Landsat Next Draft SMRD v5.0 (Science)

1.1 BACKGROUND

This document provides draft science requirements for the Landsat Next mission. These requirements are based on the "Goal" set of requirements provided in the document "SLI Draft Science Requirements for a Global Survey Mission" posted on FedBizOps in 2019 during the Architecture Study Team, modified by the Landsat Next team during 2020.

1.2 REVISIT FREQUENCY AND COVERAGE

1.2.1. Landsat Next shall acquire observatory nadir-oriented imaging over the same location over all land mass on the earth at least every 16-days.

Rationale: The area that can be imaged by the observatory while nadir-pointing must be revisited every 16 days or less to capture seasonal changes. Nadir-pointing observations must maintain the continuity provided by Landsat constellations to observe changes in vegetation/crop phenology, burn severity, water use, coastal and wetland changes, glacier and ice sheets dynamics, and water quality monitoring. Solidifies "all land, all the time requirement," excluding high-latitude areas during winter and night acquisitions.

1.2.2. Landsat Next observations shall be acquired with a viewing angle of less than 15 degrees off nadir.

Rationale: The Landsat Science Team previously endorsed limiting viewing angles to <20 degrees in order to limit the effect of Bi-directional Reflectance Distribution Function (BRDF) variability across any image extent. This requirement limits the range to 15 degrees, in comparison to Sentinel-2 (10 degrees) and past Landsat missions (7.5 degrees) to further minimize BRDF issues while permitting a wider range of view angles compared to past Landsat missions.

1.2.3. Landsat Next shall acquire mission data such that the swath width from any single platform is at least 40 km.

Rationale: This requirement in combination with requirement to image all land surfaces at the same location at least every 16-days ensures continuity of science and user community needs for Landsat observations. Optimization of system swath width to maximize revisit opportunities and better align with Sentinel-2 is a strong goal. Permits both single platform and constellation architectures but constrains constellation architecture to acquire a minimum single-platform swath. This supports applications that require uniform imagery across broad areas collected at once, including contextual analysis such as texture mapping and cloud/shadow association. In addition, atmospheric correction is improved by having a minimum image size acquired with one set of atmospheric parameters.

1.2.4. Primary Landsat Next VSWIR observations shall be acquired at 10:00 +/- 15 minutes Mean Local Time (MLT) crossing.
Rationale: The legacy requirement for Landsat 8 and 9 is 10:00am +/- 15 minutes, but typical crossing time has been ~10:11 for Landsat 8.

1.2.5. Subsequent nadir observations for any ground target shall be acquired with a relative view angle difference of no more than 1.0 degree.
Rationale: Consistent view geometry is critical for minimizing BRDF variability in time series Landsat observations. Better than 16-day coverage should be provided by observations using the same viewing geometry within the swath, not, for example, from alternating sides of a wider swath. This requirement is relaxed compared to the heritage ground track repeatability for previous Landsat missions (+/- 5km at 705km orbit altitude)

1.3 SCIENCE DATA LATENCY AND DELIVERY

1.3.1. Landsat Next shall deliver at least 98.8 percent (%) of the science data acquired by the observatory to the science data archive, measured on a quarterly average basis.
Rationale: Unchanged from Landsat 9

1.3.2. Landsat Next shall make Level 1 data products available for search and distribution within 24 hours of observations for 85% of the data received by the Ground System.
Rationale: Latency is driven by the operational needs of natural resource management programs worldwide.

1.3.3. Landsat Next shall make Near Real-Time (NRT) Level-1 data products available for search and distribution within 30 minutes (TBD) of real-time observations for 85% data received via downlink over the Contiguous United States (CONUS) and Alaska.

Rationale: Near Real-Time data for active fire monitoring, agriculture, and coastal oil spill applications (among other NRT user needs) are an important constituency of Landsat science and user communities.

1.4 REFLECTIVE AND THERMAL INFRARED BAND REQUIREMENTS

1.4.1 Spectral Bands

Landsat Next shall collect reflective and thermal infrared image data for each of the spectral bands specified in Table 1.

Rationale: Both Landsat and Sentinel-2 data have been used in conjunction to support land imaging applications since the launch of the Sentinel-2A satellites in 2015. A set of "core" bands [bands 2, 3, 4, 7, 11, 14, 15, 16a/b/c] provide continuity with Landsat 8 and 9 OLI. Additional bands [8, 9, 10, 12] are included to provide compatibility with Sentinel-2 data.

Collectively, these bands are necessary to provide shallow water imaging and characterization of atmospheric aerosols in non-vegetated regions for atmospheric correction (band 2); necessary to assess crop and vegetation health, species identification, agricultural yield/vegetation biomass estimates (bands 7-11, 15), water quality monitoring and mineral type mapping (bands 2,3,4, 16a/b/c); necessary to estimate columnar water vapor for atmospheric correction (band 12); and necessary to provide detection of cirrus clouds which interfere with spectral signature extension and surface reflectance retrieval (band 14).

Additional spectral bands are included for Landsat Next: a violet band (band 1) is necessary to characterize atmospheric aerosols and thin clouds; an orange band and red 1 band (bands 5, 6) are necessary to retrieve chlorophyll, phycocyanin and turbidity for water quality monitoring; narrow NIR bands (bands 13, 13a, 13b) are necessary to quantify snow grain size and liquid water on ice; a three SWIR-band combination (bands 16a-c) is necessary to quantify non-photosynthetic vegetation/crop residue.

Bands in the thermal infrared (bands 17-21) are necessary to support surface temperature estimation for evapotranspiration (e.g. crop water consumption) mapping, and climate studies. The additional bands compared to Landsat 8 TIRS improve surface temperature/emissivity separation and allow retrieval of surface temperature to accuracies better than 1 K, and will also provide additional spectral information for mineral composition (e.g. silicate) mapping and estimating soil and snow grain size.

Violet, water vapor and snow/ice bands all contribute to improved atmospheric correction by providing improved atmospheric aerosol and water vapor retrieval; other atmospheric gases such as ozone are better obtained using atmospheric models or other sensors. Additional auxiliary information needed for atmospheric compensation such as atmosphere pressure, air temperature, elevation, and ozone are obtained from other datasets, for example, NOAA National Centers for Environmental Prediction reanalysis fields (pressure, temperature), OMI/NPP (ozone), and Digital Elevation Models (elevation).

Table 1. Landsat Next Image Data Spectral Bands

	Band name	Center wavelength (nm)	Band width (nm)
1	Violet	410	20
2	Coastal Aerosol	443	20
3	Blue	490	65
4	Green	560	35
5	Orange	620	20
6	Red 1	650	20
7	Red 2	665	30
8	Red Edge 1	705	15
9	Red Edge 2	740	15
10	NIR_Broad	842	115
11	NIR1	865	20
12	Water Vapor	945	20
13a	Liquid Water	985	20
13	Snow/Ice 1	1035	20
13b	Snow/Ice 2	1090	20
14	Cirrus	1375	30
15	SWIR 1	1610	90
16a	SWIR 2a	2100	30
16b	SWIR 2b	2210	40
16c	SWIR 2c	2260	40
17	TIR 1	8300	250
18	TIR 2	8600	350
19	TIR 3	9100	350
20	TIR 4	11300	550
21	TIR 5	12000	550

1.4.2 Spatial Performance

1.4.2.1. Landsat Next shall provide reflective and thermal infrared image data meeting the GSD requirements specified in Table 2.

Rationale: 10m visible and NIR (VNIR) resolution and 20m SWIR and narrow VNIR band resolution are compatible with Sentinel-2. VNIR bands at 10m are necessary to support field-level crop mapping, acreage and water use estimate for water resources management; 20m Orange, Red Edge, NIR and SWIR bands are necessary to improve mapping of vegetation condition, type, land use/land cover, surface water extent, disturbance, water quality, snow and ice and mineral types. 60m TIR bands are compatible with Landsat 7, and necessary to resolve fine-scale urban heat islands, reduce errors in surface temperature/emissivity separation,

improve field-level evapotranspiration (ET) estimates, fire and volcano hotspot monitoring, and glacier and glacial lake mapping. Atmospheric bands are relaxed to 60m; a water vapor band is provided to improve atmospheric correction.

1.4.2.2. Landsat Next shall provide data with a distinct pixel edge such that the response to a unit step function/edge as measured by the edge slope is no less than the values in Table 2.

Rationale**:** To protect against data undersampling or aliasing, and to ensure that image sharpness is commensurate with the GSD

1.4.2.3. Landsat Next shall provide data with adequate sampling such that the product of edge slope and the Ground Sample Distance (GSD) is equal to or less than 0.9.

Rationale**:** To protect against data undersampling or aliasing, and to ensure that image sharpness is commensurate with the GSD **.**

Table 2. Landsat Next Image Data Spatial Performance

	Band name	GSD (m)	Minimum Edge Slope (1/m)
1	Violet	60	0.013
2	Coastal Aerosol	30	0.026
3	Blue	10	0.06
4	Green	10	0.06
5	Orange	20	0.04
6	Red 1	20	0.04
7	Red 2	10	0.06
8	Red Edge 1	20	0.04
9	Red Edge 2	20	0.04
10	NIR_Broad	10	0.06
11	NIR1	20	0.04
12	Water vapor	60	0.013
13a	Liquid Water	20	0.034
13	Snow/Ice 1	20	0.034
13b	Snow/Ice 2	20	0.034
14	Cirrus	60	0.013
15	SWIR 1	20	0.036
16a	SWIR 2a	20	0.036
16b	SWIR 2b	20	0.036
16c	SWIR 2c	20	0.036
17	TIR 1	60	0.01
18	TIR 2	60	0.01
19	TIR 3	60	0.01
20	TIR 4	60	0.01
21	TIR 5	60	0.01

1.4.3 Radiometric Performance

1.4.3.1. Landsat Next shall collect reflective image data providing signal-to-noise ratios (SNR) at least as high as those specified in Table 3, and thermal infrared data providing noise-equivilant delta temperatures (NEdT) no higher than than those specified, at the specified reference radiance levels (Lref).

Rationale: Continuity of Landsat 8 radiometric performance requirements and compatibility with Sentinel-2 radiometric performance. Necessary to provide detection of ~0.1% differences in Earth surface reflectances for discrimination of surface material composition and properties. Absolute calibration is required for retrieving surface temperatures with 1-2K uncertainty, for

combining Landsat Next data with data from other sources via an absolute scale, and for facilitating time series analyses across multiple misisons.

Table 3. Landsat Next Image Data Radiometric Performance Requirements

	Band name	L_{ref} (W/m^2 sr µm)	SNR or NEdT@Lref	Saturation radiance (W/m2 sr µm)
1	Violet	45	100	501
2	Coastal Aerosol	129	530	551
3	Blue	128	300	578
4	Green	128	315	535
5	Orange	21.5	100	397
6	Red 1	23	100	380
7	Red 2	108	260	443
8	Red Edge 1	74.5	253	417
9	Red Edge 2	68	220	378
10	NIR_Broad	103	270	299
11	NIR1	52.4	400	282
12	Water vapor	9	227	239
13a	Liquid Water	14.1	100	220
13	Snow/Ice 1	17.7	100	143
13b	Snow/Ice 2	20	100	175
14	Cirrus	6	510	107
15	SWIR 1	4	250	72.4
16a	SWIR 2a	1.9	132	29.7
16b	SWIR 2b	1.7	132	24.6
16c	SWIR 2c	1.5	132	22.6
17	TIR 1	9.38 (300 K)	0.2 K	24.7 (360 K)
18	TIR 2	9.62 (300 K)	0.2 K	24.5 (360 K)
19	TIR 3	9.87 (300 K)	0.2 K	23.9 (360 K)
20	TIR 4	9.41 (300 K)	0.2 K	19.4 (360 K)
21	TIR 5	8.96 (300 K)	0.2 K	17.8 (360 K)

1.4.3.2. Landsat Next shall collect reflective and thermal data up to the saturation radiance levels specified in Table 3 without saturating.

Rationale: Need to measure reflectance for bright objects (snow, ice, deserts, coastlines) without saturation; need to retrieve temperature of hottest Earth targets, excluding fires, lava, etc.

1.4.3.3. Landsat Next shall relate reflective data (bands 1-16c) within the Level 1 data products to at-aperture spectral radiance with an absolute radiometric uncertainty of less than 5%, 1-sigma.

Rationale: Absolute calibration is required for retrieving surface reflectance and surface temperature (this is the historical Landsat requirement).

1.4.3.4. Landsat Next shall relate reflective data (bands 1-16c) within the Level 1 data products to Top of Atmosphere (TOA) reflectance with an absolute uncertainty of less than 3%, 1-sigma.

Rationale: Absolute calibration is required for retrieving surface reflectance. Reflectance-based calibration is becoming the standard for Earth imaging sensors. Retrieval of surface reflectance starting with top-of-atmosphere reflectance does not involve the use of solar irradiance data and its associated uncertainty.

1.4.3.5. Landsat Next shall shall relate thermal data within the Level 1 data products, after calibration, to at-aperture spectral radiance with an absolute radiometric uncertainty as specified in Table 4

Rationale: Absolute calibration is required for retrieving surface temperatures.

Table 4. Landsat Next Thermal Band Radiometric Performance

Equivalent Blackbody Temperature Range	Absolute Radiance Uncertainty (1-sigma)
260K - 330K	<1%
240K - 260K	<2%
330K - 360K	<2%

1.4.3.6. Landsat Next shall provide reflective and thermal band science data of high quality that is free of artifacts and defects that would significantly reduce the science utility of the data

Rationale: Effects such as coherent noise, banding, striping, ghosting, calibration instability, stray light, bright target saturation, excessive polarization sensitivity, dead pixels, crosstalk, or other substantial data quality issues are unacceptable in Landsat data.

1.4.4 Geometric Performance

1.4.4.1. Landsat Next shall provide reflective and thermal data within the Level 1T data products with a geodetic pixel uncertainty as shown in Table 5, referenced to the World Geodetic System, 1984 (WGS84) geodetic reference system.

Rationale: Ensures a high-accuracy product suitable for Geographic Information System (GIS) applications consistent with current Landsat production systems scaled to finer Landsat Next resolution.

1.4.4.2. Landsat Next shall provide reflective and thermal data within the Level 1T data products with a band-to-band co-registration uncertainty as shown in Table 5, in the along- and cross-track directions at the 90% confidence level.

Rationale: This requirement ensures band registration accuracy that is acceptable for spectral signature identification and achievable with a pushbroom architecture.

1.4.4.3. Landsat Next shall provide reflective data within the Level 1G data products with a geodetic pixel uncertainty as shown in Tables 5, referenced to the WGS84 reference system, excluding the effects of terrain.

Rationale: Provides absolute geolocation knowledge of 12 meters root mean square radial error (RMSEr) which is consistent with the improved/re-triangulated Global Land Survey and with Landsat 8 performance. Absolute geolocation accuracy is particularly important in a pushbroom architecture as terrain compensation is likely required to achieve band registration accuracy. Absolute geolocation knowledge is required to register the terrain data to the image data for proper processing.

Table 5. Landsat Next Image Data Goal Geometric Performance Requirements

Requirement	10-meter Reflective Bands	20-meter Reflective Bands	60-meter Reflective Bands	60-meter Thermal Bands
L1T Geodetic Accuracy	8 meters CE90	9 meters CE90	11 meters CE90	21 meters CE90
L1G Geodetic Accuracy	18 meters CE90	18 meters CE90	20 meters CE90	27 meters CE90
Band-to-Band Registration Accuracy (reflective-to-reflective and thermal-to-thermal)	2 meters LE90	3 meters LE90	6 meters LE90	6 meters LE90
Band-to-Band Registration Accuracy (Thermal-to-Reflective)	-	-	-	15 meters LE90

1.5 REFLECTIVE AND THERMAL BAND CO-REGISTRATION & SIMULTANEITY

1.5.1. Landsat Next shall provide Level 1T data products with corresponding pixels from the thermal bands and reflective bands that are co-registered with an uncertainty of 15 meters or less in the line and sample directions at the 90% confidence level, as shown in Table 5.

Rationale: This requirement ensures band registration accuracy that is acceptable for spectral signature identification, and achievable using separate reflective and thermal instruments.

1.5.2. Landsat Next shall provide observations from all spectral bands listed in Table 1 within 20 seconds for any location.

Rationale: Cloud screening is important for automated processing and reducing classification and change detection errors due to clouds. Accurate cloud screening requires simultaneous VSWIR and TIR data. While it is possible to perform cloud screening with a subset of the required TIR bands, the simplest approach is simply to require consistent band simultaneity across all acquired spectral regions. This also fully supports applications in evapotranspiration and plant stress, which require data from both VSWIR and TIR parts of the spectrum.