LANDSAT Data Continuity Mission

LDCM

LANDSAT DATA CONTINUITY MISSION

Appendix A: LDCM 16-Day Design Reference Case (DRC-16)

Effective Date: November 30, 2007

Expiration Date: November 27, 2012

1 Purpose

The purpose of this document is to provide an overview of the LDCM mission operational scenarios over a sixteen-day period referred to as the DRC-16. Sixteen days was selected because it is the length of time required for the LDCM observatory to complete one Earth coverage. The DRC-16 can be used to estimate the typical orbital data volume from the instrument and spacecraft during imaging and calibrations, as well as for required ancillary and housekeeping data.

It does not include estimates for time periods required for maneuvers or information regarding the status of spacecraft energy balance during the 16-day period.

To define the DRC–16, the sixteen-day period was divided into four Microsoft Excel spreadsheets. Each of the spreadsheets contains four 24-hour days with the activities planned for each of the days.

2 Document Overview

This section contains a high-level overview of the DRC-16 and general information that will be helpful in understanding the document's content. Section 3 contains information about the OLI activities depicted in the DRC-16. Section 4 addresses the Ground Network Element (GNE) and downlinks to the Landsat Ground Network (LGN) stations. Section 5 briefly discusses the International Cooperators (IC's) and how they're addressed in the DRC-16. Section 6 provides the initial starting conditions for the mission. Enclosure A contains the DRC-16 "storyboard", which is intended to give a high-level summary of significant observatory activities during each of the sixteen days. Enclosure B contains the OLI calibration activities as define in a memorandum to the record and Enclosure C contains the TIRS calibration activities as defined in a memorandum to the record.

2.1 Reference Documents

The DRC-16 is consistent with the following documents. Unless otherwise stated in this document, all inconsistencies in the DRC-16 will be resolved as defined in the Spacecraft Requirements Document.

- GSFC 427-02-02, LDCM Operations Concept Document
- GSFC 427-03-02, LDCM Spacecraft Requirements Document

- GSFC 427-02-07, Landsat Worldwide Reference System-2 (WRS-2) Definition, January 4, 2007,

2.2 Key Features

There are several key features for the activities that take place in the 16-day period depicted in the DRC-16. They are listed below:

- The DRC-16 starts at path 1, row 1 on the WRS-2 grid, which is near the North Pole
- The start date for the DRC-16 is June 10, 2011. There is no contract implication or inference to this start date. With this start date it is possible to perform a monthly lunar calibration maneuver.
- Each day has approximately 15 orbits
- The path/row pairs represent coordinates in the second Worldwide Reference System (WRS-2) grid
- There are both imaging and instrument calibration activities
- There are limited back-to-back stress cases identified
- LDCM ground stations are assumed to be available whenever they are in view, except where an outage has been identified.

2.3 Column Headings

The column headings and their meaning are identified and described in Table 2-1.

Table 2-1 : DRC-16 Column Headings

Column Name	Description
Scene center time	UTC time of the center of each WRS Path and Row
Path	Current path being imaged on the WRS-2 coordinate system
Row	Current row being imaged on the WRS-2 coordinate system
Wrs_pr	Number equal to 1000 * path + row; provides a unique identifier for each WRS-2 grid point

Acquire	A one in this column indicates Earth imaging is taking place
Downlink	This column is currently not used
Broadcast	A one in this column indicates a real-time X-band transmission to the IC or set of IC's currently in view
LGS	A one in this column indicates LGS is in view
AGS	A one in this column indicates AGS is in view
IC1	Identifier for one of the three International Cooperator sites in view
IC2	Identifier for one of the three International Cooperator sites in view
IC3	Identifier for one of the three International Cooperator sites in view
OLI Solar Cal	A one in this column indicates an OLI solar calibration is taking place
OLI Lunar Cal	A one in this column indicates an OLI lunar calibration is taking place
TIRS Cal	A one in this column indicates a TIRS calibration is taking place
S/C Sun lit	A one in this column indicates the spacecraft is currently in the sun
Subsat sun lit	A one in this column indicates that the sub-satellite point is in sunlight. Unfortunately, this is just an approximation of the transition from night to day.
Penumbra	A one in this column indicates that the satellite is in partial sunlight. Portion of the Sun is eclipsed by the Earth.
Umbra	A one in this column indicates that the satellite is in full Earth shadow; the Earth eclipses all of the Sun.
Moon phase	The angle formed by a vector from the Earth's center to the moon's position and a vector from the Earth's center to the Sun's position.

3 OLI Activities

The OLI instrument performs both imaging and calibration activities.

3.1 OLI Imaging

The primary goal for the OLI is to produce 400 scenes per 24-hour period. As part of instrument calibration there is an interval in Day 5 that consists of seventy-seven scenes that must be contiguous and sunlit. In addition, there is an interval in Day 6 that consists of thirty-eight night scenes that must be contiguous.
In each day there are no more than five scenes that are marked “priority” per the spacecraft requirements. There are more stringent latency requirements for the processing of these scenes.

3.1.1 Off-nadir imaging

The DRC-16 also includes off-nadir imaging to account for instances in the mission when the observatory may be required to collect scenes off the nominal WRS-2 track. These off-nadir scenes are included in Days 1, 8, and 15.

3.2 OLI Calibration

The OLI uses both the Sun and the Moon for external calibration sources, as well as internal lamps. There are four different types of calibrations: dark focal plane, lamp illumination, diffuse solar illumination, and lunar imaging. Each calibration is described in further detail in Enclosure B.

3.2.1 OLI Dark Focal Plane Calibration

OLI dark focal plane calibration is performed twice every orbit prior to and after an earth scene imaging pass, at high latitudes of orbit. Each calibration takes approximately five minutes to complete.

3.2.2 OLI Lamp Illumination

Lamp illumination calibration takes place once every 24 hours prior to or after earth scene imaging, at high latitudes, and in combination with a dark focal plane event. Each calibration takes approximately five minutes to complete.

3.2.3 Diffuse Solar Illumination

Diffuse solar illumination – or solar calibration – takes place once every two weeks prior to entering earth scene imaging in high latitudes of northern hemisphere. The calibration maneuver takes approximately twenty minutes to complete. However, the data collection approximates 5 scenes.

3.2.4 Lunar Imaging

Lunar imaging calibration occurs approximately once every 28 days while the spacecraft is on the ascending path and in complete umbra. This calibration is done on two consecutive orbits. Each orbit's calibration takes approximately twenty minutes to complete.

4 Ground Network Element Downlinks

The LDCM Ground Network Element (GNE) is comprised of the Alaska Ground Station (AGS) in Fairbanks, AK, and the Landsat Ground Station (LGS) in Sioux Falls, SD. During contacts with each of these stations, the observatory will downlink stored and real-time housekeeping telemetry data. All acquired data will be stored in the spacecraft's solid-state recorder. When commanded by the Mission Operations Center (MOC), image data will be transmitted to the ground via an X-band communications stream. This Mission Data stream will contain the image data and ancillary data. The ancillary data includes imaging sensor and select spacecraft housekeeping telemetry, calibration data, and other data necessary for image processing.

4.1 Downlink Rationale/Strategy

For the purposes of the DRC-16, the spacecraft should be capable of transmitting real-time and playback data whenever an LGN station is in view. However, it is left to the vendor to specify when downlinks will occur in their mission model. A real-time broadcast should be assumed whenever OLI imaging is taking place and the LGS is in view.

4.1.1 LGN station outages

Two twenty-four hour station outages are included in the DRC-16. The LGS outage begins in Day 3, and the AGS outage begins in Day 9.

5 International Cooperators (IC's)

The Landsat User Community encompasses all those members of the general public who use Landsat data for various purposes. The International Cooperators are a special subset of the User Community that has the ability to receive LDCM data from the observatory's real-time downlink stream. This section briefly discusses the complement of IC's as it is currently known and the rationale/strategy for the real-time downlinks.

5.1 IC Ground Stations

Table 5-1 lists the current complement of IC ground stations, including the identifiers used in the DRC-16 for each station.

Station	Location	Latitude (deg)	Longitude (deg)	Altitude (km)
ASN	Alice Springs, Australia	23:45:32.0000 S	133:52:56.0000 E	0.579
BJC	Beijing, Peoples Republic of China	40:27:02.0000 N	116:51:26.0000 E	0.109
BKT	Bangkok, Thailand	13:43:48.0000 N	100:47:24.0000 E	0.002
CLT	Chung Li, Taiwan	24:58:12.0000N	121.10.12.0000 E	0.186000
COA	Cordoba, Argentina	31:31:27.0000 S	64:27:49.0000 W	0.73
CUB	Cuiaba, Brazil	15:33:10.0000 S	56:04:24.0000 W	0.268
DKI	Parepare, Indonesia	03:58:41.0000 S	119:38:59.0000 E	0.09

Station	Location	Latitude (deg)	Longitude (deg)	Altitude (km)
GNC	Gatineau, Canada	45:34:52.6800 N	75:48:22.3200 W	0.286
HAJ	Hatoyama, Japan	36:00:13.0000 N	139:20:53.0000 E	0.088545
HOA	Hobart, Australia	42:55:32.0000 S	147:25:14.0000 E	0.15
JSA	Johannesburg, South Africa	25:53:24.0000 S	27:42:00.0000 E	1.543
KIS	Kiruna, Sweden	67:52:36.0000 N	21:03:44.0000 E	0.51
MPS	Maspolomas, Spain	27:45:36.0000 N	15:37:48.000 W	0.154
MTI	Matera, Italy	40:39:00.0000 N	16:42:00.0000 E	0.53
PAC	Prince Albert, Canada	53:12:45.0000 N	105:56:01.0000 W	0.489
SGS	Svalbard, Norway	78:13:50.6006 N	15:23:22.9048 E	0.480434
UPR	University of Puerto Rico	18:12:39.9600 N	67:08:12.4800 W	0.1

5.2 Broadcast rationale/strategy

The DRC-16 assumes that real-time broadcasts to the IC's occur whenever they are in view and OLI imaging is taking place. The specific ICs and when mission data should be provided to them is identified in the DRC-16 work sheets.

6 Initial Conditions

The state propagator for this simulation used a high order Runga-Kutta integrator with a fixed step size that was adjusted each orbit to match the 248 scenes in an orbit. The step size was adjusted to maintain one step per scene using orbit period ÷ 248.1805 scenes in an orbit. The Geopotential model used both zonal and tesseral potential terms of order 21. The state propagation included the observatory mass and a constant cross sectional area provided below. The cross sectional area is used in the drag calculation.

The states provided are for the same initial conditions. They are provided for different coordinate systems that may be in use by various state propagation tools. The starting epoch is as follows:

LDCM Epoch June 10, 2011 at 13:59:07, for Path 1, Row 1.

The following table contains the Mean of J2000 Earth Equator where the elements are defined as:

- Z-axis: Vector normal to the mean equatorial plane at Julian year 2000.0, pointing towards the Northern Hemisphere
- X-axis: Vector pointing from the center of the Earth to the mean vernal equinox at Julian year 2000.0
- Y-axis: Vector perpendicular to the X- and Z-axes, forming a right-handed coordinate system
- Origin: Center of the Earth
- The V prefix represents the velocity component

X, km	Y, km	Z, km	VX, km / sec	VY, km / sec	VZ, km / sec
-415.356	1067.900	6987.590	4.916245	5.630928	-0.565289

The following table contains the standard Keplerian Elements defined as follows

- A Semi-major axis
- E Eccentricity
- I Inclination
- RAAN Right Ascension of the Ascending Node
- W Argument of Periapsis
- TA True Anomaly

A, km	E, None	I, deg	RAAN, deg	W, deg	TA, deg
7068.876	0.001749	98.21956	229.50237	287.60788	166.78471

The following table contains the J2 Brouwer-Lyddane Elements where only the J2 term is carried for the conversion:

- A J2 Mean semi-major axis
- E J2 Mean eccentricity
- I J2 Mean inclination
- RAAN J2 Mean Right Ascension of the Ascending Node
- W J2 Mean Argument of Periapsis

- MA J2 Mean Anomaly

BLJ2A, km	BLJ2E, None	BLJ2I, deg	BLJ2RAAN, deg	BLJ2W, deg	BLJ2MA, deg
7077.911	0.000335	98.21428	229.50154	0.930493	93.42460

A spacecraft mass of 849-kg
A spacecraft cross sectional area of 10-m^2

Enclosure A: DRC-16 Storyboard

	Start Time	End Time	OLI Imaging	OLI Calibration	Downlinks
Day 1	June 10, 2011 13:59:06	June 11, 2011 14:00:21	Nominal scene collection starting at Path 1, Row 1 Seven off-nadir scenes collected looking right/west of nominal track on Path 129, Rows 50 – 56; images collected of Path 130, Rows 50 thru 56	None	
Day 2	June 11, 2011 14:00:45	June 12, 2011 14:01:36	Nominal scene collection starting at Path 225, Row 142	Solar calibration starting at 14:27:53	
Day 3	June 12, 2011 14:02:00	June 13, 2011 14:03:15	Nominal scene collection starting at Path 225, Row 142		LGS station unavailable for 24-hours starting on June 13 at 00:03:19
Day 4	June 13, 2011 13:59:28	June 14, 2011 14:00:15	Nominal scene collection starting at Path 230, Row 66	None	LGS station outage continues through June 14, 00:04:10
Day 5	June 14, 2011 14:00:39	June 15, 2011 14:00:38	Nominal scene collection starting at Path 223, Row 175 77-scene interval beginning on June 15, 07:43:54 starting at Path 173, Row 8	None	Nominal
Day 6	June 15, 2011 14:01:02	June 16, 2011 14:01:01	Nominal scene collection beginning at Path 228, Row 102	None	Nominal
Day 7	June 16, 2011 14:01:25	June 17, 2011 13:59:24	Nominal scene collection beginning at Path 219, Row 243	Lunar calibration starting at 7:41:15	Nominal

	Start Time	End Time	OLI Imaging	OLI Calibration	Downlinks
Day 8	June 17, 2011 14:01:25	June 18, 2011 13:59:24	Nominal scene collection beginning at Path 219, Row 243 Eleven off-nadir scenes collected at Path 130, Rows 50 - 60	None	Nominal
Day 9	June 18, 2011 14:09:53	June 19, 2011 14:11:08	Nominal scene collection beginning at Path 226, Row 131	None	24-hour AGS station outage beginning on June 19 at 00:10:48
Day 10	June 19, 2011 14:11:08	June 20, 2011 14:12:47	Nominal scene collection beginning at Path 233, Row 23	None	Continuation of 24-hour AGS station outage through June 20, 00:10:51
Day 11	June 20, 2011 14:13:11	June 21, 2011 14:14:26	Nominal scene collection beginning at Path 224, Row 165	Calibration over Greenland at 13:44:24	Nominal
Day 12	June 21, 2011 14:14:49	June 22, 2011 14:14:53	Nominal scene collection beginning at Path 231, Row 58	None	Nominal
Day 13	June 22, 2011 14:15:17	June 23, 2011 14:16:31	Nominal scene collection beginning at Path 222, Row 196	None	Nominal
Day 14	June 23, 2011 14:16:55	June 24, 2011 14:18:10	Nominal scene collection beginning at Path 229, Row 89	None	Nominal
Day 15	June 24, 2011 14:18:34	June 25, 2011 14:19:49	Nominal scene collection beginning at Path 220, Row 230 Five off-nadir scenes collected beginning 3:57:21 looking left/east of nominal track at path 130, rows 50 - 54	Solar calibration beginning at 17:13:44	Nominal
Day 16	June 25, 2011 14:20:13	June 26, 2011 14:15:29	Nominal scene collection beginning at Path 227, Row 123	None	Nominal

Enclosure B

Date: July 16, 2007

To: File

From: OLI Systems Engineer / 556.0 / S. Bidwell

Subject: Summary of Characteristics for Operational OLI Calibration Activities

Estimated durations and frequencies are based on ALI experience. More frequent collections will occur during the 90 day commissioning phase.

On approximately quarterly intervals additional dark and lamp data sets will be acquired for radiometric characterization. This data will be acquired on long passes, approximately one-half an orbit with the "shutter" closed with regular dark and lamp collects. Data acquired for this calibration effort does not need to be included in the current study.

OLI Operational Calibration Activity	Orbit Location	Frequency	Duration	Data Volume	Spacecraft Attitude	Comments
Dark Focal Plane	Prior to and after earth scene imaging pass, at high latitudes of orbit.	Twice every orbit.	Approximately 5 minutes for completion of activity. 1 second of data collection.	**530 Mbits per orbit.** Ratio-nale: 2 s/orbit x 265 Mbits/s	No attitude maneuver. Maintain earth nadir attitude.	Likely requires "shutter" mechanism actuation for closing and re-opening the focal plane to aperture. Under consideration: If mechanism does not distur spacecraft, and can be ope and closed quickly, dark collects may be acquired between earth imaging intervals
Lamp Illumination	Prior to or after earth scene imaging, at high latitudes in combination with a dark focal plane event.	Once every 24 hours.	Approximately 5 minutes for completion of activity.	**2100 Mbits per 24 hours.** Rationale: 4 levels X 2 s/level X 265 Mbits/s	No attitude maneuver. Maintain earth nadir attitude.	Focal plane must be darke likely with same mechanism used for darkening focal pla Lamps exercised through 3 illumination levels (TBR, pe ALI experience) plus dark. Stimulation lamp sequence also be exercised for solar illumination and lunar illumination events.
Diffuse Solar Illumination	Prior to entering earth scene imaging in high latitudes of northern hemisphere.	Once every two weeks	Approximately 20 minutes for completion of activity. 120 seconds of data collection.	**34,000 Mbits every two weeks.** Rationale: 5 scenes X 23.92 s/scene X 265 Mbits + 2100 Mbits for lamps	Spacecraft attitude must be adjusted such that the sun enters the OLI solar calibration aperture. Approximately +60 degree rotation about +Z	Effectively 5 scenes of diffu solar illumination. Dark and lamp sequence exercised in combination w diffuse solar illumination ev

OLI Operational Calibration Activity	Orbit Location	Frequency	Duration	Data Volume	Spacecraft Attitude	Comments
Lunar Imaging	On ascending path with s/c in complete umbra. On two consecutive orbits.	Approximately every 28 days.	Approximately20 minutes per orbit allocated for complete data collection and spacecraft slewing. Lunar calibration will occur over two consecutive orbits. Data collection duration is bounded with the moon two diameters from 'top' and 'bottom' of each sensor chip assembly (SCA).	**217,154 Mbits for two orbits.** Rationale: 14 SCAs X 57.4 sec/ SCA X 265 Mbits/ sec +4,200 Mbits for lamps	Spacecraft attitude adjusted to image moon on each SCA of the focal plane. This entails a 'square wave' attitude maneuver to scan the 14 SCAs of the focal plane. Scan along-track extent is 3.5 degrees, (2.0 degrees for the focal plane and 0.75 degrees on each side of focal plane.) The focal plane cross-track extent is approx. 15 degrees. Scan rate across the focal plane is 0.061 deg/sec.	Requires near 'full moon'. Lunar phase angle must be range -5 to -9 or +5 to +9 degrees. Nominally -7 or + degrees. It is likely that on these two windows will be chosen and used consisten throughout the mission. It is expected that two consecutive orbits will be necessary to complete ima on all SCAs. No earth scene imaging to acquired in orbit between lu imaging sequences. No mission data transmissi will be performed between lunar events. Lamp sequence exercised combination with each luna imaging sequence.

OLI Operational Calibration Activity	Orbit Location	Frequency	Duration	Data Volume	Spacecraft Attitude	Comments
90 Degree Yaw	Over Arctic: June/July/August Over Antarctic: Dec/Jan/Feb Over Sahara: Remaining Months	Once per month.	Time necessary to yaw spacecraft plus 2 scenes of imagery.	**14,800 Mbits** Ratio-nale: 2 scenes X 23.92 s/scene X 265 Mbits/s + 2100 Mbits for lamps	Yaw 90 ± 1 degrees. Stability during collection needs to be better than ±0.1 degree.	Frequency may be relaxed once-per-quarter dependin stability observed at monthl intervals.

Enclosure C

October 17, 2
Revisi

To: File
From: TIRS Instrument Manager / 556.0 / C. Richardson

Subject: Summary of Characteristics for Thermal Infrared Sensor Calibration Activities

Revision by: T. Grems / LDCM Mission Systems Engineer on October 17, 2007 to reflect changes in the TIRS imaging data rate

Estimated durations and frequencies are based on the implementation of current mission requirements. During the 90 day commissioning phase more frequent collections will occur.

On approximately monthly / quarterly intervals additional blackbody data sets will be acquired for radiometric characterization. This data will be acquir on long passes, approximately one-half an orbit with the blackbody collects. Data acquired for this calibration effort does not need to be included in the current study.

TIRS Operational Calibration Activity	Orbit Location	Frequency	Duration	Data Volume	Spacecraft Attitude	Comments
Standard Calibration	Any	At least once every 34 minutes during imaging. Must begin 10 minutes prior to any earth scene collection.	10 minutes. Each calibration consists of 2 minutes of data collected on each of two targets, one hot and one cold. 6 minutes to position targets and stabilize temperature.	6,288 Mbits	Nadir	6,288 Mbits = 2 targets * 2 min / target * 60 sec/min * 26.2 Mbps
Stability	Any	No more than once a month (TBR)	50 minutes; stare at one of the 2 TIRS internal targets.	8,646 Mbits	Nadir (nominal) Assessing feasibility during off pointing maneuvers	30 seconds every 5 minutes over a 50 minute period. : 11 samples * 30 seconds / sample * 26.2 Mbps
Linearity	Any	No more than once a month (TBR)	2 minutes dwell at each of 6 temperatures. Total calibration data of 12 minutes; transition and stabilization times of target under study; Best estimate currently 8 hours.	19, 152 Mbits	Nadir (nominal) Assessing feasibility during off pointing maneuvers	2 minutes each at 6 data points (TBD temps): 26.2 Mbps*120 sec*6