CEOS Land Surface Imaging Constellation
Mid-Resolution Optical Guidelines
July 2011

Background

The Committee on Earth Observation Satellites (CEOS) was established in 1984 and has membership from 50 space agencies and other national and international organizations around the world that participate in CEOS planning and activities [1]. The purpose of CEOS is to promote coordination between member organizations and cooperation in the development of Earth observing satellites for the Global Earth Observation System of Systems (GEOSS) space segment. Earth observation via satellites is multidisciplinary by its very nature, and therefore coordination across the many missions flown and sponsored by many countries is of high value. The advantages of coordination include ensuring that plans are comprehensive and resources are efficiently used to accomplish important objectives. CEOS strives to provide this cross-agency coordination and collaboration. Hence the work of CEOS spans from "development of detailed technical standards for data product exchange to the establishment of high-level interagency agreements on common data principles [2]."

The Land Surfacing Imaging (LSI) Constellation is one of six constellations within CEOS. These groups are so called as the ground systems supported and missions flown by each of the member agencies virtually combine to form a constellation of satellites that work to meet the goals and measurements in a specific area of Earth observation science. Hence the constellations provide a unique forum for collaboration and mutual benefit across space agencies and organizations [3]. The LSI Constellation specifically focuses on the area of land imaging "to promote the efficient, effective, and comprehensive collection, distribution, and application of space-acquired image data of the global land surface, especially to meet societal needs of the global population, such as those addressed by the Group on Earth Observations (GEO) societal benefit areas (SBAs) [4]." This document is specifically focused on mid-resolution, instruments with spatial resolutions of 10 to 100 meters, optical imaging.

One of the objectives of the LSI Constellation is to develop and define a fairly detailed set of ideal or optimal guidelines for mid-resolution optical missions and instruments. The intent of this document is to gather parameters for different land imaging measurements from a variety of sources to serve as these guidelines. The document will be used as a reference for new groups looking to engage with the LSI community. No single mission would be expected to meet all of these guidelines. Instead, the overall virtual constellation of LSI would together achieve these objectives through the combination of the missions' specific subset of specialties and foci. Defining the LSI Constellation in this way is a long-term process that will likely take many years and support across all the member agencies and organizations with the LSI Constellation to fully complete [5]. Such highly integrated international coordination will drive the state of the art of land imaging to meet and surpass these goals.

Introduction

The LSI community of users is large and varied. To reach all these users as well as potential instrument contributors this document has been organized by measurement parameters of interest such as Leaf Area Index and Land Surface Temperature. These measurement parameters and the data presented in this document are drawn from multiple sources, listed at the end of the document, although the two primary ones are "The Space-Based Global Observing System in 2010 (GOS-2010)" that was compiled for the World Meteorological Organization (WMO) by Bizzarro Bizzarri [6], and the CEOS Missions, Instruments, and Measurements online database (CEOS MIM) [7].

For each measurement parameter the following topics will be discussed:

- measurement description,
- applications,
- measurement spectral bands, and
- example instruments and mission information.

The description of each measurement parameter starts with a definition and includes a graphic displaying the relationships to four general land surface imaging user communities: **vegetation, water, earth,** and **geo-hazards**, since the LSI community of users is large and varied. The **vegetation** community uses LSI data to assess factors related to topics such as agriculture, forest management, crop type, chlorophyll, vegetation land cover, and leaf or canopy differences. The **water** community analyzes snow and lake cover, water properties such as clarity, and body of water delineation. The **earth** community focuses on minerals, soils, and sediments. The **geo-hazards** community is designed to address and aid in emergencies such as volcanic eruptions, forest fires, and large-scale damaging weather-related events.

In a similar fashion the parameter description also includes a graphical mapping of the measurement parameter to the applicable GEO SBAs. The nine SBAs are: disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. The data shown in these tables was extracted from the CEOS Systems Engineering Office (SEO) Systems Database [8].

In both the GOS-Dossiers and the CEOS MIM database the land surface imaging instruments fall into two primary type categories of: multi-spectral radiometers in the visible and infrared spectrums, and high resolution optical imagers. The GOS-2010 document's third volume defines these instrument types as (type A) multi-purpose VIS/IR imagers from low earth orbit are described as medium-resolution multi-channel radiometers operating in the VIS and IR parts of the spectrum, and (type B) high-resolution imagers for land observation that are imagers exploiting a variety of trade-offs between geometric resolution and swath, often offering the flexibility of in-flight selection of the area to be observed [6]. The Earth Observation (EO) Handbook that is the background information for the CEOS MIM describes these two instrument types as follows.

- "Visible/IR imaging multi-spectral radiometers are used to image the Earth's atmosphere and surface, providing accurate spectral information at spatial resolutions of order 100m up to several km, with a swath width generally in the range several hundred to a few thousand km."
- "High resolution optical imagers provide detailed images of the Earth's surface. In general, these are nadir-viewing instruments with a horizontal spatial resolution in the range 10 to 100 m and swath widths of order 100 km. In the past few years, high resolution sensors have emerged with spatial resolution in the range 1 to 5 m. An increasing number of government-funded and private sector-funded sensors with sub 5 m resolution are planned for the coming years." [9]

The description section ends with a graphic showing the applicable instrument types for each measurement parameter.

The applications section describes ways in which each measurement parameter can be used by the land imaging communities. The sources of this information will vary greatly and be noted in the references section at the end of this document.

The measurement spectral bands noted for each parameter are based on instruments that are currently operating or planned for the future and are known to contribute to the parameter based on data from the CEOS MIM. The spectral ranges are defined as follows:

- Visual (VIS): approximately 0.40 μm to 0.75 μm,
- Near Infrared (NIR): approximately 0.75 μm to 1.3 μm,
- Shortwave Infrared (SWIR): approximately 1.3 μm to 3.0 μm, and
- Thermal Infrared (TIR): approximately 6.0 μm to 15.0 μm.

Finally a table listing example instruments that are currently operating or planned for the future and known to contribute to the measurement parameter is included. The table contains information on the instrument, the mission, and specific characteristics. The instruments and missions listed are taken from the CEOS MIM database (http://database.eohandbook.com). [7] According to agency leads for the missions, the listed instruments have the potential to measure the specific land surface imaging parameter from that section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

A glossary, acronym list, and reference list are included at the end of the document.

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Surface Spectral Albedo

Description

Surface spectral albedo is the ratio of the radiation reflected from an object to the total amount incident upon it for a particular portion of the spectrum. [10] More generally it is the percentage of incoming radiation that is reflected by a natural surface such as the ground, ice, snow, water, clouds, or particulates in the atmosphere. [11]

The vegetation and water user communities are the most applicable of the large and varied LSI community of users. Surface spectral albedo's applicability to the SBAs is narrowly focused to the water and climate areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X		

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
		X	X			X		

Both types of instruments are used to measure surface spectral albedo – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure surface spectral albedo fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

The applications of surface spectral albedo, as with many land surface imaging measurements and products, are quite varied. One example of the importance of these measurements is described by the United States' National Aeronautics and Space Administration (NASA) Earth Observatory webpage in describing the seasonal changes in the Earth's albedo.

> "Triggered by seasonal changes in available sunlight, about 50 million square kilometers of the Earth's land surface undergo a transition from freeze to thaw each year. Snow and ice disappear then return, frozen ground softens and hardens, vegetation "greens up" and fades. Satellite sensors can detect many of these processes through seasonal changes in the amount of sunlight reflected by the Earth's surface at various wavelengths. The percentage of light that a surface reflects out of the total light falling on it is the surface's albedo. Bright, reflective surfaces, such as fresh snow, have a high albedo; dark, absorptive surfaces, such as dense forest, have a low albedo." [12]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure surface spectral albedo for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS and NIR ranges.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed in the following table are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	SPOT-4	HRVIR	CNES-France	1998	B	10-20	5	0.5-1.75	60
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	Terra	ASTER	NASA-USA/ METI-Japan	1999	B	15-90	14	0.52-11.65	60
	SAC-C	HRTC	CONAE-Argentina	2000	B	35	1	0.4-0.9	90
	EO-1	ALI	NASA/USGS-USA	2000	B	30	10	0.433-2.35	37
	EO-1	Hyperion	NASA/USGS-USA	2000	B	30	242	0.356-2.577	7.5
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	HJ-1A	HSI (HJ-1A)	CAST-China	2008	A	100	128	0.45-0.95	50
	HJ-1A	CCD (HJ, HY)	CAST-China	2008	B	30	4	0.43-0.9	360-720
	HJ-1B	CCD (HJ, HY)	CAST-China	2008	B	30	4	0.43-0.9	360-720
	THEOS	MS (GISTDA)	GISTDA-Thailand	2008	A	15	4	0.45-0.9	90
	IMS-1 (TWSAT)	MxT	ISRO-India	2008	A	37	4	0.45-0.86	151
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
	RESOURCESAT-2	AWiFS	ISRO-India	2009	A	55	4	0.52-1.7	730
	RESOURCESAT-2	LISS-III (RESOURCESAT)	ISRO-India	2009	B	23.5	4	0.52-1.75	141
Future Planned Missions	Nigeriasat-2	Nigeriasat Medium and High Resolution	NASRDA- Nigeria	2010	B	5-32	2	0.4-1.3	20-300
	RASAT	RASAT VIS Multispectral	TUBÝTAK- Turkey	2010	A	15	3	0.42-0.73	30
	KANOPUS-V N1 (Kanopus-B2)	MSS (Roskosmos)	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	12	4	0.5-0.9	20
	KANOPUS-V N1 (Kanopus-B2)	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	25	2	0.54-0.86	250
	CBERS-3	WFI-2	CAST-China/ INPE-Brazil	2011	A	64	4	0.45-0.89	866
	CBERS-3	MUX	CAST-China/ INPE-Brazil	2011	A	20	4	0.45-0.89	120
	KANOPUS-V N2	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2012	B	25	2	0.54-0.86	250
	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	RESOURCESAT-3	WS LISS III	ISRO-India	2014	A	10-23.5	4	VNIR, SWIR	700
	EnMap	HSI	DLR-Gernany	2014	B	30	1	0.42-2.15	30
	CBERS-4	WFI-2	CAST-China/ INPE-Brazil	2014	A	64	4	0.45-0.89	866
	CBERS-4	MUX	CAST-China/ INPE-Brazil	2014	A	20	4	0.45-0.89	120
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Photosynthetically Active Radiation (PAR)

Description

Photosynthetically Active Radiation, commonly abbreviated PAR, is radiation between 400 and 700 nm used by the green canopy in the photosynthetic process. [10]

The vegetation user community is the most applicable of the large and varied LSI community of users. PAR's applicability to the SBAs is narrowly focused to the climate area.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X			

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
			X			X		X

Both types of instruments are used to measure PAR – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure PAR fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

Often PAR is discussed in reference to the measurement Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) which is the measurement described in the next section of this document. The importance of PAR is discussed in an abstract from the University of Maryland's Department of Geography as:

> "Photosynthetically active radiation (PAR) is the solar radiation in the spectral region of 0.4-0.7 μm that can be absorbed by chlorophyll in green plants and drive the photosynthetic processes in green plant tissues. Therefore, PAR is directly linked to vegetation net primary production, land-atmosphere exchange of energy, water and carbon. Surface albedo over PAR spectral region characterizes the fraction of PAR absorbed by surface, which becomes an essential parameter in many models and applications. A high-density worldwide observation network for measuring surface incident PAR has not yet been established. Satellite remote sensing, therefore, is uniquely qualified to estimate global or regional PAR and its temporal variation." [13]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure PAR for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] All five of these instruments measure in the visible range and they are split between the near infrared and shortwave infrared.

Applicable Spectral Bands			
VIS (0.40 -0.75 μm)	NIR (0.75 - 1.3 μm)	SWIR (1.3 - 3.0 μm)	TIR (6.0 - 15.0 μm)
X	X	X	

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com). [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	HJ-1A	HSI (HJ-1A)	CAST-China	2008	A	100	128	0.45-0.95	50
Future Planned Missions	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Fraction of Absorbed PAR (FAPAR)

Description

Fraction of Absorbed Photosynthetically Active Radiation, or fAPAR, is the fraction of photosynthetically active radiation absorbed by vegetation canopies. It is data necessary for understanding how sunlight interacts with the Earth's vegetated surfaces. [9]

The vegetation user community is the most applicable of the large and varied LSI community of users. fAPAR's applicability to the SBAs is narrowly focused to the climate area.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X			

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
			X			X		X

Both types of instruments are used to measure fAPAR – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure fAPAR fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

fAPAR is a measurement used by many land surface imaging groups. The Land Surface Analysis Satellite Applications Facility states the following.

> "Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) defines the fraction of PAR (400-700 nm) absorbed by the green parts of the canopy, and thus expresses the canopy's energy absorption capacity. FAPAR depends both on canopy structure, leaf and soil optical properties and irradiance conditions. FAPAR has been recognized as one of the fundamental terrestrial state variables in the context of the global change sciences (Steering Committee for GCOS, 2003; Gobron et al., 2006). It is a key variable in models assessing vegetation primary productivity and, more generally, in carbon cycle models implementing up-to-date land surfaces process schemes. Besides, FAPAR it is an indicator of the health of vegetation. FAPAR is generally well correlated with the LAI, the more for healthy fully developed vegetation canopies." [14]

Additionally the Rangeland Assessment and Monitoring Methods Guide contains a remote sensing methods abstract describing how fAPAR is used in models.

> "The fraction of PAR (fPAR) is commonly used in ecosystem models because it has an important influence on exchanges of energy, water vapor and carbon dioxide between the surface of the earth and the atmosphere. Precipitation and temperature are two of the major factors that determine the proportion of PAR absorbed by plants. It is an important parameter in measuring biomass production because vegetation development is related to the rate at which radiant energy is absorbed by vegetation. fPAR can be measured on the ground with handheld instruments or inferred from satellite imagery over large spatial scales.
> The major approaches to generating fPAR estimates from remotely sensed images are:
> - Linear Modeling - linear modeling approaches attempt to relate reflectance data recorded by a sensor to field measurements of fPAR using linear regression techniques. Such approaches may correlate field-measured fractional cover with sensor reflectance bands, or to vegetation indices like NDVI (eg. Law & Waring 1994)

- Physical Models - Physical models use principles of how light energy is absorbed or reflected from different surfaces to estimate physical characteristics of vegetation such as fractional cover, LAI and fPAR. Biophysical models incorporate parameters related to how light interacts with processes like photosynthesis, evapotranspiration, stress, and decay of plant material. Accurately determining the amount of energy absorbed (e.g. 1 – transmission) in the VNIR and SWIR wavelength is critical for estimating leaf area index (LAI) using computer modeling of canopy and landscape structure.
- Artificial Neural Networks (ANN) - ANN are networks of simple processes, decisions, or algorithms applied to data that are good at analyzing data from non-linear and non-parametric systems (see Trombetti et al. 2008)

These methods require correction for atmospheric variation and sometimes require bidirectional reflectance normalization. The images are composited over multiple days (i.e., the value for any given pixel in the final image is taken from the highest-quality readings for that pixel across multiple images) to minimize the impact of atmosphere and screening by clouds or snow. The relationship between satellite measures of reflectance and estimates of fPAR will vary depending on the type of vegetation being considered, and thus major land cover type is an important input to calculating fPAR. Satellite measurements of reflected radiation are often used to estimate the fPAR values that are used as an intermediate variable in models of [Net Primary Production].” [15]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure fAPAR for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] All five of these instruments measure in the visible range and they are split between the near infrared and shortwave infrared.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com). [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
Current Missions	HJ-1A	HSI (HJ-1A)	CAST-China	2008	A	100	128	0.45-0.95	50
Future Planned Missions	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
Future Planned Missions	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
Future Planned Missions	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Land Surface Temperature

Description

Land surface temperature is, in general terms, how hot the "surface" of the Earth would feel to the touch in a particular location. [16] The NASA Earth Observatory describes it further by stating that "from a satellite's point of view, the "surface" is whatever it sees when it looks through the atmosphere to the ground. It could be snow and ice, the grass on a lawn, the roof of a building, or the leaves in the canopy of a forest. Thus, land surface temperature is not the same as the air temperature that is included in the daily weather report." [16]

Of the large and varied LSI community of users, each of the four general user communities have interest in this measurement. Land surface temperature's applicability to the SBAs is focused to the disasters, energy, water, and weather areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X	X	X	X			X	X	X

Both types of instruments are used to measure land surface temperature – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure land surface temperature fall exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

Land surface temperature, as with many land surface imaging measurements and products, has applications to a wide variety or groups. A paper from the 1997 Asian Conference on Remote Sensing by Batatia and Bessaih describes land surface temperature as a key parameter in my remote-sensing applications. [17]

> "Land Surface Temperature is a key parameter in energy budget models, evaportanspiration models (Serafini, 1987; Bssieres, 1995), estimating soil moisture (Price, 1980), forest detection and forecasting, monitoring the state of the crops, studiyng land and sea breezes and nocturnal cooling." [17]

An article in the July 2008 issue of the Journal of the Indian Geophysical Union by Mallick, Kant, and Bharath describes land surface temperature's importance as follows.

> "Land surface temperature (LST) is important factor in global change studies, in estimating radiation budgets in heat balance studies and as a control for climate models. The knowledge of surface temperature is important to a range of issues and themes in earth sciences central to urban climatology, global environmental change, and human-environment interactions."
>
> "The climate in and around cities and other built up areas is altered due to changes in [land use / land cover (LU/LC)] and anthropogenic activities of urbanization. The most imperative problem in urban areas is increasing surface temperature due to alteration and conversion of vegetated surfaces to impervious surfaces. These changes affect the absorption of solar radiation, surface temperature, evaporation rates, storage of heat, wind turbulence and can drastically alter the conditions of the near-surface atmosphere over the cities. The temperature difference between urban and rural settings is normally called urban heat island (UHI).
>
> Land surface temperature can provide important information about the surface physical properties and climate which plays a role in many environmental processes (Dousset & Gourmelon 2003; Weng, Lu & Schubring 2004). Many studies have estimated the relative warmth of cities by measuring the air temperature, using land based observation stations. Some studies used measurements of temperature using temperature sensors mounted on car, along various routes (Yamashita 1996). This method can be both expensive and time consuming and lead to problems in spatial interpolation. Remote sensing might be a better alternative to the aforesaid methods. The advantages of using remotely sensed data are the availability of high resolution, consistent and repetitive coverage and capability of measurements of earth surface conditions (Owen, Carlson & Gillies 1998). In remote sensing, Thermal infrared (TIR) sensors can obtain quantitative information of surface temperature across the LU/LC categories." [18]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure land surface temperature for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database and from an expert review of this document. [7] The number of spectral bands in each range is nearly equal, although the TIR region is of particular focus for surface temperature measurements.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
			X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	Terra	ASTER	NASA-USA/ METI-Japan	1999	B	15-90	14	0.52-11.65	60
	EO-1	ALI	NASA/USGS-USA	2000	B	30	10	0.433-2.35	37
	EO-1	Hyperion	NASA/USGS-USA	2000	B	30	242	0.356-2.577	7.5
Future Planned Missions	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185

Permafrost

Description

Permafrost is a permanently frozen layer at variable depth below the surface in frigid regions of a planet (as Earth). [11]

The water and earth user communities are the most applicable of the large and varied LSI community of users. Permafrost's applicability to the SBAs is focused to the energy, water, and climate areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
	X	X	

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X	X				X		

The mid-resolution optical instruments used to measure permafrost are all categorized as type A (multi-spectral radiometers) according to the CEOS MIM. [7]

Instrument Types	
A	B
X	

Applications

NASA and the United States Geological Survey (USGS) have published educational materials discussing the importance of permafrost and the research to measure and study it.

> "The low-lying Arctic coastal plain of Alaska north of Teshekpuk Lake on the Beaufort Sea hosts endangered species of waterfowl, provides calving grounds for large herds of caribou, and contains potentially significant petroleum resources. For tens of thousands of years, underlying this special place has been permafrost—defined as permanently frozen ground that remains at or below 0º C (32º F) for at least two years at a time. Not only wildlife, but people too, have built their lives and livelihoods on permafrost in Alaska. Roads, buildings, and pipelines rest and rely on hard permafrost foundations. But permafrost is sensitive to climate change, and powerful warming forces are at work. … Landsat gives [NASA and the USGS] a special vantage point to monitor changes in the landscape over time." [19]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure permafrost for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7]

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185

Fraction Of Vegetated Land

Description
Fraction of vegetated land is also known as fraction of vegetation cover (FVC). It accounts for the amount of vegetation distributed on a flat background. [20]

The vegetation, water, and earth user communities are the most applicable of the large and varied LSI community of users. Fraction of vegetated land's applicability to the SBAs is fairly broad touching on the energy, water, ecosystems, biodiversity, and climate areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X	X	X	X		X	X	X

The mid-resolution optical instrument that is used to measure fraction of vegetated land is categorized as type B (high resolution optical imagers) according to the CEOS MIM. [7]

Instrument Types	
A	B
X	X

Applications
The EUMeTrain Project describes the main applications of FVC as follows.

> "FVC is relevant for agriculture and forestry, environmental management and land use, hydrology, natural hazards monitoring and management, vegetation-soil dynamics monitoring, drought conditions and fire scar extent." [20]

Applicable Spectral Bands
Based on mid-resolution optical instrument that is currently operating that measures fraction of vegetated land for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for this instrument in the CEOS MIM database. [7]

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X		

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	Terra	ASTER	NASA-USA/ METI-Japan	1999	B	15-90	14	0.52-11.65	60
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Vegetation Type

Description

Vegetation type is a conceptual grouping of a number of stands of vegetation, of similar physiognomy, composition, structure, etc., for purposes of description and mapping. The vegetation, as shown on a map, may include a small percentage of areas of different vegetation, too small to be shown separately. [21]

The vegetation, water, and earth user communities are the most applicable of the large and varied LSI community of users. Vegetation type's applicability to the SBAs is broad touching on the disasters, energy, water, biodiversity, climate, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X	X	X	X	X		X		X

Both types of instruments are used to measure vegetation type – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure vegetation type fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

The applications of vegetation type, as with many land surface imaging measurements and products, are quite varied. One example of the importance of these measurements is described by the Earth Observation Handbook.

> "Multiple types of satellite observations are used in agricultural applications. Space imagery provides information which can be used to monitor quotas and to examine and assess crop characteristics and planting practice. Information on crop condition, for example, may also be used for irrigation management. In addition, data may be used to generate yield forecasts, which in turn may be used to optimise the planning of storage, transport and processing facilities. Classification and seasonal monitoring of vegetation types on a global basis allow the modelling of primary production – the growth of vegetation that is the base of the food chain – which is of great value in monitoring global food security." [9]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure vegetation type for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS range with large quantities in the NIR and SWIR ranges. Only one applicable instrument has a spectral band in the TIR.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	SPOT-4	HRVIR	CNES-France	1998	B	10-20	5	0.5-1.75	60
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	SAC-C	HRTC	CONAE-Argentina	2000	B	35	1	0.4-0.9	90
	EO-1	ALI	NASA/USGS-USA	2000	B	30	10	0.433-2.35	37
	EO-1	Hyperion	NASA/USGS-USA	2000	B	30	242	0.356-2.577	7.5
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	SPOT-5	HRS	CNES-France	2002	B	10	1	0.49-0.69	120
	SPOT-5	HRG	CNES-France	2002	B	20	4	0.5-1.75	60
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	HJ-1A	HSI (HJ-1A)	CAST-China	2008	A	100	128	0.45-0.95	50
	THEOS	MS (GISTDA)	GISTDA-Thailand	2008	A	15	4	0.45-0.9	90
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
	RESOURCESAT-2	AWiFS	ISRO-India	2009	A	55	4	0.52-1.7	730
	RESOURCESAT-2	LISS-III (RESOURCESAT)	ISRO-India	2009	B	23.5	4	0.52-1.75	141
Future Planned Missions	CBERS-3	WFI-2	CAST-China/ INPE-Brazil	2011	A	64	4	0.45-0.89	866
	CBERS-3	MUX	CAST-China/ INPE-Brazil	2011	A	20	4	0.45-0.89	120
	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	RESOURCESAT-3	WS LISS III	ISRO-India	2014	A	10-23.5	4	VNIR, SWIR	700
	EnMap	HSI	DLR-Gernany	2014	B	30	1	0.42-2.15	30
	CBERS-4	WFI-2	CAST-China/ INPE-Brazil	2014	A	64	4	0.45-0.89	866
	CBERS-4	MUX	CAST-China/ INPE-Brazil	2014	A	20	4	0.45-0.89	120
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Leaf Area Index

Description
Leaf Area Index, commonly abbreviated LAI, is defined as half the total leaf area per unit ground surface area. More specifically, for broad leaf trees such as aspen or maple, it is the one-sided leaf area while for coniferous trees such as jack pine and black spruce, it is half the total needle area. [10]

The vegetation and geo-hazards user communities are the most applicable of the large and varied LSI community of users. LAI's applicability to the SBAs is broad touching on the disasters, energy, ecosystems, biodiversity, climate, weather, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X			X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X	X		X	X		X	X	X

Both types of instruments are used to measure land surface temperature – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure land surface temperature fall exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications
The applications for Leaf Area Index, as with many land surface imaging parameters and products, are quite varied. LAI is one of the fundamental measurements associated with carbon flux studies and global carbon cycle research. [22] The Rangeland Assessment and Monitoring Methods Guide describes the application of LAI as follows.

> "LAI directly quantifies canopy structure, and can be used to predict primary productivity and crop growth. It is commonly used in ecosystem models because it has an important influence on exchanges of energy, water vapor and carbon dioxide between plants and the atmosphere. Hence, many ecosystem process models require LAI as an input variable. LAI can be measured on the ground by harvesting leaf tissue and quantifying the leaf surface area or by various indirect techniques, such as hemispherical photography or the use of optical instruments (Plant Canopy Analyzer, DEMON, ceptometer, etc). However, over large areas it is useful to estimate LAI from remotely sensed images. LAI can be a parameter of interest on its own, or can be used as an input to models of primary productivity and fire dynamics." [15]

Applicable Spectral Bands
Based on mid-resolution optical instruments that are currently operating or planned for the future that measure LAI for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database and from an expert review of this document. [7] The largest number of spectral bands is in the VIS range with moderate quantities in the NIR and SWIR ranges. Only one applicable instrument has a spectral band in the TIR.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Normalized Difference Vegetation Index (NDVI)

Description

Normalized difference vegetation index, commonly abbreviated NDVI, is an index calculated from reflectances measured in the visible and near infrared channels. It is related to the fAPAR. [10]

The vegetation and geo-hazards user communities are the most applicable of the large and varied LSI community of users. NDVI's applicability to the SBAs is focused to the disasters, energy, and weather areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X			X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X	X		X			X	X	X

Both types of instruments are used to measure NDVI – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure NDVI fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

The applications of NDVI, as with many land surface imaging measurements and products, are quite varied. The Rangeland Assessment and Monitoring Methods Guide describes the application of NDVI as follows.

> "Many factors affect NDVI values like plant photosynthetic activity, total plant cover, biomass, plant and soil moisture, and plant stress. Because of this, NDVI is correlated with many ecosystem attributes that are of interest to researchers and managers (e.g., net primary productivity, canopy cover, bare ground cover). Also, because it is a ratio of two bands, NDVI helps compensate for differences both in illumination within an image due to slope and aspect, and differences between images due things like time of day or season when the images were acquired. Thus, vegetation indices like NDVI make it possible to compare images over time to look for ecologically significant changes."
>
> "Because of its ease of use and relationship to many ecosystem parameters, NDVI has seen widespread use in rangeland ecosystems. The uses include assessing or monitoring:
>
> - vegetation dynamics or plant phenological changes over time
> - biomass production
> - grazing impacts or attributes related to grazing management (e.g., stocking rates)
> - changes in rangeland condition
> - vegetation or land cover classification
> - soil moisture
> - carbon sequestration or CO2 flux."
>
> "[NDVI] is not, however, a direct measure of any of these things. … There are a lot of factors that influence the strength of the relationship between NDVI and rangeland ecosystem attributes. These can include: atmospheric conditions, scale of the imagery, vegetation moisture, soil moisture, overall vegetative cover, differences in soil type, management, etc… It is important when using NDVI data in analyses that steps be taken to understand and, to the extent possible, control for factors that might be affecting NDVI values before interpretations of differences in NDVI between areas of within the same area over time can be made. "[12]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure NDVI for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database and from an expert review of this document. [7] The largest number of spectral bands is in the VIS range with moderate quantities in the NIR and SWIR ranges. Only one applicable instrument has a spectral band in the TIR.

Applicable Spectral Bands			
VIS (0.40 -0.75 μm)	NIR (0.75 - 1.3 μm)	SWIR (1.3 - 3.0 μm)	TIR (6.0 - 15.0 μm)
X	X		

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (μm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	Terra	ASTER	NASA-USA/ METI-Japan	1999	B	15-90	14	0.52-11.65	60
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Fire Fractional Cover

Description

Fire fractional cover is the fraction of fire occurring in an area. [7] This term refers to instantaneous fire area (i.e. active fire characterization).

The vegetation and geo-hazards user communities are the most applicable of the large and varied LSI community of users. Fire fractional cover's applicability to the SBAs is fairly broad touching on the energy, ecosystems, climate, weather, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X			X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X		X			X	X	X

Both types of instruments are used to measure fire fractional cover – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure fire fractional cover are split between the two types with more type B instruments than type A.

Instrument Types	
A	B
X	X

Applications

One example of the importance of measurements relating to fires is discussed by the NASA Earth Observatory webpage in describing global fire monitoring.

> "Fire has always been and continues to be an integral part of land use and culture around the World. Earth Scientists are placing greater emphasis on obtaining more accurate assessments of emissions from biomass burning. Remote sensing of fires, smoke and even burn scars (transformed area where the fire burned) allows for improved detection of fire characteristics as well as their short- and long-term effects on ecosystems." [23]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure fire fractional cover for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS range, with the second highest number being in NIR, then SWIR, then TIR. The SWIR and TIR bands can be used to detect active fires, whereas the VIS and NIR can be used to assist with mapping burnt areas.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	SPOT-4	HRVIR	CNES-France	1998	B	10-20	5	0.5-1.75	60
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
Future Planned Missions	KANOPUS-V N1 (Kanopus-B2)	MSS (Roskosmos)	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	12	4	0.5-0.9	20
	KANOPUS-V N1 (Kanopus-B2)	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	25	2	0.54-0.86	250
	KANOPUS-V N2	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2012	B	25	2	0.54-0.86	250
	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290
	HyspIRI	Hyperspectral spectrometer	NASA-USA	2020	B	60	210	0.4-12	90

Fire Temperature

Description

Fire temperature is temperature of the fire occurring within an area. [7] This term refers to instantaneous fire temperature (i.e. active fire characterization). The usual context for fire temperature is the temperature during the flaming or flaming/smoldering phase.

The vegetation and geo-hazards user communities are the most applicable of the large and varied LSI community of users. Fire temperature's applicability to the SBAs is fairly broad touching the disasters, energy, climate, weather, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X			X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X		X			X	X	X

The mid-resolution optical instruments used to measure fire temperature are all categorized as type A (multi-spectral radiometers) according to the CEOS MIM. [7]

Instrument Types	
A	B
X	X

Applications

One example of the importance of measurements relating to fires is discussed by the NASA Earth Observatory webpage in describing global fire monitoring.

> "Fire has always been and continues to be an integral part of land use and culture around the World. Earth Scientists are placing greater emphasis on obtaining more accurate assessments of emissions from biomass burning. Remote sensing of fires, smoke and even burn scars (transformed area where the fire burned) allows for improved detection of fire characteristics as well as their short- and long-term effects on ecosystems." [23]

Also, a 1996 paper by Green from the Jet Propulsion Lab states that:

> "Biomass burning is an important process on the Earth at the local, regional and global scales. At the local scale, destruction of human infrastructure is the dominant concern. At the regional scale, destruction of habitat and modification of regional climate are at issue (Kirchhoff 1989). At the global scale, production of carbon dioxide (a greenhouse gas), modification of the terrestrial carbon balance, and introduction of aerosols into the atmosphere (direct and indirect impacts on the global energy balance) are at issue (Levine, 1995). Biomass burning occurs unpredictably in detail around the globe where there is dry vegetation as a function of numerous natural and human factors. Because of this global and intermittent nature, a satellite or airborne method to detect, measure and monitor biomass burning and fire parameters is desirable."
> "Biomass fires emit radiance as a function of temperature." [24]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure fire temperature for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database and an expert review of this document. [7] The TIR spectral region is of particular focus for temperature measurements. It is worth noting that it is difficult to retrieve fire temperature from the TIR band(s) because most fires occupy only a fraction of even the Landsat-class pixel, a 4 micron band is required.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
		X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
Future Planned Missions	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	HyspIRI	Hyperspectral spectrometer	NASA-USA	2020	B	60	210	0.4-12	90

Snow Cover

Description
Snow cover is the fraction of snow in a given area. [7]

The water and geo-hazards user communities are the most applicable of the large and varied LSI community of users. Snow cover's applicability to the SBAs is focused to the disasters, water, and weather areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
	X		X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X		X	X			X	X	X

Both types of instruments are used to measure snow cover – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure snow cover fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications
The CEOS MIM database describes the application of snow cover as follows.

> "Regular measurements of terrestrial snow cover are important because snow dramatically influences surface albedo, thereby making a significant impact on the global climate, as well as influencing hydrological properties and the regulation of ecosystem biological activity. Snow forms a vital component of the water cycle. In order to make efficient use of meltwater runoff, resource agencies must be able to make early predictions of the amount of water stored in the form of snow. Snow cover information has a range of additional applications such as detecting areas of winterkill in agriculture that result from lack of snow cover to insulate plants from freezing temperatures. Locally, monitoring of snow parameters is important for meteorology and for enabling warnings of when melting is about to occur – which is crucial for hydrological research and for forecasting the risk of flooding." [7]

Applicable Spectral Bands
Based on mid-resolution optical instruments that are currently operating or planned for the future that measure snow cover for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS and NIR ranges.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	SAC-C	HRTC	CONAE-Argentina	2000	B	35	1	0.4-0.9	90
	EO-1	ALI	NASA/USGS-USA	2000	B	30	10	0.433-2.35	37
	EO-1	Hyperion	NASA/USGS-USA	2000	B	30	242	0.356-2.577	7.5
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	HJ-1A	HSI (HJ-1A)	CAST-China	2008	A	100	128	0.45-0.95	50
	RESOURCESAT-2	AWiFS	ISRO-India	2009	A	55	4	0.52-1.7	730
	RESOURCESAT-2	LISS-III (RESOURCESAT)	ISRO-India	2009	B	23.5	4	0.52-1.75	141
Future Planned Missions	KANOPUS-V N1 (Kanopus-B2)	MSS (Roskosmos)	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	12	4	0.5-0.9	20
	KANOPUS-V N1 (Kanopus-B2)	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	25	2	0.54-0.86	250
	KANOPUS-V N2	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2012	B	25	2	0.54-0.86	250
	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	RESOURCESAT-3	WS LISS III	ISRO-India	2014	A	10-23.5	4	VNIR, SWIR	700

Glacier Cover

Description
Glacier cover is the fraction of an area covered by permanent ice. [7]

The water user community is the most applicable of the large and varied LSI community of users. Glacier cover's applicability to the SBAs is narrowly focused to the water and climate areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
	X		

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X	X				X		

The mid-resolution optical instruments used to measure glacier cover are all categorized as type A (multi-spectral radiometers) according to the CEOS MIM. [7]

Instrument Types	
A	B
X	

Applications
The applications of glacier cover, as with many land surface imaging measurements and products, are quite varied. A 2008 article from Sensors referred to the importance of remote sensing to the measurement of glacier cover.

> "The increased availability of remote sensing platforms with appropriate spatial and temporal resolution, global coverage and low financial costs allows for fast, semi-automated, and cost-effective estimates of changes in glacier parameters over large areas. Remote sensing approaches allow for regular monitoring of the properties of alpine glaciers such as ice extent, terminus position, volume and surface elevation, from which glacier mass balance can be inferred. Such methods are particularly useful in remote areas with limited field-based glaciological measurements." [25]

Applicable Spectral Bands
Based on mid-resolution optical instruments that are currently operating or planned for the future that measure glacier cover for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7]

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185

Land Surface Imagery

Description

Land surface imagery is a Level-1 product (not a geophysical parameter) from high-resolution imagery covering wavelengths in the range 0.4-1 µm (cloud-affected). [7]

Of the large and varied LSI community of users each of the four general user communities have interest in this measurement. Land surface imagery's applicability to the SBAs is very broad, touching the disasters, energy, water, ecosystems, biodiversity, health, climate, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X	X	X	X	X	X	X		X

Both types of instruments are used to measure land surface imagery – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure land surface imagery are split between the two types with more type B instruments than type A.

Instrument Types	
A	B
X	X

Applications

The applications of land surface imagery, as with many land surface imaging measurements and products, are quite varied. One example of the importance of these measurements is described by the EO Handbook.

> "The spatial information that can be derived from satellite imagery is of value in a wide range of applications, particularly when combined with spectral information from multiple wavebands of a sensor. Satellite Earth observation is of particular value where conventional data collection techniques are difficult, such as in areas of inaccessible terrain, providing cost and time savings in data acquisition – particularly over large areas."
>
> "On national and local scales, the spatial resolution requirements for information mean that moderate resolution imaging sensors, such as those on SPOT, Landsat and IRS, and imaging radars (such as those on ERS, Envisat and RADARSAT) are most useful. Such sensors are routinely used as practical sources of information for:
>
> - agriculture monitoring, farming and production forecasting;
> - resource exploration and management, e.g. forestry;
> - geological surveying for mineral exploration and identification;
> - hydrological applications such as flood monitoring;
> - civil mapping and planning, involving cartography, infrastructure and urban management;
> - coastal zone monitoring, including oil spill detection and monitoring;
> - topographic mapping, generation of DEMs." [9]

Research and applications have demonstrated the value of cross-calibration of sensors on different missions to extend data records, increase the temporal frequency of coverage, generate cloud-reduced composites, and develop integrated data products.

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure land surface imagery for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS and NIR ranges.

Applicable Spectral Bands			
VIS (0.40 -0.75 μm)	NIR (0.75 - 1.3 μm)	SWIR (1.3 - 3.0 μm)	TIR (6.0 - 15.0 μm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed in the following table are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	SPOT-4	HRVIR	CNES-France	1998	B	10-20	5	0.5-1.75	60
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	Terra	ASTER	NASA-USA/ METI-Japan	1999	B	15-90	14	0.52-11.65	60
	SAC-C	HRTC	CONAE-Argentina	2000	B	35	1	0.4-0.9	90
	EO-1	ALI	NASA/USGS-USA	2000	B	30	10	0.433-2.35	37
	EO-1	Hyperion	NASA/USGS-USA	2000	B	30	242	0.356-2.577	7.5
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	SPOT-5	HRG	CNES-France	2002	B	20	4	0.5-1.75	60
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	HJ-1A	HSI (HJ-1A)	CAST-China	2008	A	100	128	0.45-0.95	50
	HJ-1A	CCD (HJ, HY)	CAST-China	2008	B	30	4	0.43-0.9	360-720
	HJ-1B	CCD (HJ, HY)	CAST-China	2008	B	30	4	0.43-0.9	360-720
	THEOS	MS (GISTDA)	GISTDA-Thailand	2008	A	15	4	0.45-0.9	90
	IMS-1 (TWSAT)	MxT	ISRO-India	2008	A	37	4	0.45-0.86	151
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
	RESOURCESAT-2	AWiFS	ISRO-India	2009	A	55	4	0.52-1.7	730
	RESOURCESAT-2	LISS-III (RESOURCESAT)	ISRO-India	2009	B	23.5	4	0.52-1.75	141
Future Planned Missions	Nigeriasat-2	Nigeriasat Medium and High Resolution	NASRDA- Nigeria	2010	B	5-32	2	0.4-1.3	20-300
	RASAT	RASAT VIS Multispectral	TUBÝTAK- Turkey	2010	A	15	3	0.42-0.73	30
	KANOPUS-V N1 (Kanopus-B2)	MSS (Roskosmos)	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	12	4	0.5-0.9	20
	KANOPUS-V N1 (Kanopus-B2)	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2010	B	25	2	0.54-0.86	250
	CBERS-3	WFI-2	CAST-China/ INPE-Brazil	2011	A	64	4	0.45-0.89	866
	KANOPUS-V N2	MSU-200	ROSKOSMOS / ROSHYDROMET-Russia	2012	B	25	2	0.54-0.86	250
	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	RESOURCESAT-3	WS LISS III	ISRO-India	2014	A	10-23.5	4	VNIR, SWIR	700
	EnMap	HSI	DLR-Gernany	2014	B	30	1	0.42-2.15	30
	CBERS-4	WFI-2	CAST-China/ INPE-Brazil	2014	A	64	4	0.45-0.89	866
	Ingenio (SEOSAT)	PAN+MS (RGB+NIR)	CDTI-Spain/ESA	2014	B	10	5	0.45-0.9	60
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Land Cover

Description

Land cover is processed from land surface imagery by assigning identified cluster(s) within a given area to specific classes of object. [7]

Of the large and varied LSI community of users each of the four general user communities have interest in this measurement. Land cover's applicability to the SBAs is broad, touching the energy, water, biodiversity, health, climate, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X	X	X	X	X	X		X

Both types of instruments are used to measure land cover – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure land cover fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications

The applications of land cover, as with many land surface imaging measurements and products, are quite varied. Land cover is the one parameter that is applicable to almost all areas of research and applications. The importance of land cover change measurements is described in the EO Handbook and in the "Land-use and land-cover change" article of the Encyclopedia of Earth.

> "Changes in land cover are important aspects of global environmental change, with implications for ecosystems, biogeochemical fluxes and global climate. Land cover change affects climate through a range of factors from albedo to emissions of greenhouse gases from the burning of biomass." [9]
>
> "Land-use and land-cover change (LULCC); also known as land change) is a general term for the human modification of Earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of LULCC are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. These changes encompass the greatest environmental concerns of human populations today, including climate change, biodiversity loss and the pollution of water, soils and air. Monitoring and mediating the negative consequences of LULCC while sustaining the production of essential resources has therefore become a major priority of researchers and policymakers around the world." [26]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure land cover for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS range with moderate quantities in the NIR and SWIR ranges.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	SPOT-4	HRVIR	CNES-France	1998	B	10-20	5	0.5-1.75	60
	Landsat 7	ETM+	USGS/NASA-USA	1999	A	15-60	8	0.45-12.5	185
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	UK-DMC2	SLIM-6-22	BNSC-UK	2008	B	22	3	0.36-0.9	660
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Soil Type

Description

Soil type, or soil classification, is the systematic arrangement of soils into groups or categories based on their characteristics. Broad groupings are made on the basis of general characteristics and subdivisions on the premise of more detailed differences in specific properties. [11]

The vegetation, water, and earth user communities are the most applicable of the large and varied LSI community of users. Soil type's applicability to the SBAs is focused to the energy, water, ecosystems, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
	X	X	X					X

Both types of instruments are used to measure soil type – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure soil type are split between the two types with more type B instruments than type A.

Instrument Types	
A	B
X	X

Applications

One example of the applications of remote sensing in soil science is from the Encyclopedia of Soil Science.

> "The need for geospatial data for use in various spatial database development and analyses in industry, government, and universities have increased the demand for remotely sensed data. In the area of soil science, the remote sensing technology is used to acquire data, and digitally process and analyze it." [27]

Applicable Spectral Bands

Based on mid-resolution optical instruments that are currently operating or planned for the future that measure soil type for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS and SWIR ranges.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	Landsat 5	TM	USGS/NASA-USA	1984	A	30-120	7	0.45-12.5	185
	EO-1	ALI	NASA/USGS-USA	2000	B	30	10	0.433-2.35	37
	EO-1	Hyperion	NASA/USGS-USA	2000	B	30	242	0.356-2.577	7.5
	PROBA	CHRIS	ESA	2001	A	18-36	81	0.4-1.05	14
Future Planned Missions	LDCM	OLI	USGS/NASA-USA	2012	A	30	9	0.43-2.3	185
	LDCM	TIRS	USGS/NASA-USA	2012	A	100	2	10.5, 12	185
	Sentinel-2 A	MSI (Sentinel-2)	ESA/EC	2013	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 B	MSI (Sentinel-2)	ESA/EC	2014	B	10-60	13	VNIR/SWIR	290
	Sentinel-2 C	MSI (Sentinel-2)	ESA/EC	2020	B	10-60	13	VNIR/SWIR	290

Land Surface Topography

Description
Land surface topography is the map of land surface heights. [7]

Of the large and varied LSI community of users, each of the four general user communities have interest in this measurement. Land surface topography's applicability to the SBAs is broad, touching the disasters, energy, water, health, and agriculture areas.

Applicable User Communities			
Vegetation	Water	Earth	Geo-Hazards
X	X	X	X

Societal Benefit Areas (SBAs)								
Disasters	Energy	Water	Ecosystems	Biodiversity	Health	Climate	Weather	Agriculture
X	X	X			X			X

Both types of instruments are used to measure land surface topography – type A (multi-spectral radiometers) and type B (high resolution optical imagers) according to the CEOS MIM. [7] Mid-resolution optical instruments currently flying and planned that measure land surface topography fall nearly exactly in an even split between the two types.

Instrument Types	
A	B
X	X

Applications
The applications of land surface topography, as with many land surface imaging measurements and products, are quite varied. One example of the importance of these measurements is described by the EO Handbook.

> "Many modelling activities in Earth and environmental sciences, telecommunications and civil engineering increasingly require accurate, high resolution and comprehensive topographical databases with indication of changes over time, where relevant. The information is also used by, amongst others, land use planners for civil planning and development, and by hydrologists to predict the drainage of water and likelihood of floods, especially in coastal areas."
> "Satellite techniques offer a unique, cost-effective and comprehensive source of landscape topography data. At present, most information is obtained primarily from multi-band optical imagers and synthetic aperture radar (SAR) instruments with stereo image capabilities. The pointing capability of some optical instruments allows the production of stereo images from data gathered on a single orbit (e.g. by ASTER) or multiple orbits (e.g. by SPOT series).These are then used to create digital elevation maps, which give a more accurate depiction of terrain." [9]

Applicable Spectral Bands
Based on mid-resolution optical instruments that are currently operating or planned for the future that measure land surface topography for the LSI community, the following spectral band regions are known to contribute to this measurement based on data noted for these instruments in the CEOS MIM database. [7] The largest number of spectral bands is in the VIS range with moderate quantities in the NIR and SWIR ranges.

Applicable Spectral Bands			
VIS (0.40 -0.75 µm)	NIR (0.75 - 1.3 µm)	SWIR (1.3 - 3.0 µm)	TIR (6.0 - 15.0 µm)
X	X	X	X

Example Instruments and Mission Information

The current and future mid-resolution optical instruments and missions listed below are taken from the CEOS MIM database (http://database.eohandbook.com) and from an expert review of this document. [7] According to agency leads for the missions, the listed instruments have the potential to measure the land surface imaging parameter from this section. Due to constraints with data access and product generation, it is possible that some space-based data and products are not readily available.

Mid-Resolution (10-100m) Optical Missions and Instruments of the Present and Future

	Mission	Instrument	Country or Organization	Launch	Instr. Type	Spatial Res. (meters)	No. of Bands	Spectrum (µm)	Swath Width (km)
Current Missions	SPOT-4	HRVIR	CNES-France	1998	B	10-20	5	0.5-1.75	60
	Terra	ASTER	NASA-USA/ METI-Japan	1999	B	15-90	14	0.52-11.65	60
	SPOT-5	HRS	CNES-France	2002	B	10	1	0.49-0.69	120
	ALOS	AVNIR-2	JAXA-Japan	2006	B	10	4	0.42-0.89	70
	RESOURCESAT-2	AWiFS	ISRO-India	2009	A	55	4	0.52-1.7	730
	RESOURCESAT-2	LISS-III (RESOURCESAT)	ISRO-India	2009	B	23.5	4	0.52-1.75	141
Future Planned Missions	CBERS-3	MUX	CAST-China/ INPE-Brazil	2011	A	20	4	0.45-0.89	120
	RESOURCESAT-3	WS LISS III	ISRO-India	2014	A	10-23.5	4	VNIR, SWIR	700
	CBERS-4	MUX	CAST-China/ INPE-Brazil	2014	A	20	4	0.45-0.89	120

Glossary of Terms

Some of the descriptions below include paraphrased material from the noted references.

Term	Description
Agriculture SBA	Food supplies depend on trends in the natural environment, including weather and climate, freshwater supplies, soil moisture and other variables. Within the Agriculture SBA there is access to data resources covering areas such as land cover, land use, crop, global farming system, food security. [28]
Biodiversity SBA	Biological diversity encompasses all of the Earth's plants, animals and micro-organisms; the genetic variation within each species; and the diverse ecosystems in which living things form communities and interact with one another and with the air, water, and soil around them. [28]
Climate SBA	Global and regional resources to help in the understanding and evaluation of key indicators that define how our climate is changing. [28]
Disasters SBA	When disaster strikes, rapid access to data on land and ocean conditions, maps of transport links and hospitals, weather forecasts, and information on socio-economic variables can save uncounted lives. Within the Disasters SBA there are resources linked to emergency response, disaster warning, relief mobilization and tele-medicinal support, post-disaster damage assessment, reconstruction, and rehabilitation. [28]
Earth User Community	The earth community focuses on minerals, soils, and sediments.
Ecosystems SBA	Terrestrial, coastal and marine ecosystems provide essential socio-economic and environmental benefits. Ecosystems the world over, however, are under tremendous stress from rapid land-use change, pollution and the overexploitation of natural resources. [28]
Energy SBA	Data sets to help governments and companies manager energy resources more effectively. [28]
fAPAR	The fraction of photosynthetically active radiation absorbed by vegetation canopies. It is data necessary for understanding how sunlight interacts with the Earth’s vegetated surfaces. [9]
Fire Fractional Cover	Also known as fire cover or fire area, is Fraction of fire occurring in an area. [7]
Fire temperature	Temperature of the fire occurring within an area. [7]
Fraction Of Vegetated Land	Also known as fraction of vegetation cover (FVC). It accounts for the amount of vegetation distributed on a flat background. [20]
Geo-Hazards User Community	The geo-hazards community is designed to address and aid in emergencies such as volcanic eruptions, forest fires, and large-scale damaging weather-related events.
Glacier cover	The fraction of an area covered by permanent ice. [7]

Term	Description
Health SBA	A comprehensive series of data sets that support prevention, early warning, research, health-care planning and delivery, and public alerts. [28]
High Resolution Optical Imagers *(Instrument Type B)*	High resolution optical imagers provide detailed images of the Earth's surface. In general, these are nadir-viewing instruments with a horizontal spatial resolution in the range 10 to 100 m and swath widths of order 100 km. In the past few years, high resolution sensors have emerged with spatial resolution in the range 1 to 5 m. An increasing number of government-funded and private sector-funded sensors with sub 5 m resolution are planned for the coming years. [9]
Imaging Multi-Spectral Radiometers (vis/IR) *(Instrument Type A)*	Visible/IR imaging multi-spectral radiometers are used to image the Earth's atmosphere and surface, providing accurate spectral information at spatial resolutions of order 100m up to several km, with a swath width generally in the range several hundred to a few thousand km. [9]
Land cover	Processed from land surface imagery by assigning identified cluster(s) within a given area to specific classes of object. [7]
Land Surface Imagery	A Level-1 product (not a geophysical parameter) from higher-resolution imagery covering wavelengths in the range 0.4-1 µm (cloud-affected). [7]
Land surface temperature	In general terms, how hot the "surface" of the Earth would feel to the touch in a particular location. From a satellite's point of view, the "surface" is whatever it sees when it looks through the atmosphere to the ground. It could be snow and ice, the grass on a lawn, the roof of a building, or the leaves in the canopy of a forest. Thus, land surface temperature is not the same as the air temperature that is included in the daily weather report. [16]
Land Surface Topography	Map of land surface heights. [7]
Leaf area index (LAI)	The ratio of green leaf area per unit area. LAI is defined as half the total leaf area per unit ground surface area. More specifically, for broad leaf trees such as aspen or maple, it is the one-sided leaf area while for coniferous trees such as jack pine and black spruce, it is half the total needle area. [10]
Near Infrared (VIR)	The wavelengths of the electromagnetic spectrum classified as near infrared (NIR) span from 0.7 µm to 1.3 µm. The predominant mode of energy detection is that of reflected sunlight. [29]
Normalized Difference Vegetation Index (NDVI)	An index calculated from reflectances measured in the visible and near infrared channels. It is related to the fraction of photosynthetically active radiation. [10]
Permafrost	A permanently frozen layer at variable depth below the surface in frigid regions of a planet (as Earth). [11]

Term	Description
Photosynthetically Active Radiation (PAR)	Radiation between 400 and 700 nm used by the green canopy in the photosynthetic process. [10] It can be absorbed by chlorophyll in green plants and drive the photosynthetic processes in green plant tissues. Therefore, PAR is directly linked to vegetation net primary production, land-atmosphere exchange of energy, water and carbon. [13]
Short-wave infrared (SWIR)	The wavelengths of the electromagnetic spectrum classified as short-wave infrared (SWIR) span from 1.3 µm to 3 µm. The predominant mode of energy detection is that of reflected sunlight. [29]
Snow cover	The fraction of snow in a given area. [7]
Societal Benefit Area (SBA)	Specific areas of socio-economic benefit used by the Group on Earth Observation (GEO) to define the scope of the Global Earth Observation System of Systems (GEOSS). [28]
Soil type	Also know as soil classification, is the systematic arrangement of soils into groups or categories based on their characteristics. Broad groupings are made on the basis of general characteristics and subdivisions on the premise of more detailed differences in specific properties. [11]
Surface Spectral Albedo	The percentage of incoming radiation that is reflected by a natural surface such as the ground, ice, snow, water, clouds, or particulates in the atmosphere. [11]
Thermal infrared (TIR)	The wavelengths of the electromagnetic spectrum classified as thermal infrared (TIR) span from 6 µm to 14 µm. TIR is also referred to as long-wave infrared or LWIR. The detected energy is a mixture of solar reflected and thermally emitted radiation. [29]
Vegetation type	A conceptual grouping of a number of stands of vegetation, of similar physiognomy, composition, structure, etc., for purposes of description and mapping. The vegetation, as shown on a map, may include a small percentage of areas of different vegetation, too small to be shown separately. [21]
Vegetation User Community	The vegetation community uses LSI data to assess factors related to topics such as agriculture, forest management, crop type, chlorophyll, vegetation land cover, and leaf or canopy differences.
Visible (VIS)	The wavelengths of the electromagnetic spectrum classified as visible (VIS) span from 0.4 µm to 0.7 µm. The predominant mode of energy detection is that of reflected sunlight. [29]
Water SBA	Datasets that reflect the many different ways in which water plays a key role in many areas of the global ecosystem. [28]
Water User Community	The water community analyzes snow and lake cover, water properties such as clarity, and body of water delineation.
Weather SBA	Real-time resources providing access to global weather data and archival information. [28]

Acronyms

Acronym	Definition
ANN	Artificial Neural Networks
CEOS	Committee on Earth Observation Satellites
DEM	Digital Elevation Maps
EO	Earth Observation
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
fPAR	Fraction of Photosynthetically Active Radiation
FVC	Fraction of Vegetation Cover
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GOS	Global Observing System
IR	Infrared
LAI	Leaf Area Index
LSI	Land Surfacing Imaging
LU/LC	Land Use / Land Cover
LULCC	Land-Use and Land-Cover Change
MIM	Missions, Instruments, and Measurements
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
PAR	Photosynthetically Active Radiation
SBA	Societal Benefit Area
SWIR	Shortwave Infrared
TIR	Thermal Infrared
USGS	United States Geological Survey
VIS	Visual
WMO	World Meteorological Organization

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