Earth Observations

in support of the

2030 Agenda for Sustainable Development

GROUP ON
EARTH OBSERVATIONS





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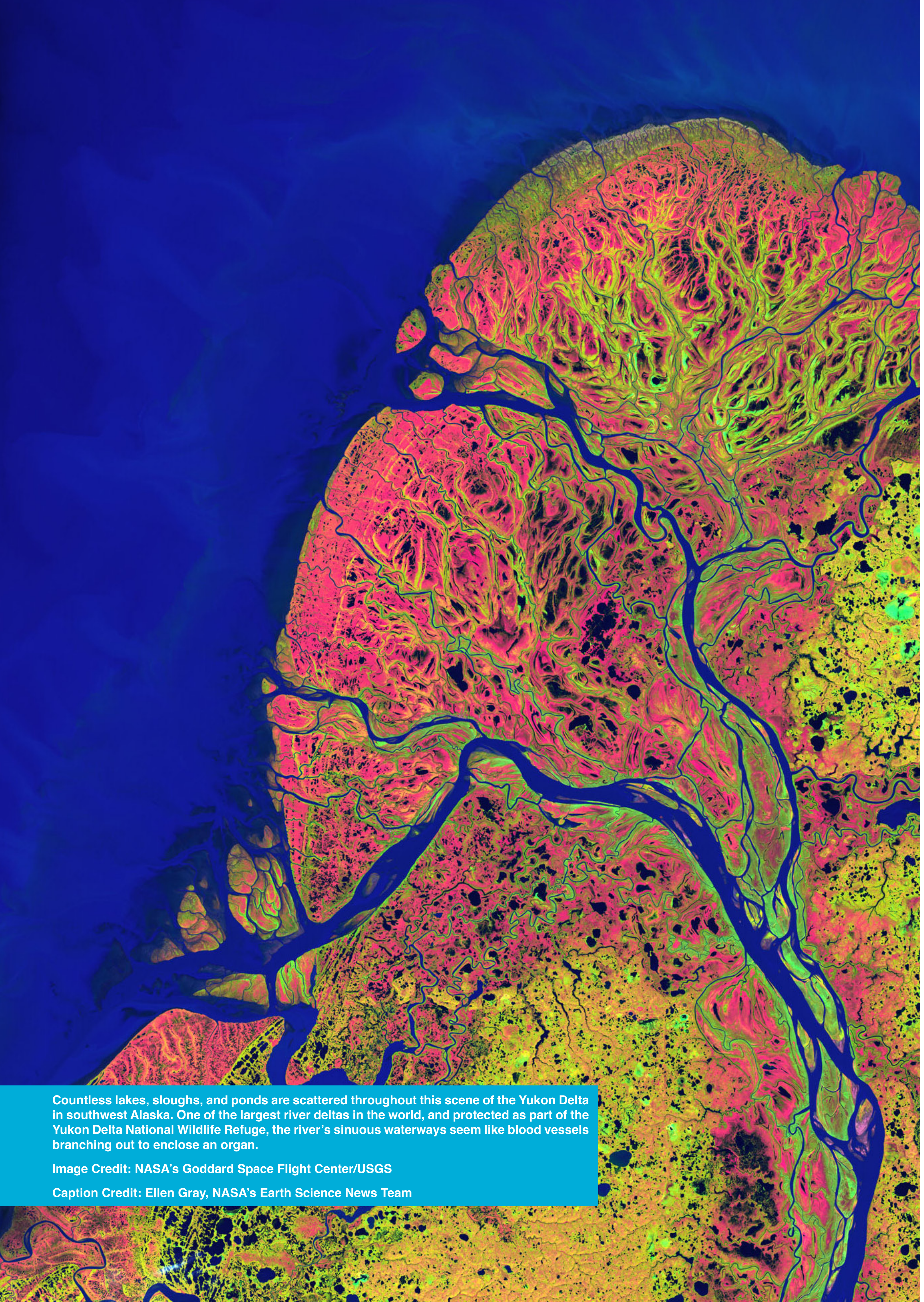


Countless lakes, sloughs, and ponds are scattered throughout this scene of the Yukon Delta in southwest Alaska. One of the largest river deltas in the world, and protected as part of the Yukon Delta National Wildlife Refuge, the river's sinuous waterways seem like blood vessels branching out to enclose an organ.

Image Credit: NASA's Goddard Space Flight Center/USGS

Caption Credit: Ellen Gray, NASA's Earth Science News Team

Contents

1 Introduction

Context

In adopting the 2030 Agenda for Sustainable Development, world leaders agreed that a global Indicator framework was necessary to measure, monitor and report progress towards the 17 transformational Sustainable Development Goals (SDGs) and 169 associated Targets. They also recognised the critical importance of “transparent and accountable scaling-up of appropriate public-private cooperation to exploit the contribution to be made by a wide range of data, including Earth observation and geospatial information, while ensuring national ownership in supporting and tracking progress”.

To track progress towards these Goals and Targets, the global Indicator framework must capture the multi-faceted and ambitious aspirations for the continued development of nations and societies. Effective reporting of progress toward these Indicators will require the use of multiple types of data, both what we have in hand – traditional national accounts, household surveys and routine administrative data – and new sources of data outside national statistical systems, notably Earth observations (EO) and geospatial information (GI), using modern data processing techniques more appropriate to large volumes of EO data.

The integration of all these data can produce a quantum leap in how we monitor and track development and advance the well-being of our societies. Since Earth observation and geospatial information are often continuous in their spatial and temporal resolutions, their use in SDG monitoring can prove essential in capturing the sustainability of developments underpinning the SDG framework. Earth observation and geospatial information, which include satellite, airborne, land- and marine-based data, as well as model outputs, will expand monitoring capabilities at local, national, regional and global levels, and across sectors.

Earth observation and geospatial information can significantly reduce the costs of monitoring the aspirations reflected in the Goals and Targets, and make SDG monitoring and reporting viable within the limited resources available to governments.

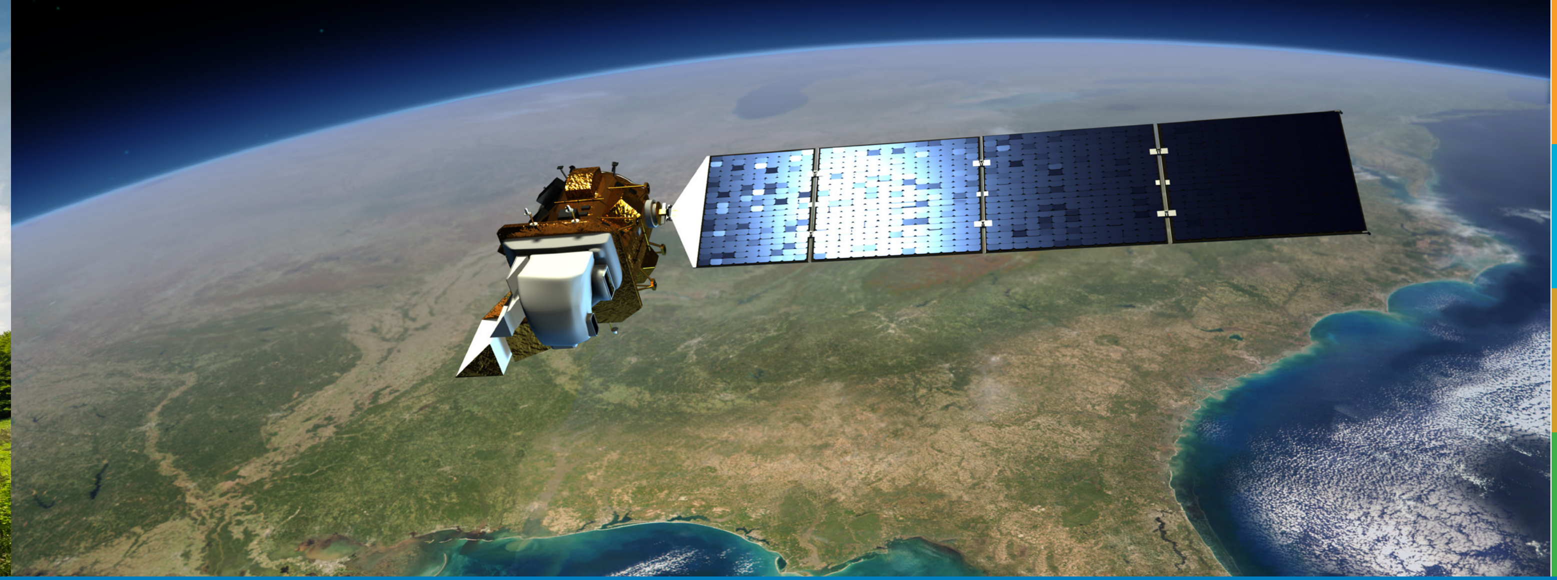
Purpose

This booklet has been developed to highlight the potential role for Earth observations in particular in supporting the global Indicator framework for the SDGs. It has been developed through a cooperation between the Group on Earth Observations (GEO) and the Committee on Earth Observation Satellites (CEOS – the peak body for coordination of satellite Earth observation programmes of all the world’s civil space agencies).

A successful sustainable development agenda will require effective partnerships for implementation. This report describes how GEO, CEOS and space agencies are working with governments, academia, scientists, and the private sector in developing such partnerships for implementation of the Sustainable Development Goals.

Contents

Section 2 explains the broad potential for satellite Earth observations to contribute to the SDGs. Section 3 contains a number of case studies supplied by governments and agencies to demonstrate specific applications of Earth observations in relation to the SDGs and national ambitions. Section 4 speaks to national statistical organisations and UN organisations considering the application of Earth observations and provides guidance around the challenges and opportunities to their use for SDG purposes. Brief conclusions and sources of further information are provided in section 5.



2 Earth Observations for the SDGs

Governments, industry, and scientists have long recognised the critical importance of Earth observations as an information source in support of many sectors of society. Earth observations (from satellite, airborne, and *in-situ* sensors) provide accurate and reliable information on the state of the atmosphere, oceans, coasts, rivers, soil, crops, forests, ecosystems, natural resources, ice, snow and built infrastructure, and their change over time, are directly or indirectly necessary for all functions of government, all economic sectors and almost all day-to-day activities of society. Earth observation programmes represent the largest investment globally in relation to applications of satellites by national governments – typically through their national space agencies – recognising their capacity to address such critical challenges as climate change, water availability, food security, natural disaster mitigation, safe and secure transport, energy and resources security, agriculture forestry and ecosystems, coasts and oceans, health issues, and national security.

In adopting the 2030 Agenda for Sustainable Development, world leaders recognised the important role that Earth observations and geospatial information could play in making the whole framework feasible through the provision of essential evidence, including the tracking of Indicators over time, and supporting the implementation of solutions to reach specific Targets. Effective use of the information in Earth observations can have a transformational impact on many of humanity’s most significant challenges, such as helping scientists globally, resource and planning managers and politicians better monitor and protect fragile ecosystems, ensure resilient infrastructure, manage climate risks, enhance food security, build more resilient cities, reduce poverty, and improve governance, among others.

The CEOS database of Missions, Instruments, and Measurements (MIM) notes that the world’s space agencies are currently operating or planning more than 300 different satellite missions, carrying over 900 different instrument payloads, spanning a diverse range of measurements of atmosphere, ocean, and land, supporting hundreds of applications related to matters that can affect the lives of citizens. Many of the datasets resulting from these missions are openly available through the GEOSS Common Infrastructure (GCI: http://www.geoportal.org) coordinated under the auspices of GEO. In addition, privately funded EO missions, including large constellations of smaller satellites with the capability to provide frequent coverage or repeat measurements, are rapidly increasing in number in recent years. Accordingly, the uptake of satellite data in support of National Statistical Offices (NSOs) and by UN agencies is increasing, made easier by:

- the availability of an increasing array of data streams of suitable characteristics and accuracy;
- the arrival of affordable technical solutions to address the size and complexity of such data;
- and the need to evolve from traditional statistical approaches to more measurement-based solutions as some challenges - including in relation to the environment and human populations - become more pressing, and with the need for more accurate, spatially explicit, and frequently updated evidence.

Whilst the nature of satellite-based measurements varies greatly across the many mission types and their applications, a number of common characteristics are driving their demand in support of global governance and derivation of Indicator information:

Scale: satellites can provide data on all scales from local to national, regional and even global. Indeed, they are likely the only source of global information for many parameters; depending on the application and resolution, large area (even global) datasets

Fig. 1 GEO document used for a side-event at the 47th Session of the United Nations Statistical Commission Statistical-Geospatial Integration Forum - Geospatial Information and Earth Observations: Supporting Official Statistics in Monitoring the SDGs (March, 2016). Credit: GEO

can be derived from satellites in relatively short timeframes, from daily to annually as needed and as the technology permits – allowing rapid refresh of Indicator information day and night, in all weather conditions;

Long time series and continuity: the ongoing acquisition of data by satellites systematically and over long periods of time, with some mission series dating back to the 1970s and planned up to 2030 or more, provides governments with unique evidence with which to track progress, including the establishment of baselines for the determination of future trends, for monitoring and compliance of agreements, for improved predictions, and for management and mitigation;

Consistency and comparability: satellites provide the means for the effective comparison of results among different countries which may otherwise suffer from lack of standardisation in measurements or methods, impeding attempts to derive meaningful comparisons or regional/global statistics;

Diversity of measurements: advances in science and in instrumentation have resulted in an increasingly diverse array of EO satellite missions with dozens of geophysical parameters being measured on a daily basis from a range of different satellite orbits. In the field of climate change alone, CEOS has identified that of the ~ 55 Essential Climate Variables (or ECVs) more than half have a major contribution from satellite observations or simply would not be feasible without satellites (such as polar ice extent, and global sea level).

Complementarity with traditional statistical methods: while EO datasets can be used to monitor directly some specific Indicators of SDGs, they can also offer a unique and complementary source of information to cross-check the validity of *in-situ* data measurements (such as survey and inventory data), communicate and visualize the geographic dimensions and context of the Indicators as needed, and provide disaggregation of the Indicators where appropriate.

Free and open data is on the increase: not all nations are able to develop and launch their own Earth observation satellites, with a relatively small (but growing) number having the capacity to do so. Hence the availability of the data from these missions, for all nations, is of fundamental importance to their uptake and global impact. US mission data has long been freely available, and with the advent of the free and open data policy of Europe's Copernicus programme of multiple satellite data streams, the prospects for access to the EO data required by developing countries have improved considerably.

High performance computing and cloud storage and processing capabilities are making it simpler to handle and apply EO satellite datasets which can be large and complex. And space agencies are prioritising efforts to further remove the burden on potential users by making more data 'analysis ready' (analysis ready data or ARD).

An analysis by GEO and CEOS has identified specific Targets and Indicators that can be supported by Earth observations, summarised in Figure 2.

For readers unfamiliar with the details of the individual Goals, Targets and Indicators listed, these can be identified from the following document:

http://unstats.un.org/sdgs/indicators/Official%20List%20of%20Proposed%20SDG%20Indicators.pdf

GEO GROUP ON EARTH OBSERVATIONS — THE GLOBAL GOALS

Sustainable Development Goals

Earth Observations in Service of the *Agenda 2030*

Target Contribute to progress on the Target yet not the Indicator per se									Goal	Indicator Direct measure or indirect support				
							1.4	1.5	1	1.4.2				
						2.3	2.4	2.c	2	2.4.1				
					3.3	3.4	3.9	3.d	3	3.9.1				
									4					
								5.a	5	5.a.1				
		6.1	6.3	6.4	6.5	6.6	6.a	6.b	6	6.3.1	6.3.2	6.4.2	6.5.1	6.6.1
					7.2	7.3	7.a	7.b	7	7.1.1				
								8.4	8					
					9.1	9.4	9.5	9.a	9	9.1.1	9.4.1			
						10.6	10.7	10.a	10					
	11.1	11.3	11.4	11.5	11.6	11.7	11.b	11.c	11	11.1.1	11.2.1	11.3.1	11.6.2	11.7.1
				12.2	12.4	12.8	12.a	12.b	12	12.a.1				
					13.1	13.2	13.3	13.b	13	13.1.1				
		14.1	14.2	14.3	14.4	14.6	14.7	14.a	14	14.3.1	14.4.1	14.5.1		
	15.1	15.2	15.3	15.4	15.5	15.7	15.8	15.9	15	15.1.1	15.2.1	15.3.1	15.4.1	15.4.2
								16.8	16					
17.2	17.3	17.6	17.7	17.8	17.9	17.16	17.17	17.18	17	17.6.1	17.18.1			

Fig. 2 SDG Targets and Indicators that can be supported by Earth observations. Credit: EO4SDGs / CEOS

3 Case Studies

Group on Earth Observations Global Agricultural Monitoring (GEOGLAM)

2.c	Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility. GEOGLAM can also support other Targets (2.1, 2.4, 2.a, 2.3) and other Goals (12 and 13, with Indicators 12.3 and 13.3).

GEOGLAM is a global initiative, initially launched by the Group of Twenty (G20) Agriculture Ministers in 2011 (Paris). The main objective was to "enhance the community's capacity to produce and disseminate timely, accurate, reliable and actionable information on food production by improving the use of remote sensing tools for crop production projections and weather forecasting".

GEOGLAM is relying on Earth observations including satellite data at various spatial and temporal resolutions to monitor diverse croplands and rangelands.

This collaborative initiative has at its core the "Coordination of Earth Observation (EO) Data," working closely with CEOS (the Committee on Earth Observation Satellites) to access specific and relevant data for free from the world's civil space agencies. Three main vehicles drive the initiative.

- #1 is "Timely & Accurate Consensus Reporting on Crop Conditions" – via the GEOGLAM Crop Monitors, which operationally provide monthly crop condition outlooks from multiple international partners, who use satellite, *in-situ*, and ancillary data to reach consensus about the world's crops in major production areas (Crop Monitor for AMIS, "CM4AMIS") and countries at risk of food insecurity (Crop Monitor for Early Warning, "CM4EW").
- #2 is "Operational Research & Development"– via Joint Experiment for Crop Assessment and Management (JECAM) R&D site network and other research projects such as Asia-RiCE, EC SIGMA (Stimulating Innovation for Global Monitoring of Agriculture), ESA Sentinel-2 for Agriculture, and GEOGLAM RAPP (Rangeland and Pasture Productivity).
- #3 covers "Capacity Development" to enhance national and regional institutional capacity to provide timely production outlooks and early warnings of food shortages.

Earth Observation Data Use

- Satellite-derived baseline datasets (e.g. GEOGLAM Crop Calendars and Crop Masks, environmental & biophysical variables);
- Satellite-based observations of land – e.g. NASA & USGS (MODIS, Landsat, SMAP), ESA (Sentinel-1, Sentinel-2, Sentinel-3), CSA (Radarsat-2, RCM), JAXA (GCOM-C, ALOS-2), DLR (TerraSAR-X, TanDEM-X), CNES (Pleiades);
- *In-situ* & agrometeorological data sets – e.g. temperature, precipitation (often in tandem with satellite sources – e.g. NASA TRMM and SMAP, ESA SMOS, JAXA GCOM-W1/W2);
- Novel crowd-sourced information – e.g. land use, weather, and crop characterization, through GEO-WIKI and other platforms.

Methodology

For the GEOGLAM Crop Monitors, agricultural experts consult a novel visualization and analysis interface containing multiple EO-based datasets, which complements their own external analyses on crop conditions. During a follow-up conference call with Crop Monitor participants, these experts' analyses are discussed to air any discrepancies and reach consensus before timely publication of qualitative condition outlooks.

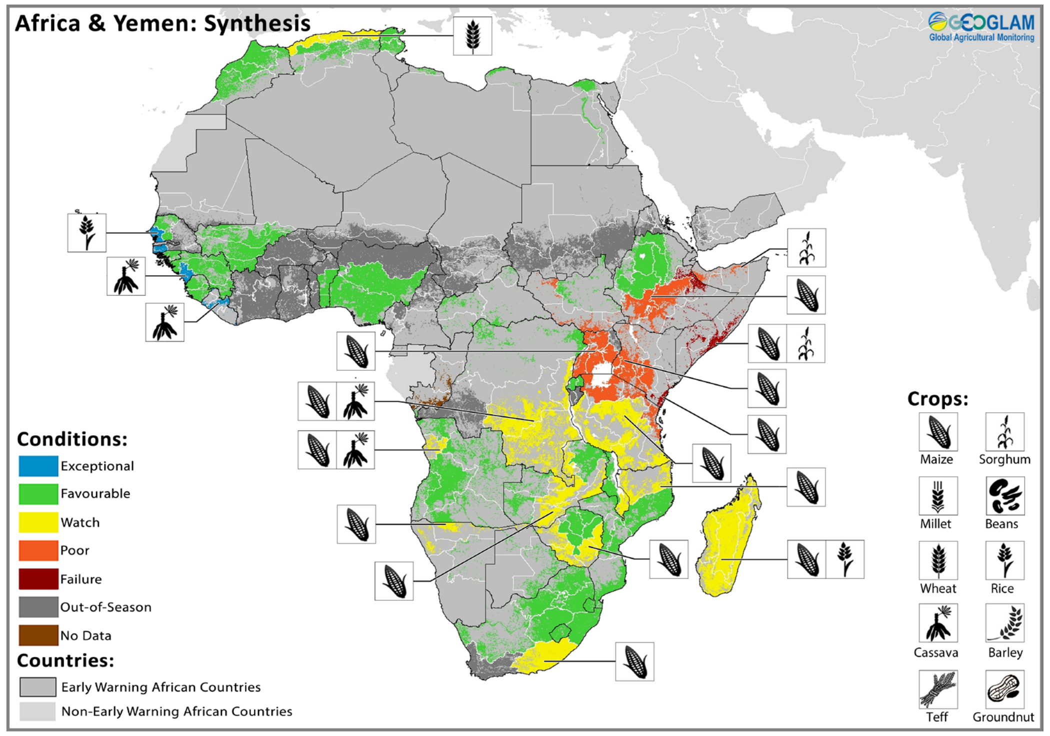


Fig. 3 Crop Monitor for Early Warning: Crop Conditions in Africa and Yemen as of 28 January 2017. Areas which are in other-than-favourable conditions are shown with the affected crop.

Key Issues and Results

The initiative has clearly demonstrated its utility:

- Improved (and earlier) outlooks on crop production: better information to ensure food volumes are well-anticipated and markets are well-calibrated for them.
- Improved early warning of food shortages: better adaptability to short and long-term changes.
- Enhanced capacity to assess inter-annual variability in cultivation practices and their impacts on productivity and the environment.
- Undertook inter-comparison of sustainable cropland management practices (impacts on productivity and local livelihoods).
- Developed international collaboration via transfer (esp. South-South) of knowledge and technology.

Analysis, Status, and Outlook

GEOGLAM and the Crop Monitors are continually strengthened by increased participation from agencies and institutions. Both are further enhanced by improved baseline datasets as well as by improved quality of and access to Earth observations. The CEOS WG on GEOGLAM has influenced individual mission acquisition strategies (e.g. Landsat 8, Sentinel-1, Radarsat-2, etc.) and future mission planning (e.g. Global-V, Landsat 8) vis-à-vis science-based requirements.

The users of the Crop Monitors – the Agricultural Market Information System (AMIS), the early warning community, agricultural ministries, members of industry, and others – have given regular positive feedback on the reports' use and value for their food policy decisions and actions. GEOGLAM research and development activities underpin and strengthen the entire activity at every level – from national capacity to conduct monitoring to GEOGLAM's efforts to create a "system of systems" that can accurately depict with regularity the status of global food production and supply.

The project relies on active participation by and support from agricultural ministries across the globe, as key end-users of derived information. Users view GEOGLAM as innovative and valuable, and hope for its continued growth, as there is a crucial need for access to sustained and reliable, Earth observations. This requires coordinated acquisition, high quality pre-processing and validation of datasets, as well as user-friendly data dissemination systems.

Partners, Contacts and More Information

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More information:
www.geoglam.org
www.cropmonitor.org

Algal Bloom Early Warning Alert System

6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.3.2	Proportion of bodies of water with good ambient water quality

All humans deserve access to clean water but one of the threats, cyanobacterial (blue-green algal) blooms, are of increasing concern in inland waters.

Some species produce potent toxins that pose a major hazard to human health, livestock, wildlife and the aquatic environment.

Traditional field monitoring for algal bloom detection involves identification and cell counting which, whilst reliable, imparts a lag time and is limited in spatial extent.

Fig. 4 Black swan paddling though algal bloom, Lake Burley Griffin, Australia

In Australia, as with other developing and developed countries, overcoming the vast areas and number of water bodies to be monitored is a challenge.

This project, the Algal Early Warning System (AEWS), is a collaboration between CSIRO and the New South Wales (NSW) Department of Primary Industries - Office of Water, to develop a remote sensing approach to monitoring algal blooms in inland waters across large spatial scales.

Earth observation data are used to complement traditional methods for water quality monitoring. The Sentinel 2 (ESA, Copernicus Programme) and Landsat 8 (NASA) satellite sensors offer high resolution, wide scale and frequent monitoring of water quality in inland water bodies in support of early algal bloom alerts for water managers.

Earth Observation Data Use

- Landsat 7 and 8 data ingested from the Australian Geoscience Data Cube.
- Shapefile of the extent of freshwater bodies in NSW.
- In the future, data from Sentinel-2 will also be ingested when it becomes available in 'analysis ready data' (ARD) form.

Methodology

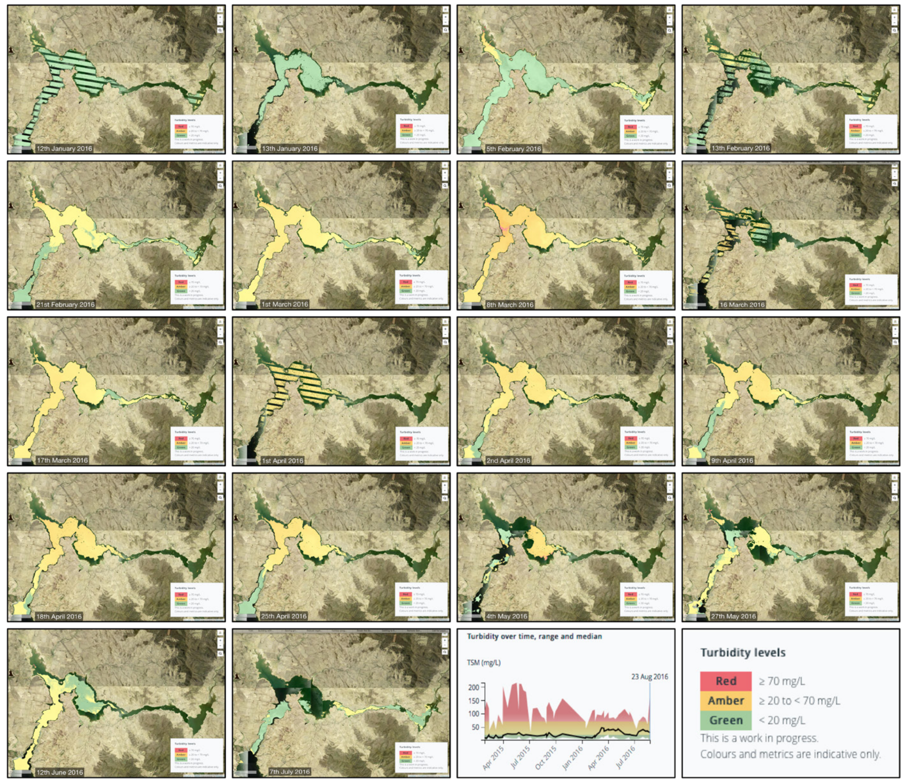
The tool is built upon the Australian Geoscience Data Cube (AGDC), a breakthrough innovation to serve standardised and calibrated satellite image data via Australia's National Computational Infrastructure (NCI) enabling the exploitation of parallel architectures.

In near real time, images are processed in the AGDC to inland water quality outputs (turbidity in the first instance). Data are presented to water managers through a visualisation interface where the turbidity data are translated to relevant bloom alert levels.

Fig. 5

Time series of Landsat 7 and 8 turbidity images for Lake Hume using the algal bloom visualisation system, covering the summer to autumn period mid-January to early July 2016.

Turbidity in this deep reservoir is primarily driven by changes in phytoplankton concentrations. The time series shows the development of an algal bloom from late February through March and April. This bloom provided the 'seed' to stimulate a bloom in the River Murray downstream of the reservoir which affected some ~1600 km of river for three months to June 2016. A full time series of turbidities from January 2015 is also depicted; the solid line represents the median concentration (in mg/L) and the range the full range of turbidities measured spatially.



The interface allows for visualisation at the regional scale to provide a rapid NSW state-wide overview of algal alert status, or at the scale of the individual water body, to allow the determination of spatial bloom dynamics.

Current data can be displayed within the context of historical data.

Key Issues and Results

The main objective of the project is to develop methodologies and procedures with remote sensing technologies to support cyanobacterial monitoring, in order to improve timeliness and a wider spatial coverage of major inland water bodies.

When fully operational, the system will revolutionise the algal management by providing better and earlier information in detection and mitigation.

It will help government agencies (various scales) to monitor wider areas and quickly deploy resources at a local scale when necessary

The development of Data Cube concepts for other parts of the globe would significantly accelerate the speed and creation of similar alert systems, particularly for developing countries.

The development of forecasting services for bloom condition will rely on the integration of satellite data with biogeochemical models.

Analysis, Status, and Outlook

The generic approach developed here for turbidity will be suitable for all optical water quality products into the future.

As new satellite sensor data (e.g. Sentinel 2) become available in 'analysis ready' form the power of algal bloom alerting and water quality monitoring will significantly increase.

Current approaches are based on semi-empirical algorithms but future work will adopt the adaptive Linear Matrix Algorithm (aLMI), developed by CSIRO for simultaneous estimation of optically active water quality parameters from remotely sensed data in water bodies with varying water types.

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More information:
http://www.water.nsw.gov.au/water-management/water-quality/algal-information/algal-early-warning-system

Flood Prediction System Using the Global Satellite Map of Precipitation (GSMaP)

6.5	**By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate**
6.5.1	**Degree of integrated water resources management implementation (0-100)**

Many countries in the Asia-Pacific region have suffered from floods caused by typhoons and heavy rains. The severity and frequency of floods are expected to increase with intensification of the hydrological cycle due to global warming.

As one of the most powerful nonstructural measures against flooding, monitoring and warning systems have been implemented in the region, which combine satellite-based global precipitation data such as the Global Satellite Mapping of Precipitation (GSMaP) dataset with ground observations (rain gauges, water-level gauges) thereby improving prediction accuracy of extreme weather events; and strengthening capacities of both governments and communities for pre-and post-disaster actions.

GSMaP provides estimates of precipitation within river basin areas, which often extend beyond national boundaries. Flood predictions are made using calibrated GSMaP data and river run-off models. Flood warnings are transmitted by mobile phone.

Earth Observation Data Use

- GSMaP data
- Rain-gauge data for correction and validation

Methodology

GSMaP is an hourly global rainfall map provided in near-real-time on a 0.1 degree (about 10 kilometer) grid over a global area (between 60N and 60S latitudes). GSMaP is produced by integrating microwave radiometer data from low Earth orbiting satellites and thermal infrared data from geostationary satellites. Methodologies and systems to calibrate and validate GSMaP data with ground rainfall data have been developed in pilot areas of each country.

The calibrated GSMaP data is used as input data for flood models in the target river basin for flood forecasting. These models include the Integrated Flood Analysis System developed by the International Centre for Water Hazard and Risk Management (ICHARM), and the Water and Energy Budget-Based Distributed Hydrological Model, developed by the University of Tokyo. Target river basins are Jamuna river basin in Bangladesh, Cagayan river basin in the Philippines, Red-Thai river basin in Vietnam and Indus river basin in Pakistan.

For flood models, satellite-based topographical information (digital elevation model [DEM] or digital surface model [DSM]) obtained from the Advanced Land Observing Satellite (ALOS) is used to make an inundation map in the pilot area as an alternate source of geographic data to those obtained from spot surveys.

Key Issues and Results

The main outcome is the mitigation of flood damage risk through improvements in flood prediction and through increased early warnings broadcast by mobile phone. The frequent updates to the data and warning systems facilitate longer times for communities to evacuate.

The accuracy of the satellite-based precipitation data is fundamental to the flood prediction reliability and the rain gauge data is absolutely fundamental to the calibration and validation of the satellite data.

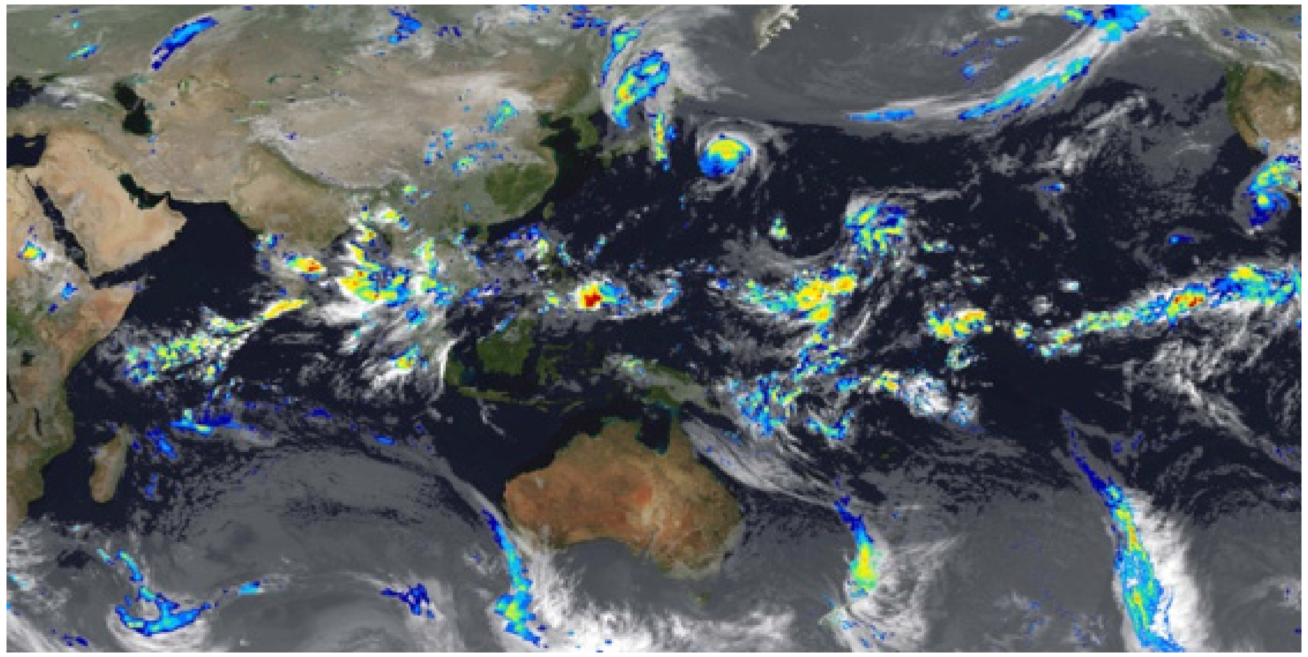

Fig. 6 **Global Satellite Map of Precipitation (GSMaP)**
Available at: http://sharaku.eorc.jaxa.jp/GSMaP/index.htm

Analysis, Status, and Outlook

Flood prediction systems using GSMaP have been implemented in Bangladesh, the Philippines, Vietnam, and in Pakistan in collaboration with the Asian Development Bank (ADB) and UNESCO.

The goal of these pilots is to increase the number of countries which provide flood prediction systems using GSMaP as an input.

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Global Mangrove Watch – Mapping Extent and Annual Changes in the Global Mangrove Cover

6.6	**By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes**

6.6.1	**Change in the extent of water-related ecosystems over time**

The Ramsar Convention on Wetlands is an international treaty for the conservation and sustainable use of wetlands, adopted in 1971 in the city of Ramsar in Iran. Together with UN Environment, Ramsar is supporting the development and implementation of SDG Target 6.6.

Mangroves are of critical importance as breeding and nursery areas for birds, fish and shellfish and play an important role in the regulation of freshwater, nutrients and sediment inputs into the marine coastal waters. They provide coastal protection from storms and tsunamis and as more organic carbon is produced than degraded they constitute significant pools for carbon sequestration. Within the UNFCCC REDD+ scheme, mangroves are categorised as forests and should therefore be included in national emissions reports.

Once abundant along the world's tropical and sub-tropical coastlines, mangroves are today in rapid decline worldwide. A large proportion has been lost or degraded by unsustainable exploitation practices, pollution and habitat destruction, in particular clearings for aquaculture, agriculture and industrial development. Mangroves are also sensitive to climate change induced effects such as sea level rise and changes in hydrology.

Information on the state and change trends of mangroves at both national and global levels is furthermore limited, in part because mangroves often fall outside national forest definitions and therefore are not included in National Forest Inventories, and in part because of their often remote and inaccessible locations which make periodic mapping and monitoring of their entire extents by conventional means costly, if not impossible. Earth Observation on the other hand, by which large areas can be observed on a regular basis, is a tool which facilitates periodic monitoring.

The Global Mangrove Watch (GMW) is an international collaborative project established within the framework of JAXA's Kyoto & Carbon Initiative science programme, set up to provide fine resolution (25 m) geospatial information about mangrove extent and changes to Ramsar, national wetland practitioners and decision makers, and NGOs. The GMW is a Pilot Project to the Ramsar Global Wetlands Observation System (GWOS) that is implemented under the GEO-Wetlands Initiative.

Earth Observation Data Use

Key Earth Observation sensors for GMW are the (L-band) Synthetic Aperture Radar (SAR) satellite series operated by JAXA: JERS-1 SAR (1992-1998), ALOS PALSAR (2006-2011) and ALOS-2 PALSAR-2 (2014-present). The ability to penetrate clouds and haze combined with the sensitivity of the long-wavelength L-band signal to vegetation structure make these data particularly suitable for regular monitoring and change detection in cloud-prone coastal regions.

The L-band SAR data are supplemented by Landsat-7/8 and RapidEye optical data and SRTM digital elevation data. The use of Sentinel-1 (C-band SAR) and Sentinel-2 data (optical) is also foreseen.

Methodology

The JERS-1, ALOS and ALOS-2 data are assembled by JAXA into annual global 25 m resolution mosaic products which are available in the public domain

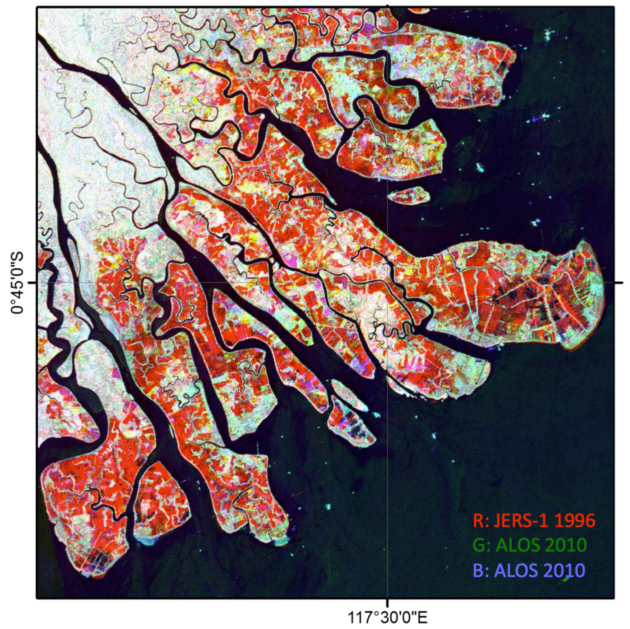

Fig. 7 **Mahakam delta, East Kalimantan. L-band SAR temporal composite. Red areas indicate mangrove loss. (R: JERS-1 SAR 1996; G & B: ALOS PALSAR 2010). © JAXA/METI**

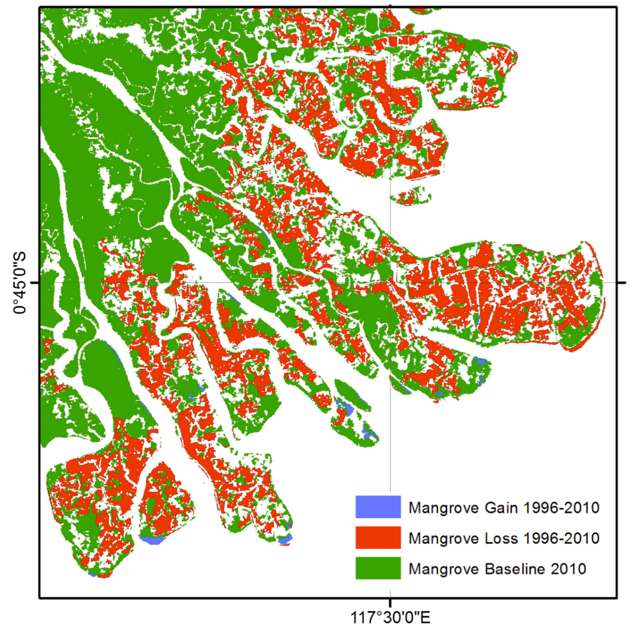

Fig. 8 **Corresponding mangrove change map, showing 2010 extent in green and changes between 1996 and 2010 in red (losses) and blue (gains) © Global Mangrove Watch, 2015.**

(www.eorc.jaxa.jp/ALOS/en/palsar_fnf/fnf_index.htm). The mosaic products constitute geometrically and radiometrically corrected "Analysis-Ready Data" which are used within the GMW to create temporal radar data stacks from which mangrove extent and changes between the years in question are derived (Figure 7).

Classification and image handling are undertaken by use of open source (RSGISLib.org) software.

Approach:

1. Coastal masking and mangrove habitat location classification using SRTM, water mask (JRC 2016) and historical mangrove extent maps from around 2000 (USGS World Distribution of Mangroves and ITTO World Atlas of Mangroves).

2a. Mangrove extent classification of L-band SAR 25m mosaics under the coastal and habitat masks (mangrove/non-mangrove).

2b. Mangrove extent classification of L-band SAR mosaics from years X and Y (mangrove gain/mangrove loss) (Figure 8).

3. Validation (by *in-situ* data over 16 pilot sites and Landsat and RapidEye optical data).

Key Issues and Results

Earth observations provide a unique means to improve geospatial information on mangrove extent and changes over national to global scales. They can provide important support to the implementation of SDG Target 6.6, sustainable management of wetlands, national accounting for REDD+, disaster risk reduction, climate change mitigation, and law enforcement.

All GMW satellite data, classification software and mangrove maps are free and open. Non-experienced users can use GMW maps as provided, Experienced users may replicate or improve classifications.

Analysis, Status, and Outlook

GMW implementation plan:

- Q1 2017: Generation of 2010 global baseline maps
- Q2 2017: Generation of 2010-2015 change maps
- Q2 2017: Generation of 1996-2010 change maps
- Q2 2017: Public release of GMW maps
- 2018+ : Generation of annual change maps

Partners, Contacts and More Information

Users:

Ramsar Convention and its Contracting Parties. Wetland users and NGOs worldwide.

Producers:

Aberystwyth University (U.K.), University of New South Wales (Australia), JAXA (Japan), soloEO (Sweden)

Collaborators:

Wetlands International, UNEP-WCMC, International Water Management Institute (IWMI), World Resources Institute (WRI), GEO Wetlands

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www.eorc.jaxa.jp/ALOS/en/kyoto/mangrovewatch.htm

Earth Observation for Water-related Ecosystem Monitoring

6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
6.6.1	Change in the extent of water-related ecosystems over time

Wetlands support some of the highest biodiversity in the world. Macrophytes (aquatic plants which grow in/near water) are of particular importance in aquatic ecosystems, as they link the sediment with the overlying water. They provide a habitat for fish and substrate for aquatic invertebrates, offering protection against both currents and predators. They also play a role in nutrient and carbon cycles (CO2 and CH4).

Phytoplankton are another critical component of water-related ecosystems. As prolific primary producers they play a key role in sustaining life and conditioning the underwater light climate around the globe.

Phytoplankton are an indicator of trophic status (water ecosystem productivity); a temporal shifting of bloom phenology as well as the spreading of cyanobacterial blooms might be an indicator of a lake's response to climate change. The occurrence of harmful algal blooms (HABs) – also often associated with cyanobacteria – might hinder the use of water resources. The measurement of Phytoplankton production/biomass is therefore a key part of water quality monitoring programs worldwide.

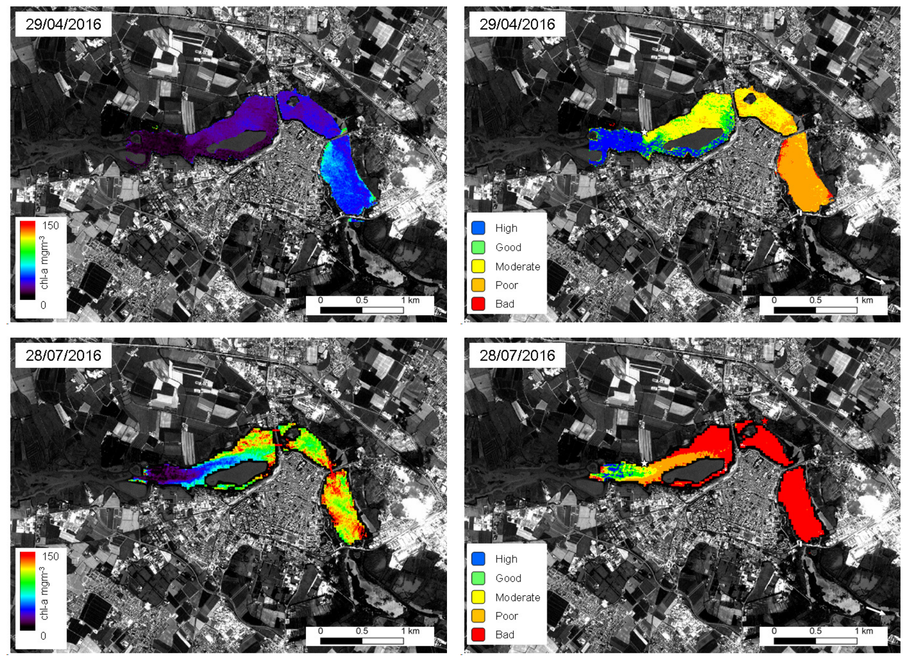

Fig. 9 Sentinel-2 discerns chlorphyll-a concentration patterns over time, which are then converted into water quality according to the EC WFD supporting water managers of Mantua lakes (Italy). Credit: INFORM and BLASCO Projects

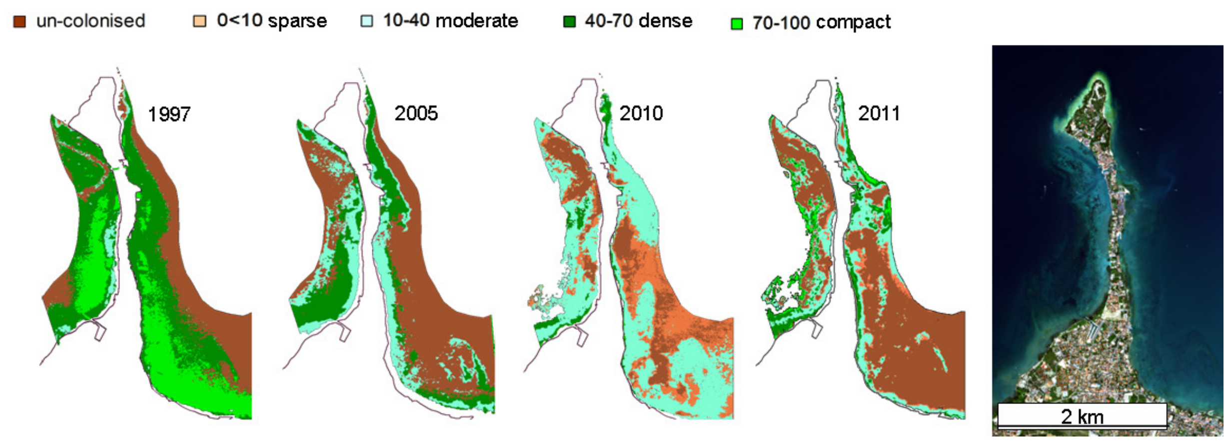

Fig. 10 Recent changes of submerged macrophytes (from sparse to compact) up to 8 m of depth in the southern part of Lake Garda (Italy) derived from airborne hyperspectral MIVIS. Credit: Bresciani et al. (2012), Giardino et al. (2012)

Earth Observation Data Use

- Landsat
- Sentinel-2/3
- Historical digital archives of satellite imagery (Landsat, Envisat, Sentinel-2/3, hyperspectral sensors).
- High-resolution airborne imaging spectrometry
- *In-situ* data (from Europe, China; LIMNADES, LTER)
- Ocean colour radiometry

Methodology

Satellite imagery is used to map the extent and distribution of macrophytes; and to assess biomass, biodiversity, and the presence of invasive species. Rule-based classifications of floating/emerging macrophyte types are based on atmospherically corrected, multi-temporal satellite data. Vegetation indices and *in-situ* data are used to map fractional cover, leaf area index (LAI), and above-water biomass. Hyperspectral inversion of bio-optical modelling is used for mapping the fractional cover of submerged macrophytes.

Phytoplankton are observed by proxy, via biomass pigment concentrations, mainly the concentration of Chlorophyll-a (through sun-induced fluorescence), secondary pigments, and harmful algal blooms (HABs). Scattering-based approaches in red wavelengths are also applicable in high-biomass waters.

Key Issues and Results

Using Earth observation to monitor macrophytes and phytoplankton supports the implementation of several EU policies (EC Habitat/WFD directives, and EC WFD and Bathing directives, respectively), and the generation of maps and forecasts is central to a number of Horizon 2020 projects (e.g., EOMORES, ECOPOTENTIAL; and CYANOLAKE, respectively).

Analysis, Status, and Outlook

Earth observation techniques are a step forward for macrophyte and phytoplankton mapping, going beyond the local-scale and supporting regional to continental monitoring of the spatial and temporal dynamics of primary producers in freshwater ecosystems. Considering the vast expanse of inland waters, their spatial heterogeneities and the high-degree of temporal changes, EO is a powerful tool for assessing water-related ecosystems.

Provided that suitable instruments remain in service, methods will continue to improve as they mature into generally accepted best-practice science, offering considerable advantages for a wide range of practical and scientific applications. The continuity of image archives and polar orbiting, global satellite missions to capture trends and ensure repeatable monitoring for ecosystem studies is critical.

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GLaSS (FP7) http://www.glass-project.eu/
GLOBOLAKES (UK) http://www.globolakes.ac.uk/
CYANOLAKES (EU H2020) http://www.cyanolakes.com/horizon-2020/

Mapping Urban Growth

11.3	**By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries**
11.3.1	**Ratio of land consumption rate to population growth rate**

From around the turn of the century, more than half of the world's human population lives in an urban environment and the dynamic trend of urbanization is growing at an unprecedented speed. In emerging economies, the urban population is expected to double in 30 years (2000-2030), adding 2 billion more people, especially in South Asia and Africa.

Rapid urbanization brings challenges, such as access to basic services and infrastructures, effective waste management, air pollution control, investment in public transportation and urban traffic control. Sustainable urban development requires an effective monitoring of urban sprawl and in particular of the relationship between land consumption and population growth. Cost effective and accurate regular monitoring of urban expansion for present and historical times is required in order to track urban development over time.

Achieving Target 11.3 requires supporting all countries in monitoring their urban extent and delineating precisely the built-up footprint of their cities.

Earth Observation Data Use

In the last decade, space-borne Earth observation has proved to be a promising tool in combination with widely automated methods of data processing and image analysis for providing up-to-date geo-information on urban settlements at global scale.

Automatic urban extent mapping is based on: annual/bi-annual temporal statistics of C-band synthetic aperture radar (SAR) backscattering data from the Sentinel-1 and Envisat satellites; and multi-spectral optical data from the Landsat and Sentinel-2 satellite constellations.

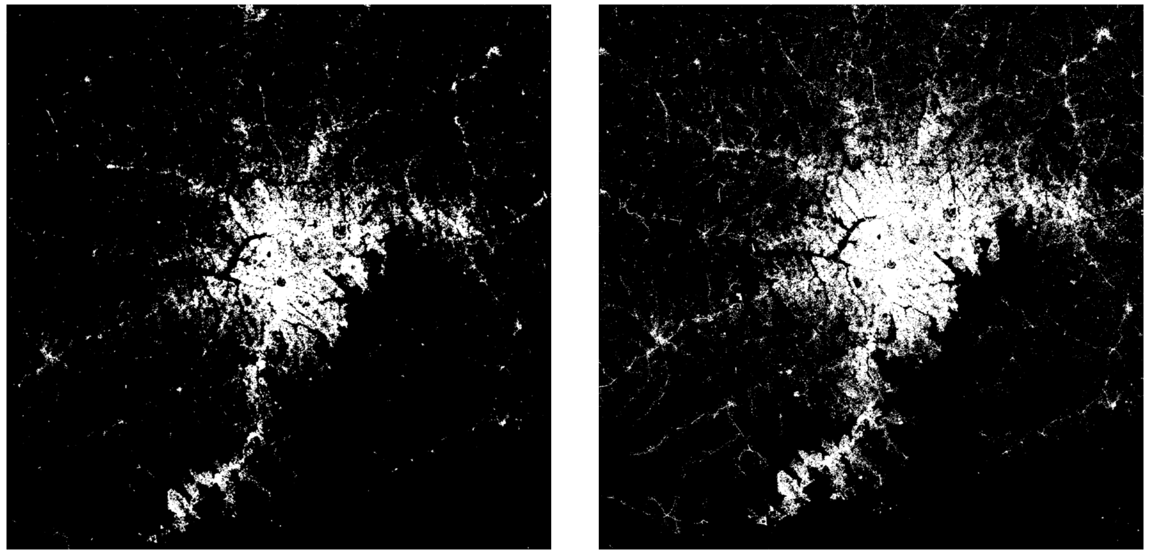

Fig. 11 **Urban Extent, Kampala, Uganda; based on ENVISAT ASAR and Landsat-5 TM / -7 ETM (left, 2002–2014) and Sentinel-1 C-SAR and Landsat-8 OLI (right, 2014–2015)**
Credit: DLR, ESA SAR4URBAN

Methodology

The methodology uses the best temporal discriminant features of optical and SAR systems in order to precisely delineate built-up areas in urban, peri-urban and rural areas.

DLR's Global Urban Footprint (GUF), ESA's Urban Thematic Exploitation Platform (U-TEP) and SAR4URBAN projects have demonstrated that the technical capabilities exist today to automatically delineate the extent of urban areas in a completely unsupervised way. This provides a novel opportunity to develop operational services for generating and updating (e.g., every 2 years) accurate global maps of urban settlements.

Such a global urban mapping service can help countries and cities without technical and financial resources to have a regular monitoring of their urban development and to characterize their human settlements – even in remote regions where no other sources of information are available.

Key Issues and Results

Until recently, the geometric resolution of global EO-based products was limited, often resulting in poor accuracy to support policy makers and urban planners. The emergence of EO satellite missions (such as the Copernicus Sentinels and the Landsat family) with systematic global observations at high spatial resolution, long term continuity, and open and free data policies offers a unique opportunity to characterize urban settlement patterns world-wide in a so far unique spatial detail.

The main issues in the full implementation of the Indicator 11.3.1 are to agree: i) on a definition of urban extent that is universally applicable; and ii) on which methods shall be used for coupling population data (with access to census enumeration and population grid) to urban extents maps.

Analysis, Status, and Outlook

The first global map of urban extent at 10-30m spatial resolution based on a data fusion of optical and SAR time series will soon be available for year 2015 (GUF+2015).

The next step is to test its quality and adequacy in a number of developing countries and to assess how it can support these countries in producing the 2015 baseline of Indicator 11.3.1. Access to national population data in a grid system will be required to fully implement the Indicator.

The main technical challenges are: i) the development of a global and robust method that provides accurate mapping results in all conditions and for all types of human settlements; and ii) the processing of the vast amount of satellite data and the derivation of the temporal statistics required by the urban extent classifiers. Such high computing and storage needs can only be achieved by running the algorithms on high-performance cloud computing platforms.

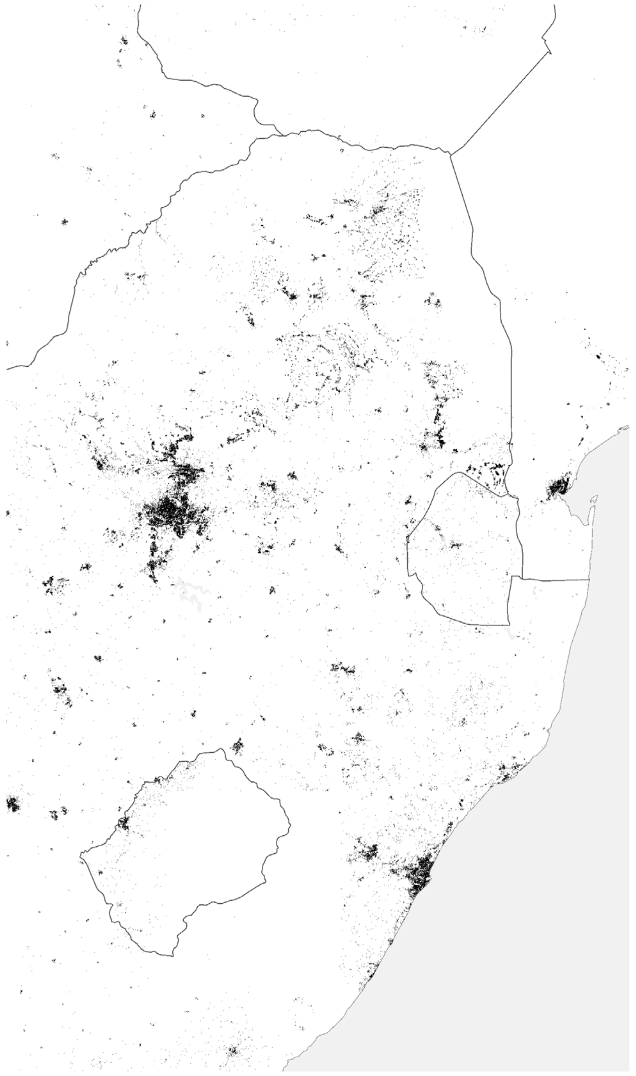

Fig. 12 **GUF+ 2015: Urban areas in Southeastern Africa.**
Credit: DLR, ESA SAR4URBAN

Partners, Contacts and More Information

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Air Pollution Monitoring for Sustainable Cities and Human Settlements

11.6	**By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management**
11.6.2	**Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)**
3.9	**By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination**
3.9.1	**Mortality rate attributed to household and ambient air pollution**

Air pollution is now considered the world's largest environmental health risk. The World Health Organization (WHO) attributes 3.2 million deaths to air pollution in 2012. People living in Asia are considered most at risk of ambient air pollution, with more than 2.6 million deaths caused by it.

Rapid urbanization and industrialization in Asia have generated increasing air pollution. The particulates PM2.5 and PM10 (tiny particles in the air that reduce visibility and cause the air to appear hazy when levels are elevated) are produced from a wide range of industrial processes through bulk material handling, combustion and minerals processing. PM2.5 particles are so small – 30 times smaller than the width of a human hair – that they can easily infiltrate human respiratory and circulatory systems, contributing to health problems such as asthma, pulmonary vascular disease, and heart attacks.

Besides industrial causes, climate change also results in more frequent drought episodes in the region, increasing the risk of forest fire, smoke haze and land degradation. All of these matters and industrial air pollution are transboundary environmental issues, and can be monitored using Earth observations.

Considering these issues, many countries realize that there is an urgent need to take drastic measures in order to reduce air pollution and improve health – especially in urban areas. Following severe land forest fires in 1997-1998, ASEAN (Association of Southeast Asian Nations) Member States signed the ASEAN Agreement on Transboundary Haze Pollution in June 2002 to prevent, monitor, and mitigate land and forest fires to control transboundary haze pollution through concerted national efforts, regional and international cooperation. The Japan-China-Korea Tripartite Environment Ministers Meeting (TEMM) in 2016 agreed on reinforcement of regional cooperation for improving the regional atmospheric air quality.

The Asia-Pacific Regional Space Agency Forum (APRSAF) 2016 discussed regional cooperation for monitoring and predicting air pollution in the region, as satellite data can complement *in-situ* observations by filling gaps in areas where data is low or non-existent. With improved modeling that integrates geostationary and low Earth orbit satellite data, together with field data, fine particulate matters (e.g., PM2.5 and PM10) will be estimated for major cities in the Asia-Pacific region.

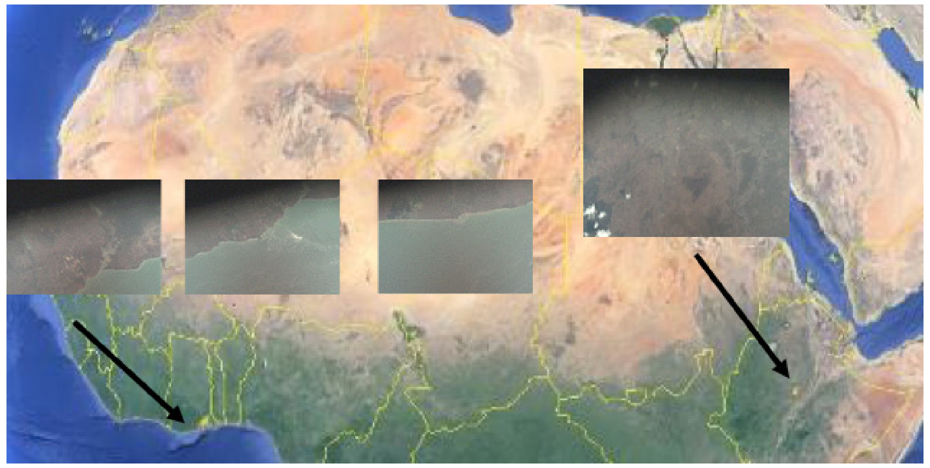

Fig. 13

TANSO-FTS has been targeting Addis Ababa and Accra since February 2016 in response to a WHO request.

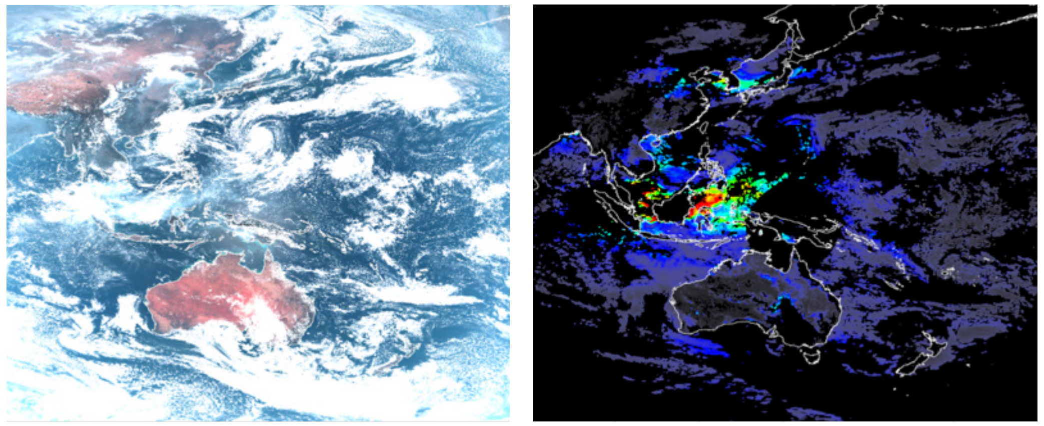

Fig. 14

Himawari-8 Product: Aerosol JAXA EORC applied the aerosol algorithm developed for JAXA LEO missions (GCOM-C, EarthCARE, GOSAT-2) to Himawari-8.

Earth Observation Data Use

Satellite data: Himawari, GOSAT/GOSAT-2, GCOM-C, Sentinels, others.

In-situ data: MOE/AEROS, US Air Now, JMA yellow sands estimation map, etc.

Numerical model data: University of Tokyo/JAMSTEC/NIES/Kyushu Univ. MICRO-SPRINTARS, University of Tokyo/RIKEN/NIES/Kyushu Univ. NICAM-Chem, MRI MASINGAR.

Methodology

Fine particulate matter concentrations over cities are estimated by numerical modelling, integrating satellite data and *in-situ* data.

Aerosol data from the geostationary satellite Himawari-8 are available every 10 min with 5 km ground resolution. Hot spot detection and forest fire/smoke haze monitoring are conducted using other geostationary and low Earth orbiting satellites. Satellite-based estimates of PM2.5 rely on this data.

This data will contribute to SDG 11 by providing annual mean of PM2.5 and PM10 concentrations and SDG 3 (Health) by assessing a causal link between air pollution and mortality. These data are critical for policy decision making on air quality management in urban areas, as well as for estimating population-weighted exposures and health outcomes.

Key Issues and Results

Monitoring air quality through Earth observation data:

- Increases cooperation between Asia-Pacific countries (data sharing) and with Europe (Sentinels) and U.S. AirNow (a unique system centralizing data from the US EPA; NOAA; National Park Service; and tribal, state, and local agency systems to provide the public with easy access to national air quality information);
- Contributes to air quality management of mega cities in the Asia-Pacific region; and,
- Fosters cooperation in monitoring of haze caused by forest fires, yellow sands and air pollution.

Analysis, Status, and Outlook

With the launch of new Japanese satellites (Himawari-8 and -9), greater satellite coverage and corresponding aerosol observations will allow better estimations of surface aerosol concentration, providing more information for civil authorities and modeling systems. JAXA began distributing Himawari-8 aerosol data in September 2015. (https://www.eorc.jaxa.jp/ptree/index.html).

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Partners:

JMA, MOE, NIES, CSIRO, WHO

Using Remote Sensing for Water Quality Monitoring of the Great Barrier Reef

14.1	By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
14.1.1	Index of coastal eutrophication and floating plastic debris density

This project provided near real-time information of remotely sensed marine indicators to assist the Marine Park management to assess trends in ecosystem health, specifically to monitor the condition and trend of the Great Barrier Reef inshore water quality.

The project collected and analysed near real-time satellite data of chlorophyll levels, suspended sediments, and dissolved organic matter.

This data provided through the Dashboard can be displayed in different formats (map, table or chart) and downloaded for further analysis and interpretation.

Earth Observation Data Use

The system operates with daily satellite observations from MODIS-Aqua, *in-situ* observations for validation.

More specifically, the Dashboard uses remotely sensed ocean-colour information from NASA's Aqua satellite, which orbits the earth approximately every 100 minutes, carrying the MODIS remote-sensing instrument.

MODIS is a sensor that measures the reflected sunlight from the earth's surface in 36 spectral bands, of which nine are primarily used to sample ocean colour. The process is similar to digital photography, except that the sensor responds to a much broader spectrum than that of visible light. Each of the spectral bands captures the energy of the reflected light within the small window of a few nanometres (one billionth of a metre).

The ocean-colour sensing bands are all within the visible and near-infrared sections of the electromagnetic spectrum.

Methodology

The remotely sensed water quality indicators were derived from daily MODIS-Aqua observations by coupling of two physics-based inversion algorithms; one addressing the atmospheric correction and air-water interface, and one the in-water constituent retrieval.

These methods were developed by the CSIRO and implemented into the Dashboard that is operated by the Australian Bureau of Meteorology.

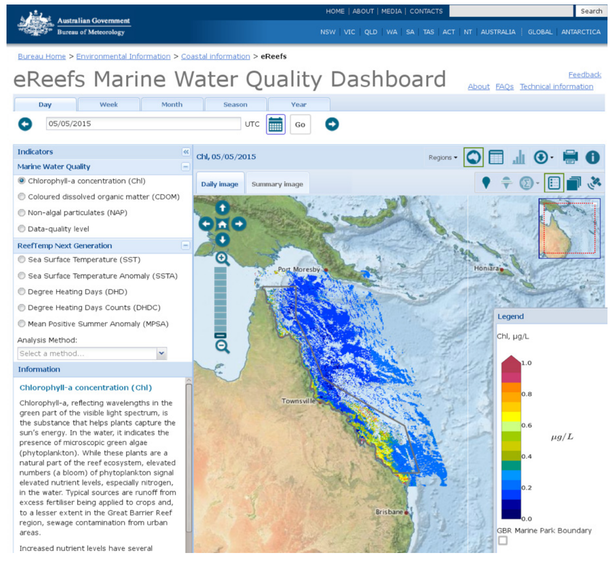

Fig. 15 Screenshot of the Marine Water Quality Dashboard operated by the Australian Bureau of Meteorology. The dashboard provides near-real-time information of remotely-sensed water quality in the Great Barrier Reef using methods developed by the CSIRO.

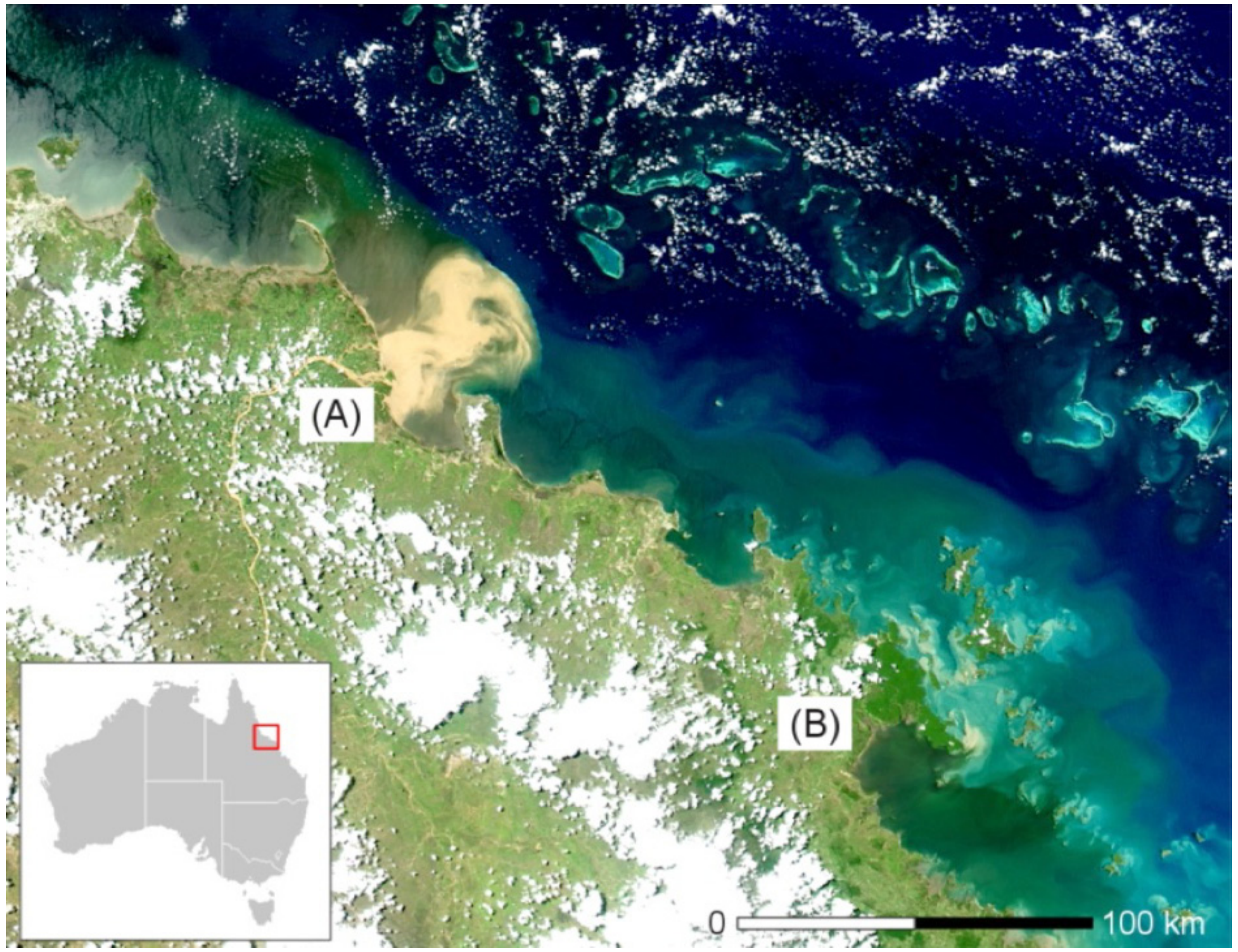

Fig. 16 MODIS true-colour image illustrating the optical complexity of Great Barrier Reef coastal waters. Discharge of the Burdekin River (A) and the O'Connell and Proserpine Rivers (B). Credit: Schroeder et al. (2012, Marine Pollution Bulletin).

Key Issues and Results

The Dashboard implemented methods lead to more accurate regionally-tuned water quality information provided for the Great Barrier Reef World Heritage Area. The policy and decision makers can use the data collected to improve the management of the Great Barrier Reef.

Analysis, Status, and Outlook

Remotely-sensed water quality information of total suspended sediments and chlorophyll-a are used by the Marine Park Authority for compliance monitoring against guideline values and annual assessment summaries in form of Report Cards.

Partners, Contacts and More Information

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Partners:
CSIRO
Australian Bureau of Meteorology
Great Barrier Reef Marine Park Authority

Dashboard access:
http://www.bom.gov.au/marinewaterquality/

Mapping Forest Cover Extent and Change, and Progressing Sustainable Forest Management

15.1	**By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements**
15.2	**By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally**
15.1.1	**Forest area as a proportion of total land area**
15.2.1	**Progress towards sustainable forest management**

Reliable satellite-based monitoring of forest cover requires Earth observation systems that have global, systematic acquisitions; free and accessible data; and high quality imagery – such as that offered by Landsat.

Given Landsat's global coverage, any methods are geographically portable and consist of standardized data inputs, mapping algorithms, and accuracy assessment protocols. The same generic approach may be applied for any geography or environment, at regional or national-scale, and for any dynamic change. Methods must be implemented in a timely and repeatable fashion and include accuracy assessments for generating valid area estimates.

Four Indicators of sustainable forest management have been identified by the United Nations. To measure and monitor these Indicators, information beyond tree cover extent and change is required, for example: forest type, disturbance history, intactness, and land use allocation. Satellite time-series observations can be used to quantify several themes that contribute to sustainable forest management objectives, in conjunction with ancillary data that are required to fully assess the implications of satellite-derived trends in the extent of natural and managed forest cover.

Earth Observation Data Use

Landsat-derived image composites and metrics are generated globally as part of the Global Forest Watch initiative and by independent laboratories such as the University of Maryland's Global Land Analysis and Discovery laboratory. The integration of Sentinel data into the forest characterization system is underway.

National-scale data are subset from the global data and delivered to the respective national counterpart responsible for mapping and monitoring of forest resources.

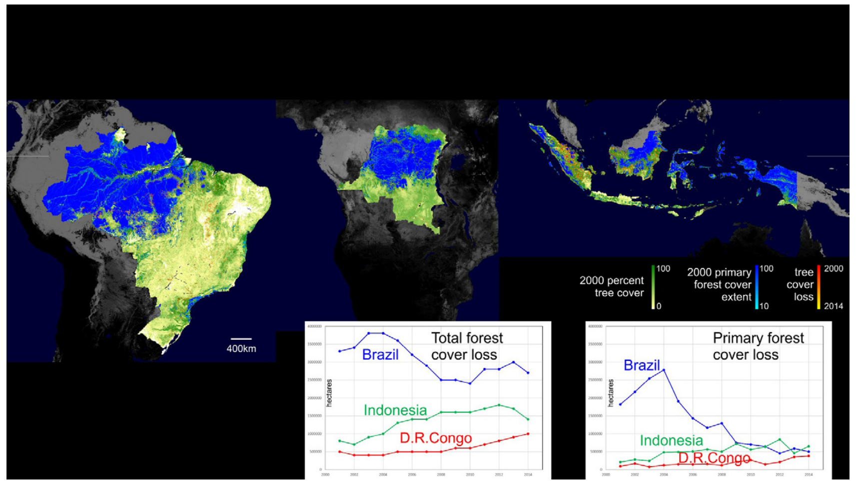

Fig. 17

All-tree cover loss, and primary forest cover loss for Brazil; Democratic Republic of Congo; and Indonesia from 2001 to 2014.

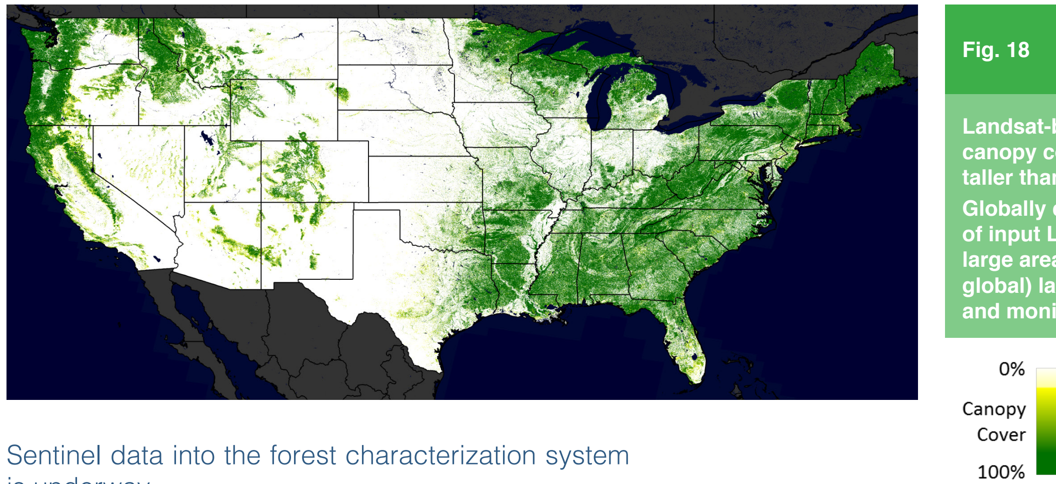

Fig. 18

Landsat-based estimates of canopy cover for trees that are taller than 5m for the U.S.

Globally consistent processing of input Landsat data enables large area (national-regional-global) land cover mapping and monitoring.

Methodology

Pre-processed data are delivered to national agencies responsible for mapping and monitoring forest resources in the form of cloud-free Landsat time-series imagery.

National analysts are trained on an 'active learning' approach using supervised classification data-mining algorithms to iteratively map forest cover extent and change for a defined baseline period. These data are used to establish reference data on emissions from deforestation, assess land use policies (protected area effectiveness), and improve transparency of national land resource information.

Reference forest types, carbon stock strata, and post-clearing land use may be similarly mapped to bring added value to the generic forest cover analysis. Subsequent updates of the map are dependent only on the delivery of new image inputs.

Upon completion of mapping, good practice accuracy assessments are performed in establishing definitive area estimates that can support Indicator 15.1.1.

Forest cover extent, loss, and gain are the primary inputs to assessing intact, primary/long-lived forests and afforestation/reforestation. All intact and primary forest lands are monitored, and a reference state (forest type/carbon stock), change factor (logging/fire), and official land use (forestry/protected area) data are integrated with forest change data to report on 15.2.1. Attribution of changes may be mapped directly or assessed using sample-based methods.

Key Issues and Results

- EO data can act as a source to help countries monitor, track, and report on Indicators 15.1.1 and 15.2.1, especially in cases where a strong forest inventory is absent.
- The methods are geographically portable and support sub-national estimates;
- EO can also be used for validation purposes, and in conjunction with forest inventory data.

National data are still needed to facilitate the analysis of satellite-based forest monitoring products and progress on sustainable forest management.

Full accounting of forest dynamics requires accurate attribution of forest-change factors. Automated change-factor mapping methods are not yet mature, and image interpretation is often used to differentiate natural from human-induced disturbances.

Analysis, Status, and Outlook

NASA and the University of Maryland have developed this methodology and are now in contact with the U.S. Forest Service and the Ministry of the Environment in Costa Rica, to identify ways to support the country-level monitoring and reporting process for 15.1.1 and 15.2.1. Additionally, the team is seeking supplemental candidate countries to test the method for SDG monitoring and reporting.

The methods have already been implemented for a number of countries, including Peru, Colombia, Republic of Congo, Bangladesh, and Vietnam with current activities focused in Guatemala, Cameroon and Nepal. Peru has adopted the method and results for official reporting.

Partners, Contacts and More Information

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NASA, USGS, University of Maryland, College Park. Also, in contact with the Office of the Chief Statistician in the U.S., the U.S. Forest Service, the Ministry of the Environment in Costa Rica, as well as the National Administrative Department of Statistics (DANE) in Colombia.

More information can be found at the Global Land Analysis and Discovery website:

http://glad.geog.umd.edu

The Global Forest Observations Initiative and Space Agency Support to Forest Monitoring

15.2	By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally
15.2.1	Progress towards sustainable forest management

The Intergovernmental Panel on Climate Change (IPCC) has reported that land-use change emissions (dominated by tropical deforestation) are equivalent to up to 25% of global human-induced CO2 emissions. Tropical forests are found in at least 56 countries, but the vast majority are found in just 30 (PRP, 2009), with most of these being developing countries. Commercial agriculture is the dominant driver of deforestation in the majority of developing countries, with commercial timber extraction, selective logging, fuel wood collection, and charcoal production also contributing (Kissinger et al, 2012).

Reducing Emissions from Deforestation and forest Degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (REDD+) looks to provide financial incentives for countries to maintain and sustain forests.

In order to ensure that countries can present the significant evidence required to demonstrate the accuracy of REDD+ claims, GFOI aims to provide countries with wall-to-wall national coverages of satellite data, in addition to methods and guidance documentation that will facilitate reporting consistent with IPCC Good Practice Guidance such that countries and donors can have confidence in agreements – as well as ensuring consistency and comparability among reporting countries.

Earth Observation Data Use

The GFOI's baseline, coordinated global data acquisition strategy involves a number of 'core data streams' (e.g., Landsat, Sentinel) that can be used free-of-charge for GFOI purposes. This involves systematic and sustained wall-to-wall acquisitions of forested areas globally (repeated on timescales consistent with national reporting commitments and requirements of national forest monitoring systems) and provides the default forest observation data for all countries.

These core data streams are complemented by contributing data streams – a wider range of satellite data sources, including data which is ordinarily provided on a commercial basis (e.g., RADARSAT, ALOS, TerraSAR-X/TanDEM-X, COSMO-SkyMed).

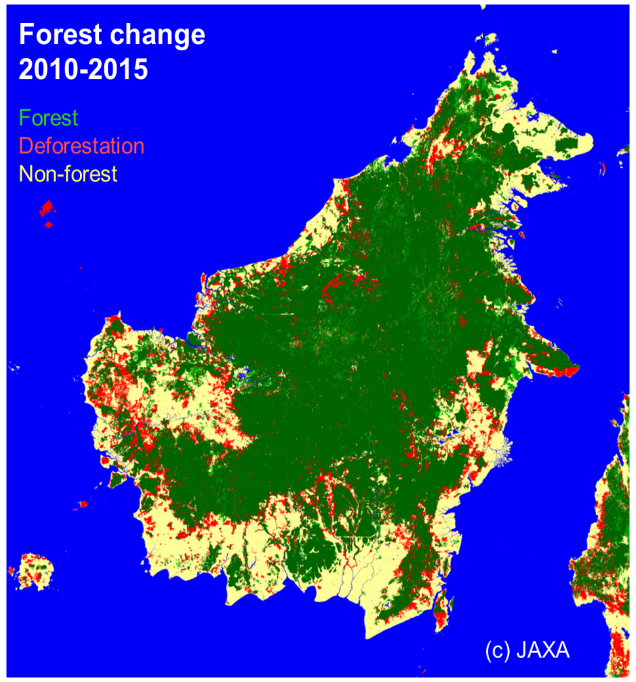

Fig. 19 ALOS-1/2 derived forest change (2010–2015) on Borneo island. Credit: JAXA

Another example of complementary products are the Japan Aerospace Exploration Agency (JAXA) global SAR mosaics and forest/non-forest maps, produced at 25m resolution using the ALOS-1/2 and JERS-1 satellites. SAR produces images of a similar resolution to those from high-resolution optical imagers, but radars have the capability to 'see' through clouds, providing data on an all-weather, day/night basis. JAXA has released these products for free in order to promote the use of L-band SAR for forest monitoring applications. JAXA plans to provide annual global forest/non-forest maps generated using ALOS-2 to help the community better understand forest distributions.

More information: http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/fnf_index.htm

Methodology

GFOI has developed a set of methods and guidelines for estimating future carbon stocks to support countries in their effort to build national forest monitoring systems. These methods and guidelines help ensure that forest carbon assessments are credible, comparable and transparent. Its first set of methods and guidance advice is titled 'Integrating remote sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests: Methods and Guidance (MGD) from the Global Forest Observations Initiative', and is now available in English, Spanish and French: http://www.gfoi.org/methods-guidance/

The MGD provides recommendations on establishing national measurement, reporting and verification (MRV) systems consistent with IPCC guidance and UNFCCC requirements for REDD+ reporting.

Key Issues and Results

CEOS has committed to providing global annual coverage of the world's forests to ensure that countries have the minimum data necessary to participate in frameworks such as REDD+ or equivalent bilateral donor arrangements focused on sustaining forest cover.

The GFOI MGD ensures that countries and donors have confidence in the derived national forest maps, such that they can form the basis of reporting to the UNFCCC or donors in a way that is compliant with IPCC guidance.

Analysis, Status, and Outlook

GFOI achieved its global baseline coverage in 2016 – with at least one annual global coverage provided by the core data streams – thanks to a series of new launches and the nominal operation of existing assets.

The CEOS Space Data Coordination Group for GFOI is also investigating further historical datasets for the purpose of baseline forest map generation.

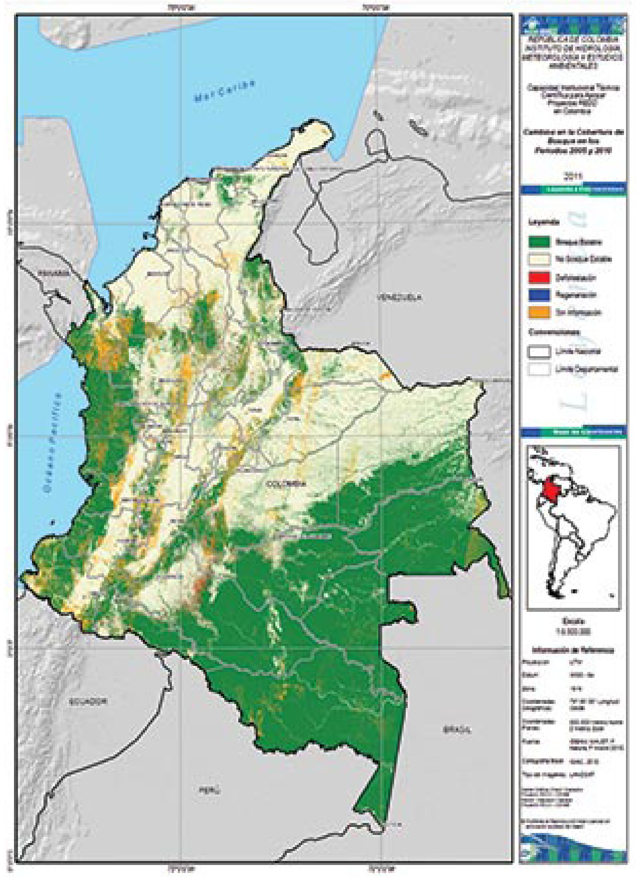

Fig. 20 MODIS Composite of Colombia

Further capacity is expected in 2017 and beyond with new launches planned, including Europe's Sentinel-2B.

In 2016, the second version of the GFOI Methods and Guidance Documentation (MGD) was released, as well as a new online tool – REDDCompass – which guides users through the core themes, concepts and actions involved in the development of National Forest Monitoring Systems (NFMS) for Measurement, Reporting and Verification (MRV). It provides contextual links to GFOI methods and guidance, space data resources, references and tools, training materials and advances in research and development as users work through the pyramid framework.

GFOI is seeking to promote one or more end-to-end country demonstrations in 2017, which would include implementation of the MGD, the GFOI Space Data Coordination Group's Space Data Services, and CEOS developed tools to demonstrate the potential of the framework for countries.

Partners, Contacts and More Information

Contact: GFOI Office: office@gfoi.org

More Information: www.gfoi.org

Efforts Targeting Land Degradation to Achieve Neutrality

15.3	**By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world**
15.3.1	**Proportion of land that is degraded over total land area**

While ensuring national ownership and retaining the flexibility for countries to use their national data, the UN Convention to Combat Desertification (UNCCD) has outlined a standardized approach for reporting on SDG Indicator 15.3.1, which focuses primarily on the use of three sub-Indicators: Land Cover and Land Cover Change; Land Productivity; and Carbon Stocks above and below ground. Such a framework gives options for countries to use Earth Observation, geospatial information and other global/regional data sources in the absence of, or to complement and enhance, national data sources.

In 2015, the UNCCD secretariat conducted a Land Degradation Neutrality (LDN) Target Setting pilot project with 14 volunteer countries from all continents to design and test a methodological and operational framework to achieve LDN and report on SDG 15.3.1. This pilot project of the UNCCD to set voluntary targets in sustainable land management and monitor progress is based on a harmonized set of 3 measurable sub-Indicators: (1) land cover and land cover change, (2) land productivity trends and (3) soil organic carbon trends, with the first two global data sets entirely based on satellite Earth Observation data. This effort is continued in a LDN Target Setting Programme (LDN-TSP) with over 100 UNCCD countries, with the objective to help countries formulating voluntary targets to achieve LDN and incorporating them in UNCCD National Action Plans (NAPs).

Earth Observation Data Use

Earth Observations from Space have proven their reliability to track land cover change and biomass activity over long periods. As many countries, in particular from the developing world, face difficulties to access this type of information, UNCCD has established partnerships with the European Space Agency (ESA), the European Commission Joint Research Center (JRC) and the International Soil Reference and Information Centre (ISRIC) to provide

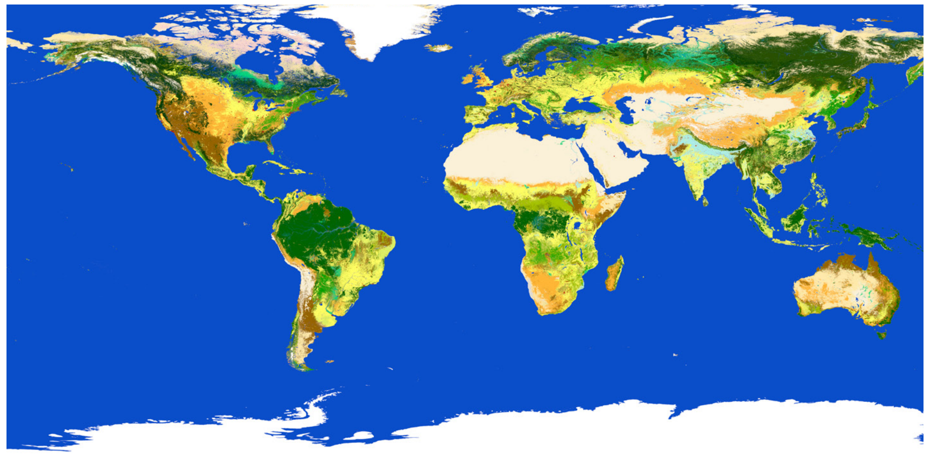

Fig. 21

Global Land Cover Map, epoch 2010, ENVISAT MERIS FRS, 300m.

The ESA CCI-Land Cover provides global land cover maps with 22 classes, at 300m resolution, for 3 epochs (2000, 2005 and 2010) and is entirely based on moderate resolution satellite data (ENVISAT MERIS, MODIS, SPOT VGT and PROBA-V).

Credit: ESA Land Cover CCI

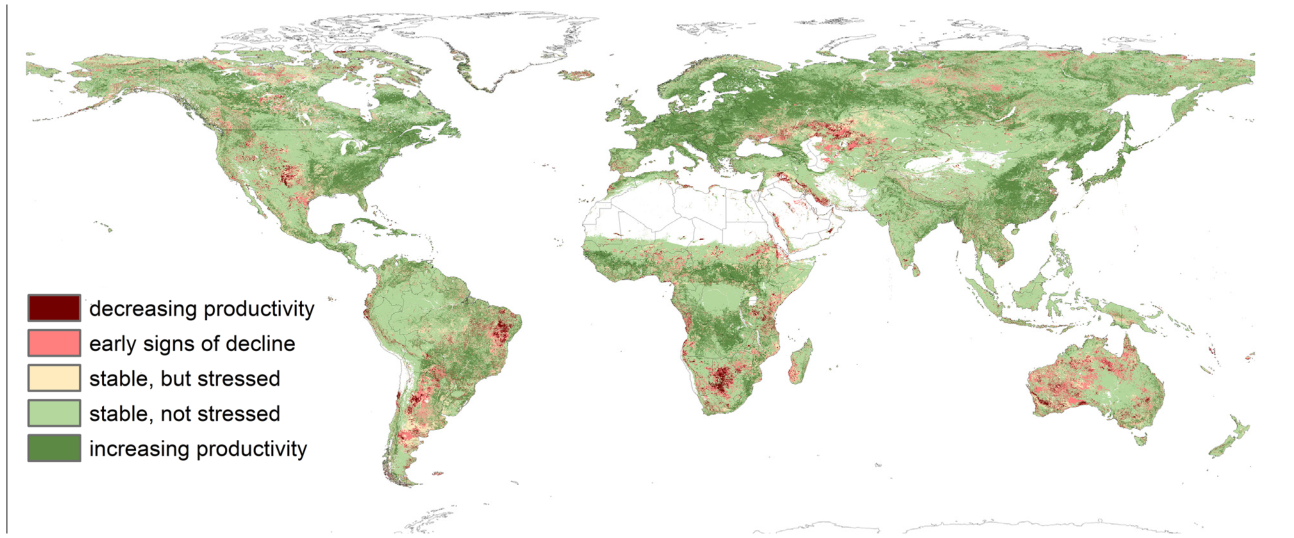

Fig. 22 **Land Productivity Dynamics (LPD), 1999-2013; SPOT VEGETATION, 1km. The LPD dataset refers to the standing biomass productivity and is derived from phenological analyses of a 15-year time series (1998 to 2013) of global normalized difference vegetation index (NDVI) observations from SPOT-VGT, composited in 10-day intervals at a spatial resolution of 1 km. The map shows 5 classes indicating areas of negative or positive change or stability and is an indicator of change or stability of the land's apparent capacity to sustain the dynamic equilibrium of primary productivity in the given 15-year observation period. Credit: Joint Research Center (JRC)**

all interested countries with extractions of global datasets as default information for their LDN target setting process: (1) Land Cover (CCI-Land Cover) from the ESA Land Cover Climate Change Initiative, (2) Land Productivity Dynamics (LPD) from JRC and (3) Soil Organic Carbon (SOC) from ISRIC.

Methodology

The work has focused on development of an agreed methodology to combine the three sub-Indicators into a measurement of the proportion of land that is degraded, which is required in order to fully implement the SDG Indicator 15.3.1.

While there is no single complex indicator which can unambiguously report on land degradation and restoration, monitoring efforts are nevertheless feasible when considering the three sub-Indicators in combination.

These methods are being developed with the assistance of institutions including the CSIRO.

Key Issues and Results

The LDN Target Setting pilot project has demonstrated the utility of global data sets on LC and LPD derived from satellite observations. Pilot countries have been able to use these global datasets in combination with their national data to set their national LDN targets.

Good practice guidance for each of the three sub-Indicators is essential to support countries in their measurement and evaluation of LC/LPD/SOC changes, and in their combination to assess land degradation. By summing those areas subject to changes (according to the three sub-Indicators), and whose conditions are considered negative by national authorities (i.e., land degradation), countries would be able to determine their pathway to deriving Indicator 15.3.1.

Analysis, Status, and Outlook

Although the existing global data sets (ESA CCI-Land Cover, JRC LPD and ISRIC SOC) have been adequately used by pilot countries to conduct their LDN target setting, the moderate resolution of these datasets is an issue, especially in mountainous regions, small island states and highly fragmented landscapes (patchiness of different LC types). There is a need to move to high resolution datasets.

The future will involve development of methodologies for the production of higher resolution (10-30m) global data sets for all three 15.3.1 sub-Indicators and support for countries on the integration of national data sets and knowledge to properly assess the complex process of land and soil degradation in their territory.

Partners, Contacts and More Information

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Partners: Contracting Parties of the UNCCD that participate to the LDN-TSP.

4 Opportunities and Challenges

Earth observation data makes the prospect of a global Indicator framework for the SDGs viable. For many Indicators, the coverage and frequency of measurements from which the Indicators are derived would simply not be feasible, technically or financially. Increasing availability and usability of the data allows NSOs and UN agencies to design the framework to make optimal use of current and planned satellite data streams. Earth observations are able to provide new and consistent data sources and methodologies to integrate multiple 'location-based' variables to support and inform official statistics and the Indicators for the SDGs.

An increasing number of NSOs are discovering the opportunities around use of new and consistent data sources and methodologies to integrate various 'geo' variables to support and inform official statistics.

Satellite data can:

- complement traditional sources (like ground or socio-economic data) when there is a lack of data;
- provide spatially and temporally denser information (on multiple scales, up to global);
- improve frequency or richness of data;
- save money on traditional methods (survey methods can be time-consuming and expensive);
- provide the only viable option in relation to global Indicators (such as those currently tracked within the GEO global forests and agricultural monitoring initiatives);
- allow consistent and comparable measurements across different countries and regions.

Modern computing and data handling capabilities permit the integration of information from a range of different sources. The GEOSS 'system of systems', through its Common Infrastructure (GCI), links more than 150 different data catalogs containing more than 200 million resources, accessible through an easy-to-use GEOSS Portal. There were more than 4.4 million inquiries to the GCI in 2016 alone.

The UN Global Working Group (GWG) on Big Data for Official Statistics is exploring the potential of satellite imagery and geospatial data, including how to make use of existing methods for estimating official statistics (eg to support the SDGs) at high temporal and spatial resolutions (report to be released in 2017).

Some international coordination organisations already exist to assist NSOs and UN agencies to navigate the transition to inclusion of EO data in the SDG Indicator framework and the development of the supporting national information. GEO's EO4SDGs Initiative focuses on realising the potential that Earth observations and geospatial information offer to the SDGs, supports collaboration with national statistical offices, and builds capacity within GEO on statistical practices for the purposes of the SDGs. The initiative promotes the emergence and scaling-up of joint efforts and collaborations between these national statistical offices, international statistical agencies, UN entities, and the EO/GI community to demonstrate the effective use of EO/GI data in complementing traditional data systems such as census data, administrative data, household survey data, and vital statistics, to help realise the SDGs.

Both the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO) have established processes aimed at ensuring readiness and support for the SDG framework and can provide practical guidance as required to national and UN agencies. GEO's EO4SDGs works closely with the Global Partnership for Sustainable Development Data (GPSDD) to help countries align their national priorities to the SDGs, and implement data roadmaps for sustainable development.

EO data and big data more broadly represent significant opportunities for complementing and enhancing official statistics. However, there are also challenges in implementing these data sources for statistical purposes:

- the data are still large and complex: there can be significant obstacles, particularly in developing countries, relating to the necessary expertise, infrastructure and internet bandwidth to efficiently and effectively access, prepare, process, and utilise the growing volume of raw space-based data for local, regional, and national decision-making;
- complementing traditional statistical methods with data derived from sensors, simulation and modelling will not be simple and will require reworking of national systems and processes;
- even though analysis ready data (ARD) may simplify the access and application of EO data, NSOs will still need to better understand how to select, access, process and apply the required data sources. There are many sources of available satellite imagery data, free or commercial, from different EO satellites, collecting various measurements about the land and land cover, water and atmosphere. Data continuity is a key consideration for countries looking towards long-term investment in their frameworks and this might naturally guide agencies towards the mission series with the greatest longevity and future continuity plans (such as Landsat or the European Sentinel series); the concept of core data streams for different Indicators is likely to emerge, just as it has been done for the existing GEO initiatives like GFOI;
- EO does not deliver any statistical Indicators by default; it provides some spatial, spectral, and temporal information which can then be related to Indicators; it is important for NSOs to identify the best algorithmic approach and statistical applications that are most suited to the use of EO data, based on clear organisational benefits, feasibility of methods and likely cost savings.

It is important for NSOs to be able to assess when to use EO data, if appropriate for their statistical purposes to monitor SDGs. A key question is whether the required data or information products can be generated from EO at all. The decision-tree above aims to help the decision as to whether it is appropriate and possible to use EO data products.

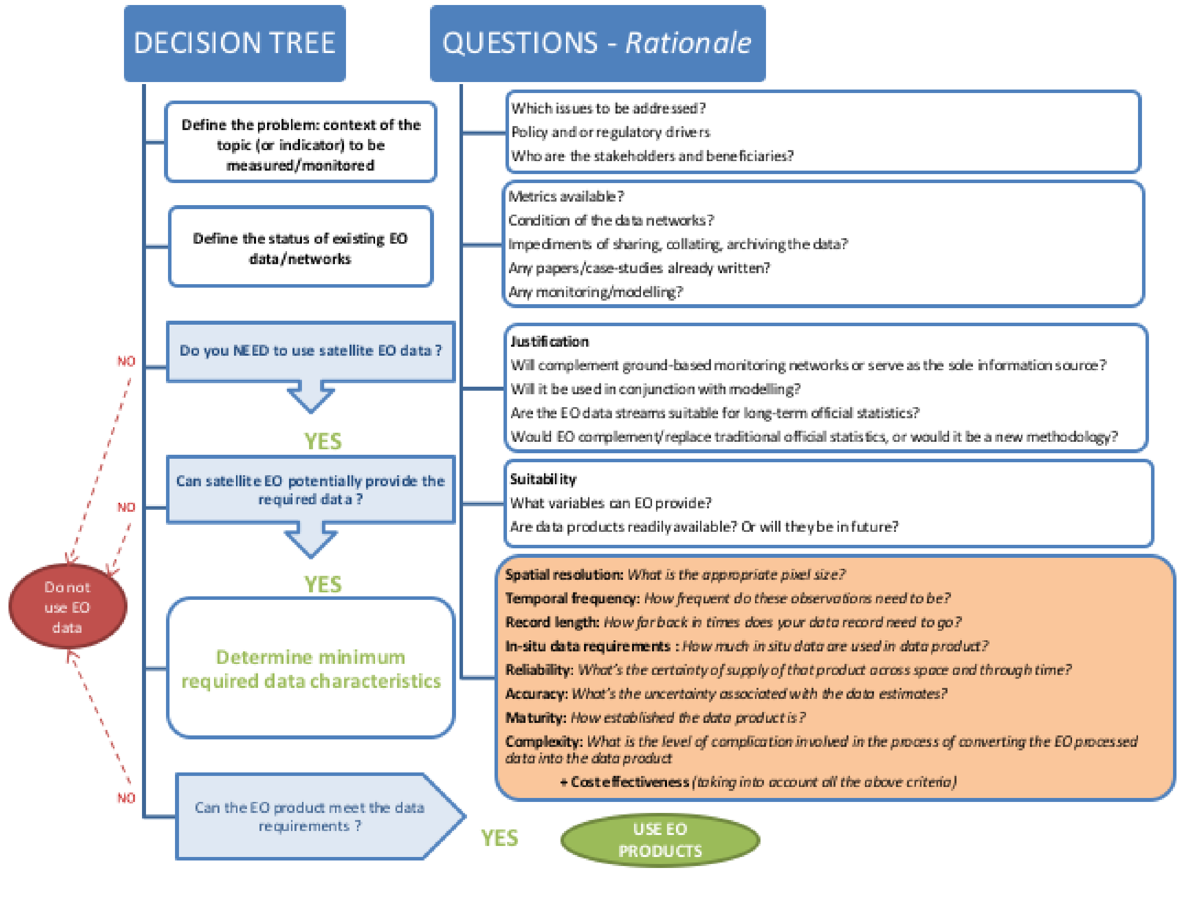
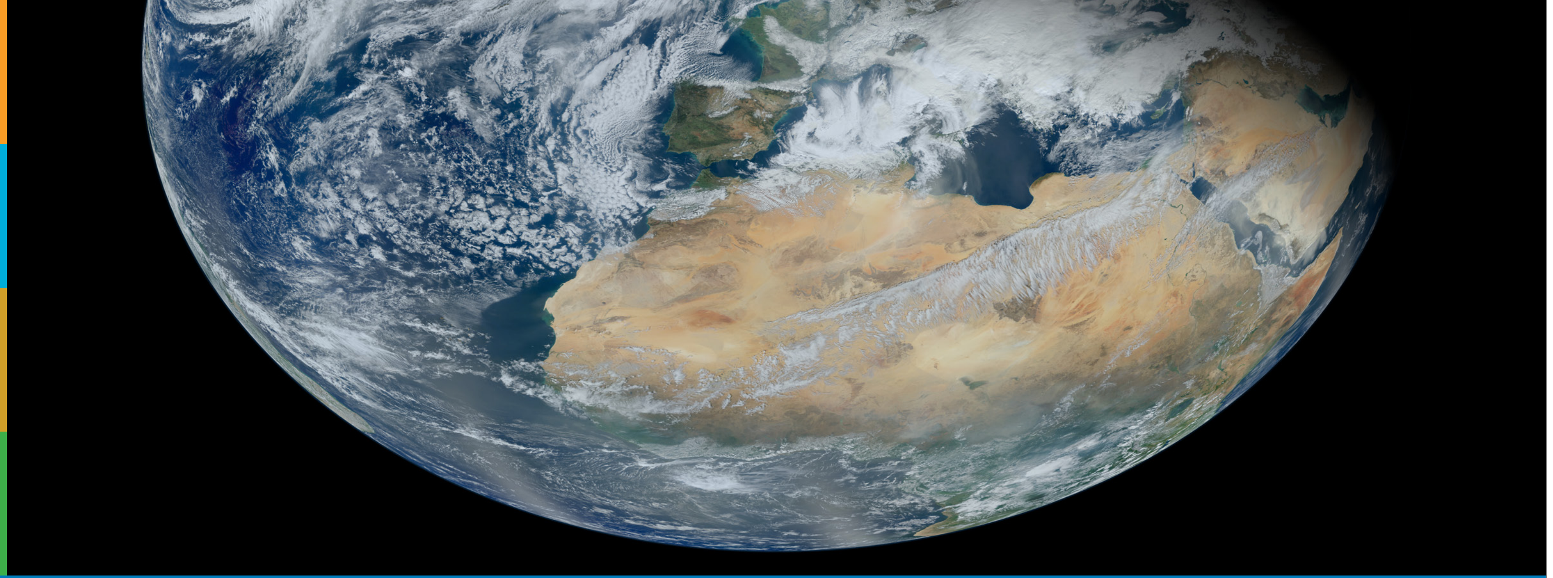


Fig. 23 Decision tree on the usage of EO data for NSOs.



5 Conclusions and More Information

The case studies compiled in this booklet illustrate a sample of the opportunities that exist for NSOs and UN agencies to effectively integrate EO data and other geospatial information into the design of their Indicator frameworks for tracking progress more accurately towards the UN SDGs. It also demonstrates how Earth observations can more generally help achieve individual Goals and Targets of the 2030 Agenda for Sustainable Development, as well as the nexus between different Goals.

Earth observation and geospatial information can significantly reduce the costs of monitoring the aspirations reflected in the Goals and Targets, and make SDG monitoring and reporting viable within the limited resources available to governments. Beyond the SDG framework, these same data can provide developing countries and regions with increased capacity to acquire, analyse and utilise information for a broad range of policy-making purposes.

The increasing capability and diversity of operating EO satellites provide significant opportunity for these data streams to support a large number of the proposed Indicators, bringing more accurate, spatially explicit, and frequently updated evidence.

Earth observation-derived monitoring and methodologies are being developed for select SDG Indicators through work done by the UN Inter-agency and Expert Group (IAEG - Working Group on Geospatial Information (WGGI)) and the UN custodian agencies, parts of the UN specifically assigned to develop the best methods to support data collection for specific Targets and Indicators. These methodologies will be integrated into statistical practice standards and manuals and supported by pre-selected ensembles of free and open data sources made available from GEO and other global data stores. NSO's should plan for incremental incorporation of Earth observations and geospatial data as work is completed on Targets and Indicators by the global community in UN organizations, GEO and CEOS.

Further Information

CEOS	**www.ceos.org**
CEOS SDG support	**www.ceos.org/ourwork/ad-hoc-teams/sustainable-development-goals**
Earth Observation Handbook	**www.eohandbook.com**
GEO	**www.earthobservations.org**
GEO SDG support	**www.earthobservations.org/activity.php?id=52**
UN SDGs	**www.un.org/sustainabledevelopment/sustainable-development-goals**
UN Inter-agency Expert Group	**www.unstats.un.org/sdgs/iaeg-sdgs**
UN Big Data Working Group	**www.unstats.un.org/unsd/bigdata/taskteams/si-gsd**

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For the Case studies (lead contributors)

1. Group on Earth Observations Global Agricultural Monitoring (GEOGLAM)
   A. Whitcraft (GEOGLAM), F. Kerblat (CSIRO)
2. Algal Bloom Early Warning Alert System
   T. Malthus (CSIRO)
3. Flood Prediction System Using the Global Satellite Map of Precipitation (GSMaP)
   R. Oki and M. Kachi (JAXA)
4. Global Mangrove Watch – Mapping Extent and Annual Changes in the Global Mangrove Cover
   A. Rosenqvist (SoloEO)
5. Earth Observation for Water-related Ecosystem Monitoring
   C. Giardino and M. Bresciani (CNR-IREA)
6. Mapping Urban Growth
   M. Paganini (ESA), T. Esch and M. Marconcini (DLR)
7. Air Pollution Monitoring for Sustainable Cities and Human Settlements
   M. Kikuchi, A. Kuze and S. Sobue (JAXA)
8. Using Remote Sensing for Water Quality Monitoring of the Great Barrier Reef
   T. Schroeder (CSIRO)
9. Mapping Forest Cover Extent and Change, and Progressing Sustainable Forest Management
   A. Kavvada (NASA, GEO) and M. Hansen (University of Maryland)
10. The Global Forest Observations Initiative and Space Agency Support to Forest Monitoring
    M. Steventon and S. Ward (Symbios)
11. Efforts Targeting Land Degradation to Achieve Neutrality
    M. Paganini (ESA), A. Held (CSIRO), M. Cherlet (JRC), S. Minelli (UNCCD Sec.), S. Walter (UNCCD Global Mechanism)

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Glossary

Acronym	Full name
ADB	Asian Development Bank
AEWS	Algal Early Warning System
AGDC	Australian Geoscience Data Cube
AMIS	Agricultural Market Information System
APRSAF	Asia-Pacific Regional Space Agency Forum
ARD	Analysis Ready Data
Asia-RiCE	Asian Rice Crop Estimation
BoM	Bureau of Meteorology (Australia)
CEOS	Committee on Earth Observation Satellites
CM4AMIS	Crop Monitor for AMIS
CM4EW	Crop Monitor for Early Warning
CNES	Centre National d'Etudes Spatiales (France)
CNR-IREA	National Research Council of Italy
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EC	European Commission
EC SIGMA	European Commission Stimulating Innovation for Global Monitoring of Agriculture
EC WFD	EC Water Framework Directive
ECV	Essential Climate Variable
Envisat	Environmental Satellite (ESA)
EO	Earth Observation(s)
EOMORES	Earth Observation-based Services for Monitoring and Reporting of Ecological Status
ESA	European Space Agency
FAO	Food and Agriculture Organization of the United Nations
G20	Group of Twenty
GA	Geoscience Australia
GCOM	Global Change Observation Mission (JAXA)
GEO	Group on Earth Observations
GEO satellite	GEOstationary statellite
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
GFOI	Global Forest Observations Initiative
GI	Geospatial Information
GMW	Global Mangrove Watch
GOSAT	Greenhouse Gases Observing Satellite
GSFC	Goddard Space Flight Center (NASA)
GSMaP	Global Satellite Map of Precipitation
GUF	Global Urban Footprint (from DLR)
GWG	Global Working Group
ICHARM	International Center for Water Hazard and Risk Management under the auspices of UNESCO
IPCC	Intergovernmental Panel on Climate Change
ISRIC	International Soil Reference and Information Centre
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JAXA	Japan Space Exploration Agency
JECAM	Joint Experiment for Crop Assessment and Management (GEOGLAM)
JMA	Japan Meteorological Agency
JRC	Joint Research Center (European Commission)
LAI	Leaf Area Index

Acronym	Full name
Landsat	Land satellite (NASA)
LC-CCI	Land Cover Climate Change Initiative (ESA)
LCC	Land Cover Change
LDN	Land Degradation Neutrality
LDN-TSP	LDN Target Setting Programme
LEO satellite	Low Earth Orbit satellite
LIMNADES	Lake Bio-optical Measurements and Matchup Data for Remote Sensing
LPD	Land Productivity Dynamics (JRC)
LTER	Long-Term Ecological Research
MGD	Methods and Guidance Document
MIM	Missions, Instruments, and Measurements (CEOS database)
MODIS	MODerate-resolution Imaging Spectroradiometer
MOE	Ministry of the Environment (Japan)
MRV	Measurement, Reporting and Verification
NASA	National Aeronautics and Space Administration
NCI	National Computational Infrastructure (Australia)
NGOs	Non-Governmental Organizations
NICAM	Non-hydrostatic ICosahedral Atmospheric Model
NIES	National Institute for Environmental Studies (Japan)
NSO	National Statistical Office
RAPP	Rangeland and Pasture Productivity (GEOGLAM)
REDD+	Reducing Emissions from Deforestation and forest Degradation
SAR	Synthetic Aperture Radar
SAR4URBAN	SAR for urbanisation monitoring
SDCG	Space Data Coordination Group (GFOI, CEOS)
SDGs	Sustainable Development Goals (United Nations); the 2030 Agenda for Sustainable Development
Sent2Agr	ESA Sentinel-2 for Agriculture
SMAP	Soil Moisture Active Passive
SMOS	Soil Moisture and Ocean Salinity (ESA)
SOC	Soil Organic Carbon (ISRIC WDC-Soils)
SPRINTARS	Spectral Radiation-Transport Model for Aerosol Species
SRTM	Shuttle Radar Topography Mission
TRMM	Tropical Rainfall Measuring Mission (NASA)
U-TEP	Urban Thematic Exploitation Platform (from ESA)
UMD	University of Maryland
UN	United Nations
UN-WCM	United Nations World Conservation Monitoring Centre
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WG	Working Group (CEOS)
WHO	World Health Organization
WRI	World Resources Institute