The Thermal Infrared Sensor on the Landsat Data Continuity Mission

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ABSTRACT

The Landsat Data Continuity Mission (LDCM), a joint NASA and USGS mission, is scheduled for launch in December, 2012. The LDCM instrument payload will consist of the Operational Land Imager (OLI), provided by Ball Aerospace and Technology Corporation (BATC) under contract to NASA and the Thermal Infrared Sensor (TIRS), provided by NASA's Goddard Space Flight Center (GSFC). This paper outlines the design of the TIRS instrument and gives an example of its application to monitoring water consumption by measuring evapotranspiration.

Index Terms— TIRS, LDCM, evapotranspiration

1. INTRODUCTION

As is implied in the mission name, one element of the LDCM project is to provide continuity with past Landsat sensors. Another element is to provide improvements in sensors where possible. The Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), and Enhanced Thematic Mapper Plus (ETM+) sensors are good examples of this philosophy as the thermal infrared band improved in spatial resolution from 120 to 60 m for the single-band, whiskbroom-approach systems (See [2] and references therin). While such data have proved important in providing land-use information, volcanic and fire-monitoring data, and resource management guidance, a dual-band sensor at lower spatial resolution but with improved sensitivity would maintain continuity and provide valuable data for water resource management and agricultural studies.

TIRS on LDCM is a 100 meter (120 meter requirement) spatial resolution push-broom imager whose two spectral channels, centered at near 10.8 and 12 microns, split the spectral range of the single TM and ETM+ thermal band while still providing thermal band data continuity with previous Landsat missions. The push-broom implementation increases system sensitivity by allowing longer integration times than whiskbroom sensors. The two channels allow the use of the "split-window" technique to aid in atmospheric correction. The TIRS focal plane operates near 43 K and consists of three Quantum Well Infrared Photodetector (QWIP) arrays to span the 185 km swath width [5]. Infrared filters are used to define the spectral coverage of the two channels. The imaging telescope is a 4-element refractive lens system. A scene select mechanism (SSM) rotates a scene mirror (SM) to change the field of regard from a nadir Earth view to either an on-board blackbody calibrator or a deep space view. The blackbody is a full aperture calibrator whose temperature may be varied from 270 to 330 K. Figure 1 shows a model of the TIRS sensor unit with the major elements identified.

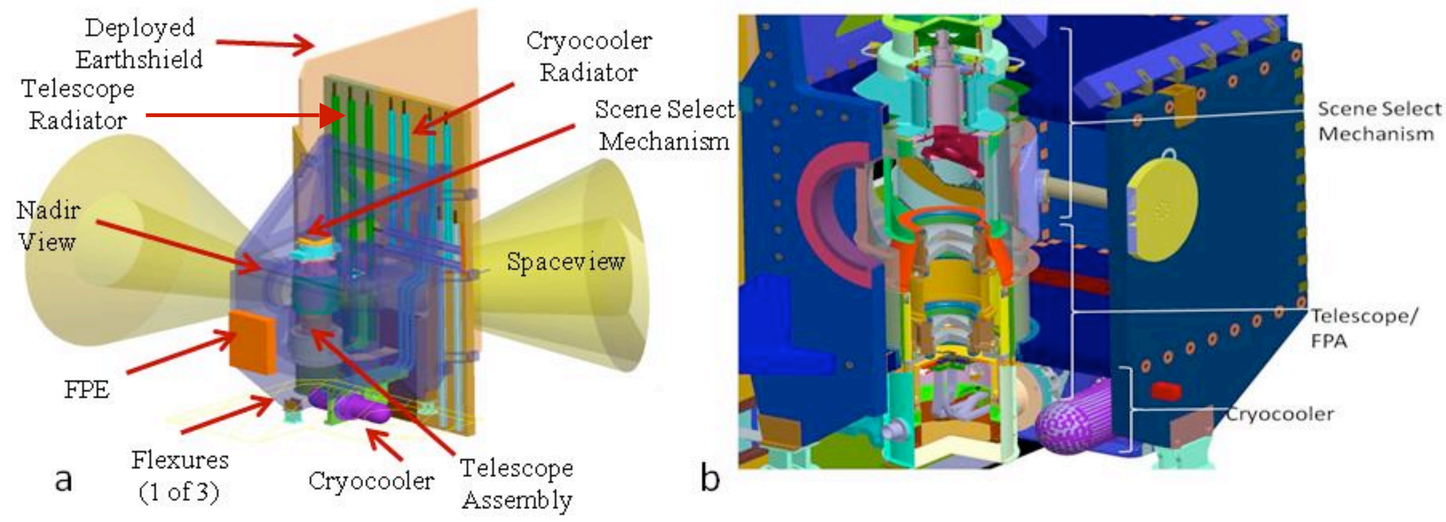

Figure 1: a) Model of the TIRS instrument showing the major components of the TIRS sensor. The scene select mechanism rotates the field of regard from the Earth view to either the spaceview or to the on-board calibrator. b) Detail of optical system showing the 4-element lens, a cut-away view of the SM and the thermal strap connecting the FPA to the cryocooler cold tip. The MEB and the CCE (not shown) are mounted to the spacecraft.

2. TIRS DESIGN OVERVIEW

In a pushbroom instrument, an n row by m column 2-D image of a scene is built-up by concatenating n successive single row measurements each containing m pixels. For TIRS on LDCM, with its 185 km swath width and 100 meter ground sample distance, a single row consists of 1850 pixels (m=1850). Because the orbital motion of the LDCM spacecraft is about 7 km/sec it takes approximately 0.014 second to move the row by 100 meters, and 70 rows of 1850 pixels are read out every second in both thermal channels.

The f/1.64, 178 mm focal length TIRS optical system, consisting of a lens with three Ge elements and one ZnSe element, produces nearly diffraction-limited images at the focal plane. All but 2 of the surfaces are spherical, which simplifies fabrication. The optics are radiatively cooled to a nominal temperature of 185 K to reduce the contribution of background thermal emission to the measurement noise. Because of the fairly strong thermal dependence of the index of refraction of Ge, the focus position of the lens is a function of the optics temperature. This provides a method of adjusting focus so that, in the unlikely event that launch conditions or some other effect defocus the system, the temperature of the optics may be changed by ±5 K to refocus. That is, thermal control of the lens provides a non-mechanical focus mechanism. A +5 K change does not significantly degrade the noise performance.

The focal plane is made up of three 640 pixel x 512 pixel QWIP detector arrays. The QWIPs have 25µm pixels producing an IFOV of 142 µradian. The arrays are bonded to a single silicon interface board that supplies the electrical connections between the detector arrays and two printed circuit "daughter boards". These latter are connected to the focal plane electronics (FPE) by two cables. The FPE provides the clocks and biases to the arrays, and converts the analog image data from the detectors to digital data which it sends to the main electronics box (MEB). The MEB, in turn, sends the digital image data to the LDCM spacecraft for transmission to the ground. The MEB also supplies power and commands to the TIRS instrument; collects and distributes housekeeping data, such a temperatures, voltages and currents; provides thermal control for the various stages of the instrument including the optics, the blackbody calibrator and the scene mirror; and controls the position of the mirror as well as sending the position data to the spacecraft for transmission to the ground. To meet the requirement that the position of a pixel on the ground must be known to 18 meters (27 µradian), the SSM encoder position measurement is accurate to 10 µradian.

The focal plane assembly (FPA) consists of an invar "spider" which is bonded to the silicon interface board containing the QWIPs and on which the "daughter boards" are mounted. The invar filter plate on which the spectral filters are bonded is also attached to the invar "spider". The FPA is connected to the cold-tip of a two stage cryocooler that cools the arrays to less than 43 K. The "warm" stage of the cryocooler is used to cool a focal plane shield to about 85 K, further reducing the background thermal noise. The cryocooler and its associated control electronics (CCE) are supplied by BATC. Figure 2 shows a picture of the FPA

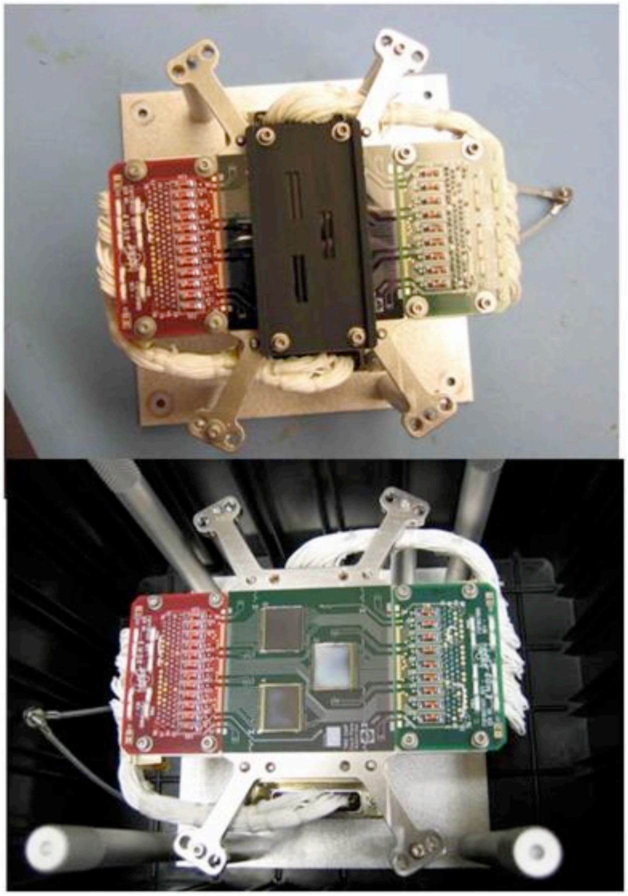

Figure2: Bottom) Picture of the FPA without the filters attached showing the 3 QWIPs in the center. The daughter boards are the red and green assemblies to the left and right respectively. The invar spider is the component with the 4 arms. Top) Picture of the FPA with the filters attached. Note that there are two filters over each array with a thin dark strip between them.

both with and without the spectral filters. As may be seen from this image the three QWIPs are in a staggered configuration. Each QWIP has two filters mounted within 300 μm of it. These filters produce two areas of 30 rows each with a spectral response corresponding to the 10.8 and 12 μm channels. There is an un-illuminated area of 20 rows between the two illuminated spectral areas. During data collection operations, two rows are read out from each of the three areas defined above for each array in each frame. That is, there are two rows of 10.8 μm data, two rows of 12 μm data and two rows of dark data read from each array at the 70 Hz frame rate. These data are all transmitted to the ground where they are geo-rectified and combined to produce 1850 pixel wide swaths of image data for each channel. This process ensures that the requirement that there be at most one inoperable pixel per row is met. It also allows for some performance optimization in the choice of pixels. In practice, most of the pixels in a given row of the QWIPs meet the operability requirements. The choice of rows can changed in flight, so that rows that contain a significant number of pixels whose performance degrades can be replaced.

In operation, the SM is usually pointed in the nadir direction. It is rotated by the SSM to view the blackbody calibrator and then deep space during calibration cycles, which occur about once every half orbit (~ 45 minutes). This allows for the correction of possible time variable offsets and gains. In order to meet the short term noise requirements of NEdT < 0.4 K for a 300 K target, and the requirement that there be less than 0.7% drift between calibrations, the temperatures of the FPA, the optics and the SM are stabilized by active control systems. The FPA temperature is controlled by the CCE. The optics and SM temperatures are controlled by the MEB. The MEB also actively controls the temperature of the blackbody calibrator to better than 0.1 K to meet the 2% absolute radiometric accuracy requirement for scene temperatures between 260 and 330 K. Because of the relatively long time between calibrations, the inherent temporal stability of the QWIP response is also very valuable in maintaining the radiometric stability. In addition as risk mitigation, if, in flight, the thermal stability of the FPA degrades, the dark pixels may be used to correct for noise arising from dark current variations.

3. CALIBRATION AND ALGORITHMS

Consistent with previous Landsat missions, LDCM TIRS will be fully calibrated prior to launch. Calibration measurements will be made at GSFC and will be done at the component, subsystem and instrument level. NIST-traceable instrument level calibration will be done using an in-chamber calibration system. A description of the TIRS calibration process may be found in [8].

TIRS algorithm development is being done in concert with the USGS and LDCM calibration validation and algorithm teams. The algorithms will be developed at GSFC, but the flight coding will be done by USGC/EROS. Since both TIRS and OLI are pushbroom sensors there is significant commonality in their algorithm requirements and structures. This commonality is taken being used to maximize parallel development. In addition, Landsat heritage algorithms are used when possible.

4. DATA USE EXAMPLE

TIRS will be operated in concert with, but independent of, OLI. Data from both instruments will be merged into a single data stream at the United States Geological Survey (USGS)/Earth Resources Observation and Science (EROS) facility. Among other uses, TIRS data will be used to

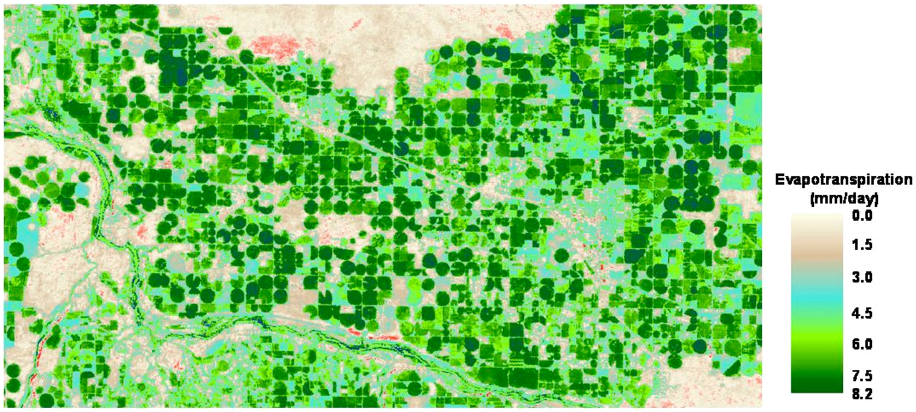

Figure 3: Evapotranspiration derived from from Landsat 5 data on July 22, 2006 from irrigated fields in the Thousands Springs area, Idaho. Round circles are center pivot irrigated fields 800 m in diameter.

measure evapotranspiration (evaporation from soil and transpiration from plants); to map urban heat fluxes, to monitor lake thermal plumes from power plants; to identify mosquito breeding areas and vector-borne illness potential; and to provide cloud measurements (see e.g. [7, 6, 3, 4]). The evapotranspiration data may be used to estimate consumptive water use on a field-by-field basis. Figure 3 shows an example of the evapotranspiration data product derived from Landsat 5 using the University of Idaho METRIC process [1].

5. CONCLUSION

TIRS is a thermal imager with two channels at 10.8 and 12 μm being developed at NASA/GSFC for delivery to LDCM by December, 2011. TIRS will provide thermal data continuity with previous Landsat missions, but its two channels will also provide new image analysis capability. Although being built in-house at Goddard with significant institutional support, TIRS development has also received active support from numerous parties including USGS, the LDCM project, The LDCM cal/val team, the Landsat Science Team and, of course, NASA HQ.

6. REFERENCES

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