12 November 2008

ENGLISH ONLY

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE
Twenty-ninth session
Poznan, 1–10 December 2008

Item 6 of the provisional agenda
Research and systematic observation

Progress in assessing the status of the development of standards for essential climate variables in the terrestrial domain

Submission from the secretariat of the Global Terrestrial Observing System

1. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its twenty-seventh session (FCCC/SBSTA/2007/16, para. 39), encouraged the secretariat of the Global Terrestrial Observing System (GTOS) and the sponsoring agencies of GTOS to finalize the assessment of the status of the development of standards for each of the essential climate variables in the terrestrial domain, and invited the GTOS secretariat to report to the SBSTA on progress at its twenty-ninth session. In response to this invitation, the GTOS secretariat has submitted the progress report contained in this document.

2. Also at its twenty-seventh session (FCCC/SBSTA/2007/16, para. 40), the SBSTA encouraged the GTOS secretariat and the sponsoring agencies of GTOS to continue developing the framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate, in response to decision 11/CP.9, in the way they consider most appropriate, making use of existing institutional bodies and processes, where appropriate, and taking into account that such a framework should meet certain criteria (for the criteria identified by the SBSTA, see FCCC/SBSTA/2007/16, para. 40 (a–e)). The progress report mentioned in paragraph 1 above also contains information on the development of this framework.

3. In accordance with the procedure for miscellaneous documents, this submission is attached and reproduced* in the language in which it was received and without formal editing.

* This submission has been electronically imported in order to make it available on electronic systems, including the World Wide Web. The secretariat has made every effort to ensure the correct reproduction of the text as submitted.

FCCC/SBSTA/2008/MISC.12

GE.08-64106

Assessing the Status of the Development of Standards for the Essential Climate Variables in the Terrestrial Domain

Progress Report to the Subsidiary Body for Scientific and Technological Advice (SBSTA)

October 2008

Prepared and submitted by the Secretariat of the Global Terrestrial Observing System (GTOS)

GTOS 69

version 1.0

Table of Content

1. Purpose of report

This report describes progress made in the identification of possible implementation options for an international framework dealing with climate-related terrestrial observations. The analysis undertaken has identified a joint United Nations and International Organization for Standardization (ISO) framework as the most appropriate mechanism.

The report also summarizes the progress made on the assessment of available standards for the 13 terrestrial essential climate variables and the recommendations proposed by the different technical groups.

2. Introduction

Globally consistent sets of observational data are needed 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. 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 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, ICSU, UNEP, UNESCO and WMO) 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 the development of possible mechanisms for a terrestrial framework and assisting in the implementation of the 13 terrestrial Essential Climate Variables (ECVs), including the assessment of the status of available standards, protocols and methodologies. 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), originally as task CL-06-03 “Key Terrestrial Observations for Climate” which has now been consolidated under CL-09-02b, a subtask of the Task CL-09-02: Sustained Observing Systems.

The following report provides a summary of the progress that has been made in the development of a terrestrial framework mechanism and the assessment of available standards for the 13 terrestrial ECVs.

3. Historic background

In its Implementation Plan (GCOS, 2004) the Global Climate Observing System (GCOS) stated: “Many organizations make terrestrial observations, for a wide range of purposes. The same variable may be measured by different organizations using different measurement protocols. The resulting lack of homogeneous observations hinders many terrestrial applications and limits the scientific capacity to monitor the changes relevant to climate and to determine causes of land-surface changes.” In response, the Conference of Parties in its ninth session (Decision 11/CP.9; UNFCCC, 2003):

> *“8. Invites the sponsoring agencies of the Global Climate Observing System, and in particular those of the Global Terrestrial Observing System, in consultation with other international or intergovernmental agencies, as appropriate, 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, taking into consideration possible models, such as those of the World Meteorological Organization/Intergovernmental*

Oceanographic Commission Joint Commission for Oceanographic and Marine Meteorology, and to submit a progress report on this issue to the Conference of the Parties at its eleventh session".

Through the Global Terrestrial Observing System (GTOS), the Food and Agriculture Organization of the United Nations (FAO) commissioned a report in 2005 on the subject of establishing a framework for terrestrial climate-related observations (hereafter abbreviated as TCF). A progress report summarizing the above report was submitted to SBSTA/COP for its 23rd Session in Montreal, November 2005. In its response (UNFCCC, 2006, p. 16):

"The SBSTA welcomed the efforts by the GTOS Secretariat to develop a framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate and encouraged the GTOS to continue its work. It also 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."

GTOS subsequently prepared and submitted two reports for SBSTA 27 in Bali, December 2007. One report was on the progress in the assessment of the status of the development of standards (GTOS 2007b) and the second on possible options for the development of a framework for terrestrial climate-related observations (GTOS 2007a). SBSTA made the following recommendations (FCCC/SBSTA/2007/16):

39. The SBSTA welcomed the progress report on the assessment of the status of the development of standards for each of the essential climate variables in the terrestrial domain prepared by the GTOS secretariat in response to an invitation by the SBSTA at its twenty-third session.20 The SBSTA encouraged the GTOS secretariat and the sponsoring agencies of GTOS to finalize the assessment and invited the GTOS secretariat to report to the SBSTA on progress at its twenty-ninth session.

40. The SBSTA welcomed the efforts by the GTOS secretariat to develop a framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate, in response to decision 11/CP.9. The SBSTA welcomed the progress report by the GTOS secretariat on this matter and took note of the different options for such a framework presented therein. The SBSTA encouraged the GTOS secretariat and the sponsoring agencies of GTOS to continue developing the framework in the way they consider most appropriate, making use of existing institutional bodies and processes, where appropriate, and taking into account that such a framework should meet the following criteria:

(a) Standards should be developed on a scientifically sound basis;
(b) The framework should provide for the involvement of governments in the development of standards and guidance materials and in their implementation;
(c) Access to those standards and guidance materials should be free and unrestricted;
(d) The process for developing the standards and guidance materials and the operation of the framework should be cost-effective and sustainable and take into account existing standards and guidance materials;
(e) The framework should be flexible in view of future needs and developments in this area.

The current report provides an overview of the final selected framework for terrestrial climate-related observations and provides a summary of findings and recommendations of the assessments undertaken on available standards, protocols and methodologies for the 13 terrestrial essential climate variables: Albedo, Biomass, Fire disturbance, Fraction of absorbed photosynthetically active radiation (FAPAR), Glaciers and ice caps, Ground water, Lake levels, Land cover (including vegetation type), Leaf area index, Permafrost and seasonally-frozen ground, River discharge, Snow cover, and Water use (GCOS, 2004).

Details of the analysis used to evaluate suitability of different terrestrial frameworks mechanisms and the review process undertaken for the analysis of available standards for the 13 terrestrial ECVs have been reviewed in GTOS reports 48 (GTOS 2007a) and 49 (GTOS 2007b)and are therefore not described in this document. In addition a summary report for the assessment of standards has been prepared for each of the terrestrial ECVs (GTOS 56 to 68). Working drafts can be access at: www.fao.org/GTOS/pubs.html and printed examples will be made available at SBSTA 29. Final reports will be submitted to SBSTA 30 where research and systematic observations will be discussed.

4. Terrestrial framework

It is evident that a terrestrial 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 obligations when confronting the effects of climate change.

In the evaluation of possible terrestrial framework mechanisms a number of essential requirements were identified including that the framework mechanism should facilitate the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate, and of associated data and products. The framework should readily accommodate other terrestrial variables at a later date (GTOS, 2005) as the possibility of expanding the scope of the framework will allow its adaptation to future monitoring needs, for example for climate impacts and adaptation assessments. Finally, the framework must accommodate satellite as well as *in situ* observations as both are needed for most of the terrestrial essential climate variables (ECVs) identified. Using the above main criteria and subsequent analysis three main potential options were identified in the GTOS report on a “Framework for Terrestrial Climate-Related Observations: Implementation Options” (GTOS 2007a). The three potential options identified were:

Option A (intergovernmental): “Terrestrial Joint Commission”

The “Terrestrial Joint Commission” option would be established as a subsidiary body of the three intergovernmental organizations that deal specifically with primary observations (FAO, UNEP, WMO). It could consist of a Management Group and initially two teams, one for hydrological and cryospheric variables and one for land surface variables. Following the precedent of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) precedent, the “Terrestrial Joint Commission” would operate under rules of procedure agreed to by the three United Nations (UN) organizations, with differences reconciled through negotiations and approved by the three Decision Bodies. Commission president/co-presidents would attend the meetings of the Decision Bodies to present results of their work and recommend action.

Option B (ISO): “Terrestrial Committee”

An alternative framework would adapt the approach used by the International Organization for Standardization (ISO) to establish international standards. A new group (or subgroup) would be created within ISO. In principle, this could be a new Technical Committee, a new Sub-Committee to an existing Technical Committee, or a new Working Group within a Technical Committee. The structure, the rules of operation, work plan, and reporting would be established through negotiations between the Technical Management Board (TMB) and the entity coordinating this work, and would be embedded in a Memorandum of Understanding between the two organizations following existing practices and precedents. The entity would need to ensure that the mechanism meets the needs of GCOS, of the COP/UNFCCC, the Group on Earth Observations (GEO), and of other intergovernmental or international organizations or programmes as appropriate. Following ISO regulations, a TerC Secretariat would be located in a country willing to support it over at least five years.

Option C (international): “Terrestrial Observations Mechanism”

In addition to the above two options, there are other potential organizational frameworks which could achieve the results desired by the COP. For example, the COP could decide to extend the mandate of the Intergovernmental Panel on Climate Change (IPCC) which has previously dealt with similar terrestrial issues under the Good Practice Guidance (UNFCCC, 2003).

Analysis undertaken

The final option developed and proposed in this report has been developed on the basis of the three main options identified, discussions with stakeholders, consideration of the recommendations of the conclusions of SBSTA 27 and the following criteria required from the framework:

i. should serve a multi-purpose role, with an initial focus on terrestrial climate variables;
ii. facilitate inputs by users and producers of observational data;
iii. is broadly acceptable and adopted by countries;
iv. can be established and run efficiently and within the budgets of the stakeholders involved;
v. allows scientific or technical input from individual “interested” countries, but does not require inputs from all countries on every issue;
vi. allows coordination at the international level with groups or organizations with similar interests, including scientific programmes, international agencies, and synthesis-producing groups;
vii. is a mechanism for arriving at an international scientific or technical consensus;
viii. is a mechanism for producing international consensus on response (by national governments);
ix. will ensure financial and in-kind support for the activity and by national governments;
x. includes a communications strategy to raise the profile of the work and raise extra-budgetary resources;
xi. has the means for ensuring continuity and for being responsive to changing requirements.

Proposed UN/ISO terrestrial framework mechanism

Based on the analysis described above and discussions with stakeholders the GTOS Secretariat would like to propose to SBSTA a joint terrestrial framework mechanism between the United Nations (e.g. FAO, UNEP, UNESCO and WMO) and the International Organization for Standardization (ISO). This combined option is considered as the most appropriate in regards to stakeholder needs, functionality, current available resources and the capacities of the international entities which have shown interest in the development of an international framework mechanism. This option also provides the flexibility to suit the COP needs and those of the Sponsors, national governments, and other stakeholders.

Such a framework would also brings together the knowledge and expertise of the UN agencies and ISO, which through its technical committees TC207 (environmental management) and TC211 (Geographic information/Geomatics) have considerable experience in the development of international standards related to environmental issues. At the core of the framework mechanism would be a Joint Steering Group which would be formed from members of ISO technical committees TC 207 and TC 211 and representatives of the UN agencies (FAO, GTOS Secretariat, WMO, etc.). The Joint Steering Group would be supported by the relevant technical groups such as the joint GCOS/GTOS Terrestrial Observing Panel for Climate (TOPC) and may include other relevant ISO technical committees such as ISO/TC 113 on hydrometry. A draft outline of the framework proposal can be viewed in figure 1.

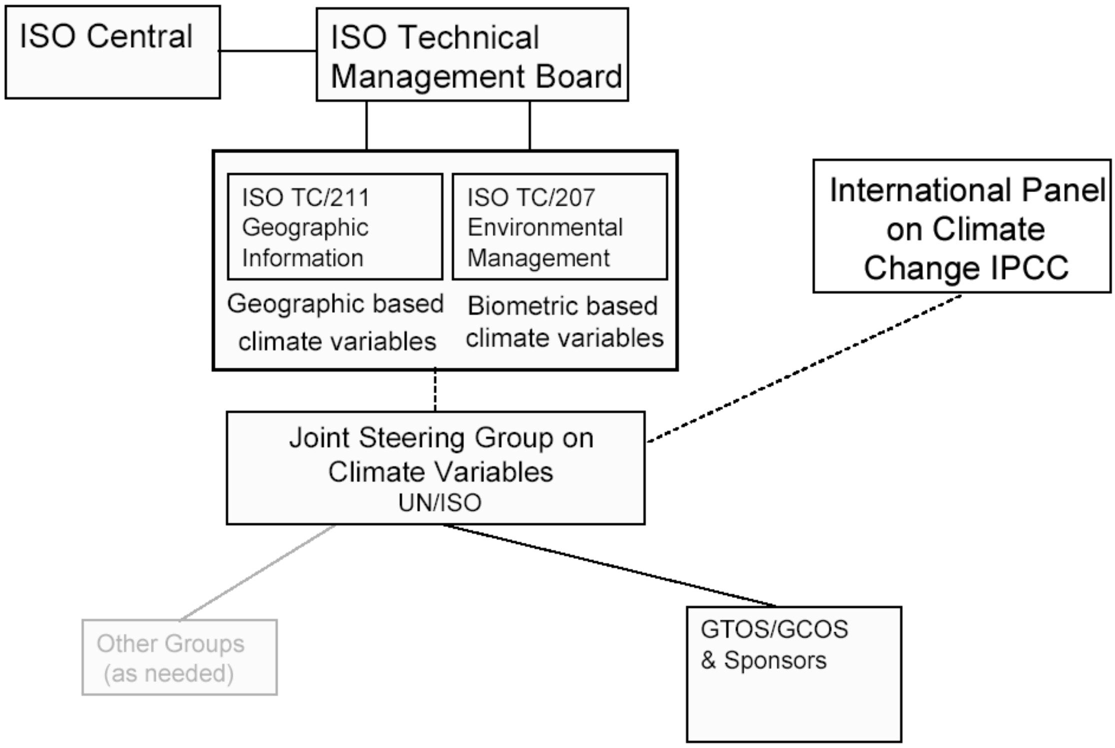

Figure 1: Draft outline of the proposed UN/ISO terrestrial framework mechanism (note that precise mechanisms and entities involvement are still to be defined). Technical inputs from GTOS and GCOS Terrestrial Observing Panel for Climate (TOPC) would be through the "GTOS/GCOS and Sponsors" entry point.

FAO, GCOS, WMO and other stakeholders have already shown support to an UN/ISO type mechanism and the ISO Central Secretariat has endorsed the idea of a joint committee with includes its two technical committees. FAO already has Category A status with ISO/TC 211 and more importantly, a Cooperative Agreement with ISO/TC 211 to establish a joint institutional programme and process for standardization between FAO and ISO/TC 211 – approved by ISO/TC 211 and the Central Secretariat. FAO has been active in establishing standards (LCCS/LCML) through the ISO process. ISO has also agreed to recognize WMO as an International Standardizing Body (ISB) and WMO already has a Category A status in several ISO Technical Committees including those related to terrestrial observations. It can therefore be seen that some of the initial components for the development of a joint UN/ISO mechanism have already been established.

GTOS will submit by SBSTA 30 (June 2009) a detailed report which provides details on the operational structure of the framework; costs of establishment and operation; process and time lines envisaged to develop individual standards; recommendations and support required by member countries, and next steps.

5. Available standards for the terrestrial ECVs

Currently terrestrial essential climate variables are 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 at the global level. Under the request of the UNFCCC, the GTOS Secretariat, with the support of its technical Panel and other partners, has undertaken the process to review the available standards, protocols and methodologies available for each terrestrial ECV and develop recommendations on the measures needed to generate the required observational products.

The question of standards for the terrestrial ECVs encompasses a very broad spectrum in terms of: (i) the environmental variables involved; (ii) the geographic coverage and diversity of these variables leading to different 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 in most cases, requiring conceptually different approaches; (vi) the number and dispersal of sources where information relevant to standardization may be generated or archived (national monitoring agencies, national or international research programmes, international scientific programmes, intergovernmental or international organizations, organizations focusing on standardization of measurements, world data centres), and others. To make the task manageable and to respond to the SBSTA request as effectively as possible, the following approach was adopted for each ECV:

a. Identify potential sources of information. Depending on the case, these included searches of the lists of publications by:
    - FAO, IGBP, UNEP, UNESCO and WMO;
    - International or important national data centres (e.g. GOSIC, GRDC, WDCs, etc.);
    - Large agencies producing or archiving terrestrial data sets (e.g. ESA, NASA,USGS);
    - Large research programmes with information available on the Web (e.g. DAACs);
    - The scientific community - international scientific panels (e.g. CEOS and GTOS), international projects and other international organizations or research programmes.
b. Identify documents that might be relevant to the development of standards for the terrestrial ECVs. This includes documents describing standards, guidelines, measurement or processing protocols, or guides that address the terrestrial ECVs directly or indirectly (e.g. documents that might contain relevant information, e.g. WMO guides dealing with hydrological measurements).
c. Obtain these documents where available (the majority through the Internet), review and extract relevant information.
d. Compile this information in a consistent format, adding conclusions and recommendations based on the materials identified.
e. Undertake an extensive review process in collaboration with relevant experts and through Web forums.
f. Generate a summary report for each ECV and circulate for further review and inputs.

Summary of the results of the review process

The review of available standards, protocols and methods has been undertaken for all 13 terrestrial ECVs. Draft summary reports have been developed and are undergoing a revision process through consultation of relevant scientific experts. A Web page has also been created which contains the materials gathered on each ECVs. This allows readers to review, comment or add additional information (see: www.fao.org/gtos/topcECV.html).

This section briefly discusses overall findings and impressions obtained so far, thus providing the rationale for the next steps. In this report, an "ECV standard" is assumed to be a document describing one specific approach to obtaining information on an ECV that has been broadly endorsed by the international community representing producers and users of such information.

Existence of standards

Overall, few standards appear to exist for the terrestrial ECVs. Although under the hydrological domain a number of ISO standards exist. On the other hand, there are guides for measurement methods 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*.

The apparent absence of standards can be understood by considering the nature of terrestrial ECVs. *In situ* measurement approaches have been initially developed by individual agencies or research groups, and this development was affected by the available equipment (often produced in that country), tradition, available expertise, etc. with no need for international coordination or standardization. As a result, the existing procedures exhibit considerable diversity in techniques and approaches. This is true even for such well-established variables as precipitation measurements, as the work of WMO technical commissions shows. WMO approaches this problem by: a) issuing "guides" which describe various procedures, their strengths and weaknesses, and applicability (e.g. WMO, 2006), and b) by supporting intercomparisons, calibration tests, and other initiatives which enable joint use of measurements by various methods (e.g. WMO, 1998).

Regarding satellite measurements, the complexity arises from differences among satellite sensors, their variable suitability to provide exactly the measurements needed, the limited spatial coverage (not all sensors provide full global coverage for an ECV), and the finite duration of individual satellite missions. To create ECV data sets required by the GCOS, comparability and consistency among products from different sensors/missions arise as key issues. This is the case when multiple products are generated or when sequential missions are launched. So the validation (for each generated product) and intercomparisons (among similar products) are the main issues. These are currently addressed by research teams, which as a matter of routine develop common protocols among themselves to be followed. Because of the diversity in input satellite data, it is not feasible (or desirable) to have one set of algorithms, although eventually the R&D can be expected to converge on the best methods and input data sources for ongoing applications. Nevertheless, the continuing technological evolution and the nature of satellite-based earth observation suggest that standardization in the above defined sense is not an appropriate approach. This is also reflected in the GCOS climate monitoring principles (GCOS, 2004) which include a suitable period of overlap between new and old satellite systems, and peer-review of new products. Such activities have indeed been taking place, e.g. intercomparisons among various LAI products by the CEOS Working Group on Calibration and Validation (see: http://lpvs.gsfc.nasa.gov/).

Other document types

In general, guides, measurement protocols, and guidelines are other means for encouraging and enabling acquisition of terrestrial observations that may lead to consistent products (in time and space) for use in climate monitoring. These have been used to various degrees for terrestrial ECVs and are established to a greater or lesser degree, depending on the ECV. The *in situ* approaches are well documented for some variables in various countries, and such information is available on the Internet. The determination of these products as candidate standards will be assessed. Depending on the ECV, few (e.g. Permafrost and seasonally-frozen ground) or many (Land cover) such documents may exist. In some cases, they obviously must exist but are difficult to access (e.g. Biomass).

In case of ECVs relying primarily on satellite measurements, the methods are evolving and often vary among programmes or satellite missions. However, the progress towards common or comparable methodologies and products has been accelerating through various projects and CEOS-supported initiatives, especially for Albedo, Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index, Fire disturbance, and Land cover (Snow cover products are fairly mature [IGOS, 2006] and relatively few at the global level). These efforts have so far resulted in best practice guidelines (e.g. for Land cover), in documents describing various measurement procedures and their proper use (e.g. for Leaf area index), and in the convergence of approaches to the generation of global products (e.g. Fire disturbance). So far, in most cases these procedures represent the view of a scientific community (or its subset) and do not have a "formal" stamp of approval.

Reports and recommendations

For each ECV a report has been prepared which summarizes the findings of the assessments and the recommendations made by the expert community. The reports are undergoing a review process and will be finalized and made available at SBSTA 30 (June 2009). However it should be noted that these reports will be updated when required to reflect new technological developments and stakeholder needs. The results and recommendations will be used to develop a strategic work plan for the terrestrial ECVs to address the issues of observational standardization.

6. Next Steps

The GTOS Secretariat is planning to take the follow steps to further development of standard methodologies and protocols for the terrestrial domain:

- In collaboration with ISO Central Secretariat and TC 207 and TC 211 and the United Nations agencies (especially WMO and UNEP) agree and develop the structure and procedures to establish make operational the UN/ISO terrestrial framework mechanism.
- Use the findings and recommendations from terrestrial ECV assessment of standards reports develop action plans for each terrestrial ECV in regards to the development of standards and the adoption of common methods and protocols.
- Review and update current status of terrestrial observational networks and their adequacy in meeting new stakeholder requirements such as local climate change adaptation.
- Report progress of activities being undertaken and raise new issues of concern relevant to research and systematic observations at SBSTA 30.

7. Overall recommendations to SBSTA

To facilitate the GTOS Secretariat and its partners in the development and uptake of standards and the use of common methodologies and protocols, it is recommended that SBSTA:

1. Encourage the support of parties to support and promote the implementation the final UN/ISO framework mechanism and encourage the development of standards and protocols as recommended by the review process undertaken for each of the 13 terrestrial ECVs.
2. Assist in generating the political and financial support to allow the development of the required standards.
3. Endorse the development of implementation plans for coordinated terrestrial observations using the standards developed and encourage member countries to undertake their observations, generate their data and undertake their reporting as specified in the implementation plans.

8. References

GCOS. 2004. Implementation plan for the Global Observing System for Climate in Support of the UNFCC. Report GCOS – 92 (WMO/TD No. 1219). 136p. + Appendices.

GCOS. 2006. Systematic observation requirements for satellite-based products for climate. Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC", Report GCOS-107 (WMO/TD No. 1338), Geneva, Switzerland. 90p.

GTOS 2007a. A Framework for Terrestrial Climate-Related Observations: Implementation Options, GTOS Progress Report to the 26th Meeting of the UNFCCC SBSTA, March 2007, GTOS 48 (at: www.fao.org/gtos/pubs.html).

GTOS 2007b. Assessing the Status of the Development of Standards for the ECVs in the Terrestrial Domain, GTOS Progress Report to the 26th Meeting of the UNFCCC SBSTA, March 2007, GTOS 49 (at: www.fao.org/gtos/pubs.html).

IGOS. 2006. IGOS Cryosphere Theme for the Monitoring of our Environment from Space and from Earth. Report Version 0.9.5.1. 118p.

McArthur, L.J.B., BSRN Operations Manual V2.1, WCRP 121, WMO/TD-No. 1274, April 2005, www.wmo.ch/pages/prog/wcrp/PG_Reports_WCRPSeries.html , www.bsrn.awi.de/fileadmin/user_upload/Home/Publications/McArthur.pdf

WMO. 2006. Guide to meteorological instruments and methods of observation. Report WMO-No. 8, Preliminary seventh edition, World Meteorological Organization, Geneva, Switzerland.

WMO. 1998. WMO Solid Precipitation Measurement Intercomparison: Final Report, (B. E. Goodison, et al.), Instruments and Observing Methods Report No. 67, WMO/TD-No. 872, Geneva, Switzerland.

9. Annex: summaries of terrestrial ECV reports

The Annex contains an overview of the draft summaries and recommendations from the analysis of available standards for the terrestrial ECVs.

Please note that these summaries and the documentation from which they are derived are undergoing a review process and updated summaries will be submitted at SBSTA 30.

Terrestrial ECV 1 :: River discharge (draft executive summary)

River discharge has a role in driving the climate system, as the freshwater inflow to the worlds oceans may influence oceanic circulation patterns at interannual to decadal time scales. At the same time river discharge serves as an indicator for climatic change and variability as it reflect changes in precipitation and evapotranspiration. River discharge, which is expressed as volume per unit time, is the rate at which water flows through a cross-section. The unit used to measure river discharge is usually m^3/s (cubic meters per second, or cumecs).

Currently *in situ* methods are the most cost-effective and reliable options for river discharge measurement. Discharge measurements are made at each gauging station to determine the discharge rating for the site. The discharge rating is a relation between stage and discharge influenced by stage, slope, rate of change of stage and other factors. The depth of flow in the cross-section is measured at verticals using different techniques. As the depth is measured, observations of velocity are obtained at one or more points in the vertical. The measured widths, depths, and velocities permit computation of discharge for each segment of the cross-section. The summation of these segment discharges is the total discharge.

River discharge measurements are described in detail in the Technical Regulations of Hydrology and Guide to hydrological practices of the World Meteorological Organization (WMO). WMO also provides a Manual on stream gauging consisting of Volume I-Fieldwork and Volume II-Computation of discharge. The ISO Technical Committee 113 is dealing with all standards related to Hydrometry. Numerous standards covering the majority of the observation methods have been published and are under development. Both WMO documentation and ISO standards are revised when needed, to incorporate latest technical and methodological developments. Existing *in situ* methods and standards meet the needed requirements.

For many rivers, discharge measurements are either nonexistent or not promptly available. During flood season, it is usually impossible or impractical to measure peak discharges, even though peak information is very important. When floods occur the use of conventional methods is not safe, consequently many peak discharges must be determined by indirect methods after the flood has passed. Methods to determine river discharge based on remotely sensed data would be most advantageous. However, the currently available methods still need to be refined in terms of accuracy and spatial resolution in order to supplement or substitute *in situ* river discharge measurements.

Most countries operate national or regional river discharge monitoring networks and corresponding data archives. The need for an International River Discharge Data Center to provide discharge data for continental or global studies has been realized by the WMO and as a result the Global Runoff Data Center (GRDC) was established in 1988. This international river discharge data repository is mandated through WMO resolutions to collect, archive and redistribute river discharge data from WMO members. Due to different national data policies, technical, political or administrative obstacles the amount of discharge data captured in the GRDC is only a fraction of the total available discharge data and in many cases outdated.

The GRDC has launched a project called Global Terrestrial Network for River Discharge (GTN-R). The basic idea of the GTN-R project is to draw together the already available heterogeneous information on near-real-time river discharge data provided by individual National Hydrological Services and redistribute it in a harmonized way. The GTN-R activity is a contribution to the Global Terrestrial Network for Hydrology (GTN-H) of the Global Climate Observing System (GCOS) and the WMO. The implementation of the GTN-R is progressing at a slow pace, due to the hesitation of many countries to fully participate and provide the relevant data.

Recommendations

- For *in situ* river discharge measurement existing standards set by ISO and guides from the WMO (WMO Technical Regulations of Hydrology, WMO Guide to Hydrological Practices, WMO Manual on Stream Gauging Volume I-Fieldwork and Volume II-Computation of Discharge, Standards related to Hydrometry set by the ISO Technical Committee 113) should be adhered to. The revision process of these standards and guides to accommodate latest developments is well established and adequate.

- The development of remote sensing techniques and the supporting satellite systems for the monitoring of river discharge must be encouraged. Remotely sensed data has advantages for many rivers where discharge measurements are not available or where the maintenance of a dense network of stream gauges is too expensive. Flood monitoring could also be achieved without the risks and shortcomings currently associated with this task.

- The free and unrestricted exchange of hydrological information must be further encouraged so that the data can be received by the international data centers in time for up-to-date assessments and forecasts.

- The decline of hydrological monitoring networks needs to be addressed and financial support is sought to establish a global baseline river discharge monitoring programme.

Terrestrial ECV 2 :: Water Use (draft executive summary)

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.

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

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

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.

Nearly all regional and global analysis of water use is based on country reports and statistics which contain a certain level of uncertainty due to the differences in methods and procedures used to gather the information and also due to incomplete data records. Programmes such as Aquastat of FAO have developed guidelines for reporting water use which contains a detailed description on how data should be processed, analysed and reported. The Aquastat guide on reporting contains sections on land use, water resources, water withdrawal, irrigation and drainage development, environment and health. In addition there is information on the preparation of country profiles with sections on: geography and population; climate and water resources; economy, agriculture and food security; irrigation and drainage development; water management, policies and legislation related to water use in agriculture, environment and health; and perspectives for agricultural water management. However, these guidelines rarely specify how the original observations should be collected or processed and there is no complete resource guide with provides specifies what observations are required and what methodologies and protocols should be used to undertake *in situ* or remote sensing observations of water use.

Recommendations

- International stakeholders should collaborate to develop an agreed list of water use observational requirements and the methodologies and protocols which should be used. Cross cutting observations (such as river discharge and groundwater) should be developed in coordination with the other terrestrial ECVs. Methods or protocols which should be developed into international standards should be identified.

Terrestrial ECV 3 :: Groundwater (draft executive summary)

Groundwater accounts for nearly 30 percent of global freshwater resources. Today, some 2 billion people rely on groundwater as a primary source of drinking water. Groundwater also provides a major fraction of the water used for irrigation. 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. In spite of its importance to the world's fresh water supply, groundwater is poorly monitored on a global basis.

Key groundwater measurements include groundwater levels, pumping rates, salinity and other measures of water quality, storage coefficients, well-head elevation, screen depth, and local aquifer properties such as aquifer type, thickness, and whether measurements are for confined or unconfined units. Many of these measurements are made within developed countries, but at varying spatial and temporal scales. In developing countries, where groundwater may account for the bulk of the fresh water supply, monitoring is not well established. Several national hydrological services are responsible for making groundwater measurements, but insufficient policy for international data sharing, even in transboundary aquifer systems, continues to hamper efforts to assemble global monitoring efforts. In short, no comprehensive, global framework for monitoring groundwater storage and quality currently exists.

The problem of global monitoring is compounded by the use of varying measurement methods and protocols. Decisions on what to measure, including how and when to do so, are the responsibility of national hydrological services, and often even vary within countries, at the state and local levels. Although the International Organization for Standardization (ISO) standards exist for measuring well levels, groundwater quality and well development, most countries develop wells and make measurements to their own methods and protocols, which vary in scope and quality. Protocols for groundwater sampling and data submission must be established as part of global monitoring framework.

Recently, the potential for groundwater remote sensing has been demonstrated. In particular, the Gravity Recovery and Climate Experiment (GRACE) mission can detect monthly changes in groundwater storage. The Interferometric Synthetic Aperture Radar (InSAR) and the Global Positioning System (GPS) can help characterize aquifer storage parameters. Given its global coverage, remote sensing provides a distinct advantage for international monitoring efforts. Moreover, when combined with numerical models for aquifer systems or for global hydrology, along with *in situ* well observations, a powerful framework for global monitoring emerges. 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.

A strategy for global groundwater monitoring will require significant international cooperation and coordination of ongoing efforts. The participation of the World Meteorological Organization (WMO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Food and Agricultural Organization (FAO) and the World Bank (IBRD) will be essential. An example of such a coordinated effort is the International Groundwater Resources Assessment Centre (IGRAC) and the recently proposed Global Terrestrial Network for Groundwater (GTN-GW). This coordinated activity will archive monthly data using 1° global grids. Data will be provided on a by-country basis, and will be uploaded via a Web interface. Groundwater variables and hydrogeologic parameters are those described above. Experts in each country would be responsible for aggregating an agreed-upon list of variables to the corresponding 1° grids and for submitting them to a Global Groundwater Monitoring System (GGMS), the data portal for the GTN-GW. Archived data would also be geo-referenced to the

Worldwide Hydrogeologic Mapping and Assessment Programme (WHYMAP) new base map of global groundwater aquifer units.

Recommendations

- Identify protocols and standards for groundwater measurements and raw and aggregated data submission.
- Identify and support IGRAC as the lead organization for coordinating and implementing the GTN-GW.
- Establish GTN-GW as a network of networks that builds on ongoing efforts and supplements them as required.
- IGRAC should convene GTN-GW and other required working groups to review and clearly define its list of monitoring variables. Currently, these include groundwater levels, pumping rates, salinity and other measures of water quality, storage coefficients, well-head elevation, screen depth, and local aquifer properties such as aquifer type, thickness, and whether measurements for confined or unconfined units.
- Identify key worldwide monitoring personnel with the assistance of WMO, FAO and UNESCO.
- Identify and support development of key remote sensing datasets and derived products from GRACE, InSAR, GPS, and future relevant satellite missions.
- Begin populating the GGMS with raw and aggregated data and derived products.
- Train end-users, particularly those in developing countries, in the use of the GGMS.
- Accelerate efforts for synergistic use of groundwater models, *in situ* data and remote observations, including algorithms for asynchronous data assimilation of ground-based and remotely-sensed data of varying origin and spatial-temporal resolution.
- Identify a core, global set of long-term *in situ* groundwater monitoring locations that report using ISO standards.
- Identify critical remote sensing missions as long-term groundwater climate data records.
- Recommend new international policy and protocol for sharing international hydrological data, including groundwater.

Terrestrial ECV 4 :: Lake level (draft executive summary)

According to the definition by the WMO International Glossary of Hydrology, lake is an inland body of water of considerable size; reservoir is a body of water, either natural or man-made, used for storage, regulation and control of water resources. Lakes level is a complex index of natural water exchange within their watersheds. Therefore, long-term level fluctuations in natural (unregulated) lakes also reflect climate changes occurring in the region. On the other hand, lake water storage, which depends on water level, is an easily available source of water for many sectors of economy such as domestic and industrial water supply, hydropower industry, agriculture, water transport and others. Lake water level is also a complex index of water exchange in the reservoir-river basin system. However, the character of this water exchange depends not only on natural processes, but on the regime of runoff operating in the reservoir. The mode of the runoff operating (runoff redistribution) is determined by reservoir water storage relative to the annual river discharge at the dam site.

Water level in lakes and reservoirs is measured in centimeters against the national reference plane or against an adopted plane (so called ‘zero’ graph). The surface area of a lake or reservoir is measured in m^2 or km^2 depending on the size. Lake or reservoir storage (volume) is measured in m^3 or km^3 depending on the size.

Volume III (Hydrology) of Technical Regulations (WMO-No.49, 2006) and the WMO Guide to hydrological practices (WMO-No.168, 1994) provide information and describe measurements for hydrological observing stations. The sections on lake level specify the requirements in the establishment and operation of a hydrometric station for the measurement of stage. Stage, or water level, is the elevation of the water surface relative to a datum. Records of water level are obtained by systematic observations on a manual (non-recording) gauge, or from a recording gauge. Gauges on lakes and reservoirs are normally located near their outlets, but sufficiently upstream to avoid the influence of drawdown. Methodologies include:

Non-recording gauges: several types of non-recording gauges for measuring stage are used in hydrometric practice. The common gauges are of the following types: graduated vertical staff gauge; ramp or inclined gauge; wire-weight gauge installed on a structure above the stream; and graduated rod, tape, wire or point gauge for measuring the distance to the water surface.

Recording gauges: many different types of continuously recording stage gauges are in use. They may be classified according to both mode of actuation and mode of recording. A commonly used installation consists of a stilling well connected to the stream by pipes and a float in the stilling well connected to a wheel on a recorder by a beaded wire or perforated tape. The modern means of measuring water level include: hydrostatic gauges; bubble gauges; non-contact gauges (radar and ultrasonic).

Establishment of gauge datum: to avoid negative readings, the gauge should be set so that a reading of zero is below the lowest anticipated stage. The gauge datum should be checked annually by levels from local benchmarks. It is important to maintain the same gauge datum throughout the period of record. If feasible, the local gauge datum should be tied to a national or regional datum.

The frequency of recording of water level is determined by the hydrological regime of the water body and by the purposes for collecting the data. A daily measurement of stage is usually sufficient in lakes and reservoirs for the purpose of computing changes in storage.

Remote sensing (satellite altimetry and monitoring of the area of lakes and reservoirs) has the potential to provide some important lakes and reservoirs attributes, such as surface area, elevation, location, etc. In addition remote sensing data allows for continuous systematic monitoring, including height information for any target beneath the satellite overpass, thus contributing information where traditional gauge (stage) data may be absent. However, limitations in satellite measurements need to be considered. For example, instruments may have not been designed specifically for the purpose; only generate an “average” topography within the instrument “footprint” (so depending on the sensor resolution measurements may not be of sufficient accuracy or even impossible to take for smaller lakes or reservoirs) and phenomena such as major wind events, heavy precipitation, tidal effects and the presence of ice will effect data quality and accuracy.

The existing methods and procedures for lakes and reservoir water level observations are well reflected in different technical documents of WMO, UNESCO and ISO (for example ISO/TR 11330:1997), but these need to compiled into a single standard reference document.

Recommendations

- The existing methods and procedures for lakes and reservoir water level observations are well established and allow data to be acquired at an accuracy for further processing and *analysis*. However, further analysis should be undertaken, through HYDROLARE, to ascertain the state of the world lakes and reservoirs level observation methods and assessing if there is a need for the development of specific ISO international standard for water level of lakes and reservoirs.

- The results of satellite water level measurements still contain substantial errors exceeding admissible limits. However this data enables the general assessment of seasonal and long-term water level trends. Further *in situ* validation of this data through ground networks and improvement of the technique of satellite water level measurements are necessary.

- Implementation of advanced automated means of measuring water level (especially on lakes which were chosen as priority lakes in GTN-L (GCOS 2004) should make it possible to avoid subjectivity and errors unavoidable when using conventional methods.

- The International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) should be made operational to allow the establishment of a global database of level observations on the world lakes and reservoirs for practical purposes and scientific analysis.

- Implementation of advanced automated means of measuring water level should make it possible to avoid subjectivity and errors unavoidable when using conventional methods.

Terrestrial ECV 5 :: Snow cover (draft executive summary)

Seasonal snow can cover more than 50 percent of the Northern Hemisphere land surface during a single winter resulting in snow cover being the land surface characteristic responsible for the largest annual and interannual differences in albedo. Surface temperature is highly dependent on the presence or absence of snow cover, and temperature trends have been shown to be related to changes in snow cover. In turn, because of the obvious dependency of snow cover on temperature, long time series of snow cover trends serve as indicators of climate change. Snow cover, with its high albedo and low conductivity, moderates the transfer of energy at the land surface and exerts a significant effect on the land surface water budget. Realistic simulation of snow cover in climate and hydrologic models and forecast schemes is essential for correct representation of the surface energy balance, as well as for understanding winter water storage and predicting year-round runoff. Improvements in methods for estimating real-time snow cover will translate into improved ability to forecast atmospheric and hydrologic variables in many regions of the world.

Interest in global snow cover data extends beyond typical climate applications. For example, in a warming climate scenario early melt leads to less stream flow during high requirement periods of mid- and late-summer, while the amount of snow and its variability influences the timing of soil freeze/thaw cycles. In addition, the area extent of snow cover is important to the study of atmospheric trace gas fluxes such as evaluating the impact of varying snow cover extent on the regional to global ozone budgets and carbon fluxes. Other applications of snow data range from the obvious examples of winter recreation industry, highway and railway maintenance, and avalanche hazard mitigation, to the study of wildlife migration and breeding patterns, and the management of domestic livestock during snow disasters.

In general, the accumulation of snow on the ground is measured in percent cover per unit area by:

Snow cover extent: the total land area covered by some amount of snow; typically reported in square kilometres.

Snow cover depth: the combined total depth of both old and new snow on the ground; typically reported in centimetres or metres.

Snow water equivalent: the water content obtained from melting snow (i.e. the thickness of the layer of water that would result from melting a given snow depth); typically reported in millimetres or kilograms per square metre.

The main *in situ* measurement methods include: *snow depth:* is the most obvious property of a snow cover, but it is less useful from a water and energy budget perspective since snow depth can change independently from snow mass due to densification over time. Manual snow depth measurements are made using a ruler or with one or more fixed snow stakes. Some judgement is required to obtain a spatially “representative” value. *Snow Water Equivalent (SWE)* is related to the depth and density of the snow cover:

$$\text{SWE (mm)} = 0.01\ d_s\ \rho_s$$

where d_s is the depth of snow (cm) and ρ_s is the density of snow (km^{-3}). The conversion from a mass of snow ($kg\ m^{-2}$) to a depth of water (mm) is based on the fact that 1mm of water spread over an area of $1m^2$ weighs 1kg. The most commonly used approach for determining total SWE is the gravimetric method which involves taking a vertical core through the snow cover, and weighing or melting the core to obtain SWE. A variety of coring and weighing systems have been used around the world with varying lengths and diameters depending on measurement units and local snow conditions. Automated methods are available to measure both snow depth (ultrasonics) and SWE (pressure transducers), each with its own set of accuracy limitations. A complete description of measurement methods can be found in: Armstrong, R.L. and E. Brun (ed.), 2008. Snow and Climate, Cambridge University Press.

Satellite remote sensing offers the opportunity to monitor and evaluate various snow parameters and processes at regional to global scales. During the past four decades much important information on continental to hemispheric scale snow extent has been provided by satellite remote sensing in the visible wavelengths. Since 1966 the National Oceanic and Atmospheric Administration (NOAA) has produced weekly snow extent charts for Northern Hemisphere land surfaces using visible-band satellite imagery. Because of the ability to penetrate most clouds, provide data during darkness, and to provide a measure of snow depth or water equivalent, passive microwave remote sensing can enhance snow measurements based on optical data alone. Similar sensors are employed on aircraft, typically with higher spatial resolution, but limited to regional scales and always intermittent in time. Details on current satellite measurement techniques can be found in: Armstrong, R.L. and E. Brun (ed.), 2008. Snow and Climate, Cambridge University Press.

Recommendations

- Compile and archive global *in situ* snow measurements in a central location.
- Achieve optimal integration of appropriate satellite and *in situ* snow products.
- Improve accuracy of SWE retrievals from active and passive satellite sensors.
- Promote assimilation of snow albedo into numerical weather and climate models.
- Increase observation of trace gas fluxes through snow to better understand net carbon balance.

Terrestrial ECV 6 :: Glaciers (draft executive summary)

Changes in glaciers provide some of the clearest evidence of climate change, constitute key variables for early-detection strategies in global climate-related observations, and have the potential to cause serious impacts on the sea level, the terrestrial water cycle and societies dependent on glacial melt water (GCOS 2004). Perennial surface ice on land includes glaciers, ice caps, ice shelves, and ice sheets, with fundamental differences in time-scales and processes involved. Due to their large volumes and areas, the two continental ice sheets in Greenland and Antarctica actively influence the global climate and react to climatic changes over time-scales of millennia. On the other hand, glaciers and ice caps with their smaller volumes and areas typically react much faster (a few decades) to climatic changes.

Internationally coordinated monitoring of glaciers and ice caps was initiated in the late nineteenth century. The active compilation and publication of standardized data has resulted in unprecedented datasets on the distribution and changes of glaciers and ice caps. The international data collection through a scientific collaboration network is coordinated within the Global Terrestrial Network for Glaciers (GTN-G). The GTN-G is run by the World Glacier Monitoring Service (WGMS) at the University of Zurich, Switzerland, in collaboration with the US National Snow and Ice Data Center (NSIDC) at the University of Colorado, Boulder, USA, and the Global Land Ice Measurements from Space (GLIMS) initiative, hosted at NSIDC. The core datasets comprise standardized information on the spatial distribution of the ice cover (extent in square kilometres) at a certain point in time, changes in terminus position (horizontal length change in metres) and mass balance (thickness change in metres of water equivalent). Several additional glacier attributes and meta-information is provided in the data sets. Glacier inventories are used to estimate the overall ice area and volume and, when available for more than one point in time, to assess (decadal to centennial) glacier changes for entire mountain ranges. Length change and mass balance measurements are carried out at a relatively small set of glaciers but with high (annual) temporal resolution. Thereby, glacier front variations constitute an indirect, delayed and filtered but also enhanced and easily observed signal of climate change, whereas glacier mass balance is a more direct and underlying signal of annual atmospheric conditions.

At present, detailed inventories are available for around the 1960s to 1970s for approximately 100 000 glaciers and ice caps throughout the world, with an overall area of some 240 000 km^2 as well as preliminary estimates of the other glacierised regions, both mainly based on aerial photographs and maps. In addition, digital outlines of 62 000 glaciers covering about 229 000 km^2 have been collected (status of June 2008), mainly from more recent satellite data, in the GLIMS database. The total number and area of glaciers and ice caps are estimated at about 160 000 and some 685 000 km^2, respectively. Glacier fluctuations are documented by a standardised dataset of approximately 36 000 length change observations from about 1 800 glaciers, reaching back to the nineteenth, and from approximately 3 400 mass balance measurements from 230 glaciers covering the past six decades. The status of the datasets is periodically published and all data are available in digital form and at no charge upon request. The main shortcomings of the presently available datasets are: (i) the incompleteness of a detailed world inventory of glaciers and ice caps; (ii) the lack of repeated detailed inventories in most regions, which are needed to assess the overall ice changes over entire mountain ranges, and (iii) the strong bias of available glacier length change and mass balance measurement series towards the Northern Hemisphere and Europe.

Change assessments based on integrative analysis of the available *in situ* measurement with remotely sensed data conclude that glaciers around the globe show a centennial trend of glacier retreat from the Little Ice Age moraines, which mark maximum Holocene glacier extents in many mountain ranges, and an accelerated ice wastage since the mid 1980s. On a decadal time-scale, glaciers in various regions have shown intermittent re-advances (e.g. around the 1970s). However, under current climate change scenarios, the ongoing trend of worldwide and fast glacier shrinkage is most likely of non-periodic nature, and may lead to the deglaciation of large parts of many mountain ranges in the coming decades.

Over the decades of glacier monitoring, several manuals and guidelines have been published describing the terminology and methodology to carry out glacier inventories, mass balance and front variation measurements. These reference documents are listed and (mostly) made available from the WGMS Web site.

Recommendations

In view of the expected rapid changes, the incompleteness of the global inventory of glaciers and ice caps, and the bias of the available fluctuation measurements, it is crucial to:

- Make *in situ* and remotely sensed glacier measurements with related meta-data readily available according to the international standards and guidelines.
- Complete a detailed baseline inventory of the world's glaciers and ice caps.
- Define key regions where the surface land ice cover is most relevant for questions related to hydrology, climate and/or sea level change.
- Continue the long-term length change and mass balance measurements.
- Extend the present *in situ* network with additional and re-initiated long-term series with a focus on the above mentioned key regions.
- Improve the metadata and quantify the uncertainties of the datasets.
- Develop downscaling techniques for running glacier impact models in mountainous terrain over large regions, using data from global/regional climate models.
- Strengthen the cooperation of the organizations involved in the international glacier monitoring within GTN-G.
- Secure long-term national and international funding for the services running the GTN-G.

The potentially dramatic climate changes, as estimated for the twenty-first century in the latest IPCC report, are related to glacier changes of historical dimensions with strong impacts on landscape evolution, fresh water supply, natural hazards, and sea level changes. In order to face the related challenges for glacier monitoring in the twenty-first century, it is required that systematic use is made of the rapidly developing new technologies in remote sensing and geo-informatics and that these techniques are related to the traditional field observations.

Terrestrial ECV 7 :: Permafrost (draft executive summary)

Decadal changes in permafrost temperatures and depth of seasonal freezing/thawing are indicators of changes in climate. Warming may result in an increase in active layer thickness, melting of ground ice and subsequent reduction in permafrost thickness and the lateral extent of permafrost. These changes can have an impact on terrain stability leading to ground subsidence or erosion, vegetation, ecosystem function and soil moisture and gas fluxes. Permafrost and seasonally frozen ground also influence surface and subsurface hydrology. Standardized *in situ* measurements are essential to understanding how permafrost conditions are changing, to improve predictions of future changes, and to calibrate and to verify regional and global climate change models. Long-term monitoring sites are contributing to the Global Terrestrial Network for Permafrost (GTN-P). These sites exist throughout the permafrost regions and have provided data that have facilitated the characterization of trends in permafrost conditions over the last two to three decades and in a few cases over much longer periods. Under the leadership of the International Permafrost Association a coordinated field campaign is under way during the International Polar Year to obtain a snapshot of global permafrost temperatures and active layer measurements.

The main parameters and measurement methods are:
Permafrost: sub-surface earth materials that remain continuously at or below 0°C for two or more consecutive years. Parameter is ground temperatures (°C) at specified depths. Permafrost temperature measurements are obtained by lowering a calibrated temperature sensor into a borehole hole, or recording temperature from multi-sensor cables permanently or temporarily installed in the borehole. Measurements may be recorded manually or by data loggers. The depth of boreholes varies from less than 10m to greater than 100m. Data loggers may be utilized for daily measurements of shallow temperatures to reduce the frequency of site visits and provide a continuous record of ground temperatures. Ideally (although not always feasible at all sites), temperatures at shallow depths (upper 10m to 20m) should be collected at monthly or more frequent intervals as this allows the annual temperature envelope (i.e. range in temperatures at depth) and mean annual temperatures to be determined.

Active layer: the surface layer of ground, subject to annual thawing and freezing in areas underlain by permafrost. Parameters are thickness (cm) and temperatures (°C). Several traditional methods are used to determine the seasonal and long-term changes in thickness of the active layer: mechanical probing annually, frost tubes, and interpolation of soil temperatures. The minimum observation required under the Circumpolar Active Layer Monitoring (CALM) protocol is a late season mechanical probing of the thickness of the active layer on a gridded plot or transect. Interpolation of soil temperature measurements from a vertical array of sensors can be used to determine active-layer thickness at a point location (see www.udel.edu/Geography/calm/)

Seasonally frozen ground: refers to soils without permafrost that are subjected to seasonal freezing and thawing. Parameters are depth (cm) and temperature (°C). Winter frost penetration in regions of seasonal ground freezing is determined by measuring soil temperatures or by use of frost tubes; similar to methods used for active layer measurements.

The methods described above are presented in a combined draft manual developed for the International Polar Year Thermal State of Permafrost (IPY/TSP) which is available on the International Permafrost Association (IPA) Web site (www.ipa-permafrost.org/). Deriving ISO standards from this manual should encourage the adoption of these standard methodologies and promote the expansion of the observational networks. Unlike ice and snow covers, properties of permafrost terrain are currently not directly detected from remote sensing platforms. However, many surface features of permafrost terrains and periglacial landforms are observable with a variety of sensors ranging from conventional aerial photography to high-resolution satellite imagery in various wavelengths.

Recommendations

- Finalize the IPY-TSP manual and ensure its endorsement by the international and national communities as the standard manual of methodologies to be followed.
- As appropriate, develop ISO standards from the IPY-TSP manual.
- Develop a permanent status for the existing GTN-P borehole and active layer networks under a spatially comprehensive "International Network of Permafrost Observatories (INPO)". National observing agencies should collect and report these observations at existing stations.
- Upgrade existing sites with automated data loggers, remote data acquisition (reduce cost associated with site visitation) and instrumentation for collection of ancillary climate and other environmental data.
- Further develop the GTN-P by creating partnerships with those monitoring other cryospheric components (e.g. snow) to co-locate monitoring sites and expand existing networks at reduced cost. Partnerships with industry can help to establish monitoring sites in key resource development areas.
- An international network for monitoring seasonally frozen ground in non-permafrost regions should be formed. Soil temperature and frost depth measurements should be recommended as standard parameters to all WMO and national cold regions meteorological stations. As part of the new network, remote sensing algorithms should be developed and validated to detect soil freeze/thaw cycles (microwave passive and active sensors).
- New upscaling techniques for research sites and permafrost networks are required to extend point measurements to a broader spatial domain, to support permafrost distribution modeling and mapping techniques within a GIS framework, and to complement active layer and thermal observing networks with monitoring of active geological processes (e.g. slope processes, thermokarst development on land and under lakes, coastal dynamics, and surface terrain stability). This approach requires high resolution DEMs of permafrost regions.
- Data rescue and management activities must be sustained. National and international funding for permafrost data management is an explicit priority. The IPY activities provide an ideal opportunity to recover and analyse permafrost-related and soil temperature data and to encourage long-term commitments to shared data practices and distributed products.
- Methods and standards for active layer and thermal measurements are available on the CALM, TSP and IPA Web sites.

Recommendations modified from Chapter 9, IGOS Cryosphere Theme Report, 2007

Terrestrial ECV 8 :: Albedo (draft executive summary)

Land surface albedo, or the ratio of the radiant flux reflected from the Earth's surface to the incident flux, is a key forcing parameter controlling the planetary radiative energy budget and partitioning of radiative energy between the atmospheric and surface. Albedo varies in space and time as a result of both natural processes (e.g. solar illumination, snowfall and vegetation growth) and human activities (e.g. clearing and planting forests, sowing and harvesting crops, burning rangeland) (GCOS 2004) and is a sensitive indicator of environmental vulnerability. Since albedo depends on both the unique anisotropy of the surface (related to the intrinsic composition and structure of the land cover) and the atmospheric condition at any given time, field tower measurements support local and regional determination of surface albedo while remote sensing offers the only viable method of measuring and monitoring the global heterogeneity of albedo and reflectance anisotropy (GCOS 2004).

Broadband surface albedo is generally defined as the instantaneous ratio of surface-reflected radiation flux to incident radiation flux over the shortwave spectral domain (dimensionless). It can be defined for broad spectral regions or for spectral bands of finite width. Albedo measures include black-sky albedo (or directional hemispherical reflectance, DHR) defined in the absence of a diffuse irradiance component (no atmospheric scattering), wholly diffuse white-sky albedo (or bihemispherical albedo, BHR, under isotropic illumination), and actual or blue-sky albedo (BHR under ambient conditions). GCOS (2004) has specified black-sky albedo as the product required for climate change purposes. Since the DHR is a function of the solar zenith angle, it is usually computed for a specific time (e.g. local solar noon).

Direct solar radiation (total or spectral) at the surface is measured by means of pyrheliometers, the receiving surfaces of which are arranged to be normal to the solar direction. Pyranometers are used to measure global radiation (direct plus diffuse) or diffuse only radiation in the spectral range from 0.3 to 3.0 micrometres (WMO 2006). The WMO guidelines are used by the Baseline Surface Radiation Network (BSRN), which has been established to provide continuous, long-term tower measurements of surface radiation fluxes adhering to the highest achievable standards of measurement procedures (McArthur, 2005). The BSRN data, archived at World Radiation Monitoring Center at the Alfred Wegener Institute, Bremerhaven, Germany, is now recognized as the GCOS baseline network for surface radiation (GCOS 2004). These BSRN sites provide the high-quality measurements of surface radiation required, but the network global coverage is insufficient for widespread validation of remotely sensed products and needs to be expanded and adequately supported (GCOS, 2004a).

In addition to the BRSN, other terrestrial networks contain tower sites that could provide the necessary infrastructure (e.g. human maintenance, instrument availability, site accessibility, and power needs) to measure radiation variables for albedo calculations; the challenges in these cases are to encourage the use of best practice measurement, calibration and archive protocols, and provide timely access. Guidelines for data collection protocols and standardization across the flux networks are currently being developed under the auspices of the Terrestrial Carbon Observation (TCO) effort. However, many such flux and ecological networks are part of national research programmes without guaranteed adequate long-term funding.

To estimate remotely sensed albedo, reflectance measurements must be interpreted with the help of radiation transfer models that can help retrieve the desired variables from the actual observations (GCOS 2006). Most satellite algorithms rely on multiple cloud-free directional satellite observations to first determine a bi-directional reflectance distribution function (BRDF) model of the surface. The model is then angularly integrated to determine the reflected shortwave flux. Because most sensors do not collect multiple observations of a target in a single pass, data from multiple orbits or acquisition times may be used, and the varying atmospheric and irradiance effects then need to be reconciled.

GCOS (2006) suggested that albedo product requirements may be met through a combination of satellite sensors, both geostationary (with wide coverage and good temporal resolution) and polar orbiting (with uniform coverage of the globe, important especially for polar regions). Because of the differences in sensors and observation conditions (orbit geometry, season, geographic region, land cover characteristics), albedo product generation procedures tend to differ depending on the specific product, the data source, and the producing organization. For climate change purposes, long time series of products are especially important, and this inevitably imposes the necessity for consistency among products from satellite missions flown at different times.

The validation of satellite-derived products for heterogeneous land surfaces poses special challenges because of the need to obtain estimates of “true” instantaneous albedo to be compared with satellite-derived values. Various upscaling methods have been utilized, ranging from the use of in situ measurements to the use of higher resolution satellite data and models. Such validation exercises and rigorous satellite product intercomparisons are facilitated by the various space agencies and the Land Product Validation Subgroup of the Committee on Earth Observing Satellites/Working Group on Calibration and Validation (CEOS/WGCV) to promote consensus procedures (GCOS 2004)

Recommendations

Official recognition of the need for long-term, high-quality, *in situ* radiation measurements for spectral and broadband albedo determination is required so that field measurements can be expanded to cover a greater diversity of land covers and ecosystems, both in existing radiation networks (such as BSRN) and in other terrestrial networks with sufficient pre-existing infrastructure. Such measurements should conform to WMO and BSRN guidelines (WMO, 2006; McArthur, 2005). The further development, validation and intercomparison of satellite-derived albedo and reflectance anisotropy products should be vigorously pursued to establish the accuracy and consistency of these critical geophysical quantities and to guarantee the production of similarly high calibre data sets from future sensors. It must be recognized that periodic reprocessing of existing archives of remote sensing data will be necessary to generate the continuous and consistent long-term global climate records required.

Terrestrial ECV 9 :: Land Cover (draft executive summary)

Land cover change is a pressing environmental issue, acting as both a cause and a consequence of climate change. Reliable observations are crucial to monitor and understand the ongoing processes of deforestation, desertification, urbanization, land degradation, loss of biodiversity and ecosystem functions, water and energy management, and the influence of land-cover changes on the physical climate system itself. A number of disciplines (i.e. geography, ecology, geology, forestry, land policy and planning, etc.) use and refer to land cover and land-cover change as one of the most obvious and detectable indicators of land surface characteristics and associated human induced and natural processes. Current and future IPCC Assessment Reports are based upon an uncertain understanding of the land surface and related processes. Applications of land cover and land dynamics in climate change related Earth System Models and Impact Assessment Models should be better linked and coordinated. The importance of these issues requires continuous monitoring systems and data.

Land cover is defined as the observed (bio)-physical cover on the earth's surface. It includes vegetation and man-made features as well as bare rock, bare soil and inland water surfaces. The primary units for characterizing land cover are categories (i.e. forest or open water) or continuous variables classifiers (fraction of tree canopy cover). Secondary outcomes of land cover characterization include surface area of land cover types (ha), land cover change (area and change trajectories), or observation by-products such as field survey data or processed satellite imagery.

Land cover in different regions has been mapped and characterized several times and many countries have some kind of land monitoring system in place (i.e. forest, agriculture and cartographic information systems and inventories). In addition, there are a number of global land cover map products and activities. These activities have been building upon the availability of continuous global satellite observations since the 1980s.

With evolving technology, it has become increasingly efficient to derive land cover information from a combination of *in situ* surveys and earth observation satellite data at global, regional, and national scales. Inconsistencies exist between the different land cover map products or change monitoring systems complicating our ability to successfully synthesize land cover assessments on regional and global scales.

Current data, products, and capabilities:

- Quasi-operational global land cover monitoring integrate information from three common observation scales: moderate resolution satellite data (e.g. MODIS- or MERIS–type satellite sensor); fine resolution satellite data (from LANDSAT- and SPOT-type satellite sensors), and *in situ* observations (or very high resolution satellite data). Continuity of observations and consistency for land cover characterization is required for all these scales.
- The UN Land Cover Classification System (LCCS) currently provides a comprehensive, internationally accepted, and flexible framework for thematic land cover characterization. LCCS uses classifiers enabling compatibility between existing datasets and for future global monitoring systems.
- Global mapping efforts (i.e. MERIS-based GlobCover and those from MODIS) are ongoing to provide consistent and validated land cover data and land cover change indicators worldwide at moderate-resolutions.
- Land cover change estimates require multi-temporal fine resolution satellite observations. Archived image data (i.e. global Landsat mosaics) and methods are available to implement a global land cover change monitoring system. Regional and national programs (e.g. CORINE, PRODES) and

international initiatives such as the Forest Resources Assessment for 2010 of the FAO use multiple data sources for regional and global assessment of historical forest change processes.

- An independent accuracy assessment using a sample of ground-reference data is an integral part of any land cover monitoring effort. Standard methods for land cover validation have been developed by the international community.

Recommendations

- Continuity and availability of data is required for all observations scales.
- Continuous monitoring of conditions is recommended through periodic mapping cycles.
- The collection of ground reference data should be continuous and national agencies are encouraged to supply ground reference data in support of calibration and validation requirements.
- Further international development and adoption of land cover and land cover change mapping standards have been initiated and this process should be further encouraged.
- The international land observation community should coordinate and cooperate to provide useful and flexible land cover validation protocols.
- Internally consistent and synoptic data sets are required to represent the global land cover ECV, requiring communication and cooperation between nations.
- Member nations are encouraged to support the continuity of existing measurement capabilities and to promote a broadening of monitoring abilities.

Terrestrial ECV 10 :: fAPAR (draft executive summary)

The Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) plays a critical role in the energy balance of ecosystems and in the estimation of the carbon balance over a range of temporal and spatial resolutions. Spatially-explicit descriptions of FAPAR provide information about the relative strength and location of terrestrial carbon pools and fluxes. It is one of the surface parameters that can be used in quantifying CO_2 assimilation by plants and the release of water through evapotranspiration. The systematic observation of FAPAR is suitable to reliably monitor the seasonal cycle and inter-annual variability of vegetation photosynthetic activity over terrestrial surfaces.

The solar radiation reaching the surface on the 0.4-0.7μm spectral region is known as the photosynthetically active radiation (PAR). FAPAR refers to the fraction of PAR that is absorbed by a vegetation canopy. FAPAR is difficult to measure directly, but is inferred from models describing the transfer of solar radiation in plant canopies, using remote-sensing observations as constraints. In environmental applications, absorption of radiation by leaves is of greater concern than of other plant elements (trunks, branches, etc.). Ground-based estimates of FAPAR require the simultaneous measurement of PAR above and below the canopy as well as architecture information to account for the non-leaves absorption. FAPAR assessments are retrieved from space remote sensing platforms by numerically inverting physically-based models. Most of the derived products represent only the fraction absorbed by the live green part of the leaf canopy. Being the ratio of two radiation quantities, FAPAR is a dimensionless variable.

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. Over ten years of space-derived FAPAR data are now available from different institutions.

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

Recommendations

- FAPAR products have proved very useful for environmental monitoring, such as for carbon assimilation by plants. Further investigations are underway to document climate changes and their impacts on the land surface, and these will require access to long time series of accurate products derived from historical data archives. This, in turn, requires reprocessing of existing database to generate the most extensive and accurate records.

- Given the demonstrated usefulness of existing FAPAR products for this and other applications, it will also be critical to ensure the continued availability of this product in the foreseeable future, on a global scale, at a high temporal resolution, and with a clear characterization of the associated measurement uncertainties. Advances in sensor design and updated retrieval procedures are expected to better characterize and further reduce the actual uncertainties, as is required for the implementation of new land surfaces data assimilation systems in Global Climate Models.

- Validation campaigns should be scheduled over selected sites, distributed globally to sample a large number of land terrestrial surface types. Long time series of field and remote sensing data suitable for validation are required for describing FAPAR seasonality.

- Protocols to acquire ground-based measurements have to be clearly defined and internationally endorsed. An assessment should be undertaken to determine if international standards need to be developed.

- Promoting extensive experiments over selected super-sites would also help narrow down the uncertainties, in particular through better identifying the various radiation transfer regimes improving on the current algorithms and understanding the sources of these uncertainties.

- Finally, research and developments efforts should focus on improving the reliability and accuracy of these products to facilitate their intake in data assimilation systems. This, in turn, will lead to a better understanding of the climate system and may also improve weather forecasts. These efforts should also lead to a better consistency between the various radiant energy fluxes (e.g. surface albedo, transmittance and FAPAR) and thus facilitate the exploitation of observations in the models.

Terrestrial ECV 11 :: LAI (draft executive summary)

The Leaf Area Index (LAI) of a plant canopy is a quantitative measure of the amount of live green leaf material present in the canopy per unit ground surface. Specifically, it is defined as the total one-sided area of all leaves in the canopy within a defined region, and is a non dimensional quantity, although units of m^2/m^2 are often quoted, as a reminder of its meaning. This concept is largely used in agro-meteorology, but many atmospheric general circulation or biogeochemical models also rely on it to parameterize the vegetation cover, or its interactions with the atmosphere. For instance, evapotranspiration and carbon fluxes between the biosphere and the atmosphere are routinely expressed in terms of the LAI of the canopy. Monitoring the distribution and changes of LAI is therefore important for assessing the state and evolution of the vegetation on the planet.

Multiple methods (including direct harvesting - a destructive method, or indirect radiation measurements such as hemispherical photography and observations of light transmission through the canopy) have been proposed to estimate LAI on the ground or remotely, and in each case different researchers tend to follow their own (non-standardized) protocols.

Space agencies and other institutional providers generate maps of LAI at various spatial resolutions for daily to monthly periods, over the globe, using mainly optical space borne sensors. In this case, the values actually delivered correspond to an allometric or an effective value that depends on the spatial resolution of observations. LAI values are occasionally estimated locally through ground-based measurements, for instance at 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 Validation (LPV) Subgroup of the CEOS Working Group on Calibration and Validation (CEOS-WGCV). The main validation efforts concentrate on improving 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 documents research sites and the observations they are undertaking including *in situ* information on LAI values (www.fao.org/gtos/tems/). For example, LAI is a standard parameter observed at all FLUXNET sites. A community effort is on going to define procedures and methods to guarantee the compatibility between the assumptions made while retrieving remote sensing products and those inherent to the applications models as well as ground-based estimates.

Recommendations

- LAI products have proved very useful in a number of environmental applications, including estimating carbon assimilation by plants. Long-time series of accurate and precise LAI products derived from space are essential for climate change studies, especially at regional and local scale, to improve the parameterization of the surface-atmosphere interaction processes in a range of models. Further investigations are underway to document climate changes and their impacts on the land surface, and these will also require access to long-time series of accurate products derived from historical data archives. This, in turn, will necessitate the reprocessing of existing database to generate the most extensive and accurate records.

- Given the usefulness of existing LAI products for this and other applications, it will also be critical to ensure the continued availability of this product in the foreseeable future, on a global scale, at a high temporal resolution, and with a clear characterization of the associated measurement uncertainties. Advances in sensor design, including multi-angular instruments, and updated retrieval procedures are expected to better characterize and further reduce the uncertainties associated with this product, as is required for the implementation of new land surfaces data assimilation systems in Global Climate Models.

- Validation campaigns should be scheduled over selected sites, distributed globally to sample a large number of land terrestrial surface types. These networks must ensure the standardization of measurements, their optimal spatial distribution, as well as the benchmarking of the acquisition protocols. The conversion of field measurements to effective values, an essential step when trying to estimate this variable from optical remote sensing observations, requires additional information about the structure and architecture of the canopy, e.g. gap size distributions, at the appropriate spatial resolutions. The consistency between this LAI, a state variable, and the FAPAR (ECV T10), a radiation flux, is important and must be guaranteed.

Terrestrial ECV 12 :: Biomass (draft executive summary)

Vegetation biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a larger global store of carbon than the atmosphere, and changes in the amount of vegetation biomass already affect the global atmosphere by being a net source of carbon, and having the potential either to sequester carbon in the future or to become an even larger source. Depending on the quantity of biomass the vegetation cover can have a direct influence on local, regional and even global climate, particularly on air temperature and humidity. Therefore, a global assessment of biomass and its dynamics is an essential input to climate change forecasting models and mitigation and adaptation strategies.

In addition there are two other emerging issues which contribute to the increasing importance of the role of biomass as an essential climate variable: (i) the growing use of biomass for energy production, so the increasing percentage of global GHGs emitted from biomass consumption, and (ii) the increasing concern on the possibility to significantly reduce global GHGs emissions by avoiding biomass losses from deforestation, forest degradation, and accounting for the effects of natural disturbances. This document will mainly address living terrestrial above-ground vegetation biomass, in particular woody biomass.

Biomass is defined as mass per unit area of live or dead plant material. The unit of measure is g/m^2 or its multiples. The carbon pools of terrestrial ecosystems involving biomass are conceptually divided into above-ground biomass, below-ground biomass, dead mass and litter.

Biomass can be measured by *in situ* sampling or remote sensing using the following methods:
i) *In situ* destructive direct biomass measurement: this method entails harvesting plant species, drying them, and then weighing the biomass. Biomass measurements can be done on single-tree basis or on area (plot) basis. While this is the most direct and accurate method for quantifying biomass within a small unit area, it is expensive, time-consuming, damaging to the environment and infeasible at a large scale.
ii) *In situ* non-destructive biomass estimations: includes measurements that do not require harvesting trees, such as height and stem diameter and uses allometry or conversion factors to extrapolate biomass to unit ground area.
iii) Inference from remote sensing: remote sensing measures the amount of microwave, optical or infrared radiation that is reflected or scattered by the imaged area in the direction of the sensor. This amount of radiation can be related to different biomass levels of the vegetation. Generally, biomass is either estimated via a direct relationship between the spectral response or through indirect relationships, whereby attributes estimated from the remotely sensed data, such as leaf area index (LAI), structure (crown closure and height) or shadow fraction are used in equations to estimate biomass. Remotely sensed data provides a synoptic view of the area of interest (that is, the entire area is characterized in the same way with the same data) that enables the estimation of biomass values over large areas.
iv) Models: different models have been developed to derive biomass estimates over large areas incorporating spatial data (such as elevation and radiation), remotely sensed data, and field samples or forest inventory data.

Allometric equations are used to extrapolate *in situ* or remote sampled data to a larger area and to derive biomass from other variables. Allometry relates the size of one structure in an organism to the size or amount of another structure in the same organism; therefore it is possible to estimate biomass from diameter, height, age, etc., and extend the datum to a larger area with the same characteristics.

In situ measurements are critical to the monitoring of terrestrial carbon stocks, but they impose many limitations. They are generally labour-intensive, expensive and time consuming, and even if potentially they can be very accurate, there can be many problems. In any case, currently the ground based national forest inventories are likely to contain the most accurate biomass estimates, suited for reliable assessments of biomass changes. *In situ* measurements should be conducted at least every five years. While satellite approaches to estimating biomass are becoming increasingly reliable, limitations remain related to accuracy and range of predictions. However, satellite technology allows for increasingly frequent measurement of biomass and several satellite methods have demonstrated potential for providing direct and indirect global above-ground biomass information at high resolution (below 1km). With improved sensor capabilities combined with previous experience and methods, it is expected that satellite and model based estimates of biomass will provide for the large area monitoring of biomass.

Recommendations

At least the following requirements need to be met in order to improve the reliability of biomass estimates and their utility to better monitor and understand climate change:

- Encourage agencies with *in situ* inventories and remote sensing data to work together to allow validation and upscaling of *in situ* measurements;
- Harmonize different methodologies for data collection and analysis of continuous, standardized and geo-referenced forest biomass inventories;
- Develop the needed *in situ* standards and the required international validated methodology for biomass estimation from remote sensing.
- Improve the quality and quantity of *in situ* biomass estimates used in remote sensing calibration and validation;
- Extend forest biomass inventories to tropical forests, non-commercial forests, mangroves and woodlands, and increase the number of permanent plots and the periodicity of data collection;
- Develop new or improved allometric functions for biomass estimations, conversion of above-ground biomass to total biomass, and applications suited for larger geographic areas;
- Define a single classification system to be used for remote sensing estimation of biomass; a good standard is the Land Cover Classification System (LCCS) and its accepted translations for countries;
- Produce more accurate tree height measurements from field laser and from LiDAR technology that may result in improved biomass estimates, and particularly within the framework of satellite-derived forest land cover; mechanisms are needed for increased acquisition and availability of LiDAR data over large geographic areas;
- Pursue a further development and integration of SAR and optical data to provide estimates of biomass in a synoptic manner over large areas and explore the possibility of defining standard biomass data products from active remote-sensing methodologies, such as SAR or LiDAR;
- Follow the IPCC Guidelines for National Greenhouse Gas Inventories (Vol.4, Agriculture, Forestry and Other Land Use), 2006, for standard *in situ* biomass measurements, especially if countries do not have any better regional or national conversion factors or biomass equations;
- Promote the development of new standards for biomass output products (that may integrate different methods and data sources, i.e. in situ and remote sensed) used in biomass estimation and mapping over large geographic areas.

Terrestrial ECV 13 :: Fire (draft executive summary)

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. Information on fire activity is used for global change research, estimating atmospheric emissions and developing periodic global and regional assessments. It is also used for fire and ecosystem management planning and operational purposes (fire use, preparedness and wildfire suppression) and development of informed policies.

The Fire Disturbance Essential Climate Variable includes Burned Area as the primary variable and two supplementary variables: Active Fire and Fire Radiated Power (or Fire *Radiative* Power - FRP). Burned Area is defined as the area affected by human-made or natural fire and is expressed in units of area such as hectare (ha) or square kilometre (km^2). Active Fire is the location of burning at the time of the observation and is expressed in spatial coordinates or by an indicator of presence of absence of fire in a spatially explicit digital raster map, such as a satellite image. FRP is the rate of emitted radiative energy by the fire at the time of the observation and is expressed in units of power, such as Watts (W).

Fire activity is a global phenomenon characterized by strong spatial and temporal variability. Documentation of fire activity by aerial means (including manned or unmanned aircraft), such as GPS plotting, post-fire photography or high resolution radiometers, is done traditionally in some countries, notably in Russia and other countries of the former Soviet Union. However, declining fire management budgets result in incomplete and inconsistent coverage. Other countries that have limited fire activity, e.g. Central European countries, are using aerial patrols for early fire detection. Ground-based observations from fire lookout towers or by automated observing systems are also in place but usually concentrated on limited areas of high-value forests or nature reserves. Data from satellite remote sensing are the most suitable and useful means for large and global scale monitoring. Observing systems have been developed using sensors on board both polar orbiting and geostationary satellites.

The methodologies used to estimate burned areas using satellite data are based on the identification of the post-fire spectral signature by various algorithms of change detection and image classification. While no single consensus approach exists, the various techniques use multi-spectral information in the visible, shortwave-infrared and infrared bands and the multi-temporal information based on comparison of satellite images over an extended period of time.

Active fire detection is based on the detection of the thermal signature from flaming and smouldering and its distinction from the non-burning surfaces based on spectral and spatial contrasts. Most methods use the thermal signal around 4 µm, but visible bands are also used at night time. A major issue is the elimination of false alarms from hot and bright surfaces from daytime data and the low saturation of some of the sensors used. The methodologies to derive FRP use physical-empirical approaches to derive rates of total emitted radiative energy from narrow-band, unsaturated radiance measurements.

Validation of satellite-derived data products with *in situ* measurements is limited. For proper validation of satellite-based products fire activity over the entire area of the satellite pixel needs to be mapped by independent means. Fire perimeter maps or high resolution airborne imagery are potentially useful reference data, but issues with limited sampling and data quality remain. Validation of the moderate and coarse resolution global products is most often performed by higher spatial resolution (e.g. 30m Landsat-class) satellite data. The standard for burned area adapted by CEOS includes the use of pairs of such imagery to validate burning mapped between their acquisition dates. For active fire products simultaneous observations are required. The prototype approach has been developed for the single-platform Terra/ASTER/MODIS configuration, but there is a need to extend it to multi-platform techniques. The validation of FRP requires unsaturated radiance measurements from high resolution space- or airborne sensors. These are currently not routinely available, but emerging systems exist.

The currently available fire products only marginally meet the requirements defined by the GCOS Implementation Plan (GCOS 2004). No global products at the specified 250m spatial resolution and daily observing cycle exist and product continuity and consistency between products derived from the various sensors remains unresolved.

The currently defined variables under the Fire Disturbance ECV focus on the presence, extent and characteristics of fires. However, there are numerous interactions between fire and climate that prompt the characterization of pre-fire conditions and post-fire impacts. The linkages between the Fire Disturbance and other ECVs need to be further explored and additional fire variables, such as fire weather, fire danger and fire-related emissions need to be considered.

Recommendations

- Finalize and adapt emerging consensus methods and standards for the validation of moderate and coarse resolution satellite-based fire products using high resolution spatially explicit reference data from *in situ*, airborne and spaceborne observations;
- Develop standards for the intercalibration of fire products from various sensors to enable the creation of a long-term fire disturbance data record
- Develop multi-sensor algorithms and multi-product suites for a more comprehensive characterization of fire activity;
- Develop systematic fire products from active remote sensing data;
- Coordinate linkages between surface and atmospheric ECVs and data requirements to model global fire danger, fire emissions, and a global early warning system for wildland fire at various time scales; specifically, these ECVs are:
    - atmospheric ECVs: surface temperature, precipitation, wind speed, wind direction, water vapour, upper air cloudiness,
    - terrestrial ECVs: aboveground biomass, burn efficiency, and snow cover (extent, duration, depth);
- Establish linkages between fire-related surface and atmospheric impacts and corresponding ECVs.

Other generic recommendations regarding the Fire Disturbance ECV

- re-evaluate the GCOS requirements to be more specific and realistic for the products generated at various time scales and resolutions;
- generate and distribute individual fire products and maintain historical archives;
- ensure the transition of experimental products to the operational domain;
- ensure data continuity to the new generation sensors on future satellite series;
- improve the exchange of information and facilitate timely and systematic availability of data.

- - - - -