GCOS

GLOBAL CLIMATE OBSERVING SYSTEM

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Indicators of Climate Change

Outcome of a meeting held at WMO 3 February 2017

GCOS-206

Prepared by the GCOS Secretariat, WMO

"A small number of vital signs and a narrative to go with it will maybe save the world"

(Chris Rapley)

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1. Introduction

This meeting was called by GCOS to consider identifying a core set of climate change indicators to be used as a basis for reporting climate change to the public. The need to inform the public on the range of climate impacts beyond temperature is clear and a small, limited, number of global indicators should, as a set, demonstrate the range and speed of climate change.

Many different bodies are presenting different sets of climate indicators, some of these are listed in Annex 1. There are in general two types of indicator, those describing the physical state of the climate system and its historical development, also sometimes called lagging indicators, and those looking at future impact, risk and adaptation, so-called leading indicators:

- ***Lagging / Historic indicators***: here the need is to identify a small set of essential climate indicators for the purpose of communication of climate change to date. Surface temperature is not the best indicator of climate change as it is a poor overall thermodynamic descriptor of the Earth's energy balance. A broader set of indicators would better describe and communicate the full range of physical climate change over the last 150 years;
- ***Leading / Future indicators***: There is also the need to identify a set of indicators that can be used to inform management of climate change and its societal impacts in the future and which will help in assessing whether policy makers are making the right decisions in terms of mitigation and adaptation. Establishing a set of future indicators requires the involvement of a broader community, including socio-economic experts.

The latest GCOS Implementation Plan was presented to the United Nations Framework on Climate Change (UNFCCC) in November 2016. The UNFCCC encouraged all parties of international organizations to implementing this plan, which includes the development of these two sets of climate indicators. The need for climate indicators and appropriate criteria for them was also discussed in papers at the GCOS Science Conference, Amsterdam, March 2016.

In December 2016 WMO held an internal meeting to discuss a core set of indicators to be used across WMO in reporting and presenting information about historic climate change.

The report of the meeting can be found in Annex 2. A set of historic (physical state) indicators were identified at this meeting, and it was agreed that they should meet the following criteria:

- ***Relevance***: each should be a clear, understandable indicator of global climate change, which has broad impact for a range of audiences. Some indicators will also have national and regional values;
- ***Representativeness***: indicators as a package should provide a representative picture of changes to the Earth system related to climate change;
- ***Traceability***: should be calculated using an internationally agreed (and published) method;
- ***Timeliness***: should be calculated regularly (at least annually) with a short lag between the end of the period and publishing the data;
- ***Limited number***: to allow clear, concise, communication the number of indicators should be limited to less than 10.

In this current meeting, the climate indicators identified by the WMO were presented to a broader audience and the way forward in developing future indicators was discussed.

1.1 UNFCCC

Indicators should support the UNFCCC, its processes and the global stocktake. These indicators need to come from an official source, they cannot be collected by the secretariat from the internet. The UNFCCC has agreed with the WMO for them to submit information through their State of the Climate report without agreement of a specific list of indicators[1]. The IPCC has also been asked to present to the UNFCCC, a "dashboard", in between assessment reports with detailed reports. These should provide a way of assessing progress: answering the question "are we on the right track?". Thus, a set of indicators that is more linked to directly to the Earth's energy balance would be ideal, e.g. top of atmosphere energy balance.

In terms of future indicators, the Paris Agreement has a mitigation goal in addition to the target of limiting temperature increase: this requires global peaking of greenhouse gas emissions (GHGs) as soon as possible, recognizing peaking will take longer for developing country Parties, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of the century (Article 4). Thus, for the convention, atmospheric concentrations of greenhouse gases are the main indicator, but to monitor the whole carbon cycle, it is important to include land use and ocean changes to cover sinks. To demonstrate whether or not Parties are decarbonizing the global and national energy supply systems indicators related to mitigation and socioeconomics are also needed.

Adaptation is an important part of the Paris Agreement: work is on-going with the adaptation committee and the LEG (the Least Developed Countries Expert Group) working together on methodologies to assess adaptation efforts, support and progress towards the goal. Initial signals point to the difficulty of monitoring adaptation with indicators: it may need sectorial monitoring and many indicators.

The UNFCCC is also compiling what relevant information is already being collected, such as vulnerability indices and indices of extreme events: these are important as they directly link to economic and human impacts and therefore to the Sustainable Development Goals (SDGs). By 2018, UNFCCC would like to have climate Indicators which will help to assess progress on UNFCCC and the Paris agreement.

1.2 Communicating Climate Change

The Paris agreement was an important turning point. The world has moved from a discussion on whether climate change was happening to deciding on what to do about climate change. Governments want to know that actions that they take are effective. This poses a problem for climate change scientists as it can take around 30 years to detect change.

The energy balance of the planet has been upset, energy accumulates leading to ice melting, sea level rising, ocean-atmosphere circulation changing, extreme weather changing and floods. These have an impact on food production and ultimately, as a consequence of climate change, people may need to migrate. Indicators need to capture these chains of events.

[1] *"The SBSTA welcomed the submissions from WMO: The Global Climate in 2011–2015 and the WMO Greenhouse Gas Bulletin, and invited WMO to provide submissions on the state of the global climate on a regular basis, as appropriate, at subsequent sessions of the SBSTA."* UNFCCC/SBSTA/2016/4 paragraph 43.

Not only do we need metrics to track changes in a way that is meaningful for humanity, we also need ways to communicate this to the general population. In order to implement policies to address climate change, people have to be persuaded of the importance of mitigation and adaptation measures. Thus, indicators need to capture risk as well as change. Policy makers are often interested in the probabilities of thresholds being exceeded: e.g. planning for a 1 in 200-year event rather than for average increases. Climate change risk assessment is also essential. In general, scientists have concentrated on projections and forecasts rather than on the probability of thresholds being exceeded, on the impacts of these "worst case scenarios", and on how these probabilities are changing over time.

Climate indicators must be useful, actionable, reliable, robust, verifiable and forecastable. However, to communicate information about climate change, these will need to embedded as part of a story that people understand and that they can relate to rather than as single numbers.

2. Indicators of historic climate chamge

The December 2016 WMO meeting discussed and agreed indicators in the following groups: temperature & energy; atmospheric composition; ocean; cryosphere; land use/vegetation change; extremes and human impacts (see Table 1). Annex 2 contains a note on the meeting outcomes. While a single indicator for most of these groups could be identified, additional subsidiary indicators providing additional information were also identified.

The meeting agreed follow-up actions to refine indicators for the cryosphere, biosphere and extreme events. Annex 3 has more recent preliminary inputs on the biospheric indicators. It was also decided that GCOS will hold a meeting with some of its broader community to see if these climate indicators are sufficient or if additions should be considered reflecting their broader expertise.

This meeting fulfils this last requirement by presenting these indicators to a wider (but still limited) audience who did not see the need to add additional indicators. It was agreed that the definition of these indicators should be completed (Action 1).

Action 1	Historic Climate Indicators
Action	Prepare a short note about what has been said today about the historic climate indicators. With input from both the WMO discussion on 15 December 2016 and the current workshop, complete the list of proposed historic climate indicators.
Who	GCOS to facilitate
When	Submit to the GCOS Steering Committee in September 2017.

Table 1. Historic Indicators proposed by WMO

Topic	Headline Indicator	Baseline	Subsidiary Indicators	Notes	Availability
Temperature and Energy	Global surface temperature	Pre-industrial temperatures	Ocean Heat Content, Top-of-the-atmosphere energy balance	The near surface temperature is important for political process, is a target of the Paris agreement, and is well understood by public. Need a more understandable name for top-of-the-atmosphere energy balance	NOAA, NASA, UK Met Office
Atmospheric composition	Atmospheric CO_2 (ppm)	Pre-industrial	Methane, N_2O, hydrogenated greenhouse gases	While mole concentrations are measures this not widely understood: talk about concentrations for wide understanding	GAW
Oceans	Sea Level Rise	1870	Ocean Acidification, Ocean Heat Content	Reconstructed from a combination of tide gauges and satellite altimetry	CSIRO
Cryosphere	Sea Ice Extent	???	Arctic and Antarctic sea ice extent	Arctic and Antarctic ice should be not reported in total as a single number and a second indicator would be needed for the terrestrial cryosphere	???
	Area of land covered by snow and Ice???	???			???
Land use/ vegetation	Area deforested	???		Derived for satellite data	???
Extremes	Heatwaves	???	???	A heatwave index needs to be agreed that reflects duration and increase over normal temperatures (e.g. using percentiles).	WMO CCI?

Notes:
??? indicates that these are items still to be finalized.

Some interesting points related to the historic climate indicators were discussed and should be considered in completing this work.

(a) Indicators:

- Precipitation is a key parameter, related to major climate change impacts such as droughts and floods. However, it is not straightforward to develop an indicator that relates well to these impacts. Projections of precipitation have higher uncertainties than for temperature. This was also noted at the WMO internal meeting but the meeting did not reach a consensus and an action from the meeting was to develop a specific proposal. This meeting agreed this task would be an important addition. One possibility would be to have a statistical quantity related to precipitation extremes.

- The record length and uncertainty of observations should be taken into consideration in identifying indicators.
- Indicators for rates of change can be used as well as the more static ones.
- The of timescale for the indicators needs to be clearly agreed and specified e.g. should sea ice be reported daily or weekly?
- Several data sets on sea ice, glacier mass change, global monthly mean temperature, CO2 trends are already available as graphs, there is now a need to target socio-economic data.
- There is reluctance of statistical agencies that monitor socio-economic data for SDG to get involved in environment statistics.
- A major objective is to harmonize all indicators and their reference baselines. For example, the definition of pre-industrial needs to be clarified. For most indicators, the pre-industrial levels can only be known by proxies so several questions arise: is using proxies acceptable, how can use of proxies be explained, would 1870 be a better baseline?
- It is unlikely that projections of the next 20-30 years will change significantly (e.g. snow and ice will continue to disappear, extremes will change) however ecosystem changes are less predictable.
- It is important to bring into the discussion communities with looking at social aspects climate change, such as the World health Organization, the International Council for Sciences Urban health and well-being program and disaster and risk reduction programmes.

(b) Communication:

- Communication is a very important component of this process. In order to communicate to the general public, things need to be kept simple even if this can lead to a less accurate description.
- Communicating indicators to policy makers is difficult, as indicators are not related to their actions. An example is emissions versus concentration. Concentration is a good indicator for climate, however the policy makers take actions on emissions and therefore there is the need to explain the link between indicators and actions.
- It is also important to get consistent information from different countries and communities especially for extreme events and impacts. Extreme events are the link between past and future and WMO is going to develop a catalogue with definition of threshold so all countries can report the same kind of extremes.

Action 2	Best practice advice communications
Action	Prepare best practice advice on how to communicate the discussed Climate Indicators and the guidelines. This can be used as a mechanism to improve communication to people.
Who	Michael Williams, Chris Rapley, Florin Vladu and any other volunteers from the meeting
When	Submit to the GCOS Steering Committee in September 2017.

3. Generating future indicators

The focus of this part of the meeting was in defining a process for establishing the best future climate indicators rather than looking for a finished solution. The process should establish the best methodologies and practice to identify such climate indicators. The meeting discussed several issues

related to future indicators and agreed on the next step in the process of developing a broadly agreed list of future indicators (see Action 3). The key issues are how to provide advice for policy makers, society, how to go from science data to useful information, what is the best way forward and how to publish the information. The future indicators need to say how well a country is adapting: is it getting better or worse?

Planning for adaptation needs an understanding of future risk and how it may change. For example, planners wish to know what a one in a hundred-year storm would look like in 100 years' time. Planing for future impacts needs an understanding now of worst-case scenarios, e.g. highest possible sea level rise, largest flood or biggest heat wave to guide planning decisions even if they are implemented over future decades.

The Paris Agreement aims for peaking of emissions and then a balance of emissions and sinks and so indicators for these are needed to monitor mitigation. Adaptation can be understood using a risk management framework: hazards, vulnerability and exposure are important along with resilience, mitigation and adaptive capacity. Developing indicators for all these is not straightforward and, while some pieces are starting to emerge from the UNFCCC processes, it is difficult to say what the outcomes will be especially at the global policy level.

There may be several different datasets for an individual indicator. GCOS does not make judgements between different data providers but determines what needs to be measured and its quality. Multiple datasets with similar trends can reinforce each other and give an idea of the uncertainties involved.

Action 3	Workshop on future indicators
Action	Hold a workshop to discuss future indicators. Discussions should cover: needs for indicators and target audiences, agree future steps to secure broad agreement on these headline indicators. To structure the workshop, a small one day meeting could be organized to prepare a focused agenda. Useful information that can be prepared will be: agreed baselines, terminology, examples, links to the Global Framework for Climate Services (GFCS) and to the global scene. Identifying links to communities will facilitate identifying the correct people to be involved in the workshop that will include a broader community able to contribute a broader set of information.
Who	GCOS
When	Hold workshop before end 2017

A range of issues were raised and these should be addressed in the planned workshop:

- Approach
  - One way is to take a stepwise approach: dealing with different communities one-by-one e.g. construction industry: start small and add more indicators later;
  - It may be more useful to provide examples and advice on the information needed rather than trying to produce the data for every situation, (e.g. the construction industry may be more interested in the probability and size in 50-100 years' time of an extreme storm than in the average storm in the future);

  - Another approach is to establish best practices for different communities with examples. This could be done as input into the global stocktake which is a cycle which will learn as it goes along;
  - Two-phase approach is possible – a global overview of how well adaptation and mitigation are being done and a few more detailed examples for one or two topics.
- Involvement
  - The UNFCC has had a workshop on indicators in some areas. Some participants want to measure finances but this is not reliable – spending money may lead to maladaptation. This process is still ongoing;
  - The UNFCCC is organising a series of workshops in developing countries involving the community of practitioners and perhaps it would be a good idea to do organize something back-to-back with these meetings;
  - The IPCC scoping meeting on the next assessment report will consider indicators;
  - Many groups address climate risk management looking at extremes and the impacts of extremes. We should use this work and therefore we need to map out what already exists;
  - Other communities, particularly interdisciplinary bodies, should be involved to get their perspectives;
  - WMO is deciding whether to stick to physical indicators (the traditional focus of WMO), or collect more on risks and impacts as that is what people care about. The biophysical domain is part of the GCOS area of interest;
  - Understanding of future hazards is based on projections: there needs to be a dialogue between observers, modellers and the adaptation and resilience community;
  - The process to identify indicators Should also involve others such as insurance communities. They aggregate the risks of many communities.
- Communications
  - In communicating uncertainty, many scientific terms are not understood by many people. Resiliency and risk management is better understood than uncertainty;
  - UNEP would be happy to transform and present data on its web platform, UNEPLive;
  - There is often confusion on the meaning of the return period for some events. Maybe there is a need to have standard ways of communicating risk;
  - This process cannot define “dangerous climate change” – that is a political/religious/ethical question;
  - Differing baselines is an issue for communications causing confusion and obscuring messages.
- Scientific and technical issues
  - Some uncertainty is irreducible – adaptive planning approaches can take this into account by allowing plans to be modified in the future as short-term outcomes are known;
  - For historic indicators, global indicators make sense. However, for the future ones, data should be more local and relevant. Local is important as it focusses on the population’s concerns and so attracts people’s attention. While the input may be global, the use is local;
  - Is it possible to develop indicators that illustrate the steps between emissions and temperature change (e.g. showing how an emissions reduction of 50% does not stop a temperature rise by same amount)?

- Attribution is interesting: it is a statistical process based on best data record. It needs agreement about processes and engagement with other partners;
- Preparation is important: the scientific community should try to ensure that, in a few years' time, when it is asked to provide data on the indicators needed for the global stocktake it can do so without much extra effort;
- It will be important to understand what is needed. For example, to understand sea level change information on carbon cycle and durability of carbon sinks, isostatic changes and the global energy balance is needed, as well as understanding changes in the ocean. However, communicating this is not easy.

4. Conclusion

The meeting agreed with the criteria identified from the first meeting of 15 December 2016 for the historic indicators and the list of indicators from that meeting.

The outcome of this meeting will serve as input to the meeting which will be held at WMO on 20 February 2017 on the WMO State of the Climate report and to the future meeting planned in Action 3.

The meeting agreed 3 specific actions:

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ANNEX 1: Overview on existing work on climate/adaptation indicators

(a) Joint CCl/WCRP(Clivar)/JCOMM Expert Team On Climate Change Detection And Indices (ETCCDI)

ETCCDI develops indices of extremes than indicators. Currently they provided 27 indices for extremes derived from temperature and precipitation but no definition of indicators yet.

Terms of Reference

- Provide international coordination and help organize collaboration on climate change detection and indices;
- Further develop and publicize indices and **indicators** of climate variability and change and related methodologies, from the surface and subsurface ocean to the stratosphere, with international consensus;
- Encourage the comparison of modeled data and observations, perhaps via the development of indices appropriate for both sources of information;
- Coordinate these and other relevant activities the ET chooses to engage in with other appropriate working bodies including of those affiliated under OPACE-4, WCRP and JCOMM as well as others such as GCOS, CBS, CIMO, CAgM, CHy, IPCC and START; and regional associations[…].

(b) WCRP

At COP22 WCRP (D Carlson) presented indicators for the entire system, mainly based on budgets

- Heat/energy
- Carbon - Co2 and Ch4
- Sea level (heat and water)

“These indicators also have in common that they are assembled and calibrated by large teams of researchers, are open access, are reviewed and published in the Earth System Science Data journal and can be supplied on annual (or at least less than 5 year) timescales.”

(c) WMO

In the WMO Statement on the Status of the Global Climate in 2015 and the Provisional WMO Statement on the Status of the Global Climate in 2016 and the presentation of WMO at COP22 (Omar Baddour), these indicators are mentioned as highlights:

- Temperature
- Precipitation
- Oceanic indicators at surface and sub-surface
- Sea levels
- Greenhouse gas concentrations
- Cryosphere: sea ice, ice-sheets, snow cover etc.
- Major modes of climate variability
- High-Impact/Extreme events
- Humanitarian consequences
- Socio economic impacts

(d) Copernicus Climate Change Service (C3S)

"[…]indicators aimed at supporting adaptation and mitigation policies in Europe in a number of sectors"; "The wealth of climate information will be the basis for generating a wide variety of climate indicators aimed at supporting adaptation and mitigation policies in Europe in a number of sectors."

- Temperature increase,
- Sea level rise
- Ice sheet melting
- Ocean warming

"The portfolio of service products will include consistent estimates of multiple Essential Climate Variables." [and] "A near-real-time climate monitoring facility". Currently the provide some monthly temperature figures and data based on Era-interim reanalysis.
C3S is looking to GCOS for further support on the development of climate indicators.

(e) IGBP (Climate Change Index, consists of 4 indicators) (IGBP closed since 2015, now Future Earth)

"Climate Change Index The IGBP Climate-Change Index provides a snapshot of global climate change. It highlights the general trend by bringing together key climate-change indicators:

- atmospheric carbon dioxide
- temperature
- sea level
- sea ice

"The reference point is 1980 - the earliest date the index has been calculated. The annual change of each parameter (carbon dioxide, sea level, temperature, Arctic sea-ice minimum) is normalised (between 1980 and 2007). Zero is no annual change. One hundred is the maximum-recorded annual change between 1980 and 2007. Minus one hundred is the minimum change between 1980 and 2007. Each year, we take the average of the normalised parameters. This gives the index for the year. The value of the index for each year is added to that of the previous year to show the cumulative effect of annual change. The Climate Change Index is in development and subject to review."

(f) NASA (5 vital signs)

- Carbon dioxide concentration
- Global temperature
- Arctic sea ice
- Land ice
- Sea level

These indicators are also used by UKCIP. Can be monitored live via app.

(g) EPA (USA) (37 indicators, mostly US focused)

Greenhouse Gases

- U.S. Greenhouse Gas Emissions
- Global Greenhouse Gas Emissions
- Atmospheric Concentrations of Greenhouse Gases
- Climate Forcing

Weather and Climate

- U.S. and Global Temperature
- High and Low Temperatures
- U.S. and Global Precipitation
- Heavy Precipitation
- Tropical Cyclone Activity
- River Flooding
- Drought
- A Closer Look: Temperature and Drought in the Southwest

Oceans

- Ocean Heat
- Sea Surface Temperature
- Sea Level
- A Closer Look: Land Loss Along the Atlantic Coast
- Coastal Flooding
- Ocean Acidity

Snow and Ice

- Arctic Sea Ice
- Antarctic Sea Ice
- Glaciers
- Lake Ice
- Community Connection: Ice Breakup in Two Alaskan Rivers
- Snowfall
- Snow Cover
- Snowpack

Health and Society

- Heat-Related Deaths
- Heat-Related Illnesses
- Heating and Cooling Degree Days
- Lyme Disease
- West Nile Virus
- Length of Growing Season
- Ragweed Pollen Season

Ecosystems

- Wildfires
- Streamflow
- Stream Temperature
- Tribal Connection: Trends in Stream Temperature in the Snake River
- Great Lakes Water Levels and Temperatures
- Bird Wintering Ranges
- Marine Species Distribution
- Leaf and Bloom Dates
- Community Connection: Cherry Blossom Bloom Dates in Washington, D.C

(h) NOAA (7 indicators, mostly US focused)

- Global Surface Temperature
- US Surface Temperature
- Sea level
- Global Upper Ocean Heat Content
- Northern Hemisphere Snow Cover
- Glacier volume
- US Climate Extremes

(i) NOAA/BAMS annual State of Climate report

The report includes almost all ECVs, however, they distinguish between fully monitored and partially monitored ECVs. Climate indicators should be fully monitored as in this list:

Atmospheric Surface:

- air temperature
- precipitation
- air pressure
- water vapor
- wind speed and direction

Atmospheric Upper Air:

- earth radiation budget
- temperature
- water vapor
- wind speed and direction

Atmospheric Composition:

- carbon dioxide
- methane
- other long-lived gases
- ozone

Ocean Surface:

- temperature
- salinity
- sea level
- sea ice
- current
- ocean color
- phytoplankton

Ocean Subsurface:

- temperature
- salinity

Terrestrial:

- snow cover
- albedo

(j) European Environment Agency (Climate state and impact indicators, 48 indicators)

Definition

The development of this indicator set has been driven by demands for developing and assessing climate change mitigation and adaptation policies. One group of indicators in this set provides information on the progress towards reducing greenhouse gas emissions reported under the EU Greenhouse Gas Monitoring Mechanism and the UNFCCC. These indicators consider past and projected greenhouse gas emissions by country as well as a sectoral breakdown and an assessment of the performance related to agreed mitigation policy targets. Another group of indicators in this set provides information on past and projected climate change as well as the observed and projected impacts of climate change on ecosystems and society. Some of these indicators describe global climate change, thereby raising awareness and informing climate change mitigation policies and actions. Others trace climate hazards or assess the sensitivity of ecosystems and society, thereby informing adaptation policies.

Indicators

- Production and consumption of ozone-depleting substances Oceans and sea levels
- Global and European temperature Rainfall patterns
- Total greenhouse gas emissions trends and projections
- Production and consumption of ozone-depleting substances
- Global and European temperature
- Total greenhouse gas emissions trends and projections
- Economic losses from climate-related extremes
- Atmospheric greenhouse gas concentrations
- Effects of climate change: Air pollution due to ozone and health impacts
- Production, sales and emissions of fluorinated greenhouse gases (F-gases)
- Soil moisture
- Floods and health

- Arctic and Baltic Sea ice
- Storms
- Global and European sea-level rise
- Precipitation extremes
- Extreme temperatures and health
- Greenland ice sheet
- Snow cover
- Mean precipitation
- Water-limited crop productivity
- Ocean heat content
- Irrigation water requirement
- Species interactions
- Ocean acidification
- Permafrost
- River flow
- Sea surface temperature
- Glaciers
- Forest growth
- Agrophenology
- Vector-borne diseases
- Soil erosion
- Heating degree days
- Forest fires
- Growing season for agricultural crops
- Soil organic carbon
- Distribution of marine species
- Phenology of marine species
- Distribution and abundance of animal species
- Water temperature
- Distribution of plant species
- Animal phenology
- Plant and fungi phenology
- Lake and river ice cover
- River floods
- River flow drought
- Progress to greenhouse gas emission targets

(k) UNEP/GEO Core Indicators

A subset of the environmental Core indicators is dedicated to climate change. This subset includes:

- Carbon Dioxide Emissions - Total (CDIAC)
- Carbon Dioxide Emissions - per Capita (CDIAC)
- Change in Glacier Mass - Mean Cumulative Net Balance

(l) UNEP grid Environmental Data Explorer

The Environmental Data Explorer lists data and data sets relevant for climate change, including datasets on:

- Average Monthly Maximum Temperature
- Average Monthly Maximum Temperature
- Change in Glacier Mass
- Emission of CH4 from different sources
- Emission of CO2 from different sources
- Emission of GHGs from different sources
- Emission of HFCs from different sources
- Emission of N2O from different sources
- Emission of NMVOC from different sources
- Emission of NOx from different sources
- Emission of SO2 from different sources
- Global Average Temperature
- Global Humidity Index
- Global Land-Ocean Temperature Anomaly
- Globally Averaged Marine Surface Annual Mean Carbon Dioxide (CO2) Concentration
- Global Mean GHG in the Atmosphere
- Global Mean Sea Level
- Global Mean Sea Surface Temperature
- Land Area where Elevation is Below 5
- Mean Annual Precipitation
- Potential Evapotranspiration
- Sea Ice Area for different regions

(m) UNEP IRIS (Indicator Reporting Information System) via UNEP Live

IRIS is an online national reporting system that has been developed by UNEP with the support of AGEDI to facilitate reporting at all levels and to make it easier to take stock of the environment. IRIS; however, has not established own indicators but depends on the input of users.

(n) IPCC AR5 list of Climate Change Indicators (WG1, Chapter 1; 1.3)

- Global and Regional Surface Temperatures
- Atmospheric Water Vapor
- Precipitation
- Greenhouse Gas Concentrations
- Severe/extreme events
- Glaciers
- Ocean Acidification
- Ice
- Sea level

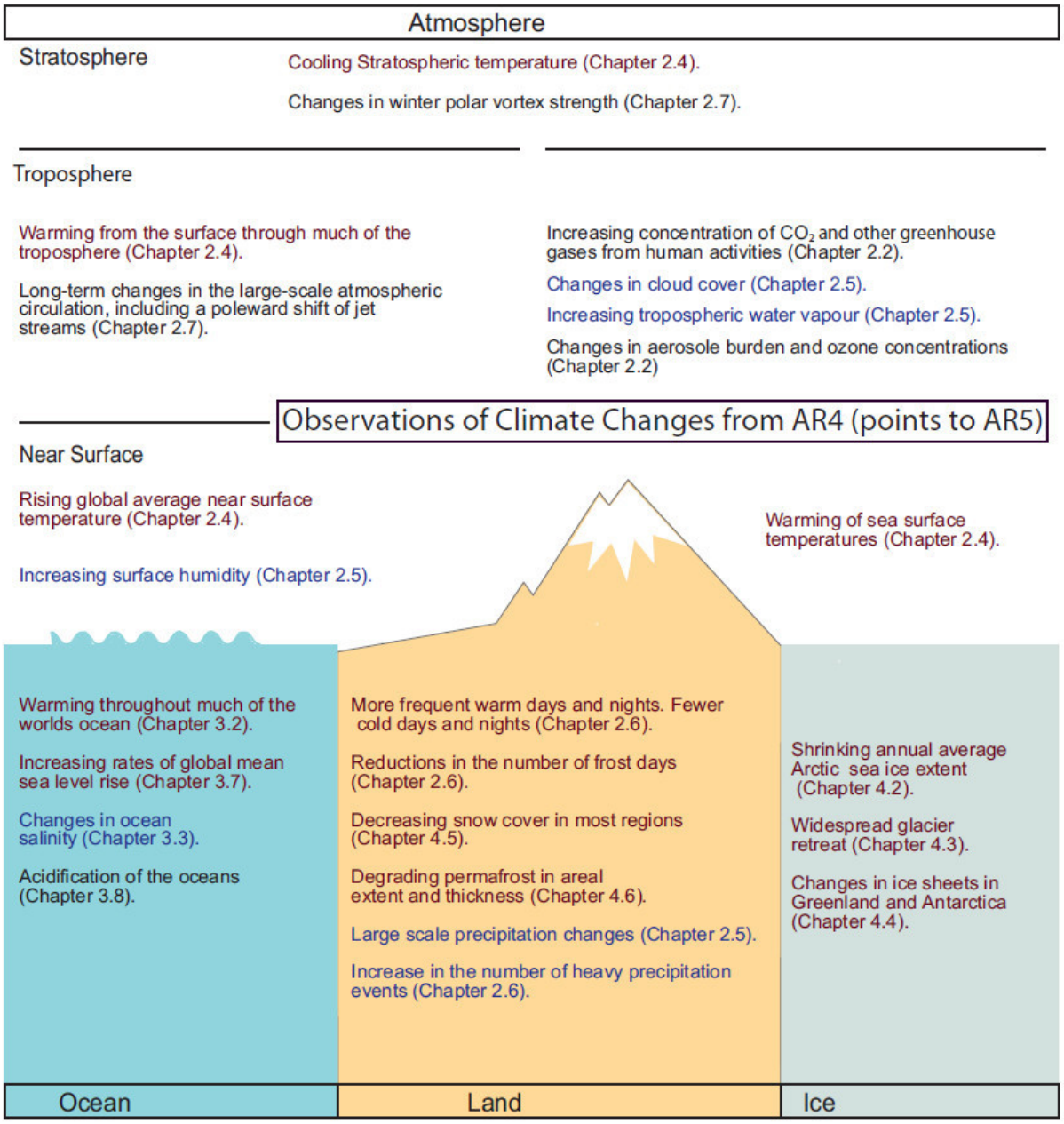

Figure 1. Overview of observed climate change indicators as listed in AR4. Chapter numbers indicate where detailed discussions for these indicators are found in AR5 (temperature: red; hydrological: blue; others: black).

Source IPCC Assessment Report 5 WG-1.

(o) GERMANWATCH (Global Climate Risk index)

The Global Climate Risk Index analyses to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.). The Germanwatch Global Climate Risk Index is an analysis based on one of the most reliable data sets available on the impacts of extreme weather events and associated socio-economic data.

(p) OOPC (State of the ocean indices)

- Global mean sea level from altimetry
- SSTAs of different regions of the Pacific, Atlantic and Indian Oceans

- Subsurface ocean index (Bermuda-Labrador Basin Transport Index, Tropical Pacific Warm Water Volume index)
- Sea Ice Extent
- Ocean Acidification
- Atmospheric teleconnection indices (AO, NAO, PNA, PDO, SAM, SOI, AMO)

(q) Notre Dame Global Adaptation Index

The ND-GAIN is a program of the University of Notre Dame's Environmental Change Initiative. The Notre Dame Global Adaptation Index, or ND-GAIN, ranks the climate adaptation performance for 177 countries over the last 17 years. A country's ND-GAIN score is composed of a vulnerability score and a readiness score. Vulnerability and readiness are based on compiled indicators. 36 indicators contribute to the measure of vulnerability. 9 indicators contribute to the measure of readiness. Each indicator comes from a public data source. Below is the overview of the methodology used to calculate the index score. Detailed explanation of the indicators with references to their sources also can be found below. A technical document provides further information.

(r) Climate Change Health Indicators EPA

- Heat-Related Deaths
- Heat-Related Illness
- Heating and Cooling Degree Days
- West Nile Virus
- Lyme Disease
- Length of Growing Season
- Ragweed Pollen Season

➔ Many groups around the world work on climate change health indicators: Impact of climate change on health is manifold and difficult to limit to one or a small number of indicators.

(s) Eurostat Climate Change and Energy indicators

- Primary Energy consumption
- Gross inland energy consumption, by fuel
- Share of renewable energy in fuel consumption of transport
- Combined heat and power generation
- Energy dependence

➔ For energy the effects of climate change are manifold and differ not only for production and consumption but also in regard of energy source, and technical levels. Therefore it is similar to health difficult to focus on a small number of key indicators.

ANNEX 2: December 2016 WMO Climate Change Indicators Workshop

(WMO Salle C2) 15th December 2016

Attendees:

- Carlos Martin-Novella (IPCC)
- Caterina Tassone (GCOS)
- Filipe Lucio (GFCS)
- Geir Braathen (WWRP)
- Katy Hill (GCOS/GOOS)
- Maxx Dilley (CLPA)
- Michael Sparrow (WCRP)
- Michael Williams (CER) (Chair)
- Paul Egerton (Liaison Office UN HQ)
- Robert Stefanski (CLW/CAg)
- Rodica Nitu (OBS/GCW)
- Simon Eggleston (GCOS)
- Stefano Belfiore (CER)
- Stephan Bojinski (OBS/Space)
- Valentin Aich (GCOS)

Regrets: Carolin Richter (GCOS), Oksana Tarasova (WWRP), Omar Baddour (DMA).

Introduction of draft criteria and audience for Climate Change Indicators by Simon Eggleston

This meeting was called to consider identifying a WMO-wide core set of climate change indicators used as a basis for reporting climate change to the public. The need to inform the public on the range of climate impacts beyond temperature is clear and a small, limited, number of global indicators should, as a set, demonstrate the range and speed of climate change. Indicators for the Sustainable Development Goals (SDG) will be discussed separately in a later meeting as the process needs coordination with other UN entities.

The aim for the climate change indicators is to be agreed headlines for consistent reporting of climate change, more detailed reporting could present a number of subsidiary datasets. It was agreed that one headline indicator should be defined per indicator group and additional supportive indicators can be defined in order to deliver more background information and to take into account different levels of reporting.

There are several different sets of global climate indicators being presented by various organizations – many with specific aims and target audiences, however these climate change indicators are intended for an audience of the interested public and policy makers.

These indicators should meet the following criteria:

- **Relevance**: each should be a clear, understandable indicator of global climate change, which has broad impact for a range of audiences. Some indicators will also have national and regional values;
- **Representativeness**: indicators as a package should provide a representative picture of changes to the earth system related to climate change;
- **Traceability**: should be calculated using an internationally agreed (and published) method;
- **Timeliness**: should be calculated regularly (at least annually) with a short lag between the end of the period and publishing the data;
- **Limited number**: to allow clear, concise, communication the number of indicators should be limited to less than 10.

The climate change indicators submitted before the meeting fell into the following groups: Temperature & energy; Atmospheric Composition; Ocean; Cryosphere; Land use/vegetation change; Extremes and human impacts.

The meeting agreed that policy makers as an audience should be defined on a global level, these indicators cannot address specific adaptation issues which are more locally specific. As impacts are outside of WMO's scope and expertise, it was also agreed that the group on extremes and impacts should be reduced to only provide information on extremes.

It was noted that an indicator for the hydrological cycle would be a useful addition, however, it is unclear what data meets the criteria and is suitable. ***Robert Stefanski will follow this up.***

Discussion of individual Climate Change Indicators per indicator group and agreement on provisional indicators

Temperature and Energy: The near surface temperature important for political process, is a target of the Paris agreement, and understood by public.

The meeting noted that top-of-atmosphere energy balance might be too complicated despite being a measure of the increase in energy of the Earth system: indicators should be understandable to the general public though it is also possible to educate the public. A simpler name for top-of-atmosphere energy balance is needed.

Headline Indicator	Global surface temperature
Baseline	Pre-industrial temperatures
Subsidiary Indicators	Ocean Heat Content, Top-of-the-atmosphere energy balance
Notes	Need a more understandable name for top-of-the-atmosphere energy balance
Availability	NOAA, NASA, UK Met Office

Atmospheric Composition: The meeting discussed that a CO_2-equivalent indicator should be used but difficulties in explaining this and lack of a widely agreed method of estimating equivalences led to CO_2 being selected.

Headline Indicator	Atmospheric CO_2 (ppm)
Baseline	Pre-industrial
Subsidiary Indicators	Methane, N_20, hydrogenated greenhouse gases
Notes	While mole concentrations are measures this not widely understood: talk about concentrations for wide understanding
Availability	GAW

Ocean: The meeting agreed sea level rise should be the ocean indicator.

Headline Indicator	Sea Level Rise
Baseline	1870
Subsidiary Indicators	Ocean Acidification, Ocean Heat Content
Notes	Reconstructed from a combination of tide gauges and satellite altimetry
Availability	CSIRO

Cryosphere: The meeting discussed if one indicator is enough for cryosphere; e.g. sea ice extent and area of land covered by snow and ice. Other possibilities are glacier mass balance, sea ice extent, snow cover. The meeting agreed that Arctic and Antarctic ice should be reported in total as a single number as this would avoid cherry-picking and be more transparent.

Headline Indicator	Sea Ice Extent
Baseline	???
Subsidiary Indicators	Arctic and Antarctic sea ice extent
Notes	
Availability	???

It was also agreed a second indicator was needed for the terrestrial cryosphere and this will be discussed during the GCW steering committee meeting on 20th January. **Rodica Nitu ensure this is addressed report back to the GCOS secretariat for inclusion in the WMO Climate Change Indicator list**.

Headline Indicator	Area of land covered by snow and Ice???
Baseline	???
Subsidiary Indicators	???
Notes	
Availability	???

Land use/vegetation change: This is difficult because not in the core of WMO's expertise, however there was preliminary agreement on deforestation as a climate change indicator. **Simon Eggleston will involve GOFC-GOLD and the GCOS/TOPC community to come up with a main indicator and supportive indicators.**

Headline Indicator	Area deforested
Baseline	???
Subsidiary Indicators	???
Notes	Derived for satellite data
Availability	???

Extremes: This is an important indicator of special interest for public as it relates to the most significant impacts on the population. There are different fields to cover, including temperature extremes, precipitation extremes and droughts. There was agreement on heatwaves as one indicator but the precise definition needs to be refined. **Robert Stefanski will propose indicators on heat waves, heavy precipitation and droughts.**

Headline Indicator	Heatwaves
Baseline	???
Subsidiary Indicators	???
Notes	A heatwave index needs to be agreed that reflects duration and increase over normal temperatures (e.g. using percentiles).
Availability	???

Notes:
??? indicates that these are items still to be finalized.

Next steps

The following actions to be completed by the end of February 2017 were agreed:

- Indicator for hydrosphere needs to be defined (proposal by Robert Stefanski), possibly being included in the indicators for extremes;
- Cryosphere: Rodica Nitu will report on agreement from the GCW Steering Committee meeting;
- Land cover: Simon Eggleston will report from discussion results of GCOS/TOPC panel;
- Extremes: Robert Stefanski will propose indicators on heat waves, heavy precipitation and droughts.

Following these the GCOS Secretariat will revise this document including the proposed climate change indicators and circulate it to the participants. GCOS will also hold a meeting with some of its broader community to see if these are sufficient or if additions should be considered reflecting their broader expertise.

ANNEX 3: Preliminary inputs on biospherical climate indicators

(a) Input from GOFC-GOLD on "Land use/vegetation change"

There was preliminary agreement on deforestation as a climate change indicator. It was agreed that GOFC-GOLD should be able to refine an indicator in this area.

Headline Indicator	Deforestation (area per year)
Baseline	Average of previous 10 years or average of previous decade (i.e. 2000-2010)
Subsidiary Indicators	Broken down by region/major ecosystems and for main change types (i.e. fire), maybe a IPCC Tier 1 carbon emissions estimation
Notes	Derived from satellite data time series using Landsat/Sentinel regular monitoring
Availability	So far only University of Maryland/Global Forest Watch (GFW) is providing annual updates in tree cover loss on a regular basis but that will be a starting point. Integration of data from FAO-FRA will have to be considered. Expectation is that this headline indicator will stimulate monitoring programs (i.e. from ESA/EU) to improve their efforts/services to improve reporting on this indicator over time. Important to note that this indicator could be interlinked with SGD indicator 15.1.1: Forest area as a proportion of total land area. As GCOS TOPC member, GOFC-GOLD is willing to coordinate the establishment of this indicator.

(b) Proposal for a cross-domain biosphere indicator

(Really preliminary) notes for GCOS Climate Change Indicators Workshop
Proposal for a cross-domain Biosphere Indicator
M.Dowell, European Commission, JRC
mark.dowell@ec.europa.eu

Headline: Biosphere and Climate Indicator - the Breath of the Earth, Greening of the Earth

Indicator Rationale: Ideally the indicator should represent a quantity that can be derived equivalently over land and ocean. Ideally this could be NPP/GPP, but this probably still has too many additional uncertainties in their derivation from ECV products, suggestion would be for a photosynthetic absorption coefficient, with could be determined from the available ECVs rather directly. This could be integrated for land and ocean over the growing season or annually. Links can also be made to amplitude of atmospheric CO_2 i.e. the breath (esp. terrestrial), following early and more recent works. E.g. http://www.nature.com/nature/journal/v382/n6587/abs/382146a0.html and http://science.sciencemag.org/content/early/2016/01/20/science.aac4971.

Such an ideally would allow to systematically inform the general public on the interactions and feedbacks between the biosphere and the rest of the climate system and provide an avenue to open discussions on the implications for agriculture, land and ocean resource management, biodiversity and as a consequence the SDGs life below water, life on land. Link also to other UN conventions UNCCD, CBD. Also linked to IPCC WGII.

Traceability/ECVs: based on cross domain datasets for land and ocean, for land the primary data source from ECVs is FAPAR and LAI and for oceans is the Ocean Colour ECV with ECV products for Water Leaving Radiance and Chlorophyll.

Input Data Commitment: for both the land and ocean the ECVs used, there are long-term commitments for the required input data (which is the same for land and ocean). These are covered by the mid-resolution multispectral imagers typical of Sentinel-3/VIIRS class mission and these present in confirmed roadmaps for the next 20+ year a as well as in WIGOS Vision for 2040.

Geographic Scope: the indicator would be produced integrated over the globe, but regional and domain specific assessments could also be considered. These could include, across land and ocean, latitudinal zones, (high-lat, temperate, tropics), for hotspot areas i.e. notable sinks regions in ocean and land and/or for specific land class groupings and ocean biomes.

Timeliness: Indicator could, at a minimum be produced with an annual update (if integrated across growing season) , but seasonal/monthly anomalies could also be produced. The ECV products used are all based on satellite data input and there could be produced very rapidly following the end of giving time period.

Media uptake: Media have picked-up and well-covered recent scientific studies on these topics e.g. see http://www.bbc.com/news/science-environment-36130346.

Additional communication opportunities: the indicator should have a "common scale" across land and ocean, it could be routinely presented with "biosphere animations" i.e. spinning globe of land-ocean greenness (from ECVs), hotspot updates i.e. sink areas and for terrestrial domain integration with land cover data

Follow-up: if there is interest Copernicus (e.g. C3S) and/or JRC could host dedicated workshop. This could include relevant UN agencies and programmes (WMO, GCOS, GOFC-GOLD, GOOS, GEO) other international partners (NOAA, NASA etc.) and members of the scientific community.

ANNEX 4: Participants

1. Stephen Briggs (GCOS SC Chairman) – Chairman of this Workshop, ESA Climate Office, Harwell, UK
2. Jean-Noël Thépaut (Copernicus Climate Change Service (C3S))
3. ECMWF, UK.
4. Dick Dee (Copernicus Climate Change Service (C3S)), ECMWF, Reading, UK
5. Chris Rapley CBE (Invited Expert on request of the Sc Chair, "Planetary Vital Signs")
6. University College London, UK
7. Simon Pinnock WGClimate / ESA Climate Office, Harwell, UK
8. Lucilla Spini (ICSU) Paris, France
9. Pascal Peduzzi (UNEP GRID) Geneva
10. Florin Vladu (UNFCCC), Bonn, Germany (via WebEx)
11. Joanna Post (UNFCC) , Bonn, Germany (via WebEx)
12. Abdalah Mokssit, (IPCC), Geneva
13. Mxolisi Shongwe, (IPCC), Geneva
14. Albert Fischer (IOC), Paris, France
15. Barbara Ryan (GEO), Geneva
16. André Obrégon (GEO Secretariat, Climate Liaison Officer) – Geneva
17. David Carlson (WCRP)
18. Mike Sparrow (WCRP)
19. Oksana Tarasova (RES / GAW, WMO)
20. Michel Rixen (WCRP, GCOS Panel Liaison)
21. Amir Delju (CLPA, WMO)
22. Omar Baddour (CLPA, WMO)
23. Maxx Dilley (CLPA, WMO)
24. Rodica Nitu (OBS/GCW, WMO)
25. Michael Williams (WMO) - Chairman of WMO internal workshop on 15 Dec 2016

GCOS-Secretariat

26. Carolin Richter
27. Simon Eggleston
28. Katy Hill
29. Caterina Tassone

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