

Terrestrial Applications of the Thermal Infrared Sensor, TIRS

Ramsey L. Smith, Kurtis Thome, Cathleen Richardson, James Irons, Dennis Reuter

NASA Goddard Space Flight Center

Greenbelt, MD, USA

Ramsey.L.Smith@nasa.gov, Kurtis.Thome@nasa.gov, Cathleen.M.Richardson@nasa.gov,

James.R.Irons@nasa.gov, Dennis.C.Reuter@nasa.gov

Abstract - Sensors on Landsat satellites have acquired single-band thermal images since 1978. The next satellite in the heritage, Landsat Data Continuity Mission (LDCM), is scheduled to launch in December 2012. LDCM will contain the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), where TIRS operates in concert with, but independently of OLI. This paper provides an overview of the remote sensing instrument TIRS. The TIRS instrument was designed at National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC) where it will be fabricated and calibrated as well. Protecting the integrity of the Scientific Data that will be collected from TIRS played a strong role in definition of the calibration test equipment and procedures used for the optical, radiometric and spatial calibration. The data that will be produced from LDCM will continue to be used worldwide for environment monitoring and resource management.

Keywords: Thermal Infrared Sensor, Landsat Data Continuity Mission, quantum well infrared photodetector, land resource management, terrestrial spacecraft.

1 Introduction

For over 30 years the Landsat satellite program has provided an extensive archive of global high-resolution, highly calibrated, multispectral data of Earth's landmasses. Since 1978, Landsat satellites have also acquired single-band thermal images. The Landsat Data Continuity Mission (LDCM) is scheduled to launch in December 2012 and it will be a polar orbiting satellite. LDCM will contain the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), where TIRS operates in concert with, but independently of OLI.

The intent of this paper is to give an overview of the TIRS instrument and its benefit to the remote sensing community. TIRS passed its Preliminary Design Review (PDR) and it will be delivered in December 2011. The PDR served as a medium for the TIRS subsystems to demonstrate that their preliminary designs met the mission requirements with acceptable risk and within the cost and schedule constraints. The TIRS Critical Design Review (CDR) will take place in early March of 2010.

TIRS is a two channel, 10.8 and 12 μm , thermal imager that was developed at GSFC. Its purpose will be to provide data continuity for the Landsat thermal band. It will produce radiometrically calibrated, geo-located thermal image data. Data products from TIRS will benefit the global community, from agriculture to public health. The data from TIRS and OLI will be processed and merged into a single data product by the United States Geological survey (USGS)/Earth Resources Observation and Science (EROS) facility.

2 TIRS Data Uses

Landsat data products are used worldwide for environment monitoring and resource management. Some of these applications include volcano surveillance, public health vector monitoring, fire-induced vegetation depletion and urban heat island evaluations. These data products are usually not measured directly, however, they are derived from computational models and image analysis. For instance, one area in which TIRS can contribute is in the area of energy budget studies. The net radiation can be written as:

$$R_{\text{NET}} = G + ET + H \quad (1)$$

$$R_{\text{NET}} = (SW_{\text{dn}} - SW_{\text{up}}) + (LW_{\text{dn}} - LW_{\text{up}}) \quad (2)$$

where R_{NET} is the net radiation of Earth. Both thermal and shortwave observations are required to calculate R_{NET} . G is soil heat conduction flux. H is sensible heat, and ET is latent heat taken to be represented by the evapotranspiration from a vegetated area. The ET is also related to the leaf-area index which is the ratio of total upper leaf surface of vegetation divided by the surface area of the land where the vegetation resides. LW_{dn} is the downwelled thermal infrared radiation. SW_{up} is the shortwave upwelled radiation and SW_{dn} is the shortwave downwelled radiation. Shortwave observations are required to calculate the leaf area index, attenuation of R_{NET} through the canopy of vegetation and the fraction of cover.

OLI data are required to calculate the shortwave albedo. TIRS data are required to calculate the upwelled thermal infrared or upwelled thermal longwave radiation, LW_{up} , from the surface temperature.

Landsat thermal data are currently used operationally to monitor water consumption on a field-by-field basis in the western states of the United States of America and internationally. This is allowed by the development of operational energy balanced-based evapotranspiration models, such as METRIC (Mapping Evapotranspiration with High Resolution and Internalized Calibration) [1]. Evapotranspiration cools vegetation and therefore shows a temperature difference between the various surfaces in the landscape frame.

Urban heat islands can be examined by comparing the net solar radiation absorbed by different surface categories and by following their transformations through different forms of thermal energies in an attempt to establish energy balance [2]. Examples of these surface categories are bare soil, forest areas, urban areas and bodies of water. Maps of sensible heat flux can be produced from data derived from TIRS.

Remote sensing thermal infrared data has been used to monitor and document active volcanoes for over 20 years. TIRS will be an additional spaceborne resource for remote sensing capability of volcanic surveillance. This is important for monitoring volcanic activity in developing countries and in remote locations. The data products will aid in mapping volcanic products and thermal volcanic features. Some of the volcanic features include volcanic craters, crater lakes and domes [3].

Monitoring fire-induced vegetation depletion can produce burnt area mapping which will lead to wildfire risk assessment and will provide an accurate account of fire severity [4]. Vegetation index, VI, is one of the variables used to determine vegetation depletion and it can be derived from thermal data provided by TIRS. Plant water content is confirmed as a key parameter in monitoring forest depletions [5].

Over the past few decades, researchers have used remote sensing data to assess environmental factors that promote disease transmission, disease vector production and the risk for human-vector contact. Some of these environmental factors include crop type, soil moisture and deforestation [6]. Public health concerns can be tracked by the aforementioned environmental factors to identify vectors associated with vector borne diseases, such as malaria and Lyme disease. These variables will be effectively mapped with the data derived from TIRS.

3 Instrument

TIRS will deliver radiometrically corrected data from two thermal channels, 10.8 μm and 12 μm , that are geometrically registered and geodetically located. Other missions have integrated thermal infrared instruments into their payload including the High Resolution Infrared Sounder (HIRS) [7], the Advanced Very High Resolution

Radiometer (AVHRR) [8], and the Moderate Resolution imaging Spectroradiometer (MODIS) [9]. The higher resolution of TIRS, at least 120-meters, will provide data that will improve thermal imaging information content and environmental monitoring when compared to the aforementioned instruments, see Figure 1.



Figure 1. An infrared image of the Middle Rio Grande near Albuquerque, NM. Landsat image is on the left and the MODIS image is on the right.

3.1 Instrument Design

LDCM has been designed to have a two-instrument payload, OLI and TIRS. Figure 2 shows the configuration of both instruments integrated on the Landsat spacecraft. An ATLAS V – Evolved Expendable Launch Vehicle (EELV) will launch the LDCM spacecraft into orbit.

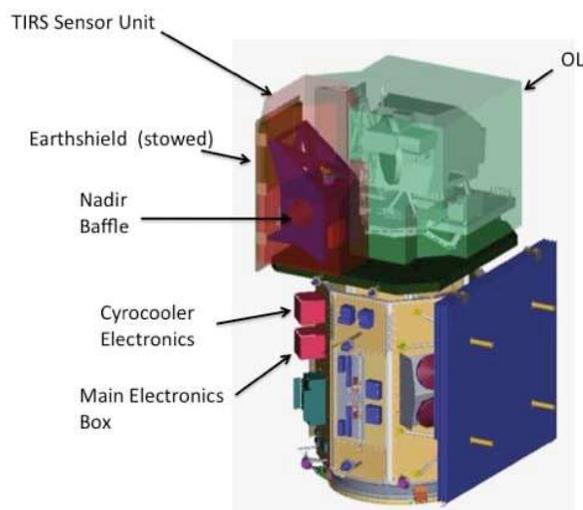


Figure 2. Instrument payload diagram of the Landsat Data Continuity Mission satellite.

The TIRS design is a product of the NASA Goddard Space Flight Center (GSFC), and the instrument will be built at GSFC.

The infrared radiation from the Earth or the onboard calibration source will traverse the optical path to be focused on the detector using the telescope assembly. The scene select mechanism and mirror are along the optical path and they will allow for the instrument to change the view from the nadir baffle to view the target planet Earth, to view one of the two calibration sources (Figure 3). The power, mechanical control and the thermal control will be conducted through the onboard TIRS electronics package.

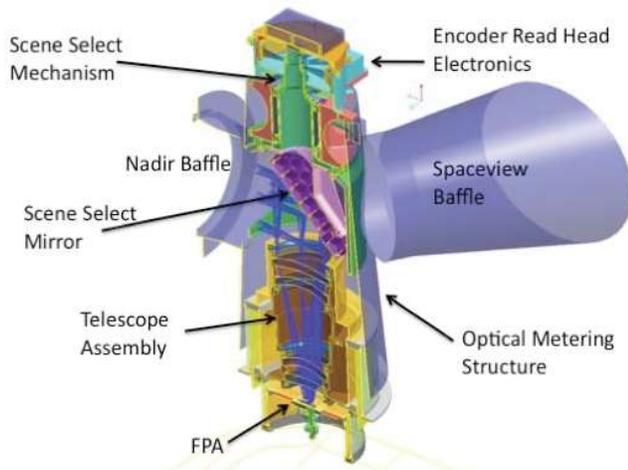


Figure 3. TIRS unit internal view.

3.2 Instrument Specifications

TIRS instrument components have been specified to meet the science goals of the LDCM mission. Instrument components include the focal plane array, the telescope assembly, the scene select mechanism/mirror, the onboard calibrator, the cryocooler which cools the focal plane to 43 K, thermal control radiators and the data collection and instrument control electronics. Figure 3 displays a cross section of the TIRS optical path.

The telescope assembly has four lenses, one lens composed of zinc selenide, ZnSe, and the other three composed of germanium. The passively-cooled telescope assembly is designed to operate at 180 K. The detector sensor on the instrument will be a quantum well infrared photodetector (QWIP) focal plane array (FPA) [10], which will be connected to the bottom of the telescope assembly.

The QWIP focal plane array is a 3-sensor chip assembly built by GSFC, Figure 4. It is actively cooled by a cryocooler to an operating temperature of 43 K. The instrument's two spectral bands are achieved through interference filters that cover the FPA.

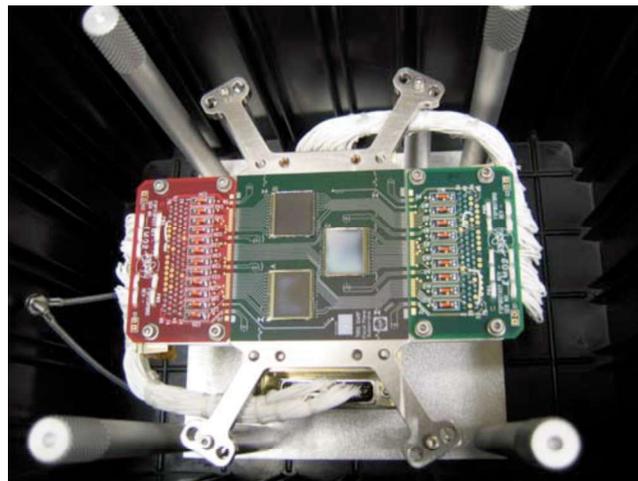


Figure 4. Fully assembled and operational QWIP focal plane assembly.

The precision scene select mirror is an essential component of the TIRS instrument and it is driven by the scene select mechanism. It rotates around the optical axis on a 45-degree plane to provide the telescope with a view of Earth through the nadir baffle and with two full aperture calibration views, the onboard variable temperature blackbody (hot calibration target) and the space view (cold calibration target). The onboard blackbody will be a National Institute of Standards and Technology (NIST) traceable reference source. The output from the onboard calibrator will be capable of providing source levels between 270 and 330 K.

TIRS operates in pushbroom mode to provide a 185 km ground swath (15° field of view). This method will have the benefit of being able to collect and record data without movement artifacts due to its wide instantaneous field of view. It also allows increased sensitivity. Frames will be collected at an operating cadence of 70 per second. TIRS is a high resolution IR sensor with a resolution that is less than 120 m. The collected data will be stored temporarily onboard and periodically sent to the USGS EROS facility for calibration, georectification and archiving. The instrument is designed to have an expected lifetime of at least a three-years.

4 Calibration

During the ground calibration testing, TIRS performance will be measured at the component, subsystem and system level. Our responsibility is to provide an instrument that is well calibrated, well characterized with specification compliant data that will ensure the data continuity of Landsat from the previous missions to the present. System-level radiometric and image quality is assessed during testing in a thermal/vacuum chamber using NIST traceable calibration equipment specifically designed for TIRS.

Calibration testing will take place in a vacuum test chamber at NASA GSFC. A clean tent covering the door opening provides a Class 10,000 clean area for integrating hardware prior to loading it into the chamber. The TIRS Calibration System, TIRSCS in Figure 5, will allow for optical, radiometric and geometric calibration of TIRS. MEI Technologies and ATK Corporation manufactured and supplied the specified calibration package.

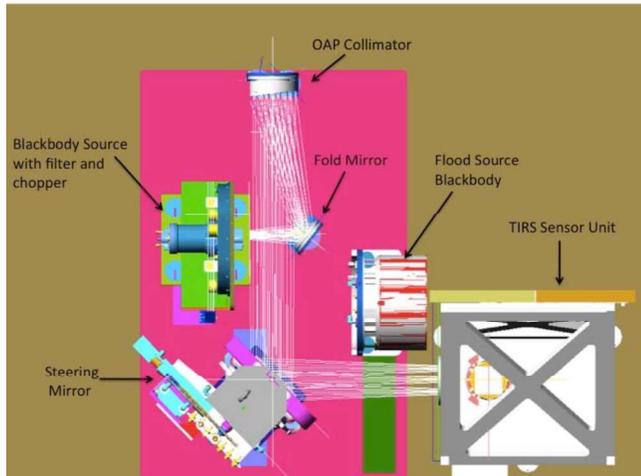


Figure 5. TIRS calibration system.

TIRS will implement two types of sources in the thermal vacuum chamber and one source outside of the chamber. The first source is a NIST traceable blackbody capable of operating at temperatures from 100 to 800 K. The output flux from the blackbody will pass through any one of 16-target apertures. The output flux can then pass through any of 9 neutral density filters to provide a target with high radiometric accuracy. The targets are at the focal point of an off-axis parabola (OAP) to provide a collimated source that can be placed anywhere in the TIRS field of view (FOV) by using a two-axis steering mirror. The second source will be the uniform flood source placed on a linear translation stage, which can move the flood source in and out of the FOV of TIRS. A monochromator source will be located outside of the chamber and its output will be transmitted to the test article through a ZnSe window. The spectrometer output can be placed at the focal point of the internal OAP by a pick-off mirror. All acceptance testing and calibration of the functional performance model (FPM) of the TIRS instrument is performed at NASA GSFC.

Data collected during calibration will validate the various instrument systems and component models. Spectral data will be collected under simulated on-orbit thermal conditions in vacuum with the focal plane and telescope at operating temperature. During thermal vacuum tests, the spectral response will be determined for each band to verify stability and spectral performance. The TIRS calibration team will provide real-time data collection and visualization of the calibration tests. All of the outputs

from the test will be saved to the appropriate media to allow for detailed post-test analysis by the science team.

5 Conclusions and Future Plans

The global community depends on Landsat data for environment monitoring and resource management. Every detail of LDCM and the TIRS instrument reflects its meticulous design and commitment to provide quality scientific data. The TIRS Instrument will be well calibrated, and well characterized to ensure the data continuity of Landsat from the previous missions to the present.

The next stage in the evolution of TIRS is the instrument Critical Design Review (CDR). The objectives during CDR are to demonstrate that TIRS is on schedule to meet mission requirements and that the maturity of the project is appropriate to continue with fabrication, assembly, integration, and test. In preparation for the CDR, the calibration team will continue the system level characterization of the FPM and prepare for the future characterization of the flight instrument.

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