Generic Requirements on Climate Monitoring

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presentation on behalf of the Climate Expert Group by Jörg Schulz

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Outline

- Introduction
- Why observe climate? – What is a climate data record?
- Current experience with satellite data
- Evolution of climate monitoring into the Post EPS era
- Associated requirements to produce climate data records
- Preliminary cross mission priorities for climate monitoring
Introduction

- EUMETSAT core mandates are detailed in EUMETSAT Convention and 25 Year Strategy
  - Support to operational meteorology
  - Contribution to operational climate monitoring
- Increasing number of operational instruments provides a major source of sustained long term observations of the Earth’s climate.
- The goal is to fully exploit these satellites to meet the needs of climate change investigators. The network of European Satellite Application Facilities strongly supports the climate mandate of EUMETSAT.
- MTG mission scoping documents do not consider climate explicitly.
- Requirements for climate monitoring are a cross cutting issue of all individual mission proposals.
Why observe climate?

- Providing evidence (or not) for policy action (or not)
- Assessing current climate for infrastructure planning (traditional)
- Assessing climate variability and change including climate change detection and attribution
- Developing and validating climate models
- Validating long range/short term climate forecasts
- Assessing climate impacts
### Why observe climate?

**Contribution of satellite data to IPCC**

<table>
<thead>
<tr>
<th>Temperature Indicators</th>
<th>IPCC (2001)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean</strong></td>
<td><strong>Land</strong></td>
</tr>
<tr>
<td><strong>Lower Stratosphere</strong></td>
<td><strong>Lower stratosphere: 0.5 to 2.5°C decrease since 1979</strong></td>
</tr>
<tr>
<td><strong>Troposphere</strong></td>
<td>* Little or no change since 1979</td>
</tr>
<tr>
<td>Upper</td>
<td><strong>0.0 to 0.2°C increase since 1979 - satellites &amp; balloons</strong></td>
</tr>
<tr>
<td>Low- to Mid-</td>
<td><strong>N.H. Spring snow cover extent: since 1987, 10% below 1966 to 1986 mean</strong></td>
</tr>
</tbody>
</table>

- **1990s warmest decade of the millennium** and 1998 warmest year for at least the N. Hemisphere
- **Marine air temperature: 0.4 to 0.7°C increase since late 19th century**
- **Near-surface**
  - **Sea surface temperature**: 0.4 to 0.8°C increase since the late 19th century
  - **Global ocean (to 300m depth) heat content increase since 1950 equal to 0.04°C / decade**
  - **Widespread retreat of mountain glaciers during 20th century**
  - **Land night time air temperature increasing at twice the rate of daytime temperatures since 1950**
  - **Lake and river ice retreat since the late 19th century (2 week decrease in ice duration)**
  - **Land air temperatures: 0.4 to 0.8°C increase since late 19th century**
  - **Increase in freeze-free season over much of the mid- to high-latitude region**

- **Red: Space-based observations used**

<table>
<thead>
<tr>
<th>Likelihood:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very likely</strong> (probability ≥ 90% but ≤ 99%)</td>
</tr>
<tr>
<td>* Likely (probability &gt; 66% but ≤ 90%)</td>
</tr>
<tr>
<td>? Medium likelihood (probability &gt; 33% but ≤ 66%)</td>
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</tbody>
</table>

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Why observe climate?
Contribution of satellite data to IPCC

Hydrological and Storm-Related Indicators

<table>
<thead>
<tr>
<th>OCEAN</th>
<th>LAND</th>
<th>OCEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOWER STRATOSPHERE</td>
<td>*20% water vapor increase since 1980 (above 18 km)</td>
<td></td>
</tr>
</tbody>
</table>
| TROPOSPHERE | | *
| Water Vapor | upper troposphere: *no significant global trends since 1980; 15% increase in tropics (10°N to 10°S) | |
| | troposphere: *many regions with increases since about 1960 | |
| NEAR-SURFACE | *no systematic large-scale change in tornadoes, thunder-days, hail | *2% increase in total cloud amount over land during the 20th century |
| | **5 to 10% increase in mid-latitudes | |
| | *2 to 3% decrease in sub-tropics | |
| | *2 to 3% increase in tropics | |
| 20th century land surface rainfall | |
| **no widespread changes in tropical storm frequency / intensity during the 20th century | |
| **2 to 4% increase in the frequency of heavy precipitation events in the N. Hemisphere since 1950 | |
| *widespread significant increases in surface water vapour in the N. Hemisphere, 1975 to 1995 | |

Red: Space-based observations used

Likelihood: {
*** Virtually certain (probability > 99%)
** Very likely (probability > 90% but ≤ 99%)
* Likely (probability > 66% but < 90%)
? Medium likelihood (probability > 33% but ≤ 66%)}
What is a climate data record (CDR)?

Climate research is generally based on data collected for other purposes, primarily for weather prediction.

To make these data useful for climate studies, it is usually necessary to analyze and process the basic observational record to create a Climate Data Record (CDR).

A CDR is a series of observations over time that measures variables believed to be associated with climate variation and change.

These changes may be small and occur over long time periods (seasonal, interannual, and decadal to centennial) compared to the short-term changes that are monitored for weather forecasting.

It is usually necessary to construct a CDR from data that span long time scales and sometimes from multiple data sources.
Scientists must characterize and quantify the sensor, spatial and temporal errors of these diverse and frequently large data sets in order to produce a sufficiently accurate time series for studying trends in climate variability and change.

CDRs provide information to:

- monitor change (climate variability and trends) of the Earth’s climate.
- predict change – especially statistical interpretation of forecasts
- input to model re-analyses (note: reanalysis is also a CDR)
- validate climate prediction models and model re-analyses
- understand processes (water vapor-cloud-radiation feedback)
Already have experience of generating climate records from polar orbiters, e.g., MSU/AMSU temperature record or SSM/I total column water vapour.
Current Experience - Problems

- Patching together a series build from several different satellites but with different orbital characteristics.

- Corrections:
  - Orbit decay - satellite gets closer to Earth
  - Diurnal drift - afternoon satellites drift so they come overhead latter in the day (aliasing in the diurnal cycle)
  - Instrument temperature - Conversion into brightness temperature has non-linear dependence on the satellite temperature.
  - Other intra-satellite bias.

- All corrections are uncertain so introduce uncertainty into the CDR → It is better to avoid needing this corrections!
Current Experience – Change in LECT

Courtesy of Simon Tett, UK Met Office
Current Experience – Diurnal-Drift Corrections

Seasonal Climate

Satellite Adjustments

Climate Change

Temperature Anomaly (K)


Courtesy of Simon Tett, UK Met Office
Current Experience – Satellite Intercalibration

DMSP F11 – F13
SSM/I horizontal polarisation

DMSP F11 – F13
SSM/I vertical polarisation

Courtesy of Karsten Fennig, MPI - Hamburg
Evolution of Climate Monitoring

Courtesy of WMO Space Program
## Evolution of Climate Monitoring – The GCOS ECVs

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric (over land, sea and ice)</td>
<td>Surface: Air Temperature, Precipitation, Air Pressure, Surface Radiation Budget, wind speed and direction and Water Vapour Upper-Air: Earth Radiation Budget, temperature, wind speed and direction, water vapour, cloud properties Composition: CO2, CH4, O3, other long lived greenhouse gases, aerosol properties</td>
</tr>
<tr>
<td>Oceanic</td>
<td>Surface: SST, Salinity, sea-level, sea state, sea ice, current, colour, CO₂ partial pressure</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>River Discharge, Water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally frozen ground, Albedo, land cover, FAPAR, LAI, Biomass, Fire disturbance</td>
</tr>
</tbody>
</table>
Evolution of Climate Monitoring

- New sensors will enable the scientific community to provide new methods to derive GCOS-ECVs, e.g., ESA opportunity missions SMOS, Earth Care, etc.
- The next decade will see a transition of the production of essential CDRs from research to operational entities (SAF-network). This will ensure the continuity of the production of long time series with high quality.
- Improved data assimilation techniques will lead to an improved model based re-analyses also producing a CDR.
- Procedures for instrument intercalibration will be applied operationally in real time and also used for archived data.
- The introduction of metrics to evaluate CDRs will provide a way of identifying maturity of data products and science data stewardship approaches. It will also help identifying areas needing improvement.
Sources of Requirements

Specific requirements on climate monitoring within the individual position papers came from:
- IGOS-P Water Cycle Theme Report (IGOS-P Water Cycle Theme, 2003)
- IGOS-P Carbon Cycle Theme Report (IGOS-P Carbon Cycle Theme, 2005)
- GTOS-Plan for Terrestrial Climate (1997)
- Satellite Instruments Calibration for measuring Global Climate Change Workshop Report (Ohring et al., 2002)

Additional Generic requirements came from:
Associated Requirements (I)

- All envisaged missions are relevant for climate monitoring.
- Space operators should obey to the GCOS climate monitoring principles, especially for satellite systems. This will avoid many of the problems discussed before.
- Climate change is slow compared to the lifetime of individual satellite missions. To create CDRs multi-annual to multi-decadal homogenised (free of non climate effects) radiance records are needed. This requires compatibility between old, current and future instruments.
- Data stewardship is necessary to guarantee that a satellite data record can become a CDR. This includes a full traceability of all observations such that propagation of errors can be traced through the processing train.
- Stability and accuracy are two mandatory requirements where stability is of higher importance.
Associated Requirements – Stability/Uncertainty relation

Detecting change

After G. Stephens, 2003
Instrument inter-calibration (simultaneously and successively flying instruments) is needed to substantially reduce uncertainty in multi decadal CDRs. Specific requirements are:
- Significant temporal overlap between successive platforms for proper cross-calibration.
- The provision of a benchmark or reference network would minimise the needed overlap by providing a further static calibration reference.

For trend detection stability of the multi-decadal record is more important than spatial and temporal resolution.

Derivation of geophysical information employing retrieval or model re-analyses must be based on homogenised radiance records.

Development of CDRs requires reprocessing capability at all levels as for instance calibration and retrieval algorithms develop over time.
The use of satellite remote sensing to produce CDRs is a relatively young scientific field. Thus it requires:

- That all raw data and products from all intermediate-processing levels be archived to allow reprocessing according to new aspects when they become available;
- Much additional data, so-called “metadata” which do not directly constitute the measurements but provide essential ancillary information;
- That different research groups need to be working on the same dataset in order that assumptions are challenged and structural uncertainty may be better characterized.
- That researchers need access to raw instruments counts, calibration algorithms and metadata in order to be able to reprocess the measurements according to best available knowledge.
Priority setting is a difficult task because you can't decide if one variable is more important than another.

The individual mission papers set priorities within the framework of the mission. Here cross cutting priorities are defined.

Two categories are used:
- Cross mission priorities are based on the list of GCOS ECVs.
- Feasibility priorities are related to the ability to provide a long record, to fulfil bias and stability requirements, and provide appropriate spatial coverage.

Feasibility priorities are set for polar orbiting and geostationary satellites as well as for in situ system to elucidate the relative benefits.

A combination scheme is used to combine the different priorities into one single priority. Caveat: This may need further development and is for information and stimulating the discussion.
Preliminary cross mission priorities (II)

Priority 1 (Very High):
The observable is listed as a GCOS ECV

Priority 2 (High):
The observable is not listed as a GCOS ECV but improved knowledge led to the conclusion within the individual mission that the observable is important. This is especially applicable for some chemical species as CFCs.

Priority 3 (Medium):
The observable may or may not listed as GCOS ECV but it is very likely that it is a dependent observable, so may be derived from basic climate variables.

Priority 4 (Low):
None of the above.
Priority 1 (Very High):
In 2020 a global record of at least 20 years fulfilling threshold bias and stability requirements exists.

Priority 2 (High):
In 2020 a global record shorter than 20 years fulfilling threshold bias and stability requirements exists.

Priority 3 (Medium):
In 2020 a global record of at least 20 years not fulfilling threshold bias and/or stability requirements exists.

Priority 4 (Low):
All other constellations of the three properties.
The priority setting is not perfect as variables that need more than one system (e.g., rainfall needing LEO and GEO) are not well represented.

Following this approach results of this priority setting for the individual climate systems are (priorities one and two):

Atmosphere (Upper Air): Temperature profile, water vapour total column, top of the atmosphere radiation (net solar and outgoing longwave), solar irradiance at surface, ozone (total column, lower and middle stratosphere) – cloud cover, cloud liquid and ice water content, cloud optical thickness, cloud top temperature, water vapour profile, spectrally resolved thermal radiation, ozone (upper stratosphere).
Atmosphere (Surface): horizontal wind vector over sea – downward short and longwave flux, precipitation accumulation.

Ocean: sea ice coverage, sea level, sea surface temperature – ocean colour, sea ice (thickness, drift, surface temperature, sea state, surface salinity.

Terrestrial variables: snow cover – surface albedo, land vegetation cover.

Priorities have been set individually for high latitudes; all priority one variables are important at high latitudes.

Priorities have been set individually for ocean and land for atmospheric variables to fully reflect value of in situ systems but differences in priorities are marginal.
Conclusion

- For the first time requirements on climate monitoring have been considered explicitly in mission planning.
- Requirements for climate monitoring are of different quality than other mission requirements. They are mostly concerned with the consistency of satellite missions over decades.
- Requirements on stability of the measurements, means to make data sets free of non climate variations, and data stewardship are the most important.
- The preliminary priority setting reflects those requirements in a reasonable way.