Space-based Essential Climate Variables for lakes

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Lakes as sentinel of climate change

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Abstract
While there is a general sense that lakes can act as sentinels of climate change, their efficacy has not been thoroughly analyzed. We identified the key response variables within a lake that act as indicators of the effects of climate change on both the lake and the catchment. These variables reflect a wide range of physical, chemical, and biological responses to climate. However, the efficacy of the different indicators is affected by regional response to climate change, characteristics of the catchment, and lake mixing regimes. Thus, particular indicators or combinations of indicators are more effective for different lake types and geographic regions. The extraction of climate signals can be further complicated by the influence of other environmental changes, such as eutrophication or acidification, and the equivalent reverse phenomena, in addition to other land-use influences. In many cases, however, confounding factors can be addressed through analytical tools such as detrending or filtering. Lakes are effective sentinels for climate change because they are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment.
1990 – IPCC – Intergovernmental Panel on Climate Change. **SCIENCE**

2000 – GCOS – Global Climate Observing System. **OBSERVATIONS**

2010 – GFCS- Global Framework for Climate Services. **SERVICES**

These programmes report directly to the United Nations Framework on Climate Change (UNFCCC) and there Parties are expected to support them.
## Table 1: Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
</tr>
</thead>
</table>
| **Atmospheric** (over land, sea and ice) | **Surface:**
Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.  
**Upper-air:**
Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).  
**Composition:** Carbon dioxide, Methane, and other long-lived greenhouse gases, Ozone and Aerosol, supported by their precursors |
| **Oceanic**             | **Surface:**
Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton.  
**Sub-surface:**
Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers. |
| **Terrestrial**         | River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture. |
GCOS and (other) Lake ECVs

Why should we care?
GCOS provides a process and an explicit set of requirements that space agencies are adopting in implementing their programmes (e.g. ESA CCI)

How could GloboLakes be a catalyst for the definition of Lake ECV requirements?
Globolakes can benefit from the iterative capability of user requirement and product definition and implementation

How do we get GCOS to take notice?
GCOS tends to be (rightly) conservative in admitting new ECVs we need to take advantage of existing references to Lakes in GCOS documentation, and expand/develop from this. (definition of a baseline set of Lake ECV products should be conservative)

On what timescale could GloboLakes contribute to the GCOS process?
Next cycle of process
Two climate action paths
our challenge
global collaborative framework
The 2010 edition of the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (IP-10) replaces a similarly titled Plan (IP-04) which was published in 2004. Its purpose is to provide an updated set of Actions required to implement and maintain a comprehensive global observing system for climate that will address the commitments of the Parties under Articles 4 and 5 of the UNFCCC and support their needs for climate observations in fulfilment of the objectives of the Convention.

This revised Plan updates the Actions in the IP-04, taking account of recent progress in science and technology, the increased focus on adaptation, enhanced efforts to optimize mitigation measures, and the need for improved prediction and projection of climate change. It focuses on the timeframe 2010-2015.
GCOS Satellite Supplement

... provides supplemental detail to the 2010 Update of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (GCOS-138, August 2010, hereafter called the ‘GCOS Implementation Plan’ or ‘IP-10’) related to the generation of global climate products derived from measurements made from satellites

News

Update of the Satellite Supplement – now open for public review

High-level requirements on the accuracy, stability and resolution of satellite-based datasets and derived products in support of the GCOS ECVs were defined in 2006 and documented in the "Satellite Supplement" (GCOS-107) to the 2004 GCOS Implementation Plan.

An 2011 Update of the Satellite Supplement is currently underway. The draft document is now opened for public review from 9 May to 1 July 2011: Draft Document
1. Products, Target Requirements, Benefits
2. Rationale
3. Currently Achievable Performance
4. Requirements for satellite instruments and data
5. Calibration, Validation and Archiving Needs
6. Adequacy and Inadequacy of Current Holdings
7. Immediate Actions, Partnerships and International Coordination.

Target Requirements

<table>
<thead>
<tr>
<th>Variable/Parameter</th>
<th>Horizontal Resolution</th>
<th>Vertical Resolution</th>
<th>Temporal Resolution</th>
<th>Accuracy</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST</td>
<td>10km</td>
<td>N/A</td>
<td>Daily</td>
<td>0.1K over 100km scales</td>
<td>Less than 0.03K over 100km scales</td>
</tr>
</tbody>
</table>
Established in 1984 under auspices of G-7 Economic Summit of Industrialized Nations

- Focal point for international coordination of space-related Earth Observation (EO) activities
- Optimize benefits through cooperation of members in mission planning and in development of compatible data products, formats, services, applications, and policies

Operates through best efforts of Members and Associates via voluntary contributions

29 Members (Space Agencies), 21 Associates (UN Agencies, Phase A programs or supporting ground facility programs)

As the space component of the Global Earth Observation System of Systems (GEOSS), CEOS is implementing high priority actions in support of Group on Earth Observation (GEO) Tasks
Primary Objectives of CEOS

1. To optimize benefits of space-borne Earth observations through:
   - Cooperation of its Members in mission planning
   - Development of compatible data products, formats, services, applications, and policies;

2. To serve as a focal point for international coordination of space-related Earth observation activities;

3. To exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.
• Responds to the GCOS Actions
• Reinforces the needs called out by the GCOS Satellite Supplement
  • Provides more detail on the deliverables, coordination, activities and who will lead the effort.
  • Calls out agency activities
  • Calls out international coordination
• Can include additional activities not called out by GCOS but may be considered important by CEOS.
The objective of Climate Change Initiative is to realize the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by UNFCCC.

It will ensure that full capital is derived from ongoing and planned ESA missions for climate purposes, including ERS, Envisat, the Earth Explorer missions, relevant ESA-managed archives of Third-Party Mission data and, in due course, the GMES Space Component.

CCI Programme following Ministerial Council in 2008, about 75MEUR over 6 years for about 20 ECVs
Starting NOW
Regional sea-level trends from satellite altimetry (Topex/Poseidon, Jason-1&2, GFO, ERS-1&2, and Envisat missions) for the period October 1992 to July 2009.
Climate Data Records

The Satellite Era Merging Data From Different Sensors Requires Expert Knowledge and Retrospective Insights

Uncorrected Data Time Series Contain Both Environmental Information and Satellite-induced Artifacts

Operational weather and hazard products are produced rapidly to potentially save life and property

Climate Data Records (CDRs) provide long term product consistency through rigorous reprocessing with advanced algorithms, ancillary data and evolved instrument understanding.

Climate Information Records (CIRs) provide specific information about environmental phenomena of particular importance to science and society (e.g., hurricane trends, drought patterns).
Geostationary surface albedo

GSA: Broad band (0.3-3.0 μm) surface albedo: 1-10 of May 2001.

From east to west, GMS-5, MET-5, MET-7, GOES-8 and GOES-10.

Products produced within SCOPE-CM initiative.

Validation of GSA time series from 1982 – 2006 at temporally invariant desert sites.

Results are indicating full capability of albedo trend detection.

Source
EUMETSAT
Committee on Earth Observing Satellites
Working Group on Climate (WGClimate)

WGClimate was endorsed as a full CEOS WG (joining WGISS, WGCV and WGEdu) and will coordinate and encourage collaborative activities between the world’s major space agencies in the area of climate monitoring.

The Mission of the Working Group Climate (WGClimate) is to facilitate the implementation and exploitation of Essential Climate Variable (ECV) time-series through coordination of the existing and substantial activities undertaken by CEOS member agencies. This includes the numerous iterative steps involved in the creation of ECVs and ensuring ECV life cycle information is gathered, organized, and preserved for future generations.

Chair of CEOS WGClimate
Mark Dowell (EC/JRC)
Vice Chair John Bates (NOAA/NCDC)
Why do we need a Climate Monitoring Architecture?

Three main "needs/usage scenarios" have emerged for a climate monitoring architecture:

A  Assist in promotion of a common understanding of the implementation implications of meeting the various space-related climate monitoring requirements (e.g. from GCOS)

B  To support an assessment of the degree to which the currently implemented systems meet the requirements (and the generation of an action plan to address identified shortfalls/gaps/duplication)

C  To improve our understanding of the end-to-end information flows and dependencies (i.e. from sensing through to decision-making)
State of the Art: Timeline for Ocean Colour ECV

Source: IOCCG
### Gap Analysis EU

#### Essential Climate Variable (mainly Space)

<table>
<thead>
<tr>
<th>8</th>
<th>Gap analysis: Table 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fundamental Climate Data Record</strong></td>
<td><strong>GCOOS Horizon Res. Goal</strong></td>
</tr>
<tr>
<td><strong>Atmospheric</strong></td>
<td>100 km (1 km for extreme events)</td>
</tr>
<tr>
<td>1 Precipitation</td>
<td>Passive microwave radiances, high frequency geostationary IR, Active radar (for cloud)</td>
</tr>
<tr>
<td>2 Earth Radiation Budget</td>
<td>Broadband radiances, spectrally resolved solar radiances, geostationary multispectral imagery</td>
</tr>
<tr>
<td>3 Upper-air Temperature</td>
<td>Passive microwave radiances, GPS radio occultation, high spectral resolution of radiances for re-analysis</td>
</tr>
<tr>
<td>4 Upper-air Wind</td>
<td>VLSR imagery, Doppler wind lidar</td>
</tr>
<tr>
<td>5 Surface Wind Speed and Direction</td>
<td>Passive microwave radiances and scatterometry</td>
</tr>
<tr>
<td>6 Water Vapour</td>
<td>Passive microwave radiances, U/VIS Radiance, TIR imagery (temperature in 6.7um band), Microwave soundings in 183 GHz band</td>
</tr>
<tr>
<td>7 Cloud Properties</td>
<td>VLSR imagery, TIR and microwave soundings, 94 - 100 km</td>
</tr>
<tr>
<td>8 Carbon Dioxide</td>
<td>NBIR retrievals, 160 - 290 km</td>
</tr>
<tr>
<td>9 Methane</td>
<td>NBIR retrievals, 10 - 50 km</td>
</tr>
<tr>
<td>10 Other GHGs</td>
<td>NBIR radiances</td>
</tr>
<tr>
<td>11 Ozone (tropospheric)</td>
<td>U/VIS radiances, E/Microwave radiances, 5 - 50 km</td>
</tr>
<tr>
<td>12 Ozone (stratospheric)</td>
<td>U/VIS radiances, E/Microwave radiances, 50 - 100 km</td>
</tr>
<tr>
<td>13 Aerosol Properties</td>
<td>VLSR/NIR/SHORT radiance, 1 - 15 km</td>
</tr>
</tbody>
</table>

#### Oceanic

| 14 Sea-Surface Temperature | Single and multi-view IR and microwave imagery, 1 km |
| 15 Sealevel | Altimetry, 25 km |
| 16 Sea Ice | Passive Microwave imagery, AMSR-E, AMSR2, SAR, TIR & VIS imagery, 12 - 100 km |
| 17 Sea State | Altimetry, scatterometer, SAR, 25 km |
| 18 Ocean Salinity | Microwave radiances, 15 - 100 km |
| 19 Ocean Colour (TOP + CHL) | Multispectral VLSR imagery, 1 km |

#### Terrestrial

| 20 Snow Cover (Extent, Snow Water Equivalent) | VIS/NIR/SWIR and passive microwave optical imagery, 100 m = 100 km |
| 21 Glaciers and Ice Caps | VIS/NIR/SWIR optical imagery, Altimetry, 30 m |
| 22 Permafrost and seasonally frozen ground | Altimetry, 250 m |
| 23 River Discharge | Altimetry, 10 km |
| 24 Lake level/properties | VIS/NIR optical radar imagery, Altimetry, 1 km |
| 25 Albedo | Multispectral and broadband imagery, 1 km |
| 26 Land Cover | Multispectral VLSR imagery, 250 m |
| 27 IAPAR | VIS/NIR imagery, 250 m |
| 28 Leaf Area Index | VIS/NIR imagery, 250 m |
| 29 Biomass | L Band / F Band SAR, Linear, 10 m |
| 30 Fire Disturbance | VIS/NIR/SWIR/TIR multispectral imagery, 250 m |
| 31 Soil Moisture (surface and root zone) | Active and Passive microwave (scatterometer and SMPSS), 50 km |

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**European**
Architecture Pillars

1. Earth Environment → Sensing
2. Observations → Climate Record Creation and Preservation
3. Records → Applications (Climate and other SBAs)
4. Reports → Decision-Making (Climate and other SBAs)
5. Decisions
**logical view**: represents the requirements baseline as a set of interlinked functions and associated dataflows (i.e. the target). Logical view is as stable as the requirements baseline and, once established, should require little maintenance.

**physical view**: describes how the logical view is implemented, i.e. how close we are to achieving the target. Needs to maintained on a regular basis to make sure it appropriately reflects the prevailing status (will take longer to determine).
Traceable to GCOS Guidelines and GCOS Climate Monitoring Principles

Traceable from ECV Inventory and physical representation of Climate Monitoring Architecture
FCDR Current/Future:
- LDCM
- Sentinel-2
- CBERS

... 

FCDR Past:
- MSS, Landsat
- Spot
- CBERS
- ASTER
- DMC

... 

Landcover Baseline 1990 (?)

Unlikely to be needed
Maybe Landuse

REDD

Anomalies
FAPAR
Fires
Event-based

Nat/Reg summary tables

National blocks

REDD

Ancillary data
Fires
Albedo
Clouds
FAPAR

NB: Continuity in change obligation is on reducing rate

NB: Timescale requirements may not be as strict as for other applications
What is at stake?

- History shows that weather observations did not become useful for society until a lexicon was agreed to
  - The Beaufort scale did this for wind climatology and maritime commerce in the 19th century
- For climate services to benefit society, they must adopt a lexicon that sets expectations for openness, process and transparency that are accessible to the public
  - How might we define a climate record lexicon useful to both scientists and the general public in the 21st century?
**Metrics**

**Maturity Matrix**

- Ultimate ambition – define CEOS “endorsed” Maturity metrics
- Starting point - NOAA effort
- Task within WGClimate, to review/modify => improve
- One size may not fit all
- It is as much a tool to monitoring progress as it is to provide a snapshot of current capability

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<table>
<thead>
<tr>
<th>Collection Methods</th>
<th>Algorithm stability</th>
<th>Metadata &amp; QA</th>
<th>Documentation</th>
<th>Validation</th>
<th>Public Release</th>
<th>Science &amp; Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>How was the data collected, sensors, surveys, etc.?</td>
<td>Are algorithms under configuration management and how mature?</td>
<td>How full and complete are the metadata and quality assessment?</td>
<td>Is the Operational Algorithm Description full, complete, and peer reviewed?</td>
<td>How complete is the validation?</td>
<td>Are the data, algorithms and software open and available to the Public?</td>
<td>How extensive is the peer reviewed literature and how varied are the applications?</td>
</tr>
</tbody>
</table>

**Digital Signature**

**Climate Portal**

[www.climate.gov](http://www.climate.gov)

**Let’s define a Maturity Matrix (1=low; 6=high) that sets expectations and assesses progress**

Source J. Bates
Action T8 [IP-04 T6]

**Action:** Submit weekly/monthly lake level/area data to the International Data Centre; submit weekly/monthly altimeter-derived lake levels by space agencies to HYDROLARE.

**Who:** National Hydrological Services through WMO CHy, and other institutions and agencies providing and holding data; space agencies; HYDROLARE.

**Time-Frame:** 90% coverage of available data from GTN-L by 2012.

**Performance Indicator:** Completeness of database.

**Annual Cost Implications:** 1-10M US$ (40% in non-Annex-I Parties).

Action T9 [IP-04 T7]

**Action:** Submit weekly/monthly lake level and area data measured during the 19th and 20th centuries for the GTN-L lakes to HYDROLARE.

**Who:** National Hydrological Services and other agencies providing and holding data, in cooperation with WMO CHy and HYDROLARE.

**Time-Frame:** Completion of archive by 2012.

**Performance Indicator:** Completeness of database.

**Annual Cost Implications:** <1M US$ (40% in non-Annex-I Parties).

Action T10 [IP-04 T8]

**Action:** Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of lakes in GTN-L to HYDROLARE.

**Who:** National Hydrological Services and other institutions and agencies holding and providing data; space agencies.

**Time-frame:** Continuous.

**Performance Indicator:** Completeness of database

**Annual Cost Implications:** <1M US$ (40% in non-Annex-I Parties).
Table 5: Essential Climate Variables for which satellite observations make a significant contribution (cf. Table 3).

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
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<tbody>
<tr>
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<td>Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature, Wind speed and direction, Water vapour; Cloud properties, Carbon dioxide, Methane; Ozone and Aerosol, supported by their precursors.</td>
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<tr>
<td>Oceanic</td>
<td>Sea-surface temperature, Sea level, Sea ice, Ocean colour, Sea state, Sea-surface salinity.</td>
</tr>
<tr>
<td>Terrestrial Lakes</td>
<td>Snow cover, Glaciers and ice caps, Ice sheets, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Fire disturbance, Soil moisture.</td>
</tr>
</tbody>
</table>
GCOS acknowledged observing networks and systems

Table 13. Observing networks and systems contributing to the Terrestrial Domain

<table>
<thead>
<tr>
<th>ECV</th>
<th>Contributing Network(s)</th>
<th>Status</th>
<th>Contributing Satellite Data</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Discharge</td>
<td>GCOS/GTOS Baseline GTN-R based on TOPC priority list</td>
<td>Stations selected and partly agreed by host countries, non-contributing stations approached</td>
<td>Research concerning laser/radar altimetry for river levels and flow rates.</td>
<td>Operational laser altimeters not scheduled; EO-based network only research.</td>
</tr>
<tr>
<td>Lakes</td>
<td>GCOS/GTOS Baseline Lake Network based on TOPC priority list. To include freeze-up/break-up</td>
<td>Stations selected, approached by HYDROLARE; GTN-L needs to be established</td>
<td>Altimetry, high-resolution optical and radar imagery and reprocessing of archived data.</td>
<td>Operational laser altimeters not scheduled. Question mark over high-resolution systems continuity. EO-based network only research.</td>
</tr>
</tbody>
</table>

Inconsistencies with later text
There are a number of other lake-specific variables needed by the climate modelling community (e.g., surface water temperature) or for climate monitoring purposes (e.g., surface and sub-surface water temperature, date of freeze-up, and date of lake ice break-up). Whenever possible, these variables should be measured by National Hydrological Services and other responsible agencies holding data, in association with measurements of lake level and area, and be submitted to HYDROLARE.

Action T10 [IP-04 T8]

**Action:** Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of lakes in GTN-L to HYDROLARE.

**Who:** National Hydrological Services and other institutions and agencies holding and providing data; space agencies.

**Time-frame:** Continuous.

**Performance Indicator:** Completeness of database

**Annual Cost Implications:** <1M US$ (40% in non-Annex-I Parties).
What to do next?

User defined – product specification (LST, Chl, CDOC ??, Turbidity ??)
User ECV product requirements (spatial/temporal res, uncertainty, stability)
Satellite WP leads implement a processing architecture that is consistent with GCOS Guidelines and GCOS Climate Monitoring Principles

Next revision of GCOS Implementation plan 2015 (draft will start in 2014) – can GloboLakes be ready to contribute to this process for the next revision?

**Target Requirements**

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<th>Variable/ Parameter</th>
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</table>
1. This may seem premature... but it is to the community’s advantage if GloboLake implements a “GCOS compliant” product generation system from the project’s inception.

2. Ultimately this will only work if multiple space agencies agree to start generating these products – although having a “champion agency” is useful.

3. Therefore it is imperative to standardize baseline products and their requirements

4. There are a lot of “chicken and egg” issues

5. Ultimately the a clear definition of a user requirement – product definition/implementatioion iterative loop is the key to success