The CEOS Constellation for Land Surface Imaging

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ABSTRACT

A constellation of satellites that routinely and frequently images the Earth's land surface in consistently calibrated wavelengths from the visible through the microwave and in spatial detail that ranges from sub-meter to hundreds of meters would offer enormous potential benefits to society. A well-designed and effectively operated land surface imaging satellite constellation could have great positive impact not only on the quality of life for citizens of all nations, but also on mankind's very ability to sustain life as we know it on this planet long into the future.

The primary objective of the Committee on Earth Observation Satellites (CEOS) Land Surface Imaging (LSI) Constellation is to define *standards* (or guidelines) that describe optimal future LSI Constellation capabilities, characteristics, and practices. Standards defined for a LSI Constellation will be based on a thorough understanding of user requirements**,** and they will address at least three fundamental areas of the systems comprising a Land Surface Imaging Constellation: the space segments, the ground segments, and relevant policies and plans. Studies conducted by the LSI Constellation Study Team also will address current and shorter-term problems and issues facing the land remote sensing community today, such as seeking ways to work more cooperatively in the operation of existing land surface imaging systems and helping to accomplish tangible benefits to society through application of land surface image data acquired by existing systems. 2007 LSI Constellation studies are designed to establish initial international agreements, develop preliminary standards for a mid-resolution land surface imaging constellation, and contribute data to a global forest assessment.

Key Words: remote sensing, land surface imaging, constellation, international collaboration, societal benefits.

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1. INTRODUCTION

The Committee on Earth Observation Satellites (CEOS) is an international organization charged with coordinating international civil space missions designed to observe and study planet Earth. CEOS is comprised of 26 Members, most of which are national space agencies, and 20 Associate Members that include various national and international organizations that apply Earth observation (EO) data in their programs. CEOS is recognized as the major international forum for the coordination of Earth observation satellite programs and for interaction of these programs with users of satellite data worldwide. It also is recognized as the coordination body of the space component of the Global Earth Observing System of Systems (GEOSS).

The CEOS Task Force charged with drafting the *CEOS Implementation Plan for Space-Based Observations for GEOSS* (Implementation Plan) have stated their belief that such a plan should be the focus for a new planning process that takes account of international users and their requirements from the outset of satellite projects. Furthermore, the 19th CEOS Plenary concluded the Implementation Plan should:

- identify the supply of space-based observations required to satisfy requirements expressed by the 10-year Implementation Plan for GEOSS; and
- *propose an innovative process* whereby the many disparate types of Earth observing programs funded by CEOS member agencies might contribute to the supply of the required observations.

The CEOS Constellations Concept has emerged as the "innovative planning process" referenced above that is being proposed by the CEOS Implementation Plan Task Force. It is intended to address the shortcomings in the international planning process for space-based Earth observations without eroding the independence of individual agencies. The concept is envisioned as a process that will engage disparate Earth observing programs of CEOS member agencies and ultimately facilitate their contribution in supplying the space-based observations required to satisfy the requirements expressed by the 10-year Implementation Plan for GEOSS. Consequently, the concept now is commonly referred to as the CEOS Constellations for GEOSS. The fundamental idea of the CEOS Constellations for GEOSS concept is to extract clear requirements from target user communities and translate those requirements into standards which can serve as guidance in the development of future systems and against which future proposed Earth observing systems can be assessed.

CEOS has established study teams to define four prototype constellations, on each for: precipitation, land surface imaging, ocean surface topography, and atmospheric composition. This paper addresses the CEOS Land Surface Imaging (LSI) Constellation.

2. POTENTIAL IMPORTANCE OF A LSI CONSTELLATION

The potential benefits offered by a constellation of satellites that routinely and frequently image the Earth's land surface in consistently calibrated wavelengths from the visible through the microwave and in spatial detail that ranges from sub-meter to hundreds of meters are significant. Such a constellation would provide the fundamental data required by scientists to help predict, and certainly mitigate the effects of, natural disasters; to explore for critical energy and mineral resources; to monitor climate change; to study ecosystems and biodiversity; to address important human health issues; and to undertake many other equally important scientific and practical endeavors with efficiency and effectiveness not previously possible. A well-designed and effectively operated land surface imaging satellite constellation could have profound impact not only on the quality of life for citizens of all nations, but also on mankind's very ability to sustain life as we know on this planet long into the future.

3. MISSION AND OBJECTIVES OF THE CEOS LSI CONSTELLATION

The fundamental mission of the CEOS LSI Constellation is 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). Significantly, this mission addresses not only the building and launching of satellite systems, but also the development and operation of associated ground segments and their ability to get critical data efficiently into the hands of many interdisciplinary science users and practical applicationists. To accomplish this mission, a LSI Constellation Study Team, charged with carrying out necessary studies and activities, has been established.

The primary objective of the Land Surface Imaging Constellation is to define a broad range of rather detailed characteristics (or *standards*) that describe optimal, end-to-end capabilities (and policies) to acquire, receive, process, archive, and distribute to the global user community space-acquired land surface image data, which users will find optimally applicable to the broadest possible range of scientific and practical endeavors important in meeting the needs of mankind. The beneficial outcomes from defining such standards will be the guidance they provide for the coordinated development of future systems, as well as the foundation they provide for establishing criteria against which future proposed Earth observing systems can be assessed. In that context, it will be an objective of the LSI Constellation studies to develop appropriate criteria, based on the defined standards, which CEOS can use to assess and endorse future systems proposed by its member agencies.

An important objective of the LSI Constellation Study Team is to extensively engage the land remote sensing user community, including those representing the GEO societal benefit areas, to fully determine the scientific information requirements desired to be met by the data acquired by and accessible from elements of the Land Surface Imaging Constellation. The beneficial outcome from user-defined requirements will be the enhanced ability to define standards, which will lead to systems that will more fully meet those requirements of the broad land remote sensing user community.

It also will be an objective of LSI Constellation studies to identify opportunities where near-term gains may be made by early determination of user requirements and development of applicable standards for urgently needed systems, from the application of newly developed policy recommendations to existing data systems, or by facilitating CEOS efforts to integrate data from multiple systems to fill a potential gap in the continuity of Landsat data, for example. The important outcomes from accomplishing this objective lie in the early benefits that will be derived by segments of the land surface imaging user community, as well as in the opportunity to demonstrate the value that CEOS Constellations can contribute to GEO and its members.

4. METHODOLOGY AND SCOPE

LSI Constellation methodology will focus on the definition and accomplishment of a series of Constellation studies and activities carried out by or under the direction of the LSI Constellation Study Team. Among other things, but most significantly, these studies and activities will result in definition of the *standards* (or guidelines) that describe optimal future LSI Constellation capabilities, characteristics, and policies. Constellation studies and activities also will address shorter-term problems and issues facing the land remote sensing community today, such as seeking ways to work more cooperatively in the operation of existing land surface imaging systems.

LSI Constellation standards will not all be defined by a single study. Rather, many studies, each focusing on a spatial-resolution-based or spectral-based subset of the full scope of land surface imaging sensor systems will be needed. These will be conducted in a phased approach based on urgency of definition. In terms of general scope, studies leading to the definition of standards for a land surface imaging constellation will address **user requirements,** and they will examine at least three fundamental areas of the systems comprising a LSI Constellation: the **space segments**, the **ground segments**, and relevant **policies and plans**.

Sec. 4.1 LSI Constellation Study Team

A LSI Constellation Study Team has been established to perform and coordinate the studies and other activities required to achieve LSI Constellation goals and objectives. Membership on that team includes representatives of eleven space agencies that have responsibility for developing, launching, and operating land surface imaging satellite systems. In addition, scientists from a representative cross-section of the land remote sensing user community serve as members on the LSI Constellation Study Team. Current membership on the Study Team is well-suited for addressing current goals

and objectives. In the future, as new goals and objectives are defined for the LSI Constellation, additional members for the Study Team likely will be recruited. The U.S. Geological Survey and the Indian Space Research Organisation co-chair the LSI Constellation Study Team and co-lead LSI Constellation activities.

Sec. 4.2 User Requirements

User requirements will be the foundation of Land Surface Imaging Constellation studies, and determining those requirements will become a major undertaking of this work. Yet, this endeavor is not the first to seek to identify comprehensive user requirements for land surface imaging data. The LSI Constellation Study Team will utilize, to the extent possible, results of other well-substantiated requirements studies conducted by CEOS organizations and by other reputable researchers. Examples of requirements studies that this study team might draw upon include those conducted by the Global Climate Observing System, the U.S. National Science and Technology Council's Future of Land Imaging Interagency Working Group, the IGOS Integrated Global Observations Land Theme, the Landsat Data Continuity Mission, and the GMES Programme. Building upon results of such other requirements studies, Land Surface Imaging Constellation Studies will implement processes to further define and compile the comprehensive set of requirements that will be translated into standards for various segments the CEOS LSI Constellation. Particular attention will be given to fully identifying those requirements that are important in addressing the nine SBAs defined by GEO.

Sec. 4.3 Space Segments

Standards developed for the space segments of the CEOS Land Surface Imaging Constellation will focus on the characteristics of various sensor systems that must comprise the constellation in order to satisfy the full spectrum of user requirements. Standards will be developed for various spectral and spatial characteristics such that user requirements for imaging in the visible, short-wave infrared (IR), thermal IR, and microwave (both passive and active) regions of the electromagnetic spectrum at high, medium, and coarse spatial resolutions are fully addressed. Geographic coverage and temporal characteristics are two other important sensor system parameters that must be addressed in the context of user requirements. Additional sensor characteristics for which constellation standards must be developed include radiometric accuracy and precision, dynamic range, polarization sensitivity, radiometric stability, pointing and geolocation accuracy, angular resolution and accuracy, band-to-band registration precision, modulation transfer function specifications and uniformity, spectral uniformity and band shape, and others.

While sensor system characteristics are the most important space segment components the CEOS Land Surface Imaging Constellation must address, they are not the only ones. Other potentially important space segment characteristics this study will examine include launch services, platform, orbital characteristics, on-board data recording capabilities, and others.

Sec. 4.4 Ground Segments

Standards developed for the ground segments of the CEOS Land Surface Imaging Constellation will focus on the characteristics of data reception, data processing, data archiving, and data distribution systems needed to satisfy identified user requirements. The design and operation of each of these ground system components can affect the ability of users to fully utilize the data collected by the space segment sensors. The ease with which users can apply data from a given system is affected by the level of processing applied by the provider, the metadata provided with the image data, and the format in which the data are delivered. Ground systems that provide for long-term preservation of data will be more beneficial over time because of the historical value of the data preserved. As a final example, ground systems that include media distribution options will be able to serve more users than one that only offers delivery via file transfer protocol (ftp). In addition to these primary ground system functions, characteristics of satellite command-and-control systems and functions, availability and qualifications of user services staff, and characteristics of associated data and information systems are examples of various other ground system components for which this study will define standards.

Sec. 4.5 Policies and Plans

As equally important as optimal sensor systems and proficient ground systems to the efficient and effective application of land surface image data are data policies and plans that promote, rather than inhibit, use of the data. Consequently,

LSI Constellation studies will examine various policies and plans, including data acquisition strategies and data distribution policies, that can affect user access to data and thus their ability to effectively apply those data in pursuit of the common good. Standards related to data policy will be developed that encourage easy access to global land surface image data and promote beneficial application of the data by users around the world.

5. 2007 GOALS, OBJECTIVES, AND OUTCOMES

Recognizing that definition, development, and implementation a CEOS LSI Constellation will not be a trivial undertaking and is one that must be accomplished over time with a phased approach, the LSI Constellation Study Team established three main goals for 2007, which address both near-term and longer-term LSI Constellation goals. Emphasis in 2007 was placed on addressing mid-resolution (10m-30m) land imaging systems. The three primary goals are:

1) establish agreement(s), among space agencies currently operating mid-resolution land surfacing imaging satellite systems, to cooperate more closely together to operate those assets as a real prototype Land Surface Imaging Constellation;
2) develop preliminary standards for a mid-resolution Land Surface Imaging Constellation; and
3) meaningfully contribute to the production of a fundamental climate data record (FCDR).

Sec. 5.1 Establish Agreement to Operate Current Mid-Resolution Systems as a Real Prototype LSI Constellation

Currently, approximately eight CEOS member space agencies independently operate a dozen or more mid-resolution land surface imaging satellite systems that routinely acquire, archive, and distribute image data to segments of the land remote sensing user community. That user community could more efficiently and effectively address many key societal problems and issues if the space agencies were to operate their mid-resolution land surface imaging systems in more coordinated ways.

In addition, the fundamental concept of the CEOS Constellations is to try to get the world's space agencies to design, build, and operate their future earth observation satellite systems according to "community-defined" standards. If this concept is to prove viable, a logical place to begin is with those agencies agreeing to cooperate more fully in operating the systems they already have in space. If they are not able to take that step, then the viability of the entire CEOS Constellations concept must be questioned.

Sec. 5.1.1 Objectives

The primary objective of this 2007 goal is get CEOS member space agencies that currently operate mid-resolution land surface imaging satellite systems to agree to cooperate more closely in the operation of those systems. That is, to agree to begin to operate their existing mid-resolution land surface imaging assets like a ***real*** prototype LSI Constellation.

It is also an objective of this goal to begin to add specificity to the higher-level agreement to cooperate more fully in operating existing systems by establishing up to three multilateral agreements that define specific cooperation in the areas of 1) improved or expanded data access; 2) operation of ground systems; and 3) development of coordinated data acquisition and data management strategies.

Sec. 5.1.2 Approach

A "Declaration of Intent for Cooperation on Mid-Resolution Satellite Systems" was drafted by the LSI Constellation Study Team and distributed to the appropriate space agencies for review (currently in process) and signature. Specifically, the Declaration of Intent asks the agencies to "resolve to realize the benefits of a Land Surface Imaging Constellation by actively seeking ways to cooperate more fully in the operation of their existing mid-resolution land surface imaging satellite system assets."

Concurrent with the review and approval process implemented for the higher-level Declaration of Intent, a series of activities is underway to develop and approve up to three multilateral agreements, or annexes to the higher-level agreement, designed to add specificity and meaning to what "cooperating more fully in the operation of existing mid-

resolution land surface imaging satellite system assets" means. Three sub-groups of the LSI Constellation Study Team are working on preparation of more detailed agreements, or annexes to the Declaration of Intent, which address areas of specific cooperation as relate to data and operations policy, ground systems operations, and data acquisition and data management strategies. Those annexes will be provided to each CEOS agency that currently has one or more mid-resolution land surface imaging system in space for review and (hopefully) signature. In drafting the annexes, sub-groups are looking to balance what users may desire and what agencies may be willing to agree to so as to present agreements to the agencies that likely will be signed by at least some of those agencies. One area of focus for the sub-group that addresses *data acquisition strategies* will be to develop a strategy to meet requirements for land surface imaging data in the event of failure of one or more existing mid-resolution satellite systems.

5.1.3 Deliverables

There are two fundamental deliverables from achieving this goal: 1) a formal agreement signed by CEOS agencies with mid-resolution land surface imaging satellite systems currently in space to cooperate more fully in the operation of those systems so that they may function like a ***real***, prototype land surface imaging constellation; and 2) up to three annexes to the higher-level agreement, signed by two or more signatories to that higher-level agreement, agreeing to cooperate in the performance of specific activities or agreeing to adopt specific common strategies related to data access, ground systems operations, and data acquisition of their existing mid-resolution LSI systems.

Sec. 5.2 Define Initial Standards for a Mid-Resolution LSI Constellation

The definition of *standards* that describe optimal characteristics of earth observation satellite systems, which can guide the definition, development, and operation of such systems in the future, is the fundamental objective of the CEOS Constellations concept. This goal ensures that 2007 LSI Constellation activities address this fundamental objective by defining initial standards for mid-resolution land surface imaging systems. Mid-resolution systems were selected because of their importance in addressing a broad range of important societal problems and issues, as well as because of concerns over potential continuity and data gap issues.

Sec. 5.2.1 Objectives

The primary objective of this 2007 goal is to define an initial set of standards that describe optimal characteristics for the space and ground segments of a mid-resolution LSI Constellation, as well as policy and operational considerations associated with such a constellation. In the process of meeting this first and primary objective, it also is an objective of this goal to engage the diverse land remote sensing user community to define a representative cross-section of their information requirements and to use those requirements in the definition of constellation standards.

Sec. 5.2.2 Approach

The initial step in meeting this objective is to compile a representative cross-section of land remote sensing user information requirements and technical requirements. This exercise is drawing heavily upon previous compilations of land remote sensing user requirements and the collective experience and expertise of LSI Constellation Study Team members and colleagues within their agencies and organizations.

Definition of standards for the space segments and ground systems of mid-resolution LSI Constellation will be accomplished separately, led by two of the LSI Constellation Study Team sub-groups. A third sub-group will define standards (or perhaps more accurately, guidelines) associated with certain policies and operational considerations, particularly those that affect data access. All sub-groups will develop the standards and guidelines in consideration of the user requirements previously compiled.

Sec. 5.2.3 Deliverables

Two primary deliverables are planned for this goal: 1) a compilation of a representative cross-section of interdisciplinary user requirements associated with land remotely sensed data; and 2) an initial compilation of standards and guidelines that describe optimal characteristics for a future mid-resolution LSI Constellation.

Sec. 5.3 Data for a Fundamental Climate Data Record

Since 1972, spaceborne sensors have provided scientists with a wealth of data that have been meaningfully applied in countless important land surface-related scientific and practical endeavors. Yet, the premise of the CEOS Constellations Concept is that we can do better…and more. This goal seeks to demonstrate and illustrate the value of the Constellations Concept by cooperating in the provision of data for the development of a fundamental climate data record (FCDR).

Sec. 5.3.1 Objectives

The objective of this goal is to facilitate and expedite the completion of the United Nations Food and Agriculture Organization's (UN FAO) Forest Resource Assessment 2010 (FRA2010) by providing coordinated access to the global land surface imaging data needed to complete the assessment.

Sec. 5.3.2 Approach

FRA2010 will utilize Landsat data from the Tri-Decadal Global Landsat Orthorectified dataset and from the Mid-Decadal Land Survey as the primary remotely sensed data to be used in the forest assessments to be conducted as part of FRA2010 studies. However, with nearly 10,000 20km x 20km global sampling sites, it is anticipated that there will be gaps in the Landsat data coverage. The LSI Constellation Study Team is working with the FRA2010 Project to identify where those gaps are and to establish the specific needs for data to fill those gaps. In addition, the LSI Constellation Study Team sub-group for Data and Operations Policy will work to establish agreements with space agencies that currently operate mid-resolution land surface imaging satellite systems to provide the data needed by FRA2010 to fill the gaps in the primary data coverage.

Sec. 5.3.3 Deliverables

The most important deliverable from this goal will be the data provided to the FRA2010 for use in performing a global forest assessment. However, two other important deliverables are needed in the process of providing access to the data. They are: 1) a report that describes the land surface image data requirements, including time epoch, geographic coverage, and optimal sensor, associated with the FRA2010 assessment, and 2) an agreement among the contributing CEOS space agencies that describes the terms and conditions under which the data will be provided and, in general terms at least, what data will be provided.

6. CONCLUSIONS

The CEOS LSI Constellation Study Team currently is engaged in the first of many studies that ultimately will define, based on identified user requirements and in terms of specific standards, the characteristics of optimal land surface imaging systems (space segments, ground systems, and related policies). Standards defined by the studies can serve as guidance in the development of future systems, as well as criteria against which future proposed Earth observing systems can be assessed. In 2007, emphasis is being place on definition of standards and guidelines related to mid-resolution land surface imaging systems. In addition, activities currently are being conducted that will result in greater coordination and cooperation among international space agencies that operate mid-resolution systems such that data from those existing systems will be more accessible, and of greater benefit, to users of land remotely sensed data worldwide. As an early demonstration of the potential value of an operational LSI Constellation, the LSI Constellation Study team is working to facilitate the provision of mid-resolution land surface image satellite data need to complete the Forest Resource Assessment 2010.

7. REFERENCES

CEOS LSI Constellation Study Team, "CEOS Land Surface Imaging Constellation 2007 Work Plan," submitted to the CEOS Strategic Implementation Team, unpublished report, 8 p., 2007

CEOS LSI Constellation Study Team, "Proposal for a CEOS Land Surface Imaging Constellation," proposal to the CEOS Strategic Implementation Team, unpublished proposal, 8 p., 2007

CEOS, "Satellite Observation of the Climate System," The Committee on Earth Observation Satellites (CEOS) Response to the Global Climate Observing System (GCOS) Implementation Plan (IP), Committee on Earth Observing Satellites, 50 p., 2006

CEOS, "CEOS Constellations Concept Paper," submitted to the CEOS Strategic Implementation Team, SIT-18 meeting document, 6 p., 2006

IGOS, "Integrated Global Observations of the Land – A proposed theme to the IGOS Partnership," Integrated Global Observing Strategy Partnership, 11th IGOS Partners Meeting, Rome, Italy, 11 p., 2004

Bailey, G. B., Lauer, D.T., Carneggie, D.M, "International Collaboration: The Cornerstone of Satellite Land Rremote Sensing in the 21st Century," Space Policy, v. 17, p. 161-169, 2001