual pixel detectors on the focal plane array. Radiometric Calibration is the process of relating the uniform values received from instrument to a standard measurement. For visual (VIS), near-infrared (NIR) and shortwave infrared wavelengths (SWIR) the conventional FPA calibration approach is to apply dark current and flat-field procedures, then perform a separate vicarious radiometric calibration to measure scene radiance. This could be performed by using an integrating sphere with a Lambertian diffuser coating the entire inside of the sphere. However, Thermal Infrared (TIR) imaging systems (such as the ECOSTRESS instrument) typically have on-board blackbody temperature emission sources which are used to radiometrically calibrate the image and perform basic FPA calibration in one step. Subsequent FPA corrections are only necessary if there are non-responsive pixels, post-imaging artifacts, or if the blackbodies should unexpectedly degrade. The ECOSTRESS payload has two on board blackbodies used for radiometric calibration. The scanning mirror and data recording system sweeps the view of the two blackbodies every 1.29s due to the geometry of scanning as shown in Figure 5.

For the five TIR bands, radiometric calibration is the process of converting incident thermal energy (in Digital Numbers; DN) on the focal plane to calibrated radiance values. For testing and evaluation purposes, the radiance values are also converted to temperature values (degrees Kelvin). This is accomplished through: 1) Pre-Flight and In-Flight on-board measurement of the cold (CBB) and hot blackbodies (HBB) temperatures; 2) Conversion of the known blackbody temperatures to radiance using the Planck function; 3) Creation of hot and cold focal plane blackbody calibration and radiance files; 4) Conversion of each focal plane DN to radiance values using a two-point affine transformation; and 5) Use of the inverse Planck function to convert each band's calculated pixel

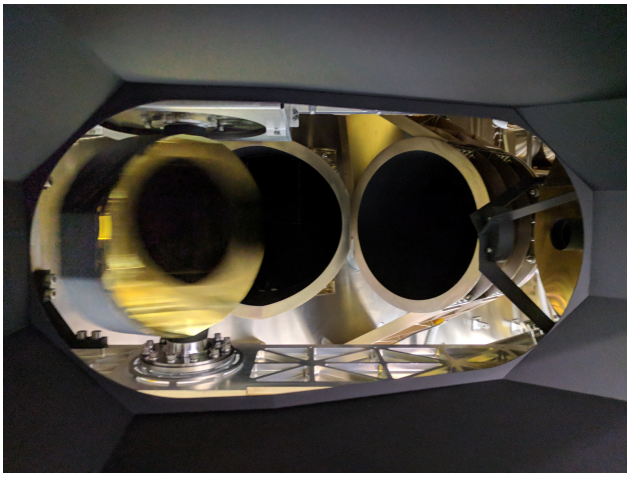

Figure 5. View looking up into the ECOSTRESS payload from NADIR shows the scan mirror moving along with the two onboard blackbodies. The telescope spider in off to the right in the image.

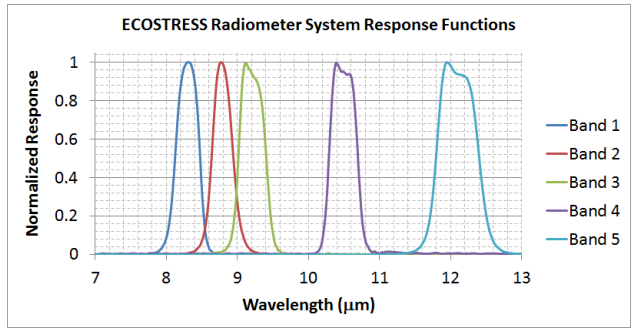

Figure 6. View looking up into the ECOSTRESS payload from NADIR shows the scan mirror moving along with the two onboard blackbodies.

radiance to brightness temperature (K). Laboratory testing indicates this radiometric calibration process is capable of better than 0.5 degree Kelvin error, which is half of the 1 degree Kelvin requirement. Pre-flight blackbody calibration is performed in the laboratory on the flight hardware. This is particularly rigorous for ECOSTRESS because the FPA flight hardware is from the PHyTIR instrument that has already been tested and evaluated numerous times. The pre-flight process involves measuring the absolute skin temperature of each blackbody using a National Institute of Standards and Technology (NIST) traceable radiometer to derive radiance versus temperature correction factors. A second thermal camera is used to map spatial gradients in the surface of each blackbody, although no gradients (+/- 0.001 degree) have yet to be measured. The final adjustments (if any) will be measured before flight and provided as part of the general metadata. In-flight measurement and monitoring of the blackbodies is performed through the use of platinum Resistance Temperature Detectors (pt-RTDs) mounted on the backside of each blackbody. Five pt-RTDs are spatially distributed across each blackbody to accurately capture the temperatures, which are then downloaded as part of the spacecrafts state-of-health metadata. The ground calibration process updates the measured blackbody temperatures approximately once every minute. The spacecrafts HBB is electrically heated with an expected constant nominal temperature of about 319 degrees Kelvin throughout the mission. The spacecrafts CBB is not explicitly managed and is allowed to drift with changes in the circulating fluids as affected by ISS activities and external space weather. The nominal range of drift is expected to be +/-0.5K over a period of days. The nominal pre-launch CBB is 293 degrees Kelvin, but could vary by +/-5K once fully configured with the ISS. The In-flight calibration process should easily correct for drift and provide for an overall thermal calibration stability and accuracy of better than 0.050K.

Spectral Measurements

A set of spectral response functions was acquired during ground operation. This data is required to fully understand the radiometric behavior ot the payload, since sampling of the Planck function isn't linear and depends on the center wavelength position and bandwdith of each individual filter. A full aperture target projector was placed in front of the NADIR baffle of the payload. The collimator has a 10" diamter output and is adequate to completely fill the field of view. The field of view of the optical scanner swept the projection of the collimator. A grating monochromator coupled to a high temperature blackbody was placed at the focal point of the collimator. The blackbody stimulus was separated into various spectral components and projected out of the collimator. This was then captured by the payload and saved for later interpretation. The spectral response of the system is shown in Figure 6. The full width half max shape of each the Gaussian defines the bandwidth of each spectral channel, while the centroid of each shape defines the center wavelength of each bandwidth.

Radiometric Measurements

A full aperture blackbody was positioned in front of the NADIR baffle of the payload. This was to verify the payload's response to external stimulus which mainly simulates ground targets of near unity emissivity. The two calibrated Blackbody temperatures are converted to spectral radiance using the center wavelength of each TIR band in the Planck function. The Planck function converts blackbody temperatures (K) to spectral radiance. The function is described by:

$$\mathbf{L}(\lambda, \mathbf{t}) = \frac{c_1}{\lambda^5(e^{\frac{c_2}{\lambda t}}) - 1} \tag{1}$$

where

- L(λ,t) = blackbody radiance (W/m$^2 - sr - \mu$ m)
- c_1 = 1.191042x10^8 (W/m$^2 - sr - \mu m^{-4}$)
- c_2 = 1.4387752x10^4($K\mu$m)
- λ = wavelength (μm)
- t = blackbody temperature (K)

Given the FPA radiance values and the corresponding FPA DNs for both the cold and hot blackbodies, it is possible to perform a two-point affine transformation that converts each unique input pixel DN from the focal plane directly to radiance. Dark current and basic FPA artifacts are implicitly corrected in the process. The linearity fit between the two blackbodies for each pixel are output as gain and offset terms.

However, for validation purposes a number of test images were converted from DN to radiance and brightness temperature (Kelvin) to verify their accuracy is within 1 degree (at 300K). The conversion from radiance to temperature is performed using the inverse Planck Function:

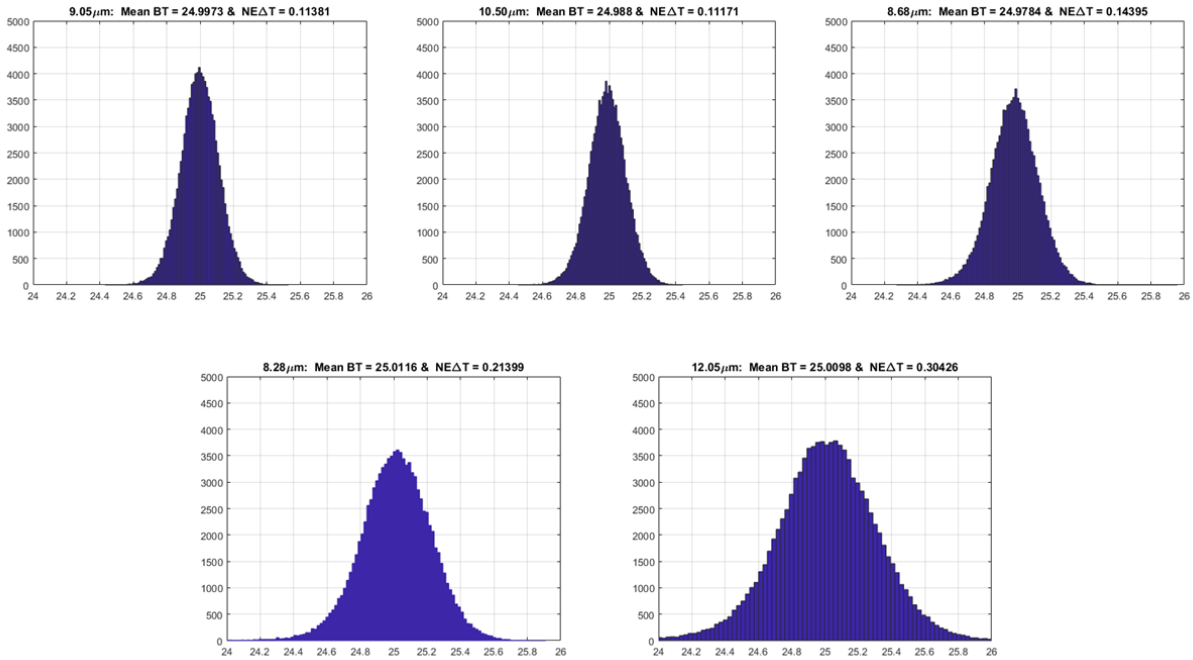

Figure 7. Set of laboratory NEΔT histograms for all the pixels in the field of view for each spectral channel. The label on the top of each histogram indicates the wavelength, mean brightness temperature and noise equivalent delta temperature.

$$\mathbf{t}(\lambda, \mathbf{L}) = \frac{c_2}{\lambda ln(\frac{c_1}{\lambda^5 L} + 1)} \tag{2}$$

where

- t(λ,L) = blackbody temperature (K)
- L = blackbody radiance (W/m$^2 - sr - \mu$ m)
- c_1 = 1.191042x10^8 (W/m$^2 - sr - \mu m^{-4}$)
- c_2 = 1.4387752x10^4($K\mu$m)
- λ = wavelength (μm)

Figure 7 shows measurements made while imaging a 25C blackbody for all five science channels. All the pixels are placed in a histogram after conversion to brightness temperature from equation 2. The shape of the histogram takes into account both the spatial radiometric noise as well as the temporal noise derived by capturing scenes over the length of an image acquisition. As expected three of the channels (8.68μm, 9.05μm, and 10.5μm) all have performance better than 150mk, while the 8.28μm and 12μm have performance of 300mk better. The BT derivations are all well within specification at 25C scene temp.

Spatial Measurements

A full aperture target projector was positioned in front of the NADIR baffle to verify the systems modulation transfer function (MTF). Various transmissive targets (slit, 1951 Air Force resolution test chart) were used to verify the spatial performance along both the sagittal and tangential planes. The full aperture (10" diameter) blackbody edge function projector provides 4.18X demagnification for a target placed at infinity. The target sizing allowed an edge response function to be acquired over the full field of view. The edge spread functions were converted using standard fast Fourier transform (FFT) techniques into modulation transfer functions which then allowed two orthogonal spatial frequency metrics to be determined. An example measurement is shown in Figure 8. This is a whole MTF measurement, but it's thought the dominate component is the optics based on previous results.

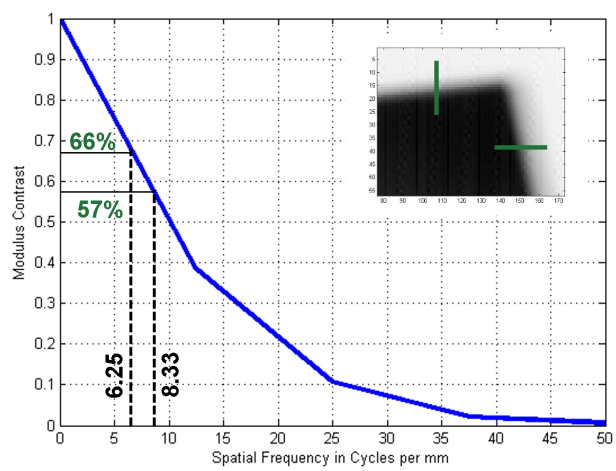

Figure 8. MTF measurement of ECOSTRESS payload for spatial frequency verification

In addition to the along and cross track FFT technique, a resolution chart was imaged to verify the contrast using the formulation given by:

$$\mathbf{M_{6.25}} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = 66\% \tag{3}$$

$$\mathbf{M_{8.33}} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = 57\% \tag{4}$$

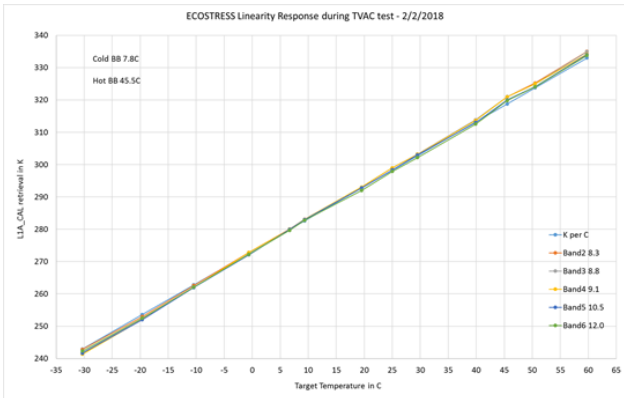

Figure 9. An external blackbody was cycled though a series of temperature. Plot of BT vs. scene temp shows the linearity at sensor for each spectral band.

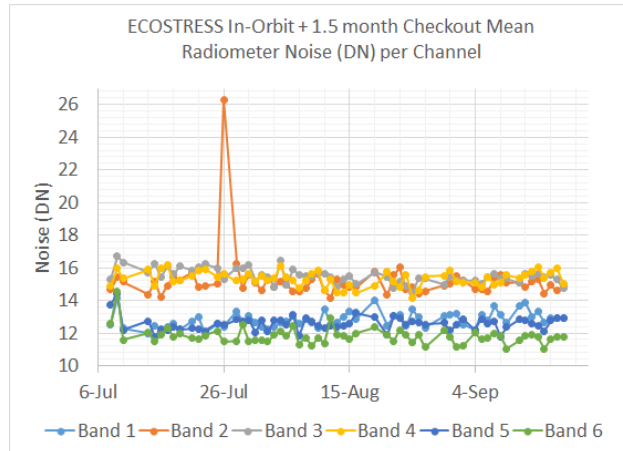

Figure 11. Detector noise counts on-orbit while observing the cold blackbody is show for the first 2.5 months of operation.

where

- M_X = is the modulation at spatial frequency X
- A_{max} = maximum radiance at peak
- A_{min} = minimum radiance at trough

4. Thermal Vacuum Measurements

After extensive end-to-end clean room radiometer testing, the payload was brought to the 10' thermal vacuum (TVAC) chamber at the JPL Environmental Test Laboratory (ETL) for complete space-like simulation. The chamber is large enough to fit the entire payload including two additional external (but still in vacuum) calibration targets. The targets are simulated blackbodies which can be heated, so their surface emission is adjustable. This allowed the calibration to be performed over an extensive range of temperatures (scene temperature from -30C to 60C). Obtaining the low end temperatures outside the chamber isn't practical, since the surface would be contaminated by water/ice build up. This layer would lower the surface emissivity hence causing linearity errors. The front surface of each calibration target is painted, so build-up would also potentially cause cracks to form.

Before installing the payload in the chamber, the small temporary vacuum housing built into the radiometer was opened up, since it's no longer needed in the larger vacuum chamber. This converted the small vacuum housing on the back side of the instrument to a contamination enclosure. There's a physical mesh to trap particles outside the contamination enclosure and keep them from leaking in and depositing on the cold focal plane surface. A similar set of radiometric tests were performed to verify system performance. In TVAC, the payload was transitioned through a larger set of temperatures to also verify the temperature linearity response. A plot of the linearity is shown in Figure 9, while the NEΔT curves are shown in Figure 10. These curves compare favorably to the previous set obtained outside of TVAC. In fact, some additional improvement is seen. This may be caused by the background room being removed and replaced with the space environment.

5. In-Orbit Checkout

ECOSTRESS was installed in position 10 of the JEM-EF module on the ISS. In-orbit checkout started soon after. Within a week, the focal plane was cooled down to its nominal operating temperature of 65K. The scan mirror was commanded into motion and the encoder counts checked to confirm accurate mirror spinning operation. Telemetry data is down linked and continuously monitored to confirm all temperatures and currents are working within their specified ranges. Science data acquisition was captured primarily over the planned ground calibration targets (Lake Tahoe, Salton Sea, Russell Ranch, as well flux towers outside California). This allowed the calibration and validation team to start assessing the preliminary performance on-orbit.

A set of plots presented here are mainly used to assess the stability of the playload during in-fight operation. The metrics are all related to the calibration stability. The raw noise counts are monitored for each spectral band. The counts are pre-radiometric conversion and would be considered a Level 0 product. The least noise is found consistently by observing the cold blackbody. The cold blackbody also is shielding from the NADIR view. The noise measured is made up from the detector dark current noise, background radiation (shot noise) from warm objects, and readout noise. An anomaly was seen around July 26th which cleared up after a FPA restart. This set of data is shown in Figure 11. The second metric observed is related to the blackbody stability. This data confirms the blackbody thermal stability isn't affected by external sources and the mounting has isolated the targets in-flight. The stability is shown in Figure 12. The along-track gradient on the front surface of the blackbody is also observed. A very small settling time is being observed most likely due to the black silicon material stack up. Although there's still settling going on, the absolute size of the slope is three orders of magnitude below the 0.5C absolute temperature retrieval so it's not expected to be a concern.

6. Concluding Remarks/Summary

ECOSTRESS was selected in 2014 as a NASA Earth-Ventures Instrument (EV-I) Class-D mission for operation on the International Space Station (ISS). It was a cost-capped mission with a rapid 3-year development cycle and 13 month on-orbit operation. It benefited greatly by having a previously developed imaging radiometer instrument named PHyTIR. The precursor instrument was funded by NASA's ESTO IIP.

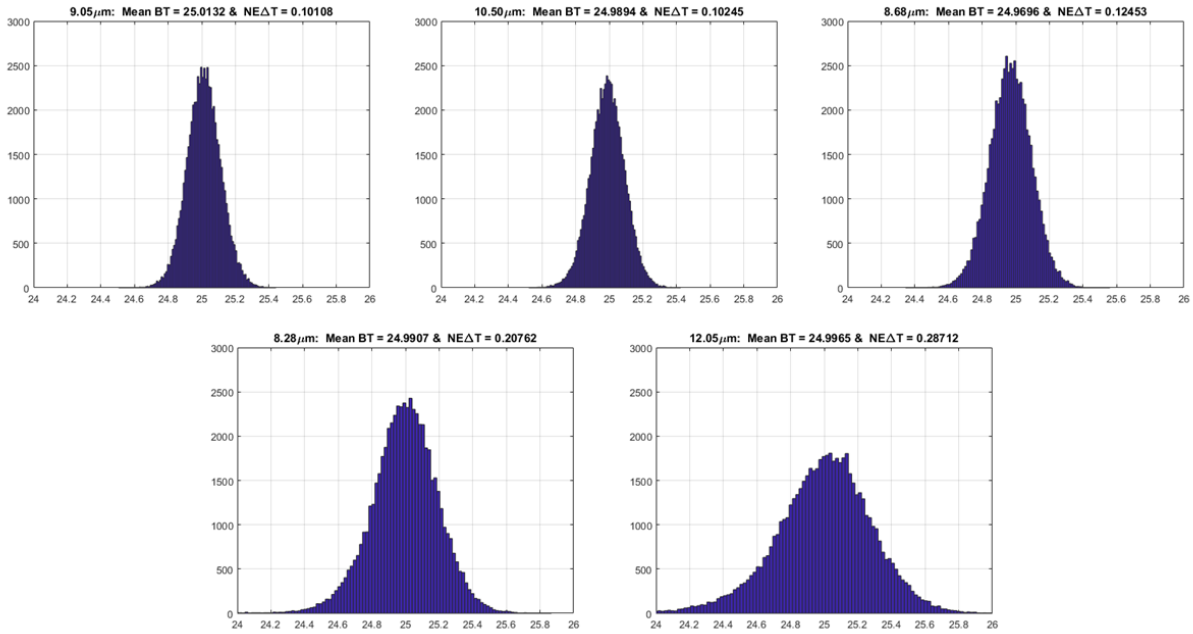

Figure 10. Set of TVAC NEΔT histograms for all the pixels in the field of view for each spectral channel. The label on the top of each histogram indicates the wavelength, mean brightness temperature and noise equivalent delta temperature.

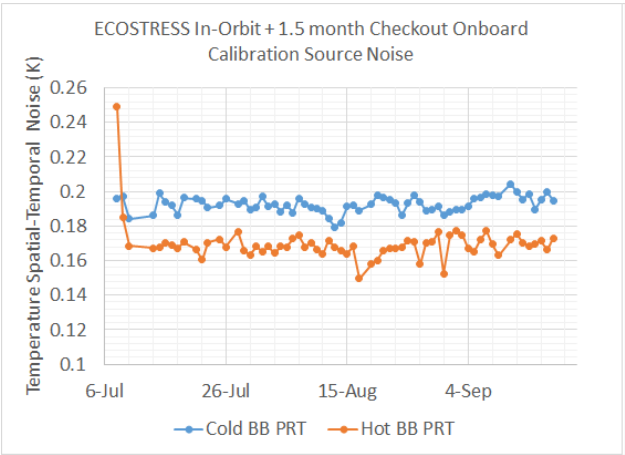

Figure 12. Blackbody temperature stability on-orbit for the first 2.5 months of operation.

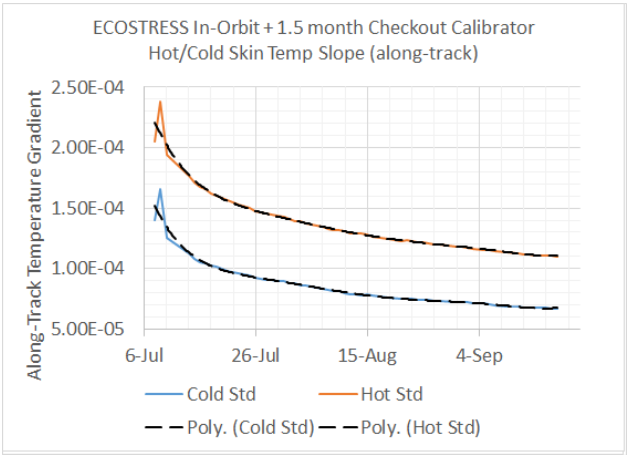

Figure 13. Along track settling of the blackbody skin temp during the first 2.5months of operation.

After completing integration and testing in a clean room environment, ECOSTRESS was calibrated pre-flight in the laboratory as well as in a space-like environment. It met expectations in terms of noise and spatial performance. It was granted permission to fly and was installed on the ISS to support future science investigations concerning the terrestrial biosphere and agricultural vulnerability. Current on-board performance is nominal with the calibration equivalent to what was observed on the ground before shipping to KSC. Noise performance shows three of the thermal bands below 150mk NEΔT, while the other two are below 300mk. First light was acquired the night of July 9 over Egypt. During the first three months, nearly 44000 scenes have been captured with three official NASA press releases [1]. Figure 14 is an example of an on-orbit daytime data acquisition over the Nile region of Africa during Orbit 706. Images from three spectral bands are used to form a color composite image. The image has undergone a moderate color enhancement stretch to bring out the surface geology, water regions, and cloud cover.

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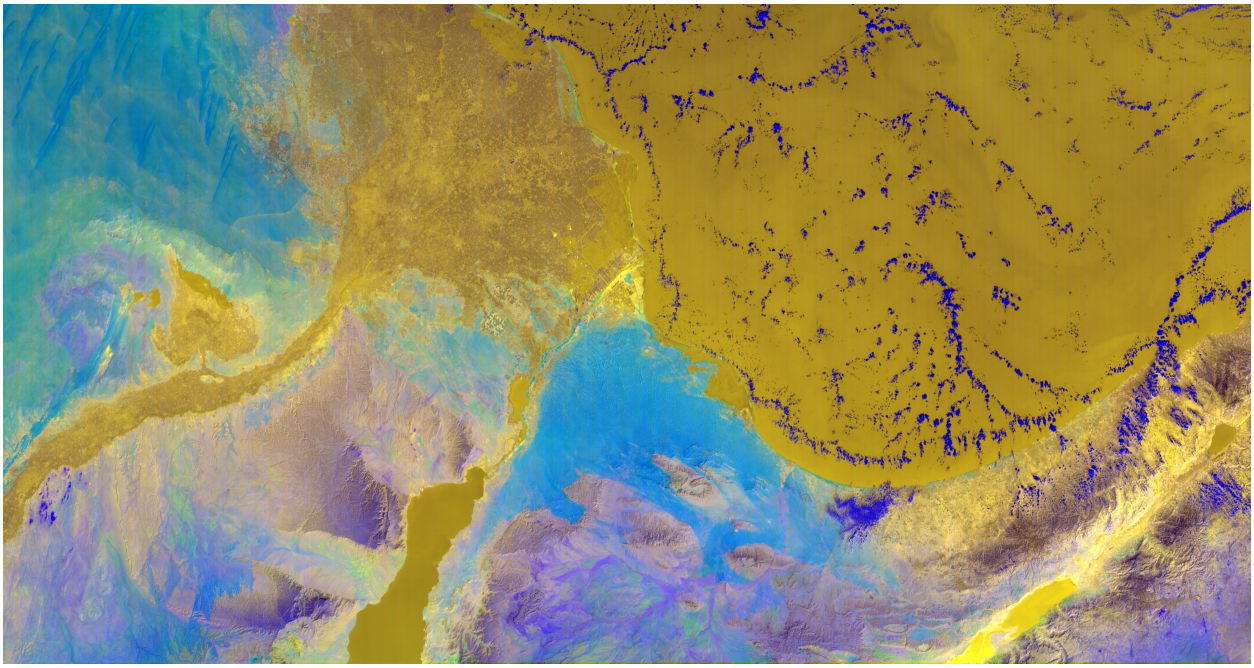

Figure 14. **ECOSTRESS color composite image taken from Orbit 706 over the Nile area. Enhancement stretch used to bring out geology, water regions, and clouds cover.**

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BIOGRAPHY

William R. Johnson *has nearly 15 years of experience at JPL. He has built, calibrated, and deployed numerous optical systems from the visible to thermal infrared. He was the lead engineer for the airborne Hyperspectral Thermal Emission Spectrometer (HyTES) optical design, system engineering and integration and test functions. He led the optics, detector and calibration development for the ECOSTRES. His main areas of expertise include optical design, IR remote sensing, imaging spectroscopy and general optical alignment and calibration techniques.*

Simon J. Hook *received his B.Sc. in 1982 from the University of Durham, England, M.Sc. in 1985 from the University of Edmonton, Canada, and PhD., in 1989 from the University of Durham, England all degrees were in geology. Simon Hook is the manager of the Science Division at the Jet Propulsion Laboratory. He was the Principal Investigator for ECOSTRESS. His research is focused on improving our understanding of geologic, hydrodynamic and ecologic processes on planets. He is currently studying large lakes and wildfires on Earth. He also applies his knowledge of terrestrial geologic processes to other planets, in particular Mars.*