This is the thermal band option addendum to the "Imagery Requirements" section of the Space Segment Requirements Document.

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Draft

Notes:
1) The imaging requirements have been renumbered after the release of the March 14, 2006 version currently on the LDCM web site. Prefix a "5." to the section numbers in the previously released imaging requirements to obtain the new section numbers, i.e., section 3.0 becomes 5.3.0 (or 5.3).
2) This document mirrors the structure of the previously released imaging requirements and in cases uses the same wording for the thermal option as for the reflective bands. Comments previously received on the reflective band imaging requirements have not been considered in the development of this document. They will be considered in the next release where they will also be considered for the reflective band requirements. If you have already made a comment on a corresponding section of the reflective band requirements, you do not need to repeat it here, unless it is peculiar to the thermal option.

5.8 LDCM Thermal Band Option Requirements

The requirements in this section are for a separate design and cost option as per 427-XXX, LDCM Space Segment Statement of Work.

5.8.1 LDCM Thermal Data Processing Algorithms

The requirements of Section 5.3, except 5.3.1.3, shall apply to the thermal bands.

5.8.2 LDCM Thermal Spectral Bands

The LDCM Observatory shall collect and transmit data for the thermal bands listed in Table 5.8.2-1.

5.8.2.1 Spectral Band Widths

5.8.2.1.1 Full-Width-Half-Maximum Points

The FWHM points of the relative spectral radiance response curve for each band shall fall within the range of the minimum lower band edge and the maximum upper band edge as listed in Table 5.8.2-1.

5.8.2.1.2 Center Wavelength

The center wavelength listed in Table 5.8.2-1 for each spectral band shall be located (within the associated tolerance listed in Table 5.8.2-1) halfway between the FWHM points of the actual relative spectral radiance response curve for each spectral band.

Table 5.8.2-1 Thermal Spectral Bands and Bandwidths

#	Band	Center Wavelength (nm)	Center Wavelength Tolerance (±nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)
10	Thermal 1	10800	100	10300	11300
11	Thermal 2	12000	100	11500	12500

5.8.2.2 Spectral Band Shape

5.8.2.2.1 Spectral Flatness

5.8.2.2.1.1 Flatness Between Band Edges

The system relative spectral radiance response between the lower band edge (lowest wavelength with 0.5 response) and the upper band edge (highest wavelength with 0.5 response) shall have the following properties:

5.8.2.2.1.1.1 Average Response
The average relative spectral radiance response shall be greater than 0.8.

5.8.2.2.1.1.2 Minimum Response
No relative spectral radiance response shall be below 0.4.

5.8.2.2.1.2 Flatness Between 0.8 response points
The system relative spectral radiance response between the minimum wavelength with a 0.8 response and the maximum wavelength with a 0.8 response point shall always exceed 0.7.

5.8.2.2.2 Out of Band Response
The ratio of the integrated relative spectral radiance response outside the 0.01 response points to the integrated response between the 0.01 response points shall be less than 2% between 3000 and 20000 nm and less than 0.5% below 3000 nm. The integrated responses will be weighted by the radiance from a 300K blackbody summed with the radiance from a Lambertian surface of 100% reflectance illuminated by the sun at a zenith angle of 30°. The 0.01 response points are the points closest to the center wavelength where the response first drops to 0.01 of the peak response on each side of the center wavelength. Electrical crosstalk is not included within this requirement.

5.8.2.2.3 Edge Slope

5.8.2.2.3.1 Wavelength Intervals – Case 1
The wavelength interval between the first 0.05 and the first 0.50 relative response points and the last 0.50 and the last 0.05 relative response points shall not exceed the values in Table 5.8.2.2.3-1.

5.8.2.2.3.2 Wavelength Intervals – Case 2
The wavelength interval between the 0.01 relative response points and the corresponding 0.50 response band edge shall not exceed the values in Table 5.8.2.2.3-1.

Table 5.8.2.2.3-1 Edge Slope Intervals for LDCM Thermal bands

#	Band	Lower Edge Slope Interval 0.01 to 0.50* (nm)	Lower Edge Slope Interval 0.05 to 0.50* (nm)	Upper Edge Slope Interval 0.50 to 0.05* (nm)	Upper Edge Slope Interval 0.50 to 0.01* (nm)
10	Thermal 1	300	200	200	300
11	Thermal 2	300	200	200	300

*Normalized to peak spectral response for the band

5.8.2.3 Spectral Uniformity
Within a band, all detector bandwidths shall be within ±5% of the mean bandwidth [TBR]. Additionally see Section 5.8.4.2.3.

5.8.2.4 Spectral Stability
Band center wavelengths and band edges shall not change by more ± 50 nm [TBR] over the life of the mission.

5.8.2.2.6 Spectral Band Simultaneity

5.8.2.2.6.1 All Spectral Band Simultaneity
For any point within a single scene observed by the LDCM, the LDCM shall acquire data for all spectral bands within a five-second period.

5.8.2.2.6.2 Thermal Band Simultaneity
The data for the two thermal bands shall be acquired within two seconds of each other.

5.8.3 LDCM Thermal Spectral Band Spatial Resolution

5.8.3.1 Thermal Bands Ground Sample Distance

Unprocessed LDCM digital image data shall provide a pixel-to-pixel increment equivalent to a GSD 90m or less (TBR) for both thermal bands across the WRS-2 scene.

5.8.3.2 Thermal Band Edge Response Slope
The mean relative edge response slope for the thermal bands in the in-track and cross-track directions (mean of slope between 40%-60%) shall exceed 0.006/meter across the entire Field-of-View.

5.8.3.3 Thermal Band Edge Response Overshoot and Aliasing
The requirements of 5.5.2.3 and 5.5.3 shall apply to the thermal bands.

5.8.3.4 Thermal Band Edge Response Uniformity
The mean relative edge response slope shall not vary by more than 10% (maximum deviation from the band average, 100%*(max - avg) / avg), in any band across the Field-of-View and by not more than 20% (maximum deviation from the two-band average) between the LDCM spectral bands 10 and 11 (thermal bands).

5.8.4 LDCM Thermal Spectral Band Radiometry

5.8.4.1 Absolute Radiometric Accuracy
The thermal band absolute radiometric uncertainty requirements are given in Table 5.8.4.1-1 with all uncertainties established relative to National Institute for Standards and Technology (NIST) standards. This requirement applies to extended, spatially uniform, unpolarized targets. Uncertainty estimates include the NIST standard uncertainties.

Table 5.8.4.1-1 Thermal Bands Absolute Radiometric Uncertainty Requirements [TBR]

Equivalent Blackbody Temperature Range	Radiance Uncertainty (1-sigma)
260 K – 330 K	2%
240K - 260K; 330K - 340K	4%

5.8.4.2 Radiometric Precision

5.8.4.2.1 Pixel Noise Equivalent Delta Temperatures

The median Noise Equivalent Delta Temperatures (NEΔT) required for each thermal band are listed in Table 5.8.4.2.1-1 and 5.8.4.2.1-2. Any pixel with an NEΔT greater than 1.25 times these values shall be considered out-of-spec per paragraph 5.6.7.4.

Table 5.8.4.2.1-1 Temperatures for Noise and Saturation for Thermal Bands

#	Band	Temperatures for NEΔT (K)		Saturation Temperatures (K)	Saturation Radiances (W/m^2 sr μm)
		Typical, $T_{Typical}$	High, T_{High}	T_{Max}	L_{Max}
10	Thermal 1	300K	320K	340K	16.4
11	Thermal 2	300K	320K	340K	14.5

Table 5.8.4.2.1-2 Noise Equivalent Delta Temperatures (NEΔT) and Radiances (NEΔL) for Thermal Bands [TBR]

#	Band	NEΔT Requirements		NEΔL Requirements (W/m^2 sr μm)
		At $T_{Typical}$	At T_{High}	At $T_{Typical}$, T_{High}
10	Thermal 1	0.4K	0.35K	0.059
11	Thermal 2	0.4K	0.35K	0.049

5.8.4.2.2 Quantization Noise Limit

Thermal band data NEΔT performance shall not be quantization noise limited at $T_{typical}$ and above, i.e., system noise is greater than or equal to 0.5 Digital Number, unless meeting this requirement would force greater than 12 bit quantization.

5.8.4.2.3 Pixel-to-Pixel Uniformity

The following environmental conditions and measurement approach shall apply to requirements 5.8.4.2.3.1, 5.8.4.2.3.2, and 5.8.4.2.3..

- The thermal band banding requirements shall apply to uniform sources with the radiance corresponding to a blackbody temperature above 260K and below 330 K.
- The thermal band radiometric values shall be corrected per paragraph 5.3.1.2.
- The thermal band temporal noise shall be averaged to verify compliance with this specification.

5.8.4.2.3.1 Full Field of View

The standard deviation of the radiometrically corrected values within a line of each thermal band shall not exceed 0.5% of the average radiance.

5.8.4.2.3.2 Banding (TBR)

a. The root mean square of the deviation from the average radiance across the full line for any 100 contiguous pixels within a line of radiometrically corrected values within a band shall not exceed 0.5% of that average radiance. See section 5.6.2.3.2a for the equation defining this banding parameter.

b. The standard deviation of the radiance across any 100 contiguous pixels within a line of radiometrically corrected data within a band shall not exceed 0.5% of the average radiance across the full line. The average radiance across the line (FOV) is used here merely as a reference for deriving the magnitude of the 0.5%. The mean in the standard deviation calculation is, by definition, the mean of the 100-pixel sample set and not the entire FOV mean. See section 5.6.2.3.2b for the equation defining this banding parameter.

5.8.4.2.3.3 Streaking

The maximum value of the streaking parameter within a line of radiometrically corrected, thermal band data shall not exceed 0.005[TBR]. See section 5.6.2.3.3 for the equation defining this streaking parameter.

5.8.4.2.4 Coherent Noise

The requirements of Section 5.6.2.4 shall apply to the thermal bands.

5.8.4.3 Saturation Temperatures

The thermal band shall detect, without saturating, signals from the noise floor (NEΔL in Table 5.8.4.2.1-2) up to the radiance corresponding to T_{Max} as shown in Table 5.8.4.2.1-1.

5.8.4.4 Radiometric Stability

Thermal band data for all pixels, after radiometric calibration per 5.3.1.2, for radiometrically constant targets with radiances greater than or equal to the radiance of a $T_{Typical}$, shall not vary by more than plus or minus 0.7%[TBR](1-sigma) of their radiance

over the time period between calibrations of the sensor. Pixels failing this specification are considered out-of-specification and are subject to the limitations of paragraph 5.6.7.4.

5.8.4.5 Image Artifacts

5.8.4.5.1 Bright Target Recovery [TBR]

The thermal band data shall be such that for an image pixel that has been exposed to a radiance level of less than or equal to 1.5 times that corresponding to a blackbody temperature of 340K, the pixels outside the 7 x 7 region around that pixel are not altered by more than 1% of their radiance at or above $T_{Typical}$.

5.8.4.5.2 Pixel-to-Pixel Crosstalk

The thermal band data shall be such that the electrical crosstalk-induced artifacts in pixels caused by regions of pixels having radiance levels less than the saturation level and which are more than ten pixels away shall not exceed 1% of the affected pixels' radiances at or above $T_{Typical}$, after radiometric correction.

5.8.4.6 Dead, Inoperable and Out-of-Spec Pixels

The requirements of 5.6.7 shall apply to the thermal bands.

5.8.5 LDCM Geometric Precision, Geolocation and Cartographic Registration

5.8.5.1 Thermal Band-to-Band Registration

Corresponding pixels from the two thermal bands in LDCM data that have been geometrically corrected, including compensation for the effects of terrain relief shall be co-registered with an uncertainty of 13.5 meters [TBR] or less in the line and sample directions at the 90% confidence level.

5.8.5.1.1 Thermal Band to Multispectral Band Registration

Corresponding pixels from the thermal bands in LDCM data that have been geometrically corrected, including compensation for the effects of terrain relief shall be co-registered to the LDCM multispectral bands with an uncertainty of 18 meters [TBR] or less in the line and sample directions at the 90% confidence level.

5.8.5.2 Thermal Band Image-to-Image Registration Accuracy

Two LDCM thermal band data sets of the same area, acquired on different dates, that have been geometrically corrected, including compensation for the effects of terrain relief, shall be capable of being co-registered by a lateral (line and/or sample) shift with no rotation or other distortion, with an uncertainty less than or equal to 30 meters [TBR], in the line and sample directions at the 90% confidence level when image-to-image correlation is applied to data from the same spectral band.

5.8.5.3 Thermal Band Geodetic Accuracy

Geometrically corrected LDCM thermal band data shall exhibit the geolocation accuracy defined in the following sections.

5.8.5.3.1 Thermal Band Absolute Geodetic Accuracy

The pixels for targets at the Earth's topographic surface in geometrically corrected LDCM thermal band data shall be located relative to the WGS84 geodetic reference system, G873 or current version, with an uncertainty less than or equal to 70 meters [TBR] (90% circular error*)*, excluding terrain effects. This specification applies to the horizontal error of ground control points measured in the processed image, after compensation for control point height.

5.8.5.3.2 Thermal Band Relative Geodetic Accuracy

The pixels for targets at the Earth's topographic surface in geometrically corrected LDCM data shall be located relative to the WGS84 geodetic reference system, G873 or current version, with an uncertainty less than or equal to 35 meters [TBR] (90% circular error), excluding terrain effects, over a WRS-2 scene, after the removal of constant offsets.

5.8.5.4 Thermal Band Geometric Accuracy

The pixels for targets at the Earth's topographic surface in LDCM data that have been geometrically corrected, including pointing refinement using ground control and terrain compensation using digital elevation data, shall be located relative to the WGS84 geodetic reference system, G873 or current version, with an uncertainty less than or equal to 30 meters [TBR] (90% circular error), including compensation for terrain effects.