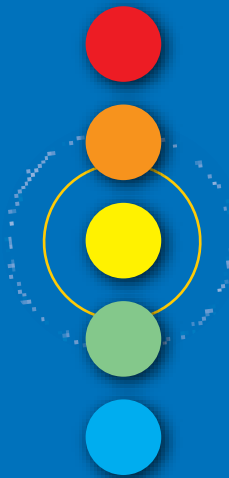


# TERRESTRIAL ESSENTIAL CLIMATE VARIABLES

FOR CLIMATE CHANGE ASSESSMENT,  
MITIGATION AND ADAPTATION



BIENNIAL REPORT  
SUPPLEMENT



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# TERRESTRIAL ESSENTIAL CLIMATE VARIABLES

FOR CLIMATE CHANGE ASSESSMENT,  
MITIGATION AND ADAPTATION

[ GTOS 52 ]

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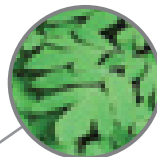
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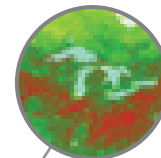
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# INTRODUCTION

by Han Dolman, John Latham and Reuben Sessa

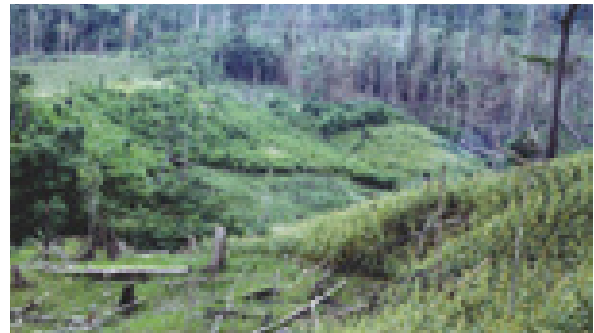
**The 2007 IPCC assessment unequivocally states that humans have significantly changed the composition of the atmosphere and that, as a result, our climate is changing. To be able to attribute the causes of climate change, analyse the potential impacts, evaluate the adaptation options and enable characterization of extreme events such as floods, droughts and heat waves, globally consistent sets of observational data are needed. Without such baseline data it will not be possible develop the products needed by policy and other stakeholders.**

The climate observing system in the terrestrial domain is, however, still poorly developed, while at the same time there is increasing significance being placed on terrestrial data for impact, adaptation and mitigation activities. The precise quantification of the rate of climate change also remains important to determine whether feedback or amplification mechanisms, in which the terrestrial surface plays an important role, are operating within the climate system.

The Global Terrestrial Observing System (GTOS) is supporting its Sponsors (FAO, UNEP, WMO, UNESCO, ICSU) and the broader stakeholder community to address issues of climate change and climate variability, especially with regard to its effects on food security, the environment and sustainable development. The GTOS Secretariat, with the assistance of its Panels, is also supporting the observational requirements of the UNFCCC. In particular it is developing possible mechanisms for a terrestrial framework and assisting the implementation of the 13 terrestrial Essential Climate Variables (ECVs), including the assessment of the status of available standards. These terrestrial, with oceanic and atmospheric, ECVs were originally identified in the implementation plan developed by GCOS and its partners as the observations that are currently feasible for global implementation and have a high impact on the requirements of the UNFCCC and other stakeholders. These activities are also recognized as an official task of the Global Earth Observation System of Systems (GEOSS).

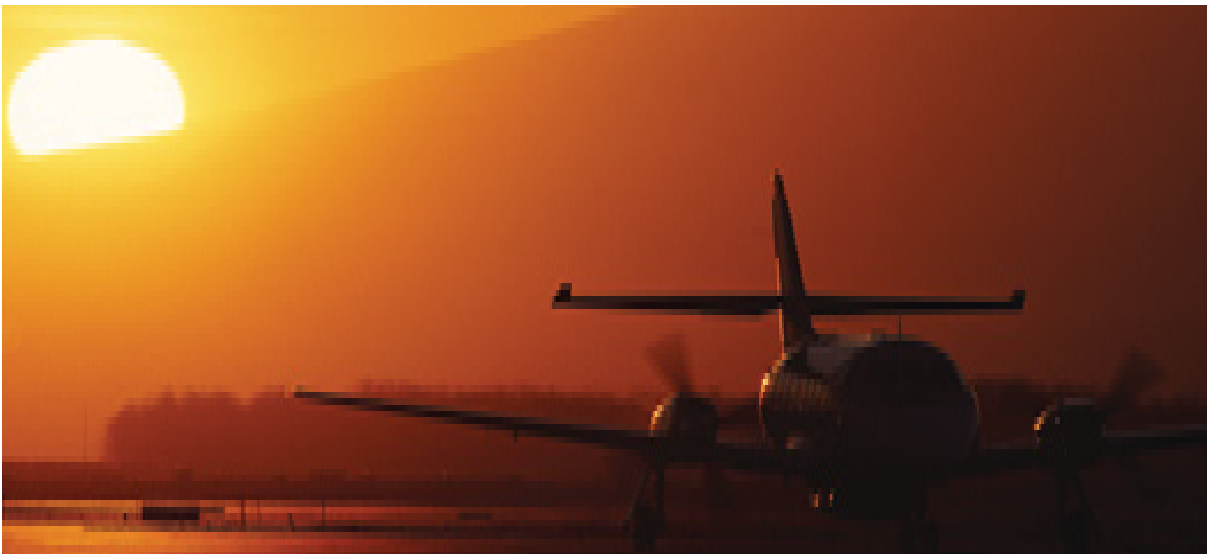
GTOS liaises with relevant research and operational communities to identify measurable terrestrial properties and attributes that control the physical, biological and chemical processes affecting climate. Through its Secretariat and its Panels, especially TOPC (a joint panel of GTOS and GCOS), GTOS is playing an important role towards improving the understanding of the terrestrial components of the climate system, the causes of change to this system and the consequences in terms of impact, adaptation and mitigation. An important role is also played in regards to international coordination; supporting the *in situ* Global Terrestrial Networks undertaking the observations; determining the requirements of stakeholders; and assessing the available methodologies and standards which are required.

The establishment of both independent bottom-up data sets of ECVs and data sets required for calibration and validation of Earth Observation data is an important activity of the networks. Only harmonized,



FAO/13903/R-Heinrich

# Terrestrial observations for addressing climate change and other related issues are crucially important for stakeholders



consistent data sets provide the multi-user community, which includes the UNFCCC, countries and other organizations dealing with elements of global change, such as desertification, with the high quality global data sets required to achieve their purpose.

The international space agencies, through the Committee for Earth Observation Satellites (CEOS), have agreed to provide multi-decadal climate products covering the terrestrial, oceanic and atmospheric domains. Internationally agreed validation protocols and benchmarks are, however, not always available for terrestrial climate variables. GTOS and its science Panels are collaborating with the CEOS' Working Group on Calibration and Validation to establish such protocols and benchmarks.

However, despite the demonstrated importance of the terrestrial climate variables and the work that is ongoing, there are still important gaps in satellite and especially *in situ* observations, and these need to be filled and resolved. These concern, for example, the apparently ever decreasing number of stations measuring river discharge, and the scarcity of suitable networks observing permafrost. A further challenge is to ensure continuity in cryospheric observations, some of which were only initiated under the International Polar Year. The hydrological variables in the terrestrial domain also require attention, especially those relating to soil moisture (which is a key variable linking

the atmospheric and terrestrial branches of the hydrological cycle) and groundwater (as a declining and often overexploited resource for fresh water). In addition, the terrestrial variables that play a role in the carbon cycle need to be monitored in a comparable way to the other terrestrial ECVs. TOPC will work closely with the Terrestrial Carbon Observation Panel of GTOS to achieve this. The importance of these observations and some of the activities, gaps, concerns and funding requirements have been highlighted in this report.

Responding to new and changing requirements of the UNFCCC and other conventions, as well as the needs of international treaties and agreements, GTOS and GCOS will assess the adequacy of current *in situ* and remote sensing observations, and review and suggest new terrestrial ECVs that are strongly needed to determine transient change, adaptation, impact and mitigation. The GTOS Secretariat and its technical Panels, especially TOPC, will continue to play a fundamental role in this process, emphasizing the need for consistent, harmonized observation of key terrestrial variables.

## ACKNOWLEDGMENTS

The GTOS Secretariat would like to thank the authors for their contributions to this report, the many individuals who provided comments and guidance (especially Josef Cihlar) and Thorgeir Lawrence and Stephanie Vertecchi for proof reading the drafts.

## RELATED LINKS:

GTOS: [www.fao.org/gtos](http://www.fao.org/gtos) | TOPC: [www.fao.org/gtos/topc.html](http://www.fao.org/gtos/topc.html) | GCOS: [www.wmo.int/pages/prog/gcos](http://www.wmo.int/pages/prog/gcos) | UNFCCC: <http://unfccc.int>

# INTERNATIONAL FRAMEWORK FOR CLIMATE-RELATED TERRESTRIAL OBSERVATIONS

by Josef Cihlar, Reuben Sessa and John Latham



## NEED FOR GLOBAL HARMONIZED DATA

The GCOS Second Adequacy Report noted that the many difficulties encountered in regards to terrestrial observations, including the lack of homogeneous observations, could be resolved by the creation of an intergovernmental technical commission for terrestrial observations, similar to those that exist for the Atmospheric and Oceanic domains. Such a body would prepare guidance materials; establish common standards for observations and data management; and would seek hosts for International Data Centres that would deal with the Essential Climate Variables (ECVs).

## SUPPORTING THE REQUIREMENTS OF THE UNFCCC

It is evident that such a framework mechanism is vital for generating the tools, methodologies, data, information and support required by the UNFCCC in meeting its long-term objective to stabilize greenhouse gas concentrations in the atmosphere, and for assisting member countries in meeting their needs when confronting the effects of climate change. Realizing the need for the development of appropriate policies to deal with climate change and based upon the GCOS Implementation Plan, the Conference of Parties in its

9th Session invited GTOS and its Sponsors “to develop a framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate, and associated data and products”. At the 23rd Session of SBSTA/COP in Montreal, November 2005, progress reports were submitted by GTOS, and SBSTA welcomed the efforts and asked that the work be continued.

## ESSENTIAL REQUIREMENTS OF A TERRESTRIAL FRAMEWORK

GTOS has examined existing mechanisms employed by intergovernmental or international organizations for similar purposes, including those of its Sponsors (FAO, ICSU, UNEP, UNESCO and WMO), as well as other mechanisms such as those used by the International Organization for Standardization (ISO). The desired framework is one which: serves a multi-purpose role, with an initial focus on terrestrial climate variables; follows an existing successful model if possible; facilitates inputs by users and producers of observational data; and is broadly acceptable and adopted by countries. In addition, the framework should: act as an international coordination mechanism; generate international scientific and technical consensus; accommodate satellite as well as *in situ* observations; be flexible to meet new observational requirements; be able to attract extra-budgetary resources; and — most importantly — ensure national endorsement and implementation.

## FRAMEWORK OPTIONS

Based on the above criteria, three candidate framework mechanisms have been identified.

- Option A (intergovernmental): A “Terrestrial Joint Commission” would be established as a subsidiary body of intergovernmental organizations that deal specifically with primary observations.



FAO/11930Z1874/6. Bizzarri



# A framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate, and associated data and products



FAO/11931A1784/G.Bizzarri

- Option B (ISO): A “Terrestrial Committee” would adapt the approach used by the ISO to establish international standards. A new group (Technical Committee, subcommittee or new working group) would be formed in agreement with the ISO Technical Management Board (TMB) and the entity coordinating the work.
- Option C (international): This option refers to other organizational frameworks that could achieve the results desired by the COP. For example, the UNFCCC COP could decide to extend the mandate of the Intergovernmental Panel on Climate Change (IPCC).

## SELECTION OF THE PREFERRED OPTION

To allow stakeholders to evaluate the different framework options, the advantages and disadvantages of each have been identified in terms of: (i) their characteristics; (ii) costs of establishment and operation; (iii) required approval and adoption of the resulting products; (iv) the likely suitability for the tasks identified; (v) the likelihood of meeting the required criteria; and (vi) the critical challenges involved in implementing each option.

## NEXT STEPS

The three options have different strengths and weaknesses but, if implemented appropriately, should satisfy the needed requirements. The selection of a preferred solution requires careful weighing of the specific characteristics of each option, and of the likelihood that its weaknesses will be overcome or mitigated during or after implementation.

After receiving guidance and recommendations from SBSTA at its 27th Session, in Bali, regarding its preferred option, GTOS will collaborate with its partners in developing a final framework proposal. Political, technical and financial support for its implementation will then be required from national governments and international organizations. Due to these additional discussions and negotiations, the final form of the selected framework may differ from the above outlined options.



FAO/14802

# STANDARDS AND HARMONIZATION OF TERRESTRIAL OBSERVATIONS

by Reuben Sessa, Josef Cihlar, Monica Monteduro, Sophie Mintier, Han Dolman and John Latham



## WHY STANDARDS?

The GCOS Implementation Plan identified 13 terrestrial Essential Climate Variables (ECVs): Albedo; Biomass; Fire disturbance; Fraction of absorbed photosynthetically active radiation (FAPAR); Glaciers and ice caps; Groundwater; Lake levels; Land cover (including vegetation type); Leaf area index (LAI); Permafrost and seasonally-frozen ground; River discharge; Snow cover; and Water use.

These observations are currently measured by numerous organizations for a variety of purposes. However, in general, a variety of different measurement protocols are used, which results in a lack of homogeneity in the data (in space and time). This heterogeneity limits the use of the data for many terrestrial applications and constrains scientific capacity to monitor and assess changes in climate change.

## UNFCCC REQUEST TO GTOS

To begin to address this important issue, the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC in 2006 “called on the GTOS Secretariat to assess the status of the development of standards for each of the essential climate variables in the terrestrial domain”.

## INVESTIGATIONAL APPROACH

The question of standards for the terrestrial ECVs encompasses a very broad spectrum of topics in terms of: (i) the environmental variables involved; (ii) the geographical coverage and diversity of these variables, leading to differing measurement approaches; (iii) the types of documents or formats relevant to the development of standards (standards, guides, protocols, guidelines); (iv) the areas in principle requiring standardization (initial measurements, data processing, analysis, final

product); (v) the need for *in situ* as well as satellite measurements; and (vi) the number of sources where information relevant to standardization may be generated or archived.

Taking into consideration the above, GTOS has undertaken a comprehensive search for standards, guidelines, methodologies and processing protocols for each terrestrial ECV. Considerable efforts were made to contact stakeholders (including UN agencies, national data centres and international observing networks) and to undertake database and Web searches. The resulting information and documentation has been compiled, and reports with a summary of the findings, conclusions and recommendations have been, or are being, developed for each ECV.

## CURRENT FINDINGS AND RESULTS

From the initial investigations, few standards appear to exist and no internationally accepted standards that directly address the needs of the user community have been identified so far. At the same time, there are guides for measurement methods—



The lack of homogeneous observations hinders many terrestrial applications, limits the ability to detect and quantify changes, and hampers understanding of the impacts of climate change



FAO/J. Spaul/72684

which may describe several methods and discuss the utility of each—and measurement protocols that describe in detail how a specific terrestrial variable should be sampled and measured *in situ*. However, for many of the ECVs, the existing procedures exhibit considerable diversity in techniques and approaches.

For satellite-based measurements, the complexity arises from differences among satellite sensors, their suitability to provide exactly the measurements needed, and the often limited spatial coverage. Of particular concern is temporal coverage, which is often limited.

Due to the diversity in satellite data, the continuing technological evolution and the nature of satellite-based earth observations, it is generally not feasible (or desirable) to have one set of algorithms. However, what is important is to ensure the validation (for each generated product) and inter-comparisons (among similar products) of satellite-derived observations. This is being addressed by research teams, which as a matter of routine develop common protocols and undertake the validation of products (e.g. the CEOS Working Group on Calibration and Validation).

#### STAKEHOLDER REVIEW AND WEB FORUM

A large stakeholder community has been informed of the process being undertaken, and a Web site (see link below) has been created that allows stakeholders to review, comment and add additional information to the work so far undertaken. It is hoped that this will facilitate the peer review process required to complete the individual products.

#### NEXT STEPS

The GTOS Secretariat will continue to compile and finalize the reports based on the peer review process, and will report on the progress made and provide suggestions on how to move forward to SBSTA at its 27th Session, in December 2007, where issues regarding systematic observations will be discussed. It is hoped that SBSTA will provide guidance and support to further continue this initiative. Once the recommendations of SBSTA have been received, GTOS will create technical working groups for each ECV to develop and propose potential standards or guidelines. However, this will only be feasible once financial support has been secured.

#### RELATED LINKS:

GTOS ECV standards activities: [www.fao.org/gtos/topcECV.html](http://www.fao.org/gtos/topcECV.html) | TOPC: [www.fao.org/gtos/topc.html](http://www.fao.org/gtos/topc.html)

CEOS Working Group on Calibration and Validation: <http://lpvs.gsfc.nasa.gov>

# THE CEOS CONSTELLATION FOR LAND SURFACE IMAGING

by CEOS



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

## THE CEOS CONSTELLATION CONCEPT

A constellation of satellites that routinely and frequently image the Earth's land surface with calibrated wavelengths from the visible to the microwave, and in spatial detail that ranges from sub-metre to hundreds of metres, would offer enormous benefits to society. Such a constellation would provide the fundamental data required by scientists to help predict, and mitigate the effects of, natural disasters; to monitor climate change; to study ecosystems and biodiversity; to address important human health issues; and to undertake many other equally important scientific and practical activities. The CEOS Constellations Concept has been created to reach such an objective and to facilitate CEOS member agencies in supplying the space-based observations required to satisfy the requirements of the GEOSS 10-year Implementation Plan. CEOS has established study teams to define four prototype constellations: precipitation, land surface imaging, ocean surface topography, and atmospheric composition.

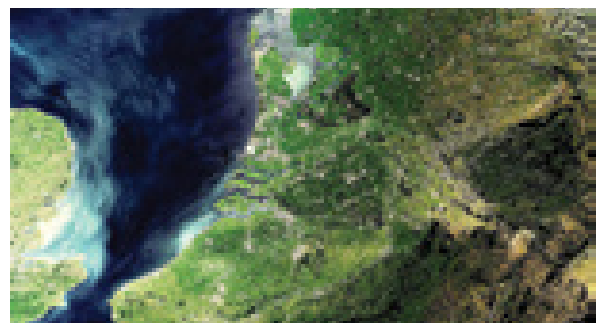
## LAND SURFACE IMAGING (LSI)

The fundamental mission of the Land Surface Imaging (LSI) Constellation is to promote the efficient, effective, and comprehensive collection, distribution, and application of space-acquired image data of the global land surface, especially to meet societal needs of the global population, such as those addressed

by the Group on Earth Observations (GEO) societal benefit areas. LSI addresses not only the building and launching of satellite systems, but also the development and operation of associated ground segments and the efficient delivery of data to stakeholders.

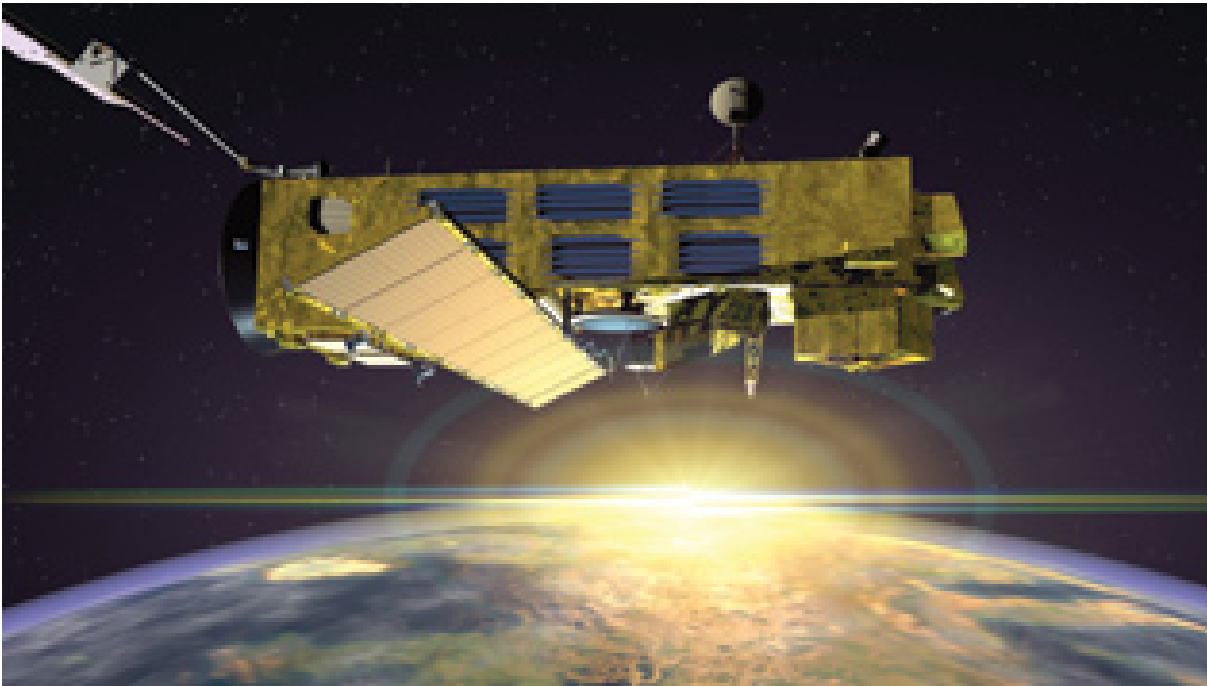
## METHODOLOGY AND SCOPE

LSI will focus on the definition and accomplishment of a series of studies and activities. These studies and activities will result in the definition of a broad range of rather detailed characteristics (or standards) that describe optimal, end-to-end capabilities (and policies) to acquire, receive, process, archive and distribute land surface image data. Constellation studies and activities will also address shorter-term problems and issues facing the land remote sensing community today, such as seeking ways to work more cooperatively in the operation of existing land surface imaging systems.



ESA Envisat image

# Looking to the future while seeking to optimize benefits from current land remote sensing systems



ESA Envisat, advanced polar-orbiting Earth observation satellite, which provides measurements of the atmosphere, ocean, land and ice

## 2007 GOALS AND OBJECTIVES

Three main LSI Constellation goals for 2007 have been established, which mainly address mid-resolution (10 m–30 m) land imaging systems. These goals are to:

- establish agreement(s) among space agencies currently operating mid-resolution land surfacing imaging satellite systems, to cooperate more closely and create a prototype LSI Constellation;
- develop preliminary standards for a mid-resolution LSI Constellation, and
- contribute to the production of a fundamental climate data record (FCDR).

The potential value of an operational LSI Constellation is being demonstrated through the provision of mid-resolution land surface image satellite data to support the implementation of the Global Forest Resources Assessment 2010 of FAO.

## CEOS SUPPORT TO UNFCCC-REQUIRED OBSERVATIONS

CEOS agencies operate satellites that collect data related to many of the atmospheric, oceanic and terrestrial Essential Climatic Variables (ECVs), which are required to meet the needs of the Parties

to the UNFCCC. The Global Climate Observing System (GCOS) report on “Systematic observation requirements for satellite-based products for climate” clearly outlines the needs of the climate community. CEOS recognizes that meeting these observational requirements would not only lead to a much improved understanding of climate issues it would also significantly contribute to the societal benefit areas (SBAs) of GEOSS.

The CEOS Constellations of satellites and associated ground support systems will therefore work in a coordinated manner to address the actions outlined by GCOS. The issues that will be addressed include:

- continuity of satellite measurements
- systematic data generation
- safeguarding of records
- data access
- international coordination addressing future measurement needs.

In addition, issues such as the reprocessing of historical data collections, improving data continuity and moving measurements from research to operational will be addressed.

## RELATED LINKS:

CEOS: [www.ceos.org](http://www.ceos.org) | GCOS report on required satellite observations: [www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf](http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf)  
Report of CEOS response to GCOS: [www.ceos.org/CEOS%20Response%20to%20the%20GCOS%20IP.pdf](http://www.ceos.org/CEOS%20Response%20to%20the%20GCOS%20IP.pdf)

# RIVER DISCHARGE

by Ulrich Looser



## OBSERVATIONAL IMPORTANCE

The monitoring of river discharge is ideally suited to detect and monitor changes resulting from climate change. At the same time, the freshwater discharge from rivers into the oceans plays a role in driving the climate system, as the freshwater inflow into the oceans may influence oceanic circulation patterns.

## CONCEPT OF GTN-R

The project Global Terrestrial Network for River Discharge (GTN-R) was launched by the Global Runoff Data Centre (GRDC) with the aim of enabling access to near-real-time river discharge data for selected gauging stations around the world, thereby capturing the majority of the freshwater flux into oceans. GTN-R plans to draw together the already available heterogeneous information on near-real-time river discharge data from individual national hydrological services, and redistribute the data in a harmonized way. GTN-R is supported by an action item in the GCOS Implementation Plan, published in October 2004.

## BENEFICIARIES

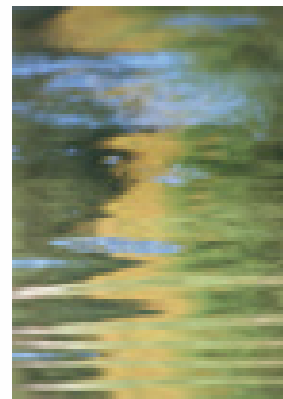
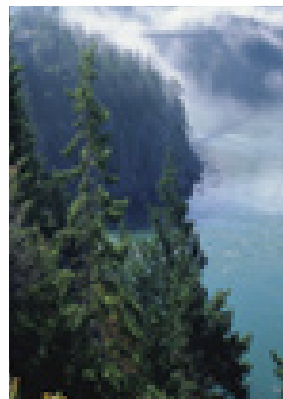
GTN-R will serve an expanding user community by supporting several activities, including: the GCOS baseline river discharge network; GTN-H; future versions of the GRDC Long-Term Mean Annual Freshwater Surface Water Fluxes into the World Oceans product; biogeochemical flux computations of the GEMS/Water Programme Office (UNEP/DEWA); the WHYMAP project, and an increasing number of activities and projects in the fields of climate and hydrological research and monitoring.

## NETWORK

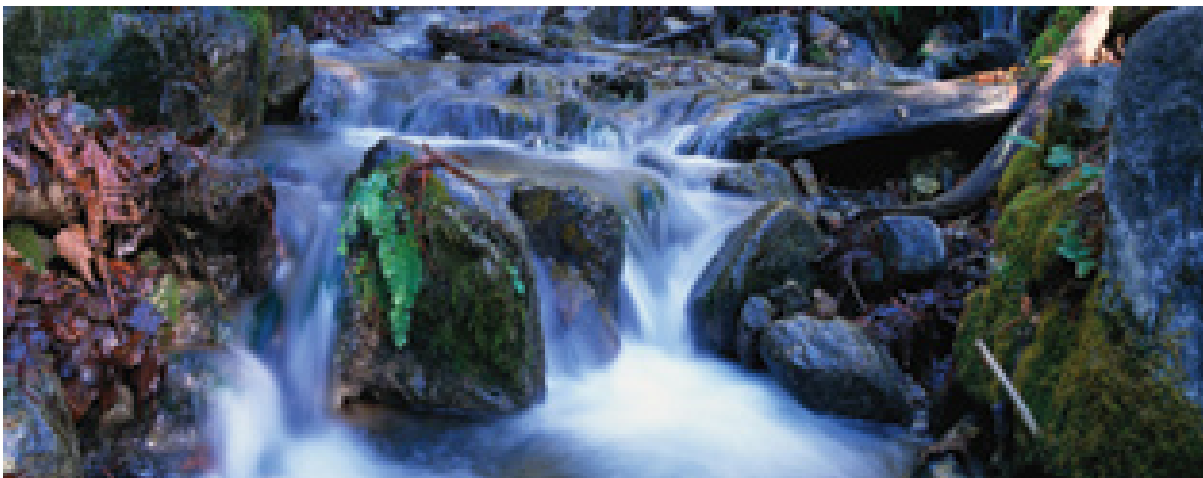
GRDC has proposed a priority network of river discharge reference stations. This network is now being adjusted in consultation with national hydrological services, and a total of 185 stations have been confirmed, with the status of another 265 stations not yet clarified. Only 25 percent of the national hydrological services identified for participation in GTN-R have responded, and now further efforts are needed to finalize the baseline network.

## UNDERLYING SOFTWARE

At the core of GTN-R is a software that collects near-real-time discharge data from distributed servers via the Internet, harmonizes and summarizes them, and makes them available in a single, standardized format. This software is currently being developed at GRDC as part of the European Terrestrial Network for River Discharge (ETN-R). This contract work is conducted for the Joint Research Centre (JRC) of the European Commission to provide European near real-time discharge data in support of the European Flood Alert System (EFAS).



# Harmonized real-time river discharge data capturing freshwater flux into oceans



## COOPERATION REQUIRED

The success of GTN-R is solely dependent on the regular provision of near-real-time river discharge data from the reference stations. GRDC thus kindly requests the assistance of all organizations able to assist in providing access to available data.

and computer programming, infrastructure and travel expenses. These funds do not cover the costs borne by the national hydrological services to operate and maintain the river discharge monitoring infrastructure.

## FUNDS

The efficient operation of the GTN-R depends on additional resources to fully implement and manage the network. Approximately €180 000 are required annually to secure such a service at the GRDC. These funds would cover salaries for network coordination

## STANDARDS

Standards for river discharge measurement are well established. Special note should be given to WMO Technical Regulations of Hydrology; ISO 1100-1 (1996); and ISO 748 (1997), dealing with the measurement of liquid flow in open channels.

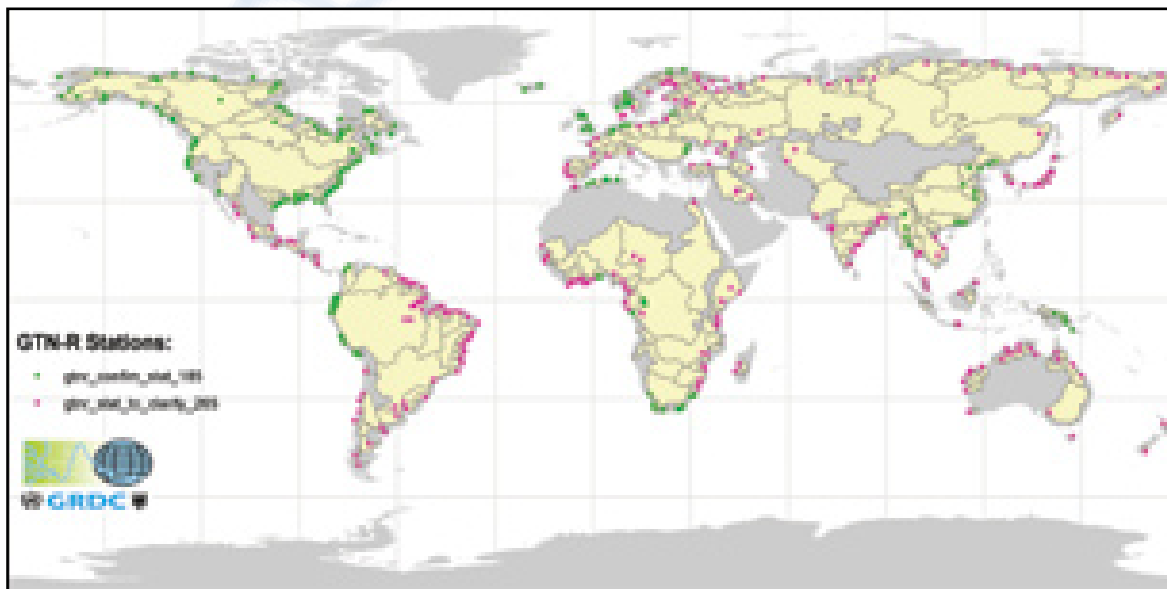


Figure to show the status of confirmation (July 2007) of the revised GTN-R network of 450 river gauges, with their respective catchment areas

## RELATED LINKS:

GTN-R: <http://gtn-r.bafg.de> | GRDC: <http://grdc.bafg.de> | River discharge standards report: [www.fao.org/gtos/ECV-T01.html](http://www.fao.org/gtos/ECV-T01.html)

# WATER USE

by Giovanna Sacco, Emelie Healy, Reuben Sessa and Jippe Hoogeveen



## THE NEED FOR WATER

Uses of fresh water include agricultural, industrial and household (including drinking, cooking, gardening and sanitation) activities. Apart from this, water for the environment is needed to maintain important ecosystems, such as wetlands. Agriculture is by far the largest water-use sector, accounting for about 70 percent of all water withdrawn worldwide from rivers, lakes and aquifers. In developing countries, irrigation can account for more than 90 percent of all water withdrawn, and it therefore plays a major role in food production and food security.

Water use in many countries is occurring at unsustainable rates; for example, the withdrawal of groundwater from aquifers is at levels greater than the replenishment rate, causing water tables to drop. In addition, many water supplies, such as summer river discharge derived from glaciers, are threatened. However, as the world population continues to grow, with an estimated 9 billion by 2050, there will be increasing pressure on water resources, not only from agriculture but also from other water use sectors.

Considering the close linkages between climate and the hydrological cycle, the effects of climate change and climate variability will have a significant impact on water resources around the world, especially in developing countries. Such climatic phenomena will also affect

non-irrigated agriculture, which depends entirely on rainfall and accounts for some 60 percent of production in developing countries. Reliable observations are therefore essential when undertaking assessments and predicting the effects of climate change on food production, and to allow the development of adequate adaptation strategies.

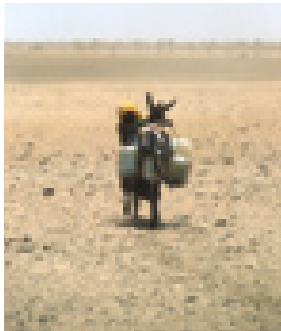
## WATER USE DATA AND INFORMATION

Major efforts have been made to assess the different elements of the water balance and to predict current and future water needs for the different use sectors. In 2005, FAO in collaboration with other partners produced a new version of the digital global map of irrigation areas. It is based on 10 825 sub-national statistical units and geospatial information on the location and extent of irrigated agricultural areas. It is therefore an important product, which will improve future global studies on water and food production.

FAO's global information system on water and agriculture, AQUASTAT, collects and disseminates data and information by country and by region. The objective is to provide users with comprehensive global, regional and national information and analysis on the state of agricultural water management across the world, with an emphasis on developing countries and countries in transition. The database includes: geospatial information (including maps); statistics; country profiles; regional reviews; thematic studies; and other information.

A number of other international and regional organizations also provide information about water use and water-use changes, these include:

- UN Water, which is the official United Nations mechanism for follow-up of the water-related decisions reached at the 2002 World Summit on Sustainable Development and the Millennium Development Goals.

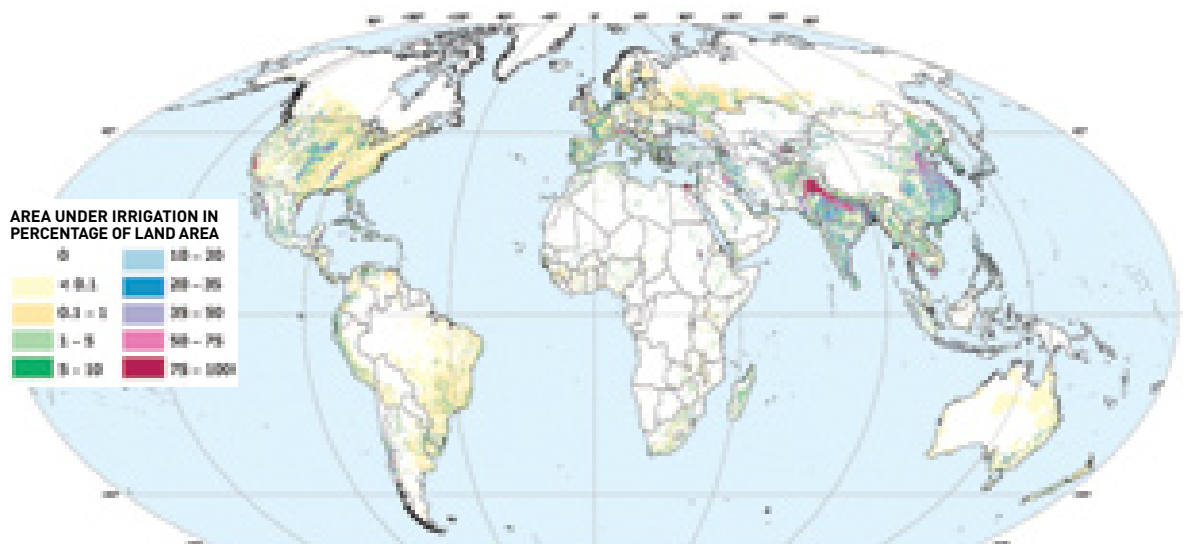


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## 2 000 to 5 000 litres of water are required to produce a person's daily food



The digital global map of irrigation areas. The map shows the percentage of each 5 by 5 arc minute cell that was equipped for irrigation around the year 2000, and is an important data set for global studies related to water and land use (*Source*: FAO and University of Frankfurt)

- The World Water Assessment Programme (WWAP), which is hosted by UNESCO, coordinates the UN World Water Development Report (WWDR), a periodic review designed to give an authoritative picture of the state of the world's fresh water resources. The report is based on data and information provided by national authorities and local institutions.
- Water Portal of UNESCO, which provides links to programmes on fresh water coordinated by UNESCO.
- The Joint Monitoring Programme (JMP) for water supply and sanitation hosts information gathered by WHO and UNICEF.
- Global Resource Information Database of UNEP, which gives access to environmental datasets from different sources worldwide.
- Water Balance Framework Models of IWMI provide software tools, including the IWMI World Water and Climate Atlas and Policy Dialogue Model.
- Satellite agencies have developed a number of products derived from satellite imagery related to water resources, such as climatic data and vegetation indices. Such data can, for example, be downloaded from the NASA Goddard Space Flight Center (GSFC) Earth Sciences, Data and Information Services Center.

### FUTURE MONITORING REQUIREMENTS

Systematic collection and monitoring of water-related data is essential for a comprehensive understanding of the state of the world's water resources. There is still considerable uncertainty concerning water use for agriculture, the extent and distribution of irrigated land, water extracted for industrial and domestic uses, as well as water needed for the environment to maintain its important ecosystem functions. To keep up with growing food demand, FAO estimates that by 2030 the effective irrigated area will need to increase by 34 percent in developing countries, and 14 percent extra water will have to be abstracted for agricultural purposes. Growing scarcity and consequent competition for water stand as major threats to future advances in food security and poverty alleviation, especially in rural areas.



#### RELATED LINKS:

**FAO-AQUASTAT:** [www.fao.org/ag/aquastat](http://www.fao.org/ag/aquastat) | **UN-Water:** [www.unwater.org/flashindex.html](http://www.unwater.org/flashindex.html) | **World Water Assessment Programme:** [www.unesco.org/water/wwap](http://www.unesco.org/water/wwap)  
**UNESCO Water Portal:** [www.unesco.org/water](http://www.unesco.org/water) | **Joint Monitoring Programme for water supply and sanitation:** [www.wssi.info/en/welcome.html](http://www.wssi.info/en/welcome.html)  
**Global Resource Information Database of UNEP:** [www.grid.unep.ch/data/index.php](http://www.grid.unep.ch/data/index.php) | **IWMI:** [www.iwmi.cgiar.org](http://www.iwmi.cgiar.org)  
**World Bank – Water Resources Management:** [www.worldbank.org/water](http://www.worldbank.org/water) | **Challenge Program on Water and Food:** [www.waterforfood.org](http://www.waterforfood.org)

# GLOBAL TERRESTRIAL NETWORK FOR GROUNDWATER (GTN-GW)

by Jay Famiglietti



Groundwater accounts for nearly 30 percent of global fresh water resources. Today, some 2 billion people rely on groundwater as a primary source of drinking water and for other uses, such as agriculture. However, in many regions of the world, available groundwater resources are under stress due to a number of factors, including groundwater depletion (when withdrawal rates exceed recharge rates), salinization and contamination. When coupled with the pressures of changing climate (including the potential for redistribution of the amounts and locations of groundwater recharge) and population growth (which will result in increased water demand) the stresses on groundwater supplies will only increase in the decades to come.

## LACK OF GROUNDWATER DATA

In spite of its importance to the world's fresh water supply, groundwater remains poorly monitored on a global basis. In developing countries, where groundwater often accounts for the bulk of the fresh water supply, monitoring is not well established. Moreover, in developed countries, many groundwater monitoring programmes are being downscaled. In short, no comprehensive, global framework for monitoring groundwater storage and quality currently exists.

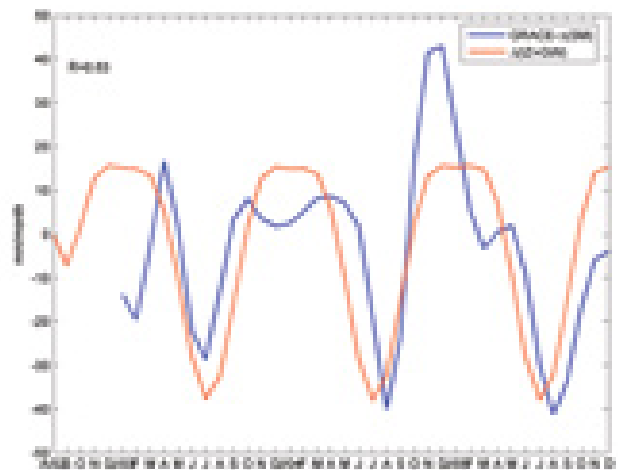
## MONITORING SYSTEM CONCEPT

A concept for a global groundwater monitoring system includes *in situ* well observations as a foundation, supplemented by satellite observations of groundwater storage changes (e.g. from GRACE and InSAR) and by outputs from regional groundwater models for the world's major aquifer systems and from global hydrologic models. The synergistic use of these information types can yield a consistent picture of the current state of global groundwater storage and its variations, and will help improve predictive model forecasts of groundwater availability in future decades.

## COORDINATED EFFORT

Such an ambitious effort will require significant international cooperation and coordination of ongoing efforts. Recently, a critical step towards a global terrestrial network on ground water (GTN-GW)

was taken in the form of a Global Groundwater Monitoring System (GGMS). A first workshop on Global Monitoring of Groundwater Resources, jointly sponsored by IGWCO, GARS and UNESCO, was held 18–19 October 2007, at the International Groundwater Resources Assessment Centre (IGRAC) in Utrecht, the Netherlands. An important outcome of the meeting was support for IGRAC as the lead institution for the development of the GGMS as a network of networks. At present, IGRAC plans that GGMS will archive monthly data using 1° global grids. Data will be



Remote sensing of groundwater in Illinois, USA, using GRACE; the blue line shows a GRACE-based estimate; the red line is from observed groundwater well levels; the time series are shown as seasonal cycles [Source: P. Yeh, S. C. Swenson, J. S. Famiglietti and M. Rodell]

Nearly one third of the world's population relies on groundwater for its major source for drinking water, yet globally the amount of available groundwater, and how it is changing, remains highly uncertain



provided on a by-country basis, and will be uploaded by national experts via a user-friendly Web interface. Candidate groundwater variables and hydrogeologic parameters for inclusion in the GGMS were discussed, and include: groundwater level, groundwater abstraction, salinity and other indicators of water quality, storage coefficients, well head elevation, screen depth, and local aquifer characteristics, including aquifer type, thickness and whether measurements are for confined or unconfined units.

#### INTERNATIONAL PARTICIPANTS AND PARTNERS

The success of any GTN-GW will depend on coordination among several existing agencies, universities and ongoing activities. These include, but are not limited to: ESA, GARS, GEMS/Water, GRAPHIC, GRDC, GTN-(H,L,P,R), IAEA, IGRAC, IGWCO NASA/Goddard Space Flight Center, TU Delft, UNESCO, USGS, University of California (Berkeley, Irvine, USA), University of New Hampshire (USA), VU Amsterdam (the Netherlands) and WHYMAP.



The Gravity Recovery and Climate Experiment (GRACE) twin satellites

#### NEAR-TERM PRIORITIES

In order for IGRAC/GGMS to mature into the role of a full GTN-GW, several near-term priorities were identified at the Utrecht meeting. First, the broader groundwater hydrologic community will have an opportunity to provide feedback to the workshop group regarding its recommendations, after publication of the workshop report. Second, GGMS capabilities should be demonstrated using readily available data from existing monitoring efforts, modelling and remote sensing products, with a focus on regional hotspots where groundwater resources are under stress. Finally, as GGMS evolves, potential users from around the world must learn of its existence via user workshops in conjunction with upcoming international conferences, such as the UNESCO groundwater conferences in Kampala, Uganda, and in Irvine, California, USA, in June and December of 2008, respectively.

#### CRITICAL VARIABLES FOR A GROUNDWATER MONITORING STRATEGY

- Groundwater level
- Groundwater abstraction
- Salinity and other water quality variables
- Well head elevation
- Screen depth
- Aquifer (hydrogeologic) unit
- Aquifer type
- Aquifer thickness
- Specific yield/specific storage
- Transmissivity

# LAKE AND RESERVOIR LEVELS AND VOLUMES

by Wolfgang Grabs



## OBSERVATIONAL IMPORTANCE

Lakes and reservoirs data and information are indispensable for water resources management and regional and global water cycle studies. Likewise, information on water volume changes in lakes can be critical indicators of regional climate change.

The creation and subsequent operation of an international data centre on the hydrology of lakes and reservoirs has been for a long time expected by the international scientific community. Despite the existence of various national and international data collections, such an international centre does not yet exist. However, such a centre would be expected to provide global data on lakes and reservoirs under the auspices of the World Meteorological Organization (WMO) in a similar fashion to the other international data centres in the field of hydrology, such as the Global Runoff Data Centre (GRDC), the Global Precipitation Climatology Centre (GPCC) and the International Groundwater Resources Assessment Centre (IGRAC).

## SCOPE

The objectives of the Centre would be the establishment, development and regular update of a global database on the hydrological regime of lakes and reservoirs in order to stimulate development of a global monitoring system on lakes and reservoirs for rational use, preservation and management of their water resources and to supply data for scientific and educational purposes, modelling and the development of different global and regional activities.

## CENTRE ESTABLISHMENT

In 2002, the Federal Service of Russia for Hydrometeorology & Environmental Monitoring (ROSHYDROMET) made the original proposal for

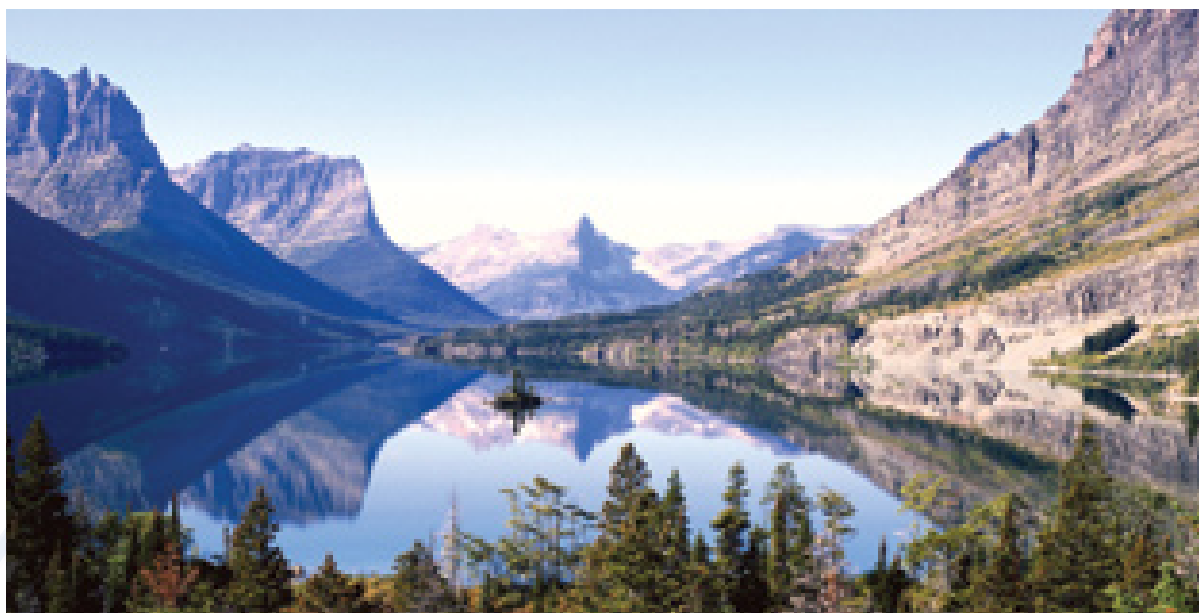
the development of an international data centre on lakes and reservoirs (HYDROLARE). The first meeting of the International Steering Committee of HYDROLARE was hosted by the State Hydrological Institute (SHI) in St Petersburg, Russia, in June 2007. The Committee noted that with the establishment of HYDROLARE as a member of the family of global data centres, one of the most critical gaps in global observations in hydrology and water resources will be closed. Facilitated by ROSHYDROMET, the final steps for the formal establishment of HYDROLARE are in progress. The Centre will be hosted by SHI and will operate under the auspices of WMO.

## OPERATIONAL OUTPUTS

The principal outputs of the Centre will be:

- Basic data on permanently studied lakes and reservoirs of the world collected and processed, including physiographic and morphometric characteristics of water bodies and their catchments.
- Global-scale inventories of existing monitoring systems of lakes and reservoirs.
- Global-scale inventories of existing data of permanent hydrological observations of lakes and reservoirs.
- Global-scale database of long-term time series of lakes and reservoirs having permanent hydrological observations.
- Development of basic processing and presentation tools for lakes and reservoirs data for distribution to stakeholders.
- Analysis and assessment of spatial and temporal tendencies of hydrological elements of lakes and reservoirs.

## Closing a critical gap in surface water observations



Although lakes and ponds cover only 2 percent of the world's land surface, they contain most of the world's fresh water

### CURRENT STATUS

The technical establishment of HYDROLARE continues, and, by March 2008, the prototype database system should be operational and contain lake and reservoir data from Russia and the former Soviet Union, as well as additional data from other countries, based on a priority list of major lakes and reservoirs. Likewise, the database system will be fully established and WMO member countries will be requested to contribute data and information on lakes and reservoirs. The Centre will undertake all

efforts to cooperate with international organizations and institutions, including those holding information relevant for the Centre. HYDROLARE will establish the observational requirements of stakeholders and will undertake activities using agreed methodologies and standards, which, when possible, will be based on existing protocols. ROSHYDROMET is providing financial support to SHI to support HYDROLARE at the national level, but additional donor support will be required to establish an operational global system.



Lake Kyoga, is a large shallow lake complex of Uganda, about 1 720 km<sup>2</sup> in area and at an elevation of 914 m. Accurate and continuous monitoring of lakes is possible using satellite altimetry, which could be used to develop temporal and spatial times series of lakes water levels for the whole Earth

### RELATED LINKS:

**Lake level standards:** [www.fao.org/gtos/ECV-T04.html](http://www.fao.org/gtos/ECV-T04.html)

# SNOW COVER

by Roger G. Barry



## THE IMPORTANCE OF SNOW

Snow can cover up to 50 percent of the Earth's land surface during the Northern Hemisphere winter. It has major effects on surface albedo and energy balance, and modifies the overlying atmospheric thickness and surface temperature. Snow characteristics, such as thickness, seasonal and interannual variability and snow-cover duration, affect permafrost thermal state, the depth and timing of seasonal freeze and thaw of the ground, as well as ablation of glaciers, ice sheets and sea ice.

The snow water equivalent (SWE) of the snow pack is important for hydrological modelling and runoff prediction. Snowmelt plays a major role in seasonal energy exchanges between the atmosphere and ground, affecting soil moisture and runoff, and thereby water resources. Snowfall as a fraction of total precipitation is important in hydroclimatic models and in monitoring climate change.

## CONTRIBUTING TO BASELINE GCOS OBSERVATIONS

Snow depth is measured once daily at weather stations, but is rarely reported over the Global Telecommunications System (GTS). However, global snow depth data are available from the WMO-GTS Synoptic Reports for stations that do report that code group in real time (see: <ftp://ftp.ncdc.noaa.gov/pub/data/globalsod>).

Snowfall is not differentiated in 6-hourly and daily precipitation measurements at weather stations, although precipitation type is reported in the synoptic weather code. Snow cover is mapped routinely by satellites. NOAA-NESDIS provides operational hemispheric products; NASA develops hemispheric research products.

SWE is determined at snow courses (North America) or along snow transects (Russia) at about

15–30 day or 10-day intervals, respectively. The data are in agency archives and many are not digitized, European data are especially difficult to access (due to cost and other restrictions).

## AVAILABLE ANALYSIS PRODUCTS

### Snow cover extent

- Daily Northern Hemisphere extent maps exist since May 1999 and gridded data (1024 by 1024 box grid, ca. 25 km) monthly statistics (frequency, anomaly) for the Northern Hemisphere, North America and Asia. Also available is the Interactive Multisensor Snow and Ice Mapping System (IMS) Daily Northern Hemisphere Snow & Ice Analysis (IMS link below).
- The Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent product, combines snow cover and sea ice extent at weekly intervals since 1978, and snow cover alone for October 1966 to October 1978. Data are provided in a 25-km equal area grid (NSIDC EASE-Grid).
- Moderate Resolution Imaging Spectroradiometer (MODIS) products include level-2 swath data at 500-m resolution, gridded daily and 8-day composites at 500-m resolution, and daily and 8-day global maps. MODIS snow cover data are based on a mapping algorithm that employs a Normalized Difference Snow Index (NDSI).

### Global snow depth

- Operational global daily snow depth analysis undertaken by the Canadian Meteorological Centre.

### National snow depth products

These include:

- Historical Soviet Daily Snow Depth Version 2 (HSDSD) of observations from 1881 to 1995 at 284 WMO stations throughout Russia and the former Soviet Union (35–75°N; 20–180°E).

## Winter snow cover is the most extensive element of the cryosphere and plays a fundamental role in climate



- NOAA Experimental Daily NWS/COOP Snow Depth and Snowfall Graphics and Data: Daily snow depth and snowfall graphics for the contiguous USA.
- Daily snow depth data for 1062 observing stations across the contiguous USA for 1871–1997 are available from the Carbon Dioxide Information and Analysis Center (CDIAC).
- Daily snow depth data for over 1 000 Canadian stations covering the entire record up to 1999 are available from the Meteorological Service of Canada on CD-ROM.

### National SWE

SWE is observed by national, state, provincial and private networks in many countries on a 10-day to monthly basis, but no central archive exists and many national and other databases are not readily accessible. No standard global SWE product exists.

NSIDC has developed a Northern Hemisphere mean monthly product for 1978–2000, based on SMMR and SSM/I passive microwave data. The Former Soviet Union Hydrological Snow Surveys are based on observations at 1 345 sites between 1966 and 1990, and at 91 of those sites between 1991 and 1996. Observations include snow depths at WMO

stations and snow depth and SWE measured over a nearby snow course transect. The station snow depth measurements are a 10-day average of individual snow depth measurements. The transect snow depth data are the spatial average of 100 to 200 individual measuring points. The transect SWE is the spatial average of twenty individual measuring points (<http://nsidc.org/data/g01170.html>).

### ISSUES AND PRIORITIES

Many problems arise because (1) snow cover data are collected by numerous agencies with differing goals; (2) funding support for snow research is fragmentary and not well coordinated; and (3) the cost of maintaining surface networks is leading to their contraction or to a switch to automated measurement using different instrumentation. Various methodologies and standards have been developed and implemented by international and national networks for snow depth and SWE; however, there is still a lack of harmonization at a global level. Development of optimal procedures to blend surface observations with visible and microwave satellite data and airborne gamma radiation measurements of SWE is only just beginning to receive attention.

### RELATED LINKS:

**NSIDC:** <http://nsidc.org> | **Snow data sets:** <http://nsidc.org/data/swe> | **WMO-GTS Synoptic Reports:** <ftp://ftp.ncdc.noaa.gov/pub/data/globalsod>  
**NOAA Snow:** [www.ssd.noaa.gov/PS/SNOW](http://www.ssd.noaa.gov/PS/SNOW) | **Global daily snow depth:** [http://weatheroffice.ec.gc.ca/analysis/index\\_e.html](http://weatheroffice.ec.gc.ca/analysis/index_e.html)  
**IMS:** <http://orbit-net.nesdis.noaa.gov/crad/sat/surf/snow/HTML/snow.htm> | **Snow cover standards:** [www.fao.org/gtos/ECV-T05.html](http://www.fao.org/gtos/ECV-T05.html)  
**UNEP Global outlook for Snow and Ice:** [www.unep.org/geo/geo%5Fice/PDF/full\\_report\\_LowRes.pdf](http://www.unep.org/geo/geo%5Fice/PDF/full_report_LowRes.pdf)

# GLACIERS AND ICE CAPS

by Michael Zemp, Wilfried Haeberli, Martin Hoelzle and Frank Paul



**Glaciers are among the most fascinating elements of nature. Due to their proximity to melting conditions, glaciers react strongly to climatic changes and thus offer information on essential variables required for global climate monitoring. Striking glacier shrinking has been reported since the end of the Little Ice Age around the world, and potential future vanishing might severely affect sea-level rise, fresh water resources and human activities.**

## GLACIER MONITORING

Worldwide collection of information about glacier changes was initiated in 1894, with the foundation of the International Glacier Commission at the 6th International Geological Congress in Zurich, Switzerland. Since 1986, the World Glacier Monitoring Service (WGMS), based in Zurich, has been continuing to collect and publish standardized information on ongoing glacier changes. The WGMS is a service of the International Association for the Cryospheric Sciences of the International Union of Geodesy and Geophysics (IACS/IUGG) and maintains a network of local investigators and national correspondents in all the countries involved in glacier monitoring. In close collaboration with the National Snow and Ice Data Center (NSIDC) and the Global Land Ice Measurements from Space (GLIMS) initiative, the WGMS is in charge of the Global Terrestrial Network for Glaciers (GTN-G). The three organizations are jointly responsible for the development and implementation of the international observation strategy for glaciers and ice caps, and provide standards for the monitoring of glacier fluctuations and for the compilation of glacier inventories.

## AVAILABLE OBSERVATIONS

The WGMS hosts an unprecedented dataset of information about spatial glacier distribution and changes over time, which is readily available to the scientific community and the public. At present, the database contains about 34 000 front variation and 3 000 annual mass balance observations for 1 725 and 200 glaciers, respectively.

The World Glacier Inventory makes available information on location, classification, area, length, orientation and altitude range for over 71 000 glaciers from around the 1970s (mainly derived from aerial photographs and maps). This corresponds to about 44% of the total number and 23% of the total estimated area of all glaciers and ice caps worldwide.

The GLIMS initiative was designed to continue this inventorying task with space-borne sensors, in close cooperation with NSIDC and WGMS. New projects, such as the International Polar Year (IPY) and the GlobGlacier data user element, by the European Space Agency, aim at making a major contribution to the current WGMS and GLIMS databases.



1928



1966



1979

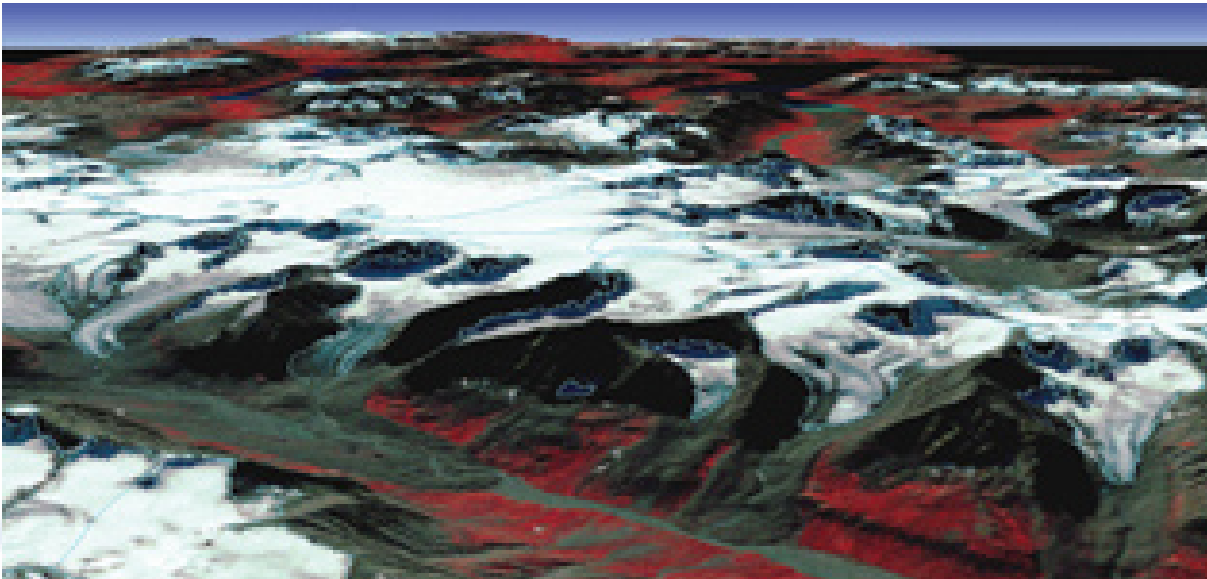


2003

Retreat of South Cascade Glacier, USA. Photographs from the US Forest Service (1928) and the US Geological Survey (1966, 1979, 2003)



# Long-term financial commitment is essential to continue worldwide glacier monitoring



Abundant valley and cirque type glaciers on Disko Island, Greenland. Many of them show pronounced trimlines, indicating their former Little Ice Age extent. The perspective view is created from a Landsat ETM+ scene (bands 4, 3, 2 as RGB) from August 2001 (obtained from the GLCF, Maryland, USA) that is draped over a DEM (provided by GEUS, Copenhagen, DK) and superimposed with glacier outlines from 2001

## RAPID ICE LOSS

Since the end of the Little Ice Age, glaciers around the globe have been shrinking significantly, with increasing rates of ice loss since the mid-1980s. On a time-scale of decades, glaciers in various mountain ranges have shown intermittent re-advances. However, under current IPCC climate scenarios, the ongoing trend of worldwide and fast, if not accelerating, glacier shrinkage on the century time-scale is most likely of a non-periodic nature, and may lead to the deglaciation of large parts of many mountain ranges by the end of the 21st century.

## RECENT ACTIVITIES

- Compilation of glacier fluctuation data for the period 2000–2005.
- Call for preliminary mass balance data for the year 2006.
- Development of new mass balance measurement programmes in Colombia, India and New Zealand.
- New remote sensing-based glacier inventories for parts of Baffin Island, Greenland and Norway.
- International workshop on glacier mass balance measurements and modelling, 26–28 March 2008, in Norway.

## FUNDING SITUATION

For many years, the WGMS has been the principal mechanism for assembling and reporting glacier fluctuation data at the global level and in a standardized manner. However, its continuing operation is threatened by the absence of a long-term financial commitment to support this essential activity. At present, the WGMS is run by a total of 150% staff positions funded by the Department of Geography of the University of Zurich (25%) and by a bridging credit of the Swiss National Science Foundation (125%, until March 2009). A secure financial basis of about US\$250 000 per year, i.e. an additional funding of US\$1 million for the period 2008–2012, is needed by the WGMS to guarantee the continuation of the operational business, to maintain the international network and to face the challenges of the 21st century—challenges that most probably are going to be of historic dimensions, both in nature and in science.



Mass balance: Cumulative mass balance of 30 reference glaciers from GTN-G network with continuous mass balance series from 1976–2005. Data provided by the WGMS

## RELATED LINKS:

**WGMS:** [www.wgms.ch](http://www.wgms.ch) | **NSIDC:** [www.nsidc.org](http://www.nsidc.org) | **GLIMS:** [www.glims.org](http://www.glims.org) | **IACS/IUGG:** [www.cryosphericsscience.org](http://www.cryosphericsscience.org)  
**ESA project GlobGlacier:** <http://dup.esrin.esa.int/projects/summary98.asp> | **WGMS and the IPY:** [www.wgms.ch/ipy.html](http://www.wgms.ch/ipy.html)  
**Workshop on glacier mass balance 2008:** [www.nve.no/mbworkshop](http://www.nve.no/mbworkshop)

# GLOBAL TERRESTRIAL NETWORK FOR PERMAFROST (GTN-P)

by Jerry Brown, Sharon L. Smith, Vladimir Romanovsky, Hanne H. Christiansen, Gary Clow, Friderick E. Nelson



Permafrost refers to earth materials that remain at or below 0°C for at least two consecutive years. In the Northern Hemisphere, permafrost regions occupy approximately 23 million km<sup>2</sup>, or 24 percent of the ice-free land surface. These regions include large areas of Canada, China, Mongolia, Russia and Alaska, and areas at higher elevations in mountain chains of many other countries in both the Northern and Southern Hemispheres. As warming occurs, permafrost landscapes are susceptible to increased thaw and associated ground settlement, erosion and slope failures. Unlike snow and ice covers, permafrost and the overlying seasonal thaw zone (active layer) is not easily observed remotely, and requires *in situ* observations to define its extent and properties. Permafrost temperature is used to detect the terrestrial climate signal since it provides an integration of changes at the ground surface, that in turn may reflect changes in climate.

## MONITORING OF PERMAFROST AND ACTIVE LAYER

Permafrost monitoring is conducted mainly through ground-based, point measurements. Permafrost thermal state (i.e. ground temperature) and active layer thickness are the key permafrost variables identified for monitoring under the GCOS/GTOS programmes.

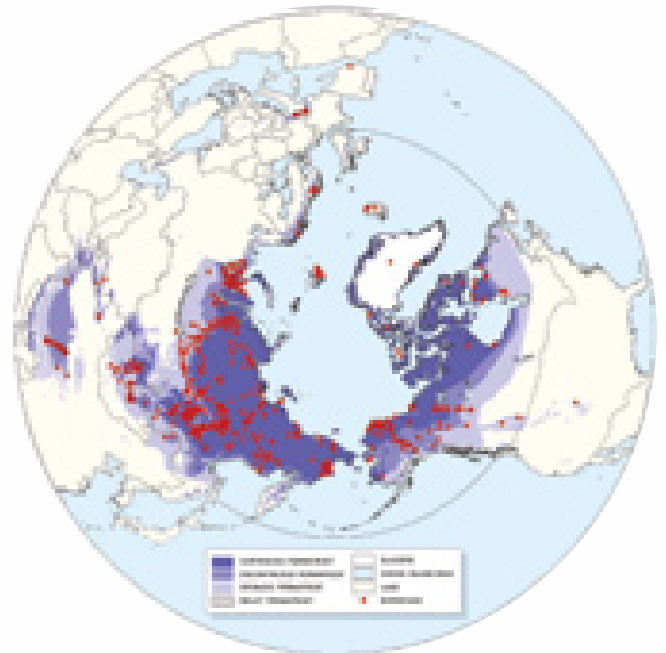
The Global Terrestrial Network for Permafrost (GTN-P), approved in 1999 and coordinated by the International Permafrost Association (IPA), comprises two international monitoring networks: Thermal State of Permafrost (TSP) boreholes, and Circumpolar Active Layer Monitoring (CALM).

More than 15 countries participate in these networks. Protocols for standard measurements and data reporting requirements are available on the Web sites.

## NETWORK EXTENT

Monitoring sites are located in the high-latitude and high-altitude regions of the Northern Hemisphere. Existing and new sites in Antarctica and the subantarctic region are being added. GTN-P largely comprises voluntary regional networks, including the Mackenzie region in Canada; an Alaskan transect and deep boreholes in northern Alaska; boreholes in Europe initiated under the Permafrost and Climate

in Europe (PACE) programme, and regional networks in China, Russia and Mongolia. Additional activities such as “TSP Norway”, several in Russia, Canada and Alaska (USA) have been initiated or expanded under the International Polar Year (IPY) and the Permafrost Observatory Project.



Active borehole sites contributing to GTN-P



## Permafrost temperature reflects integrated changes in ground surface energy balance, in turn reflecting possible climate change



Logging permafrost temperatures in an abandoned exploratory oil well, northern Alaska. Photograph provided by Gary Clow, U.S. Geological Survey

Currently, 165 sites, in both hemispheres contribute to CALM, and have operated for more than a decade. The TSP programme has identified over 550 candidate boreholes, several hundred are currently active and contribute to GTN-P.

### DATA MANAGEMENT

Metadata and site information are available for many of the boreholes and all CALM sites (see Web sites). The National Snow and Ice Data Center (NSIDC) and its Frozen Ground Data Center, based on availability of funds, provide many valuable services and products related to historical and contemporary permafrost and seasonally frozen ground data. Management and dissemination of active layer data for CALM is currently supported through 2008 by a grant from the U.S. National Science Foundation. Short-term data management for TSP is partially supported by grants or programmes at the University of Alaska, U.S. Geological Survey, Geological Survey of Canada, and the new Nordic TSP project. Both CALM and TSP contribute soil temperature and moisture data to the Terrestrial Ecosystem Monitoring Sites (TEMS) database.

### FUTURE

Funding of both field measurements and data activities are traditionally based on short-term grants from member countries.

Both IPA and IPY goals are to establish a permanent observatory network for both hemispheres and, where possible, at sites that are protected from human disturbance. Some key sites should be co-located with or near other observatories, including WMO stations.

Cost for individual sites varies based on personnel, access and logistics. National and international commitments are required at a minimum of several million dollars per year, which includes support to data management.

New regional maps of permafrost properties and areal extent are required, built on GTN-P data and related modelling. The Ninth International Conference on Permafrost (NICOP) in June 2008 in Fairbanks, Alaska, will provide published reports on many current GTN-P activities.

### RELATED LINKS:

GTNP: [www.gtnp.org](http://www.gtnp.org) | CALM: [www.udel.edu/geography/calm](http://www.udel.edu/geography/calm) | IPA: [www.ipa-permafrost.org](http://www.ipa-permafrost.org)  
Norway TSP: [www.tspnorway.com](http://www.tspnorway.com) | FGDC: <http://nsidc.org/fgdc> | NICOP: [www.nicop.org](http://www.nicop.org)

# ALBEDO AND REFLECTANCE ANISOTROPY

by Crystal Barker Schaaf



## OBSERVATIONAL IMPORTANCE

Land surface albedo, or the ratio of the radiant flux reflected from the Earth's surface to the incident flux, is a key land physical parameter controlling the planetary radiative energy budget. Variations in the extent of snow cover and flooding, and in the phenology of natural vegetation and agricultural crops are all accompanied by significant changes in land albedo. Therefore, long-term surface albedos with absolute accuracies of 0.02-0.05 are required by climate, biogeochemical, hydrological and weather forecast models at a range of resolutions, both spatial (from a few hundred metres to 5 to 30 km) and temporal (from daily to monthly).

## CURRENT OBSERVATIONS

Snow cover, hydrological processes and vegetation structure and phenological state all play an enormous role in the seasonal variation of land surface albedo.

Furthermore, the albedo at any given time depends both on the unique reflective anisotropy of the surface (related to the intrinsic composition and structure of the land cover) and the atmospheric condition. Therefore tower-based field measurements of surface albedo are required to support local and regional determination of the surface radiation, while remote sensing provides a way to measure and monitor the global heterogeneity of land surface albedo.



Comparison of the MODIS 500-m albedo product with field measurements at the ARM/SGP Central Facility #C01 (2003)

## REMOTELY SENSED ALBEDO PRODUCTS

Directional satellite observations are currently being utilized from a number of instruments (e.g. MODIS, MISR, CERES, POLDER, MERIS and MSG) to provide various routine regional and global operational albedo products at a variety of spatial and temporal resolutions. While data quality assessments and field validation exercises are routinely carried out by the respective science teams, data set intercomparisons are being facilitated through the Land Product Validation Subgroup of the Committee on Earth Observing Satellites/Working Group on Calibration and Validation (CEOS/WGCV).

## TOWER-BASED FIELD MEASUREMENTS OF ALBEDO

Long-term, high-quality, calibrated field measures of direct and diffuse land surface incident and reflected radiation are being collected from tower-mounted pyranometers at a limited number of sites by the Baseline Surface Radiation Network (BSRN). The BSRN, with its standardized measurement protocols, has already been designated by the World Climate Research Programme (WCRP) as the global baseline network for surface radiation for the Global Climate Observing System (GCOS). The BSRN archive (currently maintained by ETH, Zurich, Switzerland) will be transferred in 2008 to the Alfred Wegener Institute, Bremerhaven, Germany. Reflected radiation measurements are also frequently collected by International Long Term Ecological Research (ILTER) sites and regional flux tower networks (such as Ameriflux, Asiaflux, Fluxnet- Canada, CarboEurope, etc.). Guidelines for data collection protocols and standardization across the flux networks are being developed under the auspices of the Terrestrial Carbon Observation (TCO) effort. Additional vital atmospheric state measurements are collected at these sites by regional or global networks, such as the Aerosol RObotic Network (AERONET).

# The reflective character of a sunlit earth governs the energy absorbed at the surface



ARM/SGP Central Facility #C01

## REQUIREMENT FOR EXPANDED TOWER-BASED MEASUREMENTS

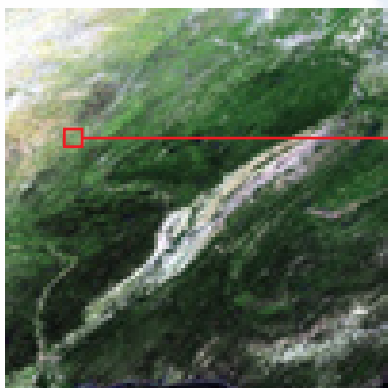
At present, only a dozen or so BSRN sites worldwide provide the calibrated tower-based reflected radiation measurements necessary for albedo monitoring. In addition to localized monitoring and modelling of surface albedo, these data are also used for validation efforts by all of the operational satellite producers. However, field measurements are needed from a greater diversity of land covers and ecological regions. Therefore, upgrading the instrumentation and data collection protocols to BSRN standards at pre-existing flux and ecological towers remains a priority. Such improvements, however, do require a significant financial commitment.

An instrumentation package recently suggested to upgrade Ameriflux measurements of both direct and diffuse shortwave and longwave radiation was priced at US\$20 000. Increased human maintenance

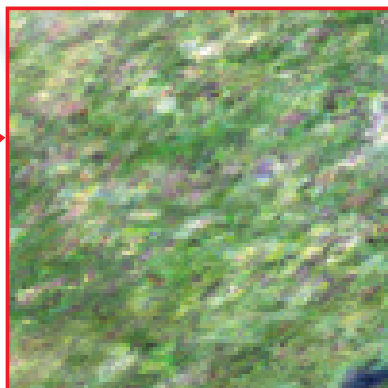
and calibration requirements, site accessibility and power needs preclude implementation of BSRN standards at all tall towers. However, for those sites with sufficient pre-existing infrastructure, only a modest capital outlay would be needed to greatly expand access to BSRN-calibre field measurements of surface albedo.

## RECOMMENDATION

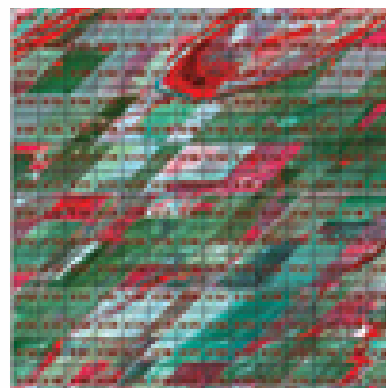
Official recognition is required of the need for long-term, high-quality field measurements of land surface albedo to monitor local climatic changes, model surface energy variations and validate regional and global albedo products. A modest increase in financial support for those field sites already equipped with sufficient personnel to maintain and monitor equipment to BSRN standards would enormously increase our ability to monitor surface albedo fluctuations worldwide.



MODIS 500-m white-sky albedo (isotropic bi-hemispherical reflectance) of the Southern Great Plains, USA. Nominal date 23 May 2006, true-color image in sinusoidal projection



MODIS 500-m white-sky albedo from the Atmospheric Radiation Measurement (ARM)/Southern Great Plains (SGP) Central Facility #C01 (subset from figure to left)



ASTER scene of the ARM/SGP Central Facility #C01 on 23 May 2006 superimposed with 500-m MODIS shortwave albedo values (bi-hemispherical reflectance)

## RELATED LINKS:

**Baseline Surface Radiation Network:** [www.gewex.org/bsrn.html](http://www.gewex.org/bsrn.html) | **Aeronet:** <http://aeronet.gsfc.nasa.gov/index.html>  
**Terrestrial Carbon Observations:** [www.fao.org/gtos/TCO.html](http://www.fao.org/gtos/TCO.html) | **CEOS/WGCV/Land Product Validation:** <http://lpvs.gsfc.nasa.gov>  
**NASA ESDR White Papers with References:** <http://lcluc.umd.edu/Documents/land-esdr.asp>

# LAND COVER

by Martin Herold, Michael Brady, Curtis Woodcock, Chris Schmullius and John Latham



**Land cover is defined as the observed physical cover including the vegetation (natural or planted) and human constructions that cover the earth's surface. Reliable land cover and land cover change observations and assessment are essential for the sustainable management of natural resources, understanding and mitigating climate change, modelling of ecosystems and biogeochemical cycling and for addressing other important issues such as food security.**

Land cover characteristics reveal ongoing processes of deforestation, desertification, urbanization, loss of biodiversity and ecosystem functions, and water and energy management. *In situ* and satellite-based land observation efforts, as well as different disciplines (i.e. geography, ecology, geology, forestry, etc.), use and refer to land cover as one of the most obvious and detectable indicator of land surface characteristics.

## LAND COVER MONITORING

The land surface of the World has been mapped and characterized several times and many countries have some kind of monitoring systems in place (i.e. forest, agriculture and cartographic information systems and inventories). There are multiple examples of countries using satellite data for national land cover and change assessments, i.e. in the context of their UNFCCC reporting. Examples include:

- Australia: National Carbon Accounting System
- Canada: Earth Observation for Sustainable Development of Forests (EOSD)
- Different countries worldwide: United Nations Global Land Cover Network (GLCN)
- European Union: Coordination of Information on the Environment (CORINE)
- Land Cover Map of Great Britain
- New Zealand Land Cover Database
- South African National Land Cover Database
- United States National Land Cover Dataset (NLCD)

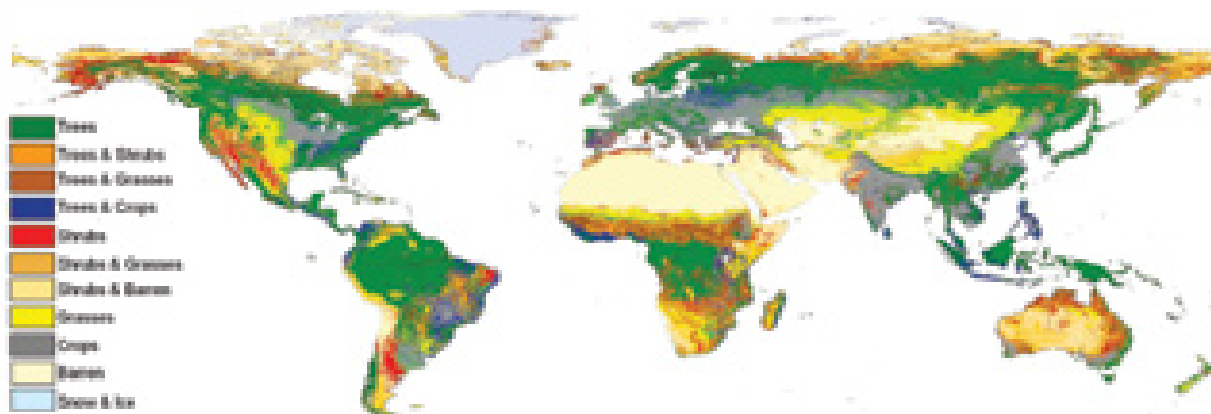
In addition there are a number of global land cover mapping activities. They have evolved with the availability of continuous global moderate resolution

satellite observations since the early 1990s and resulted in number of available 300m to 1km resolution products. While most mapping projects are developed for specific applications and purposes, the resulting inconsistency between the different land cover map products or change accounting systems undermines the ability to successfully synthesize land assessments on regional and global scales. However, the FAO/UNEP Land Cover Classification System (LCCS) is now being adopted by many countries and international initiatives and is being widely used to provide thematic land cover standardization at a variety of scales of implementation.

## AVAILABLE OBSERVATIONS

Multispectral and multitemporal global land and regional land cover data sets are currently produced by a range of space agencies and research institutes at medium resolutions (250 m to 1 km) for determining land cover type, and at fine resolutions (10–50 m) for determining type and detecting land cover change. Additionally, *in situ* data are acquired for monitoring of land cover, vegetation migration and related phenomena, and are also used as ground truth for validation of land cover and land cover change measurements by satellites. Land cover observations have historically been developed according to specific project needs. The land theme of IGOS (IGOL) defines detailed observations requirements. It advocates sustained and integrated observations on all three major scales (moderate and fine resolution satellite data, and *in situ*). Data gaps exist, especially for the more detailed scales. Near-operational annual global data products are provided for moderate resolutions,

# Operational land cover monitoring requires increasing international commitment for long-term continuity and consistency of satellite and *in situ* observations



SYNMAP – a global synthesis product of existing global land cover maps for carbon cycle modelling [Source: M. Jung, Remote Sensing of Environment]

and global mosaics of Landsat-type satellite data exist from 1990 and 2000 (2005 in progress). Thus, some basic datasets exist and detailed global land cover monitoring is possible and should be pursued. Coordinated *in situ* observations are limited to date. Nevertheless, essential challenges for building a sustained global land cover observing system remain, including international cooperation on the continuity of observations; ensuring consistency in land monitoring approaches; community engagement and country participation in mapping activities; robust product validation; suitable data access and regional networking; and capacity building.

## RECENT ACTIVITIES

- Advocating existing internationally-agreed approaches to systematic land cover characterization (LCCS) and validation (CEOS protocols).
- Release of GLOBCOVER (ESA) product to provide the highest resolution (300 m), consistent, global land cover map to date.
- Development of the Mid-decadal Global Land Survey (USGS & NASA) for consistent, preprocessed, global, free-of charge Landsat data for 2005, which extends the existing 1990 and 2000 Geocover global datasets.
- Global Remote Sensing Survey as part of FAO's Forest Resources Assessment 2010.
- Utilizing and validating moderate-resolution time-series data and land cover data sets.
- Technical inputs on available methodologies and observations for the UNCCC initiative on Reducing Emissions from Deforestation and Degradation (REDD).

- Formulating specifications and implementing production of a global high-resolution land cover and land change data set and report (GEO task).
- Strengthening national-level capacities to produce and use these products, especially in developing countries, through national and regional networks (like GOF-C-GOLD) and capacity building initiatives such as GLCN.

## INTERNATIONAL FUTURE IMPLEMENTATION NEEDS

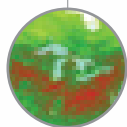
Substantial resources are required to maintain and extend space-based observation assets (fine and moderate resolution) and *in situ* observation capabilities to provide baseline data of worldwide consistency and availability. GEO, the Partners of IGOS, including the Space and UN agencies, GTOS, and other entities such as the Global Monitoring for Environment and Security (GMES) are committed to improve land observations globally, an effort that needs further international engagement and support. GTOS, through GOF-C-GOLD and its partners have provided a platform for international cooperation and communication on land cover monitoring (including standardization and validation). The Global Land Cover Network (GLCN) has furthered the implementation of national, regional and international approaches to land cover standardization and capacity development amongst its member states. However, a minimum of US\$250 000 per year is required to maintain the international networks and to ensure long-term continuity and consistency in land cover monitoring.

## RELATED LINKS:

GOF-C-GOLD: [www.fao.org/gtos/gofc-gold](http://www.fao.org/gtos/gofc-gold) | GLCN: [www.glcnc.org](http://www.glcnc.org) | Integrated Global Observations of the Land (IGOL): [www.fao.org/gtos/igol](http://www.fao.org/gtos/igol)  
CEOS Calibration and Validation Working Group: <http://wgcv.ceos.org> | UN Land Cover Classification System: [www.glcnc-lccs.org](http://www.glcnc-lccs.org)

# FRACTION OF ABSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION (FAPAR)

Nadine Gobron



## MONITORING BENEFIT

The systematic observation of the fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is suitable to reliably monitor the seasonal cycle and inter-annual variability of vegetation activity related to photosynthesis of terrestrial surfaces. This ECV plays a critical role over a range of temporal and spatial resolutions, notably in the energy balance of ecosystems and in the estimation of the carbon balance.

## DEFINITION

FAPAR is defined as the fraction of photosynthetically active radiation (PAR) absorbed by a vegetation canopy. PAR is the solar radiation reaching the canopy in the 0.4–0.7  $\mu\text{m}$  wavelength region.

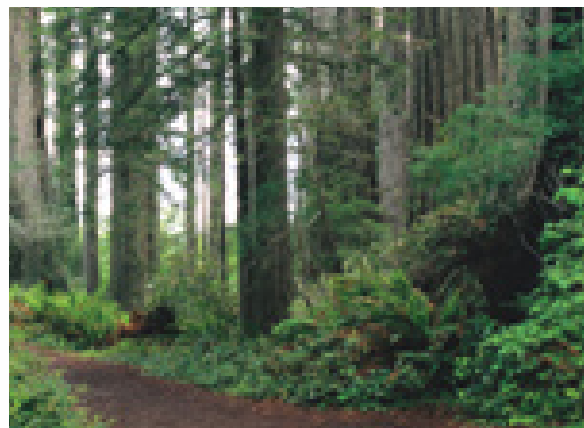
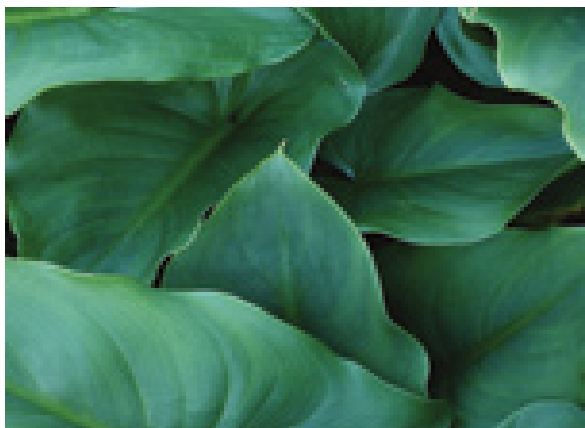
Ground-based estimates of FAPAR require the simultaneous measurement of PAR above and below the canopy, and FAPAR assessments are retrieved from space remote sensing platforms using physically-based inverse methods. Most of these derived products represent only the fraction absorbed by the green part of the leaf canopy.

## ACTUAL STATUS OF OBSERVATION

Space agencies and other institutional providers currently generate and deliver to the scientific community various FAPAR products at different temporal (from daily to monthly), and spatial resolutions over the globe. More than ten years of space-derived FAPAR data are now available from different institutions.

At ecological research sites (e.g. FLUXNET, LTER) PAR is monitored as part of the standard protocol, but few sites generate reliable measurements of green FAPAR that can be meaningfully used for validation of the satellite products. Community efforts are underway to document the accuracies of available space-derived datasets while ground-based networks, coordinated by CEOS-WGCV, will perform measurements relevant for validation exercises.

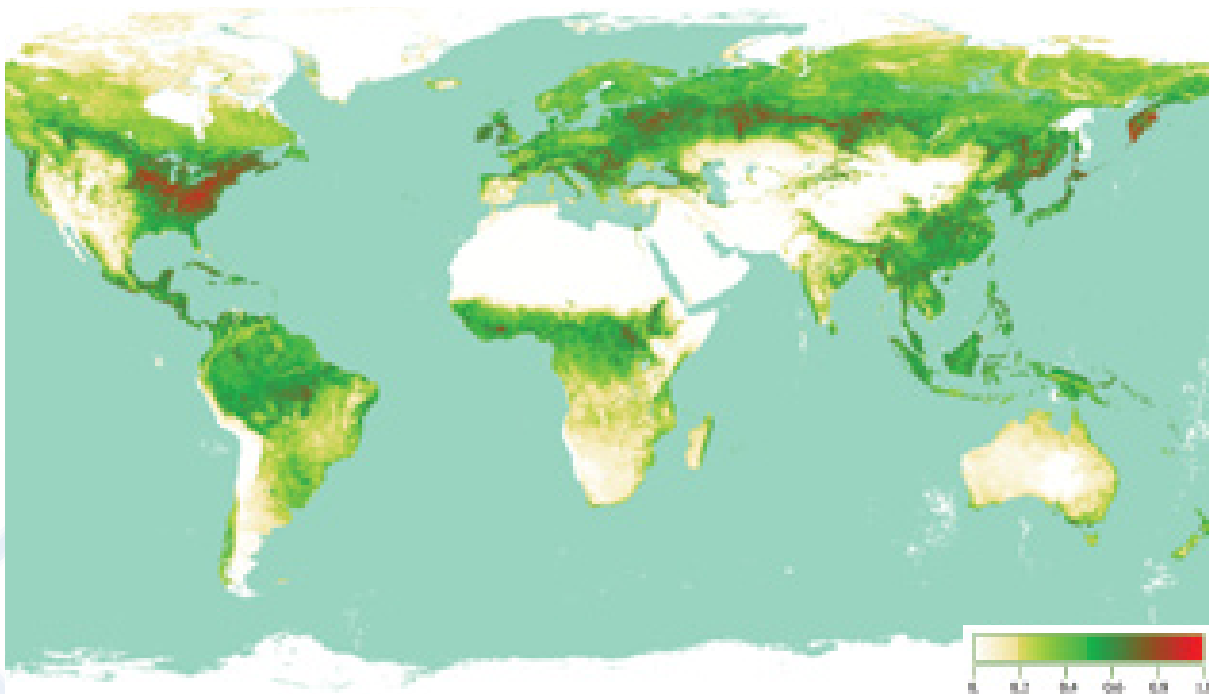
The scientific developments mainly focus on the improvement of the reliability and accuracy of these products in view of their ingestion by data assimilation systems to better understand climate changes issues. This leads, for example, to a major effort for assessing the consistency of various radiant energy fluxes between current observations and models.



Hainich forest [CarboEurope-IP site]. [Source: Werner Kutsch]



# Climate-oriented applications require global scale FAPAR time series, which can only be achieved through the use of multiple sensors



Global FAPAR from MERIS in July 2006 [Source: Processed by ESRIN G-POD with JRC software]

## CURRENT OPERATIONAL REMOTELY SENSED FAPAR PRODUCTS

Medium-resolution satellite observations are currently being utilized from a number of instruments (e.g. MODIS, MISR, SeaWiFS and MERIS) to provide regional and global operational FAPAR products at a variety of spatial and temporal resolutions.

## REQUIRED FUTURE ACTIVITIES

Long time series of accurate FAPAR products derived from space are essential for climate change studies. This requires first the development of state of the art retrieval algorithms for the reprocessing of past archive data, going back to AVHRR.

The availability of future sensors' data is also essential to ensure the continuity of systematic global scale observations. Designs of advanced sensors and updated retrieval procedures are also foreseen to better characterize and reduce the actual uncertainties as are required for the implementation of new land surfaces data assimilation systems.

Networks of ground-based measurements for the routine acquisition of relevant observations, in particular over sub-sampled geographical regions should be promoted. These networks must ensure that observations are taken in a standardized manner that allows comparison between sites. Other issues in regards to these *in situ* measurement sites is their spatial coverage, as well as benchmarking of the measurement protocols.

## FUNDS

The total expense for acquisition, processing and storage of both data and geophysical products at medium resolution amounts to about €300 000 per year. The reprocessing of archives can be estimated at €10 000 per year per sensor. Cost for ground-based measurements, including analysis of data to up-scale *in situ* estimates, depends on the site infrastructure already installed and the financial support already being received. When new advanced algorithms have to be developed, substantial research costs may be required.

## RELATED LINKS:

MERIS data products: <http://envisat.esa.int/level3/meris> | FAPAR activities of JRC: <http://fapar.jrc.ec.europa.eu>

Land Processes DAAC: <http://edcdaac.usgs.gov/dataproducts.asp> | Atmospheric Science Data Center: <http://eosweb.larc.nasa.gov>

# LEAF AREA INDEX (LAI)

by Nadine Gobron



## SIGNIFICANCE FOR CLIMATE CHANGE ACTIVITIES

Monitoring the distribution and changes of Leaf Area Index (LAI) is important for assessing growth and vigour of vegetation on the planet. It is fundamentally important as a parameter in land-surface processes and parameterizations in climate models. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration and rain interception.

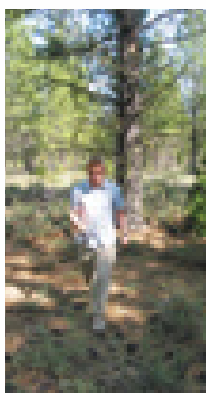
## DEFINITION AND METHODOLOGIES

LAI [ $\text{m}^2/\text{m}^2$ ] represents the amount of leaf material in an ecosystem and is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area. Ground-based measurements have no standards as several methods, like harvesting methods, hemispherical photography or light transmission through canopies, can be used. The

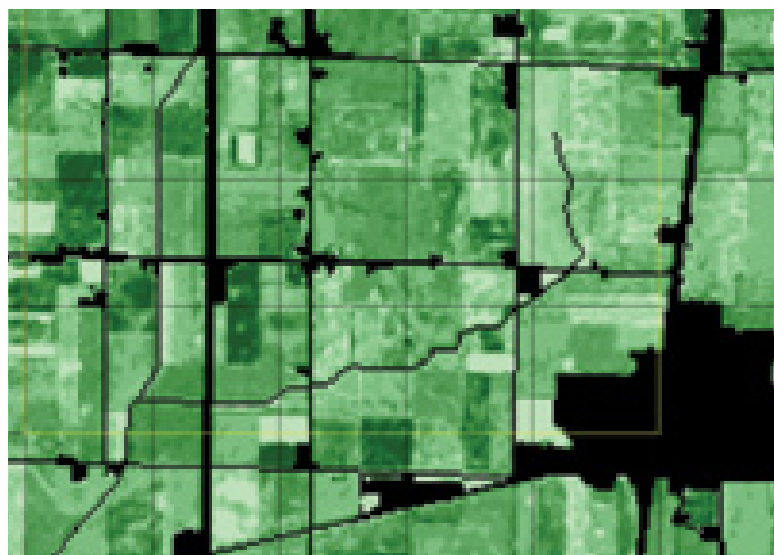
conversion of effective values, as available from measurements using optical devices, to allometric values requires additional information about the structure and architecture of the canopy, e.g. gap size distributions, at the appropriate spatial resolutions.

## CURRENT ACTIVITIES

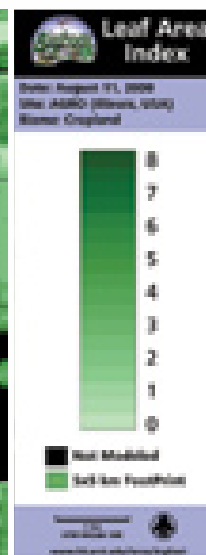
Space agencies and other institutional providers generate maps of LAI at various spatial resolutions from a daily to monthly period over the globe using optical space borne sensors. The actual delivered values correspond to an allometric or an effective value relating to the spatial resolution of observations. On the other hand, LAI values are occasionally estimated locally through ground-based measurements over several validation sites spanning a range of land cover types. These validation exercises are performed in the framework of ground-based networks, including both national research groups and international entities, such as the Land Product



Measurements using a TRAC instrument. The TRAC is used to measure gap size distribution (clumping) to later convert LAI-2000 measurements to effective LAI  
(Source: Dirk, Pflugmacher)



Example of Landsat based map of LAI retrieval for validation purposes over a cropland site



(Source: Warren B. Cohen)

# The Leaf Area Index (LAI) of plant canopies plays an important role in controlling the interactions between terrestrial environments and atmospheric variables



Hemispherical photos of the Hainich forest (CarboEurope-IP site) on June 21, 2005 (left panel) and October 25, 2005 (right panel) [Source: Werner Kutsch]

Validation (LPV) Subgroup of the CEOS Working Group on Calibration and Validation (CEOS-WGCV). The main validation efforts concentrate on the improvement of the reliability and accuracy of the ground-based estimates by defining state of the art protocols suitable to address the very different spatial dimensions of *in situ* and remote sensing measurements. The Terrestrial Ecosystem Monitoring Sites (TEMS) database contains details on research sites and the observations they are undertaking including *in situ* information on LAI values. For example, LAI is a standard parameter observed in all sites of FLUXNET.

A community effort takes place to find a compromise on providing LAI maps suitable for land-surface parameterizations for ensuring the equivalence between the current deliverable values which are observed and computed. This consistency requires also the production of associated spectral properties of the underlying soil.

## FUTURE ACTIVITIES

Long-time series of accurate and precise Leaf Area Index products derived from space are essential for climate change studies, especially at regional and local scale for improving the parameterization of the process in various classes of models. Systematic data acquisition from space sensors is thus crucial in the development of such well-documented information about the changes occurring in the biosphere.

Networks of ground-based measurements for the routine acquisition of relevant observations, in particular over subsampled geographical regions, as well as harmonization of existing data are to be promoted. These networks must ensure the standardization of measurements, the distribution of these measurements as well as the benchmarking of the measurement protocols.

The consistency between this LAI, a state variable, and the FAPAR (ECV T10), a radiation flux, is important and must be ensured. This promotes the use of modern retrieval algorithms delivering a series of by-products such as the spectral properties of the underlying soil and the vegetation canopies as well.

## FUNDS

The total expense for acquisition, processing and storage of both data and geophysical products at medium resolution amounts to about €300 000 per year. The reprocessing of archives can be estimated at €10 000 per year per sensor.

Cost for ground-based measurements, including analysis of data to up-scale *in situ* estimates, depends on the site infrastructure already installed and the financial support already being received. When new advanced algorithms have to be developed, substantial research costs may be required.

## RELATED LINKS:

**CEOS WGCV:** <http://wgcv.ceos.org> | **GTOS standards activity:** [www.fao.org/gtos/ECV-T11.html](http://www.fao.org/gtos/ECV-T11.html) | **TEMS:** [www.fao.org/gtos/tems](http://www.fao.org/gtos/tems)  
**Bigfoot activity:** [www.fsl.orst.edu/larse/bigfoot/index.html](http://www.fsl.orst.edu/larse/bigfoot/index.html)

# BIOMASS

Martin Herold, Michael Brady, Michael Wulder and Denny Kalensky

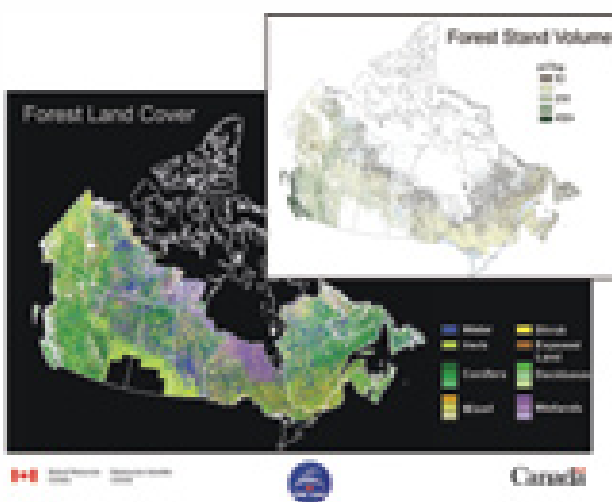


## DEFINITION

Biomass is defined as mass of all organic matter per unit area at particular time (reported in g/m<sup>2</sup> or kg/ha). It plays two major roles in the climate system: (i) photosynthesis withdraws CO<sub>2</sub> from the atmosphere and stores it as biomass; (ii) the quantity of biomass consumed by fire affects CO<sub>2</sub>, other trace gases and aerosol emissions.

Estimates of biomass change (due to land use and management practices or natural processes) enable a direct measurement of carbon sequestration or loss (as long as associated changes in soil carbon are accounted for) and can help to quantify the human induced impacts on global climate change and validate carbon-cycle models.

Carbon emission from deforestation is the largest source of greenhouse gas emissions in developing countries.



Example of a Landsat-type national product is the Earth Observation for Sustainable Development (EOSD) land cover map of the forested areas of Canada. The inset map depicts forest volume distribution, derived from integrating land cover with climate and Canada forest inventory data

(Source: R. Hall and E. Arsenault, Natural Resources Canada, Canadian Forest Service)

## ECV IMPORTANCE

Global assessment of biomass and its dynamics are essential inputs to climate change forecasting models and adaptation strategies. The importance of biomass as an Essential Climate Variable is due to both to its role as a carbon sink during photosynthesis process and its growing use for generation of bioenergy. Sustainable management of biomass sources, in particular forests, which store most of the Earth's biomass, contributes to reduction of carbon dioxide in the atmosphere, mitigation of climate change and environmental protection.

## MONITORING OF BIOMASS

In general, there are four main approaches to monitoring biomass:

- destructive sampling;
- non-destructive sampling, such as forest inventories;
- inference from remote sensing, and
- models.

In practice, the monitoring of biomass depends primarily on inventory information, even at regional and global levels. Remote sensing data can support inventory approaches by informing on current conditions and changes in forests.

## AVAILABLE OBSERVATIONS

Most countries have operational methodologies for woody biomass inventories, typically using field-based surveys, or a combination of remote sensing and field-based observations. Such national data typically form the basis for the annual reporting on forest resources (i.e. in the context of the UNFCCC). In contrast, biomass information is uncertain for many developing countries, which are often those undergoing the fastest rates of deforestation.

## Biomass is a major repository of carbon, which constitutes about half of its dry weight



National inventories differ greatly in definitions, standards and quality, and the detailed information available at national level is normally unavailable internationally. Some regional harmonization efforts, such as the European Forest Inventory, lead to improved regional information. Nevertheless, biases and uncertainties in these summary values are not quantified.

At the global level, FAO regularly monitors the world's forests through a Global Forest Resources Assessment. It is based on countries' reports and remote sensing assessment at sampling sites. FAO also conducts land cover mapping in developing countries based on remote sensing and using the Land Cover Classification System (LCCS). Furthermore, there are number of initiatives and networks that undertake *in situ* measurement initiatives. Many of these networks can be viewed in the Terrestrial Ecosystem Monitoring Sites (TEMS) database, an international directory of sites and networks that carry out long-term, terrestrial *in situ* monitoring and research activities.

Potential for estimating biomass from space has been demonstrated in a number of research projects. However, improvement, development and implementation of approaches that integrate field and satellite based observations for the estimation of biomass are required. Remote observations (combined with *in situ* data) may be particularly useful

in developing countries where the largest uncertainties in biomass estimates and carbon sequestration or loss exist. Particular direct biomass estimation potentials result from vegetation LIDAR observation. In addition, the JAXA ALOS-PALSAR L-band (24 cm wavelength) satellite radar currently in orbit should be able to supply information on the lower range of biomass (up to 50-80 t/ha). The BIOMASS mission currently under study for launch around 2014 by ESA uses a longer wavelength (68 cm) that should be able to sense higher levels of biomass.

### FUNDING SITUATION

Resources are required to maintain and extend *in situ* capabilities and space-based observation assets to provide baseline data of worldwide consistency and availability. Capacity particularly needs to be built in developing countries. International cooperation and communication on biomass monitoring is required to standardize methodology, provide effective technology transfer and advisory services to developing countries, and coordinate national efforts, in order to develop long-term continuity and consistency in worldwide biomass monitoring. It is estimated that a budget of €210 000 would be required to initiate the required international cooperation activities over the next two years (this will cover the standardization of methodologies, technology transfer and capacity building activities).

#### RELATED LINKS:

**Biomass standards:** [www.fao.org/gtos/ECV-T12.html](http://www.fao.org/gtos/ECV-T12.html) | **FAO FRA:** [www.fao.org/forestry/site/fra/en](http://www.fao.org/forestry/site/fra/en) | **TEMS:** [www.fao.org/gtos/tems](http://www.fao.org/gtos/tems)  
**Amazon Forest Inventory Network:** [www.geog.leeds.ac.uk/projects/rainfor](http://www.geog.leeds.ac.uk/projects/rainfor)  
**WRI global database:** <http://earthtrends.wri.org/gsearch.php?va=map&kw=biomass&theme=0>

# FIRE DISTURBANCE

Ivan Csiszar and Guido van der Werf



## OBSERVATIONAL IMPORTANCE

Fire is an important ecosystem disturbance with varying return frequencies, resulting in land cover alteration and change, and atmospheric emissions on multiple time scales. Fire is also an important land management practice and is an important natural abiotic agent in fire-dependent ecosystems. The Fire Disturbance Essential Climate Variable (ECV) consists of burnt-area maps, supplemented by active fires; High-Temperature Events (HTE); and Fire Radiated Power (FRP). Information on fire activity is used for global change research, estimating atmospheric emissions and developing periodic global and regional assessments, and also for planning and operational purposes (fire management, local to national) and development of informed policies (national and international, e.g. IPCC).

## OBSERVATIONS

Due to the large spatial and temporal variability in fire activity, satellite data provides the most useful means to monitor fire. There exist polar and geostationary systems with full operational status and experimental systems providing systematic observations that have been used for the creation of long-term data fire mapping. Major long-term global records of active

fires have been generated by ESA (ATSR World Fire Atlas) and NASA (TRMM and MODIS). Geostationary fire monitoring has been undertaken using GOES (WF-ABBA) and MSG SEVIRI (EUMETSAT Active Fire Monitoring). Future systems, such as NPP/NPOESS Visible Infrared Imager Radiometer Suite (VIIRS) and sensors on Global Monitoring for Environment and Security (GMES) Sentinel satellites and the provision of baseline high resolution fire observations for product validation should ensure the continuity of fire mapping and detection capabilities.

The only long-term burnt area dataset available at the moment is also partly based on active fire detections GFDE2, but true multi-year burnt area products are about to be released (MODIS, L3JRC, GLOBCARBON). Validation with *in situ* measurements is limited to only certain regions and is lacking, especially in developing countries. In other regions, calibration with high-resolution satellite data provides the best means for validation. Estimating emissions from these active fire detections or burnt areas has improved recently, with the use of biogeochemical models, but fails to capture fine-scale fire processes due to coarse resolutions. With the new burnt area products, this situation will probably be improved.



FAO/14/186/R. Faidutti



FAO/13926/M. Marzot

## RELATED LINKS (BURNT AREA PRODUCTS UNDER DEVELOPMENT)

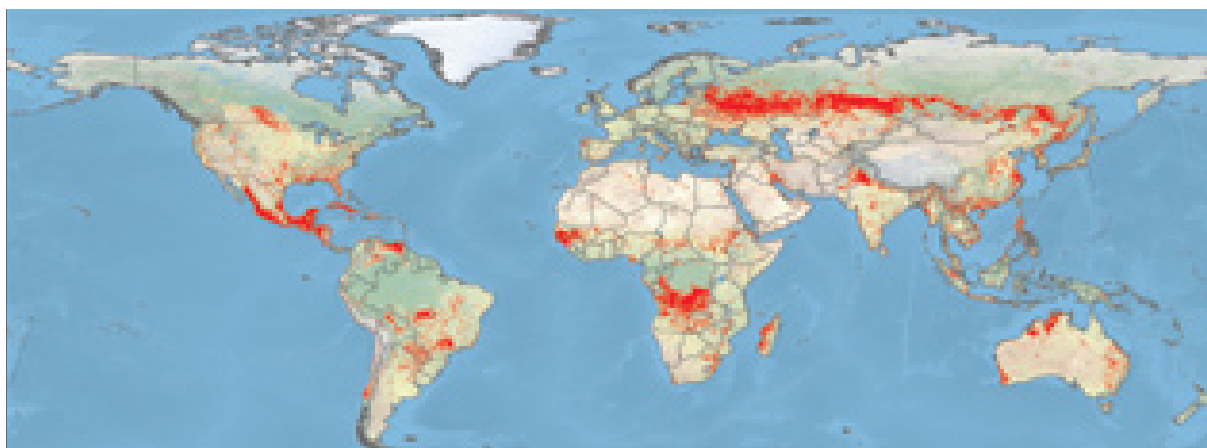
**L3JRC Global Burnt Area:** [www.tem.jrc.it/Disturbance\\_by\\_fire/products/burnt\\_areas/GlobalBurntAreas2000-2007.htm](http://www.tem.jrc.it/Disturbance_by_fire/products/burnt_areas/GlobalBurntAreas2000-2007.htm)

**MODIS fire products:** <http://modis-fire.umd.edu/products.asp> | **Globcarbon:** [www.fao.org/gtos/tcopjs4.html](http://www.fao.org/gtos/tcopjs4.html)

**GFDE2 Existing multi-year burnt area and emissions:** <http://ess1.ess.uci.edu/%7Ejranders/data/GFED2>

**The Fire Information for Resource Management System (FIRMS):** <http://maps.geog.umd.edu/firms>

# Global monitoring of fire activity for fire management, policy-making and research



Global distribution of MODIS active fire detections for May 2006 from the FIRMS system  
(Source: MODIS Rapid Response <http://rapidfire.sci.gsfc.nasa.gov> Fire Information for Resource Management System (FIRMS) <http://maps.geog.umd.edu>)

## DATA SYSTEM

A number of products are accessible through Web-based distribution systems, ranging from simple file distribution to complex visualization and search utilities using Web GIS. For example, the University of Maryland, in collaboration with NASA, FAO and Conservation International, is developing the Fire Information for Resource Management System (FIRMS); an integrated data system for easy access (through the Web, e-mail and mobile phone) of various data products.

## STAKEHOLDERS

There is a need for coordination to improve access to fire data and its use for resource managers, policy-makers and the scientific community, and to secure long-term fire observing systems. The Fire theme of GOF-C-GOLD is working on harmonization of remote sensing and *in situ* observations. This includes the development of capability for periodic global assessments of fire, and a contribution to GEO tasks by capacity building for space-based fire observations, developing a global early wildland fire warning system and a global fire monitoring network from geostationary satellites.

The UNISDR Global Wildland Fire Network and the Wildland Fire Advisory Group, facilitated by the Global Fire Monitoring Center (GFMC), is working on improving fire management capacity around the world. Many stakeholder organizations are members of the recently established Fire Management Actions Alliance.

## COOPERATION REQUIRED

Collaboration between a number of agencies and programmes is needed to ensure the optimum provision and use of fire information. Increased involvement of space agencies in fire observations and monitoring is pursued through CEOS and CGMS. GOF-C-GOLD is a main actor in creating the required regional networks of data providers and users to capture regional-specific information needs and priorities and to provide local expertise for product validation.

## STANDARDS

Various algorithms exist for burnt area mapping. Active fire (HTE) detection is performed based on consensus approaches, with necessary sensor-specific modifications. Approaches for the measurement of FRP are at the research and development stage. Protocols for burnt area validation and reporting exist and are under development for active fire detection and FRP in collaboration with CEOS.

## FUNDS

A coordination mechanism for multiple contributory activities and the maintenance of regional networks would require approximately US\$150 000 annually. Specific activities, such as the coordination of a global geostationary fire monitoring network, the development of global fire assessments, and the creation of data portals for products and validation data, require further funding, amounting to US\$50 000 each annually.

## OTHER RELATED LINKS:

Global Fire Monitoring Center: [www.fire.uni-freiburg.de](http://www.fire.uni-freiburg.de) | Fire management actions alliance: [www.fao.org/forestry/site/41315/en](http://www.fao.org/forestry/site/41315/en)  
Fire disturbance standards: [www.fao.org/gtos/ECV-T13.html](http://www.fao.org/gtos/ECV-T13.html) | GOF-C-GOLD Fire: <http://gofc-fire.umd.edu>

# ACRONYMS

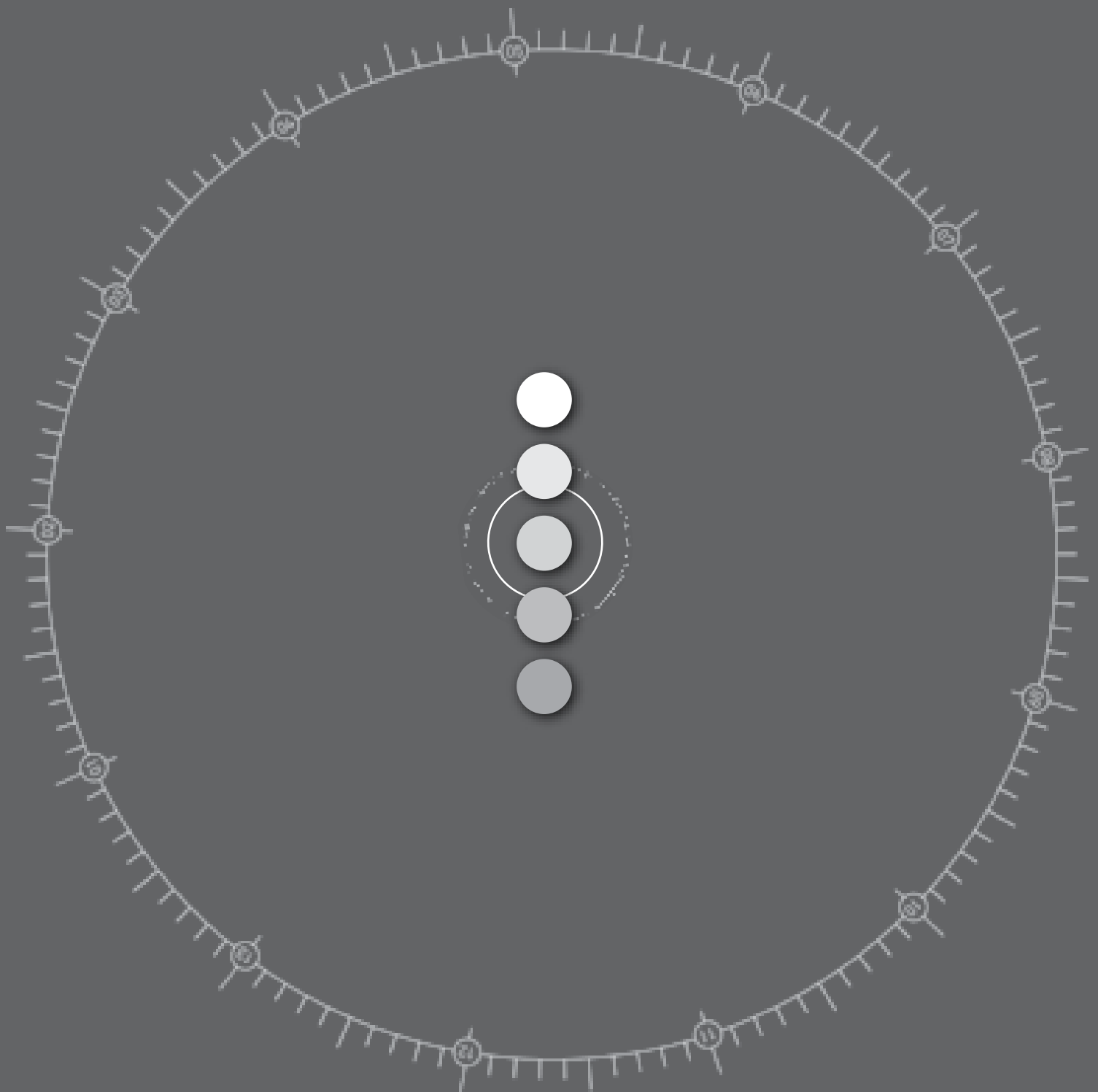
Unfortunately in Earth Observations you cannot avoid them so a summary list of those used in this document are provided below.

<b>AERONET</b>	AERosol RObotic NETwork	<b>ESA</b>	European Space Agency
<b>ALOS</b>	Advanced Land Observing Satellite	<b>ETN-R</b>	European Terrestrial Network for River Discharge
<b>AQUASTAT</b>	Global information system for water and agriculture (FAO)+	<b>EUMETSAT</b>	European Organisation for the Exploitation of Meteorological Satellites
<b>ARM/SGP</b>	Atmospheric Radiation Measurement/ Southern Great Plains [Site]	<b>FAO</b>	Food and Agricultural Organization of United Nations
<b>ATSR</b>	Along Track Scanning Radiometer	<b>FAPAR</b>	Fraction of Absorbed Photosynthetically Active Radiation
<b>AVHRR</b>	Advanced Very High Resolution Radiometer	<b>FCDR</b>	fundamental climate data record
<b>BSRN</b>	Baseline Surface Radiation Network	<b>FIRMS</b>	Fire Information for Resource Management System
<b>CALM</b>	Circumpolar Active Layer Monitoring	<b>FLUXNET</b>	a global network of micrometeorological tower sites
<b>CDIAC</b>	Carbon Dioxide Information and Analysis Center	<b>FRA</b>	Global Forest Resources Assessment of FAO
<b>CEOS</b>	Committee on Earth Observing Satellites	<b>FRP</b>	Fire Radiated Power
<b>CERES</b>	Clouds and Earth's Radiant Energy System mission	<b>GARS</b>	Geological Application of Remote Sensing
<b>CGMS</b>	Coordination Group for Meteorological Satellites	<b>GCOS</b>	Global Climate Observing System
<b>COP</b>	Conference of the Parties	<b>GEMS</b>	Global Environment Monitoring System
<b>CORINE</b>	COoRdination of INformation on Environment	<b>GEO</b>	Group on Earth Observations
<b>DEWA</b>	Division of Early Warning and Assessment (UNEP)	<b>GEOSS</b>	Global Earth Observing System of Systems
<b>EASE-Grid</b>	Equal-Area Scalable Earth Grid	<b>GFMC</b>	Global Fire Monitoring Center
<b>ECV</b>	Essential Climate Variables	<b>GFSC</b>	Goddard Space Flight Center
<b>EFAS</b>	European Flood Alert System	<b>GGMS</b>	Global Groundwater Monitoring System
<b>EO</b>	Earth observations	<b>GIS</b>	Geographic Information System
<b>EOSD</b>	Earth Observation for Sustainable Development	<b>GLCN</b>	Global Land Cover Network
		<b>GLIMS</b>	Global Land Ice Measurements from Space



<b>GMES</b> Global Monitoring for Environment and Security	<b>IGOL</b> Integrated Global Observations for Land
<b>GOES</b> Geostationary Operational Environmental Satellite	<b>IGOS</b> Integrated Global Observing Strategy
<b>GOFC-GOLD</b> Global Observation of Forest and Land Cover Dynamics (GTOS)	<b>IGRAC</b> International Groundwater Resources Assessment Centre
<b>GOOS</b> Global Ocean Observing System	<b>IGWCO</b> Integrated Global Water Cycle Observations
<b>GPCC</b> Global Precipitation Climatology Centre	<b>ILTER</b> International Long Term Ecological Research
<b>GRACE</b> Gravity Recovery and Climate Experiment	<b>IMS</b> Interactive Multisensor Snow and Ice Mapping System
<b>GRAPHIC</b> Groundwater Resources Assessment under the Pressures of Humanity and Climate Change	<b>InSAR</b> Interferometric Synthetic Aperture Radar
<b>GRDC</b> Global Runoff Data Centre	<b>IPCC</b> International Panel on Climate Change
<b>GRID</b> Global Resource Information Database	<b>IPA</b> International Permafrost Association
<b>GTN-G</b> Global Terrestrial Network for Glaciers	<b>IPY</b> International Polar Year
<b>GTN-GW</b> Global Terrestrial Network on Groundwater	<b>ISO</b> International Organization for Standardization
<b>GTN-H</b> Global Terrestrial Network for Hydrology	<b>IWMI</b> International Water Management Institute
<b>GTN-L</b> Global Terrestrial Network for Lake level	<b>JAXA</b> Japan Aerospace Exploration Agency
<b>GTN-P</b> Global Terrestrial Network for Permafrost	<b>JRC</b> Joint Research Centre [of the EU]
<b>GTN-R</b> Global Terrestrial Network for River discharge	<b>LAI</b> Leaf Area Index
<b>GTOS</b> Global Terrestrial Observing System	<b>LCCS</b> Land Cover Classification System (FAO/UNEP)
<b>GTS</b> Global Telecommunications System	<b>LPV</b> Land Product Validation [Subgroup of CEOS-WGCV]
<b>HYDROLARE</b> International Data Centre on the Hydrology of Lakes and Reservoirs	<b>LSI</b> Land Surface Imaging [Constellation]
<b>HSDSD</b> Historical Soviet Daily Snow Depth Version 2	<b>MERIS</b> Medium Resolution Imaging Spectrometer
<b>HTE</b> High-Temperature Events	<b>MISR</b> Multiangle Imaging Spectro-Radiometer
<b>IACS/IUGG</b> International Association for the Cryospheric Sciences of the International Union of Geodesy and Geophysics	<b>MODIS</b> Moderate Resolution Imaging Spectroradiometer
<b>IAEA</b> International Atomic Energy Agency	<b>MSG</b> METEOSAT Second Generation
<b>ICSU</b> International Council of Scientific Unions	<b>NASA</b> National Aeronautics and Space Administration
<b>IFPRI</b> International Food Policy Research Institute	<b>IWMI</b> International Water Management Institute

<b>NESDIS</b> National Environmental Satellite, Data, and Information	<b>TCO</b> Terrestrial Carbon Observation Panel of GTOS
<b>NDSI</b> Normalized Difference Snow Index	<b>TEMS</b> Terrestrial Ecosystem Monitoring Site
<b>NICOP</b> Ninth International Conference on Permafrost	<b>TMB</b> Technical Management Board
<b>NLCD</b> National Land Cover Dataset (USA)	<b>TOPC</b> Terrestrial Observation Panel for Climate
<b>NOAA</b> National Oceanic and Atmospheric Administration	<b>TRMM</b> Tropical Rainfall Measuring Mission
<b>NPOESS</b> U.S. National Polar Orbiting Environmental Satellite System	<b>TSP</b> Thermal State of Permafrost
<b>NPP</b> net primary production	<b>TU Delft</b> Delft University of Technology (The Netherlands)
<b>NPP / NPOESS</b> NPOESS Preparatory Program / National Polar-orbiting Operational Environmental Satellite System	<b>UN</b> United Nations
<b>NSIDC</b> National Snow and Ice Data Center	<b>UNEP</b> United Nations Environment Programme
<b>NWS/COOP</b> National Weather Service, Cooperative Observer Program	<b>UNISDR</b> United Nations International Strategy for Disaster Reduction
<b>PACE</b> Permafrost and Climate in Europe	<b>UNESCO</b> United Nations Educational, Cultural, Scientific and Cultural Organization
<b>PALSAR</b> Phased Array type L-band Synthetic Aperture Radar	<b>UNFCCC</b> United Nations Framework Convention on Climate Change
<b>PAR</b> photosynthetically active radiation	<b>USGS</b> United States Geological Survey
<b>POLDER</b> POLarization and Directionality of the Earth's	<b>VIIRS</b> Visible Infrared Imagery Radiometer Suite
<b>REDD</b> Reducing Emissions from Deforestation and Degradation	<b>VU Amsterdam</b> Vrije Universiteit Amsterdam, The Netherlands
<b>ROSHYDROMET</b> Federal Service of Russia for Hydrometeorology & Environmental Monitoring	<b>WCRP</b> World Climate Research Programme
<b>SBSTA</b> Subsidiary Body for Scientific and Technological Advice (UNFCCC)	<b>WF-ABBA</b> Wildfire Automated Biomass Burning Algorithm
<b>SeaWiFS</b> Sea-viewing Wide Field-of-view Sensor	<b>WGCV</b> Working Group on Calibration and Validation
<b>SEVIRI</b> Spinning Enhanced Visible and Infrared Imager	<b>WGMS</b> World Glacier Monitoring Service
<b>SHI</b> State Hydrological Institute (Russia)	<b>WHYMAP</b> World-wide Hydrogeological Mapping and Assessment Programme
<b>SMMR</b> Scanning Multichannel Microwave Radiometer	<b>WMO</b> World Meteorological Organization
<b>SSM/I</b> Special Sensor Microwave Imager	<b>WRMC</b> World Radiation Monitoring Centre
<b>SWE</b> snow water equivalent	<b>WWAP</b> World Water Assessment Programme (UN)
	<b>WWDR</b> World Water Development Report (UN)



# THE GLOBAL TERRESTRIAL OBSERVING SYSTEM

The Global Terrestrial Observing System (GTOS) was established in January 1996 by its five co-sponsoring organizations in response to international calls for a deeper understanding of global change in the Earth System.

The central mission of GTOS is to provide policy-makers, resource managers and researchers with access to the data they need to detect, quantify, locate, understand and warn of change (especially reduction) in the capacity of terrestrial ecosystems to support sustainable development. Since its establishment, GTOS has been working to improve the quality, the coverage and accessibility of terrestrial ecosystem data.

GTOS promotes: integration of biophysical and socio-economic georeferenced data; interaction between monitoring networks, research programmes and policy-makers; data exchange and application; quality assurance and harmonization of measurement methods; and collaboration to develop regional and global datasets.

This report reviews the terrestrial Essential Climate Variables (ECVs), which are endorsed by the United Nations Framework Convention on Climate Change (UNFCCC) and the Group on Earth Observations (GEO). Details are provided on why these observations are needed to understand the causes of climate change, analyse the potential impacts, evaluate the adaptation options and enable characterization of extreme events such as floods, droughts and heat waves. It highlights some of the activities being undertaken, the need for the standardization of methods and harmonization of data and the major observational gaps and funding requirements needed to allow countries and international agencies to monitor, implement and report on issues related to climate change.

## GTOS PARTNERS



**Food and Agriculture Organization of the United Nations (FAO)**

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**United Nations Environment Programme (UNEP)**

[www.unep.org](http://www.unep.org)



**United Nations Educational, Scientific and Cultural Organization (UNESCO)**

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**World Meteorological Organization (WMO)**

[www.wmo.ch](http://www.wmo.ch)

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[www.cooperazioneallosviluppo.esteri.it](http://www.cooperazioneallosviluppo.esteri.it)



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