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EUPORIAS

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European Provision Of Regional Impact Assessment on a

Seasonal-to-decadal timescale

Deliverable D2.1

Report of recommended priorities for Horizon 2020

EUPORIAS

Deliverable Title	Report of recommended priorities for Horizon 2020	
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Annex 1

Report of the ECOMS board, March 2013: Priorities and research needs for climate modelling and climate services within Horizon 2020

1. Executive Summary

This paper presents a proposal for a climate modelling and climate service development work programme for Europe, suitable to address Horizon 2020 Challenge 5: Climate Action, Resource Efficiency and Raw Materials. This is led by a vision of a European society capable of properly managing the risks and opportunities arising from climate variability and change. The document has been written by European experts in the field, as represented by the European Climate Observations, Modelling and Services (ECOMS) board. The document includes description of the vision, background motivation and a summary of potential benefits of the proposed programme of activities; followed by proposals for three broad initiatives for each of climate modelling and climate services, underpinned by observations.

2. Estimated Effort for this Deliverable

Total budgeted effort for this deliverable (from DOW) was 2.0 person months

Partner	**Person-Months**	**Person-Months (in-kind)**	**Period Covered**
1	1.9	0.5	January to March 2013
Total	1.9	0.5	

Priorities and research needs for climate modelling and climate services within Horizon 2020

Report of the ECOMS Board, March 2013

This document provides vision and motivation for research and development over the coming decade for climate observations, modelling and services. The document has been written by European experts in these fields and includes proposals for three broad priorities (called *initiatives* hereafter) for each of climate modelling and climate services, underpinned by observations. These large initiatives are suitable for forming the Horizon 2020 work programme under Challenge 5 and can be staggered to form three major consecutive calls for each of climate modelling and climate services over the lifetime of Horizon 2020.

Vision

Our vision is a European society capable of properly managing the risks and opportunities arising from climate variability and change.

This vision necessitates significant parallel development of climate modelling and climate services, and will maintain Europe's leadership in this field, ensuring a major role in international activities such as the World Climate Research Programme and the Global Framework for Climate Services.

The vision will be achieved through the development and incorporation of science-based climate information and predictions into planning, policy and practice. The scientific, technical and service delivery solution for achieving this vision should be firmly based on ensuring we can best meet society's needs.

Motivation

There is a growing and urgent need to improve society's resilience to hydro-meteorological-related hazards, mitigate the risk of dangerous climate change, and better manage risks and opportunities arising from climate variability and change. Whilst the combined effects of climate change and of increasing vulnerability and exposure to hazards present unprecedented challenges to society, we are not using our current understanding of climate (past, present and future) to its full potential.

To serve society better we have to dramatically improve the following: our understanding of society's needs; our understanding and predictions of climate; our capability in climate and related impacts modelling; the provision, accessibility, quality and usefulness of climate services. This has been recognised by governments, scientists and decision-makers world-wide and has led to the creation of the Global Framework for Climate Services (GFCS).

Many countries are attempting to better meet society's needs by developing and delivering climate services. A climate service can be considered as the provision of climate information in such a way as to assist decision-making. The service needs to be based on scientifically credible information and expertise, have appropriate engagement from users and providers, have an effective access mechanism and meet the users' needs. Effective climate services facilitate climate-smart decisions that reduce the impact of climate-related hazards and increase the benefits from benign climate conditions.

There is wide variation across Europe in the capabilities and capacities for understanding climate variability and change, for predicting future climate, for the generation of robust climate-impacts information and for delivering climate services. We still need to further develop and sustain a long-term and well-coordinated European modelling and climate service infrastructure. In addition, the current climate science, climate models and climate predictions are often not usable by decision makers, meaning either that climate information cannot be properly incorporated into their decision-making or their decisions are badly informed. Therefore significant and sustained development of the underlying climate science, observations, models, predictions, and impacts studies is needed to ensure reliable information can be provided on future climate at local spatial scales and on seasonal to multi-decadal timescales, creating a solid foundation for decision-making.

Horizon 2020

Horizon 2020 aims to secure Europe's global competitiveness making Europe into a world-class science performer, remove obstacles to innovation, and revolutionise the way public and private sectors work together, creating a genuine single market for knowledge, research and innovation. Horizon 2020 will tackle societal challenges by helping to bridge the gap between research and the market. This market-driven approach will include creating partnerships with the private sector and member states to bring together the resources needed. Significant funding will be available to help address major global and European societal challenges such as better climate prediction and better estimates of anthropogenic climate change, making renewable energy more affordable, and ensuring food safety and security. International cooperation is at the heart of tackling such challenges.

ECOMS Board

This document is the outcome of activities undertaken by the European Climate Observations, Modelling and Services (ECOMS) board. ECOMS was formed in June 2012 to ensure close coordination and cooperation across European

Commission-funded climate modelling and climate services projects and to act as an advisory group/think tank to identify priorities and research and investment needs in the field of climate modelling and services.

ECOMS is comprised of the coordinators of EU FP7 climate modelling and climate service projects and representatives from European climate modelling and climate service centres as follows: Chris Hewitt (ECOMS Chair, Met Office, UK), Francisco Doblas-Reyes (SPECS Coordinator, IC3, Spain), Detlef Quadfasel (NACLIM Coordinator, Univ. Hamburg, Germany), Carlo Buontempo (EUPORIAS Science Coordinator, Met Office, UK), Pier Siebesma (EUCLIPSE Coordinator, KNMI, Netherlands), Colin Jones (EMBRACE Coordinator, SMHI, Sweden), Paolo Ruti (CLIM-RUN Coordinator, ENEA, Italy), Roeland Van Oss and Wilco Hazeleger (ECLISE Coordinator and EC-Earth Chair, KNMI, Netherlands), Sylvie Joussaume (IS-ENES Coordinator, IPSL, France), Marco Giorgetta (COMBINE Coordinator, MPI, Germany), Guy Brasseur (representing IMPACT2C, CSC, Germany), Julia Slingo (Met Office, UK), Tim Palmer (Univ. Oxford, UK) and Claus Brüning (European Commission, Belgium). The group were assisted by Mar Rodriguez, Albert Klein Tank, Paula Newton, Stephen Belcher and Jane Strachan.

Benefits

The benefits of the proposed initiatives will include:

- Better decision-making based on a solid foundation of robust, credible, trustworthy, salient and legitimate science. This will be of significant value for many economic and social sectors in Europe and beyond, and will be achieved by mainstreaming the use of reliable climate information in decision-making, and strengthening the engagement between providers and users of climate services;
- More effective exchange and transfer of climate-related knowledge across the EU, strengthening European integration;
- Enhancing Europe’s scientific leadership in the fields of climate modelling and climate services. This will lead to the creation of a “European Framework for Climate Services”, an essential aspect of the GFCS at the regional level, and develop the required capabilities and capacity across Europe;
- Reducing the vulnerability of society to climate-related hazards through better provision and delivery of reliable, actionable climate information;
- Better management of European resources – for example, we need to better manage water, air quality and alternative energy resources, in part to mitigate dangerous climate change;
- Making European businesses more competitive on the global market. Public-private partnerships should be encouraged to harvest innovation and infrastructure developments;
- Maximising existing climate modelling, observations and service infrastructure.

Climate modelling

The ability to provide reliable and actionable climate services is underpinned by an in-depth understanding of the earth system and the availability of climate information. The main tools used to improve our understanding of current climate variability and change are a long-term observational network, and models based on our best knowledge of the physical, chemical and biogeochemical processes governing the climate and its constituent components.

Coordinated development of climate modelling capability to support decision-making in Europe requires a focus on the timescales on which adaptation decisions need to be made, with a growing need for the provision of climate projections on seasonal to decadal timescales. Additionally, in order for climate model output to be confidently used by decision-makers, work is required to improve trust in our simulations of the climate, and to ensure that Europe is developing leading capability for the next generation of models of the Earth system through improved resolution, initialisation of the predictions, process representation and model architecture.

There are significant challenges associated with making predictions of the Earth system. There are scientific challenges to develop sufficiently complex, realistic and efficient models. There are technological challenges associated with managing huge and complex datasets (from observations and model simulations), and having sufficient computing capability and capacity to develop and use the models.

Three consecutive priority initiatives have been identified. Each of these initiatives is addressed in detail in the accompanying subsections:

1. European Union Climate Projections 2020, EUCP20: Development of a climate prediction system for the EU region based on the **current generation** of climate models. Focussing on high-resolution climate projections, covering timescales from seasons to decades. This activity also takes into account initialisation of the predictions and evaluation of the models;
2. Developing trust in climate models: this will include the development of better observational systems; use of multi-model ensembles; more comprehensive Earth system modelling; better treatment of uncertainty, all leading to improved estimates of climate sensitivity;
3. European Union Climate Projections 2030, EUCP30: Develop modelling capabilities for the **next generation** of climate prediction system, including higher-resolution modelling, earth system modelling, process representation, prediction initialisation, high performance computing and computational efficiency capabilities.

Climate services

It is essential that decision-makers in public, private and government bodies across Europe can effectively access and utilise the wealth of climate knowledge and information gained from our collective scientific excellence. Appropriate engagement and knowledge sharing from users and providers of climate information is essential for the creation of a successful climate service, which effectively addresses users' needs. This climate service provision facilitates climate-smart decisions, reducing the impact of climate-related hazards and empowering users to exploit climate-related opportunities.

Effort must be placed both on improving the translation between the scientific knowledge and the users' needs, and on informing the research agenda through those users' needs. Similarly, the delivery mechanisms need to be co-designed for effectively exchanging climate information between providers and users. This will ensure our climate modelling and prediction capability is made relevant and accessible to users.

Climate services are underpinned by the provision of data. The data needs to go beyond climate data and include impacts data, Europe-wide on temporal and spatial scales, and in a form, of relevance to decision-making.

Three consecutive priority initiatives have been identified. Each of these initiatives is addressed in detail in the accompanying subsections:

1. Translation Science and Users: Engaging with users across multiple disciplines to co-design and provide user relevant climate information for decision-making;
2. Impacts Datasets: The provision of standardised datasets of meteorological parameters and impact relevant data, at sufficient spatial and temporal resolution for end user decision-making;
3. Downscaling and Impacts: A programme of regional downscaling of global climate projections, specifically targeting Europe, providing relevant climate predictions and impacts assessments to support planning and decision-making. Expert guidance will be developed as part of this service provision to enable the effective use of climate information.

Recommendations for a coordination action

ECOMS is operating as a coordination mechanism as part of FP7 and is due to run to January 2017. A new mechanism is required from the start of Horizon 2020 to coordinate the breadth of climate-related activities, including climate modelling and climate services, which will operate under the new EU framework programme. A seamless development of the coordination of climate initiatives will be required to sustain (and ultimately replace) the work undertaken through ECOMS.

The proposed means of doing this is through a Coordination Action to build on the progress of ECOMS, but with a broader remit. The Coordination Action needs to lead coordination and networking of the Horizon 2020 Climate Modelling and Climate Service Initiatives (such as those that would be consistent with the recommendations in this document), as well as with other relevant activities, such as the Global Framework for Climate Services, JPI-Climate, Climate-KIC, the Copernicus Climate Service, CLIMATE-ADAPT, relevant ERA-NETs and the Association of European Climate Services.

The Coordination Action would:

- Establish close links with and between climate research and climate service activities, allowing user requirements to influence and drive research and model development, and bridge the gap between research and the market, thus supporting the Europe 2020 Innovation Union;
- Specifically, coordinate climate modelling and climate service R&D projects funded under Horizon 2020, and establish close links with Horizon 2020 projects in related disciplines. This will enable and encourage open exchange of knowledge, expertise and data across Horizon 2020 climate-related initiatives;
- Through multi-disciplinary networking, join-up related Horizon 2020 initiatives and encourage participation of, and partnership development with, businesses (including SMEs), government and civil society groups. This will support the EC's aim for the EU to become a smart, sustainable and inclusive economy, securing Europe's global competitiveness;
- Allow European collaborators through multi-disciplinary networking to collectively take on tasks that they could not tackle through independent initiatives, bringing together the necessary resources available through Horizon 2020;
- Have international reach in addition to the European focus, developing activities in-line with the World Climate Research Programme, the Global Framework for Climate, the Climate Model Intercomparison Project and the International Climate Service Partnership;
- Pool knowledge and expertise from related initiatives to recommend strategic research agendas for climate model and climate service development within Europe.

Climate Modelling Initiative 1: EU Climate Projections 2020, EUCP20

Motivation

An assessment of the risks from climate variability and change is critical for developing economically and scientifically sound strategies for climate adaptation. Current climate models provide information about long-term global climate change on the one hand, and about specific seasonal climate variability (e.g. occurrence or continuation of drought over the coming months) on the other. Increasingly, climate models are used to advise on regional climate change risks on a range of timescales, from seasons to decades, covering the timescales on which adaptation decisions need to be made. The aim of this initiative is to develop a climate prediction system for the EU based on state-of-the-art climate models and multi-decadal climate projections.

Projections of long-term climate change at the regional scale have been made. For example, in 2009 the UK Met Office Hadley Centre released its UKCP09 projections dataset, placing an emphasis on estimating the relative likelihood of future changes. Data from UKCP09 provided important input into the UK's national Climate Change Risk Assessment, which in turn will inform the 2013 UK National Adaptation Programme. Other EU nations have also released climate projections, for example KNMI'06 in the Netherlands and CH2012 in Switzerland, with new scenarios and improved uncertainty estimates. An assessment of future regional climate-change risks is a priority for all European member states. It is therefore essential that the best input information that climate science can provide is incorporated into these regional scale assessments.

While these latest scenarios are in many respects ground-breaking, they mark only the beginning of what must increasingly be a coordinated international effort to provide to government, business and society in general, state-of-the-art scientific input to climate risk assessments. The models at the heart of these predictions and projections are developing rapidly. Indeed the nature of the projections being made is changing, such as the development of initialised projections for the coming few decades.

Plans and methodologies

There is no more challenging problem in computational science than that of multi-decadal climate prediction. The mathematical representation of the climate system is, at its core, the nonlinear equations of fluid dynamics. However, these fluids (essentially the atmosphere and oceans) are themselves radiatively and chemically active, and their representations must necessarily be supplemented with models of the land surface, the cryosphere and the biosphere. In the light of finite computing resources, this poses four challenges for the development of high-quality climate prediction systems with sufficient skill at regional scales to be used in regional climate risk assessments:

- Integrating the climate models at sufficient resolution to provide credible solutions of the underlying equations (for example, resolutions that resolve atmospheric synoptic systems and permit eddies in the ocean) requires substantial computing power. An increase in resolution by a factor of two requires up to a factor of 16 more computational power;
- Ensuring relevant physical, chemical and biological processes are adequately incorporated into the models adds substantially to their overall complexity;
- Ensuring uncertainties in the predictions are properly assessed, multiple ensemble integrations have to be made in which uncertain aspects of the models are perturbed;
- Using observational data to initialise the integrations and then evaluate the simulations in order to provide appropriate information of the model and forecast quality and produce a properly weighted ensemble of predictions.

Meeting these challenges requires substantial supercomputing resources.

There is a clear need to develop methodologies to design, initialise, run, combine and constrain ensembles of climate integrations using the latest available models, providing a basis for a new generation of climate scenarios. A coordinated European approach would be highly beneficial, pooling modelling resources, physical understanding and statistical expertise to create a new generation of climate products to support European impacts assessments. We propose the development of a programme under Horizon 2020, named EUCP20, to provide to European government, business and society, a sound foundation for assessment of climate risks.

Outcomes

The components of EUCP20 will be the following, which would then be of use to the Climate Services initiatives:

1) Definition of the requirements of climate information for impact and adaptation assessment. Experience indicates different users require different information, which suggests that a joint team of climate and impact scientists will be required to consider the range of information likely required and how it can be understood by diverse stakeholders. The range might include, for example, case studies of recent climate events, single shot scenarios or story lines of future climate, and probabilistic predictions of future climate;

2) A multi-model ensemble of contemporary climate models from leading climate institutes. The design of the ensemble will provide a challenge, likely requiring a

range of models with different physical and dynamical schemes and a range of resolutions;

3) Techniques should be developed to incorporate initialised predictions into the ensemble, both in terms of making progress in initialising coupled models and in incorporating such information into a full projection portfolio;

4) Statistical techniques need to be developed to design the ensemble and combine the model projections with observational constraints to achieve robust estimates of the range and relative likelihood of future outcomes;

5) Models will be run at higher resolution, with greater sophistication (including a range of Earth system components), and focus on the near term (~1-40 years) than was possible in earlier national climate scenarios. The models will be initialised with the best available observations. Full Earth system models would be considered more completely under other initiatives.

Links and synergies

The EU has a strong record of funding coordinated climate modelling projects which have led to new operational forecast systems (e.g. EUROSIP for seasonal-to-interannual prediction). The proposed EUCP20 initiative, whilst the most ambitious of its kind, will build on these successes, maintaining Europe at the forefront of international climate modelling, while also providing a strong climate science basis for the development of European climate service initiatives, both within and in addition to, Horizon 2020.

Climate Modelling Initiative 2: Developing Trust in Climate Models

Motivation

Climate information forms the basis of risk assessments and many decisions on adaptation and mitigation strategies. Climate services are being developed, within which information from climate predictions and projections are tailored to meet user needs. Outputs from climate and Earth system models form the basis for climate service development. The European climate modeling community works towards more reliable models and plausible predictions and projections of a future climate. A central element is to characterise the response of the climate system to changes in external forcing, in particular related to human activities, such as emissions of greenhouse gases, aerosols and their precursors, and changes in land use, constrained by observations. Ongoing research is needed to better understand processes that determine the climate response to external forcing.

Despite decades of progress, the range of estimates of equilibrium climate sensitivity (the equilibrium global average surface warming following a doubling of CO_2 concentration) is still large, and is likely to be between 2ºC and 4.5ºC with a best estimate of about 3ºC. Other climate parameters, such as changes in sea level and the hydrological cycle, show a large spread in the future projections. Climate sensitivity is a global measure for an equilibrium situation. As a basis for usable climate services, there is particular interest to reduce uncertainties in the transient climate response at regional spatial scales.

The large uncertainty in future changes displayed in models is not well constrained by observations. For EUCP20, reliable simulation information is needed, which implies that models should be confronted with observations to determine the reliability of the simulated climate response, in particular for regional changes. In addition to information on changes in the mean climate, changes in extremes and compound effects will be required. To obtain trustworthy regional responses to changes in external forcing, knowledge on interaction between physical, chemical and biogeochemical processes and atmospheric dynamics needs to be further developed.

Future climate projections from multi-model ensembles reflect uncertainties related to the chaotic nature of the flow, parametric uncertainties and uncertainties in the external forcing. Bayesian and stochastic frameworks have been developed based on single and multi-model ensembles. Some probabilistic scenarios are based on multivariate methods of combining multiple lines of evidence, but cannot account for unquantifiable uncertainties arising from common missing processes or systematic errors in models. Moreover, the effectiveness of observational constraints depends on whether model biases can be related to future changes driven by the global and regional sensitivities to changes in external forcing.

This initiative will better characterise uncertainties in climate model projections from global to regional scales and constrain the regional and transient response of models at decadal to centennial time scales to changes in anthropogenic drivers using observations to obtain reliable, trustworthy and plausible probabilistic predictions in support of EUCP20.

Plans and methodologies

Central to the problem of climate change is the response of the Earth's energy balance to changes in emissions of greenhouse gases, aerosols and their precursors, and land use. Both global and regional manifestations of the response need to be identified and validated in climate models. While the mean state of the Earth's energy balance is well-known, long-term variability of the balance is less well described by observations. Also, the changes in some important forcing agents are poorly known. This hampers attribution of occurred changes, such as the recent pause in global warming and regional climate changes. This initiative will help constrain the response of the Earth system to external forcing at global and regional scales, in order to obtain increased process-based understanding of regional climate changes and develop new methods to characterise uncertainties in Earth system models. The following activities are envisaged:

1) To quantify the Earth's energy balance, heat storage and their variability up to multi-decadal time scales and constrain transient climate response. The community should utilise the well-observed variability of the Earth system during the 20th century, with particular attention on the last two decades. During this period, when the Earth went through a period of reduced surface warming, an unprecedented number of Earth observations have become available. Palaeoclimate data showing decadal variability over the past 2000 years may complement recent observations to better evaluate multi-decadal variability simulated by climate models;

2) To develop robust regional climate projections requires a better understanding of the key processes and feedbacks controlling both the regional and global response to changing external forcing. In particular, aerosol-cloud-radiation interactions and vertical mixing processes in the ocean remain highly uncertain. An improved understanding and modelling of such phenomena should lead to more reliable regional climate projections, which are a key component of projecting changes in regional hydrological cycle and weather variability;

3) To quantify the response of the climate to external forcing, all relevant forcings should be known. There is a need to construct data sets of external forcing for the 20th and 21st century that can be used as input to Earth system models;

4) To develop new methods for representing uncertainties in Earth system models and model ensembles and assess the reliability of the regional responses. Statistical and/or stochastic frameworks should be developed to enable the range of simulated

climate responses to external forcing to be refined by application of a wider set of observational constraints;

5) To develop future regional sea level scenarios constrained by observations. Uncertainties in storm surges, ocean expansion, cryospheric processes, terrestrial water storage, isostatic adjustment and the gravity field should be taken into account. A process based understanding of regional coastal changes is needed.

Outcomes

- Quantification of global and regional energy budgets and ocean heat uptake, including estimates of their variability up to multi-decadal time scales;
- Quantification and reliability estimates of the transient regional climate and sea level response to changing external forcing;
- Improved estimates of past external radiative forcing;
- Better understanding of processes and feedbacks central to the regional response of climate and sea level to changes in greenhouse gases, aerosols and their precursors, and land use;
- New methodologies for combining Earth system model output with observations to constrain the range of future regional climate responses.

Links and synergies

Recent EU FP7 projects have contributed to increased understanding and representation of climate feedbacks (COMBINE), cloud processes (EUCLIPSE) and biases in climate models (EMBRACE). THOR and COMBINE offered examples of how the initialisation changes the regional climate response in near-term predictions and illustrated the usefulness of process-based evaluation. IS-ENES provided support for model and data infrastructure and start-up climate services. Building upon these projects there is a need to combine knowledge on biases and regional climate processes and work towards reliable and plausible climate information for the future. This should provide a trustworthy basis for Global Framework on Climate Services.

The initiative has close links with the Grand Challenges defined by WCRP; in particular those on Clouds, Circulation and Sensitivity, Regional climate information and Sea level rise.

Climate Modelling Initiative 3: EU Climate Projections 2030, EUCP30

Motivation

One of the main challenges in climate modelling is how to faithfully represent all relevant processes that emerge from atmosphere and ocean dynamics from planetary scale to small scale turbulent processes. Present day global climate models still operate at relatively coarse resolutions (> ~100km), and as a result many crucial processes are only taken into account indirectly in an approximate parameterised form. Uncertainty in both the description of these unresolved processes as well as their coupling to the resolved dynamics are the prime sources of uncertainty in climate model sensitivity and the probable cause of many long-standing biases in current models (e.g. double ITCZ, Southern Hemisphere convergence zones, equatorward bias in mid-latitude westerlies, diurnal cycle of convection, continental surface temperature biases).

A number of recent activities, critically dependent on high-performance computing, have demonstrated significant improvements in several long-standing model biases by explicitly resolving certain aspects of atmospheric deep convection and ocean eddy exchange. As exascale computers become increasingly available during the 2020s, the climate modelling community must be well placed to take advantage of such computer power with a view to delivering convection-resolving climate predictions by ~2030. To attain this goal requires a major effort in model development during the period ~2016 to 2030. Such development is the essence of this initiative.

Plans and methodologies

Developing ultra-high resolution climate models will require development of explicit representation of deep convection as well as non-hydrostatic dynamical cores. Optimal development of sub-gridscale processes will need to be investigated using different approaches, perhaps scale-aware parameterisations and stochastic parameterisations. These models will also need to efficiently utilise a very large number of processors on future computer architectures, requiring revised numerical schemes, improved management of large data sets and increased fault tolerance.

In order to evaluate models at these high resolutions, observational datasets will need to be gathered and new metrics for model evaluation developed. Evaluation will help identify which phenomena are represented better in a robust way in response to higher resolution, which model biases are resolved at these resolutions, which biases still remain, and which (regional) aspects of precipitation, storminess, extremes etc. depend critically on the step changes in spatial resolution. It will also allow an exploration of whether the spread in model sensitivity is affected by model resolution.

Supporting collaborative development of the future generation of Earth system models will enable the sharing across Europe of the large range of tests and developments that need to be performed. It will also allow better utilisation of the diversity of European climate models, which are required to sufficiently sample parametric and structural uncertainties.

These global climate modelling developments at ultra-high resolution will also benefit from collaborations bringing together a range of models, from regional models to cloud resolving models, which will leverage valuable information on parameterisations.

Realisation:

- *Dynamical core*: which non-hydrostatic core (probably already decided by the various climate modelling centres);
- *Sub-gridscale Processes*: Optimal choice/development of sub-grid processes for a convection permitting (1~5km) atmosphere and eddy-resolving resolution (1-5km) ocean;
- *Protocol for Runs:* atmosphere only/ocean only/ coupled. Frequent initialised hindcast versus Free Climate. GHG-perturbed, SST perturbed;
- *Initialisation and ensemble generation, efficient use of the new generation of Earth observations and reanalyses;*
- *Optimisation, I/O Data management and on-line post-processing.*

Evaluation:

- *Metrics:* New techniques to evaluate skill at high resolutions, forecast reliability assessment including the role of stochastic parameterisations;
- *Resolution Issues:* Which phenomena are represented better in a robust way due to increased resolution? Which model biases are resolved at these resolutions and which biases still remain? What is the minimum resolution required to find such improvements? Exploration of improved fidelity of phenomena crucial for regional weather and climate (regional distribution of precipitation, forced climate response, extreme statistics, etc.);
- *Climate Sensitivity*: Is the spread in model sensitivity changing with resolution? Which (regional) aspects of precipitation, storminess, extremes, etc. depend critically on the step increase in spatial resolution?

- *Virtual Climate Laboratory:* Global Cloud Resolving Simulations are resolving processes that still require parameterisations at more conservative resolution and are therefore leveraging valuable information for parameterisations.

Expected Outcomes

1. The future generation of Earth system models will better resolve key processes and provide more reliable information at the regional scale;
2. An assessment of which phenomena will be better simulated at higher resolution, which model-biases will be resolved, and which climate feedback mechanisms are robust and which are not, at horizontal resolutions relevant to stakeholders;
3. An assessment of improvements (from stakeholders' perspective) in regional climate aspects, extreme events, climate forecast skill and reliability (especially for extreme events);
4. Improve the efficiency of European climate models on future computer architectures;
5. More efficient use of the new generation of dense Earth observations for initialisation and model evaluation

Links and synergies

This initiative will build on technological developments from the FP7 project IS-ENES, which promotes the development of a common distributed modelling infrastructure in Europe. It will make further use of evaluation and initialisation strategies and tools developed through EUCLIPSE, SPECS, NACLIM and EMBRACE. It will also have close connections with climate modelling initiatives through collaborations with WGCM (Working Group on Coupled Modelling), WGNE (Working Group on Numerical Experimentation) and WGSIP (Working Group on Seasonal-to-Interannual Prediction).

Climate Services Initiative 1: Translational Science and Users

Motivation

Climate information needs to be tailored to users' requirements and informed by users' decisions in order to realise the full potential benefits for the EU society. This means there is a need to develop two-way interaction between producers and users of climate information. In such a process, mapping users' needs onto our knowledge of climate, and additionally using user requirements to drive climate research, should be seen as important as making the climate information relevant to decision makers.

This initiative is intended to design a new protocol for translating and delivering relevant and actionable climate information to stakeholders so that it can be used for specific applications. At present most activities in this field follow what has been called a *dock-loading* approach. Climate information is produced from a discussion occurring mostly within the climate modelling community, and thus addresses mostly science-based questions and perceived user-needs. The information is then made available to the user community for eventual application. Through this route, the needs of the stakeholders are only considered late in the process, so that the information they receive is often of little or limited use to their specific application.

To provide strong climate science support to developing European climate service activities, this initiative is based on involving users in co-designing research activities in the climate arena (e.g. through public-private partnerships) and on the cross-disciplinary fertilisation of European research (e.g. prediction skill and decision making on different time-scales).

This initiative has the following priorities:

- To develop a common vocabulary and shared knowledge between users and providers of climate information;
- To co-design the next generation of impact predictions;
- To influence climate model development and its post-processing (e.g. timescales of relevance, types of ensembles, output variables, spatial scales);
- To integrate multi-disciplinary expertise (social and economic values need to be defined and factored in) into a complex, holistic modelling framework.

Plans and methodologies

European climate service activities need to be integrated to actively involve stakeholders in the design process in order to create trust in the transfer and use of climate information.

The GFCS will have strong engagement with users (through what GFCS is calling a User Interface Platform) which will bring people together, provide targeted training, and continuously monitor the requirements for climate services and user satisfaction.

The complexity of European society, which is characterised by a high level of connectivity or interdependence between its parts, requires an approach involving multi-disciplinary expertise to develop cross-sectorial modelling

A key aspect of the initiative will be some coordination and monitoring of relevant national, European and international projects, dealing with a variety of stakeholders for climate-related applications. While the main focus of the initiative should be seasonal to multi-decadal time scales, the initiative will learn from and build upon the user engagement experience and expertise in weather forecasting.

The initiative will assess user needs and develop a cognitive mapping of how the users in different sectors perceive the role of climate information in the decision making processes. The ultimate goal is to develop a framework for considering social and economic interactions and how they can evolve under climate-related pressures and interact with other evolving future pressures/changes that impact society and business.

The initiative will map user-relevant variables and thresholds onto our climatic ignorance (e.g. climate uncertainty, non-conventional climate parameters). Often decisions are triggered by exceeding specific thresholds. Understanding which climate condition or parameter configurations are more likely to map onto these impacts is of crucial importance. The initiative should be considered as a zero-order source of information, which in many cases is not currently available to users.

Looking forward, future changes in the climate have the potential to lead to new, unprecedented events and to other extreme climate variations with cross-sector consequences and potential crises. Methodologies should identify drivers/stresses and indicators/impacts, where the former are monitored closely and are then transformed into a set of indicators, which are tied to tolerance levels or thresholds. The levels of these thresholds should be informed by expert knowledge (e.g. on the resilience of specific systems) and by the decision-makers'/stakeholders' preferences and priorities, leading to a co-designed impact modelling framework.

A specific effort should be devoted to modelling the economic value of climate information and the associated level of uncertainty as a function of forecast lead time, geographical location, time horizon and parameter. The evaluation of different steps in the decision-making process is crucial for determining the economic value. Failure to account for differences in decision-makers characteristics (e.g. risk aversion), the decision-makers environment (e.g. existence of relevant government policies or programs, crop prices and other market characteristics), or realistic management options, can result in the underestimation or overestimation of value.

The primary goal of the initiative would be to design a scalable user-scientist interface for Europe, considering not only climate science aspects, but other fields involved in the understanding of the evolution of European society and its interaction with the rest of the world.

Outcomes

- A science-user platform for engagement, which would represent an important contribution towards GFCS objectives;
- Improved use and uptake of climate information by users, but also a better knowledge of users' needs by climate service providers and developers;
- A route for users to influence research and operational prediction agendas;
- An improved sense of ownership, confidence and trust in climate information;
- Improved methodologies for the two-way transfer of science and socio-economic knowledge.

Links and synergies:

This initiative will build on, and link with, existing activities at both national and European scale (e.g. JPI-Climate, Climate-KIC, EUPORIAS, CLIM-RUN, ECLISE) and take consideration and benefit from ongoing national climate service activities and, where suitable, operational weather prediction activities. It is also important to ensure good connections are kept with international efforts such as Future Earth, the GFCS, the International Climate Service Partnership and the Belmont Forum.

Climate Services Initiative 2: Impacts datasets

Motivation

In order to develop and deliver robust climate services across Europe there is great need to develop Europe-wide standardised data sets on impacts data and impacts-relevant meteorological variables. In many cases, existing data need to be digitised from paper archives or brought together in a consistent format.

Looking ahead, a standardised and consistent methodology for measuring and reporting geo-located impact relevant data across Europe is needed. Where data on impacts are not available, impacts models, driven by meteorological reanalyses, in-situ or satellite data could be used to provide estimates of the required information. An efficient, scalable data interface service, where all the impact relevant datasets can be stored and accessed, is also needed. Relevant variables, appropriate standards and delivery mechanisms should be refined by means of a scoping study, involving stakeholders and scientists across Europe

Important initiatives, such as ECA&D, HadISD, EM-DAT, ESA's Climate Change Initiative, CLIM-ADAPT, ERA-CLIM and EURO4M are filling some of the gaps, but this is an ongoing process and the level of standardisation (grid, common repository, common format, etc.) means these datasets are still largely under exploited.

New datasets also need to be developed to address emerging needs of European society. For example, attribution products should be developed to provide information on the extent to which high-impact environmental disasters are attributable to natural climate variability or to human influence on climate. Such attribution products will be needed to inform better adaptation strategies.

The situation becomes more complex when engaging with the impact community, given that often the basic information doesn't exist, or isn't publicly accessible, or isn't standardised across Europe. Data related to wind storms and floods damages, agricultural productivity, temperature related mortality, energy production are examples of datasets of huge relevance which are not easily available. There are often not central data sources, or defined sets of data to work with.

Other non-conventional networks should be considered in order to gather relevant climate information. For instance, new sensing technologies for air quality control are being deployed (EuNetAir), the integration of this data across Europe would provide added value.

Plans and methodologies

Identification of clear standards to collect, report and distribute impact relevant data across Europe is a key requirement for the development of a coherent and uniform set of climate services in Europe. For example, coordination between member states, similar to the one OECD developed for economics and legislation, could be extended to all climate-relevant information. A close collaboration among all relevant European organisations will ensure an effective harmonisation across Europe.

The definitions of the information contained in these datasets should be the results of a co-designed approach based on the users' perspectives, which directly engages both the producers and the potential users of this information.

While a number of obstacles have made the free exchange of both meteorological and impact-relevant data challenging, overcoming these difficulties should be an important priority of the EU in the coming years. This could be achieved by harmonising all available resources and whenever possible making them available into common data portals. Such harmonisation and continent-wide standardisation should also extend to metadata (to provide information on data quality and uncertainties) and traceability methods. This will also allow for some standard post-processing of the datasets directly on the data interface portal. Whenever appropriate, the initiative should take advantage of new developments in data management, visualisation and dissemination. A number of working examples demonstrating different approaches on data management are now available (e.g. Google earth-engine and Amazon cloud)

Discussion within the climate and impact communities on the way data (e.g. for rivers, use a standard set of gauges globally) could and should be used to validate models (e.g. core assessment metrics that all would use) should be promoted. Such a discussion could lead toward the establishment of sector specific practices to evaluate impact models, such as the JULES benchmarking suite and the Australian PALS system. Moreover, the survey of other observational networks for gathering non-conventional climate information should be explored (e.g. air quality).

Given that our ability to assess future climate risk is largely based on our ability to assess present and past vulnerability, an effort should be put in recovering data that is not currently available in digital format. Such an activity will also improve our ability to assess the probability of specific events. Initiatives such as ACRE and Eye on Earth should be promoted and supported. They could also provide the basis for regional modelling reanalysis and regional impact evaluations of the past.

Outcomes:

- A standardised and consistent methodology for measuring and reporting geo-located impact-relevant data across Europe;
- The provision of a set of attribution products that quantify current climate risks and puts them into the context of climate variability and change;
- An efficient, scalable data interface service where all the impact relevant datasets can be stored and accessed;

- This will result in better management of the climate risk portfolio.

Links and synergies:

Whilst this activity naturally links to the European regional modelling activity (e.g. CORDEX, EUCP20) it is also important to ensure strong connections are kept with reanalysis efforts, such as ERA-CLIM, EURO4M and ERA-Interim; and with climate service activities such as GFCS, CLIM-RUN, ECLISE, EUPORIAS, SPECS, NACLIM and JPI-Climate.

Climate Services Initiative 3: Downscaling and impacts

Motivation

During Horizon 2020 coupled General Circulation Models (CGCMs) used in predicting future climate variability and change will increase in resolution and complexity. The EUCP20 initiative calls for European collaboration to develop a multi-CGCM, multi-member set of predictions for the next ~1-40 years, running the models at the highest possible resolution and initialised with observations.

Two key aspects of EUCP20 are the unprecedented CGCM resolution and an ensemble of simulations covering the recent past (*hindcasts*) and near-term future (*predictions*). Such an ensemble will support the development of *likelihood of occurrence estimates* for future climate outcomes, providing robust and useable information on future climate variability and change. The high CGCM resolution will result in more realistic simulated synoptic to sub-seasonal climate variability. Examples of relevance to Europe include: more realistic mid-latitude cyclone statistics, improved anticyclonic blocking, improved precipitation variability, more accurate representation of the Gulf Stream and North Atlantic Ocean variability, and in general a more realistic representation of North Atlantic-European-Arctic (NAEA) variability. To build on the outcomes of EUCP20 and provide strong climate science support to European climate services, this initiative would concentrate on:

- Assessment of climate predictability over the NAEA region as available from high-resolution global climate predictions, such as those in EUCP20;
- Regional downscaling of high-resolution predictions targeting Europe;
- Development of an ensemble of Europe-wide climate impacts for the coming ~1-40 years based on outcomes of these regional downscaling activities.

The initiative will have the following priorities:

- Provision of climate predictions and impact assessments of relevance to European decision-makers, society and business, delivered at temporal and spatial scales matching user needs;
- Support of national and European climate service needs;
- Support of national and European climate adaptation strategies;
- Delivery of pan-European *likelihood of occurrence estimates* for user-relevant climate and impact parameters covering the recent past and near future;
- Assessment of accuracy and robustness of such climate and impact estimates;
- Guidelines on how to best utilise such data in decision-making and planning.

Plans and methodologies

Future high-resolution CGCMs; such as those from the EUCP20 initiative; offer the potential to deliver much more realistic and useful predictions of climate variability and change. In particular, realistic predictions of the large-scale climate variability over the NAEA region will offer a range of opportunities to the climate service sector and for planning near-term climate change adaptation. To make optimal use of these simulations, this initiative will be a collaborative effort to establish the level of predictability over the NAEA region and to downscale EUCP20 predictions over Europe to spatial scales of direct utility for climate services and decision-makers. High-resolution CGCM hindcasts of the past few decades and predictions (~1-40 years into the future) will be downscaled using the best available, and newly developed, dynamical and statistical methods.

Dynamical downscaling should address three focus areas:

- Quasi-operational provision of a multi-GCM, multi regional climate model (RCM), multi-member (M4) ensemble of European regional climate predictions at RCM resolutions of ~10km;
- A smaller number of pan-Europe M4 regional climate predictions/projections made with RCMs at resolutions of ~ 5km;
- National/sub-national M4 predictions made with convection-resolving RCMs, at resolutions of ~1-3km.

Where appropriate the RCMs should include: coupled European seas, including ocean biogeochemistry, to enable the downscaling of large-scale climate information to the scale of regional/national seas and coastal regions in support of climate change adaptation and service activities in coastal zones; the ability to perform interactive or offline assessment of future climate-air quality interactions, in particular with respect to major European urban areas; interactive impact models, allowing feedbacks between climate impacts (e.g. on natural ecosystems, regional water bodies) and climate variability to be investigated; and the ability to observationally-initialise important components of the regional climate system.

The RCMs should be carefully evaluated in terms of their ability to simulate the full spectrum of climate variability at the spatial scales targeted. Emphasis should be placed on regional water and energy cycles, including interactions between these cycles and other dependent phenomena. In this respect, a major challenge will be the provision of observational data of sufficient resolution and quality spanning the range of climate and impact parameters required to fully evaluate model performance. Attention should be paid to the development of suitable evaluation methods for such high-resolution simulations. The development of probabilistic estimates of regional climate outcomes at high spatial resolution will be an important component of the initiative, requiring innovative approaches to the generation of ensembles of regional climate information.

Advanced statistical methods should be explored both for direct downscaling of large-scale climate parameters and, where feasible, to generate regional impact parameters directly from CGCM output. Statistical methods should consider multi-variable downscaling and output that is both point-wise and gridded, preferably at national and European levels. Methods should be developed and as appropriate applied to bias-correct both the CGCM and dynamically downscaled data to generate a homogeneous ensemble of high-resolution climate data across Europe relevant to European climate services, decision-makers, and the impact and adaptation communities. The impact of bias-correction on both predicted climate change signals and climate change impacts should be assessed. An important component of the programme will be a thorough evaluation of the downscaled data, accompanied by documentation of the procedures used in generating such data with an aim to increase trust and uptake among the user communities.

Building on the downscaling activities, a range of climate impact assessments should be developed addressing both potential climate change impacts and near-term (~1-10 year) forecasts of impact parameters, the latter being intended to support climate service activities. Models should be developed and applied that address the full range of climate impacts/services important across Europe, such as: water resources, agriculture, health, energy, transport and tourism. Such models should be run both in hindcast and prediction mode, with hindcasts used to evaluate the impact models themselves as well as the full CGCM-regional downscaling-impacts chain. Techniques should be developed that allow *likelihood of occurrence* estimates of climate impact parameters across the range of prediction timescales: ~1-40 years, with due consideration paid to the quantification and communication of total prediction uncertainty as it develops through the forecast chain. Impact models may be region/nation/sector specific as well as multi-sectorial and scaled up to the European scale. An ability to function across the range of scales implied in the downscaling activities is an important requirement. Evaluation of the benefits of performing the impact assessment interactively within a climate model versus offline assessment should be made. The role of prediction inaccuracies and bias correction in the resulting impacts and the robustness of the results should also be assessed.

A key aspect of the initiative will be a continuous interaction with European climate service providers and decision-makers to ensure the data provided is fit for purpose. Such an interaction will provide input to best-practice user-guides for European climate services with respect to the use of high-resolution climate predictions.

Outcomes

- Harmonised, high-resolution ensemble of climate predictions for Europe with accompanying uncertainty estimates;
- Harmonised, high-resolution *likelihood of occurrence estimates* for future regional climate outcomes over Europe on timescales of ~1-40 years;

- Harmonised pan-European to sub-national climate impact assessments, *including likelihood of occurrence estimates,* for a range of sectors using documented ‘best’ methodologies;
- A clear methodology and guidelines for delivering climate and impact information into sector-specific decision-making and climate services.