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DRAFT

GMES CLIMATE SERVICE:

TOWARDS A EUROPEAN KNOWLEDGE BASE IN SUPPORT OF MITIGATION AND ADAPTATION

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1 INTRODUCTION

The changing climate has been accepted worldwide as one of the main challenges of our century. Consequently policy and decision makers and industries are concentrating on reducing the extent and magnitude of change through reducing main assumed causes of the change (mitigation) while at the same time developing strategies in order to cope with unavoidable changing conditions (adaptation) of our planet.

Climate change is a real and overarching challenge. The dominant processes occur throughout the entire earth system and the resulting consequences for the natural environment have an impact at all spatial scales from individual, local to global, and all temporal scales from short-lived extreme events to long-term climate trends and low-frequency variations. Finally, the effects of climate change are manifested across all economic and societal dimensions.

With GMES (Global Monitoring for Environment and Security), the European Commission has begun to sustain and enhance an observations infrastructure that is complementary to the existing operational and research observation infrastructure. At the same time it is crucial to build the analysis tools that will permit the comprehensive monitoring of land, atmosphere and ocean (the entire earth system) utilising these combined infrastructures.

A recent study[1] foresees increases in the volume of climate data of one order of magnitude every 12-15 years due both to the increase in space-based observations and climate model simulations. In 2005, a study of the socio-economic value of earth observation in atmospheric sciences estimated the costs of operational centres exploiting space based and *in-situ* observations to be approximately 5% of the total investment in the observational infrastructure[2], which in turn is estimated by the Global Climate Observing System (GCOS) to be € 3.5-5.0 billion per year[3]. Given the importance of climate change, the existing scientific uncertainties in its understanding and its potential impact, together with the considerable investments into observational infrastructure for earth observation it is of paramount importance to ensure proper stewardship of climate information for the future and to encourage the development of applications that more optimally exploit these investments. According to the Stern Review[4] the benefits of actions to combat climate change outweigh the investment costs. Knowledge of the best available global and regional descriptions of the earth system therefore serves the urgent need of policy and decision makers to decide on effective and sustainable measures for mitigation and adaptation.

The WMO Global Framework for Climate Services (GFCS)[5] defines Climate Services as "climate information prepared and delivered to meet users' needs", indicating that Climate Services have to be user driven and secondly that they have to be flexible to be able to react to evolving user needs.

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[1] Jonathan T. Overpeck, et al. Science 331, 700(2011)
[2] Anthony Hollingsworth et al., Q. J. R. Meteorol. Soc. (2005), 131
[3] http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf
[4] The Economics of Climate Change, The Stern Review, Nicholas Stern, Cabinet Office - HM Treasury (2007)
[5] WMO Position paper on Global Framework of Climate Services

2 USER NEEDS AND CLIMATE QUALITY

GMES services are expected to support both users at European and national levels, either directly or through the development of downstream applications. For the Climate Service, the primary users will be the European and national actors in European Union Climate policy development. At the European level this is the responsibility of the European Commission Directorate General Climate Action (DG CLIMA). European policies are in the end executed at national, regional and even local level. Consequently additional requirements may also come from the public institutions in the Member States responsible for policy execution at all levels. At the member state level National Meteorological Services are already advising their governments on climate and expect to continue to do so in the future. This is one of several examples of how the GMES Climate Service will have to complement and interact with existing services and activities.

In 2009 the Commission White Paper "Adaptation to climate change: Towards a European framework for action"[6] sets out a framework for the EU and the Member States. The White Paper states that "*a considerable amount of information and research already exists, but is not shared across Member States. An effective way to improve knowledge management would be to establish a Clearing House Mechanism (CHM) as an IT tool and database on climate change impact, vulnerability and best practices on adaptation. The CHM would also rely on geographical information provided by GMES*". The White Paper states that climate information includes both observations and model results. The adaptation CHM aims to enhance information structuring and sharing, by combining consistent scientific information on impacts, vulnerability, risks and adaptation. At the same time it will promote the effective use of this knowledge by offering tools and guidance on best practice for the assessment of vulnerability at different geographical scales. The CHM is under development by contractors on behalf of DG CLIMA. The first stage of the service development is due to be operational in 2012 at which point it will be transferred to the European Environment Agency (EEA) who will host and maintain the Clearinghouse.

A common requirement of all users is products with sufficient precision and accuracy to meet their needs. The ambition of the GMES Climate Service must be to provide information products which are of climate quality i.e. products that together are capable of meeting the first three goals of GCOS:

- Monitoring the climate system
- Detecting and attributing climate change
- Assessing impacts of, and supporting adaptation to, climate variability and change.

How to meet these goals has been extensively debated in the relevant international fora and is best encapsulated by GCOS monitoring principles[7] which have been variously endorsed by the

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[6] Commission of the European Communities, White paper COM (2009) 147 final on 'Adaptation to climate change: Towards a European framework for action'.

[7] http://www.wmo.int/gcos/ Climate Observation needs

World Meteorological Organization (WMO), the Committee on Earth Observation Satellites (CEOS) and the Conference of the Parties (COP) to the United Nations framework Convention on Climate Change (UNFCCC).

In terms of content, climate quality products for the 50 GCOS Essential Climate Variables (ECVs) are by definition fundamental components of any Climate Service, including the GMES Climate Service. As started by GCOS:

- All ECVs are required to support the work of the UNFCCC and the IPCC (Intergovernmental Panel on Climate Change)

- All the ECVs are technically and economically feasible for systematic observation

- International exchange of these variables is required for both current and historical observations.

GCOS defines the climate quality standards for each of the ECVs and the goal of the GMES Climate Service should be to ensure that the climate service products covering the ECVs meet these standards.

While ensuring provision of the majority of the ECV products is essential for climate system monitoring, detection and attribution of climate change and assessing the impact of and supporting adaptation to climate variability and change pose additional requirements:

- Climate quality monitoring products need to be of sufficient length, normally a minimum of 30 years to be able to detect trends and longer, 100 years plus, to be of value in attribution studies and determining the frequencies of extreme events and any changes thereof

- Studies of climate change impact normally utilise indicators

- Adaptation to climate change and variability requires additional information, on for example vulnerability;

- Mitigation studies require information on anthropogenic emissions of the climate modifying agents, and projections of these emissions in the future.

These requirements motivate the need to define the role for the Climate Service for the period 2014-2030 so that it can add value to existing climate information, and create an optimum environment for the use of historical observed information and deliver consistent products with maximum quality for the downstream applications.

Even if the Climate Service will benefit from the current climate and operational numerical weather prediction activities a strong research component has to be included in order to increase the product quality and to apply new methods to historical data. It is obvious that the Climate Service has to evolve with technological and scientific developments as well as the evolving requirements. In this context the traditional research to operations paradigm is not applicable and the Climate Service therefore needs to be flexible enough to adapt to the iterative injection of new research into the service at variable intervals. Therefore the requirements in the early “setup phase” of the Climate Service will be different from the later years, when a comprehensive set of updated climate information should be provided at regular intervals, each set of products benefitting from the user feedback, results and developments since the previous.

There is a need to provide guidance and expertise, to train people on the use of climate information and its associated uncertainty, and to provide generic tools to build the bridge between the climate information and the users' need. It does not imply that the GMES services should address all needs (agriculture, fisheries, …), but it should provide guidance about what can be done and with whom.

3 PRODUCTS AND TOOLS FOR MONITORING POLICIES

The combined European Climate Service infrastructure, of which the GMES Climate Service will be part, must provide a unified and consistent framework for climate data and information products, whether produced by the GMES Climate Service *per se* or from existing national, European and international infrastructures.

The elements, which the combined service must deliver, are:

(1) A climate **monitoring** service providing integrated and cross-calibrated climate quality data sets from both observations and models

(2) A next generation **re-analysis** using historic data to better characterise and interpret past, recent and current changes

(3) A **portal** for climate impact indicators providing global and European climate trends, which give a more informed indication of what changes are occurring faster than predicted and where they are occurring

(4) A **process for delivering consistent sets** of observational data for climate model initialisation, together with emissions projections to support seasonal and decadal prediction as well as for validation of climate projections, as well as access to the projections themselves

(5) An **attribution** service which delivers tools and results for interpretation of extreme events in terms of climate change or other causes.

In more technical terms, the combined European Climate Service should concentrate on:

- Data integration and climate monitoring: To integrate observational sources from satellite and ground-based measurements in order to systematically contribute to the development of value added climate monitoring products (focusing on GCOS ECVs) and climate impact indicators. This includes recovery, logging and digitally archiving of historical records, their homogenization as well as reprocessing of satellite products. These tasks need to be prioritized and carried out in international collaboration. In particular:
  - Development of tools to help users understand correlations between physical climate metrics and impact metrics
  - Common benchmarking assessments of data sets and models

  - Tools to validate and cross calibrate multiple data sets
  - Tools to support users in nesting and downscaling applications
  - Create suites of visualisation tools to sub-sample in space and time, including presentation of uncertainty information
  - Application of ECVs and/or enhanced integrated observational products, to climate change model evaluation and verification of both hindcasts and projections. This will in particular support the major international initiatives (WMO-GFCS) and national programmes.

- Earth system re-analysis (including the interactions between Atmosphere, Ocean, Land, etc) at global scale with downscaling at the European scale. This will go beyond existing re-analysis projects to provide a truly integrated re-analysis, which incorporates full exchange and interaction between land, ocean and atmosphere. Earth system re-reanalysis will, by using the latest data assimilation methods together with the integrated observational data, generate important improved historical climate records for several ECVs. The historical records also serve as validation data and initial states for climate model integrations and provide a benchmark for sustainable records for the future policy development and implementation. The re-analysis monitoring of ECVs and other products (trends, means, anomalies) provides an important resource for climate monitoring.

- Gridded climate impact indicators: For environmental impact policy development and implementation there is a recognisable need to improve the historical records of impact indicators. There is a recognisable need to convert site-specific records of relevant indicators into gridded datasets covering data sparse regions. The resulting gridded data will be directly applicable to adaptation policy development, particularly in sector specific areas. Providing topic specific indicators like for example forest fire potential would support policy needs more directly.

- Attribution information products: To provide a significant step in linking Disaster Risk Reduction work with identified Climate Change through information on how likely high impact environmental disasters are attributable to natural climate variability or human-induced effects. This will help quantify enhanced risk of future high impact environmental events due to climate change. Adaptation strategies are best developed through an improved understanding of how predicted future changes relate to the observed past and recent variability and changes, either natural or due to human influence. Although individual events cannot be attributed unequivocally to climate change, a system to quantify enhanced risk of extreme climate states and severe weather can be developed using a combination of climate change modelling and historical (> 100 years) climate records.

The elements of the above services that will need to be provided by the GMES Climate Service are largely dependent upon the ability of the existing infrastructure to sustain and enhance existing contributions. The actions proposed for the GMES Climate Service will thus vary from:

- publicising and providing access to those sustainable climate quality contributions to the service from the existing infrastructure

- to sustaining and enhancing existing contributions as appropriate, where sustainability and/or climate quality are not yet guaranteed

- setting up and providing for the entire contribution where it is technically proven but not yet provided for by the exiting infrastructure

- supporting research into the development of feasible methods for delivering climate quality contributions to the service where no such methods currently exist.

The GMES Climate Service will provide the latest products up to the present day and regularly updated with a time delay in generation and availability as appropriate. It will also provide public access to products and observations while respecting national and international data policies, and provide tools to explore the information.

4 ACTIONS

4.1 Actions on Essential Climate Variables (ECVs)

At the European level there are major programmes, which provide products and services and which are relevant to climate monitoring across the Earth system compartments. These are the various EUMETSAT Central applications and distributed Satellite Application Facilities including Climate Monitoring (CM-SAF), which altogether generate products relevant to 17 ECVs and the European Space Agency Climate Change Initiative (ESA-CCI), which addresses the production of 11 ECVs with plans to extend to 3 additional ones. The GMES Climate Service will need to interact with these activities in order to ensure continuity, further development and quality control of products fit for climate monitoring. The accepted standards for data access, continuity and quality are captured by the GCOS climate monitoring principles[8] and the EC by virtue of having signed the UNFCCC. The proposed actions that the GMES Climate Service will need to take to secure the provision of ECVs at European and global scale are listed in Table 1 in Annex 2.

4.1.1 Atmosphere

A large portion of the atmospheric ECVs can be considered to be provided for GMES as a part of the core mission of the European Meteorological Infrastructure. Several ECVs are intrinsic to global atmospheric re-analyses (cf. JRC Report[9]). Re-analyses ensure the physical consistency between different ECVs and thus can provide consistent climate datasets for downstream applications.
Some direct involvement of the GMES Climate Service will nevertheless be required to ensure the provision of climate quality data records from these observational infrastructures. In addition to the cross compartmental activities of the EUMETSAT-SAFs and the ESA-CCI the GMES precursor service MACC (Monitoring Atmospheric Composition and Climate) also contributes towards the development of Atmospheric ECV datasets. For now they only provide a very limited range of products fit for climate monitoring purposes. This is primarily due to insufficiently long time periods of records. Wherever possible these datasets have to be increased in length to be close to or exceed 30 years in length. Monitoring Greenhouse Gases

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[8] http://www.wmo.int/pages/prog/gcos/index.php?name=ClimateMonitoringPrinciples

[9] J.Wilson, M. Dowell, and A. Belward. European capacity for monitoring and assimilating space-based climate change observations – Status and prospects. EUR 24273 EN - 2010

is an obvious area for improvement. It is also important to remember that many surface atmospheric variables are also key land surface parameters (precipitation, radiation and near-surface air temperature) for terrestrial applications.
Where there are several sources of products covering many of the atmospheric ECVs, the GMES Climate Service provides an opportunity for assessment of their quality with the goal of developing and sustaining improved climate quality products. Assessment results should be used to improve the quality of next generation ECVs. Since the re-analysis datasets provide a continuous description of climate from pre-satellite to satellite era, the validation products can also be used to assess the re-analysis product quality throughout the period.

4.1.2 Marine

Effort is needed to work on longer re-analysis covering several decades. This requires an effort of data rescue and development of historical datasets for physical, biological and chemical ECVs. All the available data should be collected, archived and shared. Although progress has been made on recovery of the ocean historical datasets, continuing efforts in data rescue, digitization and data sharing are needed. The measurements from space for selected variables (ocean colour, Chlorophyll-a concentration) do not yet meet the GCOS requirements, specifically in term of accuracy. For these variables several products exist and are available in the GMES Marine project MyOcean, but there is no consensus on their quality and there is a need to build some quality assessment in this field. These are key observations for the ocean of tomorrow, and already now policy requirements for coastal areas, acidification, resources and GHG are necessary. Full access to at least the GLOSS Core Network of tide gauges remains to be achieved. More timely and complete data sharing within the ocean water survey community is desired especially to achieve higher quality sea level information.

4.1.3 Terrestrial

Important requirements are already outlined by considerations on the Global Component of the GMES Land Monitoring: In particular, with respect to Kyoto reporting, it is stated that '*terrestrial ecosystems are the largest single source uncertainty in the global carbon budget*'[10]. In order to attain the goal of reducing uncertainties in the global carbon cycle several key parameters need to be consistently integrated into a global environmental modelling system. Similarly the capacity to monitor the global water cycle is crucially linked to observing water stocks in forms of snow, glaciers, ice sheets and land water bodies. Variation in these stocks may contribute to sea-level rise, which is the second most important effect of global warming. Cryosphere ECVs and water reservoirs need sustaining and operational space/in-situ verification.

The space and *in-situ* components of the observing system need to be linked as they both contribute to the accuracy of the products. In-situ observations are essential as i) independent datasets to validate and calibrate the quality of space observations, ii) as independent monitoring datasets, and iii) as part of the integrated system observing climate change variables. Their long-term sustainability needs to be protected.

[10] IPCC Fourth Assessment Report: Climate Change - 2007

Sustained *in-situ* measurements are required for river discharge, lake levels, snow water content, permafrost active layer thickness & soil temperature, soil carbon, soil moisture, and water use because they cannot be inferred from remote sensing operations. All ECVs require continued *in-situ* measurements for validation and calibration of satellite products. Refined satellite products must be validated with concurrent ground conditions and cannot rely on less exact, older satellite products. These in situ measurements must be conducted at representative sites at sufficient number.

For upscaling of in-situ measurements and downscaling of national statistics (e.g. fossil fuel emissions, water use for irrigation, forest biomass, land use, land cover) it is necessary to support international efforts to develop a common terminology and definitions of sample classes and accounting schemes.

4.2 Actions on re-analysis

Reanalysis has come to be seen as an iterative process, where developments in four areas are needed: modelling, data-analysis techniques and computing power are used together with new data. New observation systems improve our future look, but especially new historical data from rescue efforts produce a succession of reanalyses of increasing quality. Currently, major European effort on re-analysis comes from the experience and expertise of the meteorological community. ECMWF produces the 3rd generation global re-analysis activity (ERA-Interim), which is now populated from 1989 to present day. ECMWF also coordinates the next generation re-analysis project, ERA-CLIM, with a number of European national Meteorological services. ERA-CLIM and ERA-Interim benefit from the analysis and model developments since ERA-40, in particular in the assimilation of satellite radiances. Through three decades of Numerical Weather Prediction (NWP) development and feedback from the scientific community reanalyses have now achieved the qualities required for climate change studies. Reanalyses conducted in Europe have so far been global. A new regional European reanalysis project EURO4M works to provide more precisely reliable information about the state and evolution of the European climate. By closely monitoring European climate, its variability and change can be better assessed and predicted. The global reanalysis is used as the boundary condition in EURO4M and therefore the improvements in the global reanalysis contribute to the quality of regional reanalysis. Similarly ocean reanalyses need the atmospheric reanalysis to force the ocean model together with observations.

The components of hydrological cycle, land surface interaction and surface analyses have improved over several areas. Equally modern analysis schemes during the data sparse historical periods have demonstrated their capabilities to add value to non-observed areas. 15 years ago temperature trend estimates from reanalysis were poor, but since ERA-40 the trends have become comparable to those based on observations only. Currently ocean reanalyses are carried out after each main atmospheric reanalysis. It has been shown that by improving reanalysis quality better forcing for the ocean models has been obtained resulting in better quality ocean products. But as it is also obvious that an improvement for the atmospheric reanalysis will be achieved from an improved ocean surface interaction, doing the reanalyses separately slows overall progress. To faster improve the quality of ECVs and quality of all downstream applications coupling of the models is beneficial. It would also mean integration of atmospheric and marine observations into the same data stream. The same integration should be done for the products to increase the use of these data.

A coupled Atmosphere – Ocean – Land - Ice/Snow – Hydrological Cycle – Dynamical Vegetation model in the reanalysis model should be the long-term target for GMES Climate Service. The development of such a model will be a significant research requirement within this service. The key actions are to sustain global re-analysis after 2013 when ERA-CLIM finishes and European regional downscaling after early 2014 when EURO4M finishes. In parallel also actions to extend coupling are needed.
Because of its important role in the hydrological cycle, it is worth mentioning that precipitation is not analyzed in the global reanalysis, but is produced during the model integration. However in the European downscaling actual high resolution precipitation observations are used.

4.3 Actions on impact indicators

Impact indicators have evolved from simple ECV statistics such as global temperature or precipitation averages to more complex ones. Demand is for cost information, more accurate extreme statistics and higher resolution localized application specific information. GMES Climate Service will have great potential to add value to this area of the already vast variety of climate services and research.

There are limits to deriving indicators as some change parameters like wheat yields or some animal or tree species abundance are not directly related to ECVs, but some application specific indices (like forest fire potential, aviation turbulence or winter road conditions) are. In an initial phase indicators to be derived by the GMES Service are those that can be calculated from one or many ECVs in a straightforward manner. These could even be integrated into reanalysis computing runs for timely and efficient production of information and related statistics (including trends).

For additional, more complex, indicators it is foreseen that downstream applications are required to implement more intelligent algorithms for relating ECVs to the indirect impact indicators. To contribute to this process the Climate Service will need an efficient and user-friendly statistics tool for Climate Service output information.

4.4 Actions on access to climate prediction[11] data

At the European level, future development plans will have to incorporate climate information at all time scales from history to a few decades into the future. DG CLIMA's ClearingHouse Mechanism effort to share all climate change related information across the EU is yet to prove itself, but it is clear that also the value of a GMES Climate Service depends on having climate prediction information available. Otherwise the downstream applications are left short of crucial information to make meaningful assessment of climate change. Under the UNFCCC auspices WMO is arranging a Global Framework for Climate Services (GFCS) with climate prediction being a key ingredient. The European meteorological infrastructure is preparing its action and a coherent approach would benefit Europe the most. For IPCC Assessment Report 5 research includes the Coupled Model Intercomparison Project 5 run by the US (Lawrence

[11] Here we follow the IPCC and WMO terminology: "Forecast" for a short-time period of less than a month, "Prediction" for a climate forecast of between seasonal and decadal time-scale, "Projection" for a climate forecast of beyond decadal (to centennial and beyond) in time-scale, "Scenario" is a term used to describe anthropogenic GHG emissions for a period into the future, used as constraining conditions for IPCC model runs.

Livermore National Lab) providing technical means for all modelling centres to share their output data. Many necessary parts therefore exist. A common decision in Europe is yet to be formed to combine IPCC efforts with more practical user demand.

It is known that climate prediction information from all stakeholders in Europe is already a huge pool of data with significant growth in the future. GMES Climate Service data should include climate predictions enabling the access and ability to process data, and lowering the barrier to downstream users.

4.5 Actions on attribution

Attribution is the process of establishing the most likely cause for a detected change with some level of confidence. It seeks to determine which external forcing factors have significantly affected the climate, where external forcing factors are agents outside the climate system that cause it to change by altering, for instance, the radiative balance or other properties of the climate. The major factors are considered to be anthropogenic external forcing factors including increases in greenhouse gases and changes in atmospheric aerosol concentrations. Attribution products are developed using a climate model to determine the expected response to a particular climate forcing. Model projections are performed with different climate forcings; i) with natural forcings (solar radiation and geological factors) only; ii) with natural and anthropogenic forcings. Differences in the projections can then be attributed to the effect of anthropogenic forcing. With an increasing number of climate change impacts being reported, many related to extreme weather, an objective method of distinguishing actual impacts is needed. An Attribution Service will provide a significant step in linking Disaster Risk Reduction with Climate Change through information on whether high impact environmental disasters are attributable to natural climate variability or non-natural effects. This will help quantify enhanced risk of future high impact environmental events due to climate change, and provide a useful tool for evidence based climate change adaptation policies.

5 INFRASTRUCTURE

5.1 Satellite observations

Satellite monitoring capacity for climate monitoring has been analysed in the 2009 report by JRC[12]. It recommends raising climate monitoring to a much higher priority in future satellite mission planning.

The global observing system contains a lot of operational and research missions that constitute today's potential for climate monitoring. To cover the needed ECVs several components of the global observing system need to be better sustained in the future. This is in particular true for research missions that serve a specific scientific purpose but not necessarily a monitoring application. A highly complementary system consisting of the GMES space infrastructure, operational meteorological missions and specific research missions is the most promising way to achieve consistent product quality over long times which is key to many climate applications. Sustainability is often best achieved in multipurpose mission concepts that take

[12] J.Wilson, M. Dowell, and A. Belward. Ibid.

specific climate monitoring requirements into account, thereby following the GCOS Climate Monitoring Principles. In cooperation with non-European space agencies Climate Services need to support this for other satellite systems. Regular reanalyses and production of ECVs are integral parts in improving the exploitation of satellite data. Europe should take a role in continuing the infrastructure needed for the satellite data and their use. The historical satellite data together with derived ECVs and user applications can also support the definition of requirements for the planned new missions.

All in all it would be very beneficial to identify and carry out a user requirements review process to feed the climate monitoring requirements to the GMES space component. GMES Climate Services have to impose their requirements into the multipurpose Sentinel missions and other complementary multipurpose missions, such as the operational meteorological missions. EUMETSAT is expected to play a role for atmosphere and ocean requirements and it would seem beneficial to expect the same for climate.

5.2 In-situ observations

The main global surface based observations are radiosonde and surface stations around the world. These can be either used directly to estimate the atmospheric ECVs or indirectly through data assimilation together with all satellite data. The Climate Service will need to rely on the WMO for the global exchange of national observations and for the European exchange of national observations on EUMETNET coordinated programmes such as EUCOS (EUMETNET Composite Observing System) and ECA&D (European Climate and Assessment Dataset).

For the historical observations Climate Service will rely on international collaboration. The collection of observations and their digitization programmes in Europe and worldwide are fundamental. The planned Global Reference Upper Air Network (GRUAN) should be supported to provide benchmark profile measurements for comparison with satellite. The in-situ observations as well as aircraft data provide a key anchoring data for the bias adjustments carried out within data assimilation and therefore are important elements in derivation of climate quality ECVs.

For atmospheric composition, data from different networks should be combined to achieve an optimal coverage and to facilitate assessment of the needs for improvement. Likewise data availability from multiple networks to users needs to be facilitated. In Europe the Research Infrastructure projects ICOS (Integrated Carbon Observing System) and IAGOS (In-service Aircraft for a Global Observing System) begin to form into more operational observation providers. This process needs to be supported for operational status upgrades and close to real time dissemination.

For oceanic ECVs the international ARGO network is essential to form the basis for most subsurface variables. In Europe the EuroARGO research infrastructure is to be supported to be able to sustain 25% of this global system as a justified share for Europe to carry. Also the deep ocean mooring station network EuroSITES is essential to have fixed point verification sites with long time series. Also ICOS includes an oceanic centre for carbon related ECVs that are not in EuroARGO and/or EuroSites.

5.3 Supercomputing facilities, Data portals and clearing houses

The computing infrastructure needs are also increasing for network and data handling capacity. As a crucial part the GMES Climate Service should provide advanced data mining (KDD - Knowledge Discovery in Data) and visualization tools adding to the necessary processing power and network capacity. The climate data holdings are spread out in several institutes now. So a comprehensive database including data mining tools should be developed to contain all observed information for each new generation of observations. Various database concepts should be explored such as the EUMETNET showcase portal EUROGRID[13], or the European Virtual Observatory[14], developed and used currently to manage and explore astronomical datasets. There should be a possibility to add information to the database on datum level from models and downstream applications e.g. feedback data (QC, departure) from the data assimilation systems and ECVs from different sources. This will increase interaction between climate service components, improve the product quality and help to reduce redundancy.

There is a need to provide input to the DG CLIMA funded activity to develop an EU Clearinghouse Mechanism on Adaptation (CHM). This will be an information storage structure to be populated with data on both monitoring and projections. The ESA-CCI, WMO-GFCS programme, GMES, FP7/Climate and other data sources are contributing and are expected to contribute more data information in the course of the development phase by the contractor and thereafter for maintenance by the EEA.

5.4 Governance and operation

Governance of a GMES climate service is challenging, because there exist several global international and European frameworks with differing scopes and organisational backgrounds. The Group on Earth Observation and the World Meteorological Organisation have global efforts to shape partly overlapping actions to enable observation based information provision. Overlap is not a negative issue as GEO aims to achieve a system of systems GEOSS under which many of the WMO efforts like GCOS, GFCS, WCRP and others are accredited. Still the leading requirements process is diffused a little. GMES is safe to follow at least the GCOS requirements and their respective governance process as these are acknowledged by both GEO and WMO. The ultimate customer is the UNFCCC.

The development of an operational GMES Climate Service, will involve the EC in the operational support of several European organisations with their own Member States, charters, statutes and rules. In designing the funding mechanisms for the operational services, finding a balance between the financial support of these organisations by the EC for the provision of said operational services, and the involvement of the EC in the decision making processes relating to the provision of the same operational services, within the organisations, will be very important.

A second feature of the European situation is the prior existence of several consortia providing services to *inter-alia* the other GMES services, the EUMETSAT-SAFs, the ESA-CCI and DG RTD funded consortia that are actively developing new indicator and attribution

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[13] http://www.e-grid.eu/public/

[14] http: //www.euro-vo.org/pub/

methodologies. In preparing the future GMES service it will be important to respect both the prior existence of expert consortia for particular service elements (such as individual ECV records, global reanalyses, regional reanalyses, climate predictions etc) and the need to provide for and encourage flexibility in the composition of the consortia, allowing members to join and leave as appropriate.

Thirdly the GMES Climate Service will need to be sufficiently flexible to be able to adapt to the evolution of users needs over time

The GMES Climate Service will thus need a centralized governance structure to deal with:

i. Scientific analysis of the evolving needs of the service users and the capabilities of the current service providers to meet these needs

ii. Liaison with and co-ordination of the pan-European actors among the service providers (ESA-CCI, EUMETSAT-SAFs & Central Facilities, ECMWF, EUMETNET) to ensure concurrence between the GMES Climate Service and their own activities

iii. Formulation of calls for the provision of GMES Climate Services

iv. Evaluation of the tenders to the above calls

v. Evaluation of the performance of service providers in meeting the users needs for the services.

These tasks should be covered by the European Commission, in particular taking into account DG-CLIMA's political mandate and responsibility, DG-JRC's technical and scientific expertise, and DG-ENTR's overall responsibility for the GMES programme.

6 CONCLUSIONS

Information derived from the application of Earth Observations for the monitoring and assessment of climate change must sufficiently describe the current and historical status of the Earth environment from national to global scales and from essential climate variables (ECVs) to impact indicators. It should also provide tools to develop European and national climate change policies to monitor policy implementation, and to provide information on attribution of high impact events such as recent European heat-waves, cold winters, and flooding. A range of spatial- and time-scales should be considered to provide systematic, up-to-date credible information for climate change impact, assessment, policy and attribution strategies to reduce the anticipated detrimental environmental and socio-economic impact of climate change.

It is proposed that a GMES Climate Service should comprise the following initial service elements:

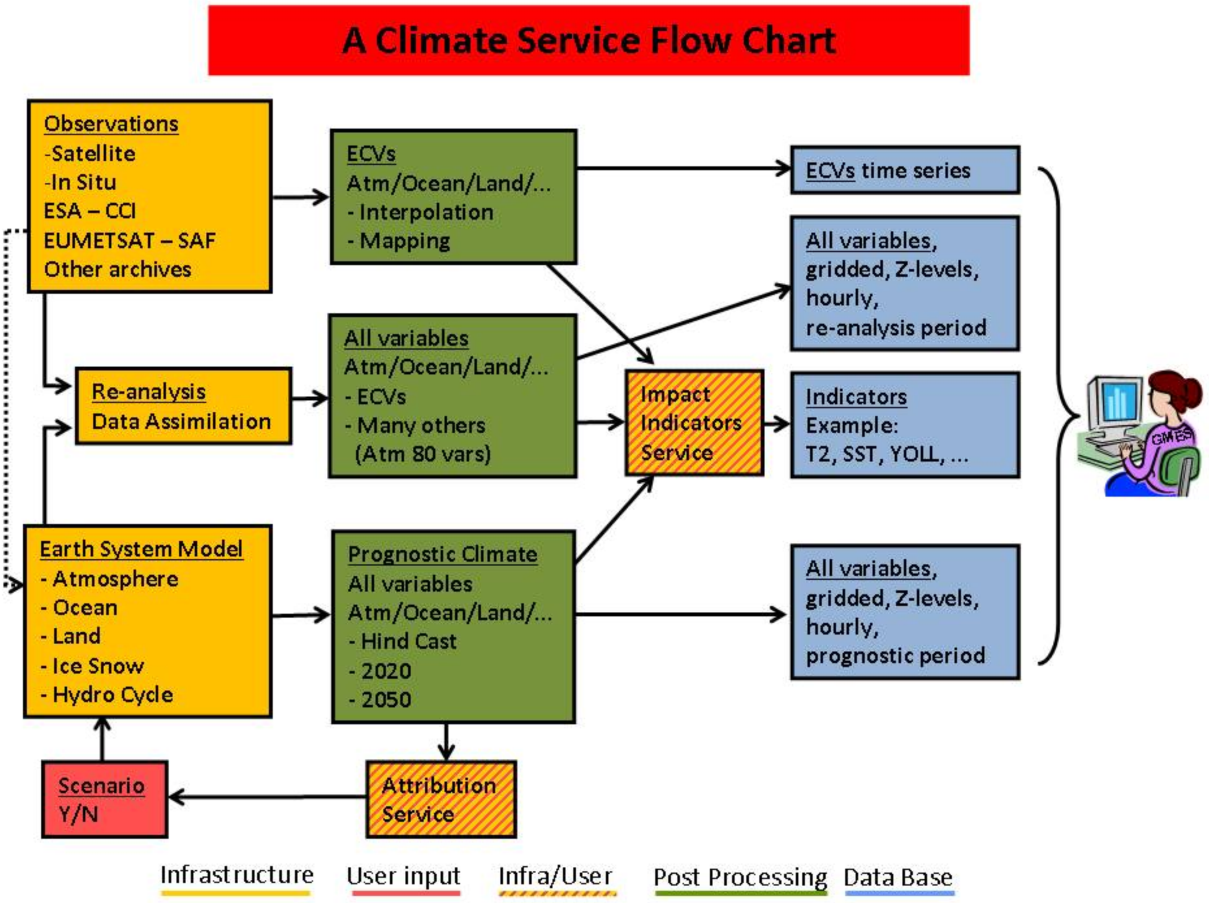
- **Data integration** from various sources and **climate monitoring**
- **Re-analysis** of the Earth system (with interactions between Atmosphere, Ocean, Land Services, etc)
- **ECVs** quality control and assessment through targeted activities

- Climate **prediction/projections**
- Gridded climate **impact indicators**
- **Attribution** information products
- Gridded GHG **emission inventories**.

It is essential that any GMES Climate Service respects, supports and coordinates effectively with the major global initiative on the development of a Global Framework for Climate Services (GFCS) in order to avoid duplication. The GFCS is in the process of submitting its recommendations to the UN agency WMO for endorsement by Governments at the WMO Congress in June 2011. It is expected that one of the key objectives of the GFCS will be the development of climate projection products and services to support countries around the world for developing adaptation initiatives.

In conclusion, the above elements of a GMES Climate Service will substantially support (in combination with other major climate prediction service initiatives) Climate Change impact, mitigation and adaptation action assessments, policy development and policy monitoring for Global, European and national users. It will also be an important asset for the academic community, and the development of downstream sector specific, regional and local climate application services. Finally, with appropriate development and support tools, this will become a useful tool for the public.

ANNEX 1 FLOW CHART



ANNEX 2 LIST OF ECVS

From the GCOS Web site:

The Essential Climate Variables (ECVs) are required to support the work of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority. Currently, there are 50 ECVs.

ATMOSPHERE (over Land, Sea, and Ice)

Surface: Pressure, Air Temperature, Precipitation, Surface Radiation Budget, Water Vapour, Wind Speed and Direction

Upper-air: Cloud Properties, Earth Radiation Budget, Temperature, Water Vapour, Wind Speed and Direction

Composition: Aerosols properties, Carbon Dioxide, Methane and other Long-Lived Green House Gases (N_2O, CFCs), Ozone, Ozone and Aerosol Precursors (NO_2, SO_2, HCHO, CO)

OCEANIC

Surface: Carbon Diozide Partial Pressure, Current, Ocean Acidity, Ocean Colour, Phytoplankton, Sea Ice, Sea Level, Sea State, Sea Surface Salinity (SSS), Sea Surface Temperature (SST)

Sub-Surface: Carbon, Current, Nutrients, Ocean Acidity, Ogygen, Salinity, Temperature, Tracers, Global Ocean Heat Content (?)

TERRESTRIAL

River Discharge, Water Use, Ground Water, Lakes, Snow Cover, Glacier and Ice Caps, Permafrost, Albedo, Land Cover, Fraction of Absorbed Photosynthetically Active Radiation, Leaf Area Index, Above Ground Biomass, Fire Disturbance, Soil Moisture, Soil Carbon, Ice Sheets

Table 1. Actions for the GMES Climate Service to secure provision of ECVs.

[Table to be completed with help of ESA, EUMETSAT, Pascale]

ECV	access	sustain	set-up	Research	**ECV**	access	sustain	set-up	research
Surface Air temperature	X				Phytoplankton				
Wind speed and direction	X				Sub-surface temperature				
Surface Water vapour					Sub-surface salinity				
Surface Pressure					Sub-surface current				
Surface radiation budget					Nutrients				
Precipitation					Sub-surface Carbon dioxide partial pressure				
Upper Air Temperature					Ocean acidity,				
Upper Air wind speed and direction					Oxygen				
Upper-air Water vapour,					Tracers				
Cloud properties,					River discharge,	international distribution of data restricted			remote sensing
Earth radiation budget (including solar irradiance)					Water use			international statistics, gridded data	
Carbon dioxide,					Groundwater	international distribution of data restricted	GTN-GW	sparse in some regions	
Methane,					Lakes	international distribution of data restricted	HYDROLARE		
Other long-lived greenhouse gases,					Snow cover	X	depth	snow-water-exquivalent archive	
Ozone					Glaciers and ice caps		WGMS, GTN-G		in-situ measurements, glacier

									inventory
Aerosol,					Ice sheets		PARCA, ITASE		ice thickness, mass
Aerosol & Ozone precursors					Permafrost		GTN-P	denser network	model of landscape consequences
Sea-surface temperature,					Albedo	X			
Sea-surface salinity,					Land cover (including vegetation type),	X			resolution, wetlands
Sea level,					FAPAR	X			accuracy
Sea state,					Leaf area index (LAI)	X			accuracy
Sea ice,					Above-ground biomass			Earth Explorer	X
Surface current,					Soil carbon	X	repeated surveys		frequency distributions of soil characteristics
Ocean colour,					Fire disturbance		GFMC		biomass burnt parameters, accuracy (radiative power)
Surface Carbon dioxide partial pressure,					Soil moisture			X	moisture in greater depths
Surface Ocean acidity									

ANNEX 3 ACRONYMS

AMIP	Atmospheric Model Intercomparison Project
ARGO	Array for Real-time Geostrophic Oceanography
CCI	Climate Change Initiative (ESA)
CEOS	Committee on Earth Observation Satellites
CHM	Clearing House Mechanism of DG-CLIMA
CM-SAF	Climate Monitoring - Satellite Application Facility (EUMETSAT)
COP	Conference of the Parties
CORINE	Coordination of information on the environment
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variables
EEA	European Environmental Agency
ERA-40	European Re-Analysis project (1957–2002)
ERA-CLIM	European Re-Analysis of global CLIMate observations
ERA-Interim	ECMWF Re-Analysis in preparation for the next-generation extended reanalysis to replace ERA-40.
ESA	European Space Agency
EU	European Union
EUCOS	EUMETNET Composite Observing System
EUMETNET	Network of European Meteorological Services
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EURO4M	European Reanalysis and Observations for Monitoring
EUSC	European Satellite Centre
FAO	Food and Agriculture Organization (United Nations)
FLUXNET	coordinates regional and global analysis of observations to measure the exchanges of carbon dioxide (CO2), water vapour, and energy between terrestrial ecosystems and the atmosphere.

FP7	Seventh Framework Programme of the European Commission
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GHG	Green House Gas
GLOSS	Global Sea Level Observing System
GMES	Global Monitoring for Environment and Security, EU Commission
GRUAN	GCOS Reference Upper-Air Network
GTOS	Global Terrestrial Observing System
IAGOS	In-Service Aircraft for a Global Observing System
ICOS	Integrated Carbon Observation System
IPCC	Intergovernmental Panel on Climate Change
KDD	Knowledge Discovery in Data
MACC	Monitoring Atmospheric Composition and Climate
NWP	Numerical Weather Prediction
QC	Quality Check (here by observation screening for data assimilation)
SMOS	Soil Moisture and Ocean Salinity
UN GFCS	Global Framework for Climate Services
UNFCCC	United Nations Framework Convention on Climate Change
WCRP	World Climate Research Programme
WDC	World Data Centre
WMO	World Meteorological Organization
WMO GAW	Global Atmosphere Watch