# Developing Climate Data Records and Essential Climate Variables from Landsat Data

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**Abstract -** The series of Landsat missions has compiled the longest record of satellite observation of the Earth's land surface, extending for more than 38 years for most areas of the globe. Landsat data are particularly important as long term climate data records because the scale of observation is sufficient to differentiate between natural and human drivers of land cover change. The USGS has established consistent radiometric calibration across the Landsat TM and ETM+ sensors, and have extended the calibration back to the earlier MSS sensors. The USGS is developing capabilities to create fundamental climate data records (FCDRs), thematic climate data records (TCDRs), and essential climate variables (ECVs) from the Landsat data archive. Two high priority TCDRs were identified: surface reflectance and land surface temperature because they have direct application or are required as input to the generation of ECVs. We will focus development on a few of the terrestrial ECVs that have a high potential for being derived from Landsat data, that include land cover, albedo, fire disturbance, surface water, snow and ice, and leaf area index (LAI). We are collaborating with scientists who have demonstrated successful algorithm development and application of these science products to develop a framework of processing capabilities to support research projects and land management applications, along with an independent strategy for product validation. Our goal is to scale the creation and validation of these products from specific sites in the conterminous U.S. and Alaska, for extension to continental and global scales.

Keywords: fundamental climate data record, thematic climate data record, essential climate variables, Landsat, terrestrial monitoring.

## 1. INTRODUCTION

The series of Landsat missions has compiled the longest record of satellite observation of the Earth's land surface, extending for more than 38 years for most areas of the globe. Landsat data are particularly important as long term climate data records because the measurements are at a scale that allows differentiating natural from human-induced influences for land cover change. The USGS has established consistent radiometric calibration across the thematic mapper (TM) and enhanced thematic mapper plus (ETM+) sensors, and consistent radiometric calibration of the multispectral sensors (MSS) has been achieved using Lanbdsat 5 MSS as the reference. The USGS changed its policy in 2008 to make standard products from all data in the Landsat archive available at no cost and without constraints on redistribution.

The concept of Climate Data Records (CDRs) as established by the U.S. National Research Council represents an appropriate framework for creating long-term Landsat land records (NRC, 2004, 2007). CDRs are defined as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. Consistency in processing and reprocessing over years and decades is required in order to permit the detection of changes in environmental conditions. Through international scientific input and review, the Global Climate Observing System (GCOS) defined *fundamental climate data records (FCDRs)* as calibrated and quality-controlled sensor data that have been improved over time. Long term satellite data records, derived from different instruments and retrieval methodologies, and intercalibrated to allow the generation of homogeneous products over time providing estimates of independent variables which are sufficiently accurate and stable for monitoring impacts of climate change. Sensors should be thoroughly characterized before and after launch, and their performance should be continuously monitored. Sensors should be thoroughly calibrated, including calibration of sensors in orbit, vicarious calibration with in situ data, and satellite-to-satellite cross-calibration.

*Thematic climate data records (TCDRs)* are defined as geophysical variables derived from the FCDRs. These must have well-defined levels of uncertainty; an ongoing program of correlative in situ measurements is required for validation. *Essential climate variables (ECVs)* were defined as measurements of atmosphere, oceans, and land that are technically and economically feasible for systematic observation and that are needed to meet UNFCCC and IPCC requirements. FCDRs and TCDRs are the fundamental inputs for deriving many ECVs.

## 2. SCIENCE STRATEGY

The USGS will develop science-quality, applications-ready time-series of key terrestrial variables using historical and current Landsat data on an operational basis. The terrestrial variables will follow the guidelines established through the GCOS (GCOS, 2010) and include FCDRs of calibrated radiances across Landsat instruments, thematic climate data records (TCDRs) that represent geophysical transformations of Landsat radiances (e.g., surface reflectance and surface temperature), and ECVs that represent specific geo-and biophysical land surface properties. Surface reflectance and land surface temperature were identified as priority TCDRs that either have direct application or are required as input to the generation of ECVs. The ECVs that have been identified as candidates for development include

land cover, albedo, fire disturbance, surface water, snow and ice, and leaf area index (LAI).

Current USGS science strategies (USGS, 2007) exploit the unique characteristics of Landsat to make the Landsat archive more valuable for a wider range of uses. Central to those uses is the need to provide application ready datasets representing land and water characteristics that are consistent over the full 38+ year record and suited to detecting and monitoring changes in land surface conditions and to supporting analysis and modeling of climate and other related earth system processes. The value of Landsat observations for science and applications has also been noted by many U.S. organizations (e.g., Office of Science and Technology Policy, NASA, National Science Foundation, U.S. Department of Agriculture, Environmental Protection Agency) and international (e.g., Group on Earth Observations, Intergovernmental Panel on Climate Change, World Meteorological Organization, GCOS). There are a number of international research initiatives that are reliant on Landsat data to achieve their objectives: GEO Forest Carbon Tracking, the U.N. Food and Agricultural Organization Forest Resource Assessment, monitoring forest change in the Amazon River basin and the tropical forest regions of the world, and the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries. Each of these activities requires the historical perspective and spatial resolution that are uniquely afforded by Landsat data.

Beyond the USGS and DOI, the need for land variables to identify and assess changes in land cover and condition is significant. Collaboration between the USGS and the U.S. Forest Service (fire issues, forest inventory), National Agricultural Statistical Service (crop area estimation), the U.S. Environmental Protection Agency (environmental quality studies), NOAA (coastal zone management), and NASA (Earth science investigations) require land variables at Landsat scales. Information derived from Landsat data represent a significant continuous record of observations, providing a framework within which to integrate data collected at multiple spatial and temporal resolutions.

## 3. TERRESTRIAL MONITORING

The USGS recognizes that comprehensive and integrated land-change monitoring capabilities are required to quantify and understand natural- and human-induced patterns of land change, provide inputs to land-change models, and inform scientific assessments and decision making. Stakeholders require a foundation of consistent science data (CDRs, ECVs) relevant to a wide range of users and applications. Assessments of land change enabled by long term data records will inform scientists, policy makers, and land managers operating at local, regional, and global levels of emerging land trends.

Landsat represents the only historically consistent set of observations for many parts of the world. The demand for web-enabled Landsat scenes continues to climb: data users in over 185 Nations have downloaded more than 4 million Landsat scenes during the past two years. In addition, there are a number of international climate change, biodiversity, land degradation, and other environment and natural resources treaties that have assessment and reporting requirements for which Landsat land data are key inputs. Thus, Landsat system is on of the most important observation platforms for observing global phenomenon over decadal time scales.

## 4. IMPLEMENTATION PLAN

The establishment of collaborative working relationships with partners from U.S. Federal agencies, universities, and international organizations is critical to the success of this activity. There is a substantial body of knowledge and expertise that stems from the development of higher-level science products from data collected by wide field-of-view instruments such as AVHRR, MODIS, and MERIS. The USGS will seek opportunities for collaboration with science investigators that have developed and successfully demonstrated the application of these algorithms and products. These partnerships are critical for understanding requirements and leveraging expertise.

Products will be validated using *in situ* measurements, airborne observations, or other geospatial data collected through USGS research, by existing and planned observational networks such as Aeronet, AmeriFlux, Long Term Ecological Research sites, the National Ecological Observation Network, monitoring and inventory activities conducted by Federal operational land management programs, and international activities being conducted under the auspices of the GEO and the CEOS. Characterization and quantification of errors and uncertainties will be reported in product metadata.

Product evaluation will be performed through reanalysis of previously demonstrated applications using the new CDR and ECV products, using selected sites or areas defined by research and applications users that trace back to previously defined requirements. The USGS will perform product validation and evaluation using independent sites in order to identify geographic areas and land surface conditions for which algorithms, processing parameters, and products have limitations. Results from product validation and validation will be documented and presented for independent peer review.

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