JPI CLIMATE WORKSHOP ON EUROPEAN OBSERVATION NETWORKS-REPORT

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Final version

High-quality, long-term observation networks are the backbone for the validation of Earth System Models and the understanding of climate processes as well as for setting-up operational climate services. Europe has a strong added value through its capacity to coordinate observing networks, to enhance spatial coverage and increase visibility compared to national levels. Moreover, through its capacity to coordinate activities, Europe can play a leading role at the international level.

This workshop has gathered experts on marine, atmosphere, biosphere, cryosphere components of the climate system to promote active collaboration between the data users and their providers, and investigate possible further European coordination. The workshop has emphasized the need to improve accessibility of data, to close the gap between models and observations and to build an international system of standardised and sustained observation systems.

The participants consider that JPI climate can play an important role in strengthening observational networks by bringing the communities together and by supporting collaborative actions and sustainability. The workshop participants recommended more specifically to prepare a roadmap for collaborative activities on identified needs, to foster interactions between modellers and data providers, to support targeted actions and promote European participation to international activities.

I- Introduction

Europe is at the forefront for establishing operational climate services and developing Earth System Models for future IPCC reports (e.g. CMIP6 inter-comparison). High-quality, long-term observations (ground-based in-situ and remote-sensing observations) are the backbone for the validation of Earth System Models (ESM) and the understanding of climate processes as well as for setting-up operational climate services. Therefore, it is crucial to ensure that the European long-term observing systems meet the needs and criteria of the climate/Earth system modelling and have the capabilities to provide seamless data flows to the operational climate services. In addition, collecting and harmonizing the observational research data for the various multidisciplinary research communities is of fundamental interest. Currently, national, European and international institutions associated with transnational initiatives, monitoring programs and research infrastructures are strongly involved in long-term observing systems aiming at providing the data that are needed within the full scope of the services.

JPI Climate gathers 16 European countries and the respective national funding organizations to collaborate and align their activities in the field of climate and climate change research. JPI Climate aims at being a catalyst and an interactive platform to bring together all relevant European actors to discuss on the topical matters related to the provision of climate information. The JPI Climate module "towards decadal prediction" organized a 2-day workshop in Paris on "the role of the European long-term observing networks" to promote active collaboration between the data users and their providers, and investigate possible further European coordination.

The sessions around the Earth system focused on marine, atmosphere, biosphere, cryosphere components and emphasized needs for climate services. They aimed at assessing: (i) the requirements from the Earth System Modelling (ESM) communities and from the operational climate services for the long-term observing networks, (ii) the quality and quantity of available data, and their main gaps, (iii) a more efficient use of observational data in applied research and services and, (iv) the establishment of seamless connections towards the ESM and climate service providers.

The goals of the workshop were to strengthen the collaborative work on long-term observing systems through the reinforcement of the dialogue between climate data providers and users in order to analyze the possibilities for JPI Climate to provide further support for the observing systems on the sustainability challenge. During these 2 days, 39 participants from 10 European countries discussed together in plenary and group sessions to address 3 major challenging questions:

- Can we develop a common vision as to long-term observing services within the European scientific community?
- What are the needs from the users' communities regarding the observation networks?
- How to improve the coordination of observational networks in Europe?

At the end of the workshop, relevant recommendations have been suggested as reported below for a better European coordination of Climate Observation Systems.

II- Summary of plenary sessions

After a brief introduction by Philippe Bertrand about the support from the French CNRS-INSU to the JPI Climate initiative, Sylvie Joussaume and Sanna Sorvari presented the objectives of the workshop. Then, 12 speakers addressed major topics related to modelling and perspectives of earth system, atmosphere, ocean, ecosystem and cryosphere. In addition, a multi-disciplinary approach was addressed as well as the available satellite data and Copernicus services.

Earth system modelling – Veronika Eyring (VE)**,** *Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany*

The Coupled Model Intercomparison Project (CMIP) has been a major, very successful endeavour of the climate community for understanding past climate changes and for making projections and uncertainty estimates of the future in a multi-model framework. CMIP has developed in phases, with the simulations of the fifth phase (CMIP5) now completed. In her talk, VE described the new design and organization of CMIP and the suite of experiments in its next phase (i.e., CMIP6) with a focus on Earth System Model (ESM) evaluation. The evaluation of ESMs with observations is crucial for model improvements and a better process understanding of the climate system. It is also a vital prerequisite for trustworthy climate projections to be used for policy guidance. While progress has been made in ESM evaluation with observations over the last decades, there are important opportunities and challenges for CMIP6 which were discussed in this presentation. Requirements for the long-term observing network, main gaps, and opportunities for a more efficient use of observational data in ESM evaluation towards the establishment of seamless connections with the ESM community have been reviewed.

Adressing multi-disciplinary approach – Werner L Kutsch, *Director General of ICOS RI and Coordinator of ENVRIplus*

European environmental research infrastructures (RIs) are long-term facilities, resources, systems and related services that are used by research communities to conduct top-level research in their respective fields. They are designed as long-term entities to meet the requirements of continuous environmental observation. Furthermore, they are “single-sited” “distributed” and/or “virtual” infrastructures. Each environmental research infrastructure has its own particular set of science questions, defined environmental challenges for what purposes it provide its RI services; however every research infrastructure is also providing its data and services and most of the RI have a well-developed e-infrastructure component.

The broader landscape of environmental RIs contributes to the wider, trans- and interdisciplinary science questions and grand environmental challenges regardless of the particular field of interest of single RIs. Therefore, there are many issues that most of the RIs share, for example instrumentation, data collection, preservation, quality control, integration and data availability, as well as providing the computational capability to perform the analyses of interest to researchers (or vice versa). Moreover, whilst each RI is separately concerned with the integration of data within its domain of interest, it is also imperative to find robust yet lightweight means to integrate data and RI services across RIs to serve an increasingly multidisciplinary scientific community. The H2020 project ENVRIplus aims at providing common solutions for these shared problems. It builds on the FP7 project ENVRI and clusters 21 infrastructures from the environmental field.

Although the grand environmental challenges are defined much broader (e.g. Rockström et al. 2009), some infrastructures are focussing on the fields that are also in the interest of JPI Climate:

- the global Carbon Cycle (e.g. ICOS, IAGOS, LTER, AnaEE, SIOS, FixO3);
- concentrations of GHG in the atmosphere and their fluxes between the atmosphere and land and ocean surfaces, respectively (e.g. ICOS, IAGOS, FixO3);
- fluxes and concentrations of aerosols and other trace gases as well as cloud formation (e.g. ACTRIS);
- impact of climate change (e.g. LTER, AnaEE, EUROARGO, SIOS).

Further efforts are needed to connect the observation and experimentation data to integrated modelling efforts as provided by the modelling RI IS-ENES. In addition, international cooperation in the framework of IPCC, WMO, GCOS, GEO etc. needs to be further developed.

Modelling the atmosphere –Hendrik Elbern and coworkers, *University of Cologne, Germany*

In atmospheric chemistry, model set-ups remain incomplete, due to the quasi unlimited number of chemical compounds, and the manifold processes, impinging on them. With hundreds of constituents per grid point, and small scale earth surface characteristics acting on them, the control of the system proofed critical and depends on comprehensive measurement systems. Accordingly, spatio-temporal data assimilation methods are introduced in the realm of atmospheric chemistry simulations, benefitting from the increasing wealth of direct and remotely sensed earth observation data. However, the question remains, to what extent existing and scheduled measurement systems serve to control model simulations and help to provide significant chemical state analyses and, perhaps more importantly, surface flux assessments of related processes. Given the observation network this presentation placed this problem mathematically in the context of system observability, which provides an avenue for the identification of observed and unobserved/unobservable sections and processes.

Atmospheric data and perspectives – Andreas Petzold **,** *Forschungszentrum Jülich, Germany*

Understanding the global distribution patterns of climate-active air constituents and reducing the uncertainty of climate predictions crucially requires data from an integrated system of long-term observation infrastructures, both as boundary conditions and for the evaluation and improvement of model parameterizations. The pressing scientific issues of a changing climate further require an integration of existing infrastructures to constrain feedback mechanisms by detailed trace gas and aerosol observations, and to evaluate products from global chemistry-climate models. Across Europe, existing research infrastructures address routine atmospheric observations of greenhouse gases, reactive trace gases, volatile organic compounds (VOC), aerosols and clouds by in-situ networks (ACTRIS, ICOS, InGOS) including the use of tall towers and flux towers, by remote sensing networks (active and passive) for profiling (ACTRIS, InGOS), and by instruments operated on board of in-service aircraft (IAGOS). This presentation outlined the set of atmospheric composition data which is provided by these networks. It has discussed links to the air quality monitoring networks and highlight current efforts towards real-time provision of data and towards the development of inter-infrastructure data products and services particularly in the framework of ENVRIplus.

Modelling the Ocean – *James Orr, Laboratoire des Sciences du Climat et de l'Environnement (LSCE) , Institute Pierre Simon Laplace (IPSL), CEA-CNRS-UVSQ, Gif-sur-Yvette, France.*

Different ocean modelling approaches require different types of data. Virtually all ocean model efforts use modern-era physical and biogeochemical data sets to initialize and evaluate simulations. Modellers often rely on annual and monthly mean climatologies. Such data is used heavily for ocean components of 'coupled' models (climate or earth system models), even though the quality of future projections may well be disconnected from their quality assessments based on modern mean states and variability. Forced ocean models, typically hindcasts over the last 60 years, are further linked to their forcing data sets (atmospheric reanalyses, e.g., ERA40). Conversely operational ocean models, which are used to make 2-week forecasts, require dense real-time initial conditions. There are large differences in data requirements between global and regional models, in terms of necessary data density and frequency. Global-scale forced and coupled model simulations over the next decade and beyond will be largely carried out within the international framework of the Ocean Model Intercomparison Project (OMIP). That includes both physical and biogeochemical components, part of the Coupled Model Intercomparison Project (CMIP6), whose protocols and data requirements are under definition. Ocean modellers rely on traditional ship-based data such as from repeat hydrography programs (e.g., temperature, salinity, nutrients, carbon, chemical tracers), volunteer observing ship (VOS) data (e.g. for pCO2), remotely sensed data (e.g., temperature, salinity, winds, SSH, ocean colour), and autonomous floats and gliders. The latter are driving a revolution in how physical ocean models are being assessed, namely with the ARGO float program, with about 4000 floats currently spread across the global ocean. A parallel revolution in biogeochemical ocean modeling may be possible thanks to the recently initiated ARGO-BGC and BIO-ARGO projects if those current pilot studies can be diversified and increased dramatically. Another recent critical international effort is the elephant seal tag program that has dramatically enhanced data density and seasonal coverage over the Southern Ocean, even under sea ice, for salinity, temperature, chlorophyll, oxygen, and soon perhaps for pH. Other ocean acidification data, both chemical and biological, is being collected in the recently launched Global Ocean Acidification Observing Network (GOA-ON), information crucial for modelers to assess impacts from ocean acidification. In summary, operational oceanography modeling will continue to require that dense global data streams be maintained and improved, i.e., from satellites (SSH, SSH, OBP, Winds, ocean color), floats, gliders, and ships. Models in general will require improved data for bathymetry and atmospheric reanalysis. Hindcasts (forced) and projections (coupled) will require improved estimates of momentum fluxes (scatterometer missions), rainfall, latent and sensible heating, relative humidity and fluxes through sea ice. It is critical for carbon cycle assessments that satellite missions for ocean color be maintained over the next decade and beyond. Efforts must also be redoubled to improve currently poorly constrained estimates of surface level and vertical penetration of shortwave radiation, which are critical to model ocean circulation. Traditional ship-based measurements of passive chemical and biogeochemical tracers (e.g., CFCs, SF6, C-14, surface pCO2, interior ocean and carbon, as well as pH, must be maintained to track the evolution of changes in ocean ventilation and uptake of carbon.

Marine data and perspectives – Jean-François Rolin & Fabienne Gaillard, *Ifremer, Brest, France*

Collection of marine data has been slowly reoriented from the strict expeditionary tradition of oceanography to the time series acquisition over a significant spatial coverage required by climate studies. Two examples can illustrate this promising tendency: ARGO profiling floats and thermosalinograph on ship of opportunity (Global Ocean Surface Underway Data). The need of decadal description by in-situ measurements is a prerequisite to predictions. The buffer role of the ocean even pushes towards accurate deep water series of temperature, salinity and other tracing parameters. Data management issues for the ocean are widely addressed although in disorder by many initiatives and actors. A French initiative well integrated in a wider Earth Environment data management shows a way of improvement. The Research Infrastructure landscape in Europe takes benefit from EC support and national decadal funding on Lagrangian (EUROARGO ERIC) and Eulerian (EMSO ERIC) in-situ observation. The limitation for a better description of essential climate variables such as pH, pCO_2 and alkalinity comes from the lack of maturity of buoy based or immersed instruments. Several projects are underway on sensors but a wide automated implementation is not expected before 4-5 years. The priority in the marine field is to mobilize the existing infrastructures and data centers, enlarge the coverage of continuous in-situ observation. A citation system which recognizes data collection and quality validation through DOI would stimulate the support of scientists. A better coordination between international, national, public and private initiatives is welcome.

Modelling the ecosystem – Ben Smith, *Lund University, Lund, Sweden*

Terrestrial ecosystems are part of the climate system, responding to and affecting the atmosphere via biogeochemical and biophysical feedback mechanisms. The new generation of Earth system models (ESMs) used as a basis for upcoming climate impacts research and synthesis efforts such as IPCC assessments are being developed to include an interactive biosphere, simulating responses of ecosystem carbon balance and other biogeochemical exchanges, vegetation and land cover dynamics. Frontiers in such developments include realistic representations of forest stand dynamics – important in accounting for the carbon cycle consequences of secondary forests regenerating on abandoned agricultural land – nutrient cycles, non-CO_2 greenhouse gas emissions, natural emissions of aerosol precursors, peatlands and their interactions with vegetation, permafrost and hydrology. ESMs typically incorporate biosphere dynamics via coupling of a stand-alone land surface or dynamic vegetation model. Data assimilation techniques are increasingly used to calibrate the parameters of such models based on multiple observational data streams. Relevant data sources include ecosystem flux tower measurements, forest inventory data, hydrological measurements and remote sensing products.

Ecosystem data and perspectives – Abad Chabbi[1], Henry W. Loescher[2] and Claus Beier[3], *[1]INRA, UMR 1402 ECOSYS, pôle soil - Ecologie fonctionnelle et écotoxicologie des agroécosystèmes, Grignon, France,[2] National Ecological Observatory Network (NEON) Institute for Alpine and Arctic Research (InstAAR) University of Colorado, Boulder Colorado, USA & [3] University of Copenhagen Institute for Geosciences and Natural Resource Management, Denmark*

The land based sectors (agriculture, forestry and other land use; AFOLU) are responsible for ~24% of all anthropogenic greenhouse gas emissions (this does not include urban environment), yet these land sectors provide the needed goods and services upon which humans rely for food, fibre and energy. The scientific community generally accepts that climate is changing and that this changes the frequency and severity of extreme climatic events (e.g., storms, heat and drought) which have severe impacts on food security, ecosystem sustainability, and on the needs for ecosystem goods and services. Hence, we need to understand how to best balance the role of AFOLU in climate mitigation and to develop the tools to best plan for the ecosystem services to be provided by AFOLU in light of a changing climate. This is already becoming a major societal challenge, and will continue over the coming decades. Development of these prognostic tools and methodologies are essential to provide decision makers a range of potential outcomes given a specific planning scenario, thereby providing the best possible decision-making trade-space in the face of environmental change and its impact on land use. Essential to this approach is the need to include the human dimension. We advocate a philosophy for ecological AFOLU forecasting through (i) the iterative integration of theory, observation, experimentation and modelling, and (ii) enhancing the synergies among environmental research infrastructures. Mitigation of the impacts of climate change requires advance warning and prognostic capability of emergent environmental conditions, and developing the decision-making space to appropriately reduce vulnerability to ecosystem goods and services. This talk has provided an overview on how research infrastructure in ecosystem science could be structured to provide (i) integration to develop ecological forecasting, and (ii) new innovative experiments to better assess climate change risk and future frontiers in ecosystem sustainability and food security.

Modelling the cryosphere – G. Krinner, *LGGE, Laboratoire de Glaciologie et Géophysique de l'Environnement, France*

Due to remoteness and harsh climatic conditions, long-term observations of the state and evolution of the cryosphere, and of cryospheric processes, are sparse and often incomplete. In addition, the vast majority of satellite missions, even those designed specifically for the cryosphere, do not entirely cover the polar regions. This is an obvious obstacle to progress in the scientific understanding of climate-relevant cryospheric processes and mechanisms, and makes model development, improvement and evaluation particularly difficult. This talk gave a brief and necessarily somewhat subjective overview of the most pressing needs for long-term observations of the cryosphere relevant for climate modeling, covering a variety of cryospheric components of the climate system such as seasonal snow, permafrost, mountain glaciers, sea ice, and ice sheets. As to long-term site observations, there is a need for model development and evaluation, (gap-filled) ancillary data including meteorological forcing, representative sites and additional observation data regarding snow, permafrost and ice sheets (e.g. blowing snow). Gridded large-scale data are the main challenges for a better understanding of the seasonal snow variability in terms of mass and extent, the evolution of the permafrost which is not observable from space, sea-ice beyond its extent and ice sheet mass balance.

Cryosphere data and perspectives – Wolfgang Schöner, *University of Graz, Austria*

The cryosphere is a component of the Earth System that includes snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost, seasonally frozen ground, and solid precipitation at the surface. The cryosphere is global, existing not just in the Arctic, Antarctic and mountain regions, but also in various forms at all latitudes and in approximately one hundred countries. It provides some of the most useful indicators of climate variability and change, yet is one the most under-sampled domains of the Earth System. Improved cryospheric observation is essential to fully assess, predict, and adapt to variability and changes in the Earth's weather, climate and water cycles. Consequently, improving cryospheric observations is a common interest of several international projects, networks and programs such as International Arctic Science Committee (IASC), World Meteorological Organisation (WMO), Global Earth Observation System of Systems (GEOSS) or the European Union Project EU-PolarNet. Key aims of all these activities are to: (i) meet evolving cryospheric observing requirements of the scientific community and end-users, (ii) improve the utilization of satellite products that exist in order to provide higher-level information and services, (iii) enhance the quality of observational data by improving observing standards and best practices for the measurement of essential cryospheric variables, (iv) improve exchange of, access to, and utilization of data and products and (v) foster research and development activities and coherent planning for future observing systems and global observing network optimization. Cooperation between different cryospheric monitoring activities is therefore essential. WMO together with many partners of cryospheric organizations has started the Global Cryosphere Watch program, which could serve as nucleus for future coordinated observational program of the cryosphere on a global scale.

EEA climate change indicators and related long-term observation needs – Hans-Martin Füssel, *European Environment Agency, Europe*

The European Environment Agency (EEA) has published indicator-based reports on climate change and its impacts regularly since 2004. These reports provide quality-controlled information for European, national and subnational policy-makers, scientists, NGOs and the wider public. The 2012 EEA Report and the forthcoming 2016 EEA report include around 40 indicators on climate change and its impacts on environment and society, which represents about a third of all EEA indicators. The EEA climate change indicators cover the atmosphere, cryosphere, oceans, freshwater systems, ecosystems and others; most of them include both observations and projections. Whereas most other EEA indicators rely on statistical data reported by EEA member states, often based on EU legislation or other formal agreements, the climate change indicators rely primarily on international scientific databases, research networks and individual research projects. The highly heterogeneous and distributed nature of the data underlying the EEA climate change indicators creates challenges for identifying, evaluating and communicating relevant data sources. The Copernicus Climate Change Service (C3S) will facilitate access to many relevant climate-related data sets in Europe. EEA is working closely with ECMWF, the EU delegated entity for C3S, in shaping its development. Relevant data for many EEA climate change indicators are often not easily available. As a result, these indicators rely on model-based estimates for past trends, on data provided by institutions from outside Europe, or they have limited geographic coverage. Some thematic indicators of high potential interest to EEA and its stakeholders are not developed at all due to the lack of available data with European coverage. Long-term observation networks are essential for providing data on climate change, climate variability and extremes, and its impacts to researchers and policy-makers. EEA as a “boundary organization” bridging between the scientific and policy communities considers itself as a key user of long-term, comprehensive and quality-controlled data on climate change and its impacts. EEA is ready to provide perspectives on how long-term observation networks can provide relevant data to EEA indicators and assessments, and thereby to policy-makers in Europe.

Satellite data – D. Dee[1] and P.-P. Mathieu[2], [1]*European Centre for Medium-Range Weather Forecasts, UK,* [2]*Earth Observation Applications Engineer in the Earth Observation Science & Applications Department of the European Space Agency, Italy*

1. Copernicus Climate Change Service

Here is presented an overview of the Copernicus Climate Change Service (C3S), one of six services established by the European Commission as part of its Copernicus Earth Observation Programme. C3S aims to be an authoritative source of climate information for Europe, to build upon national investments and complement national climate service providers, and to support the market for climate services in Europe. The service will provide open and free access to climate data from Earth observations and models, as well as the necessary tools for transforming those data into actionable information. C3S will rely on the best available estimates of Essential Climate Variable (ECV) products derived from observations and climate reanalyzes, and on predictions and projections from state-of-the-art climate models. It will deliver impact indicators at temporal and spatial scales relevant to adaptation and mitigation strategies of the European Union's sectoral and societal benefit areas.

2. Copernicus Satellite Data (presented on behalf of P.-P. Mathieu)

This talk has presented an overview of the series of six Sentinel missions, which represent the Earth Observation component of the ESA and European Commission's Copernicus programme. The Sentinels are designed to provide sustained and high-quality data on Essential Climate Variables related to the ocean, atmosphere, cryosphere and land, with global coverage and at high spatial and temporal resolutions. Open and free access to all data is provided via the Sentinel Scientific Data Hub at sentinel.esa.int, which also includes various services and tools designed to facilitate uptake and analysis of the data.

III- Group session

The second day of the workshop was dedicated to group sessions where participants had to debate about (i) their common vision for Europe, (ii) identify the needs/gaps in the long-term ground-based observational landscape and (iii) the strengths, weaknesses, opportunities and threats (SWOT) on enhancing European collaboration for the provision of ground-based observations data for climate science and services. The group as a whole was divided into two working groups, one led by Sylvie Joussaume and another led by Sanna Sorvari. After discussing for an hour and a half, the two groups gathered and outlined their proposals.

1) Common vision for Europe

The questions asked to both working groups regarding their common vision for Europe were the following:

- What do we want to build together?
- What should we aim at?
- What could be the added value for collaborating at the European level?

The two groups agreed on the fact that we need to elaborate major priorities at the European level regarding the spatial and temporal coverage of measurements of climatic variables through enhanced collaborative work. This work should not strictly involve scientists but a wider community including the end-users. International cooperation and coordination are often arising from European led initiatives as Europe initiates and support financially and logistically relevant projects. Through coordination at the European level, huge progress can be achieved in Earth system science and for building European operational climate services. The workshop participants also claimed that European researchers should remain involved all along the process regarding the provision of data for science and observation services, as the role of the scientific community in securing quality control is fundamental. It remains clear that the impact analysis, difficulties encountered to gather high quality data and assessment of the risks should not discuss data provisions solely in terms of services. The ultimate aim is not only to provide data, but to additionally provide fundamental knowledge for all the user communities. Eventually, the added value for collaborating at the European level is therefore the visibility, coverage, financial support for elaborating standards, exchange and coordination within the European borders. Furthermore, it can represent a major stepping-stone for a better collaboration at the international level.

2) Needs/ Gaps

The participants identified the needs and gaps in the long-term ground-based observational landscape by evaluating the topics, missing variables, the technical requirements and availability of data as well as the status of collaboration with user communities (e.g. modellers). The maturity levels of different science communities vary (among Earth system domains) and thus different science communities are facing both common and domain specific challenges.

They first pointed out that there are still some lacks of coordination within Europe regarding sustained funding for continuous observations, while time series are required. Even simple ECV (Essential Climate Variables) monitoring is not secured presently. In addition, there are still missing variables such as data for assessing ocean acidification, snowfall and more widely the cryosphere (e.g. permafrost). In contrast to other domains, a gap exists in the cryosphere domain between country-level contributions and the international framework. New technologies and sensors also need to be developed to further investigate ECVs. There is therefore a need for more financially supported science activity to improve our understanding of the climate system.

From the users' point of view, too much information is available. A clear guidance is needed as some areas are better organized than others for which well-established groups are identified. Data-Combining level is therefore a crucial point to address.

As to the availability and accessibility of existing data (metadata): the importance of giving insights into quality/uncertainty which helps for a better interpretation of data is highlighted; also some data/metadata remain inaccessible. Legacy data is also a key issue, e.g. when it comes to their preservation, their quality, ..). A significant amount of information has been lost from past programs owing to the difficulties on data storage. One-stop-shop could be an alternative; however, there is a non-deniable risk if traceability is not sufficiently addressed. Interoperability could be the key as used in ENVRI+ project. Progress should also be made in optimising spatial coverage and improving data availability and traceability, as well as in supporting Europe to take the leading role in the international arenas.

Continuity in the projects as well as in measurements is a main issue that needs to be solved. There is a need to support the coordination activities among the European long-term observation networks and research infrastructures. Some opportunities already exist in ENVRI+ for discussing the optimization of measurements The workshop participants suggested the creation of an ERI (European Research Infrastructure) as a reliable tool although sustaining funding at national level raises numerous issues especially due to its complexity. ESFRI (European Strategy Forum on Research Infrastructures) has already started to build a more coherent European RI landscape, however, there are still gaps in observation systems. More coordinated efforts for interacting with higher international levels are therefore highly recommended. However, the participants wonder whether GCOS (Global Climate Observing System)/GEO (Group on Earth Observations) could be the right level of coordination.

The participants also emphasized the need to close the gap between observers and modelers. Observations are crucial for model evaluation and a strong international effort is ongoing to gather observations for model evaluation within the obs4MIPs project. The European modeling community is also working to gather and share expertise with community evaluation tools (e.g. ESMValTool). As seen from observations, models could also help to design observational networks and to identify key variables sensitive to change. More generally sustained collaborative work between data providers, modellers and users could favour identification of new data needs, novel use of data and enhance their analyses.

3) SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis on enhancing European collaboration for the provision of ground-based observational data for climate science and services

Strengths	Opportunities
▪ Enhanced visibility of the European led initiatives (proper coverage) ▪ Construction of an efficient observing system, significantly improved by the ESFRI (European Strategy Forum on Research Infrastructures) ▪ European leadership favored by European level organization ▪ Realizing the need for better coordination	▪ Establishment of Copernicus C3S ▪ Extent to all European ▪ Improvement of the coordination of the existing infrastructures
Weaknesses	**Threats**
▪ Federated group may limit the impact of the European organization ▪ Missing organizations for some of the domains (cryosphere, water) ▪ Complexity of the observing system ▪ Difficulties to have a coherent strategy in the European Commission (GEO initiatives versus ERI initiatives, not always well organized)	▪ Need to interlink climate services with science but not the only driver (need for science, not for only operational) ▪ National strategies opposite to European strategy on long-term funding ▪ Issues on long-term sustained funding in many countries ▪ Recognition of RI initiatives in several countries ▪ Many global initiatives which require a better European strategy

IV- Recommendations and concluding remarks

The overall global landscape of observing networks in the field of climate is quite complex with its different layers and organisations at national, European and international. An overall strategy is still missing. However, Europe has a strong added value through its capacity to coordinate observing networks, to enhance spatial coverage and increase visibility compared to national levels. Moreover, through its capacity to coordinate activities, Europe can play a leading role at the international level. ESFRI has already started to build a more coherent European research infrastructure landscape but there are still gaps in observation systems, such as for cryosphere and freshwater systems, as well as on the development of sensors. The need for well-coordinated observational networks is important not only to increase knowledge but also for the development of services (e.g. Copernicus). However, services cannot be the only driver, and a close relation between providers and users is required.

The workshop more specifically emphasizes the following needs:

- The need to improve the accessibility of data and metadata, while keeping the traceability of data. The need to ensure the quality of data through close integration of scientific expertise within data management. The need to support co-work between users and providers in order to enhance analyses and favour novel use.
- The need to close the gap between models and observations through a better coverage of observations for model evaluation, the support of community tools for model evaluation and the contribution to international initiatives such as obs4MIPs. The need to favour co-design of observations in areas sensitive to change.

- The need to build an international system of standardised and sustained observation systems.

The participants consider that JPI climate can play an important role in strengthening observational networks by bringing the communities together and by supporting collaborative actions and sustainability. The workshop participants recommended more specifically:

- The preparation of a roadmap for collaborative activities and identified needs. This could lead to a common platform gathering the different domains. JPI Climate could also foster modelling-observations-users interactions through a set of common workshops
- JPI climate could also, through dedicated joint calls or through recommendations to research projects, support targeted actions to fill some of the above mentioned needs
  JPI Climate could also promote the participation of European actors in the international activities and contribute to promote European leadership at the international level.

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ANNEX

- Brochure
- Participant list